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PROCEEDINGS
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NORTH DAKOTA ACADEMY OF SCIENCE

Volume 53 April 1999

NORTH DAKOTA ACADEMY OF SCIENCE
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1998–1999

91st Annual Meeting

April 15–16, 1999

Grand Forks, North Dakota

HISTORY

The Proceedings of the North Dakota Academy of Science (NDAS) was first published in 1948, with Volume I reporting the business and scientific papers presented for the 40th annual meeting, May 2–3, 1947. Through Volume XXI, the single yearly issue of the Proceedings included both abstracts and full papers. Commencing with Volume XXII, the Proceedings was published in two parts. Part A, published prior to the annual meeting, contained an abstract of each paper to be presented at the meeting. Part B, published later, contained full papers by some of the presenters.

In 1979 (Volume 33) the Proceedings changed to the present 8 ½ x 11-inch format. It was produced from camera-ready copy submitted by the authors and issued in a single part to be distributed initially at the annual meeting. Commencing with Volume 51 all submissions were on computer disk; the entire Proceedings was then assembled by desktop publishing software. This approach allowed the Editor control over all formatting; many of the papers were reformatted, giving the Proceedings a more consistent look. Also, incorporating all of the submissions on computer allowed production of an electronic copy of the Proceedings for the first time.

VOLUME 53 ORGANIZATION

The communications of this volume of the Proceedings are presented in three sections. The first section contains presentations of the symposia offered at the 91st annual meeting. These papers are organized in the same sequence as presented in the respective symposium. The second section contains the collegiate communications presented in the A. Roger Denison Student Research Paper Competition. The third section of this volume contains the communications presented in the professional sections of the annual meeting. Readers may locate communications by looking within the major sections of these Proceedings (see table of contents) or by referring to the author index.

Symposia Communications

The symposia presented in this issue represent a variety of strategies to convey information to other scientists, scholars, students, and the public. As a result, greater flexibility was required in organizing symposia agenda (verbal presentations) with respect to written communications; thus please note that there is not necessarily a one-to-one match between titles of verbal and written communications. This approach has allowed speakers to present more educationally oriented lectures or workshop-type discussions and still provide a rigorous or more technical professional paper to the Proceedings. In a few cases, a speaker does not have a written communication. Again, this approach was taken to allow the symposia convenors the greatest flexibility possible in organizing speakers for the benefit of the audience. Also note that *The Animal Feedlot Operations and Environmental Quality Symposium* will have its written communications and panel discussion published as a supplement after the annual meeting.

Collegiate and Professional Communications

Each Collegiate and Professional presentation at the annual meeting is represented by a full-page communication which is more than an abstract, but less than a full paper. The communications contain results and conclusions, and permit data presentation. The communication conveys much more to the reader than did the abstract, but still provides the advantage of timeliness and ease of production. Commencing with Volume 50, presenters of the Symposia of the 88th annual meeting were given the opportunity to contribute an expanded or full-length article consisting of a multiple-page contribution, thus providing a presentation of much greater depth and scope than possible in a singe-page communication.

Constitution and Bylaws

This issue of the Proceedings also contains the Constitution and Bylaws of the Academy, a list of officers and committee members, a list of all Academy members as of March 1999, a copy of unapproved minutes from the 1998 annual meeting, a listing of past presidents of the Academy, and a copy of the 1995, 1996, 1997, and 1998 financial statements.

IN APPRECIATION

The Academy wishes to specially acknowledge President Kendall Baker of the University of North Dakota (UND), Dr. Gerald Groenewold of the Energy & Environmental Research Center (UND), and Dr. Forrest Nielsen of the USDA Grand Forks Human Nutrition Research Center in supporting the activities of 91st Annual Meeting of the North Dakota Academy of Science. The Academy also wishes to express its thanks to the convenors of the symposia for organizing, reviewing, and editing their respective communications. The President of the Academy also wishes to sincerely thank David Krause of the State University of New York at Stony Brook for speaking on the fossil treasures of Madagascar at this year's banquet.

Eric O. Uthus
Joseph H. Hartman

Symposium Agenda

AN UPDATE ON THE FLOODING OF THE RED RIVER OF THE NORTH AND DEVILS LAKE BASINS, NORTH DAKOTA: DEVELOPING A COMPREHENSIVE WATER STRATEGY

April 15, 1999 (Thursday)

Location – Memorial Union

Convenors and Moderators – Ed Steadman, Energy & Environmental Research Center and Paul Todhunter, University of North Dakota Department of Geography

8:00 a.m. Welcome and Overview

Red River Basin Water Management Initiatives

8:10 a.m. David Loss – U.S. Army Corps of Engineers
Water Management for the Red River of the North Basin

8:30 a.m. Lee Klapprodt – North Dakota State Water Commission
North Dakota's 1999 State Water Management Plan

8:50 a.m. Gene Krenz – Red River Basin Board (RRBB)
Red River Basin Board Watershed Management Plan Status

9:10 a.m. Thomas Moe – Red River Water Management Consortium, Energy & Environmental Research Center
Developing Water Strategies for the Red River Basin: An Update on the Red River Water Management Consortium

9:30 a.m. Tom Sawatzke – U.S. Bureau of Reclamation
Municipal, Rural, and Industrial Water Needs in Eastern North Dakota: An Appraisal-Level Study

9:50 a.m. Mid-Morning Break

Water Management Issues and Perspectives

10:10 a.m. Larry Leistritz – Department of Agricultural Economics, North Dakota State University
Socioeconomic and Land Use Trends in the Red River Basin

10:30 a.m. John Towle – Pembina River Basin Advisory Board
Pembina River Basin – Building Consensus for a Sustainable Future

10:50 a.m. Roger Hollevoet – U.S. Fish & Wildlife Service
A Comprehensive and Multipurpose Approach to Watershed Management – A Concept

11:10 a.m. Richard McCabe – Environmental Consultant to the Garrison Conservancy District
Science and Policy, Interbasin Water Transfer of Aquatic Biota

11:30 a.m. Joe Belford – Ramsey County Commissioner
The Devils Lake Dilemma (presentation only)

12:00 p.m. Break for Lunch

Flood Response Status and Strategies

1:00 p.m. David Loss – U.S. Army Corps of Engineers
Status of Flood Control Activities in the Red River Valley

1:20 p.m. Bill Rannie – Department of Geography, University of Winnipeg
Manitoba Flood Protection and Control Strategies

1:40 p.m. Ken Vein – City of Grand Forks Engineering Department
Red River Valley – Grand Forks, Two Years After (presentation only)

2:00 p.m. Pat Zavoral – City of Fargo Public Works
Flood Control in the City of Fargo

2:20 p.m. Donald Ogaard – Red River Watershed Management Board
Flood Damage Reduction – Tributary Storage

2:40 p.m. Gerald Groenewold – Energy & Environmental Research Center
Basinwide Flood Control: The Waffle

3:00 p.m. Mid-Afternoon Break

Climatic Factors

3:10 p.m.	Allan Ashworth – Department of Geosciences, North Dakota State University *Paleoclimatology – North Dakota Prairie Pothole Region* (see page 171)
3:30 p.m.	Will Gosnold –Department of Geology and Geological Engineering, University of North Dakota *Estimating Flood Recurrence: Climate and the Geologic Record*
3:50 p.m.	William Schuh – North Dakota State Water Commission *Climatic Effects on Groundwater in Eastern North Dakota*
4:10 p.m.	Q. "Steve" Hu and Kenneth Hubbard – High Plains Climate Center, University of Nebraska-Lincoln *An Overview of the Current Status of GCM Forecasts for Future Climate in the Northern Plains of the United States*
4:30 p.m.	Wendy Pearson – National Weather Service – Eastern North Dakota *Basic Procedures, Approaches, and Assumptions Associated with Flood Forecasting in the U.S. Portion of the Red River Basin*
4:50 p.m.	Joseph Hartman – Energy & Environmental Research Center Leon Osborne, Jr. – Regional Weather Information Center, University of North Dakota *Closing Comments*

WATER MANAGEMENT FOR THE RED RIVER OF THE NORTH BASIN

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The 1997 flood generated a strong determination by the governments of the United States and Canada to "examine and report on the causes and effects of damaging floods in the Red River Basin, and to make recommendations on means to reduce, mitigate, and prevent harm from future flooding in the Red River Basin."

One of the objectives of this task force is to facilitate integrated flood management in the basin. The task force will review the role of current and proposed organizations and evaluate the roles they might have in future integrated flood planning. The review will result in recommendations as to what institutional arrangements should be established to carry on basinwide transboundary flood planning and other water management issues.

The presentation at the symposium on April 15th will focus of how this objective is intended to be addressed in the context of other work being done by the task force.

NORTH DAKOTA'S 1999 STATE WATER MANAGEMENT PLAN

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INTRODUCTION

Support for Water Development with Controls

North Dakota leaders have long recognized the importance of managing the state's water resources. In considering the state constitution, the founding fathers determined that because of North Dakota's climate and its position on the continent, careful use of limited water resources would be critical to the state's prosperity. As a result, the constitution reserves the ownership of all water resources, below, on, or above the land surface, for the people of the state.

Since early in North Dakota's history, anyone wishing to put water to a beneficial use must obtain a permit from the State Engineer to secure the right to do so. Like other western states with limited water resources, North Dakota water rights are managed on the principle of first in time is first in right. In 1937, after experiencing the agonies of a major drought, the legislature created the State Water Commission to help facilitate orderly development of the state's water resources. While the State Engineer regulates water use, the State Water Commission provides state technical and financial support in implementing water infrastructure deemed important to the health and welfare of state residents.

Purpose and Authority in Developing a Statewide Plan

Developing a state water management plan has several purposes. The first is to clearly define water development and management needs across the state. This includes identifying the array of water project needs present in a state as geographically diverse as North Dakota. As the 1999 State Water Management Plan was developed, the State Engineer also requested a review of the many public policies that impact the way water is managed in North Dakota.

North Dakota Century Code Section 61-01-26 requires the State Water Commission to complete and periodically update comprehensive, coordinated, and well-balanced short- and long-range plans and programs for water management. Direction from the State Engineer and the 55th Legislative Assembly initiated the process that resulted in the 1999 State Water Management Plan. In the interest of securing North Dakota's right to a fair share of Missouri River water, the legislature specifically asked that the new plan address future needs from this important water source.

Building a Foundation for the 1999 State Water Management Plan

North Dakota has had a number of statewide water management plans going back to the original published by the State Planning Office in 1937. The most recent plans, published in 1983, 1992, and now the 1999 plan, have been different than their predecessors in that they placed great importance on public involvement. Experience in many planning efforts led to the conclusion that plans that do not have strong "grass roots" participation will not get buy-in by the public they are meant to serve. Poor public buy-in ensure that a plan will languish on the shelf.

The State Engineer and State Water Commission, with Governor Schafer as its chair, adopted the 1999 State Water Management Plan in December of 1998 as their vision for water management in the 21st century. As this is written (February 1999), the state senate has also adopted the new plan, stating its commitment to its implementation to meet the long-term needs of North Dakota residents. Legislators have said they believe this level of endorsement for a state water plan is historically significant.

PLANNING PROCESS

Thirteen-Month Timetable

It was necessary to develop the 1999 Water Management Plan within a 13-month timetable to meet the expectations of the State Engineer and Legislature. Regardless of the relatively restrictive deadline, a planning process was devised that allowed for substantive input from the public, local governments, other natural resource agencies, nongovernmental organizations, and major water development project sponsors. Organized water groups, including the North Dakota Water Coalition and North Dakota Water Users, were important contributors. The process involved extensive staff effort, but the State Water Commission retained control and responsibility for the final report.

The planning process included three rounds of eight public meetings held primarily in the state's major cities. A random survey of 2500 licensed drivers early in the process provided important supplemental information (conducted during December 1998, 20 percent usable returns). Response to the survey and meeting input aided the planning staff in defining the most important water issues and the public's perception of the most critical water needs.

PRODUCTS OF THE PLANNING PROCESS

Two Major Focus Areas Addressed

The planning process focused on two primary products: the first a listing and analysis of public policies that impact the way water is managed in North Dakota, and second the development of an inventory of water management project and program needs.

Vision of the New Millennium

Water management policy and identification of project/program needs are complemented in the report with additional information. One of the more important items is a vision statement for the 21st century. The philosophy that will be applied in managing the state's water resources is concisely stated as follows:

> "It is the vision of water management for the 21st Century that North Dakota will enjoy an adequate supply of quality water. Water resource management will ensure health, safety, and prosperity; and balance the water needs for present and future generations."

Goals and Objectives

Beyond the vision statement, the planning staff used the public input to refine a basic set of goals and objectives that will guide water management decisions in the future. The goal and objective statements cover major topical areas. Listed alphabetically they include atmospheric water, economic development, energy goals, environmental quality, flood mitigation, irrigation, water supply, and water quality.

Policy Review and Changes Needed

The main report of the 1999 plan will provide a comprehensive list of water management-related state and federal policies. Recommendations for potential changes are made that will reshape policies to more accurately reflect North Dakota's contemporary concerns and needs. Clearly, federal policy changes will be much more difficult to implement than state policies. However, it is important that they be identified for North Dakota decision makers. This information will support efforts through various channels to promote the proposed changes.

Because of the flooding crisis experienced in 1997, the planning process placed special emphasis on flood plain management policies. Several specific recommendations were made in the new plan which ultimately translated to legislation in the 1999 Legislature. As of this writing, the recommendations requiring legislative action are faring well in the legislature. The number and complexity of water management policies require that studies continue past the completion of the 1999 plan.

Water Projects and Program Needs

Project and program recommendations are of primary importance to many state residents as this affects their immediate and future needs. Public input, feedback from water management districts, and regional water project sponsors provided a comprehensive listing of project/program needs. Because of the short time allotted to this study process, only limited project/program evaluation could be accomplished. Existing data were used extensively.

Evaluation Process Used in Weighing Proposed Projects and Programs

Information gained through public surveys and meetings was supplemented by contacting all water resource management districts. Each district was asked to provide information on water issues and projects under local consideration. All feedback was filtered through a set of basic criteria that helped place potential projects in an appropriate implementation time frame. All potential water development projects in the 1999 plan are categorized into one of three time frames. The following criteria were used to assign time frames:

- Status of applicable environmental and feasibility studies
- Status of project design
- Status of necessary permits
- Status of funding

While these criteria are useful for this planning process, it is important to note that all projects must pass detailed economic, environmental, and cultural resource analysis prior to implementation. The ability of local project sponsors to meet applicable cost-share requirements and the limited availability of State Water Commission funds represent important hurdles for all projects.

Project proposals not meeting the plan's basic criteria were moved to later time frames, usually the 2001 to 2011 time frame. Projects that were merely concepts or had been identified but are not actively promoted at this time were moved to the 2011 and beyond time frame.

In listing the major or regional water projects, the plan utilized the information and implementation time frames provided by project sponsors. Each major project has its own implementation timetable, review mandates, and project payment scenario.

PLAN RECOMMENDATIONS

Broad Input Identifies Growing Water Needs

Input obtained through the planning process was refined into a presentation of contemporary water management needs across North Dakota. Even with steady progress having been made in meeting North Dakota's water needs, this planning effort confirms that needs far exceed the means of the current dedicated resources. Even when significant cultural and environmental hurdles can be overcome, funding remains a major challenge.

Mapping the Needs

While the severity of needs varies, no area of North Dakota is without some type of water need. Figure 1 illustrates water management needs occurring statewide. Several types of projects are needed from simple stream maintenance to major flood control. Because of the uncertain nature of the supply or quality problems with the existing supplies, meeting North Dakota's municipal, rural, and industrial water supply needs is one of the most prevalent and most pressing. State leaders recognize that assuring the availability of high-quality water in adequate quantities when needed is vital to North Dakota's economic growth potential.

Costs of Meeting Contemporary Water Needs Are High

The 1999 State Water Management Plan main report will contain a detailed listing of projects for all areas of the state. For purposes of this report, the information has been refined down to a list of major project needs and their cost over time. It is the same information presented in the Executive Summary document. Table 1 contains information on the major or regional-scale projects and a tally of smaller project needs. Included are the Dakota Water Resources Act projects that represent one of North Dakota's best means to utilize the abundant resources of the Missouri River. Other potential projects address immediate needs for flood control at Grand Forks and Devils Lake in addition to the host of smaller-scale projects normally funded by the State Water Commission's contract fund appropriation.

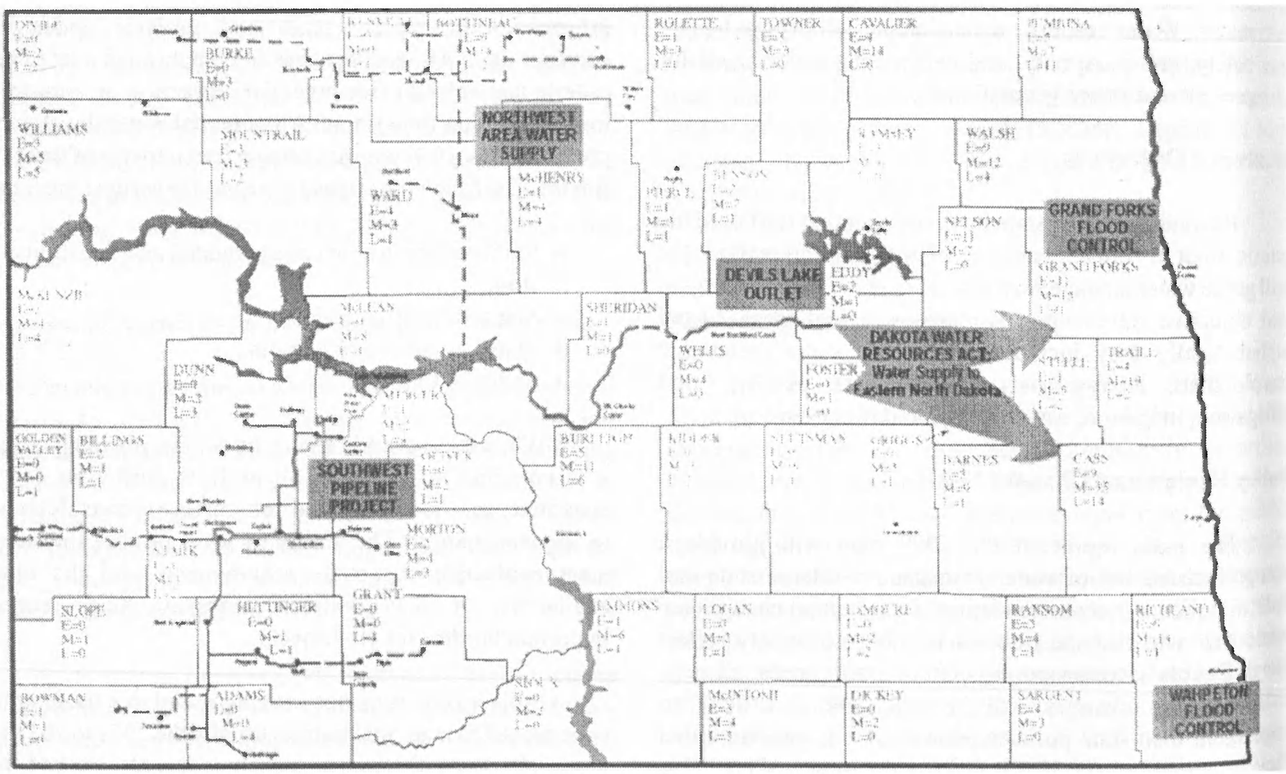

Figure 1. State Water Management Plan Projects.
Legend: COUNTY NAME
E (early) = # of projects in 1999-2001 time frame
M (middle) = # of projects in 2001-2011 time frame
L (late) = # of projects in Beyond 2011 time frame

Table 1. State Funding Needs

	DAKOTA WATER RESOURCES ACT (in millions)			OTHER POTENTIAL PROJECTS (in millions)				
	Water to Eastern ND $	Southwest Pipeline Project $	Northwest Area Water Supply $	Other MR&I $	Grand Forks Flood[1] Control $	Devils Lake Outlet 1 $	General Projects $	State[1] Total $
1999 - 2001								
Local		0	8.2	25.5	25.0	0	31.7	
State	—	6.0	0 2	0	25.0 (0)[3]	17.5 (0)[4]	25.9	74.4 (31.9)
Federal		11.5[5]	14.8	39.9	38.5	32.5	39.8	
Total		17.5	23.0	65.4	88.5	50.0	97.4	
2001 - 2003								
Local	Undetermined[6]	0.5	8.7	17.7	35.7	0	24.0	
State	0	1.7	0	0	27.0 (7.8)[3]	0 (3.0)[4]	18.4	47.1 (30.9)
Federal	17.0	12.5	16.3	32.8	62.9 7	0	5.5	
Total	17.0	14.7	25.0	50.5	125.6 (7.8)	0 (3.0)	47.9	
2003 - 2005								
Local	Undetermined[6]	1.0	11.8	17.7	0	0	24.0	
State	0	5.0	0	0	0 (7.8)	0 (3.0)	18.4	23.4 (34.2)
Federal	6.0	11.4	21.8	32.8	0	0	5.5	
Total	6.0	17.4	33.6	50.5	0 (7.8)	0 (3.0)	47.9	
2005 - 2007								
Local	Undetermined[6]	1.0	5.8	17.7	0	0	24.0	
State	0	9.5	0	0	0 (7.8)	0 (3.0)	18.4	27.9 (38.7)
Federal	84.0	19.5	10.9	32.8	0	0	5.5	
Total	84.0	30.0	16.7	50.5	0 (7.8)	0 (3.0)	47.9	
2007 - 2009								
Local	Undetermined[6]		3.7	17.7	0	0	24.0	
State	0	—	0	0	0 (7.8)	0 (3.0)	18.4	18.4 (29.2)
Federal	59.0		7.0	32.8	0	0	5.5	
Total	59.0		10.7	50.5	0 (7.8)	0 (3.0)	47.9	
2009 - 2011								
Local	Undetermined[6]		1.7	17.7	0	0	24.0	
State	0	—	0	0	0 (7.8)	0 (3.0)	18.4	18.4 (29.2)
Federal	2.0		3.3	32.8	0	0	5.5	
Total	2.0		5.0	50.5	0 (7.8)	0 (3.0)	47.9	
Beyond 2011								
Local	Undetermined[6]		8.7	130.2	0	0	196.2	
State	0	—	0	241.2[8]	0 (58.5)	0 (15.0)	138.0	379.2 (452.7)
Federal	0		16.3	0	0	0	25.8	
Total	Undetermined[6]		25.0	371.4	0 (58.5)	0 (15.0)	360.0	
Grand Totals								
Local	Undetermined[6]	2.5	48.6	244.2	60.7	0	347.9	
State	0	22.2	0	241.2	52 (97.5)	17.5 (30)	255.9	588.8 (646.8)
Federal	168.0	54.9[5]	90.4	203.9	101.4	32.5	93.1	
Total	168.0	79.6	139.0	689.3	214.1 (259.6)	50 (62.5)	696.9	

1 The cost in parenthesis ( ) reflects a bonding financing option.
2 An option being considered is State Water Commission bonding the local cost share with local repayment to State Water Commission resulting in no real cost to SWC.
3 State total cost share of $52 million will be bonded, requiring a loan repayment estimated at $3.9 million per year with repayment beginning in 2001.
4 The total state cost share of $17.5 million, which includes mitigation costs, will be bonded, requiring a loan repayment estimated at $1.5 million per year; the split between state and local is not determined.
5 Assuming Perkins County Water System payment to State Water Commission of $4.5 million.
6 The local cost is not determined at this time and will be determined after project configuration is complete.
7 Components of the Grand Forks Flood Control Project involve Water Treatment Plant improvement. Those federal costs are reflected in the "Other MR&I" column because of potential cost share using Garrison Diversion MR&I funds. Other projects such as Greenway are listed in "General Projects."
8 The anticipated $345 million in federal cost share, including SWPP and NAWS, has been used in the previous bienniums; the remaining cost share for projects has been identified as a potential state cost share.

The 1999 plan organizes water needs around watershed boundaries to help foster the understanding of how important watershed-based planning is to coordinated water management. Table 2 summarizes the number of projects and costs by major watershed for all three time frames used in this study.

CONCLUSION

Meeting North Dakota's Water Needs Will Require New Thinking

As suggested earlier, one of the most daunting hurdles to implementing needed water management projects and programs is the cost. Unfortunately, water development and management objectives will not move forward without adequate fiscal resources to support it. As the cost of new projects rises and the money available at federal and state levels decreases, funding mechanisms must also change. North Dakota has a history of financial reform efforts designed to meet water project needs. Specific examples are the bonding legislation proposed in 1979 and an initiated measure in 1991 to dedicate sales tax to water needs. These and other efforts have been unsuccessful.

In addition to building new partnerships, state and local leaders must develop innovative financing arrangements. Bonding for any water project is a policy matter for legislative discussion. What is clear is that North Dakota's water needs are critical and require action in the immediate future. Delay will only increase the costs. The potential economic and social development of the state is dependent on consistent quantities of clean water, and the state has not perfected its claim to Missouri River water. Regardless of the source of funding and associated risks, the state faces a greater risk if it fails to develop its water resources and meet the needs of state residents.

Table 2. Potential General Projects

	No. of Projects	Local	State	Federal	Total
Devils Lake	11	$ 1,042,169	$ 2,326,056	$ 26,000	$ 3,394,225
Red River	63	$ 17, 654,408	$ 14,594,536	$ 21,916,000	$ 54,164,944
Souris River	6	$ 1,278,000	$ 597,000	$ 0	$ 1,875,000
James River	3	$ 94,800	$ 63,200	$ 0	$ 158,000
Missouri River	23	$ 11,663,150	$ 7,714,850	$ 17,235,000	$ 36,613,000
Statewide	1	$ 0	$ 630,000	$ 630,000	$ 1,260,000
Total 1999-2001	**107**	**$ 31,732,527**	**$ 25,925,642**[1]	**$ 39,807,000**	**$ 97,465,169**
Total 2001-2011	**107**	**$ 119,977,500**	**$ 92,100,000**	**$ 27,375,500**	**$ 239,453,000**
Total Beyond 2011	**97**	**$ 196,201,500**	**$ 137,977,500**	**$ 25,845,000**	**$ 360,024,000**

[1] State Water Commission 1999-2001 budget request for general projects is $100.7 million; therefore, resulting in an unmet need of $14.2 million.

RED RIVER BASIN BOARD WATER MANAGEMENT PLAN STATUS

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INTRODUCTION

The Red River Basin Board (RRBB) is a nonprofit corporation dedicated to wise water management in the Red River Basin. It is governed by a 21-member board of directors, whose backgrounds are as diverse as the entities they represent. Most board members represent local units of government. The RRBB charter also calls for appointments by the governors of North Dakota, Minnesota, and South Dakota and by the premier of the province of Manitoba. First Nation representatives serve as full members of the board, together with four at-large delegates.

BACKGROUND

Several factors provided the impetus for creating a mechanism to more effectively deal with water and related land resource issues in the Red River Basin. Chief among them was the decision of the ProGold corn-processing group to locate its plant in southeastern North Dakota. Local leaders learned early that there did not exist within the basin or outside the basin, for that matter, a central place they could go to meet their needs for information. At the same time, state officials charged with administering certain permit processes found no central forum for the discussion of issues regarding the permit applications. Local government leaders from both sides of the international border met in October 1995 and quickly agreed that a meeting to discuss how to better manage the basin's resources should be held early in 1996.

A Red River Basin Leaders Summit held in Grand Forks on February 15, 1996, attracted nearly 240 participants. Following a full day of discussion, basin leaders named an Interim Planning Group (IPG) and charged it with designing a new, locally driven mechanism to facilitate the development of a basinwide water plan and to provide a mechanism for addressing interjurisdictional disputes.

The IPG was charged with determining 1) the appropriate structure for such an organization, 2) the basinwide planning process, and 3) long-term funding needs. To accomplish these objectives, work groups were created for organizational structure, the plan, and core budget.

The Organizational Structure Work Group

This group defined the new entity in terms of its membership, mission, goals, objectives, etc., in sufficient detail to facilitate the completion of Articles of Incorporation and a set of by-laws. With regard to membership, the IPG recommended seven directors from Manitoba, five each from Minnesota and North Dakota, two from South Dakota, and two from the tribal/aboriginal reserves in Manitoba, Minnesota, and North Dakota.

The Plan Work Group

This group was responsible for defining a basinwide planning process to be used in guiding local interests and others in how best to increase future water supplies and identify opportunities for more retention structures. Improving flow management practices and developing a system for establishing priorities based on current science were additional objectives.

The Core Budget Group

This group was given responsibility for identifying a variety of means to provide the funds needed to support—on a sustained basis—the operating budget of such a locally led water management planning mechanism. A variety of funding sources currently supports the work of the RRBB. Sources include the three states and the province together with grants from local units of government and the Federal Emergency Management Agency. A RRBB finance committee continues to identify sustaining sources of funding.

The 1996 Leaders Summit clearly articulated that the objective of the new entity should not be to supplant government agencies having responsibilities for water management in the basin but only to accomplish objectives that government had not seen fit to pursue. The charter meeting of the Red River Basin Board was held in Pembina, North Dakota, on July 24, 1997.

Mission and Goals

The overall mission of the RRBB is to develop and cause to be implemented a comprehensive water management plan for the Red River Basin and to facilitate the resolution of interjurisdictional issues.

Goals to be achieved include 1) increased involvement by local governmental officials and rank-and-file residents of the basin in the water management decision-making process, 2) a more concerted effort to promote cooperation and coordination, 3) the creation of a central access point for information in the basin, 4) a process for consensus building on how issues should be handled, 5) an information–education program that contributes to making informed recommendations, 6) a center for monitoring, planning, and implementation of activities ongoing in the basin, 7) a locally led forum to discuss and seek consensus on water-related issues, and 8) a combined process that facilitates the basin speaking with "one voice."

THE BASINWIDE PLANNING PROCESS

General

The formal planning process adopted by the RRBB was forged initially by the IPG's Plan Work Group. It was endorsed by The International Coalition's Summit Conference held in Winnipeg in November 1996.

The road to be traversed in dealing with water management issues in the Red River Basin is always "under construction." It is a condition certainly not unique to the Red River Basin. Where water management problems and issues exist, numerous forces are at work...tugging first in one direction then in another. Most of the time...though not always...there is some semblance of agreement about the nature and extent of the problems to be resolved, but divergent points-of-view surface quickly when it comes to the matter of "how" to address problems. There is the "brick and mortar" element, if you will, that favor structural solutions. At the other end of the spectrum are those who prefer non-structural remedies in every instance. In the middle of these two are those who say, "leave things as they are; there has already been too much tampering with nature." To complicate things, there is yet a fourth element representing by far the largest single point-of-view. This cross-section of basin residents simply does not care...so long as their basements are dry and there is water at the spigot.[1]

Most of the "technical" solutions are out there. Still, given the diversity of opinion about how to manage the basin's water resources, it is clear that the key to finding solutions is never going to be easy or expeditious. Success in implementing projects and programs is as much a matter of involving, early in the planning process, those who will eventually be impacted by a project or program or policy as it is a matter of having accurate factual information and technical know-how.

To accommodate this reality, components in the RRBB basinwide planning process are designed to ensure that decisions are based on sound, factual data and that basin residents are involved in the decision-making process from the very beginning.

A Consensus-Building Program. This program for validating clear regional goals serves as the cornerstone of the board's planning process. This component involves the development of a set of guiding principles for water management in the basin.

Initially, the responsibility for forging a set of draft guiding principles was delegated to a Guiding Principles Task Force. The first step was to develop a "workbook-questionnaire," which reflected the current policies and objectives of implementing entities, based on information collected over the years by The International Coalition together with other initiatives such as the 1996 Leaders Summit. The workbook was distributed randomly to hundreds of basin residents and to others requesting copies. It addressed all water uses (municipal and industrial, irrigation, self-supplied industrial, rural domestic, etc.) and water management categories (flooding, outdoor recreation, fish and wildlife, drainage, etc.). The workbook included a tear-out survey through which recipients could express their views. Feedback occurred as well through public meetings and the International Summit Conference.

The guiding principles, which were the subject of several months of deliberation and review by a Guiding Principles Task Force and the public, have been approved by the Board of Directors and are being submitted to all levels of government at this time.[2] They are intended to serve two fundamental purposes: 1) as an expression of how the various levels of government should manage the basin's water resources and how problems should be addressed, and 2) as a guide to the board itself in selecting elements for inclusion in its basinwide plan.

A Coordinated Inventory Process. This is a high-priority component of the overall planning process. This initiative involves the identification and compilation of relevant information reflected in earlier studies on some facet of water management problems and issues. For the most part, the planning process is based on existing information. Much of the information needed to assist the board in making wise decisions is already available in the various studies completed over the years and through various government agencies. Most of it is relatively up-to-date and part of a variety of databases

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[1] RRBB meeting minutes, November 6, 1997, Grand Forks, North Dakota.

[2] RRBB meeting minutes, March 4, 1999, Grand Forks, North Dakota.

maintained by the agencies. Additional, more detailed information will be collected as needed.

The inventory process is intended, among other things, as the first step in identifying the basin's water problems. A third important function of the inventory process is to help define a "planning base" or "baseline condition." The basin can be described in terms of a multitude of parameters, including the nature and extent of water resources; current water use by function; land use and ownership; in-place structural features (such as dams, dikes, drainage works, etc.); and nonstructural management features (such as floodplain zoning, water-related outdoor recreation, fish and wildlife, etc.). The baseline condition provides a basis for making comparisons, and it is an important tool in measuring cumulative impacts.

A Problem Identification Procedure. This procedure is employed to more clearly define those problems and potential solutions identified in the inventory process. An important aspect of this is for stakeholders to agree early in the process with the definitions being used by the Problem Identification Work Group. Obstacles to problem solving may occur when contending parties disagree on definitions, including whether or not a problem truly exists, what the nature of the problem is, and whether or not the problem—perceived or real—actually matters. Defining problems is not just a question of semantics. The board recognizes that it is an essential step in the process of solving problems, and all too frequently it has been a step that was either ignored or downplayed in importance. Problem solvers who must deal with "personalized" interpretations of the facts are traveling a perilous road. Time spent shaping alternatives that do not fit real problems is time ill spent.

A Screening Procedure. This procedure documents the current status of projects and programs. If they are judged to have merit for possible inclusion in the basinwide plan, but are not moving forward in terms of implementation, the board identifies steps to be taken to change the status quo. This is a unique feature of the RRBB process, primarily because it is a systematic, third-party approach, which documents actual impediments to progress and seeks agreement among stakeholders on new initiatives for moving projects forward. It is also a mechanism for the board to impact on water management activities before its basinwide planning process is complete.

A Plan Formulation Procedure. This procedure is geared to producing a basinwide plan, which includes components for each functional water use and management category for a succession of benchmark years (2000, 2005, 2010, 2030, and 2050). It provides continuing opportunities for residents to participate in the decision-making process by becoming involved with one or more of several task forces, work groups, and committees. The "early action" program spells out in considerable degree project and program characteristics as measured in economic, environmental, social, and cultural terms. It identifies implementation responsibility and assesses actions in terms of their compatibility with the "guiding principles" alluded to earlier.

The RRBB plan formulation process is unique in that while state/provincial and federal governmental interests are fully involved, primarily local interests drive it. Its uniqueness is further underscored by the fact that actions included in the plan are the result not only of a systematic analysis, which results in a set of findings, but as a consequence of a petitioning procedure. Project sponsors can petition the board to have their project or program included in the basin plan. This means that projects need not "mark time" while the planning process runs its full course. The basinwide plan is—in the truest sense—the product and property of basin residents because it is they who agree upon the guiding principles.

An Implementation Facilitation Feature. This feature was incorporated into the planning process at the outset. It involves a monitoring system to systematically record project and program status through the basin. When they are judged to be compatible with the board's plan and guiding principles, the board will take the initiative in fostering implementation. The board is on record that it intends not only to take positions of support or opposition on individual projects and programs, but that it intends to do both in "a most aggressive manner."

A User-Friendly Water Accounting System. This system will be employed to facilitate timely analysis of various types of actions and levels of development. This feature of the basinwide planning process is a tool that gives decision makers the ability to visualize the hydrologic consequences of taking certain specific actions. It also makes it possible for the Plan Work Group to determine the cumulative impact of a host of alternative "mixes." It is a feature that makes possible the rapid-fire evaluation of a host of possible scenarios.

SCHEDULE AND STATUS

Overview

The Red River Basin Board's planning initiative is the first of its kind in the Red River Basin. That is not to suggest that government has ignored water problems and issues. Indeed, there is a plethora of water-related studies covering every aspect of water management in the basin. The scope of such studies has varied, but it has never been comprehensive or basinwide.

It is fair to say that the Red River Basin Board knows what it wants to do. It agrees about general goals and objectives, it has forged a set of principles to guide its deliberations, and it recognizes that "bottom-up" planning initiatives have the best prospects for implementation. Still, not all of its members have come to fully appreciate the magnitude of what is involved in accomplishing those goals. The board's knowledge and understanding continues to grow.

The board initially approved a timetable for completing its plan by mid-2001. That has now been extended to the end of 2001. Extending the timetable was made necessary by funding uncertainties, questions about staffing, reliance upon a high level of in-kind services, the province of Manitoba's lack of involvement early on, and a host of other factors.

Current Activity and Status

At this time, work associated with the board's planning process is accomplished through several task forces, work groups, and committees.

The Plan Management Work Group. This group guides the activities of all other working groups. Its membership includes three members of the Board of Directors and the team leaders for nine functional planning teams. It facilitates coordination with agency representatives and others. It assists in developing modifications in the planning process, and it brings proposals to the board on any matter thought to improve and accelerate the planning process. The group will function until the basinwide plan is complete.

The Sector Activation Task Force. This task force is charged with organizing sector groups to represent the broadest possible range of interests and stakeholders. Sectors to be formed include local government, agribusiness, water users, business, environment, recreation and tourism, agriculture, and commodities. Core groups have been formed for each sector, and they are responsible for expanding membership and for naming individuals to represent them in the board's working groups. The sector groups will continue to function until the basinwide plan is complete and beyond.

The Guiding Principles Task Force. This task force, mentioned earlier, has completed the development of the board's guiding principles. Its focus now is on the crafting of a series of operating procedures. These procedures are intended to serve as a guide for how the board deals with a variety of administrative and planning issues. It is envisioned that this task force will continue to function on an intermittent but continuing basis as needed.

The Inventory Work Group. This group is organized around nine planning teams, as follows: flood damage reduction, water supply, water quality, drainage, fish/wildlife and outdoor recreation, conservation, hydrology, water law, and institutional. All teams are currently active. Their work, which has been expanded to include detailed problem identification, is projected to be complete in the fall. Planning team participants are, for the most part, representatives of state/provincial and federal agencies. They represent a wide variety of technical and nontechnical disciplines, and their services are provided to the board without cost.

SUMMARY

The Red River Basin Board has charted a new course for local involvement in water and related land resources planning.

It is potentially an agent for genuine change in the fabric of water management in the basin. It continues to mature as an organization, but its success or failure hinges on its resolve to maintain a basinwide perspective, its ability to cast out narrow. self-serving agendas, and a steadfast commitment to excellence.

DEVELOPING WATER STRATEGIES FOR THE RED RIVER BASIN AN UPDATE ON THE RED RIVER WATER MANAGEMENT CONSORTIUM

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INTRODUCTION

When one looks at a map of the drainage basin, it becomes clear that we all share one resource. From Wahpeton to Winnipeg, from Devils Lake to Detroit Lakes, we are connected by the rivers. Water management decisions must reflect this connection. The flood of 1997 clearly illustrated that what happens in one part of the drainage basin affects the other parts, without regard to city, county, state, or national boundaries. Because we all share one resource, wise water management is, by necessity, a process of building partnerships and fostering communication between those who share the river basin. To this end, the Energy & Environmental Research Center (EERC) established a partnership between the U.S. Department of Agriculture (USDA), state and local agencies, and several of the municipalities and industries that rely on the water resources of the Red River Basin to survive and grow. The objective of the partnership was to provide stakeholders with the technical information they need to make prudent water management decisions and provide a forum for them to exchange knowledge.

In March 1996, the Red River Water Management Consortium (RRWMC) was established with an ultimate goal of developing a long-term watershed management strategy for the Red River Basin. Through the years, many attempts have been made to develop water management plans for various portions of the Red River Basin. The approach taken in the formation of the RRWMC was to invite major municipal, industrial, and rural entities throughout the region with a vested interest in water resource issues to join together in directing a technology-based research and planning effort that encompasses the entire Red River Basin. From the initial stakeholder group, a board of directors was established that includes the RRWMC members, an advisory group made up of representatives from state regulatory agencies and local environmental groups, and a USDA representative. The board was formed to ensure that the components of the annual work plan and the technical solutions proposed for those work plan items are realistic from governmental, regulatory, and business perspectives.

The RRWMC is distinguished from many other groups currently dealing with water management issues in that the focus is strictly on providing members with information. The RRWMC provides its members with the information they need to make decisions in the context of the latest scientific data and a basinwide perspective. While others seek to develop plans that make water management decisions for stakeholders, the RRWMC seeks to give members all of the tools needed to develop their own strategies.

APPROACH

Under the direction of the founding consortium members, a work plan outline was developed consisting of activities in the following areas:

- Technology assessment, development, and demonstration
- Water resource assessment and analysis
- Agricultural, industrial, municipal, and recreational impacts on water resources
- Water resource monitoring
- Education and information dissemination
- Development of a watershed management strategy

Funding for the program is provided through federal grants secured through the USDA and leveraged by annual membership fees. Annual RRWMC research activities are developed and directed by the members within the framework of the six major tasks initially identified, each task having its own unique background and objectives.

The members of the consortium and the advisory board are called together two times per year. The annual meeting is used to kick off a new operational year and review the results of research performed during the previous year. A tentative work plan for the next operational year is also developed during the annual meeting. Copies of an annual report that details the research conducted during the previous year are distributed. A semiannual meeting, held at about the midpoint of the operational year, is designed to provide an update on progress of research to date, review the status of the budget, and provide an opportunity to introduce new members, discuss new issues, or make minor adjustments to the work plan.

Specific Task Structure

Task 1– Technology Assessment, Development, and Demonstration. Task 1 seeks to find solutions to water-related issues by either implementing new technologies or evaluating existing alternative processes. Water-related problems are identified by consortium members, and the RRWMC then identifies or develops technological solutions. The technologies are tested and/or assessed to determine if they are technically and economically feasible. The goal is to identify innovative operational practices or processes and improved or alternate technologies to the members. This will ensure that members have all of the information needed to make sound management decisions on implementing new technologies.

Task 2 – Water Resource Assessment and Analysis. Considerable information is available on the water resources of the Red River Basin. Numerous studies have been performed on a variety of issues, including watershed management, flooding, drought, water supply concerns, and environmental problems. Water quality and quantity data have been collected through the monitoring programs of the various regulatory agencies operating in the region, along with other federal and state agencies. In addition, monitoring data have been generated from more focused projects performed by various groups within the basin. Unfortunately, much of this information is not readily available to those individuals who need access to water-related data specific to critical management decisions. Additionally, different data sets are sometimes used by different parties when discussing issues, resulting in confusion and conflicting conclusions. The objective of Task 2 is to provide consortium members with access to data and related monitoring information so that scientifically valid management decisions can be made on important issues that impact the water resources of the basin.

Task 3 – Agricultural, Industrial, Municipal, and Recreational Impacts on Water Resources. New and more stringent federal regulations governing drinking water and receiving water quality are making it more difficult for municipalities to meet drinking water quality standards and for industry and municipalities to meet wastewater discharge limits. Changes in agricultural production and the introduction of new value-added agricultural processing facilities are adding to the demand on the existing water resources in the basin. Municipalities and rural water systems within the basin, especially along the Red River mainstream corridor, continue to grow. There is a valid concern for certain systems in the basin with respect to meeting expected water demands during future dry cycles similar to that experienced during the 1930s. Continued growth and economic development in the region will require an informed knowledge base with respect to basin water resource information.

This task provides the members with a current assessment of the demands on water resources in the basin, water resource supply alternatives, and research into processes that will lessen the impacts of human activities associated with the basin water resources. The original objective of Task 3 was to assess the current and future water quality and quantity requirements of agriculture, industry, and municipalities in the Red River Basin. The objective has since expanded to include innovative means of dealing with water quality and quantity issues.

Task 4 – Water Resource Monitoring Program. Water resource monitoring is necessary to protect human health and to address water supply and quality problems for sustained, environmentally responsible economic development. Presently, no basinwide strategy exists for monitoring water quality in the Red River Basin. Although numerous monitoring efforts are currently in place, there is little or no coordination of efforts. The lack of a coordinated monitoring effort within the basin may result in duplication of work, wasting limited financial resources for collecting needed data. This task aims to work with federal and state agencies and other entities that have monitoring programs to coordinate the use of resources in order to get the best and most complete information and data possible. The overall objective of Task 4 is to develop a coordinated monitoring effort that will address long-term water quality issues in the basin as well as short-term problems identified by consortium members.

Task 5 – Education and Information Dissemination. An integral component of this water management program is to provide a forum dedicated to identifying and discussing relevant water-related issues. This forum is structured toward a broad sharing of data, information, experience, technology, and perspectives on key issues of importance targeted by consortium members and the advisory group. A component such as this helps to foster partnerships and raise the level of awareness in the water resource community. A proactive water management strategy is maintained through education and the open exchange of information and expertise. These activities allow members to be involved in the maintenance of an environmentally sound water resource management process. The task also allows for the sharing of consortium technologies and experiences with other groups at regional and national gatherings, and the opportunity to keep abreast of new developments in watershed management outside of the Red River Basin for the benefit of the consortium members. The goal of Task 5 is to facilitate the sharing of ideas and generate discussion on water-related issues important to the members, report on the results of task-specific research, provide members with a presence at various meetings and symposia, and inform other interested parties of RRWMC activities.

Task 6 – Development of a Watershed Management Strategy for the Red River Basin. Task 6 makes use of the results of Tasks 1 through 5 to develop an overall watershed management strategy for the basin. The emphasis will be on the development of a strategy rather than a plan. This distinction is important to making tangible progress in resolving present and future water management issues. Rather than making decisions for the RRWMC members, the watershed strategy will provide consortium members with the information that they need to make informed decisions as new opportunities and challenges arise. The objective of this task is to develop an evolving strategy for water management in the Red River Basin that will guide management decisions now and into the future.

RESULTS AND DISCUSSION

The RRWMC is currently beginning its fourth year of operation. During the initial 3 years, a considerable amount of work has been performed addressing a wide range of topics. All of the work items have fallen under one of the six operational tasks described above and were developed at the request of one or more of the consortium members. Table 1 shows the growth in membership, as well as the makeup of the advisory board, from the initiation of the program to present. As Table 1 shows, consortium membership has increased steadily. Increased interest in the program is also reflected in the addition of some key advisory board members, as shown in Table 2.

As mentioned, a wide variety of work tasks have been requested and completed over the first 3 years of operation. Certain of the requested subtasks have proven to be extremely beneficial, not only for the requesting member, but also for others outside of the basin with similar problems. Some of the more significant work plan items are discussed below, with the subheadings giving an indication of the operational year in which the work was performed and the corresponding subtask designation.

Year 1

Subtask 1.1 – Evaluation of the Technical Feasibility of the Freeze–Thaw Process for Minn-Dak First-Pass Yeast Plant Wastewater. Minn-Dak Farmers Cooperative, Wahpeton, North Dakota, operates a yeast production plant from byproducts derived from the beet sugar-refining process. One of the waste streams from the yeast plant contains high concentrations of dissolved solids and organics, which raised questions about treatment and disposal. The natural freeze–thaw (FT) process being developed as a collaboration between the EERC and B.C. Technologies, Laramie, Wyoming, appeared to be a good fit for treatment of this waste stream. A bench-scale FT simulation using samples of Minn-Dak yeast plant wastewater demonstrated the technical feasibility of the process for treating the high-strength wastewater. Product water yields from the simulation were about 67% of the original feed volume, with the majority of the dissolved solids and organics concentrated in a brine volume of 28%.

Subtask 2.1 – Inventory of Surface and Groundwater Quantity and Quality Data. An important step in the accumulation of water quality and quantity for the Red River Basin was the purchase of the Red River Hydrodata® GeoSelect® CD-ROM from Hydrosphere Data Products, Inc. The single CD-ROM contains water quality data derived from the EPA's STORET database and water quantity data from the U.S. Geological Survey WATSTORE database for the states of Minnesota and North and South Dakota. Those portions of the three states drained by the Red River and her tributaries contain 5000 reporting stations, which are included in the Hydrosphere database. The data contained in the Hydrosphere database can be easily exported to common spreadsheet format for convenient data manipulation and presentation and have proven to be extremely helpful to several of the consortium members at various times.

Table 1. Red River Water Management Consortium Members, Years 1–3

Year 1	Year 2	Year 3
City of Fargo	City of Fargo	City of Fargo
City of Grand Forks	City of Grand Forks	City of Grand Forks
Red River RC&D[1]	City of Moorhead	City of Moorhead
Pembina Trail RC&D	Grand Forks County	City of East Grand Forks
Lake Agassiz RC&D	Red River RC&D	Grand Forks County
Simplot	Pembina Trail RC&D	Red River RC&D
American Crystal Sugar Company	Lake Agassiz RC&D	Pembina Trail RC&D
ProGold	Simplot	Lake Agassiz RC&D
Minn-Dak Farmers Cooperative	American Crystal Sugar Company	Simplot
	Cargill (formerly ProGold)	American Crystal Sugar Company
	Minn-Dak Farmers Cooperative	Cargill
		Northern States Power
		North Dakota Pigs Cooperative

[1]Resource Conservation and Development Council.

Table 2. Red River Water Management Consortium Advisory Group, Years 1–3

Year 1	Year 2	Year 3
U.S. Department of Agriculture	U.S. Department of Agriculture	U.S. Department of Agriculture
ND State Health Department	ND State Health Department	U.S. Environmental Protection Agency
ND State Water Commission	ND State Water Commission	U.S. Fish and Wildlife Service
MN Department of Natural Resources	MN Department of Natural Resources	ND State Health Department
MN Pollution Control Agency	MN Pollution Control Agency	ND State Water Commission
Manitoba Environment	Manitoba Environment	MN Department of Natural Resources
The International Coalition	The International Coalition	MN Pollution Control Agency
	Sierra Club	Manitoba Environment
		The International Coalition

Subtask 3.4 – Use of Natural Processes for Improving Water Quality. This subtask focused on the development of a strategy to inventory and assess the quality of riparian areas in the Red River Basin. The work begun under this work item during Year 1 continues and has actually expanded to include RRWMC participation with other groups in the basin working to restore riparian areas in a number of different watersheds.

Year 2

Subtask 1.1 – Facilitation of Odor Control Demonstration at American Crystal Sugar Company, East Grand Forks, Minnesota. American Crystal Sugar Company (ACS) expressed an interest in testing an odor control concept originally developed for the Canadian hog industry. The technique, developed for one-half-acre manure lagoons, makes use of barley straw as a self-supporting biocover to reduce the transfer of odorous compounds from wastewater to the air. The ACS demonstration proved that the barley straw lagoon cover concept was feasible and effective for ponds as large as 5 acres. The demonstration also provided insight on factors that help to insure a durable, long-lasting cover. ACS is now using the technique at a number of its factories to help reduce chronic odor problems associated with the wastewater ponds.

Subtask 1.4 – Runoff/Detention Study for the Simplot Soil Builders Plant in Langdon, North Dakota. Simplot owns and operates a bulk fertilizer distribution facility near Langdon, North Dakota. Fugitive dust and minor spillage during fertilizer transfer operations creates the potential for nutrient transfer from the facility's buildings and grounds off-site with precipitation and runoff events. Untreated runoff can potentially enter a drainage ditch that slopes toward the city's water supply reservoir. An investigation of the transfer facility, operating practices, and surrounding topography resulted in recommendations for possible mitigation options for both plant operations and stormwater remediation alternatives.

Subtask 2.1 – Data Accessibility. A geographic information system (GIS) capability was added to the RRWMC during Year 2 to provide consortium members with the means to portray and analyze data in a geographic format. GIS services were provided to the Red River Regional Council through the Red River RC&D to produce maps for a final report on the Homme, Renwick, and Mt. Carmel watersheds in northeast North Dakota. The final product involved the integration of various data layers from multiple sources. The data layers included hydrology, the local road system, the watershed boundaries, and distribution of various land practice areas.

Subtask 4.2 – Provide Assistance in Developing Water Quality Monitoring Programs. One of the goals of Task 4 was to help coordinate water quality monitoring activities within the basin. As a first step, information on monitoring activities of the consortium members was to be assembled and updated as needed. During Year 2, the monitoring requirements of all of the industrial members was collected and presented, with similar information from other applicable members to be collected in subsequent years.

Subtask 5.1 – Storm Drain Stenciling Project. A storm drain stenciling project was held in a portion of Grand Forks to promote environmental education and public awareness of stormwater pollution. A team of volunteers from the city of Grand Forks and the EERC joined to paint a pollution prevention message next to a total of 233 storm drains and distribute informational flyers door-to-door in an area covering approximately one-half square mile.

Year 3

Subtask 1.1 – Alternative Treatment/Beneficial Reuse of Water Treatment Plant Sludges. Recent discussions involving the new Grand Forks levee alignment and a possible relocation of the water treatment plant have provided the impetus to evaluate alternative and/or innovative sludge plant dewatering options. A number of alternative residuals dewatering processes were identified, with indications that a natural FT treatment process warranted additional investigation. References indicated that FT treatment showed good promise for excellent dewatering of low-solids-content alum sludges. Bench-scale FT testing of sludge samples collected at the Grand Forks Water Treatment Plant showed similar positive results that were corroborated by results from the city of Duluth, Minnesota, which operates a commercial-scale sludge FT operation.

Subtask 1.6 – Special Topics: Activities Completed for the North Dakota Pigs Cooperative. The NDPC owns and operates a 5200-head hog-farrowing facility located approximately 7 miles northwest of Larimore, North Dakota, commonly referred to as EnviroPork. A number of issues were addressed for NDPC, including groundwater and odor monitoring, manure lagoon cover installation, an evaluation of the integrity of the lagoon liner, and assessment and implementation of odor control measures for ventilated barn odors. A significant product of this effort was the design and construction of an innovative filter wall to reduce odors of tunnel ventilation exhaust. The filter walls, which proved to be successful for control of odors from the gestation barns during warm weather operation, are a completely new odor mitigation technique that has never before been utilized in North America.

Subtask 2.3.2 – Spiritwood Aquifer Assessment. Research on the Spiritwood Aquifer, located in eastern North Dakota, continued during Year 3 and expanded on introductory work performed during the previous year. Results showed the potential of the aquifer as an alternative water supply source for demands within the Red River Valley, with that portion of the aquifer lying beneath Griggs and Barnes counties showing the best promise in terms of additional appropriations and proximity to end users. These investigations were based on county water reports and must be considered as preliminary. Considerable additional work needs to be completed to define the quantity and quality characteristics of the resource at different points in the system.

Subtask 3.6 – Investigation of Reuse Alternatives for Treated Effluent from the Moorhead, Minnesota, Wastewater Treatment Plant. As a result of a total maximum daily load (TMDL) process nearing completion for the Red River at Moorhead, the city may have to reduce treated effluent discharge volumes during certain periods of low river flow. The city is currently considering a number of alternatives to accomplish the required flow/load reductions. The purpose of this subtask was to evaluate and report on additional alternatives for reducing load impacts to the Red River. Some of the alternatives identified included water conservation, rate restructuring, reuse, storage, groundwater recharge, and innovative effluent treatment.

SUMMARY

The Red River Water Management Consortium has completed 3 years of operation and is currently entering its fourth. The task structure established by the consortium coordinators and founding members provides a guideline for the identification of water-related issues and problems important to consortium stakeholders. The program is unique in its funding mechanism that leverages membership fees with federal dollars to provide a technically based research service. The research performed under this program provides RRWMC members with the information and tools that they need to make educated decisions regarding water management using up-to-date scientific data within a basinwide perspective. In this manner, members of the RRWMC can develop the strategies that they need to deal with water-related issues now and into the future.

MUNICIPAL, RURAL, AND INDUSTRIAL WATER NEEDS IN EASTERN NORTH DAKOTA AN APPRAISAL-LEVEL STUDY

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In 1994, under the direction of the Executive Steering Committee of the North Dakota Water Management Collaborative Process, Reclamation began an appraisal-level study to investigate and evaluate existing and future municipal, rural, and industrial (MR&I) water use in the Red River Valley of North Dakota and in three cities located along the Red River in Minnesota. Ten cities were identified as the municipal component of the study. These cities are Drayton, North Dakota; Fargo, North Dakota; Grafton, North Dakota; Grand Forks, North Dakota; Valley City, North Dakota; Wahpeton, North Dakota; West Fargo, North Dakota; Breckenridge, Minnesota; East Grand Forks, Minnesota; and Moorhead, Minnesota. Future water supply demands were estimated by projecting population, per capita water use, and industrial water use trends. Population projections indicate that the Red River Valley region will continue to grow over the next 50 years. The population and industrial projections indicate that continued growth in urban areas will contribute to a significant increase in overall water demand. The economic strength of the area will likely cause industrial activity to grow, particularly in the agricultural products-processing area. Based on surface water availability analyses, significant future municipal shortages would occur in Fargo and Moorhead if a drought comparable to the 1930s reoccurred. Also, the availability of water supplies for new stand-alone industrial facilities are severely limited in the future under both normal and dry climatological sequences.

SOCIOECONOMIC AND LAND USE TRENDS IN THE RED RIVER BASIN

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The drainage basin of the Red River of the North encompasses all or part of 46 counties in North Dakota (24 counties), Minnesota (20 counties), and South Dakota (2 counties). The purpose of this paper is to briefly review recent economic, demographic, and land use trends in this region.

ECONOMIC TRENDS

The economy of the Red River basin has been growing over the past two decades, as indicated by the change in employment in the region. Over the period 1980-1996, total employment in the 46-county region increased by 26.8 percent. Wage and salary employment grew by 30 percent while proprietors' employment increased 17 percent (Table 1).

Employment grew in most of the major sectors of the regional economy, with the services sector registering the largest percentage increase (66%), as well as the largest number of new jobs (46,340). The manufacturing sector has the next highest rate of growth, an increase of 54.5 percent or 14,268 jobs. Other sectors with growth rates higher than the overall average included construction (34%) and retail trade (28%). The growth of the services sector reflects both the national shift of employment from goods-producing to services-producing sectors and the growth of services as an export activity for the Red River basin. Particularly over the last decade, a variety of service sector firms have established facilities in the region that are intended to serve regional and/or national markets. The export of these services (e.g., telemarketing, data processing) results in a flow of income into the region similar to that associated with exports of agricultural commodities or manufactured products.

Agriculture was the only major sector of the regional economy that did not register employment growth during the period 1980-1996. Farm employment decreased about 26 percent during this period, a decrease of about 14,427 jobs (i.e., farm proprietors and/or hired workers). The decrease in farm employment reflects the continuing trend of mechanization in the farm sector, with fewer and larger farms.

While the region as a whole experienced substantial employment growth, this growth was not uniformly distributed. Of the 24 North Dakota counties in the basin, only 4 had rates of employment growth above the regional average, 13 had positive growth rates which were less than the regional average, and 7 recorded decreases in total employment from 1980 to 1996. Of the 20 Minnesota counties, 7 had above average employment growth, 7 had rates that were positive but less than the regional average, and 6 had employment decreases from 1980 to 1996. The two South Dakota counties had rates of employment growth that were positive but less than the regional average. The high growth counties included Cass and Grand Forks Counties in North Dakota. These two metropolitan (metro) counties accounted for more than 48,000 new jobs during 1980-1996, more than half of the region's total job growth. Cass County alone accounted for 37 percent of total regional employment growth. The other two North Dakota counties that fell into the high-growth category (Richland and Rolette) both benefitted from substantial increases in manufacturing and exported services employment. Among Minnesota's high-growth counties, Roseau County benefitted from a more than four-fold increase in manufacturing employment while Mahnomen County experienced more than five-fold growth in its services sector (which in large measure resulted from a new casino). The other five high-growth counties (Becker, Beltrami, Clearwater, Lake of the Woods, and Ottertail) all are in areas with substantial recreation and second home development.

Per capita income is another key indicator of economic conditions. The counties of the Red River basin have achieved moderate rates of per capita income growth over the past two decades. From 1976 to 1996, the study area counties' per capita income (adjusted for inflation) increased 35.5 percent, on average (Table 2). The rate of growth ranged from 26 percent for Minnesota counties to 60 percent for South Dakota counties, which also started from a substantially lower income level. Over the period 1986-1996, the growth in per capita income for each of the three state's portions of the study area was between 15 and 16 percent.

The growth of per capita income in the Red River basin counties compares favorably with national rates over the same period. For 1976-1996, U.S. inflation-adjusted per capita income increased 33.8 percent, compared to 35.5 percent for the basin counties. For 1986-1996, U.S. per capita income grew 14.5 percent, compared to 15.6 percent for the basin. However, per capita income levels in the region continue to lag behind national levels. In 1996, the basin average of $19,137 was only 78 percent of the U.S. level; in 1976, basin average per capita income was 77 percent of the U.S. average.

Table 1. Employment by Sector, Red River Basin Counties, 1980-1996

Sector	1980 Number	1980 Percent	1996 Number	1996 Percent	Percent Change 1980-1996
Wage and Salary Employment	264,318	74.1	344,098	76.0	30.2
Proprietors' Employment	92,565	25.9	108,385	24.0	17.1
Total Employment	356,883	100.0	452,483	100.0	26.8
Employment for Selected Sectors:					
Farm	54,935	15.4	40,508	8.9	-26.3
Construction	17,704	5.0	23,763	5.3	34.2
Manufacturing	26,170	7.3	40,438	8.9	54.5
Transportation & Public Utilities	17,758	5.0	21,698	4.8	22.2
Wholesale Trade	19,026	5.3	22,357	4.9	17.5
Retail Trade	60,756	17.0	77,812	17.2	28.1
Finance, Insurance, & Real Estate	20,365	5.7	25,633	5.7	25.9
Services	69,946	19.6	116,286	25.7	66.3
Government	66,732	18.7	72,120	15.9	8.1

Source: (1)

DEMOGRAPHIC TRENDS

The population of the Red River basin has been increasing during the 1990s, after a period of population decline in the 1980s. The population of the 46-county region grew from 688,447 in 1970 to 728,518 in 1980, fell to 714,453 in 1990, and then increased to 730,527 in 1996 (Table 3). Both North Dakota and Minnesota sub-regions have followed this general pattern, while the South Dakota counties recorded population decreases for all three time periods.

Net migration has been a key factor in the region's population change. During the 1970s, the region had substantial net in-migration (i.e., more people moved to the area than moved away). During the 1980s, the situation was reversed, and substantial net out-migration occurred. During the 1990s, the basin again has experienced net in-migration.

While region-wide population statistics reflect a pattern of moderate population growth, substantial population shifts have been occurring within the region. For example, the 46-county region recorded a population gain of 42,080 (6.1%) from 1970 to 1996, but over this period only 12 of the 46 counties (4 in North Dakota and 8 in Minnesota) registered population growth. Within North Dakota, the two metro counties (Cass and Grand Forks) accounted for a combined population growth of 49,270 from 1970 to 1996, while the 22 nonmetro counties together lost 30,584. In Minnesota, the counties with population growth were those identified earlier as having high rates of employment growth, plus Clay County (part of the Fargo-Moorhead metro area).

The age distribution of the region's population has also been shifting, with older persons accounting for a growing share of the population. The proportion of the population over age 65 for the region as a whole rose from 12.3 percent in 1970 to 15.4 percent in 1997 (Table 3). At the same time, the proportion of the population age 19 and under has been decreasing.

LAND USE TRENDS

The Red River basin counties have a land area of about 34.8 million acres (Table 4). Agriculture is the dominant land use in much of the region. In 1997, about two-thirds of the basin's total land area was included in farms. This percentage ranged from 87 percent for South Dakota counties to 47 percent for the Minnesota counties. The proportion of land in farms varied substantially on the Minnesota side of the basin, ranging from 4 percent in Koochiching County and 6 percent in Itasca County to 95 percent in Wilkin County and 87 percent in Clay County. In North Dakota, there was much less variability as the percentage of land in farms ranged from 79 percent in Sheridan County to 94 percent in Cass County.

Crop production is the major use of agricultural land in the basin. In 1997, about 71 percent of land in farms was harvested cropland, ranging from 73.5 percent in North Dakota to 55.3 percent in South Dakota. The acreage of cropland harvested in 1997 was nearly the same as that recorded in 1978.

A definite trend in agricultural land use over the past two decades has been an increase in irrigated acreage. From 1978 to 1997, irrigated acreage expanded by 71 percent in North Dakota and 72 percent in Minnesota. However, in 1997 irrigated acreage

Table 2. Per Capita Income for Red River Basin Counties, 1976-1996

Item	North Dakota Counties	Minnesota Counties	South Dakota Counties	All Basin Counties
Per Capita Income (1996 dollars):				
1976	15,854	15,383	11,132	14,121
1986	17,546	16,715	15,402	16,555
1996	20,197	19,389	17,824	19,137
Percent Change:				
1986-96	15.1	16.0	15.7	15.6
1976-96	27.4	26.0	60.1	35.5

Source: (1)

Table 3. Demographic Trends in the Red River Basin, 1970-1997

Item	North Dakota Counties	Minnesota Counties	South Dakota Counties	Basin Total
Population:				
1970	333,272	337,532	17,643	688,447
1980	347,518	364,685	16,315	728,518
1990	347,371	352,324	14,758	714,453
1996	351,958	364,013	14,556	730,527
Percent Change:				
1970-80	4.3	8.0	-7.5	5.8
1980-90	-0.1	-3.4	-9.5	-1.9
1990-96	1.3	3.3	-3.3	2.2
1970-96	5.6	7.8	-17.5	6.1
Percent of Population Over Age 65:				
1970	11.8	12.7	15.5	12.3
1997	14.2	16.4	19.4	15.4

Source: (2)

Table 4. Land Area, Land in Farms, Cropland, Irrigated Land, and Number of Farms, Red River Basin Counties, 1978-1997

Item	North Dakota	Minnesota	South Dakota	Basin Total
Land Area (000 acres):	17,531	16,028	1,242	34,800
Land in Farms, 1997:				
Acres (000)	14,879	7,472	1,076	23,426
Percent of Land Area	84.9	46.6	86.6	67.3
Cropland Harvested, 1997:				
Acres (000)	10,941	5,196	595	16,732
Percent of Land in Farms	73.5	69.5	55.3	71.4
Irrigated Land, 1997:				
Acres (000)	84	91	3	177
Percent of Cropland Harvested	0.8	1.8	0.5	1.1
Number of Farms, 1997	10,475	8,244	971	19,690
Percent Change:				
1978-1997	-46.4	-55.3	-41.6	-50.3
1987-1997	-36.0	047.2	-35.9	-41.2

Source: (3)

still represented only 1.1 percent of all cropland harvested in the basin (1.8 % for Minnesota counties, 0.8 % for North Dakota).

Another major trend in the agricultural sector has been a decrease in the number of farms. From 1978 to 1997, the total number of farms in the basin counties decreased by 50.3 percent, with the largest decrease (55.3%) occurring in the Minnesota counties. Most of this decrease has occurred in the period 1987-1997 (Table 4).

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PEMBINA RIVER BASIN – BUILDING CONSENSUS FOR A SUSTAINABLE FUTURE

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The Pembina River watershed (drainage basin), which covers 3959 square miles, is one of the 24 subbasins that make up the Red River Basin (excluding the Assiniboine River Basin). The Pembina River Basin lies in the south-central portion of the Province of Manitoba in Canada and in the northeastern part of the state of North Dakota in the United States.

The Pembina River is one of the major tributaries of the Red River. Fifty-one percent of the watershed area, or 2002 square miles, is in Canada, and 49 percent, or 1957 square miles, is in the United States. The basin length (east and west) is about 130 miles, and its width (north and south) varies from a maximum of about 35 miles in the western portion to about 18 miles in the eastern portion.

The Pembina River has its source about 10 miles south of Boissevain, Manitoba. The main stem flows easterly across southern Manitoba, then southeasterly across the international boundary into North Dakota, after which it turns eastwardly again in a winding course across northern North Dakota. About two miles south of the international boundary near Pembina, North Dakota, the river empties into the Red River. The total length of the Pembina River is about 310 miles. The river begins at an elevation of approximately 2000 feet above sea level (asl) and empties into the Red River at 750 feet asl. The river gradient is steepest in the Manitoba portion of the watershed. The principal tributaries of the Pembina River are Badger Creek, Long River, Little Pembina River, and Tongue River which have drainage areas of 832, 293, 182, and 479 square miles, respectively.

The health of the Pembina River Basin needs to be improved. The economic damage, social problems, and international concerns brought about by major floods as well as water quality and water quantity issues have brought some people together to establish, in 1998, the Pembina River Basin Advisory Board (PRBAB). During the last 60 years, many studies and reports have been completed on the water and related land resource problems in the Pembina River Basin. However, no comprehensive water management plan for the Pembina River Basin has been developed. The purposes of the PRBAB are "to develop and to cause to be implemented a comprehensive water management plan for the Pembina River Basin, and to facilitate and pursue the resolution of interjurisdictional issues."

I believe that the process of consensus-based decision making could be used by the PRBAB in achieving its purposes. There are numerous difficult conflicts in the basin at this time, and the consensus process is very useful when integrated decision making is needed and when environmental, economic, and social needs are complex. There are four basic steps in a consensus process (1):

- Assessment – Talking About Whether to Talk
- Getting Started – Talking About How to Talk
- Running the Process – Talking
- Implementing and Monitoring the Results – Turning Talk into Action

In order to achieve the goals of sustainable development in a watershed, the "Consensus Process" should be considered for use. It is a process that will reward the expenditures of people's time and effort by generating creative and lasting solutions to complex problems.

With the formation of the PRBAB in March 1998, the first step in the consensus process is well under way. The challenge of the PRBAB is now in completing the second step—Getting Started – Talking About How to Talk. Starting a consensus process requires taking time to identify the participants. The task consists of two parts—identifying the interests and then identifying the appropriate representatives of those interests.

To identify the interests, it is essential to focus on groups affected by the decision and those with the power to implement or block potential outcomes.

To identify the representatives, it is important to consult with various agencies, organizations, businesses, etc., to develop a sense of who is viewed with credibility as a leader or as an accepted spokesperson and identify existing or potential mechanisms that will enable participants to represent their groups or organizations. Reaching agreement on how to proceed provides participants with an opportunity to practice and experience reaching agreement before they address the issues.

The third step is talking, that is, discussing the issues and developing the action plan, or in this case, the comprehensive water management plan for the Pembina River Basin. The process of talking among the parties proceeds according to ground rules established in the second step. A degree of flexibility must be maintained in order to foster consensus. Implementation is the fourth step, that is, turning talk into action.

Consensus processes are participant-determined and driven – that is their very essence. The same approach may not work for each situation because of the varying issues involved, the conflicting interests, and the surrounding circumstances. Experience points to certain characteristics which are fundamental to consensus; these are referred to as the guiding principles. The Roundtables on the environment and economy in Canada developed the following ten principles:

- **Principle 1 – Purpose-Driven**
  People need a reason to participate in the process.

- **Principle 2 – Inclusive Not Exclusive**
  All parties with a significant interest in the issue should be involved in the consensus process.

- **Principle 3 – Voluntary Participation**
  The parties who are affected or interested participate voluntarily.

- **Principle 4 – Self-Design**
  The parties design the consensus process.

- **Principle 5 – Flexibility**
  Flexibility should be designed into the process.

- **Principle 6 – Equal Opportunity**
  All parties must have equal access to relevant information and the opportunity to participate effectively throughout the process.

- **Principle 7 – Respect for Diverse Interests**
  Acceptance of the diverse values, interests, and knowledge of the parties involved in the consensus process is essential.

- **Principle 8 – Accountability**
  The parties are accountable both to their constituencies and to the process that they have agreed to establish.

- **Principle 9 – Time Limits**
  Realistic deadlines are necessary throughout the process.

- **Principle 10 – Implementation**
  Commitment to implementation and effective monitoring are essential parts of any agreement.

A consensus process is one in which all those who have a stake in the outcome aim to reach agreement on actions and outcomes that resolve or advance issues related to environmental, social, and economic sustainability. In a consensus process, participants work together to design a process that maximizes their ability to resolve their differences. Although they may not agree with all aspects of the agreement, consensus is reached if all participants are willing to live with the "total package."

Consensus processes do not avoid decisions or require giving up leadership, but call upon leaders to forge partnerships that work toward developing solutions. A consensus process provides an opportunity for participants to work together as equals to realize acceptable actions or outcomes without imposing the views or authority of one group over another. There are many forms that a consensus process can take. Each situation, issue, or problem prompts the need for participants to design a process specifically suited to their abilities, circumstances, and issues.

The impact of decisions involving the quality of life for current and future generations have prompted many people to demand the right to meaningfully participation in decision-making processes. Consensus processes ensure that the people affected are involved from the start in identifying and agreeing on issues, sharing different perspectives, and making choices with which people can live.

The future decisions we face in water management within the Pembina River Basin demand that we find ways to listen to opposing points of view and accommodate deeply held and differing views. We know from past experiences that the conventional/traditional decision-making mechanisms tend to exclude rather than include diverse interests and do not cope well with the complexity that issues of sustainability present.

The PRBAB, as it begins to nurse the basin back to health, will be addressing the challenges of a sustainable future by using the consensus process.

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A COMPREHENSIVE AND MULTIPURPOSE APPROACH TO WATERSHED MANAGEMENT – A CONCEPT

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INTRODUCTION

The Red River of the North Basin in the United States and the Devils Lake Basin cover about 38,800 square miles. The area was originally a large expanse of tall or mixed grass prairies, riparian woodlands, tracts of pine and hardwood woodlands, and a complex of prairie wetlands, lakes, rivers, and streams (1). At the heart of the Red River Basin is the Red River, which starts at the confluence of the Otter Tail and Bois de Sioux Rivers. Its meandering path stretches out for 394 miles up to the Canadian border (2). At the bottom of the Devils Lake Basin lies the state's largest natural lake, Devils Lake, which fluctuates dramatically. In modern times, Devils Lake has been at a low of 1400.9 ft mean sea level (msl) in 1940 and reached its record high of 1444.7 ft msl in 1998. In the last 5 years, Devils Lake has risen 22 ft, from 1422.6 ft msl in 1993 to 1444.7 ft msl in 1998 (3).

Today, this large area harbors a host of land uses and land cover types. Currently about 74 percent of the land area in the Red River Basin is being utilized for agricultural production. The remaining 26 percent of the basin is occupied by forests (12 percent), water and wetlands (4 percent), urban land (3 percent), and various other land uses (7 percent). Agricultural cropland is the predominant land use (2).

As of late, water and water management issues have been a dominant topic in the Devils Lake and Red River basins. The historic flood of 1997 in the Red River Valley and the ever-growing flooding issues in the Devils Lake region, which started in 1993 and continues today, are major concerns. Many individuals, businesses, communities, organizations, politicians, and government agencies are looking for solutions and hope for improved conditions. Improved conditions for economic growth, agriculture, recreation/tourism, and the human environment is occupying the interest of many leaders, economic sectors, and professionals. Implementation of actions to resolve the issues appear to be advancing slowly, and the patience of many is dwindling. In addition to the water issues, another concern is the agricultural economy and its effects on the future of farming and the overall economy.

CURRENT SOLUTIONS AND PROCESSES

The Red River Basin has many organizations and agencies working to address the future management of water and the reduction of flooding in its watershed. The Red River Basin Board is working on developing a comprehensive basinwide planning effort. They are developing guiding principles and have nine plan inventory teams dealing with flood damage reduction, water supply, water quality, drainage, fish/wildlife and outdoor recreation, conservation, hydrology, water law, and institutional similarities and differences. Their ultimate goal is the implementation of a comprehensive plan. There is also The International Coalition, the International Joint Commission, the Red River Joint Basin Board, the Red River Water Management Consortium, and various water boards or watershed districts all involved in Red River issues.

Projects being discussed or implemented in the Red River Basin by various entities include diking in several communities, diversions, water storage, relocation out of flood-prone areas, greenway developments, building dams, drainage developments and cleanouts, clearing and snagging, riparian enhancements, buyouts along the river in rural locations, rural diking concepts, the "waffle" concept, and many more.

In the Devils Lake Basin, a lot of coordination has taken place and the state of North Dakota and various federal agencies have settled on a three-part approach to solving the Devils Lake flooding issue. These include completing upper basin management and storage, infrastructure protection and maintenance, and construction of an outlet from Devils Lake to the Sheyenne River (4). The current strategy is to store 75,000 acre-feet of water in the upper basin, build up major roads and highways, construct the Devils Lake dike to 1457 ft msl to afford protection to 1450 ft msl, and construct a buried pipeline outlet to remove water out of Devils Lake and into the Sheyenne River at a rate of 300 cubic feet/second (cfs). In some recent meetings, a fourth approach to managing the flood is to include a "contingency plan," although no formal agreement has been reached as to what this means. Ideas include building an outlet from Devils Lake to Stump Lake, installing a fixed weir out of Stump Lake to allow flows to move freely downstream to the Sheyenne River once the lake reaches a certain level, increasing the level of the dike around Devils Lake as needed, or relocating communities.

ISSUES/CONFLICTS/CONCERNS

The Red River Basin suffered monumental losses from the flooding of 1997, which caused major economic and personal damages. Fortunately, various sources of funding are helping to solve some of the short-term issues while a long-term plan is being developed. In the Devils Lake Basin, the losses started in 1993 and the flooding continues, causing increased economic and personal losses and a continual need for government funding to address the associated issues.

Devils Lake Basin

Officials have had a longer opportunity to develop short-term and long-term planning in the Devils Lake Basin. The current plan is to develop an outlet, raise the dikes and protect or maintain infrastructure, and manage water in the upper basin. This plan is not being implemented in all aspects as a result of various concerns and issues. The lack of implementation is creating great social concern while the water continues to rise.

Upper Basin Management Issues. The goal of 75,000 acre-feet of upper basin storage was set when the lake was approximately 75,000 surface acres in size. It was hoped to store 1 foot of water to prevent that amount of water from entering the lake as a tool in flood management. This may have to be modified to 109,000 acre-feet of storage in order to meet the goal of keeping 1 foot of water off of the lake level. However, that is not the major issue. The issue that is concerning many people endorsing the concept of upper basin management and storage is the ability to accomplish this goal.

Private landowners have many concerns or conflicts regarding upper basin storage. These include economic issues, farm income, salinization of soils, wetland designations and regulations, antiwetland views, wanting the opportunity to drain wetlands to improve their lands, private property rights, a belief that drainage has no impact on flooding, and just plain apathy toward the need to store water. There is conflict amongst agencies or boards on the amount of drainage that has been done in the basin, if drainage affects lake levels to any significant degree, and if storage is even an effective tool in reducing flooding.

Another issue is the storing of water on public lands. This was thought to be a good and easily implemented idea, but the U.S. Fish and Wildlife Service is having trouble getting support to develop wetlands on the public lands they manage. There is a strong antigovernment and anti-Fish and Wildlife Service attitude in the basin, so there are problems getting flowage easements, water board approvals, township board approvals, and getting permits from the State Water Commission.

In spite of these issues, some success has been accomplished. The State Water Commission is storing 21,000 acre-feet of water in 1–2 year agreements in one of its programs (3). The U.S. Fish and Wildlife Service has been able to complete construction of 15 projects that restore, create, or enhance wetland habitats on a permanent basis, which totals 1512 surface acres of wetland habitat and stores and manages 3146 acre-feet of water. The North Dakota Wetlands Trust Conservation Reserve Program (CRP) incentive program has had sign-ups and hopes to complete 1584 acres of wetland restoration, and the State Waterbank program has enrolled 1600 acres of land, which includes wetland set-aside.

The Outlet and Associated Issues. Several locations for an outlet have been considered, but because of water quality concerns downstream, a west-end location for the outlet has been proposed. Other concerns downstream include flooding of infrastructure, cropland, and communities; stream bank stabilization and stream bed erosion; salting of soils; water treatment costs; and effects on instream flows and ecosystems.

The proposed outlet would be a pipeline that follows the approximate route of the Peterson Coulee in Benson County and would flow water at a rate of 300 cfs. An operating plan will be developed to minimize downstream flooding. In fiscal year 1998, appropriations totaling $5 million to start construction of the outlet were approved. Final approval of the money is contingent upon completing economic and environmental analyses, consulting with the International Joint Commission on meeting the Boundary Water Treaty Act, and preparing a final report to Congress on their findings. The appropriations also had language that an inlet would not be built that diverted Missouri River waters into Devils Lake.

Water quality is the primary concern with the outlet design and operation. Devils Lake is characterized by wide fluctuations in lake levels and in concentrations of dissolved solids. The concentrations of dissolved solids increase as one progresses from the west end of the lake to the east end. Average concentrations during 1988–1990 ranged from 3400 mg/L in the west to 10,000 mg/L in the east. As water levels increased, the concentration in the west end of the lake in 1995 had improved to 1280 mg/L. Water quality in the Sheyenne River from 1951 to 1997 averaged 480 mg/L (5).

Dissolved solids concentration is an important factor in determining flow rates and location of an outlet to the Sheyenne River. For example, if 200 cfs of water is taken from Devils Lake west bay and pumped into the Sheyenne River, dissolved solids concentration in the river increases from 480 to 780 mg/L. If that same amount was pumped from East Stump Lake, concentrations in the Sheyenne River would change from 480 to 7200 mg/L. Consequently, this is the reason for a west-end outlet (5).

As far as water quantity is concerned, the long-term average annual streamflow in the Sheyenne River gauged near

Warwick is 62.4 cfs. Daily average flows are highly variable between a dry year and a wet year. During 1990, a dry year, streamflow was less than 50 cfs for almost the entire year. In 1997, a very wet year, streamflow was greater than 500 cfs from April 1 to May 9 and greater than 200 cfs for 57 days (5). The proposed outlet would pump 300 cfs for 7 months, and this is the concern of many downstream interests as this is greater than the flows they endured during a sustained period during a large flood year.

Red River Basin

In the Red River Basin, concerns exist that must also be addressed. Currently there are numerous boards, commissions, and groups investigating and developing plans and actions. It is hard to say who or what entity is in charge. Is it the state or federal agencies, which have the appropriate legislation or regulatory power and often funding? Is it the Red River Basin Board, which has no regulatory power? How about the local boards or the International Joint Commission? While no one may be addressing this issue openly, many actions are being planned throughout the basin—actions such as building dikes, relocating structures, creation of diversions, and plans to build dams or new drainage. Who is coordinating these efforts and the impacts that individual actions may have on other actions or future plans? Are these efforts going to sidetrack the long-term planning for the basin, and will these actions all work together for effective water and basinwide management? The development and implementation of a holistic or comprehensive plan must be expertly coordinated and collaborated using good scientific and technical data. This will require good leadership and an effective way to fund and control the implementation of watershed- based actions. This issue needs to be addressed.

POTENTIAL SOLUTIONS – A CONCEPTUAL IDEA

Most people are aware that creating a watershed strategy that will address the myriad of issues identified will take intensive planning, leadership, and strategic implementation. Focusing on some of the largest landscapes and the premier topics may be a logical way to start planning and implementing. Earlier in the paper, it was identified that some of the top areas of discussion were water management and the agricultural economy. Other issues that are always at the forefront include economic growth and the environment. It was indicated that 74 percent of the land area in the Red River Basin is being utilized for agricultural production (2). Additionally important is that projects or actions should be planned to be as multipurpose as possible. So with those thoughts in mind, a conceptual idea was formulated.

This concept will be called "conservation agriculture." Selecting the agricultural industry as a starting point is preferred, since 74 percent of the landscape is in agricultural use, the agricultural economy is struggling, and large-scale conservation or hydrologic practices on the ground can accumulate into improved watershed management. The premise is to develop actions or programs to increase the profitability of agriculture. The strategy is to put all on farm efforts into the most productive soils and incorporate alternative uses or programs on lands that are not considered prime farmland. A slogan could be "Farm the Best, Alternatives on the Rest." Setting aside less than prime farmland and getting payments for those acres could give producers a chance to focus their farming expertise into the most productive soils. This strategy will ultimately lower input costs, make farming more efficient, lower the use of fuels, herbicides, and fertilizers, and allow those alternative lands to provide a host of societal functions within the watershed. The producers will be putting their efforts into and getting returns from the best land and receiving alternative payments on the lands that could be contributing to low profit potential on the farm. This theory would lead to increase net profits by lowering input costs and getting profits by providing landscape functions on the remaining, less productive, acres.

The impetus for selecting sites on the farm would ultimately be landowner-driven, but based on soils, farm efficiency, and program payment schedules. Some soil selection criteria would be productivity, salinity, and wetness. The programs would be voluntary and fully compensated. The programs would be accompanied by the development of a resource analysis team to help landowners better understand the various programs and to provide technical assistance. Resource analysis teams would include economists, agronomists, soils experts, and conservation planners. These teams would provide advice on soil management, erosion prevention, wetlands development, crop selection and management, herbicide and fertilizer management, program selection, alternative use management, and minimum and no-till practices. As the program grows, with key criteria being increased farm profits and efficiency, anywhere from 5 percent to 30 percent of farms could be enrolled in alternative practices.

If 74 percent of 38,800 square miles is given to agricultural production in the basin and 15 percent of that is enrolled into alternative uses, that would equate to 4307 square miles or 2.8 million acres. This acreage could help farm profits and provide a host of watershed management functions in terms of improved water quality, slowing water flows for improved flood management, lowered erosion and downstream siltation, improved conditions for wildlife habitat, and the use of that habitat by wildlife and outdoor enthusiasts. This is the multipurpose concept: to improve agriculture, improve watershed management, and to create an alternative industry such as ecotourism by attracting hunters, wildlife watchers, and other wildlife-dependent recreation. This will assist in diversifying the overall economy and increasing the aesthetics of the area to attract new industry. In addition to conservation agriculture, we also need to look at land purchase by agencies or organizations in selected sites to facilitate additional water storage or recreational development.

A properly implemented holistic, comprehensive plan that helps the profitability of agriculture, that improves the economy, and improves the overall quality of life and the environment is paramount to the future of the Red River and Devils Lake basins. With proper planning and the proper use of scientific and technical data, basin leaders can develop such a plan. The equation of this plan includes improved agricultural net profits, a landscape that functions for overall watershed management, the use of conservation practices, the creation of an outdoor recreation industry, and the ability to attract new industry. This proper mixture or diversity can create a healthy environment for people, wildlife, and wise economic growth.

The key is the good use of science, engineering, and facts while getting communities, landowners, leaders, and conservationists all working together. Conservation agriculture just makes sense for farmers, taxpayers, conservationists, and industry—all leading to a better way of life in the Red River and Devils Lake basins.

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SCIENCE AND POLICY, INTERBASIN WATER TRANSFER OF AQUATIC BIOTA

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The Garrison Diversion Project has long had the reputation for taking on difficult issues. This is also true with the biota issues. Garrison was opposed by U.S. and Canadian environmental groups because some of the canals would transfer water from the Missouri River Basin into the Hudson Bay Basin and with that, it was assumed, undesirable fish and fish diseases.

In 1988, the state embarked on a project to address the biota issue. The scientific study began with support from the Garrison Diversion Conservancy District, the North Dakota State Water Commission, and the U.S. Bureau of Reclamation. The North Dakota Water Resources Research Institute was selected to be study project manager. A team of scientists was appointed to identify specific, researchable topics; to develop requests for proposals; and to select principal investigators. From 1987 through 1995, 20 studies involving scientists from both the United States and Canada were funded; all but two of the studies were completed by early 1996.

Canadians were initially concerned about the transfer of four fish species: Utah chub, shortnose gar, gizzard shad, and rainbow smelt. Some fish pathogens were also identified (IHN, infectious hemapoietic necrosis; entenic red mouth, *Yersinia ruckeri;* and *Polypodium hydriforme)* as potentially harmful to Hudson Bay Basin ecosystems.

Interbasin transfers of water are not new phenomena. There are many pathways for waterborne biota to move from one watershed to another. Bait bucket transfer and high water, for example, are two pathways that "connect" the Red River Basin with the Missouri River Basin. The record flood of 1997 in the Red River of the North Valley provided evidence that "natural" connections between the two watersheds occur. Natural pathways include connections between basins at times of high water, animal transport, and extraordinary weather events. Introductions by humans also can result from a variety of activities, including escapes from aquaculture, aquarium releases, stocking activities, ballast release, and angler escape or release. The undesirable species may be serving as bait, an aquaculture species, or an aquarium species, or it may be hitchhiking in water used to transport desirable species.

Authors of a bait bucket study concluded that while the potential for bait bucket transfer is low for a single angler for a single angling day, the cumulative effect of 19 million angling days over the course of a year brings the annual probability close to, but never reaching, 1.0.

An initial assessment of the range distribution of the undesirable fish species found that they had not changed much since the concerns were initially raised more than 10 years earlier, although rainbow smelt and gizzard shad were found in some waters where they had not been reported earlier. Rainbow smelt were found in the Hudson Bay Basin in September 1990, thus eliminating them as a species of concern.

Some parasites and pathogens not previously known to exist in the Hudson Bay drainage were found there during this study. Some species previously identified by Garrison Diversion opponents were found in the Hudson Bay drainage.

Many water treatment mechanisms were suggested as ways to prevent the transfer of unwanted biota via interbasin transfers of water. Among those suggested are screens, chemicals, and biocontrols. The technology exists, using one or a combination of techniques, to treat Missouri River water well beyond any reasonable (i.e., efficient) risk management level. Ozone treatment was found to result in significant risk reduction in this study.

CONCLUSIONS

This study set out to answer five general questions:

1. What are the current (1988) concerns regarding the project's potential for aquatic biota transfer?

They found that Canadians were concerned about several specific fish species and the potential damage they might cause to fish communities and economic activity. They were also concerned about "as yet unidentified" species.

2. What is the present distribution of species in the areas of concern?

The distribution is dynamic, with species showing up in new places on a regular basis.

3. Why aren't the fish species of concern already in certain waters?

Some species are not in certain waters either because they have not arrived there yet or they cannot survive the environment.

4. What impacts would nonindigenous species have in certain waters?

The impact varies from positive to negative and from almost none if it was a formerly displaced species to substantial impact on biodiversity in the case of some invasive exotic species. There are too many potential species to know with much certainty what each would do and what would happen with different combinations of species and environmental changes.

5. What are the paths for transfer and how can those paths be blocked or eliminated?

There are multiple paths for transfer, from bait buckets, to floods, to aquarium releases, and others. The likelihood of biota transfer via interbasin transfer of water can be reduced to next to nothing using chemical treatment, while the likelihood of biota transfer via other means approaches certainty. Reducing the likelihood via these other means is far more problematic.

STATUS OF FLOOD CONTROL ACTIVITIES IN THE RED RIVER VALLEY

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INTRODUCTION

Status reports will be provided for some of the key activities involving the Corps of Engineers in the Red River Valley, including the following:

UPDATING OF THE MAIN STEM HYDRAULICS AND HYDROLOGY

The existing main stem hydrology is being updated with a combination of Corps of Engineers and Federal Emergency Management Agency (FEMA) funding. The work includes updating the discharge frequency curves from Wahpeton to Pembina. The existing HEC-2 models are being recalibrated to the 1997 flood. The 10-, 50-, 100-, and 500-year flood profiles are being recomputed using the recalibrated HEC-2 models and revised frequency curves. Flooded outlines on flood insurance maps are to be reviewed in light of the above revisions.

INTERNATIONAL STUDY OF FLOODING IN THE RED RIVER BASIN

The 1997 flood resulted in catastrophic damages to residential, commercial, industrial, agricultural, and public properties in large portions of the Red River Valley along the Minnesota and North Dakota border and in the province of Manitoba. Significant emergency flood control measures were implemented in the United States and Canada to reduce the magnitude of damages in the larger urban centers. However, these measures were at times inadequate to protect against the magnitude of the flood experienced and incomplete to protect many of the smaller communities, rural areas, and public transportation infrastructure. In 1997, floods of record were experienced at many locations in the United States and Canada.

This assessment, international in scope, will involve a number of U.S./Canada federal and state agencies, complemented by key local Red River Basin interests serving as study advisors. The assessment will be based on broad concepts using the volumes of information collected and available on past flood events and the most recent information collected during the 1997 flood. Objectives concerning direction, scope, and results have been established to guide the assessment. It is understood that the task force team is to consult with the public on needs and concerns and, where feasible, to provide an empirical basis for making policy recommendations to the two governments on flood preparedness, response, recovery, and risk reduction measures for the Red River Basin.

Efforts are under way for data collection, development of a decision support system, hydrologic and hydraulic modeling, and the addressing of several specific issues identified in the basin. A report summarizing study results to that point is scheduled to be provided in late 1999. The study is to be completed by December 2000.

RED RIVER BASIN FLOOD DAMAGE REDUCTION WORK GROUP AGREEMENT

The Red River Basin has experienced extensive drainage and flood control activities for most of the twentieth century. Flooding and related soil erosion have continued to plague the region. In recent years, there have been frequent disagreements between watershed districts and resource management agencies over the most effective and least environmentally destructive methods to reduce flood damage. After the U.S. Army Corps of Engineers and the Minnesota Department of Natural Resources (DNR) completed a joint environmental impact statement on cumulative effects of flood control projects in the Basin, the controversy reached its peak. In May 1997, the Minnesota legislature authorized funding for a "mediation" process to resolve the disputes regarding environmental effects of flood control and to break the gridlock blocking many new impoundment projects. The work group includes representatives of the Minnesota DNR, Red River Watershed Management Board, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, National Audubon Society, Minnesota Center for Environmental Advocacy, Minnesota Pollution Control Agency, Minnesota Board of Water and Soil Resources, and citizens of the basin.

After an 8-month journey, an agreement was reached in December 1998. In January 1999, a conference of representatives from participating state and federal agencies, watersheds, environmental groups, and interested citizens met to review the agreement and set in motion its implementation. The next step is the annual conference of the Red River Watershed Management Board, which has been restructured as a key component of the agreed-to process for planning and implementing flood damage reduction and natural resource development projects in the Minnesota portion of the basin. The conference is scheduled for March 1999. The work group, which is responsible for formulating the agreement, will continue to oversee the new planning and project coordinating activities to ensure they are consistent with the content and spirit of the agreement.

EAST GRAND FORKS, MINNESOTA–GRAND FORKS, NORTH DAKOTA

Following the devastation in Grand Forks and East Grand Forks resulting from the spring flood of 1997 on the Red River of the North, the Corps of Engineers has been assisting with restoration activities and long-term planning in these communities.

The recommended plan for the communities consists of approximately 26 miles of permanent levees, floodwall, and road raises, two small diversion channels to direct flows in the English and Hartsville Coulees out of town during flood events, riprapping of some river reaches, and removal of an existing pedestrian bridge. These recommended features of the permanent levee system will provide both communities with a 210-year level of flood protection.

CROOKSTON, MINNESOTA

The 1950 flood inundated most of the flood-prone properties. However, for subsequent floods in 1965, 1969, 1979 and 1997, the city of Crookston had erected levees that together with emergency flood fights prevented major damages to the flood-prone residential areas.

The local levees at Crookston were not constructed to permanent levee standards and have deteriorated considerably since construction. There are six separable flood-prone reaches in Crookston, and each reach is protected by a local levee, now in unreliable condition. The risk of failure of these levees during a major flood event such as in 1969, 1979, or 1997 is very high. Failure of these levees during a large flood could cause catastrophic damages. The city of Crookston is very concerned about the adequacy of the levee system. At the request of the city, the St. Paul District conducted a reconnaissance study to determine the viability of providing local flood protection. The Reconnaissance Report, completed in July 1990, determined that there was sufficient federal interest to proceed with a cost-shared feasibility study. A Feasibility Cost Share Agreement was signed in October 1992. The feasibility study was initiated in November 1992 and completed in July 1997 and now awaits construction funding.

GRAFTON, NORTH DAKOTA

Recurrent flooding along the south branch and the main stem Park River causes significant flood problems at Grafton. The largest flood of record, which occurred in 1950, inundated almost the entire city. More recent floods occurred in 1962, 1965, 1969, 1979, and 1997.

A flood control project on the Park River at Grafton was authorized for construction by the Water Resources Development Act of 1986. The Phase I General Design Memorandum was completed in January 1983. The city of Grafton, by letter dated September 19, 1985, indicated that it could not afford the project. The project was subsequently deauthorized on November 18, 1991.

The previously recommended plan would provide flood protection for the city of Grafton; it consists of a 3.75-mile-long bypass channel that would extend upstream and to the west of Grafton along the south branch Park River. The tieback levee would direct the floodflows to the inlet of the bypass channel. A diversion structure would be at the point where the levee crosses the Park River. Riverflows that exceed 2000 cubic feet per second (cfs) would be diverted through the proposed bypass channel. During periods when the riverflow is less than 2000 cfs, the entire flow would go into the natural channel of the Park River through Grafton.

WAHPETON, NORTH DAKOTA

Approximately 14,000 feet of emergency levees were constructed in the spring of 1997 to protect Wahpeton from flooding. The floodwaters came within inches of overtopping the emergency levees. During the summer and fall of 1997, Wahpeton began construction of permanent levees on its own. A shortage of funds caused the city to stop construction short of complete protection. The level of protection was to the level of the 1997 flood plus 3 feet of freeboard.

The city of Wahpeton requested a feasibility study from the Corps on January 21, 1998. Funds are available to initiate a reconnaissance study for the purpose of determining federal interest. The Federal Interest Report was completed in September 1998. It showed a likely federal interest and the District is now pursuing feasibility studies.

BRECKENRIDGE, MINNESOTA

Flooding in Breckenridge can occur from either the Red River of the North and Bois de Sioux River or from the Otter Tail River. Two peaks occurred during the spring 1997 flood. The first peak occurred on April 6, with a stage of 19.42 feet. The second peak occurred on April 17, with a stage of 19.22 feet. The previous flood of record occurred in 1989, with a peak stage of 17.95 feet. Sandbagging of the existing levees is required at a flood stage of 16 feet.

In a May 23, 1997, resolution, the city of Breckenridge requested that the Army Corps of Engineers assist in short- and long-term mitigation projects that would prevent flood damage. Section 205 funds for initiating a feasibility study were received in December 1997. The feasibility study is scheduled to be completed in September 2000.

WILD RICE–MARSH RIVER DIVERSION

A 1988 reconnaissance report presented the results of an investigation into the flooding problems on the Wild Rice River. The report identified a plan that met all the preliminary screening criteria of technical, economic, environmental, and social acceptability. This plan involves restoring a portion of flow for more frequent flood events (i.e., less than 20-year frequency) from the Wild Rice River into the Marsh River by constructing a diversion structure on the Wild Rice River.

The feasibility study is currently under way. Alternatives for reducing flood damages will be evaluated to see if there is a federal interest in continuing with detailed investigations of the flooding problem.

ADA, MINNESOTA

A reconnaissance report completed in January 1984 showed a positive benefit–cost ratio, but the plan lacked local support. In April 1997, most of Ada was flooded and Ada received millions of dollars in flood damages. Flooding occurred from the south side of Ada from the old Marsh River and from the north side of Ada from Judicial Ditch No. 51. Ice jams on the Wild Rice River exacerbated the flooding at Ada.

The Wild Rice Watershed District, acting as the sponsor for the city of Ada, requested a feasibility study from the Corps on December 10, 1997. Funds are available to initiate a reconnaissance study for the purpose of determining federal interest.

NECHE, NORTH DAKOTA

Recurrent overbank flooding of the Pembina River causes damage to residential and commercial property and to the transportation system.

An allotment of funds was requested in 1996, 1997, and 1998 to initiate the feasibility phase of a flood reduction project. Funds in the amount of $100,000 were received in December 1997. The feasibility study will be completed in January 2000.

OAKPORT TOWNSHIP

Oakport is located on the north side of Moorhead, Minnesota, along the Red River of the North. During high flows on the Red River, floodwaters leave the main channel and flow through an old Red River oxbow. Homes on both sides of the oxbow and along the Red River receive flooding.

Approximately 150 homes were damaged in Oakport during the spring 1997 flood. The flooding caused 200 homes to be isolated when all roads to the area became impassable and these homes lost sanitary sewer service for approximately 2 weeks. Sewer backup occurred in homes protected by individual earthwork or sandbag dikes. A county road culvert on the north side of Oakport has limited flow capacity and this causes higher flood stages to the homes along the oxbow. Oakport Township requested a feasibility study from the Corps on November 3, 1997.

MINTO, NORTH DAKOTA

Approximately 12 homes were flooded during the April 1997 flood. The city did its own emergency sandbagging and dike construction in preparation for the April 1997 flood. The city of Minto requested a feasibility study from the Corps on August 14, 1997.

MANITOBA FLOOD PROTECTION AND CONTROL STRATEGIES

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INTRODUCTION

General strategies of flood hazard reduction programs may involve combinations of three elements: (a) structural measures such as dams, dykes, or diversion channels; (b) land management measures which alter the rate of runoff, control land use in the hazard zone, or require flood-proofing; and (c) institutional measures such as improved forecasting and emergency procedures, flood insurance plans, or governmental assistance to flood victims.

Flood protection planning in Manitoba began in the aftermath of the 1950 flood which had caught the entire valley completely unprepared. The solutions available were constrained by a number of circumstances. First, during large floods, most of the water originates south of the border, beyond Canadian jurisdiction. Thus such options as headwater storage or land management in the source area were not possible. Second, the consequences of flooding were heavily concentrated in Winnipeg where discharges are greatest and where the established land use pattern and heavy occupation of the riverbanks limited the immediate land use measures which were feasible. Finally, the Assiniboine River joins the Red at the "Forks" in the heart of the city. Although much smaller than the Red, the Assiniboine has the potential to make critical contributions to large floods which cannot be controlled by measures on the Red.

Shortly after the 1950 flood, the Red River Basin Investigation began examining the history and causes of flooding in the basin and its 1953 report proposed a number of possible solutions (1). An important result was a better appreciation of the magnitudes of the large floods in the 19th Century in 1826, 1852, and 1861. The incorporation of these floods into the frequency curves greatly improved the awareness of the magnitude of the hazard and led to the ultimate decision to design for protection from floods much larger than that of 1950.

No action was taken until 1956 when the threat of another large flood caused the government to appoint a Provincial Royal Commission to consider the benefits and costs of the alternative protection schemes and recommend a course of action. The Commission's report (2), issued in 1958, recommended a combination of structural measures to protect Winnipeg from floods up to 169,000 cfs compared with the (revised) flow of 108,000 cfs in 1950. Although the Royal Commission privately favoured land use controls and riverbank acquisition, these were politically unpopular (3) and only the structural measures were recommended.

STRUCTURAL MEASURES

Primary Dyking System in Winnipeg

The immediate response, begun virtually as the 1950 flood receded, was to consolidate and extend the emergency dykes which had been built within Winnipeg during the flood. With subsequent additions, this became the Primary Dyking System, a 110-km system of dykes parallel to the river augmented by permanent secondary dykes (Figure 1). The Primary Dyking System (mostly completed in 1952) was designed to contain flows up to a stage of 26.5' (all stages are feet above datum in downtown Winnipeg) with provision that they could be increased to approximately the 1950 peak stage of 30.4' under extreme conditions (although it is unlikely that this would be feasible in the time available during an emergency). The design peak of 26.5' was subsequently reduced to 25.5', and in 1997, water levels were limited to 24.5' because of the location of many sewer outfalls and to maintain 2' of freeboard. Where residential areas along the riverbank could not accommodate the Primary Dyke because of available space or bank stability, lower secondary dykes were constructed with provision that they could be raised temporarily during an emergency.

The structural measures recommended by the Royal Commission to protect Winnipeg were the Red River Floodway, the Assiniboine Diversion, and the Shellmouth Dam (Figure 2).

Winnipeg Floodway

The largest and most important element of the protection scheme is the Winnipeg Floodway, a 47-km excavated earth channel designed to divert flow around the eastern perimeter of Winnipeg. The diverted water is spilled back into the Red River near Lockport, 18 km north of Winnipeg where the channel is large enough to convey the entire flow. The Floodway control structure on the Red River at the southern boundary of Winnipeg creates a dam across the valley which regulates the discharge in the channel through the city. Flow into the channel is caused by gates in the structure which, when raised, elevate water levels upstream and cause excess flow to

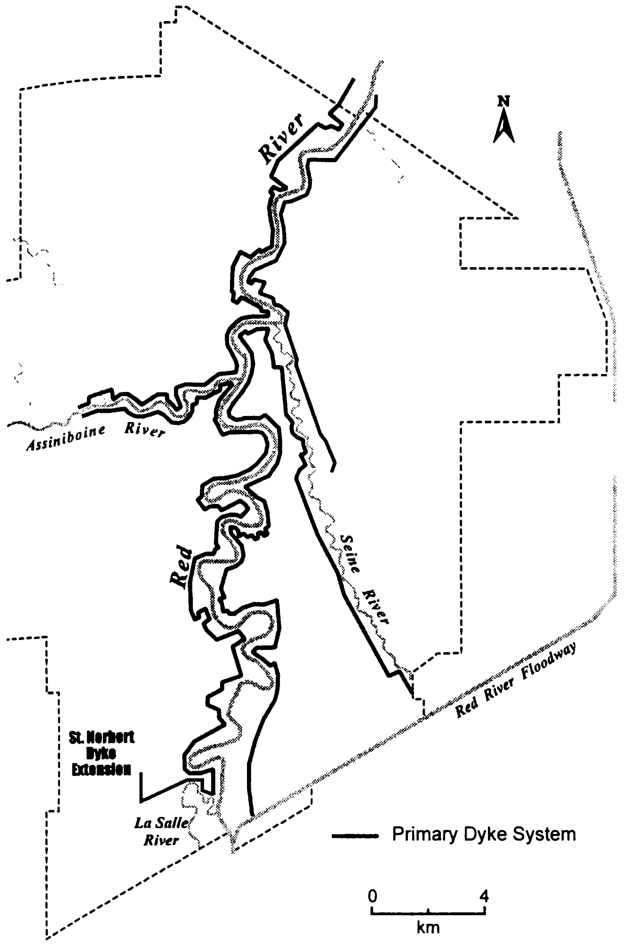

Figure 1. Location of Primary Dyke within Winnipeg (modified from Hiebert, 1997 (4)).

be diverted around the city. East and west of the river, 43 kilometers of dykes complete the dam and prevent water from bypassing the control structure.

Assiniboine Diversion

Second in cost and importance is the Assiniboine Diversion, a 29-km long excavated and dyked channel 3 km west of Portage la Prairie which can divert up to 25,000 cfs from the Assiniboine to Lake Manitoba, thereby increasing the amount of Red River water which can be passed through the city.

Shellmouth Dam

The final structure is the Shellmouth Dam which impounds a 55-km long reservoir, in the upper Assiniboine valley permitting further control over Assiniboine water flowing toward Winnipeg, in addition to providing a conservation pool of water and flood control downstream along the Assiniboine.

Community Ring Dykes

After extensive flooding in 1966, attention turned to the Red River Valley south of the city. There, ring dykes were constructed around eight communities to provide protection up to the 1950 level (Figure 2).

Even with a federal contribution amounting to about 60% of the total, the cost of the system (about $100 million) was very large for a small province like Manitoba. Construction of the Floodway began in 1962 and was available for use in 1969; by 1972, all structural components had been completed. With some emergency dyking in Winnipeg, the system was designed to protect the city from floods up to 169,000 cfs with a Return Period of 165 years (based on the 1958 frequency curves). The routing of water during the design scenario is shown on Figure 3a.

The effectiveness of these structures was quickly demonstrated. From 1969-1979, the average flow of the Red River was the highest in the entire period of record and the system was used to manage flows exceeding minimum flood stage in 9 of the 11 years. Most of these were relatively minor events but the 1974 and 1979 floods were large, with discharges similar to that of 1950. In addition, in 1974 and 1976, discharges on the Assiniboine River exceeding previous records by about 50% and 150% respectively were accommodated by the Assiniboine Diversion with little downstream flooding. Mudry et al. (5) estimated that by 1979, gross damage reduction achieved by the structures exceeded $1 billion (1979 dollars) and that the entire cost of the system had been recovered from foregone damages. In 1996, another

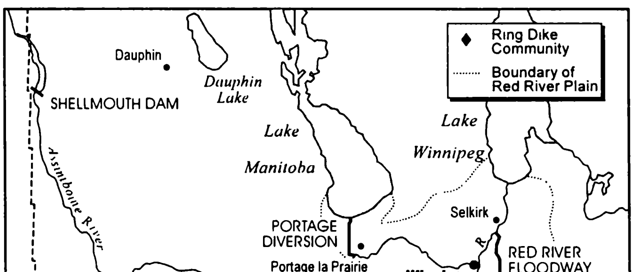

Figure 2. Location of major flood control structures in Manitoba

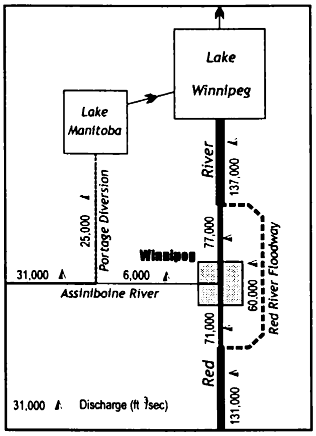

Figure 3. Routing of water (a) during design flood, (b) on May 4, 1997.

1950-magnitude event required evacuation of only about 100 homes in the Valley and total costs of less than $12 million. These savings were eclipsed in 1997 when, without the system, the $500 million costs may have been 10-20 times greater. Thus, in the numerous floods following the construction of the system, the structural measures probably prevented 90% of the damages that would otherwise have been sustained and virtually 100% of the damages they were designed to prevent.

LAND MANAGEMENT AND INSTITUTIONAL MEASURES

Until the 1970's, the entire emphasis in flood hazard reduction was upon structural measures and in most respects, the system worked exactly as designed (although all floods until 1997 were well within the system's capacity). As was being realized elsewhere, however, structural measures by themselves are rarely adequate if they are not accompanied by land use controls. In 1953, Kollmorgen (6) published a paper "Settlement Control Beats Flood Control" but the lesson was learned only slowly through the 1950's and 1960's. After the 1950 flood, growth of Winnipeg was mainly southward, directly into the area of maximum inundation, almost as if the flood had not occurred; by 1976, the number of occupied dwellings in this area had trebled and the population had more than doubled. From 1958 onward, some of the continued expansion could probably be ascribed to the confidence produced by the projects themselves and thus would be classified as project-induced. In Winnipeg, the most serious zoning oversights permitted a number of residential developments *in the unprotected zone between the Primary Dyke and the river.*

Another region of serious difficulty was on Turnbull/ Red River Drive along the river and in other ex-urban developments in the Rural Municipality of Ritchot. These properties are located in the "backwater" zone south (i.e. upstream) of the Floodway control structure and thus are potentially affected by the operation of the control gates. The Operating Rules for the structure are codified according to the discharge but, in brief, they require that except under extreme conditions the water surface upstream of the Floodway cannot be raised higher than the "natural" level which would have occurred in the absence of <u>all</u> flood control measures (including the Assiniboine Diversion and the Shellmouth Dam). In the floods of the 1970's, property owners in this area claimed that the Floodway control structure had created higher-than-natural upstream stages. After the 1979 flood, a permanent earth dyke was constructed to protect Turnbull Drive in return for a waiver of future claims for assistance.

Flood insurance has never been available to assist individuals in Manitoba. Rather, such assistance is viewed as a societal responsibility, distributed through municipal and provincial governments, with federal assistance during large disasters negotiated with the provinces on a case by case basis. In 1970, a national cost-sharing formula for disaster assistance was negotiated whereby, in Manitoba, the Federal government assumes 90% of the disaster relief costs above $5 million. Very large national flood damage in 1974 and 1975 raised concerns about the mounting disaster assistance being paid by the federal government under this system. A federal/ provincial Flood Damage Reduction Agreement, signed in 1976 (and extended in 1981 and thereafter) provided for the raising of community ring dykes to the 100-year flood level, mapping of flood hazard zones, flood proofing existing buildings in the hazard zone, and improved forecasting. More importantly, the Agreements marked a shift in emphasis from structural to non-structural measures, explicitly recognizing the need for land use controls which would discourage development in flood-prone areas.

Implementation of the Agreement was slow until 1979 when the consequences of inaction were once again demonstrated by extensive emergency measures required to protect properties in the hazard zone. As a consequence, serious attention was paid in subsequent Agreements to controlling development in flood prone areas. Senior governments undertook to withdraw mortgage guarantees and development incentives for new buildings in the hazard areas unless they were flood-proofed to 3' above the 100-year level. Under this program, about 900 participants were assisted in flood-proofing (raising, dyking or moving) properties in the designated flood area and enforcement of the regulations governing new construction was strengthened, although some properties continued to fall short of the design standard (6).

LESSONS FROM 1997

In 1997, the design capacity of the entire system was seriously tested for the first time (Figures 3b, 4). Calculated peak "natural" flow in Winnipeg was 162,000 cfs and there is some evidence that flow on the Red River upstream of the Assiniboine exceeded that of 1852 with which it is normally compared. Furthermore the situation could have been considerably worse. The major blizzard which produced the record runoff in the Red River basin missed most of the Assiniboine basin and although peak discharge on the Assiniboine was relatively high, it occurred two weeks earlier than the crest on the Red. As the Red was peaking in Winnipeg, the Assiniboine flow was only about 11,000 cfs, all of which could be diverted through the Assiniboine Diversion. If the Assiniboine had produced large discharges, similar perhaps to 1976 or even 1996, and if the peaks had been closer

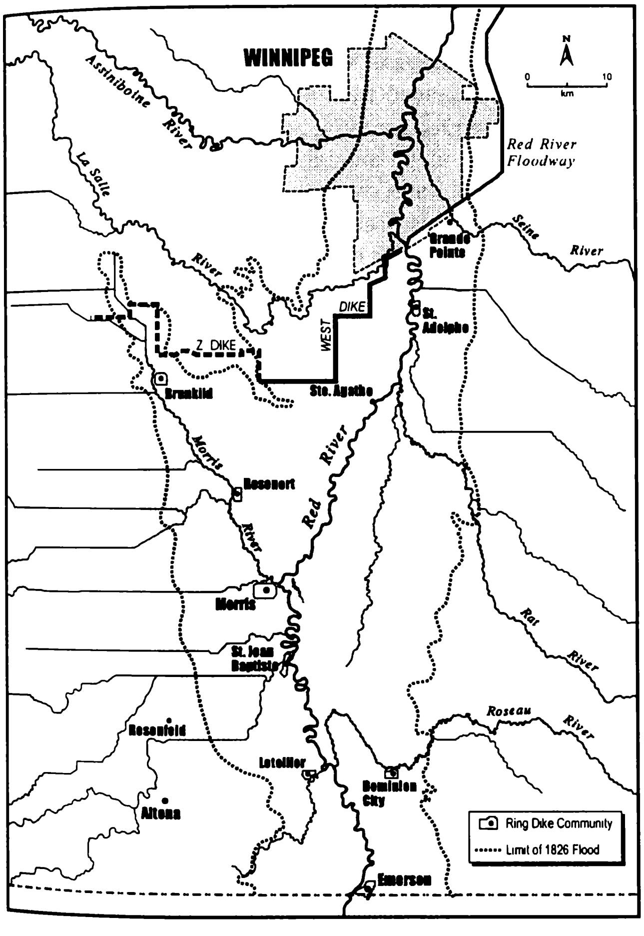

Figure 4. Flooded area in Manitoba, 1997.

in time, the excess flow downstream of the Diversion might have been unmanageable in Winnipeg without further elevating the water levels in the upstream area. Weather was also generally favourable; if there had been considerable rainfall during the flood, and/or if south winds had persisted for longer periods, it is likely that the design conditions would have been exceeded.

After the flood, numerous studies were conducted by governmental and other bodies to examine all aspects of the event- the operation of the control system, the quality of forecasting, the emergency response, the role of governmental and non-governmental agencies, the timing, level and conditions of financial assistance to victims and municipalities, the societal impacts, etc. (e.g., 7-11). The conclusions and recommendations of these studies are exhaustive and cannot be reviewed here. Most of them, if implemented, will improve aspects of Manitoba's preparedness and response to future floods but are essentially improvements or additions to existing procedures and do not signal a fundamental change in approach. Three aspects, however, deserve special mention.

Land Use Control

Probably the greatest lesson learned in 1997 concerned the need for zoning control and rigorous enforcement in the hazard zones both within and outside Winnipeg.

In Winnipeg, even with the Floodway operating at (or even above) capacity to maintain stages at the intended level, emergency dyking (involving 6.5 million sandbags and many earth dykes) was required to protect about 600 (mostly residential) properties. Much of this effort was in older sections of the city which had been built before the 1950 flood demonstrated the magnitude of the hazard (and thus could be excused). As was noted above, however, other developments had been approved between the Primary Dyke and the river after the construction of the Floodway began and because of their desirable location near the river, were of above-average value (average 1998 assessed values exceeded $200,000 in several of these areas). Thus while the protection system functioned much as intended, a substantial portion of the emergency response was created by the consequences of inadequate flood hazard zoning over the previous 40 years. Some of the earth dykes constructed in 1997 have been made permanent, increasing the protected area of the city and reducing the need for future emergency measures. However, the need for rigidly enforced zoning controls on future development was abundantly clear.

In the Valley, the situation was more complex. Much of the urban fringe development south of Winnipeg had occurred in the decades following construction of the Floodway in response to lower taxes and land costs, a non-urban lifestyle, and more permissive or more weakly enforced zoning by Rural Municipalities. Some poorly-protected properties still existed but many had been flood-proofed as a result of the post-1979 initiatives and much new construction had in fact complied with the design standards (100-year stage + 2'). These standards, however, were below the stages experienced in 1997 and in some cases emergency dyking could not prevent flooding. Compounding the problems in the "backwater" zone immediately upstream of the Floodway was a controversy over the operation of the control structure. In order to prevent flooding and sewer backup in Winnipeg, particularly in the southern part of the city, upstream water levels were raised above "natural" flow to limit city stages to 24.5' (the small contribution of the Assiniboine meant that stages of 24.5' in downtown Winnipeg translated into higher-than-design stages upstream, nearing the top of the Primary Dyke in south Winnipeg). Opinions differ over the amount of this "artificial" elevation (generally 1-2.5') but it seems certain that the operation of the control system did exacerbate conditions somewhat in the immediate upstream area. This led to an inflammatory May 3 headline in the Winnipeg Free Press "*Suburbs Sacrificed to Spare Winnipeg*". Whatever the truth of the charge, a more fundamental issue is the fact that the presence of these buildings, many constructed after the Floodway had been planned, compromises the most effective operation of a system designed to control flooding in the adjacent city of 650,000 but outside of its jurisdiction.

As a consequence of the 1997 flood, the design standard for flood proofing (by dyking or raising) buildings in the hazard zone in the Valley was raised to 2' above the 1997 stage.

Adequacy of System for Extreme Floods: Structural Measures Revisited

As was noted above, but for fortunate circumstances the design capacity of the system would have been exceeded, causing major flooding in Winnipeg. Furthermore, the exceedance probabilities of the design conditions have increased over the 40 years since the Royal Commission's report and the damage potential is very much greater. This "near-miss" has raised new questions about the design level of protection the system provides for Winnipeg and whether it should be increased, perhaps to accommodate floods to the 1826 level (approximately 40% larger than 1997). Particular concerns have been raised about the integrity of the east-west dyke under such extreme conditions. Failure of that dyke by overtopping or breaching would release into the city a huge volume of water stored in the "Red Sea" with a suddenness which could not be contained by further emergency measures. The dyke was identified as a "weak link" during the rising stage of the 1997 flood, when it appeared that water might bypass the western end of the dyke and enter the city via the La Salle River. To prevent this, the 21-km long "West Dyke Extension" was constructed and 13 km of the existing dyke were raised in a week, a remarkable engineering feat which involved 400 pieces of equipment and 450 people and was supported at night by airdropped flares. Much of this new dyking has now been made permanent. Other improvements to the structures which have been suggested include enlarging the Floodway and raising the Primary Dykes.

Drainage and Land Management

The 1997 flood also refocused attention on the controversial question of land drainage. The possibility that the extensive drainage systems in the Red River Valley were partly responsible for the increased flooding since 1950 had been raised after the 1979 flood but the subject died away during the drier 1980's. The drainage systems were constructed to eliminate wetlands and remove water more quickly in the spring and they have been effective for both purposes. In North Dakota and Minnesota, the pre-agricultural wetlands have been reduced by almost 50% (12), mostly in the Red River Valley and similar losses have occurred in Manitoba. This has dramatically reduced natural storage and, in fact, has increased the contributing area of the basin from within. Brun et al. (13) found that the contributing areas of Maple and Goose Rivers in North Dakota had increased by 64% and 180% and that these increases accounted for 50%, 36% and 70% respectively of the increases in mean annual flow, maximum daily flow, and mean spring flows over several decades. There can be little doubt that this drainage increases the magnitude of large floods and a fully effective flood damage reduction strategy will have to address the question of land drainage and other land use practices. This would provide a significant addition to the current flood control strategy-that of actually attempting to reduce flood peaks rather than merely dealing with their consequences.

CONCLUSIONS

In response to the 1950 flood, Manitoba undertook to build a very expensive system of controls designed mainly to protect Winnipeg, but extended to include eight communities in the Valley. These structural measures have accomplished their intended purpose during several floods following their completion, repaying the investment many times over. The overall efficiency of the damage reduction strategy was compromised, however, by inattention to land use control. This was addressed in part after 1979 and the vigilance and enforcement of zoning in hazard zones will undoubtedly be strengthened as a result of the 1997 experience. This experience will also lead to a reconsideration of the design standards and the need to modify the structural measures to control even more extreme floods such as occurred in 1826. Finally, there seems to be some resolve to take the issues of land management, particularly drainage, more seriously, to actually reduce flood peaks as well as manage them.

ACKNOWLEDGMENTS

The writer is grateful to Weldon Hiebert of the University of Winnipeg for the preparation of the figures.

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FLOOD CONTROL IN THE CITY OF FARGO

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FARGO FLOOD HISTORY

In the last 30 years, the city of Fargo has faced a major spring flood event in 1969, 1978, 1979, 1989, and 1997 and major summer flood events in 1975 and 1993. All of these events warranted Presidential Disaster Declarations. The 1997 flood event exceeded all other local floods of record dating back to 1890, both in terms of water volume (cfs) and river stage (ft).[1] Many have called the 1997 flood a 500-year event, but hydrologists don't necessarily agree. Most place the 1997 flood at a 50–100-year-frequency interval. This would suggest that, at some time, the magnitude of a flood in the city will probably be greater than that experienced in 1997.

DESCRIPTION OF FLOOD RISK

While it is true that all water events seem to have a similar impact on community residents, the differing characteristics of each particular flood event require community response to vary. Fargo is affected by three types of flooding: river, street/internal, and overland.

River Flooding

The official flood stage of the Red River in Fargo is 17 feet. While flood-fighting efforts increase as the river rises, the city does not consider an event to be "significant" until the river tops 34 feet.[2] In fact, only the Public Works Department gets involved in the flood fight up to a river level of 30 feet.

The 1997 experience revealed that the amount of effort required to fight a spring flood increases by approximately $1 million per foot once the river rises above 36 feet. However, since the 1997 event, mitigation efforts have effectively raised the threshold of "significance" from 36 to 38 feet in most parts of Fargo.

Street/Internal Flooding

Street flooding can either be a by-product of a river flood event or it can be a separate occurrence caused by significant rainfall. In Fargo, a rainfall is considered "significant" if more than 5.5 inches fall in 24 hours. A severe event is only likely to occur approximately once every 10 years. The primary impact is on infrastructure, transportation networks, and structural flooding in the lower levels of buildings in low-lying areas.

Overland Flooding

Overland flooding occurs in conjunction with spring river flooding. It approaches Fargo from the south and west, with water coming from Wild Rice and Sheyenne River overflows. It occurs less frequently than the almost annual occurrence of river flooding but exposes otherwise unaffected areas of the city to a significant flood risk.

An overland flood acts much like other types of flooding, in that the primary impacts are on infrastructure, the transportation network, and the lower levels of vulnerable structures. The difference is that the people and properties at risk from overland flooding are often not well protected against flooding because they are typically not in a floodplain, nor are they exposed to a flood threat as often as properties in the river corridors.

FLOOD CONTROL STRATEGY

The goal of flood mitigation is to reduce both the damages caused by floods and the intensity of emergency protective measures required to mount a successful flood fight. The city has in place both short- and long-range strategies for flood prevention and mitigation within the following general categories.

Restoration of Emergency Dikes

Conversion of appropriate temporary emergency flood protection measures to permanent during the postflood cleanup and restoration period.

Acquisition

Acquisition and removal of flood-prone property.

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1 Direct comparisons of historical flood events are very subjective because the type of human development that has occurred since 1897has changed runoff characteristics. Prior to development, all runoff could flow naturally to the streams and rivers. Now, hundreds of square miles of impervious surface and the construction of dams, roadways, and drainage ditches all interrupt and change the natural flow of water to the river.

2 The 100-year event occurs in Fargo at 38.2 feet.

Infrastructure

Protection and flood enhancement for public infrastructure, particularly sanitary and storm sewer facilities.

Diking

Levee and flood wall enhancements at critical locations.

Development Regulation

Enhancement of city policies on flood-proofing code requirements for private construction.

Emergency Operations

Critical review of actual 1997 emergency operations to develop long-term emergency operations strategies.

Funding

Development of a sustainable funding mechanism for flood mitigation improvements.

Basinwide Coordination

Promotion of interjurisdictional cooperation to review flood mitigation opportunities at a basinwide level.

The combined effect of these flood control measures is to reduce the possible impact floods will have on the community in any of the three types of flood situations.

	River	Street	Overland
Restoration of Emergency Dikes	X		X
Acquisition	X		
Infrastructure	X	X	X
Diking	X		X
Development Regulation	X	X	X
Emergency Operations	X		X
Funding	X	X	X
Basinwide Coordination	X		X

COMMUNITY RESPONSE TO FLOODING

The existing Flood Control strategy in Fargo is both multifaceted and well implemented. There is no lack of local technical expertise when it comes to shaping city flood control policy. However, everyone involved in the 1997 flood fight agreed that the provision of information and coordination with the public and other local organizations was essential to the city's ultimate success.

Public Involvement

Most flood fights in the Fargo area have traditionally involved citizens in the areas of the city that are actually affected by the flood. However, in 1997, officials decided to provide assistance and materials (sand and sandbags) to anyone who lived in the city. This, in effect, allowed the public to become part of the city's defense strategy. The coordinated communitywide effort enabled city leaders to address emerging situations and shore up some of the "weak links" in the overall flood control plan in a timely and efficient manner. Protecting private property at strategic locations with "free" sand and sandbags served the broad public purpose of protecting the city's infrastructure.

Project Impact

All mitigation is undertaken to minimize the impact disasters have on the community. Project Impact is an initiative of the Federal Emergency Management Agency (FEMA) that is designed to encourage communities to become disaster- resistant. It is essentially an endorsement of the power of mitigation. Project Impact takes the concepts of multihazard mitigation to the public by helping people understand that everyone has a role to play in enhancing the overall level of safety in the community.

A portion of the monies allocated for Fargo's Project Impact initiative will be spent on "soft mitigation" projects. These projects include efforts to educate the public about mitigation; enhance the distribution of flood-relevant information to the public before, during, and after an emergency; and organize a process that will promote coordinated emergency planning. The majority of the local Project Impact funds will be used to help fund more traditional "hard mitigation" projects. The flood projects include a lift station and retention basin (street flooding), both a residential and utilities substation flood-proofing project (river flooding), and a contribution to the countywide flood control plan (overland flooding).

This renewed focus on educating and involving the residents of the community in flood control strategies and mitigation principles will eliminate a potentially weak link in the city's overall approach to flood control. Effective coordination and communication can help to minimize the risks associated with the city of Fargo's annual flooding ritual.

FLOOD DAMAGE REDUCTION – TRIBUTARY STORAGE

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The topography of the Red River Basin (RRB) is very often described as flat as a pancake (or waffle). This is basically not true. The valley portion of the RRB is usually geographically determined by the historic Lake Agassiz beach ridges on its outer perimeter. The area of the valley is approximately 17,000 square miles out of the total RRB area of 45,000 square miles. The land slope of the valley area averages approximately 2 feet per mile in a northwesterly direction. The actual grade of the Red River is approximately 2 feet per mile in the southern reaches and reduces to less than 1 foot per mile in the northern reaches. The topography of the transition area of the beach ridges can vary from 4 to 30 feet per mile, and in the area above the beach ridges, it is not unusual to experience an elevation increase of 4 to 8 feet per mile.

A major factor in watershed management in the Red River is the inherit flow capacity of the Red River and its tributaries. It is commonly accepted that the Red River has a capacity to carry the flows generated by a 3- to 5-year, 24-hour summer storm event. The tributaries, while varying considerably in their flow capacity in relation to their watershed, generally can transport a similar 10- to 15-year event. The minor watersheds of the area above the beach ridges, which comprise over 60 percent of the RRB watershed, can generally transport 100-year-frequency storms with little or no flooding of adjacent land. Therefore, the ability of the upper watershed areas to generate and carry more flows than the capacity of the downstream valley rivers can transport is a major factor in determining the location and design of potential measures to reduce flooding and the resulting damages.

Another issue involved in flood flow reduction is the need to understand the timing and volume contribution of each tributary watershed. It is entirely possible to slow up the flow in one area of the RRB and have the discharge add to the peak flow in a downstream area. Therefore, it is essential to have the knowledge of the historic peak flow attained at the Red River gauging stations and the ability to determine the incremental contribution of all watersheds upstream. That information is available and is used by engineers and watershed managers in making decisions on project location and design. The most effective way to control excess upstream flows is the construction of either on-stream or off-stream gated storage sites.

The primary focus of my presentation will be a series of pictorial slides.

BASINWIDE FLOOD CONTROL: THE WAFFLE

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Although the flood of 1997 was traumatic and costly, it awakened us to the need for fundamental reevaluation of our approach to flood protection in this region. Since then, however, we have done little to evaluate and implement basinwide strategies to prepare ourselves for a flood of similar or greater magnitude. According to the U.S. Army Corps of Engineers, the theoretical maximum flood height at Fargo is 60 feet (as opposed to 39.6 feet in 1997) and 67 feet at Grand Forks (as opposed to 54.4 feet in 1997). A recent publication from the University of Manitoba estimated that there is a 50% chance that a flood approaching the theoretical maximums will occur in the next 50 years. In simple terms, a comprehensive basinwide flood protection program is critical to the very survival of our communities in the Red River Basin.

We cannot afford, in any sense of the word, to continue to address water issues by approaching these topics from a town-by-town basis. Case in point: flooding in Grand Forks–East Grand Forks is not a Grand Forks–East Grand Forks problem. It is a basinwide problem that can only be addressed through the implementation of effective, practical, technically sound basinwide strategies. Indeed, this is just as much a rural problem as an urban issue. We must all work together for the best interests of all our citizens. Currently debated basinwide water retention approaches include reestablishment of drained wetlands, expansion of Lake Traverse, other new main stem dams, and nonstructural options such as short-term basinwide microstorage using a small percentage of existing section line roads (the "waffle" concept). Although these various approaches are dramatically different both conceptually and with respect to implementation, all reflect a growing consensus that meaningful flood protection will require the development of strategic basinwide partnerships. The challenge facing us is particularly critical because essentially the entire infrastructure of this region was built during the drier portion of a climatic cycle.

None of the existing or proposed levee projects in the Red River Basin will provide protection from the great floods as they have occurred in the past and most certainly will occur in the future. Long-term security for our cities can be achieved in one of two ways: either move our cities away from the Red River or implement a basinwide water retention strategy. The second option is clearly the most desirable.

The Energy & Environmental Research Center (EERC) is seeking to establish a program to evaluate the feasibility of a nonstructural basinwide system for temporary storage of floodwater in the Red River Basin. This microstorage, or Waffle, flood mitigation concept would be accomplished using low-relief fields bounded by county roads to temporarily create microstorage pools during major flood events. The fields, raised roads, and drainage structures should act as a network of channels and control structures, and the stored water can be released into the Red River as the flood crest passes.

Rough estimates indicate that using the waffle method could reduce the volume of water at any location along the Red River during flood events by 30% to 35% for several consecutive days. The entire Red River drainage basin encompasses about 49,000 sections of land. The very flat (lake plain) portion of the basin in North Dakota and Minnesota encompasses approximately 14,950 sections. We estimate that only about 700 sections need to be used for 5 to 10 days to achieve the desired level of reduction and only once every 15 to 20 years (major floods). Any sections having buildings would be excluded from consideration. We feel that ultimate implementation of this concept could be achieved through voluntary participation by land owners. GIS (geographic information system) technology would be used to locate those areas ideally suited for holding water with minimal impact to property owners. This plan will benefit the entire region, not just a few larger communities.

Using the waffle to manage water throughout the Red River Basin could provide benefits in both wet and dry years. On average, nearly a third of the water that flows down the Red River each year comes during April. Therefore, in most years, the problem is not that there is too much water, but that water is not available when it is needed most. For example, during dry years, rather than allowing water from snowmelt to run off, it could be stored to help farmers retain soil moisture through flood irrigation. Water captured in the waffle during the spring could also be used to recharge aquifers that are depleted by droughts and pumping for irrigation. This is currently being done along the Assiniboine River in Manitoba.

It will cost approximately $4.5 million and take 2 years to evaluate the waffle concept. The waffle evaluation project has been receiving a broad base of support in North Dakota, Minnesota, and Manitoba. The waffle project is consistent with the national trend toward nonstructural basinwide approaches to flood control. The waffle could become a national model for flood control strategies in the new millennium. The waffle project deserves evaluation as an innovative, cost-effective means of providing real basinwide security against flooding for everyone in the Red River Basin.

In 1996, the EERC and major stakeholders in the Red River of North Basin teamed to develop the Red River Water Management Consortium (RRWMC) to find economical, practical, and timely solutions to water supply, flood protection, and water quality issues. The RRWMC is taking a basinwide approach to all aspects of water management, including flood protection. The RRWMC's program is strictly technical.

Current RRWMC members include American Crystal Sugar Company, Cargill, city of East Grand Forks, city of Fargo, city of Grand Forks, city of Moorhead, Grand Forks County Commission/Water Board, Lake Agassiz Resource Conservation & Development Council (RC&D), North Dakota Pigs Cooperative, Northern States Power Company, Pembina Trail RC&D, Red River RC&D, and Simplot Soilbuilders (J.R. Simplot Company).

The RRWMC is the only group providing unbiased answers to complex technical, water-related questions faced by leaders in our region. The RRWMC's inclusive, team-building approach has brought the public and private sectors together. The EERC's RRWMC represents the only nonregulatory group with the technical expertise needed to address critical basinwide water management issues in our region. The proposed waffle evaluation project would be coordinated through the RRWMC.

ESTIMATING FLOOD RECURRENCE: CLIMATE AND THE GEOLOGIC RECORD

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INTRODUCTION

Human habitats are predominantly located near water courses such as sea and lake coasts and river systems, and population centers in continental interiors are necessarily located along river systems. Consequently, humans have experienced floods for millennia. Despite a long history of interaction between human civilizations and rivers, we still suffer flood disasters. The fact that flood disasters repeatedly occur raises questions about our understanding of flood dynamics (i.e., flood frequency, flood magnitude, flood duration). Is it that we have not yet developed an understanding of flood dynamics? Are our means of analysis in error? Do we not have enough data? In this paper, I examine some aspects of conventional methods of estimating flood recurrence intervals and question the validity of assumptions underlying these methods. I show that three of the fundamental assumptions in estimates of flood recurrence intervals are invalid for the Red River of the North drainage basin. Comparison of flood gauge data to climate data suggests that flood recurrence on the Red River is intricately related to climate change and that recent climate change adds uncertainty to our attempts to estimate flood recurrence. With the uncertainties in conventional techniques and the more recently recognized impact of climate change, it is clear that a better approach to understanding flood dynamics would be to include flood geomorphology and paleoflood hydrology in the analysis.

ESTIMATES OF FLOOD RECURRENCE

Flood recurrence interval implies that a flood which attains a specific level above base stream flow will occur an average of once in a specific time interval. Thus one finds specific elevation levels in floodplains designated as 100-year, 200-year, etc., flood levels. Interestingly, the 1997 flood of the Red River of the North in Grand Forks, ND, exceeded the highest level recorded since a flood gauge was installed in 1882. Subsequent estimates of the recurrence interval for a flood of this level included the 1997 data and some did not. The result was that a wide range of estimates of flood recurrence interval for the 1997 flood level appeared during the months following the flood disaster (Table 1).

Table 1. Some Flood Recurrence Interval Estimates for the 1997 Flood, Grand Forks, ND

Method (period of record)	Recurrence Interval
Weibull (1882–1997)	117 years
Historic Accounts + Records (1776–1997)	37 years
Log-Pearson Type III (1882–1997)	350 years
Log-Pearson Type III (1882–1996)	1050 years
USACE[1] (1882–1997)	172 years
USACE (1776–1997)	135 years

[1]U.S. Army Corps of Engineers.

Each method listed in Table 1 uses the historical record and proven techniques of statistical analysis to provide an estimate of recurrence interval. However, one might reasonably ask, if the methodology for such estimates is valid, why are the estimates different? The simple explanation is that each method is different and each method treats the historical record in a different way. Yet that still leaves the consequence that the range of estimates generates confusion rather than imbues confidence for flood control planners. A more rigorous explanation was provided by Baker (1), who categorized the two standard approaches used to estimate recurrence intervals as follows: 1) generalization from historical records of small floods to, "... idealized properties of the large, rare floods ..." or 2) "... explanation of detailed, specific flood phenomena through theoretical generalizations that are assumed to apply to the entire class of phenomena." Baker (1) argues that the flaw in these approaches is that they do not deal with real flood phenomena but with idealized parameters that have floodlike properties. He further argues that natural floods are far more diverse and complex than the simplifications used in statistical analysis and that such analysis tends to ignore the rarest and largest floods which are, in fact, the main interest.

This last point can be demonstrated by applying the method recommended by the U.S. Water Resources Council, i.e., assuming a Log-Pearson Type III distribution, to the East Grand Forks flood gauge data. With the 1882–1996 data, this approach predicts a recurrence interval of 1050 years, but inclusion of the 1997 data predicts an interval of 350 years Figure 1).

THE BASIC ASSUMPTIONS USED IN FLOOD RECURRENCE INTERVAL ESTIMATES

Compounding the problems with the theoretical approaches to recurrence interval estimates are the problems

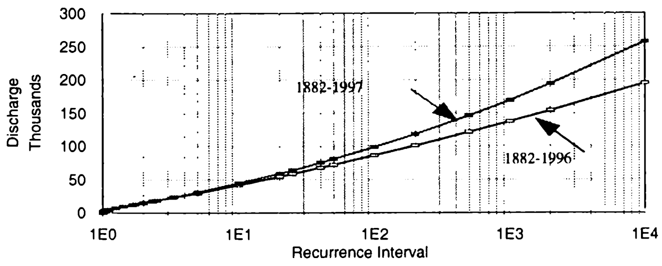

Figure 1. Log-Pearson Type III recurrence estimates for the East Grand Forks gauge data for periods 1882-1996 and 1882-1997.

associated with assumptions underlying the methods. This point also was made by Baker (1) who pointed out that the assumptions may apply to idealized flood parameters but not to natural floods where, "Nature may or may not load the dice." Other than the underlying foundation of statistics, the assumptions used in flood recurrence interval estimates are as follows:

- Climate is invariant. "Available evidence indicates that major changes occur in time scales involving thousands of years. In hydrologic analysis it is conventional to assume flood flows are not affected by climatic trends or cycles" (2).
- The sample is a single population.
- No changes in the watershed have occurred. Catchment and retention of water in the basin have remained constant, so there has been no systematic increase or decrease in the rate of water flow into a stream with time.
- Flood events are random. There is no systematic pattern to flood events.
- Measurement errors are random. Any errors in the data are random and are not the result of any systematic change in recording instruments or procedures.

Multiple Populations

A brief examination of published data allows one to determine that three of the five assumptions are invalid for the Red River of the North drainage basin. First, two distinct flood populations have been used in the estimates in Table 1, the spring snowmelt and summer storms. Floods created by summer rain storms are from a different population than those created by spring snowmelt, and these should be separated in any analysis (Figure 2). These data commonly have been treated as a single population in published analyses (3).

Land Use Changes

Second, land use and watershed management have changed dramatically. Between 1900 and 1967, 3176 miles of ditches were excavated and now drain 4,285,454 square miles within the basin (3). Although Miller and Frink (3) found that flooding increased from 1897 to 1980, they suggested that the increase could not be conclusively shown to be the result of manmade changes in the drainage basin. Conversely, Kingery and others (4) found a significant difference in discharge associated with land use changes.

Climate Changes

The third assumption in question is climate invariance. Precipitation and temperature data (5) show that the climate has varied from cool and wet from 1870 to 1910, to warm and dry from 1920 to 1940, to warm and wet since 1950. Warming and precipitation reached new levels in the 1990s, and both are still increasing (Figure 3).

This observation is particularly important as a number of researchers (6–11) have reported that small changes in climate lead to large changes in flood magnitude. These findings may be of major importance since climate change in the Red River Valley has been significant during the past century. Average annual ground surface temperature has increased 2.5°C, and the average annual air temperature has increased 2°C (12). Precipitation dropped from 1890 until the mid-1930s and has been rising since (5). The effects of changing climate are apparent in the flood record. Between 1882 and 1950, a severe flood (gauge level >12.2 m) occurred approximately once every 6 years at Grand Forks–East Grand Forks. This corresponds to the interval of generally diminishing precipitation from 1890 until the mid-1930s (5). Since 1950, Grand Forks has experienced a severe flood once every 3 years, with an increasing trend toward greater frequency of

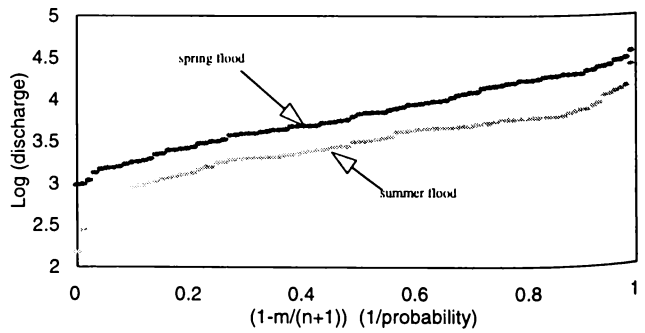

Figure 2. Flood probability curves for the East Grand Forks gauge data. Note the distinct difference between the snowmelt-caused spring flood and the precipitation-caused summer flood curves.

large-scale flooding (13). This interval corresponds to generally increasing precipitation and rising regional temperature (5, 12).

Climate and Flood Recurrence

The effects of climate change on flood recurrence estimates have been discussed in depth by Hirschboeck (14)

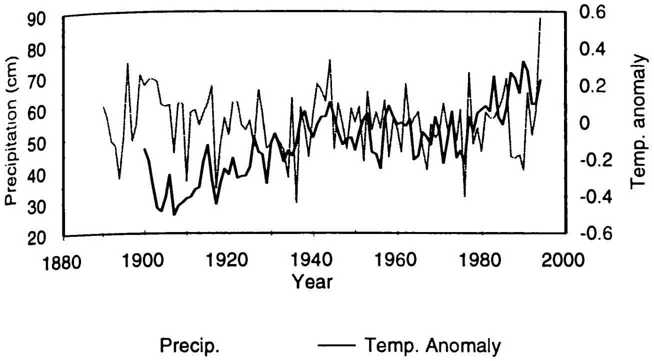

Figure 3. Mean annual precipitation and mean annual temperature anomaly in the Red River drainage basin.

who recommends reevaluating assumptions about climate and flood hydrology. Hirschboeck (14) specifically recommends using flood data from distinct climate patterns rather than mixing different populations. An example of how this might apply to the Red River at Grand Forks is found in Fig. 9 of Miller and Frink (5) who analyzed four 25-year periods in the historical record. Their four curves predict that the 50-year recurrence interval discharge, in cubic feet per second, would be 108,000, 41,000, 59,000, and 89,000, for the periods 1882–1904, 1905–1929, 1930–1954, and 1955–1979, respectively. Interestingly, Miller and Frink (5) concluded that the different curves indicated that the longest possible time series should be used in recurrence estimates. This is opposite to the recommendation of Hirschboeck (14), i.e., that the data should be separated according to climatic patterns. This implies that only the flood record from 1950–1998 would be appropriate for flood recurrence estimates for the Red River since only it includes the warmer and wetter climate pattern now extant.

Adding the Geologic Record

With the uncertainties in conventional techniques and the more recently recognized impact of climate change, it is clear that a different approach to understanding flood dynamics is needed. During the past decade, a number of scientists have recommended a new approach that uses flood geomorphology and paleoflood hydrology to understand flood dynamics (15–23). Geomorphological evidence of floods is recorded in the geological record, i.e., sediments, landforms, and erosional scars of past floods. Paleoflood hydrology uses the geological record to understand the movement of water and sediment in channels. Techniques used include examination of overbank and slack-water deposits and radiometric dating of samples obtained from the deposits. An example of how this approach can improve flood recurrence estimates was given by Stedinger and Cohn (16).

DISCUSSION

Baker (23) suggests that prediction of the future is beyond our ability, but understanding the past can provide a guide for preparedness. We might ask, if floods of a particular level have occurred with a known frequency, can we suggest that they will to continue to do so? The findings of Knox (10) and Hirschboeck (14) suggest that only if the climate during

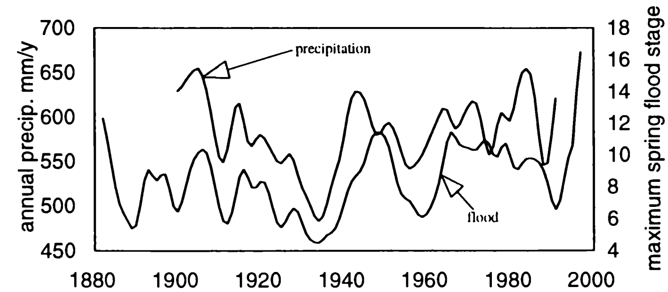

Figure 4. Correlation between mean annual precipitation in the Red River Basin and maximum flood stage at East Grand Forks.

the period of observation matches the climate of the period in question, can the answer be affirmative. Small changes in climate can cause large changes in flood magnitude. We are presently experiencing a climate that is not sampled by historical gauge data, but that may have been sampled by the geologic record. That is, a wetter and warmer period. We cannot yet predict how warm or how wet, but we can examine the flood record from the time when a past climate was similar to the present. It is recommended that integration of paleoflood information from an applicable climate pattern with the most recent decade of gauge records may improve flood recurrence estimates.

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CLIMATIC EFFECTS ON GROUNDWATER IN EASTERN NORTH DAKOTA

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INTRODUCTION

In June of 1998, an article comparing 200 years of Red River flood and Devils Lake elevation data was published in *North Dakota Water* (1). Without repeating the data, graphics, or details of analysis, the conclusions of that paper can be summarized as follows. Peak annual discharges at Winnipeg and elevations of Devils Lake display a similarly scaled pattern. Both, with considerable annual variability, display a clear pattern of decreasing peak flow or storage, dating from the 1820s to 1940. From 1940 to the present, both have displayed a clear pattern of increasing flow or storage. These, particularly Devils Lake which is an enclosed basin, indicate a general climate regime in which evaporation exceeded precipitation for the century prior to 1940 and a shift to an overall climate regime wherein precipitation exceeds evaporation from 1940 to the present. The relationship between annual peak flows in the Red River and rising Devils Lake elevations indicates that large events are likely to be partially responsible for rising lake surface elevations.

The cited paper (1) attempted to broaden common awareness of catastrophic flooding experienced in the Red River and Devils Lake to an understanding of a more encompassing problem in eastern North Dakota. Climatic events causing floods are also causing rising groundwater levels throughout eastern North Dakota, particularly in areas having poorly integrated drainage in the prairie pothole region. All of these problems are exacerbated by design and placement deficiencies brought about by a limited comprehension of climatic variability in North Dakota at the time of settlement and during the period in which the state infrastructure was built. Settlement of North Dakota by those of European descent occurred predominantly from 1880 to 1920. This time period corresponded to the lower half of the drying curve for Devils Lake, and large floods occurring in the Red River were much smaller than peak floods occurring both earlier in the 19th century and recently. Construction of basic state infrastructure, sewage and drainage systems, roads, buildings, etc., occurred predominantly from the 1920s to the 1970s. This entire time period spanned the lower half of both drying and wetting cycles for Devils Lake. The problem, then, is that limited historical memory and comprehension of the climatic and hydrologic extremes of which this region is capable caused the placement of an infrastructure that is often inadequate to cope with current climatic and hydrologic events. In addition, designs built to accommodate events of a given probable recurrence interval, based on assumptions of random and normally (or log-normally) distributed precipitation over 30-year periods of record are of questionable value when hydrologic events are nonstationary with respect to time. For example, designs for hydrologic structures based on a limited period of climatic record from 1940 to 1970 would be of questionable value for predicting flood recurrence under current, systematically wetter, conditions.

The remaining portion of this paper will focus on the hydrology of rising groundwater in eastern North Dakota and a brief documentation of some of the types of damage occurring. It is hoped that in doing so, we might broaden the understanding of current climatic effect from awareness of a few highly visible communities to a sense of ongoing impact on farms and communities throughout eastern North Dakota.

DISCUSSION

Within any given area of a climatic and physiographic region, there is a characteristic balance, or dynamic equilibrium, between groundwater recharge and discharge that determines the water-table elevation, which is the expression of residual storage. Groundwater sinks include seepage to waterways through springs, evaporation, and human use. Under natural conditions, the plant community is adjusted to water availability, so that a characteristic range of evaporative withdrawals occurs. Evaporation occurs from soil water and from coupling of shallow saturated groundwater to plant roots or to the surface. If water in excess of normal dynamic equilibrium reaches the water table, groundwater storage will increase, raising groundwater levels until gradients driving lateral flux and increasing evaporation and runoff of accumulating water at or near the surface are sufficient to restore balance.

Groundwater elevations are sufficiently sensitive to changes in net recharge that single large short-term changes or relatively small long-term changes in climatic input or output can have a substantial effect on water tables. In eastern North Dakota, which is borderline between a semiarid and subhumid climatic regime, soil storage, the volume of water held between the "wilting point" and "field capacity," may serve as a partial buffer. Normal cyclical annual soil drying conditions can enable the immobilization of precipitation for vegetative use before it reaches the water table. However, soil and groundwater interactions are highly complex, and even under relatively dry conditions, precipitation can reach groundwater through various mechanisms, including macropores, topographically concentrated recharge (2), and microtopographically concentrated recharge (3). When prolonged wet conditions occur so that soil storage is full, all of these mechanisms increase, and the "piston," or darcian, component of flow is also increased on a broader portion of the landscape.

Once drainage has carried water beneath the drying influence of plant roots, air-filled porosity available for storage is dominated by the capillary influence of the water table (Figure 1). The capillary influence extends upward for about 1 or 2 meters from the phreatic surface. Above the zone of capillary influence, the vadose zone is approximately at field capacity to the bottom of the root zone. Within the zone of capillary influence, fillable porosity is negligible at the capillary fringe adjacent to the phreatic surface and increases gradually to field capacity with distance from the water table. On fine materials, the increase is approximately linear and extends for about 2 meters above the water table. On sands, the increase is often described as a power function, which levels off about 1 meter above the water table. For a depth greater than a few meters to the water table, the overall fillable porosity would be approximately the difference between saturated water content and field capacity. If the water table is shallow, the actual fillable porosity would be somewhat less because of large water content near the phreatic surface.

For fillable porosity, θ_f, water table rise (or drop) Δh for recharge amount R can be estimated as:

$$\Delta h = \frac{R}{\theta_f}$$

Fillable porosity available for storage would have a maximum value that is equivalent to the storage coefficient. Because sands have a small field capacity and a large fraction of drainable pores, water levels usually rise much higher per unit of recharge on fine materials than on sands. Storage coefficients on sands vary from about 0.15 to 0.35 (4). On sands, water- table rise per unit of water input would thus be about 3:1 to 6:1. This means that for 1 inch of recharge beneath the root zone (or for a water table within the root zone with the soil at or near field capacity) water levels would rise about 3 to 6 inches.

On finer soils, fillable porosity values have been found to range from as little as 0.03 to 0.06 in very fine soils (5) to as much as 0.15 on coarser loam and silt loam materials. Water-table rise per unit of recharge would thus range from 6:1 to as much as 33:1. That is, for a worst-case scenario, the water table could rise as much as 33 inches per inch of input. This would occur for a moist and compressed silt or clay. For most till soils in the prairie pothole region, the fill ratio would be in

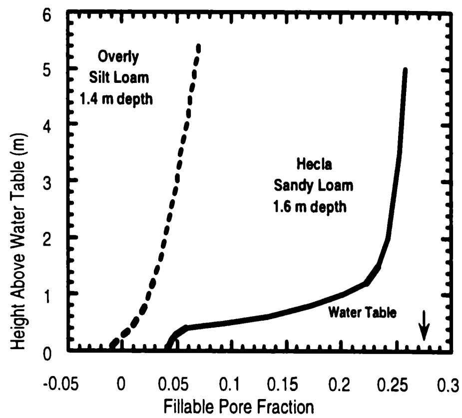

Figure 1. Fillable porosity for the vadose zone under influence of the water table between the water table and the bottom of the root zone.

the range of 10:1 to 16:1. This means that under wet conditions, the water table might rise a foot or more for each inch of water added to the system that is not drained away, evaporated, or transpired. The higher water table will remain until excess water is drained, seeped, evaporated, or pumped from the system.

Pingree: Water-Table Rise on Fine Soil

Pingree is a community of 61 people in Stutsman County, located 21 miles north of Jamestown and 19 miles south of Carrington. It is located on level (< 1% slope) terrain on the divide between the James River and Pipestem Creek. Pingree has poorly integrated surface drainage. Surface gradients are small, and street drains are inadequate. Soils in Pingree are of the Barnes (moderately well drained) and Hamerly (somewhat poorly drained) series. Well completion reports for shallow large-diameter bored wells used for water in the city prior to introduction of rural water indicate that the water table has commonly been between 10 and 17 feet from the land surface. Some nearby wells drilled following the 1930s drought indicated that water levels may have dropped as deep as 30 feet below land surface. Analysis of water-table response to loading indicated that the till in Pingree had a storage coefficient of about 0.07 (6). For this material, a water-level drop of about 15 feet would require a net increase of discharge over recharge of about 1 foot.

In 1993, large precipitation (31.77 inches measured at Jamestown and 26.06 inches measured at Carrington) occurred in the area of Pingree. Thirty-year mean annual precipitation was 18 and 17 inches for the two measurement sites, respectively. Water levels at Pingree rose an average of 11 feet from previous (pre-1993) levels. Part of the increase (about 0.5 to 2 feet) was caused by increased hydraulic loading from importation of rural water without removal of the water to a municipal sewage treatment system. Imported water was discharged to septic fields and therefore to the groundwater system, increasing local hydraulic loading. It was estimated that water level increases of 9 to 10.5 feet were caused by increased precipitation alone. With a storage coefficient of 0.07, this increase would require 8 to 9 inches of additional water. This would correspond well with the 9.7 inches of additional precipitation for 1993 measured at Carrington.

During and following 1993, a wetland of several acres formed southwest of the town on a soil classified as a Hamerly, which was not previously flooded. The newly flooded area, previously farmed, served as a recharge area. It has remained flooded to the present time and now has a full complement of wetland vegetation. Rising water levels have caused severe basement flooding for many homes on a year-round basis. The basement of St. Michael's Catholic Church was constantly flooded until recently tile-drained. Many homes are using sump pumps year-round. Some basements have shown signs of severe erosion and structural damage. Septic fields have also been flooded, resulting in inadequate treatment of sewage, and homeowners have been pumping groundwater near septic fields to street ditches to keep septic fields operating. In some cases, septic fields have backed water into basements. The situation has at times been unsanitary. A 1994 analysis indicated that because there was no external drainage, this water often remained in the ditches and flooded roads. In some cases roads have been damaged. In the end, the water simply infiltrated back into the ground, again to be pumped to the surface. While some efforts have been made to facilitate drainage, the flooding problem in Pingree has not been solved. Options discussed for Pingree have ranged from construction of a municipal sewer to government buyout of the entire community.

Hydrologic conditions in Pingree have not changed much from 1993 to 1998. Viewed on a 6-year timescale, events causing a sustained change of 11 feet of water in the water table would have required an average annual increase in net recharge to discharge of about 1.15 inches per year. If the entire water level change (about 26 feet) from dry conditions at the end of the 1930s to flooded conditions in 1999 were averaged for the 58-year period from 1941 through 1998, then a shift of recharge to net discharge of about 0.5 inch per year would have been sufficient to cause it. If surface runoff and seepage to streams were not greatly changed, then a shift of climate causing a change of less than 0.5 inch per year in the combined increase of precipitation and decrease of evaporation and use would be sufficient to cause a mean overall water-table rise at a rate of about 0.5 foot per year. There are, of course, upper and lower limits of this sort of "average" behavior. For example, as the water-table approaches the surface, lateral flux to more distant discharge points increases, evaporation rates greatly increase, and at some point of surface ponding drainage begins to integrate and the runoff factor becomes more influential. As local groundwater depth increases beyond the root zone, discharge at more distant points and flux to those locations becomes more dominant. The main point is that a relatively small long-term sustained climatic shift can have large effects on water tables.

Kidder County: Water-Table Rise on Coarse Soil

Kidder County has many lakes and potholes. The Kidder County aquifer complex consists of variably confined aquifer units underlying predominantly sandy soils. Much of this aquifer complex is unconfined, with a water table at about 10 to 20 feet below land surface. Since 1993, water levels at most locations have risen 4 to 5 feet. Wetlands have expanded past previously well-developed zones of older cottonwood trees. Historical water levels have varied widely. In sandy areas such as Kidder County, many wetlands and even large bodies of water such as Ranch Lake near Pettibone and Tappen Slough near Tappen were completely dry by the late 1930s. Boundaries of these water bodies have been expanding since 1941. In Kidder County and in nearby McLean and Stutsman counties, rising water levels caused the flooding of several abandoned farmsteads established in the early 20th century.

Wet conditions prevailing in the 1990s have not only caused expansion of existing wetlands, but the formation of new ones. One example is in the NE 1/4 of Section 8, Township 142N, Range 70W, about 2 miles northwest of Pettibone, North Dakota. In Section 8, a new pothole covering about 5 acres appeared in 1994, following large rains in 1993. It remained flooded in the fall of 1998. According to the landowner, the newly flooded area had always been farmed and had never been flooded. Annual ASCS aerial photos dating back to the early 1980s indicate that the land was in a normal crop rotation through all of those years. According to the soil survey (1974), the soil on this location is mapped to the Glyndon series, which is somewhat excessively well drained.

A water-table rise of 4 to 5 feet over 6 years (1993 to 1998) on a sandy vadose material having a storage coefficient of about 0.2 would require a sustained increase in recharge over discharge of about 1.6 to 2 inches per year. This compares with an estimated increase in recharge over discharge of about 1.2 inches for the finer till materials near Pingree.

Other Cases of Flooding

Cogswell and Forman. In the last 2 weeks of June, 1998, the cities of Cogswell and Forman in Sargent county received 6 to 10 inches of rainfall. About 600 acres were flooded in and near Forman. About 400 acres were flooded in and near Cogswell. As reported to the State Engineer (7):

Lift stations in both communities . . . still appear to be operational to a limited degree. If the lift stations stop function, the city's sanitary sewer systems will be off line. The lagoon systems are close to overflowing . . . Potable water is also in short supply and the Red Cross is furnishing bottled water. The telephone system in Cogswell is not operational. Some families have been evacuated in both cities. A trailer court in the city of Forman has been flooded to a depth of approximately four to five feet. Also the railroad is under water, the railroad is not operational in Forman or Cogswell. An emergency exists and both communities have applied for an emergency drainage license.

Forman is built predominantly on soil of the Aasted series, which is loamy, deep, and well drained. However, some areas of the city are of the Parnell series, which is poorly drained-to-very poorly drained. The borders of the city are of the Forman soil, which is deep and well-drained, but has higher clay content in the subsoil. The flooded areas occurred primarily as expansions of the Parnell soils which filled with water from the rains, and on the finer Forman soils on the town borders, following flooding of outlying areas. In the case of Forman, high clay content may have caused perching. Cogswell is built predominantly on deep sandy soils of the Hecla and Maddock Series, but the eastern portion of Cogswell is underlain by Gardena and Forman soils which are finer. Most flooding in Cogswell occurred in the eastern portions of the city.

McLeod. The city of McLeod is located in a sandy area overlying the Sheyenne Delta aquifer. Flooding in McLeod occurred primarily as a result of rising water table in the sands. According to the "Emergency Statement for McLeod" (8), the city of McLeod in Ransom County, flooded after "unusually heavy rainfall over the past six years" which created saturated conditions that

have now accelerated to an emergancy situation in the McLeod area following more than 20 inches of precipitation during the spring and summer of 1998. The unusually high water is threatening the health and safety of the residents. There is standing water throughout the town and in numerous basements. The City sewage system consists of individual septic tanks and they are no longer functioning due to the saturated soil conditions. The concern for public healthy and safety is very real in this emergency situation. There has also been a substantial impact to the area highway system due to the high water.

Enderlin. The city of Enderlin in Ransom County is built on sand and gravel deposits, sometimes called the Enderlin aquifer, along the Maple River. Underlying materials are coarse, and water levels were generally at 10 to 15 feet below land surface during the 1980s. Enderlin has suffered considerable flooding of basements. According to the investigating hydrologist (9):

. . . the problem with ground water seepage into their basements began in the spring of 1996 and has continued to this date (August of 1997) . . . following the recent rains seepage flow into their basements increased . . . All of the homes had noticeable damage from seepage, with heaved, cracked, and crumbling basement floors and walls. At the time of my inspection water was seeping through the cracks in the floors and from cracks at the base of the basement walls. Many of the homes have older wooden support beams that are beginning to rot. Water damage from wet sheet rock was very evident . . . the basements were very damp and musty. During my inspection of (a local church) I was shown the continued seepage that is occurring into the lowest level of the new addition. The one aspect of this seepage that was most noticeable was the putrid smell emanating from the basement . . . the water was black and very viscous . . . Ground water is seeping into the newly dug (elevator) shaft . . . at the Enderlin School.(9)

Other Examples. Many other communities, including Tappen, Kensal, Woodworth, Minot, Bismarck, Jamestown, Valley City, Lisbon, and Devils Lake have reported serious seepage problems. In addition, farm homes throughout the prairie pothole region have reported rising water tables and seepage problems. In June of 1997, I visited one farm home north of Northwood in Grand Forks County, which was pumping from its basement. Its retired owners had returned from winter vacation in the south to find the basement flooded. They claimed to have never been flooded before.

CONCLUSION

Damage from excessive moisture, both flooding and high water tables, has been widespread in eastern North Dakota during the 1990s. Damage has included flooded basements, damage to basement structures, damage to road and railroad beds, crop loss, inoperable and sometimes reversed septic fields, and in some cases losses of farmsteads to rising waters. Weather events and climatic trends causing rising groundwater phenomena correlate with climatic conditions causing large floods on the Red River and with rising elevations in Devils Lake. If we use historical records of Red River flood data and Devils Lake elevations as temporal scalars, we may view current groundwater conditions as a result of an overall wetting trend that has been in progress since 1941. We may also view them as a likely recurrence of conditions that prevailed in the early part of the 19th century. While the Red River floods and relatively brief periods of large precipitation, such as the summer of 1993 or wet conditions in southeast North Dakota in 1998, indicate that groundwater is strongly influenced by large events, they need not be frequent. Long-term rising groundwater levels can be caused by combinations of events that effect relatively small changes in the balance of recharge to discharge when expressed as long-term mean values.

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AN OVERVIEW O F THE CURRENT STATUS OF GCM FORECASTS FOR FUTURE CLIMATE IN THE NORTHERN PLAINS OF THE UNITED STATES

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INTRODUCTION

Forecasts of future climate of the earth by general circulation models (GCMs) are made based on statistical analysis of model results obtained under various forcing scenarios. Motivated by the concern for the projected increase of the amount of greenhouse gases (specifically CO_2) in the atmosphere and the role of CO_2 in changing the radiative forcing to the atmospheric as well as oceanic circulations and hence, the climate, GCMs have been used to examine and evaluate the climate responses to the anthropogenic forcing (Mitchell et al. 1990). Such responses have often been used in estimating what the future climate might be under the projected rate of increase of the CO_2 amount in the atmosphere and how it might be different from the present climate.

Before we discuss the specifics of the predicted future climate in the Northern Plains of the U.S. by GCMs it is important to bare in mind the following facts concerning GCMs capability to simulate and predict the earth's climate.

Climate is a long-term statistical state of the earth atmospheric system and is affected by both the atmospheric and oceanic processes. These processes have very different spatial and temporal scales. For example, the oceanic eddies that contain most of the kinetic energy in the ocean have a much smaller spacial scale than the synoptic scale of the atmospheric motion. Because of limitations in computing resources and our limited understanding of these processes and their interactions, many of these processes, and therefore their effects on the atmosphere, can only be included in GCMs through "parameterizations" at the present time. Many of these parameterizations are crude and cannot yet provide a faithful description of the complex processes in reality. Because of this, GCMs have some ill-behaved "symptoms." For instance, a currently debated issue on coupled ocean-atmosphere GCMs is how to treat a significant bias of the ocean surface energy and water fluxes self arisen from the models during their long-term integrations (Watterson and Dix 1996). Although several "adjustment methods" have been deployed in coupled GCMs to correct the fluxes the relevance of these methods to the physical process they describe remains to be confirmed. Likewise, the impact of these methods and the fluxes on model results requires further study.

Because of these and other restrictions (Wild et al. 1997) in our understanding and modeling capability of the earth climate it is wise to use GCM forecasts of future climate as general guidance or direction of the climate change, and not to focus on the actual predicted values of temperature and precipitation in different locations. With this perception, we will discuss, in this short note, the GCM predicted trend of climate change in the Northern Plains of the U.S. and where the region's climate is expected to evolve if the CO_2 concentration continues to increase at the currently projected rate.

PREDICTED FUTURE CLIMATE IN THE NORTHERN PLAINS OF THE U.S.

Figure 1 (from Murphy and Mitchell 1995) summarizes that major GCMs predict an increase of *global averaged* surface air temperature by 1.5 to 4.5°C *after* the doubling of the CO_2 amount in the atmosphere. The increase rate of the CO_2 in the atmosphere in these calculations used either the IPCC scenario-A (time for doubling the CO_2 concentration is 60 yrs) or a similar one with a 1% compounding increase of CO_2 on an annual basis (doubling period is 70-75 yrs).

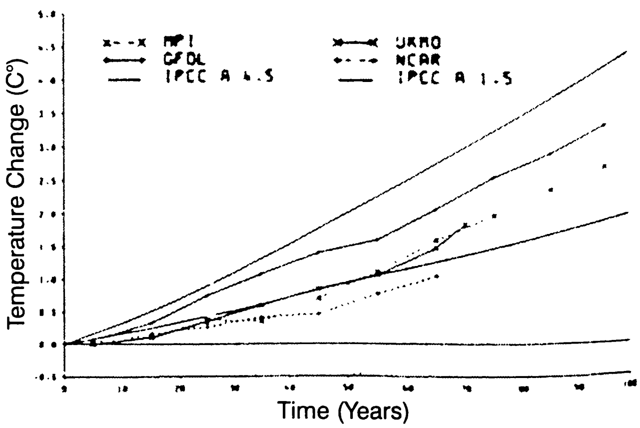

Figure 1. Prediction of global averaged surface temperature change by major GCMs.

Focusing on regional temperature change Cubasch et al. (1995) used a transient modeling study in which two GCMs of different resolutions are integrated simultaneously; the coarse resolution model has the transient ocean-atmosphere interaction dynamics and provides to the fine resolution atmospheric model coarse resolution surface temperature and sea-ice distributions. Figure 2 (from Cubasch et al. 1995) shows the change of annual surface temperature variation in the Central North America (85-105°W, 35-50°N) under different CO_2 scenarios. The future surface temperature in the region after the doubling of CO_2 amount is shown by the dotted line and is about 1K warmer than the model simulated current temperature (the thin solid line in the figure). (We notice the bias in the model simulated temperature of the current climate from the observed current temperature shown by the bold solid line in the figure.) The result also shows that the increase of the surface temperature has a larger amplitude in the warm season than in the cold season.

Mearns et al. (1995) selected four regions in North America in a detailed study of changes of the *daily temperature range* in a doubled CO_2 climate. One of the four regions is the North Central Great Plains including the state of North Dakota. Mearns et al.'s study used a nested modeling technique in which a coupled GCM's output is used to drive a regional scale circulation model placed over the region of interest. The GCM they used is a modified National Center for

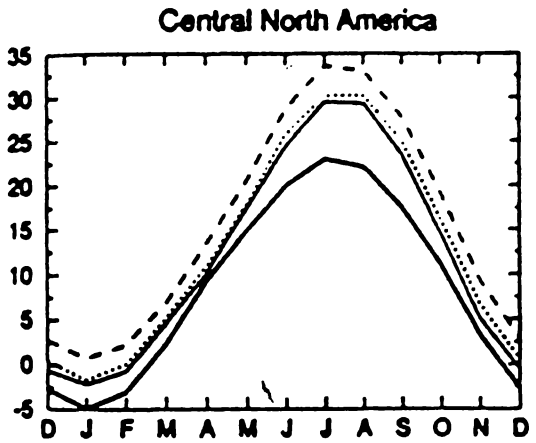

Figure 2. The annual cycle of the observed (bold solid line), and GCM predicted 1 time CO_2 (thin solid), 2 times CO_2 (dotted), 3 times CO_2 (dashed) surface temperature in central North America.

Atmospheric Research (NCAR) Community Climate Model (CCM) and the regional climate model is based on a mesoscale model developed at NCAR. Their model prediction indicates that in the enhanced CO_2 climate the daily temperature variation range in North Dakota will decrease in cold season (November through March) and increase in warm seasons (May-October). The largest increase appears in October.

The decrease of daily temperature range in cold season is consistent with a concurrent model prediction of increased cloud cover in the enhanced CO_2 climate. The increase of cloud amount in the cold season ranges 10-20% of the current value. Cloud reduces the night time loss of terrestrial radiation and keeps the daily minimum temperature from being low so that the diurnal range of temperature decreases.

The increase of the daily temperature range in the warm season is related to the reduction of the cloudiness in the warm season in the enhanced CO_2 climate. In the CO_2-rich climate the middle troposphere in the equatorward side of the middle latitude rain belt (~60°N) is expected to have a smaller water content during the warm season. Low cloud amount in such dry conditions allows more insolation during the day and a greater cooling during the night (Wetherald and Manabe 1995) and enlarges the diurnal range of the surface temperature.

The prediction from the Mearns et al. (1995) models also indicates a decrease of the cold season meridional temperature gradient in the middle latitude troposphere in North America. Consequently, the middle latitude westerly jet stream weakens in the cold season. There are likely fewer winter storms in the north-central regions of the U.S., consistent with the result in Lambert (1995) from the Canadian Climate Center GCM. However, the storm intensities are predicted to increase primarily due to the overall increase of moisture in the atmosphere in the doubled CO_2 climate (Lambert 1995). Mearns et al. also show that the strength of both the meridional gradient of the temperature and the middle latitude jet stream will increase in the warm season. Because the jet position is likely to shift northward of its current position there could be little impact on the warm season weather in the North Dakota area from this intensifying jet stream in the enhanced CO_2 climate.

The most striking change in precipitation for the inland region, e.g., North Dakota, is the summer dryness (Manabe et al. 1981; Mitchell and Warrilow 1987; Wetherald and Manabe 1995) resulting from the warming of the climate due to increase of CO_2 amount in the atmosphere. During the late spring months the depletion of the local atmospheric moisture in the rain belt allows an increase in radiation energy at the ground. Because of the warm air temperature in the climate of enhanced greenhouse gas and the nonlinear increase of the saturation vapor pressure of the atmosphere with increase of temperature, more heat at the surface will be used in evaporation than in conduction of sensible heat from the surface. As a consequence, soil moisture will be depleted quickly. Warmer air and drier soils will be less favorable for development of rainfall in the following summer months. The evaporation rate will greatly exceed the rainfall rate thus exacerbating the drying condition in the soils when the summer proceeds. Figure 3, taken from the idealized modeling study of Wetherald and Manabe (1995), shows the development of the dryness in the inland areas at latitudes similar to North Dakota's. This summer dryness in the Northern Plains of the U.S. will cause a shift of the main rain belt northward of the

60°N. This result is consistent with the northward shift of the westerly jet stream in the warm season shown in the GCM prediction in Mearns et al. (1995).

Most of the GCM predictions show that there will be a slight increase of winter season precipitation in the Northern Plains of the U.S. in the enhanced CO_2 climate (e.g., Murphy and Mitchell 1995). This increase is attributed to an increasing supply of moisture from the warm ocean surfaces upstream of the land areas and low evaporation rate over the land areas in the winter season (Wetherald and Manabe 1995). However, the warmer air temperatures in the enhanced CO_2 climate will likely increase the fraction of the rain precipitation and decrease the snow fall amount in the winter season. The soils will be likely saturated during the winter months. This situation will be favorable for spring flood development in the latitudes between 45-60°N, because the saturated soils will not absorb the combination of water from the melting snowpack when the temperature rises in late spring and from the rainfall during this relatively wet period. Most of the water from the melting snow and rainfall will contribute to the surface flow and therefore elevate the potential of frequent floods.

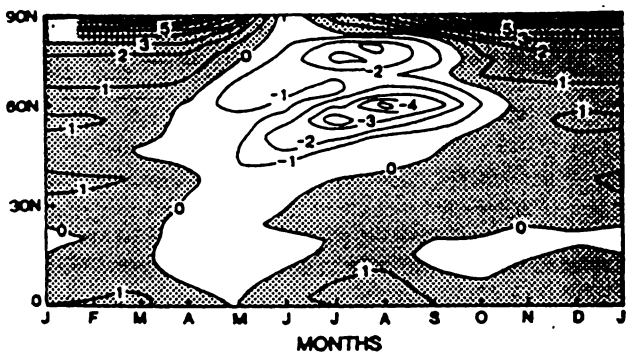

Figure 3. The latitude-month distribution of zonally averaged monthly mean difference of soil moisture between 4 times and 1 time CO_2 amount integrations. (Four times CO_2 concentration is used to enhance the signal of the CO_2 effect. A variation of similar structure is expected for 2 times CO_2 amount.) The land distribution is made ideal in this integration to illustrate the physical mechanism of the summer dryness. Similar results have been obtained by integrations with realistic land surface distributions (e.g., Manabe et al. 1981; Mitchell and Warrilow 1987).

DISCUSSION

From a hydrological perspective, the GCM predicted future climate with a doubled CO_2 amount in the atmosphere is likely to formulate a challenging situation for management of water resources and environment in North Dakota and the neighboring states of the Northern Plains of the U.S. In the enhanced CO_2 climate, the total winter season precipitation amount in the region will increase. In the meantime, there will be an increase in the rainfall portion and decrease in the snow fall portion of the total cold season precipitation. The wet winters are likely to keep soils near saturation in the cold season. Snowpack will melt earlier in the warmer climate. With the saturated soils waters from melting snow and rainfall in late spring months will increase the surface runoff volume in the region. Dependent on the conditions and configuration of the surface channel networks floods may develop more frequently in spring months in the region in a warmer climate. In addition, the ground water resources could be affected dependent on changes in the recharging process resulting from the alteration of the surface water availability.

The evaporation will dominate the surface water budget in the summer months. Summers will be dry. Soil moisture will be lower than in the current climate and the base flow of the rivers in the region could be reduced as well. Prolonged dryness in the region can enhance the vulnerability of this semi-arid region in the Northern Plains of the U.S. to droughts and threaten the region's agriculture, natural resources, and environment.

Before closing, we want to remind the readers that these predicted changes of climate are made by the GCMs which the Atmospheric Science community still strives to improve through advancing our understanding of the physics and interaction mechanisms of the ocean and the atmosphere. There are no absolutes in prediction of future climate. These GCM predictions are best interpreted as possible directions of the climate change under the currently assumed increase rate of the CO_2 amount in the atmosphere.

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BASIC PROCEDURES, APPROACHES, AND ASSUMPTIONS ASSOCIATED WITH FLOOD FORECASTING IN THE U.S. PORTION OF THE RED RIVER BASIN

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INTRODUCTION

The National Weather Service Hydrologic Service Program mission statement is: to mitigate loss of life and property damage caused by floods and to provide the nation with timely issuance of river and flood forecasts. This mission is accomplished through data acquisition, river modeling and forecasting, and product dissemination. The following discussion will provide information on basic procedures, approaches and assumptions that the National Weather Service uses to accomplish its mission.

DISCUSSION

Procedures, Approaches, and Assumptions

Data Acquisition. The five elements which contribute to major snow melt flooding in the Red River basin are 1) High fall soil moisture, 2) Deep hard frost, 3) Heavy snowcover, 4) Heavy rains during the melt, and 5) Rapid melt. To monitor these elements, the National Weather Service (NWS) relies on a variety of data sources. The National Operational Hydrologic Remote Sensing Center collects terrestrial gamma radiation data in the fall, to observe the fall soil moisture, and again in the spring to collect snow water equivalent data. Frost data is observed through the use of frost tubes. Daily precipitation and temperature data is recorded by NWS cooperative volunteer network. Some of the cooperative observers also collect snow depth and water equivalent data on a weekly basis during February and March. As the spring season approaches, careful attention is given to precipitation and temperature forecasts so that the threat of heavy rains or rapid melting conditions can be anticipated and simulated in river models and represented in river forecasts.

River Modeling and Forecasting. The river basin model used by the North Central River Forecast Center (NCRFC) in Chanhassen, Minnesota is actually comprised of three separate models: the snow model, the rainfall and runoff model, and the flow model. Inputs to the snow model are observed temperatures and precipitation that are converted into mean areal temperatures and mean areal precipitation values for each sub-basin. Outputs from the snow model are rain and snow melt amounts. The rain and snow melt amounts are then used for input to the rainfall and runoff model that calculates runoff. The flow model or routing model takes the computed runoff values, instantaneous discharges, unit hydrographs, established routing techniques, mean discharges, and forecast point hydrographs to produce forecasted discharges. The last step is to convert the forecasted discharge to a forecasted stage level using a rating curve.

Product Dissemination. The NCRFC provides the NWS forecast offices with guidance products that are to be used to produce public river forecasts. The two main types of products that are issued to the public for snow melt flooding are "outlooks" and "river flood forecasts". There is a higher level of uncertainty associated with outlooks than there is with river flood forecasts based on the fact that the outlooks are usually released six to eight weeks before actual crests occur.

Outlooks come in two formats. Narrative outlooks are issued in February to describe the conditions that are present in the basin and what the potential for flooding appears to be at that time, assuming normal temperatures and precipitation through the month of April. In March, Numerical outlooks are issued to indicate what crest levels may be anticipated under two conditions. The first condition assumes no additional precipitation and the second condition assumes normal precipitation. Outlooks are to be used for long range planning and readiness construction planning.

River flood forecasts are issued for designated river forecast points along the Red River and its tributaries when the melt season begins, and the rivers are forecast to rise above flood stage. Daily river forecasts and crest forecasts are issued in the form of flood statements for the river forecast points until they are forecasted to fall below flood stage. These river flood forecasts are to be used for short range planning.

Outlooks and river flood forecasts are necessary for informing the people of the Red River basin about what they can anticipate for the spring snow melt season. These products are composed of the best assessment of hydrologic conditions in the basin at the time they are produced. Their accuracy is limited by the unknown factors that influence hydrologic conditions such as changing meteorological conditions.

HOLOCENE CLIMATE CHANGE INTERPRETED FROM FLUCTUATIONS IN ALLUVIAL SEDIMENTATION IN WESTERN NORTH DAKOTA

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INTRODUCTION

The record of climate change during the Holocene (10,000 years to the present) and earlier geologic epochs, regardless of interpretation, is one of change without human involvement (Figure 1). Recent anthropogenic effects on climate and other biosphere systems, however apparently obvious, beg a significant question — what effect are humans having on top of an already significantly varying climate record. Is the effect a cumulative response (a compounded trend) or is it a complex record of positive and negative responses. Unfortunately, with as much Holocene climate-related data as there are, separating out cause and effect has proven very difficult. This may not be surprising in that this question, and our interest in very specific answers have only recently emerged. One of the ways climate change phenomena can be understood is to look for patterns or cycles. Much effort and thought have been given this subject (1), and cycles at many scales have been recognized. As a report on ongoing research, this paper considers proxy climate variation data as recorded in the occurrence of paleosols in semiarid plains and badlands in western North Dakota (2, 3). The goal was to determine if short-term cycle patterns are present in geomorphically dynamic terrains.

BACKGROUND

Climatic variation during the Holocene has been documented through a variety of environmental indicators. Studies typically involve evidence of changes in the biota as a result of fluctuations in precipitation, reflecting periods of increased aridity, followed by times of more equitable climate. Variation in the relative percentage of palynomorphs, indicating changes in vegetational patterns, has been widely used in areas with mixed vegetation types, where lakes or other depositional sinks are relatively common (4). Diatoms and ostracodes have been used to indicate the variation in the salinity of bodies of water in more arid environment, but such studies are associated with semipermanent bodies of water (5–7). In the Southwest and elsewhere, variation in past climates has been interpreted from tree rings. Organisms used to track seasonal and general climatic variation as a function of habitability necessarily already live in a wet or generally compatible environment. In semiarid settings, which can be virtually devastated by drought, very little effort has been given to establishing a pattern of climatic variation recorded in cycles of alluvial sedimentation in highly erodible bedrock. The grasslands and badlands of the northern Great Plains conserve few permanent bodies of water to record variation in biotic productivity. These distinctive habitats do, however, record wet and dry periods by decreased and increased rates of cut and fill and by alluvial fan deposition. Unlike changes in the various biotic components of a diverse ecosystem, which may require substantial lag times to reflect climatic patterns, increased or decreased erosion and deposition may be an immediate reaction to wet and dry cycles. As a corollary, badlands sedimentation patterns are such a potentially sensitive environmental indicator that they may be capable of recording short-period cycles, thus providing additional objective information useful in correlating cause and effect.

RESEARCH PREMISE

Climate, particularly insolation and moisture, has a direct influence on vegetation. Together, both climate and vegetation, rather than structural or eustatic changes or cultural modifications, are the major driving forces behind the weathering, erosion, transportation, and deposition of sediment (8–10). Landscape form is therefore determined by the balance between deposition, erosion, and stability (9, 11).

Several basic geomorphic models utilizing the above-mentioned climatic–geomorphic relationships have been developed within the last several decades. The one presented in Butzer (8), taken from Erhart's (12) concepts of biostasis and rhexistasis, is a good, albeit somewhat simplistic, example. Basically stated, during periods when landforms are stable, hillslopes are covered by a protective mat of vegetation, and a balance is established between weathering (soil formation) and valley sedimentation. The weathering of surface sediments produces soils during periods of landscape stability. During periods of landscape instability, vegetation is significantly reduced, if not removed completely. This leads to slope disequilibrium as erosion outpaces soil formation. Disequilibrium results in the total and/or partial truncation of soils, which, in turn, accelerates the transfer of sediment to lower slopes and valley bottoms. Critical to this study, however, is the hypothesis that at the scale of individual geomorphic landscapes, change can also occur as a result of "complex response" to intrinsic variables (13). Complex response is an

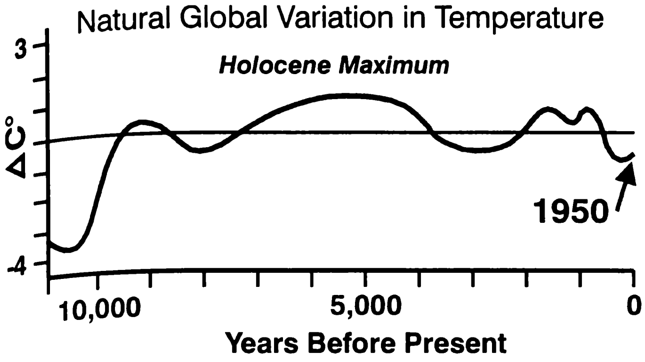

Figure 1. Natural climatic variation. Variation in climate, reflecting changes in CO_2 levels as well as many other biospheric components, has occurred continuously throughout billions of years of earth history (27). Of concern today is the exacerbation of normal climate change as a by-product of human industry. Understanding the history and extent of climate change and the magnitude of human impact is necessary to develop effective policy on resource management and utilization.

active process in most landscape settings, especially fluvial, and is most acute in highly dynamic landscapes such as badlands, where geomorphic thresholds are in constant adjustment (14).

As demonstrated by Langbein and Schumm (15), slope erosion and/or runoff are most directly affected by precipitation, although temperature is also a key factor, as it greatly affects evapotranspiration. In semiarid regions, including all of western North Dakota, the effects of temperature and precipitation on runoff and sediment yield are particularly salient (11, 15). In such areas, rather modest changes in mean annual precipitation (i.e., 10%) and temperature (i.e., 2°C) can result in dramatic changes in mean annual sediment yield to valley settings in particular (11). Therefore, periods of warm and dry climate valleys are likely to be associated with episodes of eolian, fluvial, and slopewash aggradation, as hillslopes and uplands are stripped of vegetation and sediment is eroded, transported, and redeposited. On the other hand, periods of cool and moist climate are likely to result in landscape stability and soil formation. Under these conditions, sediment yield from slope runoff and wind deflation is reduced, and streams, denied sediments, begin to cut down. This model formed the conceptual framework for the interpretation of depositional and climatic environments associated with the late Pleistocene/Holocene-age Oahe Formation in North Dakota (16). Studies in the badlands of western North Dakota and elsewhere have since verified the basic features of this pattern, but have also identified the importance of local geomorphic conditions and, hence, accentuate the need to consider scale when interpreting soil, climatic, and landform data (17).

On the scale of physiographic sections, subsections, and regions, the basic climate/landscape model of Knox (11), Langbein and Schumm (15), Clayton and others (16), and others holds great promise. Problems arise at the local level or when an attempt is made to correlate patterns noticeable at a number of small, isolated localities scattered over a large region. In general, particularly in semiarid regions, episodes of alluvial aggradation, as represented by discrete accumulations of floodplain and former floodplain sediments at various elevations and ages, suggest that warm and dry conditions prevailed or were at least more prevalent during aggradational events (Figure 2). Episodes of valley downcutting suggest the opposite, that is, that cool and moist conditions prevailed during periods of alluvial degradation. The aggradation and degradation of windblown sediments (i.e., eolian or loess deposits) in western North Dakota appear to follow this same basic pattern (16, 17).

Paleosols reflect periods of landscape stability. Landscape stability can result from a change in 1) climate, 2) local geomorphic conditions, and/or 3) other factors such as tectonics, eustatic activity, biologic activity, cultural activity, and fire. As a causal factor behind paleosol formation, climate is suspected when 1) synchronous soils are widespread and correlated beyond individual localities or drainage basins, 2) soil formation is occurring at multiple places at the same time, or 3) stable carbon isotope and other proxy sources indicate that soils are associated with episodes of cool–moist climate. Local geomorphic conditions are suspected 1) in extremely dynamic landscapes such as badlands, 2) when soils are thin and discontinuous at a single location (e.g., Figure 3), 3) when soils are generally thin and cannot be correlated within even a single drainage basin, and 4) when soils, regardless of thickness, cannot be correlated between different drainage basins or physiographic regions.

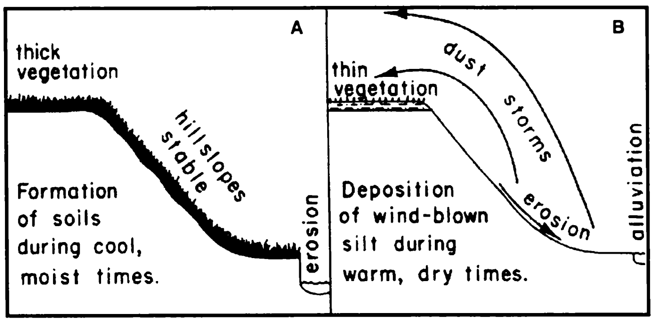

Figure 2. Relationship between climate and landform stability and paleosol formation (16). A. A time period of landform stability, with well-developed vegetation cover, soil formation, and limited erosion. B. A time period of landform instability, with thin vegetation cover, limited or no soil formation, and extensive erosion.

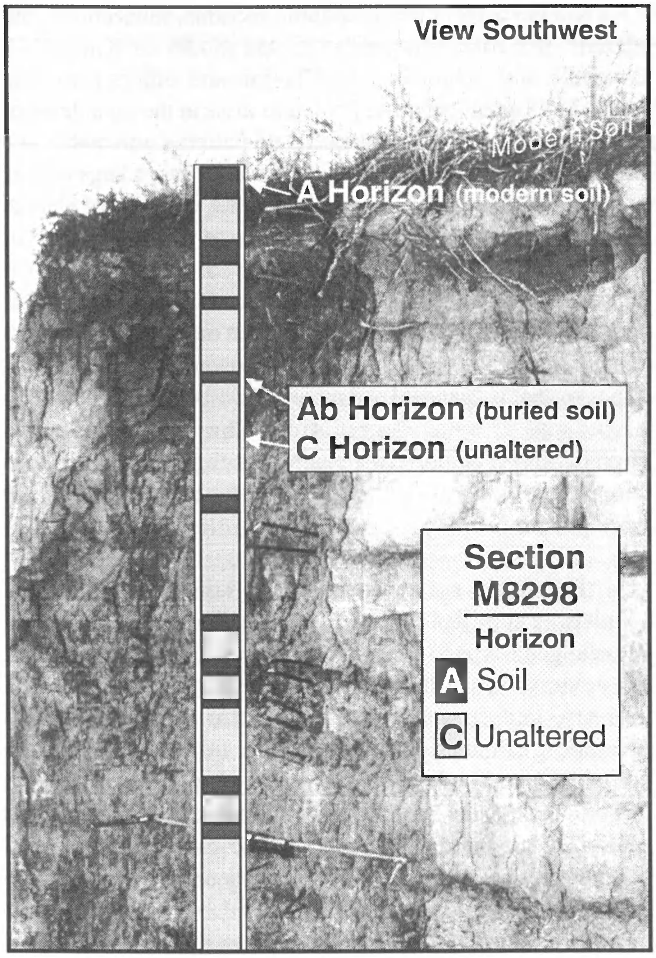

Figure 3. Paleosols at Knutson Creek Locality M (2). This figure illustrates numerous paleosols in Section M8298 and the soil nomenclature used in this report. A horizon = modern soil and includes organic mat (O); Ab horizon = buried soil (= paleosol); C horizon = unaltered material.

In western North Dakota, these climate, soil, and geomorphic relationships strongly suggest that investigations must focus on the analysis of data at all scales, including 1) intrasite, or small, scale (i.e., within a single stratigraphic section); 2) intersite, or medium, scale (i.e., between different stratigraphic sections within the same subregion); and 3) large scale (i.e., between subregions, regions, and provinces). The types of data to be considered in such multiscaled investigations include 1) geomorphic setting; 2) geomorphic history; 3) soils (including thickness, level of development, and correlation); 4) unit contacts and general stratigraphy; 5) evidence of geological unconformities; 6) textural changes and changes in depositional environments; and 7) proxy climatic data, such as stable carbon, pollen, phytoliths, diatoms, and snails.

In order to draw meaningful inferences concerning the relationships between climate, geomorphology, and soils, research focused initially at the locality level where geologic sections were measured. This represents the main emphasis of the project reported here. Subsequently, however, data concerning intersite correlations and regional phenomena must be incorporated to weigh the significance of local results and interpretation.

STUDIES IN WESTERN NORTH DAKOTA

Late Holocene sediments in the badlands terrain of Theodore Roosevelt National Park, Billings County, North Dakota, and in prairie settings of Knife River Indian Village National Historic Site, Mercer County, North Dakota, and along the north shore of Lake Sakakawea (Missouri River), McLean County, North Dakota (Figure 4; Table 1), preserve records of numerous paleosols buried by alluvial deposits. Along the headwaters of Knutson Creek in Roosevelt Park, Ab horizons occur in minor sections (<1.4 m) with as many as ten paleosols. Although these were not dated directly, a date from a nearby section suggests formation of these paleosols over the last 1430 years (all dates are from AMS radiocarbon analyses). The Knife River Elbee Bluff Locality contains eight Ab horizons in a 2.4-m section, the middle portion of which has five thin, evenly spaced paleosols from about 2000 to 2974 (radiocarbon years) before present (YBP). The Lake Sakakawea Douglas Creek Locality consists of a stacked, apparently conformable sequence of 15 Ab horizons in a 2.8-m section that can be traced laterally across a small paleovalley. The occurrence of paleosols at this locality can be interpreted over a span of 2655± years. In the prairie setting of Douglas Creek, landform instability, although quite variable in pattern of occurrence, may have resulted in alluvial depositional recurrence every 170 to 180 years. The paleosol record preserved in both badlands and prairie localities indicates that soils seem to have been the result of relatively stable environments interrupted

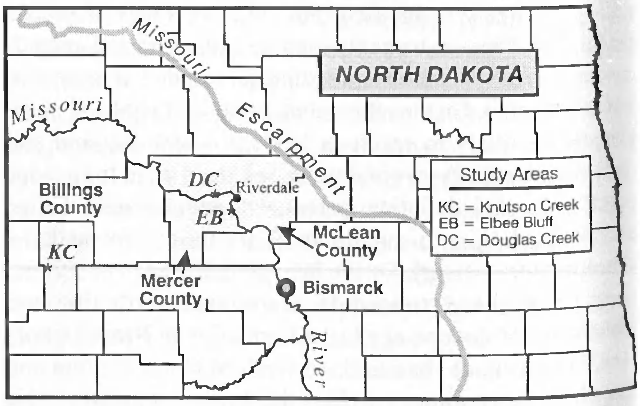

Figure 4. Paleosol study localities in North Dakota (2). This figure illustrates the occurrence of project localities on a map of North Dakota counties. The eastern edge of drier conditions is represented by the Missouri Escarpment.

Table 1
Basic Paleosol Locality Data

Knutson Creek Locality D	On south side of Knutson Creek on 9-m-high slumped cutbank, about 465 m north of the south section line and 935 m east of the west section line (park boundary), in sec. 4, T. 140 N., R. 102 W., Medora Quadrangle, Billings County. Locality D includes three terraces (17), from youngest to oldest, T1, T2, and T4. T4 includes the main section M8297 at 46°50'2.17"N-103°33'2.38"W. Sections were also measured on T2 (M8311) at 46° 57' 56.69"N, 103° 33' 14.04"W and T1 (M8312) at 46° 57' 6.90"N, 103° 33' 4.84"W.
Knutson Creek Locality M	North side of Knutson Creek on west-facing exposures at the top of a high cutbank, about 450 m north of the south section line and 180 m east of the west section line (park boundary), in sec. 4, T. 140 N., R. 102 W., Medora Quadrangle, Billings County. Section M8298 was measured on Terrace T4 at Locality M at 46° 57' 56.57"N, 103° 33' 51.37"W.
Elbee Bluff	On a 6- to 7-m-high, actively slumping cutbank, 2.4 km north of Stanton in the SW¼ NW¼ SE¼ sec. 28, T. 145 N., R. 84 W, Stanton Quadrangle, Mercer County. The bluff is located about 0.4 km north of a river fishing access and trail that leads to the Sakakawea Villages (Awatixa). The Elbee Bluff Locality includes Section M8299, which is near protected archaeological sites, at 47° 20' 43.36"N, 101° 23' 11.87"W.
Douglas Creek	Along the north shore of Lake Sakakawea in the Douglas Creek State Game Management Area, northwest of Riverdale, Emmet SE Quadrangle, McLean County. The locality includes observation sites and Sections M8301, M8302 (main), M8303, M8304, M8310, and M8313–M8315, which are near the center of the SE¼ sec. 11, T. 147 N., R. 86 W. The center of the tributary valley at the lake bluff is at 47° 33' 49.11"N, 101° 35' 43.37"W.

by brief episodes of burial every 140 to 200 years. The regularity of these burial events may stand as possible proxy indicators of minor climatic variation on an otherwise general record of climate stability. Stable carbon studies of these paleosols indicate generally cool and moist conditions (−22.6 ± 0.6 $\delta^{13}C_{PDB}$‰), except for those forming about 2585 YBP (Douglas Creek) to at least 2165 YBP (Elbee Bluff), during which warmer and drier conditions (−20.0 ± 0.4 $\delta^{13}C_{PDB}$‰) more likely prevailed.

INTERPRETATIONS

Following the principles outlined in the above basic landscape/climatic model, especially the need to focus on various scales or levels of information, the discussion below concerns project data in a larger regional–interregional perspective. In other words, what similarities, differences, or possible patterns emerge from an interpretation of the soil, geomorphic, and radiometric records from the study sections as a whole? The following discussion refers to project localities in Billings County (Localities C, D, and M), Mercer County (Elbee Bluff Locality), and McLean County (Douglas Creek and Riverdale localities) in western North Dakota.

Badlands Localities

Unfortunately, little in the way of substantive comparable data was recovered from Localities D and M in the Little Missouri badlands physiographic region. This is due largely to 1) the paucity of radiocarbon dates; 2) the possibility that the crux of the investigation was limited to loess and/or colluvial mantles that cover the major localities and may be substantially younger than the underlying alluvium; 3) the nature of geomorphic processes in badlands environments, which are unlike those of other landscapes in that they are extremely dynamic and sensitive to both climatic and local geomorphological variability; and 4) proxy data regarding paleoclimatic conditions, particularly stable carbon isotope analyses, being inconclusive or demonstrating little change through time. This is contrary to previous paleoclimatic studies that concentrated on upland landforms in the region (17) of which the results may be attributed to the riparian settings of the study sections. Both studies were from perennial stream locations where evidence of climate change via fluctuations between C_3 and C_4 biomass may have been masked by greater water availability and the riparian nature of the localities. In very broad terms and in a manner not particularly well-suited to interregional correlations, the following inferences may be drawn from the badlands data:

- Previous research (17) indicates that relatively warm and dry conditions prevailed during the aggradation of the area's four major terrace (e.g., T4) fills (T4, 7000–6000; T3, 5500–4500; T2, 2700–800; and T1, 400–150 YBP) (Figure 5).

- From Terrace T2 at Locality D, it can be argued that three episodes of landscape stability and limited soil formation were interrupted by valley aggradation between about 2700 and 800 YBP.

- From the probable loess/colluvial mantle at the top of T4 alluvium at Locality D, it appears that during the last approximately 1400 years at least six periods of landform stability and soil formation were interrupted by periods of aggradation.

- From Terrace T1 at Locality D, it appears that at least two periods of stability occurred within the last approximately 300 years.

- Because of a complete lack of direct chronological control, the data derived from Locality M cannot be correlated with those from other sections at this time (see below).

Although charcoal was recovered from Locality M, the samples were too small to permit radiocarbon analysis. The age relations of Localities D and M may possibly be inferred to be approximately the same on the basis of the similarity of the shape of the stable carbon curves for the two localities. The possibility that 10 paleosols of Locality M formed in the last 1430 ± 50 years indicates landform instability on the order of every 140 years or so. That the thin paleosols of Locality M may be autocyclic in nature is possible. However, the similar pattern of stable carbon data between Localities D and M possibly suggests a similar span of time (H.E. Wright, verbal communication, 1998).

The likelihood that individual soils at either Locality D or M are chronostratigraphically equivalent to soils outside of the badlands region is slim. Indeed, even the correlation of soils within a single drainage system appears difficult at best. Geomorphic processes such as slopewash deposition, gulling, piping, and mass movement are virtually ongoing and certainly affect local conditions of landscape stability, deposition, and erosion. These localized processes are related to a number of factors, particularly to 1) variable lithologic composition among exposed slopes, which can range from highly impermeable clay to very weakly cemented sandstone, and 2) slope aspect, which affects the amount of solar radiation reaching the surface, which, in turn, influences vegetative cover and slope morphology (18). Badlands environments, especially in lowland, hillslope, or valley settings, are extremely complex in terms of the number and timing of geomorphic processes. While research in more stable upland badlands settings has indeed yielded significant information on changing climatic conditions during the Holocene, the same cannot be said of lowland settings, other than making climatic inferences based on the timing of areawide periods of valley aggradation and degradation.

Prairie Localities

By far, the most useful data regarding the relationship between Holocene climatic conditions and alluvial sedimentation were those derived from the Elbee Bluff (Figure 6) and Douglas Creek (Figure 7) localities. Both demonstrate the highest degree of buried soil development (or at least the thickest), and both have good-to-excellent chronological control. A word of caution, however—at both sections there are stratigraphic characteristics that could complicate the drawing of certain climatic–geomorphic inferences. At Elbee Bluff, for example, there is uncertainty as to the depositional environment associated with the upper approximately 0.3–0.8 m of sediment. Reiten (19, 20) suggested that a period of downcutting of the Knife River channel occurred sometime between about 2000 and 1100 YBP. This incision created Terrace A and led to the aggradation of a lower floodplain. If this were the case, it would have been very difficult for the Knife River, under normal flood regimes, to deposit other than very fine-grained (i.e., suspended load) sediments to the top of the A surface during subsequent flood events (21). The

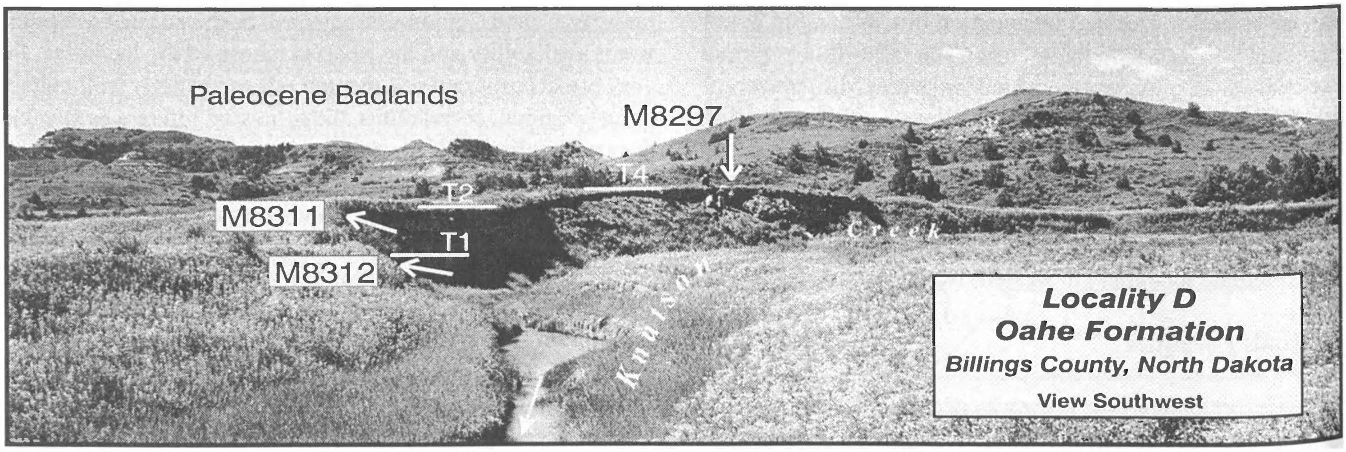

Figure 5. Knutson Creek Locality D sections and terraces (after 2). View upstream of cutbank exposures. Badlands of the Paleocene-age Tongue River Formation, seen on the horizon, provide one source of alluvial sediments.

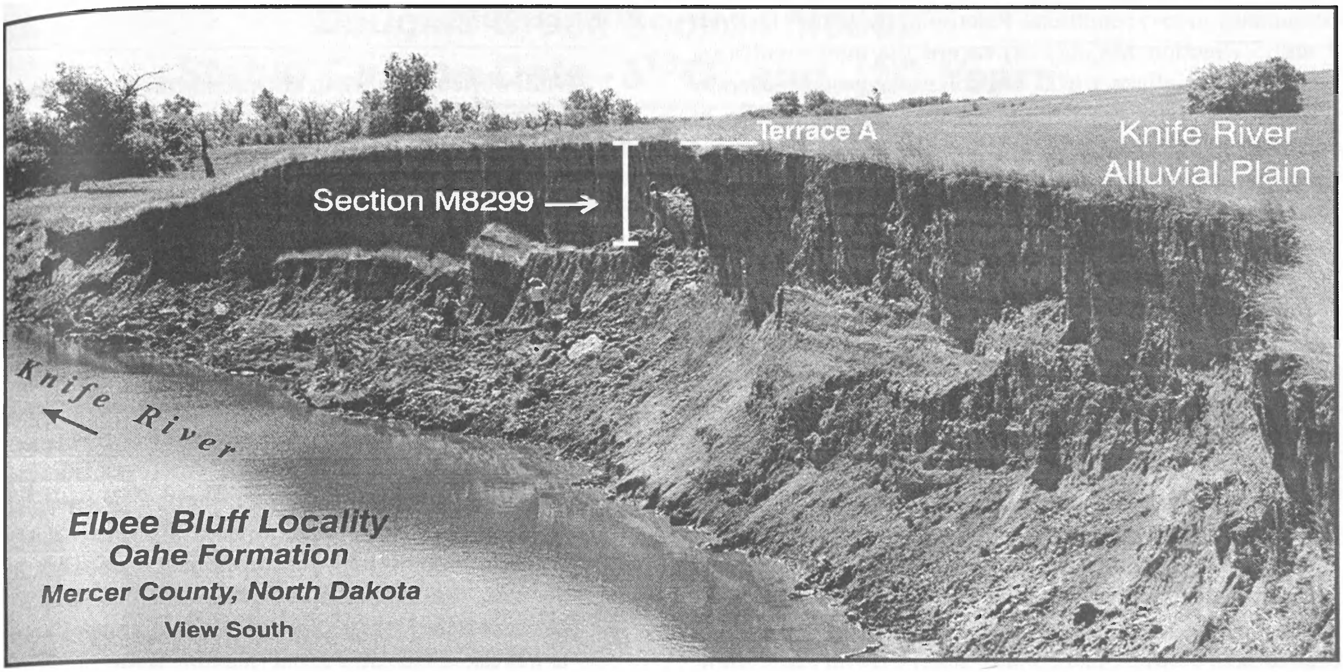

Figure 6. Elbee Bluff Locality, Mercer County, North Dakota (2). View downstream across the Knife River, a tributary of the Missouri River. This figure illustrates the location of Section M8299 and level of Terrace A.

textural data obtained as a result of this study, however, indicate a slight decrease in clay and a rather significant increase in sand in the deposits above Units 5 and 6 (Section M8299a) (2). This leaves open the possibility that eolian processes may have been responsible for the deposition of the upper portion of the exposure.

At Elbee Bluff, there are no less than eight episodes of landscape stability and soil formation over a period of about 2000 years, while at Douglas Creek, the number rises to 15 during a roughly 3000-year interval. These are impressive pedogenic/geomorphic records. Given these general observations, what pedogenic events or groups of events stand out as potentially significant at the regional and interregional scale? In the case of the Elbee Bluff Locality, there is good evidence for soil formation under relatively cool and moist conditions from about 3900± to 3800± YBP and from 3300± to 2900± YBP. In addition to the soils themselves, mesic conditions in all instances are evident on the basis of the $\delta^{13}C$ data, which indicate the predominance of C_3 plants during these intervals. The only evidence of significant C_4 vegetative input was recovered from Unit 9 (Section M8299a) (2), a thin soil that appears to have formed shortly before about 2000 YBP. Short-term cycles at the Elbee Bluff Locality may be evidenced by the middle portion of the section, which has five thin, evenly spaced paleosols from about 2000± to 2974± YBP. A potential average occurrence of landform instability may be about 195 years.

At the Douglas Creek Locality, on the other hand, a cross-sectional view reveals a concave, basinlike depression. Several of the thickest (and most fine-grained) soils are those in the bottom of the basin. These, as well as several others, appear to pinch out laterally along the sloping sides. This type of morphology suggests that Section M8302 may have contained some sediments that are at least partially paludal in origin (22). Additional evidence for ponding may be indicated by the phytolith data (23); samples from the lowest and deepest portion of the possible depression suggest climatic conditions more mesic than those of modern times. If indeed a ponded environment did exist, in some respects the data recovered from Douglas Creek may not be representative of so-called "normal" alluvial terrace and floodplain fills along other meandering streams in the northern plains. However, in the absence of additional data, including soil chemical and organic composition, diatoms, pollen, or freshwater snails, such a possibility must be viewed as tentative. There is every reason to believe that significant and applicable information regarding Holocene climatic and geomorphic relationships can be recovered from paludal or eolian sediments (see 24, 25).

In the case of the Douglas Creek Locality, there is good evidence for soil formation at about 5200, 3500, between about 3200 and 3000, about 2500, and to a lesser extent, possibly about 2200± YBP (Figure 8). Again, high negative $\delta^{13}C$ values suggest that all of these episodes, with the possible exception of the last group, occurred under mesic (or at least cool and presumably moist) conditions. Paleosols represented by Units 3 and 5 (Section M8302) (2) record the most significant increase in the influence of C_4 vegetation, suggesting generally warmer and drier conditions. An average occurrence of paleosols at the Douglas Creek Locality can be interpreted from the conformable sequence of 15 Ab horizons. Over a span of 2655± years, landform instability resulted in alluvial deposition on average about once every 170 to 180 years. The paleosol record preserved at all three localities indicates that soils are the result of relatively stable environments interrupted by brief episodes of burial every 140 to 200 years. A statistical analysis on the Douglas Creek Locality record, using a lognormal distribution, indicates a maximum recurrence interval of 250 years (with a 90% probability) (2).

At both the Elbee Bluff and Douglas Creek Localities, periods between soil-forming intervals appear to correspond to episodes of alluvial aggradation. Under our basic climatic/geomorphic model, it could be further argued that these periods were relatively warm and dry. If so, xeric conditions may have been present between about 3700 → 3500 YBP (at Elbee Bluff, especially) and between about 2900 → 2600 YBP (at Douglas Creek, especially). Finally, the stable carbon data in particular appear to indicate that both sections experienced somewhat warmer and dryer conditions toward 2000 YBP. These are among the strongest and most convincing examples of potentially nonlocal pedogenic episodes that may have direct bearing on Holocene climatic conditions in western North Dakota. Additional interpretations relevant to larger-scale interregional correlations are possible, but are based on weaker evidence.

CONCLUSIONS

While difficulties exist in interpreting the timing of Ab-horizon paleosols in badlands and prairie terrains, present studies suggest that they may serve as potential climate proxy indicators for climate change. Although individual paleosol distributions in time and space at project study localities cannot be correlated directly to each other, their stratigraphic regularity under suggested allocyclic conditions at Locality M, Elbee Bluff, and Douglas Creek indicates the utility of paleosols in climate studies.

- The climate model presented by Bluemle and Clayton (26) suggested Holocene time intervals of greater and lesser geomorphic stability (e.g., Wolf Creek Unstable Episode, Thompson Stable Episode). The temporal occurrence of most project paleosols within stable episodes supports their general climatic framework. In addition, the formation of Section M8302 - Unit 31 paleosol at the Douglas Creek Locality may correspond to a break in the Altithermal (maximum warming).

- Small-scale phenomena studies can identify periods of climate change. However, when separate locations are compared for the same time period, the indicated climates may not be identical. Factors such as differences in geomorphic processes, microclimates, and time delays are present in complex response relationships.

- The only evidence of significant C_4 vegetative input was from the uppermost parts of the Elbee Bluff and

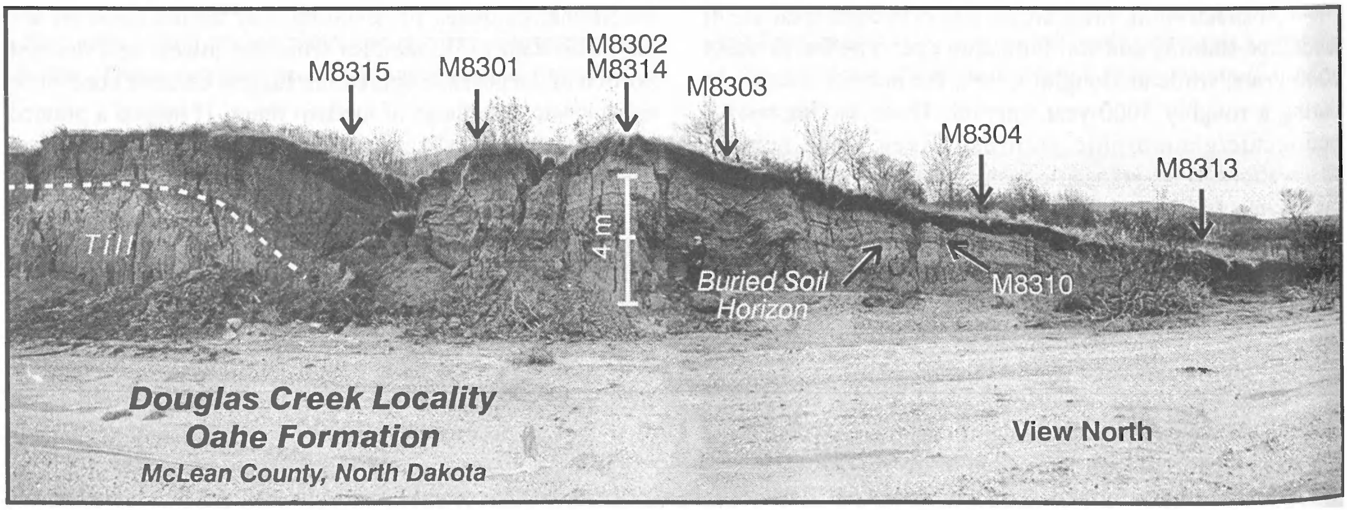

Figure 7. Douglas Creek Locality sections (2). View across swash zone of eroding cutbank exposures. Significant geologic sections include M8301–M8304. Section M8302 represents the thickest section, and all radiocarbon dates are correlated to it. The Holocene Oahe Formation locally overlies either glacial deposits of the Pleistocene Coleharbor Formation or the Paleocene Sentinel Butte Formation (about 57 Ma). This shoreline has since been ravaged by the high waters of Lake Sakakawea, but note that a condensed paleosol section is seen above the till to the west.

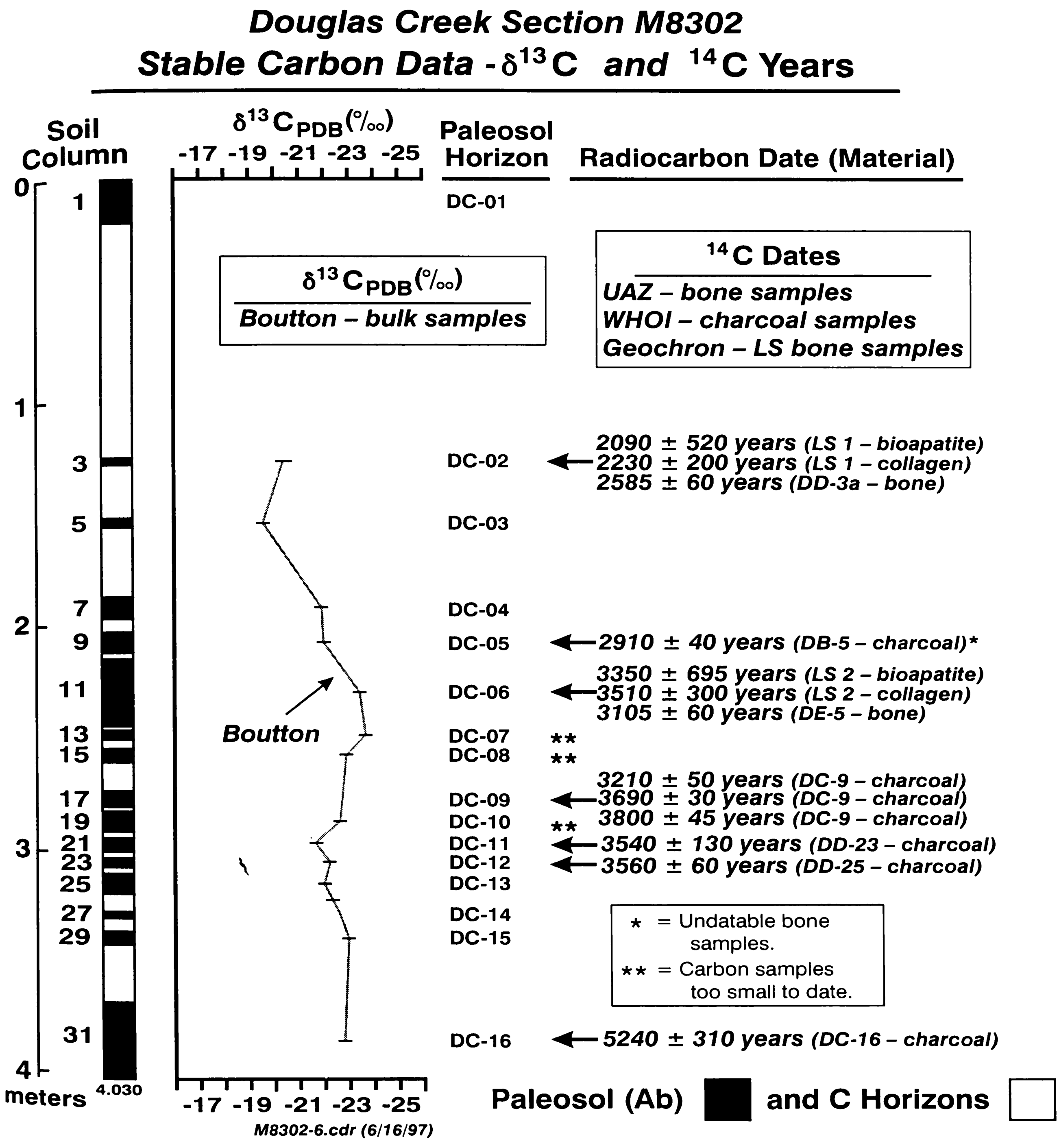

Figure 8. Section M8302 stable carbon values correlated with radiocarbon dates (2). The curve shown here is from the analyses by Boutton (written communication, 1996). All radiocarbon dates are correlated with Section M8302 (as in Figure 7), including multiple analyses on charcoal or bone from the same sample. The Geochron (e.g., LS-1) radiocarbon date was based on a bone sample using a non-AMS dating technique.

Douglas Creek Locality sections. Radiocarbon dates suggest that a change to drier and warmer conditions commenced at about 2700 YBP.

- The stable carbon data support the following theory by Knox (11): Hot, dry climates promote aggradation of material; cold, moist climates induce downcutting of stream channels and promote pedogenesis in other geomorphic settings. The stable carbon data on organic matter from the soil horizons indicate relatively cool and moist climates in every case but one.

- Although known from localities that cannot be directly correlated, paleosols in the studied sections in the semiarid lands of western North Dakota appear to recur within a maximum period of 200 years.

FUTURE STUDY

The key to further work is in determining a way to obtain information from the unaltered material between soil horizons. This could include using textural, radiometric, and structural information to reconstruct the environment of deposition. The depositional environment would indicate whether rapid or slow deposition has occurred. Also, in cases where soils are located in a well-studied area, the mineralogic composition of the material can be used to identify its source area in an effort to determine rate and distance of transport, which should also provide information about the environment. Localities such as badlands that are excessively geomorphically dynamic should be augmented from other environmental study localities because the sedimentary records badlands preserve may mask more significant climate signals. Although these environments require more detailed work, they are still good candidates for short-term cycle study because there are highly sensitive to climate change.

ACKNOWLEDGMENTS

This research was supported through an EERC joint venture with EPRI and the U.S. Department of Energy. We wish to thank our research collaborators Deborah Beck, John Reid, and Jon Reiten for their important contributions to this effort. We also wish to specifically acknowledge Gerald Groenewold, who conceived of the idea for this project and, along with Michael Jones, enthusiastically promoted it.

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Symposium Agenda

NUTRITIONAL SUPPLEMENTS: CAN GREAT PERFORMANCE, GOOD HEALTH AND LONG LIFE COME FROM A BOTTLE?

April 15, 1999 (Thursday Morning)

Location – Memorial Union

Convenor and Moderator – Forrest H. Nielsen, USDA, ARS Grand Forks Human Nutrition Research Center

8:30 a.m.	Welcome and Overview
8:35 a.m.	Janet Hunt – USDA, ARS Grand Forks Human Nutrition Research Center *Vitamins and Minerals: To Supplement or Not to Supplement?*
9:15 a.m.	Annette Dickinson – Council for Responsible Nutrition *Nutritional Supplements: Providing a Significant Boost for Good Health and Long Life*
9:55 a.m.	Robert Heaney – Creighton University *The Role of Calcium Supplements in Health and Well-Being*
10:35 a.m.	Mid-Morning Break
10:50 a.m.	Forrest Nielsen – USDA, ARS Grand Forks Human Nutrition Research Center *The Balderdash and Realities of Health and Performance Claims for Supplements as Exemplified by Calcium, Chromium and Vanadium*
11:30 a.m.	Henry Lukaski – USDA, ARS Grand Forks Human Nutrition Research Center *Can Nutritional Supplements Enhance Sports Performance?*
12:10 p.m.	Patricia Moulton – Department of Psychology, University of North Dakota *The Effects of Subchronic Dosage of Ginkgo Biloba on Short Term Memory in a Double-Blind and Placebo Controlled Study on Healthy Volunteers*
12:30 p.m.	Closing Comments

VITAMINS AND MINERALS: TO SUPPLEMENT OR NOT TO SUPPLEMENT?

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USDA, ARS Grand Forks Human Nutrition Research Center
Grand Forks, ND 58202

Dietary supplements, a 1990's marketing phenomenon, are used to market everything from frozen yogurt to shampoo, and US sales are rapidly expanding to at least $9 billion annually. Amid the commercial hype, there is considerable scientific interest in determining the possible value of nutrient supplements for improving diets, promoting health, and preventing disease.

Why do people take supplements? Many consumers conclude that if a little is good, more must be better, but they should be warned that the ratio of toxic dose to recommended intake is as little as 5 to 10 fold for some nutrients, such as vitamin A, calcium, phosphorus, iron, and fluoride (although it is as high as 500 to 1000 fold for other nutrients, such as riboflavin, pyridoxine, and folacin). Other consumers believe that they are unlikely to be able to get enough nutrients from food; these people are usually surprised to learn that that, on average, US diets meet or exceed the Recommended Dietary Allowances (RDA) for most nutrients. Some people believe that the RDAs are established to meet minimum requirements, and are too low to optimize health. They should be assured that while the interpretation of new and expanding scientific knowledge may be reasonably debated, the RDAs are established by nationally renowned scientists, selected by the National Academy of Sciences to provide an independent, noncommercial interpretation of the best scientific information. A common rationale is to use vitamin and mineral supplements as an insurance policy, that is, to ensure the consumption of enough nutrients. Scientific and professional groups have generally acknowledged that vitamin and mineral supplements, taken in reasonable proportion to each other and in amounts that do not exceed the RDA, are probably not harmful, and will help to meet newly increased recommendations for nutrients such as folic acid.

Vitamin and mineral supplements cannot replace good diets because not all healthful food components have been identified, a variety of foods provides a balanced nutrient distribution, and exposure to small quantities of a large variety of compounds in foods activates physiological defenses. Fortunately, most supplement users do not take vitamins and minerals instead of choosing a good diet. Several large surveys have established that nutrient supplement users also eat better than average; they obtain more nutrients from foods and eat more fruits and vegetables than those who do not use supplements. Supplement users are more likely to believe that diet affects disease. In the US, they are more likely to be white, female, older, from Western states, have a higher personal income and more education than those who do not use supplements.

Because those who use supplements also consume more fruits and vegetables and more nutrients from foods, any observations of reduced disease risk cannot accurately be attributed to supplement use rather than diet or other differences. This limitation of survey results can be overcome by placebo-controlled, randomized double-blind supplementation studies. In recent years, such controlled studies have indicated that beta-carotene was not effective in reducing the risk of lung cancer. Alternatively, such controlled studies have demonstrated that calcium supplementation for 2-3 years reduced bone loss in postmenopausal women, which probably reduced the risk of osteoporosis. Additional controlled studies have indicated a benefit of folic acid supplementation of child-bearing age women; it reduces the risk of neural tube defects in newborns. Iron supplements are commonly used to reduce iron deficiency and the associated risk of premature delivery by pregnant women. Promising results have been obtained with vitamin E supplementation reducing the risk of heart disease and prostate cancer, and with selenium supplements reducing cancer risk. In response to such research, the National Academy of Sciences has increased recommended intakes for calcium and folic acid, and advised people to consume adequate calcium from dietary or supplemental sources and extra folic acid from supplements or fortified cereals.

The safety of nutrient supplements cannot not be assumed based on widespread random usage in the population. Such practice only reveals severe toxic effects; for example, documenting that iron supplements (intended for others) are the most common cause of pediatric poisoning deaths in the US. While beta-carotene had for years been generally considered non-toxic, long-term controlled supplementation trials were required to reveal that beta-carotene supplements adversely affected cancer risk for smokers.

In evaluating whether to supplement or not to supplement, emphasis should be placed on the need for sound scientific evidence to determine both safety and effectiveness.

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Required amounts of most nutrients can be met by diet alone, but supplementation may be beneficial in some circumstances, when indicated by well-accepted scientific evidence of safety and effectiveness. The Dietary Guidelines and the Food Guide Pyramid issued by the U.S. Department of Agriculture and Department of Health and Human Services are useful public guidance for choosing a variety of foods for good health. The best nutritional strategy for promoting optimal health and reducing the risk of chronic disease is to consume and enjoy a wide variety of foods.

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NUTRITIONAL SUPPLEMENTS: PROVIDING A SIGNIFICANT BOOST FOR GOOD HEALTH AND LONG LIFE

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A large and rapidly expanding body of research suggests that increasing the intake of specific nutrients may be helpful in protecting against debilitating and deadly conditions such as osteoporosis, birth defects, heart disease, stroke, infectious disease, macular degeneration, and cataracts. (1) For many consumers, an easy and economical way to add specific nutrients to the diet is through the use of dietary supplements.

About half of the American population uses dietary supplements, at least some of the time, and at least half of those use supplements on a daily basis. In 1997, more than 130 million Americans spent an estimated $12.8 billion for dietary supplements, or an average of $8 per person per month.

Vitamin and mineral products account for half of retail sales of supplements. Multivitamins are by far the most commonly purchased supplement. There is no cause for concern regarding the safety of multivitamins, and there is a strong liklihood of substantial health benefit. Studies indicate that users of multivitamins are significantly protected against the risk of heart disease, some cancers, cataracts, and infectious illnesses ranging from colds and flu to pneumonia. In a large cohort of nurses, the use of multivitamins with folic acid reduced the risk of heart disease by 24% (2). Nurses who used multivitamins for 15 years had a 75% reduced risk of colon cancer (3) and physicians who used multivitamins had a 27% lower risk of developing cataracts (4). In an elderly population, Chandra observed a 50% reduction in sick days among people given a multivitamin, compared to controls (5). Based on the totality of the evidence regarding nutrient intake and immune function, Chandra recommended that "it would be prudent to opt for a suitable micronutrient supplement in modest amounts for all elderly individuals," in order to improve their health, with virtually no risk of adverse effects (6). He suggested that a multivitamin is also cost effective in the elderly, with a year's supply costing less than three visits to a physician and much less than hospitalization for a day.

Women of childbearing age who take multivitamins with folic acid have a lower risk of having a baby with a neural tube birth defect. The Centers for Disease Control and Prevention (CDC) led the U.S. Public Health Service to recommend in 1992 that all women capable of pregnancy should obtain 400 mcg (0.4 mg) of folic acid daily (7). The Food and Nutrition Board, in its 1998 report on dietary recommendations for several B vitamins, recommended that women of reproductive age should "take 400 mcg of synthetic folic acid daily, from fortified foods or supplements or a combination of the two, in addition to consuming food folate from a varied diet." (8)

This year (1999), the March of Dimes and the CDC are leading a national campaign to increase awareness of this message and to encourage behavioral change. The central message of the campaign is that in addition to improving dietary folate intake and using foods fortified with folic acid, women should take a multivitamin to be sure of getting the recommended protection. The campaign is supported by a National Coalition on Folic Acid, composed of more than 20 national associations of physicians and other health professionals including nurses, pharmacists, and dietitians. With societal support, including the support of health care providers, use of multivitamins by women of childbearing age can be predicted to rise. The impact of societal support for a specific behavior is seen in the fact that more than 80% of pregnant women take a prenatal multivitamin supplement – a behavior universally recommended by physicians, friends, and family and also reimbursed by health insurance. (9)

After multivitamins, the most commonly purchased supplements are vitamin C, vitamin E, and calcium. Epidemiological studies done at Harvard using cohorts of nurses and male health professionals found that people who used vitamin E supplements at levels of at least 100 IU, for at least 2 years, had approximately a 40% reduced risk of heart disease. (10, 11) Generous intakes of vitamins C have been associated with reduced risk of gastric cancer. (12) Calcium supplementation has been shown to increase peak bone mass and reduce the rate of bone loss, thus protecting against osteoporosis. The evidence on the benefits of calcium is so strong that it has been endorsed by two NIH Consensus Conferences, and FDA has approved a health claim for it. The health claim may appear on dietary supplements or low-fat foods which provide at least 200 mg of calcium per serving.

These examples provide only a glimpse of varied ways in which nutritional supplements have been shown to have positive impacts on health. The evidence indicates that most diets fall short in one of more nutrients, and that these shortages are significant. Among health professionals, the concept of supplementation is becoming more and more acceptable for consideration in developing public health policy. For example, in January of this year, researchers from Tufts published a Food Guide Pyramid for the elderly, with a pennant flying from the peak of the pyramid to indicate that supplements of some nutrients may be necessary (13). The nutrients specifically mentioned in this case include calcium, vitamin D, and vitamin B_{12}. The notion of a pennant to flag the need to consider supplementation is a positive model that could be applied to food guide pyramids for other risk groups or for the population as a whole.

Herbal or botanical products represent the fastest-growing segment of the dietary supplement industry, yet these products account for less than 1/3 of total sales of dietary supplements. In 1997, almost half of all sales in this category were attributed to the following eight botanicals: echinacea, ginseng, ginkgo biloba, garlic, St. John's wort, goldenseal, saw palmetto, and aloe. These products have a long history of traditional use, and also are the subject of considerable clinical research documenting health benefits. These and other botanicals have been extensively monographed in official pharmacopeias, and their potential benefits and side effects are described in commonly available references such as Dr. Varro Tyler's *The Honest Herbal*, the newly published *Physicians Desk Referencefor Herbal Medicines,* and a new consumer guide to vitamins, minerals and herbs from *Reader's Digest.* The proliferation of reference materials, in print as well as online, will be valuable in helping consumers use botanical products safely and appropriately.

In short, dietary supplements can indeed make a positive contribution to the health of individuals and the general population, contributing not only to decreased morbidity and mortality from major illnesses but also to decreased health care costs.

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THE ROLE OF CALCIUM SUPPLEMENTS IN HEALTH AND WELL-BEING

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As recently as 1-2 generations ago most adults did enough physical work to allow them to consume 2500+ calories per day. A varied, balanced diet providing these calories generally provided enough micro-nutrients so that supplements would not have been required. But today, with caloric expenditures for many of us in the range of 1400-1800 kcal/d, and particularly with the increased availability of junk foods, our diets can no longer be counted on to meet all of our nutrient needs. This is particularly true for calcium, as soft drinks have displaced milk in our diets.

The calcium content of the diet of evolving hominids would have been 3-4 x higher than the diets of contemporary humans in the industrialized nations. Correspondingly, our physiologies are adapted to prevent an *excess* of calcium, and we do a poor job of coping with a calcium shortage. Our digestive systems absorb calcium inefficiently, our kidneys only weakly conserve calcium, and losses through the skin can be excessive, particularly with sweating. Furthermore, our ability to conserve calcium, weak at best, deteriorates with age. That, basically, is the reason why the calcium requirement is high, throughout life.

There are at least four reasonably well established health consequences of inadequate calcium intake: osteoporosis, high blood pressure, colon cancer, and premenstrual syndrome. All of these problems have other causes as well, and inadequate calcium intake explains only a part of each problem. Nevertheless, it is a part that is susceptible to correction, and it seems essential that we take the steps needed to increase calcium intake of the North American population without further delay.

It is helpful to understand that bone is the body's calcium nutrient reserve. Calcium, in fact, is a unique nutrient, in that the nutrient reserve has acquired a function in its own right: structural support. We literally walk around on our calcium reserve. If the calcium intake of growing children and adolescents is less than optimal, the size of the reserve - the massiveness of our skeletons - is less than it might have been under the genetic program. Similarly, in adults, if losses from the body are not offset by corresponding dietary inputs, the body simply tears down units of bone to scavenge their calcium. The result is structural weakening that gets worse with age. There have been in excess of 30 randomized controlled trials of calcium interventions with skeletal endpoints at various life stages published in the last 10 years. All but one have shown a strong positive benefit of increasing calcium intake – greater bone gain during growth, reduced bone loss with age, or reduced fracture risk. The benefits are seen most dramatically in the old elderly, who would otherwise be losing bone at a relatively rapid rate. High calcium intakes stop or greatly reduce that loss, and reduce fracture risk almost immediately.

High calcium intakes, particularly from food and vegetable sources, reduce blood pressure sufficiently to reduce the number of strokes and heart attacks by perhaps 15 to 25 percent in the population at large; and high calcium intakes during pregnancy substantially reduce the risk of pre-eclampsia and pregnancy-induced hypertension. The benefit of a high calcium intake in colon cancer is less well established in humans, but is very strong in animal models. Here, calcium acts as an anti-promoter of cancer development, by complexing irritant fatty acids and bile acids which otherwise stimulate precancerous cell growth in the colon. Recent studies have shown that high calcium intakes reduce adenoma recurrence and mucosal mitotic index in susceptible individuals. Finally, a recent multicenter trial showed a reduction in PMS symptoms of nearly 50 percent with calcium supplementation.

A calcium intake in the range of 1500-2000 mg per day, throughout life, optimizes the benefits for all organ systems. Since most people today cannot get that much calcium from the foods they are likely to select, there is need both for widespread, low level calcium fortification of various processed foods, as well as for calcium supplementation. Finally, given the widespread inadequacy of vitamin D status in North America, it is necessary to ensure some degree of vitamin D fortification and supplementation, as well.

THE BALDERDASH AND REALITIES OF HEALTH AND PERFORMANCE CLAIMS FOR SUPPLEMENTS AS EXEMPLIFIED BY CALCIUM, CHROMIUM AND VANADIUM

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INTRODUCTION

It is well known that diet is linked to risks leading to chronic diseases that are disabling and terminate life prematurely. Moreover, intakes of dietary components other than essential nutrients (e.g., phytochemicals), or of some essential nutrients (e.g., selenium) beyond those that prevent deficiency pathology have been found to promote health and reduce risks leading to chronic disease. Thus, a new paradigm has evolved in nutrition that recognizes the need for prevention of deficiency pathology as the basis for the formulation of nutritional guidance such as the Recommended Dietary Allowances (RDA), or the new Dietary Reference Intakes (DRI), to be complemented by consideration for the total health effects of a nutrient (1). In other words, the new paradigm considers the beneficial effects of nutrients, including the reduction in the risk of chronic disease at intakes higher than necessary to prevent deficiency, and the determination of upper safe levels of intakes.

Recent recommendations for calcium, including its new DRI, exemplify the new approach for formulating dietary guidance. Numerous studies have shown that an intake of 600 to 800 mg of calcium per day is adequate to maintain calcium balance and to prevent adverse changes in indicators of calcium status or metabolism in humans when they consume diets adequate in all known nutrients important in calcium utilization including vitamins D and K, boron, copper, magnesium, manganese and zinc. Nonetheless, consensus statements promulgated by various work groups and reports by numerous calcium metabolism experts support the recent action of the Food and Nutrition Board to increase the RDA, now the DRI, for calcium from 800 mg/day to 1000 to 1300 mg/day for people aged 9 and over (2) because high intakes of calcium can slow bone loss in post-menopausal women and promote bone formation during adolescence. Many people find it difficult to achieve the new DRI through diet alone, and thus use supplements.

Luxuriant intakes of other nutrients are being recommended because of health benefits; these include folic acid to prevent neural defects and cardiovascular disease, vitamins E and B_{12} to prevent cardiovascular disease, and selenium to prevent cancer. These recommendations are supported by creditable research findings. Supplements or fortified food is the only way some of these recommended intakes will be reasonably achieved by some people.

The preceding indicates that there are instances where the use of supplements is desirable. Unfortunately, the prudent and appropriate use of supplements has been overshadowed by unrealistic health benefits expectations by consumers, and by economic interests. As the result of the nutrition preventing disease concept, health enhancing foods, now called "functional foods," or supplements, sometimes called "nutraceuticals," represent an exploding market in the United States conservatively estimated at $29 billion a year. Many of the health claims for these supposed health enhancing foods and supplements, however, have not been substantiated by basic research and human trials. This has not prevented a multitude of mountebanks or charlatans from touting all kinds of supplements as magic bullets that cure or prevent many of the feared diseases such as Alzheimer's disease, cancer, heart disease, osteoporosis, arthritis, and diabetes in the quest for financial gain. In other words, supplements are not inherently good, bad or worthless, it is the manner in which they are presented to the consumer that determines their merit. When one decides to use supplements, there is a need to know that most all of them have some balderdash and realities associated with their marketing. Calcium, chromium picolinate, and vanadium supplements can be used to demonstrate this point.

CALCIUM

Policy makers, researchers and clinical professionals have identified osteoporosis as a major public health problem that affects 28 million Americans and costs $14 billion annually in nursing home and hospital expenditures. Osteoporosis affects 200 million people world wide. In the United States, one out of every two women and one out of eight men over the age of 50 will have an osteoporosis-related fracture in their lifetime. As the population of the United States ages, the cost of osteoporosis is projected to reach $50 billion by the year 2050 unless some progress is made in its prevention or alleviation. Osteoporosis is a painful, disfiguring, debilitating and life threatening disease. Moreover, the physical deformities

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and limitations resulting from broken hips and crushed bones in the spine including the stooped posture, dowager's hump and protruding abdomen can viciously assault self-image and how one feels about themselves. This tremendously affects emotional well-being and often leads to depression.

Based upon media and advertising informational pieces, osteoporosis should not be such a huge problem because all that is needed is to get people to consume more calcium. The usual approach of the advertisements is that "osteoporosis affects us all, thus for protection against bone loss, calcium intake must be high to the point of taking supplements, fortified foods, or specific foods." Because calcium is a major component of bone and some research reports show that high calcium intakes slow bone loss after menopause, this approach seems to be reasonable. However, there is evidence showing that this approach is not adequate and that it is misleading an immensely large number of women into a false sense of security in terms of protecting against osteoporosis.

The Balderdash of Calcium Supplementation for Osteoporosis

International comparisons of the dependence of osteoporosis incidence on dietary calcium intake show that the incidence is generally *lower* in countries where calcium intakes are traditionally low, often 500 mg/day or less (3). Countries including the United States that consume the most calcium per capita, and also are the largest consumers of dairy products have the highest incidence of osteoporosis. The high incidence occurs in the United States despite being the country which consumes the greatest amount of calcium supplements. Reports by reputable researchers have shown that calcium supplementation does not prevent post-menopausal spinal bone loss or significantly reduce the incidence of fracture, especially if usual intakes before supplementation exceed 500 mg/day (4-6). Some of the statements by people who have concluded that calcium supplementation is ineffective by itself in preventing osteoporosis include "calcium is the laetrile of osteoporosis" and "it seems clear that calcium alone, even in massive doses, does not prevent bone loss" (6).

It can be safely stated that osteoporosis is not necessarily a nutritional calcium deficiency disease. On the other hand, osteoporosis is a calcium deficiency in bone. It is surprising that many people have accepted the concept that if bone is deficient in calcium, the way to overcome the problem is to put more calcium in the gut and that will result in more calcium in bone. This concept ignores the fact that before calcium can be made into bone a large number of other essential nutrients, especially micronutrients such as some trace elements and vitamins, are needed to stimulate the formation of osteoblasts, to make proper collagen and proteoglycans on which calcification occurs, and to be involved in calcification initiation and proper bone crystal formation in addition to proper bone resorption. Suboptimal status in any of these nutrients could result in one portion of bone metabolism going awry which would lead to an imbalance between bone breakdown and formation. If a nutrient is essential, it means no other substance can replace its need in the diet. Thus, it should not be expected that a high dietary intake of calcium or calcium supplementation will prevent osteoporosis caused by the lack of some other essential nutrient such as boron, copper or magnesium. Basically, the recommendation to take calcium supplements is a pharmacological not a nutritional recommendation. Supra nutritional intakes of calcium most likely slow bone loss by suppressing the secretion of parathyroid hormone which induces bone resorption. Thus, supra nutritional intakes of calcium can be considered a cheap alternative to other pharmacological approaches used to prevent bone loss such as estrogen therapy, calcitonin injections and diphosphonate drugs.

The Realities of Beneficial Calcium Supplementation

Two studies have effectively shown that more than calcium supplementation is needed to have a major impact on the incidence or severity of osteoporosis. In one study (7), 59 healthy older post-menopausal women were fed a placebo, a trace element supplement, a calcium supplement, or the combined trace element and calcium supplements. Over a two-year period, the women on the placebo lost an average of 3.53% of their bone density. When only the trace mineral supplement containing 15 mg of zinc, 5 mg of manganese and 2.5 mg of copper was fed, the average bone density loss was 1.89% while the calcium supplement of 1000 mg/day allowed a loss of 1.25%. On the other hand, the combined calcium and trace element supplement not only stopped bone density loss, but actually resulted in an apparent increase of 1.48%. In the other study (8), post-menopausal women who were on hormone replacement therapy were given either no supplement (7 women) or a multivitamin, multimineral supplement containing 500 mg of calcium, 600 mg of magnesium, 2 mg of copper, and 10 mg of manganese (19 women). Bone density did not change over 10 months without the supplement, but with the supplement, the average bone density increased from 0.303 g/cm^2 to 0.337 g/cm^2.

The preceding discussion should not leave one with the impression that calcium in not important in the osteoporosis story. The two studies described above indicate this. There are several reports that indicate the consumption of less than 500 mg of calcium daily greatly increases the risk of bone loss, and that many post-menopausal women routinely consume less than this (4,5). This implies that inadequate calcium intake is a real nutritional concern because it significantly contributes to the incidence of osteoporosis. Although the consumption of foods luxuriant in calcium is the desired method to meet calcium needs, calcium supplements or fortified foods may be useful for the achievement of desired intakes because of difficulties in consuming those foods. Some people will want to take a calcium supplement for insurance purposes. In these instances, the best calcium supplement is one that is part of multinutrient supplement because it also will contain other nutrients required for bone health.

In summary, the balderdash of calcium supplementation is that by itself it will not prevent post-menopausal bone loss. The realities of supplementation is that it may help achieve intakes needed for proper calcium status, and in conjunction with other essential nutrients, assure good bone growth and maintenance.

CHROMIUM PICOLINATE

The touted benefits realized through chromium picolinate supplementation are numerous and often outrageous. For example, one weight loss advertisement stated "Since picotrim (chromium picolinate) is so effective at removing fat and cellulite and has no side effects some people can lose weight too fast. Don't allow yourself to become too thin." Another claim appearing in a supermarket tabloid was that chromium picolinate can increase average life span 25 years, or from 75 to 100 years. Other advertisements and tabloid-type articles claim that chromium picolinate supplementation can build muscle, enhance athletic performance, prevent osteoporosis and ischemic heart disease in addition to being effective in preventing and treating type II diabetes. With such claims it is no wonder that some ten million Americans consume $150 million worth of chromium supplements a year, which makes it the largest selling mineral supplement after calcium in the United States. However, many of these sales are based on misleading and fraudulent claims.

Chromium Picolinate and Weight Loss

The astonishing claims for weight loss with chromium picolinate supplementation are quite flabbergasting when one considers the data on which they are based. In one study (9) on which the claims are based, the average fat loss was 4.2 pounds with a 1.4 pound increase in fat free mass over a 72 day period of taking 200 μg/day of chromium as a picolinate supplement. Stated another way, this is only a loss of 2.8 pounds after 10 weeks of supplementation. Another study (10) used to support weight loss claims was not limited to just chromium supplementation. The program included moderate caloric restriction combined with nutritional support from dietary fiber and L-carnitine. Thus, although a respectable weight loss of 15 pounds was achieved in 8 weeks, the loss could not be attributed to solely the chromium picolinate supplement. In a third study (11), only after adjustments were made for energy expenditure in daily activities was a significant difference in weight loss achieved with a 400 μg/day chromium picolinate supplement compared to a placebo (-2.8 vs -1.9 kg in 90 days). In contrast to these studies, another study found that chromium picolinate supplementation resulted in significant weight gain in young obese women (12). To summarize, there are no data from well-controlled studies to support the claim that chromium picolinate is an effective weight loss modality.

Chromium Picolinate as an Ergogenic Aid

The notion that chromium picolinate would have an ergogenic effect is suggested by its apparent nutritional or biochemical actions. Chromium is known to potentiate insulin action. Insulin has an anabolic effect on skeletal muscle and other tissues through the promotion of amino acid uptake and protein synthesis while retarding protein degradation. Thus, when it was reported that 42 off-season college football players undergoing a weight training program exhibited a significantly higher increase in lean body mass, based on skin-fold measurements, when supplemented for six weeks with chromium picolinate that supplied 200 μg of chromium/day and compared with receiving a placebo (13), the findings seemed reasonable. This report precipitated tremendous interest in chromium picolinate by athletes and body builders looking for a possible substitute for performance enhancing anabolic steroids. As a result, over 100 products containing chromium picolinate alone, or in combination with other nutrients, herbs, and amino acids in the form of tablets, capsules, powders and beverages have appeared in the marketplace as muscle and strength enhancers. Unfortunately, as so often happens when some flashy or spectacular finding appears for a substance that could possibly be put in a supplement form, subsequent well designed experiments with sophisticated methods did not confirm or support the initial anabolic findings for chromium picolinate. Several studies (14-16) have shown that 200 μg chromium/day as a chromium picolinate supplement did not significantly affect body fatness, fat free mass, strength and performance in young men in weight training programs. In other words, the data related to chromium supplementation improving lean body mass, strength gain, and athletic performance are mostly negative.

Chromium Picolinate and Lifespan Extension

The basis for the claim that chromium picolinate will extend your lifespan is an experiment which showed that after 41 months of being fed a diet supplemented with chromium picolinate, chromium nicotinate or chromium chloride, all rats fed chromium chloride or chromium nicotinate had died, while 80% of the rats fed chromium picolinate were still alive (17). The role of chromium in this experiment is unclear because all three supplements contained this element. Moreover, the life extending findings need confirmation before any claims can be justified for chromium supplementation having such an effect.

Chromium Picolinate and Osteoporosis

The basis for the suggestion that chromium may be effective in preventing osteoporosis is that postmenopausal women taking a chromium supplement exhibited increased plasma dehyroepiandrosterone, a precursor of estrogen which inhibits bone loss, and decreased urinary calcium and hydroxyproline excretion (18), which are indirect rather variable indicators of bone loss. These provocative findings need to be confirmed, and the prevention of bone loss needs to be validated by the use of methods that can directly detect changes or no changes in bone composition with chromium supplementation. Until then, chromium supplementation should be viewed as only one of a number of speculative methods that may help in maintaining healthy bones.

Chromium Picolinate as Treatment for Diabetes

Recent findings indicate that one claim for a beneficial action of chromium supplementation is valid, that is for the treatment of diabetes. In a double-blind randomized study of 180 Beijing, China, residents, high blood glucose measures were reduced to near normal by a chromium picolinate supplement providing 1000 μg chromium/day (19). For example, glycated hemoglobin was reduced from an abnormal 9.4% to a high normal 6.6%. Since about 1970, numerous other reports (20,21) have appeared which indicate that chromium can potentiate the action of low amounts of insulin or improve the efficacy of insulin such that the need for exogenous sources is reduced or eliminated for some type II diabetics. Thus, there is a growing body of evidence suggesting that chromium supplementation might be a viable treatment option for some people with diabetes resulting from inadequate synthesis of insulin or with insulin resistance. However, it needs to be emphasized that only a select group of people can use this as a basis for taking high, or pharmacological, doses of chromium, and this probably is best when done while under the care of a physician.

Chromium as an Essential Nutrient

There is another basis for taking chromium supplements. The evidence for chromium being an essential nutrient is quite substantial, and that an intake of less than 20 μg/day is generally inadequate to meet its nutritional requirement. Based on dietary surveys, a significant number of Americans consume less than 20 μg/day. As a result, it is not surprising that many studies have identified individuals who responded in a desirable manner in regards to glucose metabolism and to composition and concentrations of blood cholesterol, when given supplements of chromium. It should be pointed out that a larger number of individuals in these studies did not respond to chromium supplementation. This suggests that the chromium supplementation was not of value because of an adequate chromium status.

In summary, most marketing claims for chromium, especially for weight loss and as an anabolic substance, are balderdash. However, chromium in pharmacological amounts, which can be achieved only by supplementation, may be an effective treatment option for diabetes. The finding of some responders in studies involving a relatively small number of subjects indicates that there are a significant number of people that could benefit from an increased chromium intake. One way this could be achieved is through supplementation, but a preferable and more enjoyable method would be through a diet containing high chromium foods such as whole grains, pulses, selected vegetables, liver and perhaps beer.

VANADIUM

In the last 15 years, high doses of vanadium have been shown to have efficacy in some animal models of both type I and II diabetes (22). Vanadium does this by directly acting on tissues normally affected by insulin, that is, it mimics insulin. Because insulin has an anabolic effect on skeletal muscle, the finding that vanadium mimics insulin was quickly extrapolated by supplement marketers as support for the claim that vanadium has anabolic effects, and thus can be used to enhance muscle building, strength and performance. This is the basis for the recent proliferation of powders, beverages, formulas and supplements containing alarming amounts of vanadium.

Vanadium supplements available today are of concern because they may contain toxic amounts of this element. The amounts of vanadium needed in animal studies to mimic insulin were extremely high to the point of being toxic. Poor appetite, poor growth, diarrhea, and death have commonly occurred in these studies. In addition vanadium has been shown to induce transformation of different cell lines (23) which indicates that high vanadium intakes may be potentially carcinogenic. Moreover, long term vanadium supplementation has been shown to induce hypertension in rats (24).

The circumstantial evidence suggesting that vanadium is an essential nutrient indicates that a daily dietary intake of 10 μg will meet any postulated requirement. Most mineral elements consumed in amounts 100 times their nutritional requirement show some toxicity. This suggests that a safe daily intake of vanadium is under 1 mg/day. There are some findings that indicate an intake of over 10 mg/day is toxic (25). Many supplements contain greater than 10 mg of vanadium. There is no question that more needs to be known about the consequences of high vanadium intakes that result from the use of vanadium supplements available today. Vanadium supplements is an example of where the balderdash associated with their marketing is not only worthless, but most likely harmful to health.

In summary, the balderdash of vanadium is its marketing as an anabolic agent because the amounts in supplements may have toxic consequences. The reality is that there is no nutritional basis for vanadium supplementation.

CONCLUSION

Calcium, chromium picolinate and vanadium have been used as examples to show that mineral supplementation is a tricky venture. Many supplements are worthless because the body has no need for them. Some supplements may be harmful. Some supplements may have beneficial effects in pharmacological amounts which could adversely affect the need or metabolism of other nutrients. Some supplements may actually help one achieve the objective to live a higher quality, longer life. Because deciding whether the marketing of a supplement is based on balderdash or authentic information is such a difficult task, a good recommendation is to consume a diet based on the USDA food pyramid. Eating a healthy diet will assure the intake of all essential and many beneficial substance such as phytochemicals; the likelihood that vitamin and mineral supplements will do the same is not very great. However, for those people who insist that they want an alternative method than a balanced diet to assure the intake of substances that can help them "live longer and live better," a one-a-day vitamin and mineral supplement that provides all known essential nutrients in amounts near their RDAs is all that is necessary. This type of supplementation does no harm, may actually help some people, and should not be tough on the pocketbook.

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CAN NUTRITIONAL SUPPLEMENTS ENHANCE SPORTS PERFORMANCE?

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As people begin to follow public health recommendations to improve the nutritional quality of their diet and to increase physical activity to promote health, there is an increasing concern that diet may not provide adequate amounts of nutrients to support the building of physical fitness and to heighten physical performance. This apprehension emanates from national surveys indicating that many Americans do not consume nutrients in amounts equivalent to national recommendations and that exercise enhances losses of nutrients. These findings have fueled the advertisement and sales of nutritional supplements to physically active people. Despite the fact that unequivocal scientific evidence of the benefit of nutritional supplements to enhance performance generally is lacking, there is compelling evidence that certain nutrients in specific circumstances benefit specific types of physical performance.

MACRONUTRIENTS

These nutrients, which are consumed in large amounts daily, play key roles as energy substrates (carbohydrate and fat), body structure (protein) or temperature regulation (water) during exercise. Increased consumption of some macronutrients improves physical performance in certain types of activity. Boosting water intake before and during prolonged exercise alleviates dehydration and hyperthermia, and promotes endurance performance particularly in hot and humid conditions (1). Similarly, increases in carbohydrate intake from 3-4 g/kg body weight to 8-10 g/kg promote performance during both repeated, high-intensity exercise and long-duration activities (2). Increasing dietary fat to promote prolonged work is conjectural because of inconsistent results in performance and potential adverse health effects. Enhanced protein intake from 1 to 2 g/kg body weight facilitates muscle building during weight training particularly in adolescents and the elderly (3). Thus, scientific evidence supports the use of additional amounts of water, carbohydrate and protein to promote temperature regulation, fuel availability for muscle work and to build new muscle. The increased amounts of the macronutrients can be easily obtained from the diet or enriched dietary products.

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MICRONUTRIENTS

In contrast to the macronutrients which serve as fuels for work, maintain fluid balance or promote muscle mass accretion, the micronutrients (vitamins and minerals) regulate a wide variety of biological functions that utilize the macronutrients. Because the micronutrients behave as regulators of energy production and use, the roles of vitamin and mineral supplements in performance have been examined.

Vitamins

These compounds are organic molecules; they are classified based on their solubility in water or fat. The water soluble vitamins include the family of B vitamins that are involved in transduction of food energy into chemical energy and the antioxidant protector, vitamin C. Other vitamins that are soluble only in fat include vitamin A and E, which act broadly as antioxidants, vitamin D which regulates calcium absorption and utilization, and vitamin K which is needed for blood clotting or hemostasis. Studies of animals and humans supplemented with these vitamins, individually or in various combinations, fail to demonstrate any benefit in performance or increased ability to train or recover from heavy training (4).

Minerals

These nutrients, which also are required in very small amounts, are inorganic elements that regulate the structure and function of many enzymes or proteins that function in energy production and utilization. As found with the vitamins, generalized supplementation of minerals does not enhance physical performance (4).

BENEFICIARIES OF NUTRIENT SUPPLEMENTATION

As demonstrated in numerous studies and confirmed in supplementation trials of elite athletes, generalized supplementation of vitamins and minerals does not benefit physical performance. However, controlled studies of individuals with marginal or severe nutritional deficiencies clearly illustrate restoration of physiological function and enhancement of performance when the nutritional deficit is remedied with appropriate nutritional supplementation. Some examples include a beneficial effect of iron supplementation on enhanced aerobic capacity and increased endurance performance in anemic runners and a reduced reliance on glycolytic metabolism during exercise in iron-deficient, non-anemic women (5, 6). Also, a reversal of energy inefficiency and increased heart rate during submaximal exercise with magnesium depletion (7) and an amelioration of blunted aerobic capacity and decreased ventilatory elimination of carbon dioxide with zinc depletion (8) were manifested when dietary inadequacies were remedied.

EXAMPLES OF NUTRITIONAL SUPPLEMENTS AND THEIR IMPACT ON HUMAN PERFORMANCE

Two nutritional supplements, chromium picolinate and creatine, have gained a prominent position among physical activity enthusiasts because of their purported value as potential ergogenic aids.

Chromium Picolinate

The biological role of chromium is to potentiate insulin action after the hormone binds to its receptor at the cell membrane by activating insulin receptor kinase activity. In this manner, chromium facilitates the maintenance of blood glucose homeostasis and promotes amino acid uptake into cells when insulin is available. Thus, chromium may be considered an anabolic nutrient. Because intakes of chromium are considered to be less than those recommended, and intense exercise is associated with increased urinary chromium losses, chromium supplementation has been advocated to enhance performance and to promote muscle gain (9). The chemical form of chromium selected for supplementation is chromium picolinate because of its apparent increased absorption and utilization in the body (10). The dose of chromium often used is 200 micrograms because it represents the upper limit of the estimated safe and adequate intake range.

Numerous studies of chromium supplementation and resistance training have been reported with an emerging consensus of a lack of ergogenic effect on performance (i.e., strength gain) and enhancement of muscle gain or preferential loss of body fat (11). These studies have included young and older men and young women. Thus, generalized supplementation with chromium picolinate does not enhance performance in resistance training or beneficially affect changes in body composition.

Creatine Loading

In contrast to vitamins and minerals, creatine is not a nutrient because the body can synthesize this compound, although the source of the vast majority of creatine in the body is the diet. Creatine and phosphocreatine serve to replenish cellular adenosine triphosphate (ATP) during periods of high ATP turnover such as high-intensity exercise. Because ATP is limited in skeletal muscle, increases in phosphocreatine are hypothesized to enhance performance during short-duration maximal work (12).

Short-term supplementation with creatine (20 grams/day; 4 doses of 5 grams for 5 days) increases muscle phosphocreatine concentration by 20% and enhances isolated muscle function. Creatine supplementation significantly enhances the ability to maintain power during short-term maximal bouts of exercise, including cycling, sprinting, jumping, and weightlifting exercises. Other studies failed to show positive effects of creatine supplementation using various swimming, cycling and longer duration running tests. Thus, creatine supplementation enhances function only in certain types of activity - short duration maximal activities.

Creatine supplementation promotes weight gain with or without strength training (13). An increase of body weight of about 1 kilogram or 2 pounds after ingestion of 2-25 grams of creatine daily for 5-7 days may be observed without any measurable change in body composition. This weight gain is presumably associated with an increase in body water (13). Ingestion of 5 grams of creatine daily during 10-12 weeks of resistance training promoted increases in strength gain, body mass, and fat-free mass while body fat mass did not change in both men and women.

A CAUTIONARY NOTE: POTENTIAL ADVERSE EFFECTS OF SUPPLEMENTS

The indiscriminate use of any nutritional supplement may be hazardous. Symptoms such as gastrointestinal distress, nausea and vomiting may occur. Use of large doses of single nutrient supplements may induce depletion of other nutrients because of competitive inhibition, particularly with minerals (4). Preliminary evidence suggests that creatine supplementation may induce an altered fluid distribution with a depletion of the plasma volume that can promote dehydration (14).

RECOMMENDATIONS

The general use of nutritional supplements is not recommended unless under the guidance of a physician or a registered dietitian. Individuals should seek evaluation of current dietary intake from a dietitian experienced in counseling physically active individuals. Emphasis should be directed to consuming a variety of foods with an emphasis on foods with high vitamin and mineral nutrient density. If such a dietary program is unattainable for an individual, intermittent use of a vitamin-mineral supplement that provides only the recommended daily intake of essential nutrients may be initiated (15).

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THE EFFECTS OF SUBCHRONIC DOSAGE OF GINKGO BILOBA ON SHORT TERM MEMORY IN A DOUBLE-BLIND AND PLACEBO CONTROLLED STUDY ON HEALTHY VOLUNTEERS

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INTRODUCTION

Ginkgo biloba was the third most purchased herbal supplement in the United States in 1997 (1). It has become so popular that it can be found on the shelf of any department store and has been advertised as a substance that can enhance concentration, improve short term memory and relieve symptoms of Alzheimer's disease. However, there is very little research to support these claims. Ginkgo biloba extract is derived from the leaves and nuts of the ginkgo or maidenhair tree. The ginkgo tree dates back to nearly 200 million years ago, but almost became extinct during the ice age. A small group of trees in Northern China survived and were protected by Monks. Many years later, the sole survivor of the Hiroshima bomb was a ginkgo tree. An individual tree can live up to 1,000 years and is revered for its longevity in Eastern culture. The leaves of the ginkgo tree were prescribed in China for medical problems and were mentioned in major Chinese medical texts dating back to 1436 A.D. during the Ming Dynasty (2). Currently, it is approved for use as a medication by the German Health Department for cerebral dysfunction (Alzheimer's disease), hearing loss, and peripheral arterial circulatory disturbances (3). In France and Germany, the ginkgo biloba extract, EGb 761 marketed under the names Tanakan and Ipsen are claimed to increase blood flow to the nervous system, which improves cognition (4). Current research presented in this paper includes studies on the preparation of Ginkgo biloba extracts and pharmacokinetics, physiological effects, safety and use on healthy human volunteers.

Preparation of Ginkgo Biloba and Pharmacokinetics

Modern use of ginkgo is that of distilled ginkgolides, the active ingredients in the ginkgo extract, from the leaves and nuts of the tree. The roots of the ginkgo tree actually contain a greater concentration of the active ingredients, but because of the slow growth of the tree, the use of the roots is impractical. One standardized extract of ginkgo, EGb 761, was patented more than 20 years ago and is prepared by a four step production. The first step is a water/acetone extraction, then the strong lipophilic parts are separated out, active components are then enriched and finally the condensed polyphenolic compounds are removed to give the standardized extract. Flavonoids, terpene and bilobalides are the three primary constituents of the ginkgo extract. The flavonoids are chemicals of low molecular weight that chemically resemble nucleosides, isoallxazine and folic acid. This chemical structure and electrical charge of the flavanoids may lend to their free radical scavenging abilities as they are able to bind with other molecules. The extract also contains terpenenoids including ginkgolides that are only found in Ginkgo biloba. Terpenes may act by antagonizing the platelet activating factor, PAF. The bilobalide's action is unknown other than to protect the tree from bacterial infections. EGb 761, the first extract developed, contains 24% flavonoid glycosides and 6% terpene lactones. The other primary standaridized extract, LI 1370 contains 27% flavonoid glycosides and 7% terpene lactones. It is theorized that with an increase in the amount of flavonoids and terpenes in the extract, an increase in the amount of antioxidant action and its PAF antagonist ability will occur. When choosing a ginkgo biloba product, it is important to make sure that it is a standardized and guaranteed extract containing ginkgo active ingredients, flavonoids and terpenes, as there are products on the market that do not contain sufficient active chemical to have the desired effect (5).

Nieder as cited by Kleijnen and Knipschild (2), administered doses of 50, 100 and 300 mg of the ginkgo biloba extract LI 1370 to two healthy human volunteers. The extract was absorbed by the small intestine with peak plasma concentrations at 2-3 hours; the half-life of the flavonal glycosides were found to be between 2-4 hours. After 24 hours the values had returned to normal (2). Moreau, also cited by Kleijnen and Knipschild found in rats, a half life of 4.5 hours of the ginkgo extract EGb 761, absorption of at least 60% of the extract and a peak in 1.5 hours of the specific activity of blood. The highest values at 3 hours were found in the stomach and small intestine, which Moreau attributed as the site of absorption. After 72 hours, 38% of the extract was exhaled as CO_2, 22% excreted in urine and 29% in feces. Data obtained from original unpublished human experiments, when the extract was first developed by Schwabe, indicated that when administering 80 mg of the EGb 761 extract orally to human participants, the absolute bioavailability of ginkgolides A (half life 4 hours) and B (half life 6 hours) active components of the extract were more than 80% and the bilobalide component was 70% (2).

Li and Wong (6) compared the bioavailability of EGb 761 and LI 1370 extracts. BioGinkgo, a commercially prepared extract was administered to eight rabbits in three groups. The first group received 40 mg/kg of the LI 1370 extract labeled as BioGinkgo 27/7. The second received 60 mg/kg of BioGinkgo

27/7. The third group received 40 mg/kg of BioGinkgo 24/6 which is the EGb 761 extract. Samples of blood were then taken at 0.5, 1, 2, 3, 5, 8 and 12 hours after the supplement was given. The EGb 761 extract displayed a single in ginkgolide plasma peak concentration at 3 hours. The LI 1370 extract of 40 mg/kg displayed two peak concentrations at 2 and 5 hours with the 60 mg/kg dosage of LI 1370, plasma concentration peaked at 1 and 5 hours, with the second peak slightly higher than the first. In addition the response to the LI 1370, 60 mg/kg dose resulted in a 50% higher peak plasma concentration than the 40 mg/kg dose; this demonstrates a dose-related relationship. The authors believed that with the LI 1370 extract, the higher terpenoid content and the fact that the extract also contained ginkgolide B was the reason why it had two plasma concentration peaks. The ginkgolide B component has been shown to have a longer half life than the ginkgolide A component of the extract (6).

Physiological Effects

According to Itil and Martorono (5) "The pharmacologic applications of EGb are many, primarily owing to it's remarkable ability to 1. aid in the revascularization of ischemic tissues through improved micro circulation, 2. suppress the autocoid known as platelet activating factor (PAF), and 3. scavenge harmful free radicals- substances known to be harmful to cell membranes". Because of these abilities Egb has been used to treat tinnitus, retinal damage, arthritis, vertigo, water retention, circulatory dysfunctions, and have also been used as a cognitive activator to treat Alzheimer's disease. These applications were examined in a meta-analysis by Kleijnen and Knipschild in 1998. (2).

The first application, to improve micro circulation, was examined by Koltringer, Eber, and Lind, as cited in Kleijnen and Knipschild (2), whom administered 200 mg of the extract EGb 761 daily in 250 ml of 9% sodium chloride to 60 patients. After four days of dosage, an increase in skin perfusion and a decrease in blood viscosity and elasticity were observed. However, the viscosity of the plasma and the packed cell volume of the blood did not change. This may mean that the decrease in blood viscosity could be attributed to the red blood cells and not the plasma or fluid portion of blood. Jung, Mrowietz, Kiesewetter and Wenzel, as cited by Kleijnen and Knipschild (2), found an increase in blood flow in the capillaries underneath the fingernails and decreased erthyrocyte aggregation in 10 subjects that received 45 ml of the LI 1370 extract. A study by Le Poncin Lafitte, also cited by Kleijnen and Knipschild (2), found that pretreatment with EGb 761 increased blood flow, energy metabolism (measured by adenosine triphosphate, and glucose content) and reduced brain edema in rats. Another study by Karcher et al., as cited by Kliejnen and Knipschild (2), found that after treating with EGb 761, rats exposed to hypoxia survived longer and had an increased energy metabolism when compared with the control group.

The second application of ginkgo biloba is suppression of PAF. PAF has been found to induce platelet aggregation or clotting, neutrophil degranulation and increased oxygen radical production. These effects lead to an increased micro-vascular permeability and bronchoconstriction. Ginkgolides apparently act as antagonists to PAF, which helps protect brain tissue from hypoxic damage. This may also be the reason behind ginkgo's use in asthma patients. In-vitro studies conducted by Robak and Gryglewski, as cited by Kleijnen and Knipschild, showed that administration of the ginkgo extract resulted in relaxation of contracted blood vessels by prolonging the half-life of the endothelium derived relaxation factor.

The third application of ginkgo biloba is scavenging of free radicals; this is especially relevant to Alzheimer's disease. Dementia is thought to be caused by degeneration of brain tissue with neuronal loss and impaired neurotransmission. This decline may be attributed to an interference with the oxygen or glucose supply to the delicate brain tissue. When a shortage occurs, free radicals may be released and lipid perioxidation might occur. The effects of oxidation of biological molecules by free radicals have been implicated as a primary event in oxidative cellular damage. According to Itil and Martorono (5), antioxidants serve to inhibit this oxidation, thus preventing cellular damage. Ginkgo biloba, has been reported to scavenge these free radicals; which prevents this cellular damage. In erythrocytes, EGb 761 has an increased effect on hydrogen peroxide-induced lipoperoxidation with larger doses and incubation time. This effect results in an increase in the amount of oxygen in the red blood cells (5). A study by Kose and Dogan (7) compared the effects of EGb 761 to other well known water soluble and lipid soluble antioxidants. An EGb 761 extract consisting of 9.6mg of ginkgoflavoglycosides was used. Blood was collected from 16 male medical students ranging in age from 19 to 30 years. The EGb 761 extract was diluted with saline and 1.0 ml was added to test tubes containing 5.0 ml of a red blood cell suspension, with a final concentration of EGb 761 of 25 and 250 ug. The other antioxidant chemicals, alpha-tocopherol, ascorbic acid, glutathione, uric acid and retinol acetate were prepared similarly to give the same final concentrations of antioxidant compound. The presence of lipid perioxidation was measured by the production of the chemical MDA, malondialdehyde bisacetal in proportion to the grams of hemoglobin present in the red blood cells. For all of the antioxidants except ascorbic acid, significant inhibition of MDA formation was found at the higher concentration mixtures ($p < 0.05$). The high concentration of EGb 761 (250 ug) showed significantly higher antioxidant activity than ascorbic acid, glutathione and uric acid, and equaled the effect of the lipid soluble antioxidants. Also, the polyphenolic substances in ginkgo biloba were found to transform into quinone. Quinone is a crystalline compound that can give up two hydrogen atoms and the electron to the lipoperoxides. This provides an additional amount of protection from oxidation damage. The EGb 761 may also stabilize cell membranes by decreasing the osmotic fragility of erythrocytes and penetrating into the membrane phospholipid layer (7)

Safety Concerns of Ginkgo Biloba

As this is a relatively new chemical used in the United States, the safety of its use is of importance. A commercial preparation of ginkgo biloba, Bio-Ginkgo™ was reported in the *Physicians Desk Reference* in 1997 (8). This commercial product is available in both standardized extract forms, EGb 761 and LI 1370. This reference stated that patients who should not use the ginkgo biloba preparation include those found with a hypersensitivity to ginkgo, and it should be used by pregnant or lactating women only under the advice of their physician There are no known interactions of ginkgo biloba with other drugs but a formal study has not been done on drug interaction. Most research using ginkgo has used clinical populations who were on other medications and no interactions with the ginkgo extract were reported. The use of ginkgo biloba on children under 18 years of age has not been studied. No significant adverse reactions have been reported even with doses as high as 600 mg in one dose. Mild adverse reactions were found in less than 1% of people using this drug in the recommended daily dosage of 120 mg as BioGinkgo™. These reactions included mild gastrointestinal discomfort, some allergic skin reactions, and a mild, transient headache during the first three days of use. With very large dosages (>600mg) of the supplement, effects may include restlessness, diarrhea, nausea, and vomiting. Safety was also assessed in a 1997 study of the effects of ginkgo biloba on dementia (9). Thirty percent of the patients of the treatment group reported having at least one side effect, of which 16% of these patients attributed this effect to ginkgo biloba. The majority of these side effects were of mild to moderate intensity with gastrointestinal tract symptoms attributed slightly more often to the treatment group. In the meta-analysis performed by Kleijnen and Knipschild (2) no serious side effects were found from the administration of ginkgo biloba. On rare occasion (<5%) mild gastrointestinal complaints, headache and allergic skin reaction were reported. Included in this analysis were 303 patients in a German study of which four subjects had headaches, one subject had burning eyes, and one subject experienced breathlessness.

Use of Ginkgo Biloba in Healthy Volunteers

In view of the safety of the ginkgo biloba extract, the question may be raised as to what effects the extract has on healthy volunteers? In 1989, in an internal report at Schwabe Industries, described by Defeudis (10), Kunkel gave results from a study comparing the total EGb 761 extract to two different preparations containing parts of the extract. Fraction I included only the flavanoids. Fraction II included the flavanoids and the ginkgolides. These were administered orally at 80 mg, three times a day, and were compared to a placebo group in a crossover design with 12 participants. Kunkel reported that all 4 groups differed in the effects on EEG. Fraction I showed the most cerebral electroactivity in the frontal region of the brain. Fraction II showed activity in the temporobasal region. The total extract EGb 761 showed electrical activity in both of these areas. This study, according to Kunkel, demonstrated that the ginkgo extract as well as it's constituents affect the brain. In 1993, Kunkel (11) also administered 40, 80, and 160 mg of EGb 761 (Tebonin) to 12 healthy male volunteers. After three days of oral administration, five EEG recordings were taken between 8:00 and 1:00. Twenty-five parameters were recorded including total power, dominant frequency and whole spectrum difference. Significant differences were found in 15 of the 25 parameters. Kunkel also experimented with different extractions of ginkgo biloba, one including only flavonoid concentrate and ginkgolides and another containing only flavonoid concentrate. Both of the extracts yielded differences in most of the 25 parameters, however, the differences were not consistent over all three types of extracts. Kunkel concluded that event related potentials may be a better measure of supplement effects, and that with this experiment the action of the supplement was questionable.

Krauskopf in 1983 as reported by Defeudis (10) administered doses of 0, 120, 240, and 600 mg of EGb 761 to 12 healthy young volunteers for 7 days in a double blind, crossover study. As shown by an EEG, the 120 mg dose increased the alpha spectrum in all leads except for the frontal lobe. This dose also decreased beta-1 activity in the occipital regions. The 240 mg dose increased the alpha wave spectrum except in the frontal lobe and the decrease in beta-1 waves was larger than that of the 120 mg group. The 600 mg dose demonstrated after 100 and 120 minutes an increase in alpha waves in both the frontal and occipital lobes in both sides of the brain. The authors theorized that this induced a state of increased alertness. A study by Itil and Martorano (5) compared the effects of three commercial preparations of EGb 761, Ginkgo Power™, Ginkgold™, and Super Ginkgo™ in 12 healthy male volunteers ranging in age from 18-65. A quantitative Pharmaco-EEG method was used one and three hours after ingestion. Ginkgold (60 mg) was found to increase alpha wave activity in one hour at 7.5 - 13 hz, as shown by CEEG dynamic brain mapping. The Super Ginkgo (40 mg) also increased alpha wave activity, but to a lesser degree, while the Ginkgo Power (40 mg) gave the smallest increase. However, at the three hour test the Super Ginkgo had increased in alpha wave activity more than the Ginkgold. When the total frequency spectrum was analyzed, it was found that the

Ginkgold not only produced an increase in alpha waves, but also a decrease of slow and fast waves in 9 out of 12 volunteers. These changes have also been found with other cognitive enhancing drugs. These effects may be applicable to the treatment of dementia, because these patients may have a decrease in alpha activity and an increase in slow waves, when compared with normal volunteers.

Subhan and Hindmarch (12) studied the effects of a placebo, 120, 240 and 600 mg of the EGb 761 ginkgo biloba extract manufactured as Tanakan on eight healthy female volunteers in a crossover design. Subjects were administered the critical flicker fusion test, Leed's psychomotor test of reaction time, Sternberg memory scanning test and LARS scale for perceived drug effects The only test in which supplement effects were observed was the Sternberg Memory Scanning test in which the 600 mg group showed a significant advantage over the placebo group. This study is the only known study to directly test the effects of ginkgo with cognitive measures of memory. However, a dosage of 600 mg is not a realistic dose for the average user. Recommended doses are about 120 mg per day given in 2 separate tablets of 60 mg. If a person was to take 600 mg, 10 tablets would need to be ingested! The null hypothesis of the present study was that the standardized extract of ginkgo biloba does not improve short term memory of a group of healthy male participants as compared to a placebo. The use of a directional hypothesis was supported by the prior research showing positive effects of ginkgo biloba.

METHODS

BioGinkgo™ 27/7 (LI 1370) which provides 120 mg at a 50:1 ratio and is standardized to contain 27% ginkgo flavone glycosides and 7% terpene lactones was used in this study. All 30 treatment subjects received their dosage from the same package lot of extract in order to ensure a consistent dosage. The placebo group received tablets that matched the appearance of the BioGinkgo and included the same constituents except the ginkgo biloba. Both the BioGinkgo and the placebo were generously donated by Pharmanex, Inc. Neither the subjects nor the experimenters administering the memory tests were aware of what treatment the subjects received. Participants were selected from male student volunteers at the University of North Dakota that were screened for their health prior to participation. Subjects using prescription medication, ginkgo biloba and other herbal supplements, having chronic health conditions, hypertension, blood clotting disorders, recurring gastrointestinal problems (ulcers), drug or alcohol abuse problems or that were regular smokers or hypersensitive to ginkgo biloba were not included in the study. A total of 60 participants with 30 participants in both the treatment and the control group participated in the study.

The first day of the study, each participant signed a consent form, completed the Wahler Physical Symptom inventory (13), the vocabulary subtest of the WAIS-R (14) and received a blood pressure check, (those testing greater than 130 systolic/ 80 diastolic were dismissed). The participants were then given tablets containing either 120 mg of LI 1370 or a placebo with a glass of water and a granola bar. The participants reported to the lab at the same time for 5 days and received either BioGinkgo or a placebo. The participants also refrained from using alcohol and over-the-counter drugs such as aspirin for 24 hours before the fifth day of the experiment. Blood pressure was taken a total of seven times during the five day trial in order to ensure the safety of the participant. On the 5th day, the participants waited two hours in the lab and refrained from ingesting caffeine or nicotine. After two hours each subject received another blood pressure check. Each subject was then tested using the Sternberg memory scanning test (15), a reaction time control test, a prose recall test (16), the digit span subtest of the WAIS-R (14) , and the reading span test developed by Daneman and Carpenter (17). The Sternberg memory scanning test measured the subject's latency to correctly matching target stimulus digits to an initial set of 2, 4, and 6 numbers. The reaction time control test was used to test for raw reaction time to the same type of digit sets as the Sternberg. The prose recall test measured subject's recall of idea units in reading passages. The digit span test measure the subject's memory of digit sets containing 2-9 digits both forward and backward. The reading span test presented a series of sentences in which the last word of each sentence was recalled. Each subject was questioned about side effects throughout the study and on the last day reported what treatment they believed they received. One week after testing, the participants were called and asked about side effects, changes in memory and were told which treatment group they were in for the study. Each participant received 5 hours of extra credit for their Psychology classes at the University of North Dakota.

PRELIMINARY RESULTS AND DISCUSSION

At the time of this writing, 26 subjects have participated in the experiment, 13 in the experimental group and 13 in the control group. Preliminary findings on these subjects are reported here. The average age of the experimental group was 21.83 with a standard deviation of 2.52. The control group mean age was 20.69 with a standard deviation of 2.06. The vocabulary subtest scores were used to ensure each group had equal verbal ability before receiving treatment. The mean vocabulary score for the treatment group was 44.84 (SD = 9.99) and the control group was 40.92 (SD=7.11). This was a non-significant difference showing that the groups were equivalent. In the digit span subtests and the reading span tests, the ginkgo group showed higher mean scores, but, they were not significantly different. A manova of the Sternberg memory scanning showed faster mean latencies on all conditions for the ginkgo group. However, this difference was not large enough to result in a significant difference for the interactions of group by size, size by decision, and group by size by decision. The group by decision interaction resulted in a $p = 0.128$ which was closer to the desired 0.05 level than the other interactions. A significant size effect was found with $p < 0.05$. This reflects a difference in the latency of responding to the 2, 4, and 6 digit conditions. All of the subjects that received ginkgo reported that they felt they received the placebo, while none of the placebo subjects believed they had received ginkgo. Only one side effect was reported in the 26 subjects which was a mild stomachache several hours after receiving ginkgo. It is not clear if this can be attributed to the ginkgo.

Although, non-significant findings are being reported at this time, it is believed that some of the tests may reach significance upon completion of the study of the full 60 subjects. One of the most interesting findings of this study thus far has been the report by the subjects as to what treatment group they felt they were in. Ginkgo biloba may work its effects without conscious knowledge of the person taking it. This is unusual as many supplements which are thought to enhance ability have definite effects that can be felt. Caffeine when ingested results in the person feeling more alert and awake, and someone who has ingested caffeine can normally detect that it has had an effect. Ginkgo also may require a sustained chronic dosage in order to sustain marked effects, whereas caffeine and other drugs have their effects almost immediately. Further studies of interest include longer term dosage of ginkgo, gender differences, and examinations of ginkgo's effects on healthy older adults.

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Symposium Agenda

MATHEMATICAL AND COMPUTER APPROACHES TO BIOLOGICAL SYSTEMS

April 15, 1999 (Thursday Afternoon)

Location – Memorial Union

Convenor and Moderator – Eric O. Uthus, USDA, ARS Grand Forks Human Nutrition Research Center

1:30 p.m. Welcome and Overview

1:35 p.m. Eric Uthus – USDA, ARS Grand Forks Human Nutrition Research Center
Compartmental Modeling of Nickel Metabolism in Rats Based on Orally Administered ^{63}Ni

2:35 p.m. Boris Zaslavsky – USDA, ARS Grand Forks Human Nutrition Research Center
Predominant Physiological Factors in the Response of Rats to Changes in Dietary Vanadium

3:05 p.m. Mid-Afternoon Break

3:20 p.m. Stephen Lowe – Department of Chemistry, Minot State University
Using Molecular Modeling to Relate Biological Activity to Structure

3:50 p.m. Kathryn Thomasson – Chemistry Department, University of North Dakota
Using Brownian Dynamics to Predict Interactions Between Large Molecules

Poster Presentations

4:20 p.m. Fan Yang – Department of Chemistry, University of North Dakota
Ionic Strength Dependence of the Free Energy of Nonspecific Association of Cro Repressor Protein with B-DNA Predicted by Brownian Dynamics
Igor V. Ouporov – Department of Chemistry, University of North Dakota
Brownian Dynamics Simulations of Rabbit Muscle Aldolase Binding Rabbit Muscle Actin, Actin Mutants and Yeast Actin

4:40 p.m. Closing Remarks

COMPARTMENTAL MODEL OF NICKEL METABOLISM IN RATS BASED ON ORALLY ADMINISTERED ^{63}Ni

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ABSTRACT

Female weanling Sprague-Dawley rats were fed a skim milk-based diet containing 1 μg Ni (as $NiCl_2 \cdot 6H_2O$)/g. After 62 days, the rats were given an oral dose of ^{63}Ni (10.7 μCi ^{63}Ni as $NiCl_2$, specific activity: 12.7 mCi/mg Ni; ~0.84 μg Ni/10.7 μCi). Immediately following dosing, 6 rats were placed in metabolic cages for urine and feces collection. The remaining rats (N=15) were killed at various time points (16 min to 7 days) after dosing. Following whole-body perfusion with saline, organs were removed, weighed, digested with HNO_3-H_2O_2 and counted for ^{63}Ni. Data were modeled by using SAAM II software. Based on 7-day cumulative excretion, the rats absorbed 2.5% of the dose. After 7 days, approximately 97.5% of the dose was excreted in the feces and only about 2.4% in the urine. For liver, peak ^{63}Ni counts occurred within 30 min of dosing and reached a maximum of about 0.09% of the dose. The peaks of ^{63}Ni counts in whole blood, kidney, and bone were broad and occurred between 30 and 180 min. Peak counts for whole blood represented approximately 0.06% of the dose. Peak counts for kidney represented about 0.04% of the total dose and only about 0.001% of dose for bone (femur). Three compartments were necessary to approximate the data for each tissue modeled.

INTRODUCTION

Mathematical modeling has been used to study the metabolism of many elements including nickel. Nickel absorption, distribution, and elimination has been studied in human volunteers by using non-radiolabeled $NiSO_4$ (1). Onkelinx et al (2) developed a compartmental model for rats and rabbits given an intravenous injection of $^{63}NiCl_2$. In each study, however, the dose of nickel given was large (12 to 50 μg Ni/kg body weight in the human study and 17 μg Ni per animal in the rat study). Both studies were designed to help reduce the uncertainty of toxicologic risk assessments to nickel exposure. There are no mathematical models that study nickel from a nutritional point of view where animals are given an oral tracer dose of radioisotopic nickel in which the amount of nickel given minimizes alterations to the steady state of the system (that is, where the tracer, ^{63}Ni, does not significantly affect the tracee). This study was designed to develop a compartmental model of nickel metabolism in rats given an oral dose of ^{63}Ni. This paper describes a preliminary nutritionally-based mathematical model of nickel metabolism in rats.

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MATERIALS AND METHODS

Female weanling Sprague Dawley rats (Sasco Inc., Omaha, NE) were housed in all-plastic cages in laminar flow racks (Lab Products, Maywood, NJ). Room temperature was maintained at 23°C and humidity at 50%. Automatically controlled lighting provided 12 hours light daily. Animals were weighed and provided clean cages weekly. Animals had free access to food and deionized water (Super Q Systems, Millipore Corp., Bedford, MA), which were provided fresh daily, in plastic containers. Absorbent paper caught droppings and was changed daily. Rats were fed a skim milk based diet (Table 1) supplemented with 1 μg Ni (as $NiCl_2 \cdot 6H_2O$)/g.

Table 1. Basal Diet[1]

Ingredient	g/kg diet
Dried skim milk, Carnation	375.00
Ground corn, acid washed	496.25
Corn oil	100.00
dl-α-Tocopherol	0.06
Mineral mix[2]	20.00
Vitamin mix[3]	4.19
Ferric sulfate mix*	2.00
L-Cystine	2.00
Choline chloride	0.50
Total:	1000.00

[1] Basal diet contains less than 30 ng Ni/g.

[2] Content of mineral mix in g/kg diet: ZnO, 0.0062; $MnSO_4 \cdot 4H_2O$, 0.0812; $CuSO_4 \cdot 5H_2O$, 0.0500; KI, 0.0005; Na_2SeO_3, 0.0006; $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, 0.0040; $Cr(C_2H_3O_2)_3 \cdot H_2O$, 0.0020; NaF, 0.0060; H_3BO_3, 0.0060; NH_4VO_3, 0.0005; $Na_2HAsO_4 \cdot 7H_2O$, 0.0050; $NaSiO_3 \cdot 9H_2O$, 0.5000; ground corn, 19.3380.

[3] Content of vitamin mix in g/kg diet: vitamin K_1, 0.0008; nicotinic acid, 0.0150; biotin, 0.0002; thiamine·HCl, 0.0027; pantothenic acid, Ca salt, 0.0080; vitamin B_{12} (0.1% in mannitol), 0.0500; pyridoxine·HCl, 0.0075; riboflavin, 0.0050; inositol, 0.0050; folic acid, 0.0040; glucose, 4.0919.

Oral dosing of ^{63}Ni (New England Nuclear, Boston, MA) began 62 days after the rats had been placed on the experimental diet. The time was recorded when each rat received the dose (25 µl of a saline solution containing 10.7 µCi ^{63}Ni as $NiCl_2$, specific activity: 12.7 mCi/mg Ni; ~0.84 µg Ni/10.7 µCi). Two sub-groups of rats were used in the experiment. One group (N=6) was placed in individual metabolic cages (Nalge Co., Rochester, NY) immediately after dosing for collection of urine and feces; urine and feces were collected daily over a 7-day period. The other group of rats (N=15) was killed at various time points (t = 16 min to 7.15 d) after oral dosing of ^{63}Ni. After anesthesia with Inactin (sodium thiobutabarbitol, Research Biochemicals International, Natick, MA), about 0.2 ml heparin (10000 units/ml) were injected directly into the left ventricle. The rats were then whole-body perfused through the aorta with room temperature saline by using a perfusion pump at a flow rate of approximately 6.3 ml/min. Two ml of blood was collected from the right atrium by using a needle and syringe at the very beginning of the perfusion. The atrium was then cut and used as the bleeding point. Perfusion of saline continued for 15 min. Organs were collected and weighed. Total blood volume was calculated as 6.5% body weight. At the time of termination, all rats weighed approximately the same (217±15 g). Feces and tissue samples, including blood, were digested with HNO_3-H_2O_2. After digestion, 1N HCl was added to dissolve the digested sample. Scintillation fluid was added to either an aliquot or the whole sample, depending on the sample. Liquid scintillation techniques were used to determine ^{63}Ni activity (dpm). Urine was counted without prior digestion. Mathematical modeling of the data was done with SAAMII software (SAAM Institute, University of Washington, Seattle, WA).

RESULTS

The model is shown in Figure 1. Compartments are numbered and individual or grouped organs are boxed. The model is based on oral ingestion of nickel; thus, the single arrow at compartment one designates oral intake of nickel. The double arrow indicates the route (oral) of isotope delivery into the system. Arrows between the compartments represent the transport of isotopic nickel with rate constants *k(i, j)* as shown in Table 2. The rate constant, *k(i, j)*, is defined as the fractional pool of isotopic nickel in compartment j going to compartment i per minute (3). Nickel that is not absorbed passes from the GI (compartments 1, 2, and 11) to the feces (compartment 3). Absorbed nickel enters a blood compartment (compartment 4) where it can be routed to different organs including liver, grouped organs, or other blood compartments. A delay compartment (compartment 10) was needed to visually fit the model predicted response to the actual blood data. Nickel is excreted into the urine (compartments 13 and 9) from blood compartment 4. Compartment 13 was needed to delay the final excretion of ^{63}Ni by urine. Possibly, this compartment is analogous to the bladder storage of urine until excretion. The grouped organs include all organs excluding liver and blood. These grouped organs were not sampled for ^{63}Ni; the curve for the grouped organ compartment was calculated by the model. Cumulative excretion of ^{63}Ni is shown in Figures 2 (feces) and 3 (urine) and Table 3. The model predicted nickel absorption to be 2.5%.

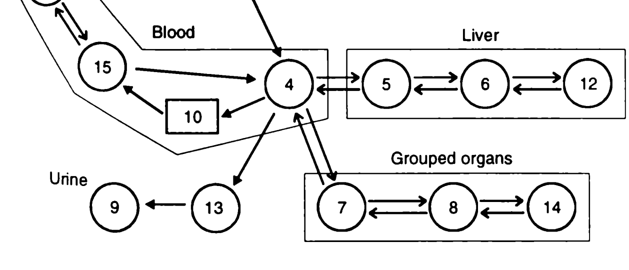

Figure 1. Compartmental model of nickel metabolism in rats.

Table 2. Rate Constants for Model Shown in Figure 1

	Rate constant, min^{-1}		
k(2,1)	0.975	k(8,7)	0.05
k(3,11)	0.000543	k(8,14)	0.0004
k(4,1)	0.025	k(9,13)	0.0007
k(4,5)	0.14	k(10,4)	0.0525
k(4,7)	0.3	k(11,2)	0.001
k(4,15)	0.02	k(12,6)	0.00175
k(5,4)	0.1550	k(13,4)	1.05
k(5,6)	0.055	k(14,8)	0.0075
k(6,5)	0.05	k(15,10)	0.066667
k(6,12)	0.00003	k(15,16)	0.0015
k(7,4)	1.0	k(16,15)	0.01
k(7,8)	0.005		

Actual and model-derived retention of ^{63}Ni in blood are shown in Figure 4. Blood retention peaks at about 0.06% of the dose at about 120 min. After one day, less than 0.011% of the dose remains in the blood. The transfer of ^{63}Ni into and out of liver is relatively fast (Figure 5). The peak ^{63}Ni retention occurs at about 30 min and is only about 0.09% of the dose. Retention of ^{63}Ni in grouped organs is shown in Figure 6. Because all organs were not sampled, only model derived data are available for the grouped organ compartments. The model predicts that the peak retention of ^{63}Ni in the grouped organs amounts to approximately 0.34% of the dose and that after 7 d

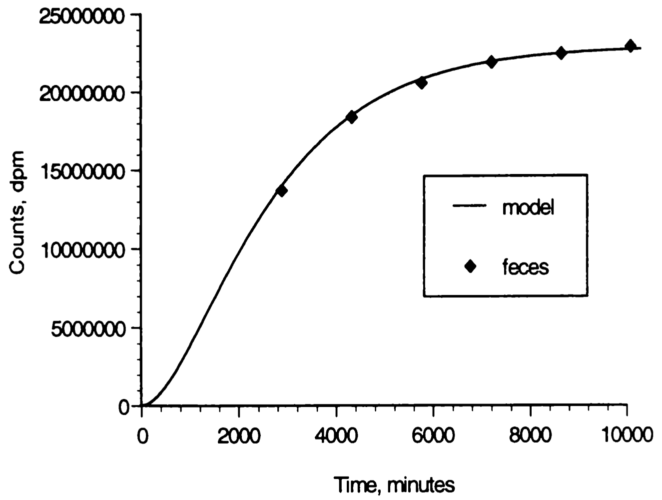

Figure 2. Cumulative excretion of ^{63}Ni in feces.

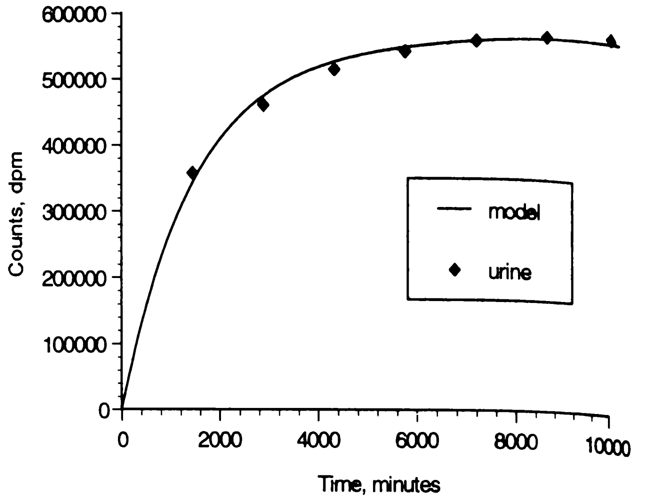

Figure 3. Cumulative excretion of ^{63}Ni in urine.

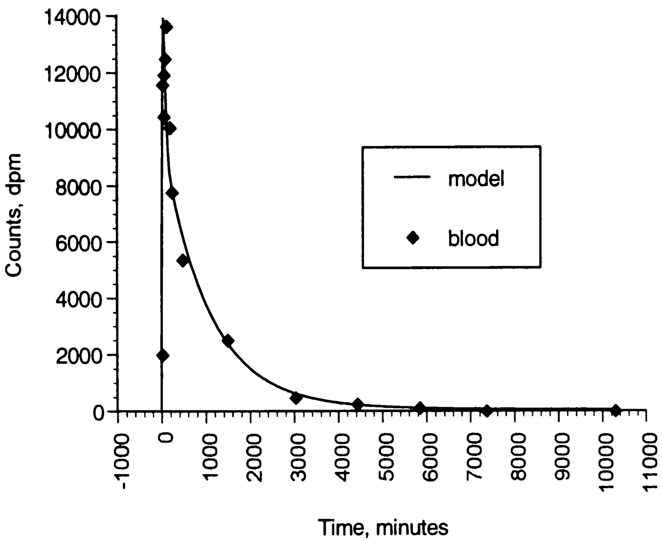

Figure 4. ^{63}Ni retention in blood.

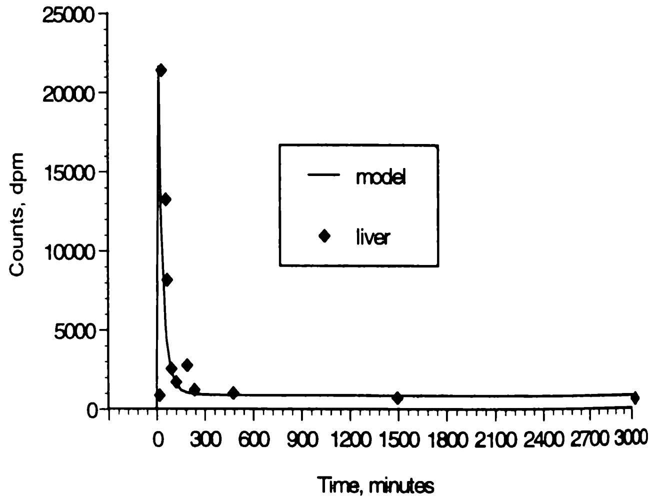

Figure 5. ^{63}Ni retention in liver.

Table 3. Fecal and Urinary Excretion of ^{63}Ni after an Oral Dose of 10.7 µCi

Time, d	Feces (% dose)	Feces-cumulative (% dose)	Urine (% dose)	Urine-cumulative (% dose)
1	27.7±14.0[1]	27.7	1.52±0.26[1]	1.52
2	30.8±18.0	58.5	0.44±0.17	1.96
3	20.0±9.38	78.4	0.23±0.10	2.20
4	9.25±2.63	87.7	0.12±0.04	2.31
5	5.63±3.79	93.3	0.07±0.03	2.39
6	2.31±1.35	95.6	0.04±0.03	2.43
7	1.92±1.51	97.5	0.03±0.02	2.46

[1]Mean ± standard deviation. N=6.

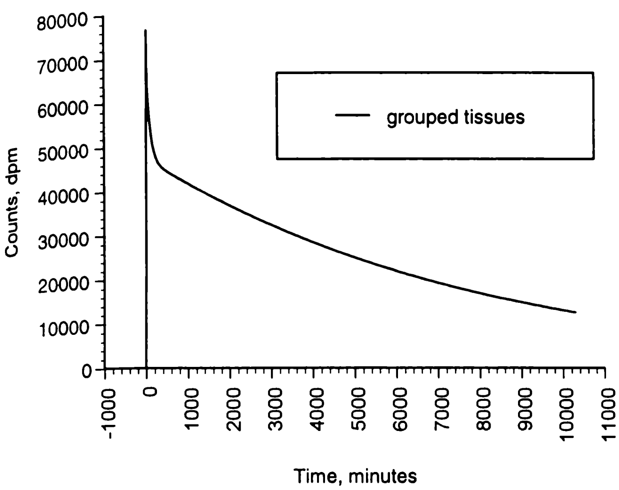

Figure 6. ^{63}Ni retention in grouped organs.

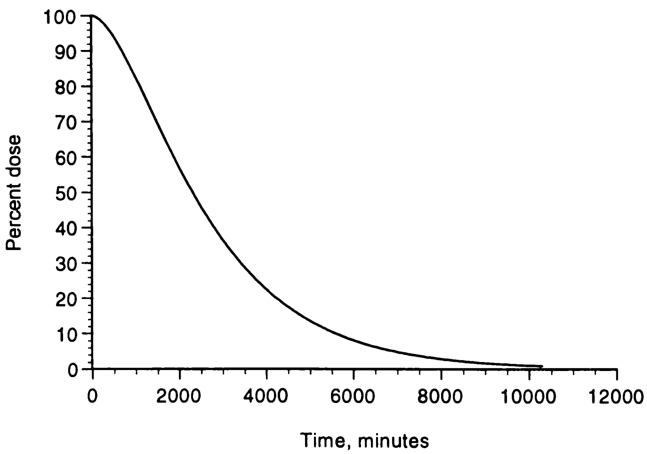

Figure 7. Model predicted whole body retention of ^{63}Ni in rats.

less than 0.09% of the dose remains in these tissues. Although whole-body retention of nickel was not directly measured, the model predicted retention is shown in Figure 7. Based on this curve, a biological half-life of approximately 1 d for nickel was calculated.

A steady-state model was derived from the compartmental model. A system is in steady-state over a defined period of time if, for every compartment, the total rate of appearance of the substance of interest (nickel) is equal to its total rate of disappearance (3). The steady-state model was based in an oral intake of 25 µg Ni per day. This model predicts a total body nickel concentration of 50 µg under these dietary conditions and a body weight of 217 g. Steady-state predicted values of nickel concentrations for liver and blood are shown in Table 4.

DISCUSSION

In this study the dose given to the rats corresponds to approximately 0.83 µg Ni. Typically, rats will ingest 25-30 µg Ni per day. Although the dose given corresponds to about 3% of the daily intake of nickel for the rats, the dose was assumed to be small enough not to affect the normal homeostatic mechanisms governing nickel metabolism.

Three compartments were necessary to visually fit the model to the data for blood and liver. Because of this, 3 compartments were used in modeling the grouped tissues. One compartment was needed for the very fast initial peak, the second compartment was needed for the isotope that had a slower elimination rate, and the third compartment accounted for little of the total isotope but was the main constituent of the curve after several hours. Figure 8 shows the individual component make-up of the retention of ^{63}Ni in liver. The physiological meaning of each of the compartments within a given organ is not known. Individual components may depict, for example, transport phenomenon, nickel speciation, or differential binding of nickel to various cellular components. Further studies are needed to better define the individual compartments.

The model predicted nickel absorption of 2.5%, which is in the same range of absorption as determined by using the

Table 4. Actual and Model Calculated Concentrations of Nickel in Whole Blood and Liver

Tissue/organ	Ni concentration	Model calculated concentration[1]
Whole blood	0.3 ng/ml [<0.05-1.1][2]	0.62 ng/ml[3]
Liver	8 ng/g [2-21][4]	3.2 ng/g[5]

[1]Based on a steady state intake of 0.0174 µg Ni/min (25 µg/day).
[2]Median [range], N=30 (6).
[3]Based on sum of compartments 4, 15, and 16 and an average body weight of 217 g and a blood volume of 6.5% (14.1 ml total blood volume).
[4]Median [range], N=10, wet weight basis (7).
[5]Based on sum of compartments 5, 6, and 12 and an average liver weight of 7.70 g.

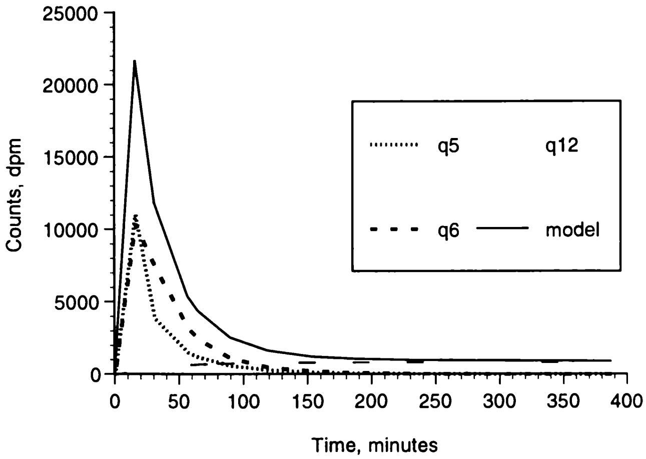

Figure 8. Individual compartment contribution to ^{63}Ni retention in liver.

first 5 days of cumulative tracer excretion in the feces (4), which determined absorption to be 6.7%. Limited studies with humans indicate that less than 10% of ingested nickel is normally absorbed. Also, biliary excretion of nickel in rats has been shown to be quantitatively unimportant in rats, amounting to less than 0.5% of the dose (5). Thus, biliary excretion and reabsorption of nickel was not modeled. After 7 days less than 1% of the dose was retained and greater than 97% had been eliminated in the feces. An exponential curve was fit to the model-predicted whole body retention of ^{63}Ni; a biological half-life of nickel was estimated to be approximately 1 d.This preliminary model approximates the retention of nickel in whole body, blood, liver, and grouped organs. The steady-state concentrations (model-derived) also approximated actual nickel concentrations in liver and blood (Table 4), further validating the model. Because there are few animal data available for comparison, data from human tissues were used. The comparison of human and animal tissue nickel data is not unreasonable as, albeit there are limited data, the distribution pattern of nickel in humans parallels, to some extent, that observed in animal experiments (8).

The present model is built around nickel metabolism in rats fed a diet containing 1 µg Ni/g. An additional model will be developed to include animals fed no supplemental nickel (basal diet concentrations of less than 30 ng Ni/g). It is important to determine what rate constants, if any, will be affected by different dietary intakes of nickel. The affected rate constant(s) could help determine which homeostatic mechanism is most important, thus allowing for a better understanding of nickel metabolism.

Modeling can provide unique insights into the underlying processes and control mechanisms in metabolism. It can also be used to generate hypotheses that can be tested experimentally; these experiments can then be used to validate and enhance the model. Thus, modeling and animal experimentation are complementary. These studies should help shed new light on nickel metabolism at not only toxicologic concentrations but also at physiologic concentrations where there is very limited information. Future models may be developed by modeling more tissues or by using animals fed different forms or amounts of nickel. Mathematical modeling has been and will continue to be used in elucidating the physiologic and toxicologic mechanisms of nickel.

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PREDOMINANT PHYSIOLOGICAL FACTORS IN THE RESPONSE OF RATS TO CHANGES IN DIETARY VANADIUM

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INTRODUCTION

Although no specific biological function for vanadium is known, it has been long suspected to be essential for animals. Recent studies have shown that vanadium-deprived goats exhibit an elevated abortion rate and depressed milk production (1). In another study, vanadium deprivation affected indices of iodine metabolism (2). Also, enzymes that require vanadium have been found in lower forms of life (3, 4). Thus, there is strong circumstantial evidence that vanadium is essential in higher forms of life. However, signs of vanadium deficiency have been difficult to establish because of the ubiquitous nature of this ultratrace element and the very low amount of vanadium apparently required by animals (5). This research used discriminant analysis to separate from a myriad of experimental observations a small subset of parameters that could be used to determine the main response factors to vanadium deprivation in rats. These main response factors were also tested to determine which combination of parameters best exhibited (under current conditions) differences among dietary groups. The factor (or combination of factors) was then used to predict dietary intake based on values of the parameter(s). The closer the prediction to 100% the better the parameter(s) in predicting dietary treatment. Future studies will determine the ability of the main response factors to provide the physiological explanation for observed biochemical and physiological changes. Also, the studies may be used as guidelines in developing dietary recommendations of vanadium for rats and eventually for humans.

METHODS AND MATERIALS

In this report, data from 2 independent vanadium experiments were used. Both experiments were designed to determine the effect of inhibition of nitric oxide (NO) synthesis on vanadium deprivation. NO synthesis was inhibited by providing Nω-nitro-L-arginine methyl ester (NAME), an inhibitor of NO synthetase, in drinking water. Both experiments were factorially designed and used male weanling Sprague-Dawley rats. Dietary variables in the first experiment were vanadium (as ammonium metavanadate, 0 or 0.5 μg V/g diet) and NAME (0 or 75 mg/100 ml drinking water). Variables in the second experiment were identical to the first with the exception of one additional vanadium group (0.1 μg V/g diet). The first experiment used 5-6 rats per group and the second used 7-8 per group. Parameters that were used in both experiments included 16 hematological measurements: white blood cell count (WBC), neutrophil count (Neut), lymphocyte count (Lymp), monocyte count (Mono), eosinophil count (Eos), basophil count (Baso), red blood cell count (RBC), hemoglobin (Hb), hematocrit (Hct), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), red cell distribution width (RDW), platelet count (Plt), mean platelet volume (MPV), and platelet distribution width (PDW). Some of the blood parameters are not independent. For example, Neut, Lymph, Mono, Eos and Baso are components of WBC. However, all parameters were used in the analyses without decreasing the precision of the method. Additional parameters used from experiment 2 included organ weights (liver, heart, spleen, kidney and thyroid); plasma triglycerides (TG), total creatine-creatinine (Creat), ceruloplasmin (CP), glucose (Gluc), cholesterol (Chol), alkaline phosphatase (AP), urea nitrogen (BUN), triiodothyronine (T3), thyroxine (T4), and corticosterone (Cort); the specific activites of liver arginase (Arg), pancreatic amylase (PancA), plasma amylase (PlasA), and thyroid peroxidase (TP); and blood pressure.

Statistical Methods

The purpose of discriminant analysis is to define a small number of linear combinations of a set of variables that summarize between class (e.g., between dietary groups) variation and retain as much of the information of the original variables as possible (6-8). The coefficients of the linear combinations of original data are canonical coefficients or canonical weights and are weighted to maximize the difference among the treatments (dietary groups). The variable defined by the linear combination is a canonical component (CAN). The first canonical variable provides the maximal multiple correlation, the second canonical variable provides the next most maximal multiple correlation, and so on; up to 3 canonical components were used in this study. The small number of canonical components can be used in place of original variables for plotting and evaluation of group differences.

The diet groups are the ordinal variables (i.e., dietary variables: 0, 0.1 and 0.5 μg V/g diet; 0 and 75 mg NAME /100 ml drinking water). Logistic regression analysis was used to

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investigate the relationship between the ordinal classification variables (diet groups) and continuous explanatory variables (hematological measurements, organ weight, etc.). Logistic regression (9) calculates the probability function that links these variables. The concordant (discordant) number presents the percent of successful (unsuccessful) responses to the predicted events. In the following, this number was used to measure the connection between the diet and physiological response.

RESULTS AND DISCUSSION

Initially, each experiment was investigated separately and then jointly by using data from the 16 hematological measurements that were determined in both experiments. When the experiments were combined, discriminant analysis was used to develop a universal formula useful in predicting dietary vanadium by hematological response. Because the first experiment did not have the groups of rats fed 0.1 μg V/g diet, data from these groups were not used in the joint experiment analysis. Finally, discriminant analysis was used on data from the remaining parameters of the second experiment to ascertain whether or not these factors would be more useful than hematological parameters as predictors of diet.

Experiment 1. Distinguishing dietary vanadium and NAME by using 16 hematological parameters

Canonical discriminant analysis of the hematological data was implemented. The canonical coefficients for standardized data are presented in Table1. These coefficients were used as the weight factors to calculate 3 weighted averages (CAN1, CAN2 and CAN3) of 16 parameters. For these calculations the raw experimental data that have different units and different exponents were scaled to make unit standard deviations for all 16 variables. Figure 1 illustrates that discriminant analysis has the capability to distinguish individual dietary groups.

Logistic regression was used to estimate how well the canonical variables CAN1, CAN2 and CAN3 can predict the dietary groups in hypothetical circumstances when the diet groups are assumed unknown and only the hematological information is available. The best resolution for the 4 dietary groups was achieved with CAN1 which gave 83.9%. When the diet was distinguished by NAME only (vanadium was treated as a random unknown diet factor) CAN1 separated the 2 groups (±NAME) in 100% cases. CAN1 proved almost useless in the separation of dietary groups by vanadium (NAME was considered to be a random unknown factor); the success was 60.8%, i.e., very close to the flipping coin 50% outcome. On the other hand, CAN2 provided 88.3% of success, while CAN2 and CAN3 together were successful in 96.7% cases. Thus, it can be concluded that CAN1 is mainly NAME sensitive, while CAN2 is mainly vanadium sensitive (CAN3 adds some small vanadium sensitivity).

Experiment 2. Distinguishing dietary vanadium and NAME by using 16 hematological parameters

Because of the very small population under investigation for the first experiment (5-6 rats for each diet group), it would be unreasonably optimistic to expect that the weighting coefficients from Table 1 would be statistically representative of a larger population. To use these formulae successfully from one independent experiment to another, the hematological data has to be relatively similar. To test this assumption the t-test was applied to the hematological data from the groups of rats where the dietary treatments were identical between the 2 experiments (i.e., the 0.1 μg V/g, ±NAME diet groups were not included). Surprisingly, some hematological characteristics were markedly different. For example, the probability of identity for several parameters follows: $p<0.01$ for WBC, $p<0.0005$ for Lymp, $p<0.002$ for Baso, $p<0.01$ for MCV, and $p<0.007$ for MCH. Possibly, these differences could be the result of different study lengths (63 days for experiment 1, 54 days for experiment 2) or housing conditions. The ability to distinguish the groups of the second experiment (all dietary groups including those receiving 0.1 μg V/g, N=45 rats) by NAME from CAN1 was calculated by using coefficients obtained from the first experiment (Table 1; vanadium was conceded an unknown random factor). The result was 69.2% success. Using all 3 canonical components together and the coefficients again obtained from experiment 1 (Table 1) resulted in little improvement (less than 2%).

To distinguish vanadium groups from the second experiment by using formulae from the first experiment, data from the 15 rats that were fed 0.1 μg V/g (±NAME) were removed. For the remaining 30 rats CAN1, CAN2, and CAN3 were calculated by using the factors from Table 1. CAN2 and CAN3 together were unable to distinguish between the dietary vanadium groups (50.7% of success); CAN1, CAN2 and CAN3 together also gave very low resolution, 66.7%. To achieve a better resolution in the second experiment, discriminant analysis was applied to the subpopulation of 30 rats. The resulting weight factors are presented in Table 2. Comparing Tables 1 and 2 shows that the absolute values of factors are different while the sign pattern is mainly unchanged. Therefore, as will be shown below, the search for common formulae is justified. Logistic regression was then used to estimate how well the new canonical variables CAN1, CAN2 and CAN3 predicted the dietary groups under the hypothetical assumption that the groups are unknown and only the hematological measurements are available. Variable CAN1 (calculated by Table 2) predicted the 4 dietary groups with 68% of

Table 1. Standardized Canonical Coefficients Based on Parameters Measured in Experiment 1

	WBC	Neut	Lymp	Mono	Eos	Baso	RBC	Hb	Hct	MCV	MCH	MCHC	RDW	Plt	MPV	PDW
CAN1	364.80	-150.45	-322.74	-87.93	-10.91	-19.68	126.32	-83.64	-51.07	35.19	15.44	6.04	-4.72	0.95	2.37	1.12
CAN2	-300.53	128.39	264.78	73.25	7.82	15.77	-28.56	-28.83	62.82	-24.34	11.41	-0.18	0.04	-1.06	-0.60	-0.48
CAN3	-413.50	117.81	365.04	98.51	9.54	23.41	-9.96	16.63	-7.35	-10.76	6.13	-3.61	1.22	-1.53	-2.24	7.73

Table 2. Standardized Canonical Coefficients Based on Parameters Measured in Experiment 2*

	WBC	Neut	Lymp	Mono	Eos	Baso	RBC	Hb	Hct	MCV	MCH	MCHC	RDW	Plt	MPV	PDW
CAN1	59.51	-16.43	-43.50	-12.09	-0.97	0.92	11.98	-13.47	4.90	-7.14	16.13	-1.09	-0.83	0.47	-1.73	2.01
CAN2	-147.58	39.85	107.90	28.36	1.75	2.14	0.22	3.71	-3.75	-3.98	4.67	-2.41	-0.65	0.61	0.74	0.34
CAN3	-33.07	10.02	23.96	6.47	-0.01	-0.19	4.72	5.46	-8.47	1.96	1.68	-1.76	-0.46	0.05	0.61	-0.79

*Data from rats fed 0.1 μg V/g diet not used.

Table 3. Standardized Canonical Coefficients Based on Parameters Measured in Experiments 1 and 2*

	WBC	Neut	Lymp	Mono	Eos	Baso	RBC	Hb	Hct	MCV	MCH	MCHC	RDW	Plt	MPV	PDW
CAN1	34.49	-10.06	-28.80	-7.12	-0.97	-0.29	9.07	-10.20	2.38	-1.41	6.52	0.24	-0.72	0.19	-0.60	0.75
CAN2	-126.52	38.35	105.92	24.36	1.70	5.91	-2.61	8.01	-5.41	3.22	-4.50	-0.27	-0.24	0.44	-0.08	0.81
CAN3	-41.14	12.33	34.03	8.75	1.06	1.60	0.94	-17.26	16.89	11.00	-10.54	5.16	0.27	0.35	-1.29	0.99

*Data from rats fed 0.1 μg V/g diet (experiment 2) not used.

Table 4. Standardized Canonical Coefficients, Based on Parameters Measured in Experiment 2, for Absence (0 μg V/g) or Presence (0.1 or 0.5 μg V/g) of Dietary Vanadium

	WBC	Neut	Lymp	Mono	Eos	Baso	RBC	Hb	Hct	MCV	MCH	MCHC	RDW	Plt	MPV	PDW	CP	PlasA	AP	Gluc	Chol	TG
CAN1	-28.88	9.61	20.83	0.58	-2.35	4.41	5.88	-0.58	-2.41	-13.51	12.64	-4.73	-0.64	0.50	0.20	1.05	-0.85	-0.45	-0.88	0.65	-0.20	0.84
CAN2	-9.35	3.02	6.75	0.49	6.04	-17.07	1.36	0.69	12.30	-5.31	10.73	2.02	0.00	0.00	0.71	-0.52	0.03	0.43	0.29	0.07	-0.07	0.08

Table 5. Standardized Canonical Coefficients, Based on Parameters Measured in Experiment 2, for 3 Concentrations of Dietary Vanadium

	WBC	Neut	Lymp	Mono	Eos	Baso	RBC	Hb	Hct	MCV	MCH	MCHC	RDW	Plt	MPV	PDW	CP	PlasA	AP	Gluc	Chol	TG
CAN1	-30.90	10.15	22.46	0.74	-1.88	4.13	6.27	-0.67	-2.41	-13.46	12.91	-4.56	-0.66	0.41	0.28	1.01	-0.88	-0.43	-0.86	0.71	-0.24	0.78
CAN2	13.70	-3.61	-11.03	-1.09	-3.27	1.98	-2.61	0.64	-0.02	-0.39	-1.81	-1.22	0.14	0.64	-0.57	0.28	0.23	-0.14	-0.17	-0.42	0.30	0.43

Table 6. Standardized Canonical Coefficients, Based on Parameters Measured in Experiment 2, for Absence or Presence of Dietary Vanadium

	BUN	Creat	Arg(-Mn)	Arg(+Mn)	T3	T4	Cort	PancA	TP
CAN1	0.40	-0.07	-0.19	0.09	0.53	0.94	0.15	0.47	-0.57
CAN2	0.14	0.25	-0.17	0.53	0.44	-0.40	-0.57	1.23	0.04
CAN3	-0.37	0.22	-0.92	0.95	1.02	-0.60	0.04	-0.05	0.53

Table 7. Standardized Canonical Coefficients, Based on Parameters Measured in Experiment 2, for 3 Concentrations of Dietary Vanadium

	BUN	Creat	Arg(-Mn)	Arg(+Mn)	T3	T4	Cort	PancA	TP
CAN1	0.56	-0.09	0.07	-0.30	0.49	0.87	0.24	0.72	-0.67
CAN2	-0.27	0.02	-0.66	0.90	0.24	0.42	-0.18	-0.46	0.07
CAN3	-0.16	0.31	-0.64	1.11	1.15	-0.81	-0.29	0.64	0.29

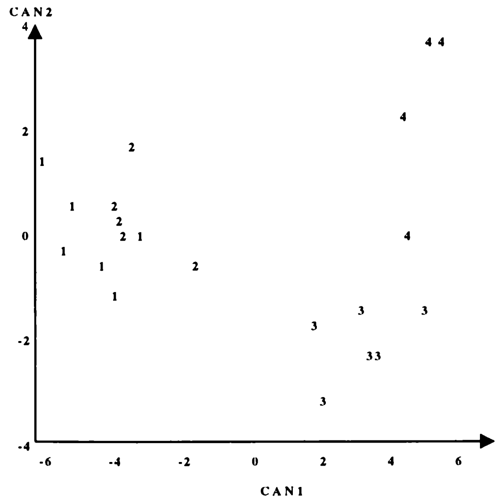

Figure 1. The notation '1' stands for V=0 μg/g and NAME=0 mg/100 ml; '2' stands for V=0.5 μg/g and NAME=0 mg/100 ml; '3'stands for V=0 μg/g and NAME=75 mg/100 ml; and '4 stands for V=0.5 μg/g and NAME=75 mg/100 ml.

success, while CAN1 and CAN2 together gave 78.9% of success. Adding CAN3 did not improve the result.

At this step, one of the goals of the research was to distinguish vanadium groups (disregarding NAME) and NAME groups (disregarding vanadium) by hematological parameters. The variable CAN1 was able to distinguish NAME diet groups with 86.6% of success. Adding variable CAN2 slightly increased the success to 90.2%. Combining the 3 canonical variables gave 91.1% of success. Thus, CAN1 is the NAME sensitive criterion. Variable CAN2 was instrumental in distinguishing vanadium groups, 92% of success, while CAN3 brought no noticeable increase. Thus, CAN2 is the vanadium sensitive criterion.

Combined Experiments. Distinguishing dietary vanadium and NAME by using 16 hematological parameters

To develop general criteria of dietary vanadium and NAME, the data from the 22 rats of the first experiment were combined with the data from the 30 rats (the rats fed 0.1 μg V/g were not used) of the second. The weight coefficients for these 52 rats are presented in Table 3. The values are close to those in Table 2. This can be explained by the larger N of the second group. It also confirms the statistical principle that a sufficiently large population is able to generate relatively stable values. Variable CAN1 (calculate for 52 rats) was able to distinguish the 4 dietary groups with 78.9% of success. Addition of CAN2 increased this to 83.2%; further addition of CAN3 brought no increase.

Canonical variable CAN1 was successful predicting NAME groups in 94.2% cases. CAN2 alone was unable to distinguish between the NAME groups (49.8% success). This observation strengthens the hypothesis that CAN1 is the NAME driven characteristic. Therefore it is justified to name it the NAME component for this particular trial.

Canonical variable CAN2 was successful in separating the groups by dietary vanadium concentration (80.9%). Adding CAN3 did not increase this value. Therefore it is justified to name CAN2 the vanadium component. Thus, dietary groups in two independent experiments were successfully distinguished by using only hematological measurements.

The next step of the research was directed to the reduction of the number of parameters that were used to calculate the canonical variables and thus reduce the volume of data necessary to distinguish the dietary groups. That is, of all parameters measured, these are most likely the most important parameters related to correlating physiological response to dietary intake (of vanadium, for example). Because NAME is a relatively easily demonstrable factor, further analysis was restricted to the dietary vanadium component by using the 52 rats from the V=0 μg/g and V=0.5 μg/g groups (regardless of NAME). Prior to statistical analysis WBC, Neut, Eos and MPV were selected from the 16 hematological measurements as the parameters predicted as being most responsive to dietary vanadium (FHN, personal communication). This hypothesis was tested by logistic regression. The success of this combination was 72.9% and turned out to be the second best evaluation of dietary vanadium groups based on 4 hematological parameters. The best result (73.9%) was from WBC, Neut, Eos and PDW. The best evaluation of vanadium by 3 hematological parameters was achieved with Eos, Plt, PDW or Eos, WBC, PDW, 69.5%. The best evaluation of vanadium by 2 hematological parameters was provided by Plt and PDW, 68.7%, as well as by PDW with either Eos or RBC, 68.4%. The single hematological parameter that was most responsive to vanadium was PDW, 65.5% of success.

Experiment 2. Distinguishing dietary vanadium by using the 16 hematological parameters and 6 additional plasma parameters

Further analysis was performed on data from experiment 2 because it had 3 concentrations of dietary vanadium (0, 0.1, and 0.5 μg/g), had a larger N, and more parameters were measured. In the second experiment 22 hematological and plasma characteristics were measured. Parameters anticipated as being most responsive to dietary vanadium were WBC, Neut, Eos, MPV, CP, Gluc, Chol, TG (FHN, personal communication). These 8 blood characteristics were able to distinguish among the 3 vanadium diet groups (regardless of NAME) with 80.9% of success (N=45).

Logistic regression using these 8 blood characteristics from rats fed 0 or 0.5 μg vanadium/g gave 92.4% of success

(N=30). There was a very small decrease to 91.1% when TG was omitted. Combinations of the best parameters for predicting dietary vanadium were determined by looking at all possible combinations and then selecting the combination with the largest percent of success. Using 5 parameters (WBC, Neut, Eos, MPV, TG) or 4 parameters (WBC, Neut, Eos, MPV) made no difference; in both cases there was an 80% success in predicting dietary vanadium (0 or 0.5 µg/g). When WBC, Neut, Eos, PDW were used, the result was better (82.7% success). Logistic regression was used to test whether or not WBC, Neut, Eos were the 3 most useful parameters to predict dietary vanadium; the result was 74.7% of success. The results for the combinations of Eos, Plt, PDW or Eos, WBC, PDW were 72.4 % and 67.6%, respectively. Therefore WBC, Neut, Eos were the best predictors when only 3 blood parameters were used. PDW was selected as a parameter because it was found to be the most responsive to vanadium in the combined experiments (see above). To evaluate the importance of PDW, parameter pairs were tested (PDW, EOS: 69.3%; PDW, RBC: 64%; and PDW, Plt:63.1%) as well as PDW alone (63.1%). Thus it was found that PDW is also a very important factor of blood response to dietary vanadium.

To evaluate how close the above numbers are to the maximal possible, discriminant analysis using all 22 parameters was used to distinguish between 2 groups of animals, those receiving no dietary vanadium (V=0 µg/g) and those receiving dietary vanadium (V=0.1 µg/g or V=0.5 µg/g). The weight coefficients for CAN1 and CAN2 are presented in Table 4. The component CAN1 is able to distinguish the diet groups with 99.3% of success. The components CAN1 and CAN2 together gave a slightly better result.

Next, analysis using all 22 parameters was performed in an attempt to distinguish the dietary groups by 3 concentrations of dietary vanadium (0, 0.1, and 0.5 µg/g). The weight coefficients for CAN1 and CAN2 are presented in Table 5. Logistic regression gave 86.5% of success for CAN1 and 60.6% for CAN2. Components CAN1 and CAN2 together gave 93.2% of success. Thus, it is theoretically possibile to distinguish the concentration of vanadium in diets eaten by animals by using hematological parameters.

Experiment 2. Distinguishing dietary vanadium or NAME by using other parameters

The possibility of distinguishing dietary groups by plasma and enzyme data alone was investigated. Parameters used were BUN, Creat, Arg (±Mn stimulated), T3, T4, Cort, PancA and TP. These data were subjected to discriminant analysis in an attempt to distinguish between animals that were not fed dietary vanadium (0 µg/g) and those that received dietary vanadium (0.1 or 0.5 µg/g). The weight coefficients are presented in Table 6. The component CAN1 separated diet groups with 85.3% success, adding CAN2 and CAN3 gave only 1% of improvement. Therefore, under these conditions, CAN1 has incorporated almost all response to vanadium. Next, discriminant analysis was used to distinguish 3 dietary groups: V=0 µg/g, V=0.1 µg/g and V=0.5 µg/g. The weight coefficients are presented in Table 7. The component CAN1 gave 64% of success, CAN1 and CAN2 together gave 71.4% of success; addition of CAN3 resulted in no further increase. Thus, these plasma and biochemical parameters were less effective in predicting dietary vanadium than using the 22 hematological and plasma parameters (see above).

Before statistical analysis, it was anticipated that TP, T3, T4 would demonstrate the largest response to vanadium (FHN, personal communication). Logistic regression showed that the ability of these 3 parameters to distinguish vanadium/no vanadium was 83.3%. These 3 parameters were able to distinguish all 3 dietary concentrations of vanadium with 70.1% success. These parameters demonstrated the strongest response to dietary vanadium because these numbers are very close to the maximal values (86.2% and 71.4%, respectively) found for canonical components (those that incorporated all 9 plasma and enzyme parameters). To distinguish between absence (0 µg V/g) or presence (0.1 or 0.5 µg V/g) of dietary vanadium when data are restricted to two variables, T3 and T4 gave the best result, 80.9%: second was the pair of T4 and TP, 78.2%. The single parameter that gave the best response was either T4 (74.7%) or T3 (73.4%). TP yielded only 60.9%.

Thus, the plasma and enzyme analyses are in general more sensitive to the presence (0.1 or 0.5 µg V/g) or absence (0 µg V/g) of dietary vanadium than hematological parameters. Better resolution by the hematological data was acquired because of the larger volume of data (16 parameters). However, when hematological, plasma, and enzyme data were restricted to 3 or fewer parameters, plasma and enzyme data were much better in predicting dietary vanadium.

The weight of organs and blood pressure were very good criteria to predict dietary NAME. For example, blood pressure alone can separate NAME/no NAME with 99.2% success. Body weight and blood pressure provided 100% of success. Combined organ weights (liver, heart, spleen, kidney, and thyroid) successfully characterized dietary NAME in 89.7% cases. These physiological parameters, however, were not very good criteria for dietary vanadium. Logistic regression showed that when the organ weight and blood pressure were used, or when organ weight alone was used, or when organ weight without thyroid weight was used, predicting vanadium/no vanadium was successful in 78.2 to 74.2% of the cases.

SUMMARY

The availability of data from two independent experiments provides a unique opportunity to check the robustness of the method which was implemented in this study. For acceptably large populations, it was observed that the numerical criteria of discriminant analysis were sufficiently stable. Hematological, plasma, and biochemical data were found to be very reactive to the presence or absence of dietary vanadium. However, the dietary concentration of vanadium in the interval of 0.1-0.5 was of small importance in these reactions. Because the physiological effect of NAME administration is so pronounced on many of the parameters measured, discriminant analysis can easily predict NAME status (i.e., ±NAME). NAME was included as a dietary variable because it was thought that NAME would exacerbate vanadium deficiency and thus make the signs of vanadium deprivation easier to show. Results in both experiment 1 and experiment 2 suggested that with discriminant analysis, NAME was not consistently helpful in predicting dietary vanadium based on measured hematological, plasma, or enzyme parameters. The results do suggest, that discriminant analysis can be useful in predicting dietary status from easily obtainable parameters (i.e., blood parameters). This information could then be used, for example, in helping determine nutrient requirements for groups or individuals. Also, this method could be useful to help determine which parameters are the best or most appropriate status indicators for specific nutrients.

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USING MOLECULAR MODELING TO RELATE BIOLOGICAL ACTIVITY TO STRUCTURE

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INTRODUCTION

In recent years the ability of the computer — even desktop models — to perform ever more complex calculations has increased the use computational methods in chemistry. Among these methods is 3D QSAR (Three Dimensional Quantitative Structure-Activity Relationships) which, because of its ability to predict properties of new compounds, is used in the pharmacological industry as a powerful aid to drug design. In our laboratory we are using this method to gain a better understanding of the binding of cAMP to cAMP dependent protein kinase and of the molecular basis for the difference in selectivity of cAMP and cGMP protein kinases.

This presentation will summarize the basic principles of this and other computational methods we have applied to our project.

PRINCIPLES OF QSAR/CoMFA

The most commonly used 3D QSAR method is Comparative Molecular Field Analysis (CoMFA). The basis of this technique is generation of a three dimensional grid of points around each molecule in a database to evaluate steric and electrostatic interactions with a probe atom. A QSAR analysis, typically partial least squares, is then performed to generate predicted values and a three dimensional CoMFA map showing regions where electrostatic and steric factors affect the target property (such as binding to a protein).

Steps in Applying the Method:

In our study we used the program SYBYL (Tripos, Inc.) on Silicon Graphics workstations; the steps required to perform QSAR's are:

- Create a molecular database
- Perform energy minimizations
- Align the database
- Create a molecular spreadsheet with CoMFA data
- Perform Partial Least Squares

Each of the steps involves choices which may affect the success of the analysis.

A graphical interface is used in SYBYL to create molecules from an extensive menu of atom types with different kinds of bonding. Atomic charges are assigned using one of several empirical methods provided.

After charge assignments are made, energy minimizations of each molecule are performed using molecular mechanics. It should be realized that these energy minima are local rather than global minima.

Since the purpose of such studies is prediction of interactions with a macromolecule, a choice of a common alignment of the molecules in the database is required. Appropriate alignment is critical to the validity of the analysis.

In SYBYL a molecular spreadsheet links molecular databases to their related data including experimental values for the target variable (such as binding constants) to be predicted and the CoMFA data. The CoMFA data is generated by the program using a probe (the default is a C^+ ion) to calculate steric (using the 6-12 Lennard-Jones potential) and electrostatic (Coulombic) factors at lattice points surrounding each molecule. This data is represented in the spreadsheet by a single column of numbers but represents a hundred or more separate data points for each molecule.

Partial least squares is an extension of the method of multiple regression which is less sensitive to the distribution of variable values and produces more robust equations. Two kinds of PLS analyses are run: cross-validated and noncross-validated. The cross-validated analysis yields an optimum number of components to use in deriving the mathematical model and a cross-validated r^2 value which is a measure of the predictive value of the model. Cross-validated r^2's greater than 0.4 are considered to have some predictive utility; values greater than 0.7 are considered good. The noncross-validated PLS is run using the optimum number of components to produce a CoMFA map, a noncross-validated r^2, predicted values, standard errors etc.

Factors to Consider When Using This Method

Preferably the molecules used in a database should have only limited flexibility; otherwise there may be too much uncertainly in the molecular geometries used. Also, if molecules with widely varying structures and functional groups are used, the nature of the interactions with the macromolecule in the study may be different and interpretation of the results complicated.

In SYBYL molecular geometries are obtained by energy minimizations using molecular mechanics; that is, using classical mechanics rather than quantum mechanics. This method is fast but not necessarily as accurate as *ab initio* methods. Also, atomic charges are calculated by one of several available empirical methods. Which one to use? This is a question without a clear answer.

The correct alignment of molecules in the database relative to each other also may not be obvious; this depends on how they bind to the macromolecule in question. A further complication is that even if a good geometry and set of atomic charges for the isolated molecule are obtained, the most appropriate geometry to use may be that of the ligand in its binding site. If the three dimensional structure of the binding site is known, energy minimizations can be done in the site.

The basic CoMFA is based only on nonspecific steric and electrostatic interactions with a probe atom using default settings including the grid spacing and types of fields used for calculating the CoMFA. These settings may be altered and other explanatory factors may be added to the analysis (such as hydrogen bonds, dipole moments etc.).

As stated earlier, energy minimization routines find local rather than global minima; simulated annealing in which the program performs virtual heating and cooling of the molecules can be used to find global minima.

EXPERIENCES IN APPLYING THE METHOD TO cAMP DEPENDENT PROTEIN KINASE

cAMP-dependent protein kinase is a tetrameric enzyme, R_2C_2, composed of two regulatory (R) and two catalytic (C) subunits. Binding four molecules of cAMP causes dissociation of the catalytic subunits which then become active. Two major regulatory subunit isoforms are known (RIα and RIIα) and each has two cAMP binding sites (A and B) that have distinct analog specificities and kinetic properties; relative inhibition constants for a large number of analogs have been measured (1). The X-ray crystal structure of the type Iα R subunit has been determined (2).

Relative inhibition constants for approximately ninety analogs from Ogreid et al. (1) for the A and B binding sites of both type I and II regulatory subunits were used for our first study. With the availability of the X-ray structure of the type I subunit, further analyses were performed with the analogs minimized in the AI and BI binding sites. We obtained much better results for the type AI and AII sites than for the BI and BII sites and also found that removing two analogs [cXMP and 8-aza(OH)cAMP] dramatically improved our results (3).

Since elimination of cXMP and 8-aza(OH)cAMP from our analyses dramatically improved our results, we examined these analogs more closely (4). cXMP was found to have a preferred conformation in which there is a hydrogen bond between the protonated N3 of the purine and the 4'O of the ribosyl ring; this conformation does not fit in the binding sites of cAMP dependent protein kinase. Finding the preferred conformation for 8-aza(OH)cAMP required use of simulated annealing; this analog prefers the *anti* rather than the *syn* conformation required for binding.

As the poor predictions for 8-aza(OH) cAMP and for cXMP were the result of their preferred conformations, we decided to perform simulated annealings to investigate the effect of preferred conformation on binding of all the analogs in our database. Results from simulated annealing were used to calculate the percentage of *syn* conformers based on Boltzman distributions for each analog to use as an additional explanatory factor for predictions of binding constants (5). For the A site of the RI type subunit the percent *syn* did not improve predictions but did improve predictions for the B site. Since the allowed torsion angle between the ribosyl ring and the purine ring is more restricted in the B site than in the A site, this difference seems reasonable. Additional improvement was also found for the B site using the energy difference between the lowest energy conformation and the energy at the preferred torsion angle for the binding site.

SUMMARY/CONCLUSIONS

There are a number of other variations and refinements one can attempt. We have tried additional explanatory factors (such as dipole moments) and variations of molecular geometries without significant improvement of our results. Other variations which we plan to study include using pK_a's as an additional explanatory factor, calculating atomic charges by different methods and working with subsets of the database to focus on factors affecting particular substituent sites.

At this point it is reasonable to say that molecular modeling has provided insights which would not have been possible by other means. With further study we hope to better understand why B site binding is more difficult to predict well that is A site binding. This should help us understand the critical factors involved in both kinds of sites and for the difference in specificity between cAMP and cGMP dependent protein kinases. Eventually we hope to be able to make suggestions for possible highly specific activators of both kinds of protein kinases.

Many papers and books are available which review in detail the theory and practice of QSAR/CoMFA; reviews used in preparing this presentation include those of Martin (6) and of Norinder (7).

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USING BROWNIAN DYNAMICS TO PREDICT INTERACTIONS BETWEEN LARGE BIOLOGICAL MOLECULES

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Brownian dynamics (BD) is a trajectory method developed to simulate the Brownian motion of whole macromolecules under the influence of the complicated electrostatic and excluded volume interactions present in biophysical systems. The BD method is well suited to the study of interacting biomolecules such as proteins and DNA. BD is useful for studying the kinetics and energetics of rigid-body bimolecular associations in complicated and realistic electrostatic fields. It is also proving useful in identifying possible binding modes between proteins or proteins with DNA. The details of the BD method are described and a few examples are provided.

WHAT IS BROWNIAN DYNAMICS?

The BD method simulates the random walk diffusion of biomolecules steered by electrostatic forces [1]. Brownian motion of two irregularly shaped interacting macromolecules is represented by a series of small displacements chosen from a distribution which is equivalent to the solution of the diffusion equation with forces [1]. The method has been developed [2] and successfully applied as an alternative to conventional molecular dynamics or simple analytical diffusion theories to study the dynamics and interactions between two biomolecules [1, 3-8]. The method described includes detailed molecular shapes and has been assembled into a software package, MacroDox [3]. MacroDox has been used successfully for a variety of different systems including cytochrome c/cytochrome b_5, λ Cro repressor/DNA, and F-actin/aldolase.

The Algorithm

The Brownian motion of two interacting biomolecules in a solvent is simulated by a series of small displacements governed by the diffusion equation with forces using the Ermak and McCammon algorithm [9].

$$\mathbf{r}(t + \Delta t) = \mathbf{r}(t) + \frac{\Delta t D \mathbf{F}}{kT} + \mathbf{S} \qquad (1)$$

Where $\mathbf{r}(t+\Delta t)$ is the new position vector; $\mathbf{r}(t)$ is the old position vector; D is the spatially isotropic translational diffusion coefficient for relative motions; $\mathbf{F}$ is the systematic interparticle (electrostatic) force; k is the Boltzmann constant, and $\mathbf{S}$ is the stochastic component of the displacements arising from collisions of particles with solvent molecules and is generated by taking normally distributed random numbers obeying the average relationship $\langle S^2 \rangle = 2D\Delta t$ [8]. A similar equation governs the independent rotational Brownian motion of each particle, where force is replaced by torque and D is replaced by an isotropic rotational diffusion coefficient for each biomolecule [8].

For the reaction between two biomolecules, one of a reacting pair is designated the target. All motion is monitored in the reference frame chosen to rotate and translate along with the target. Thus, while rotations and translations of both biomolecules occur, rotation of the target appears as translations of the other biomolecule in the reference frame of the target [9]. Excluded-volume interactions between biomolecules are handled by storing a cubic spatial exclusion grid about the target to define its excluded volume [9]. All surface atoms of the nontarget molecule are tested against this grid after each Brownian step to check for atomic overlaps; steps which violate the exclusion grid are rejected, and a new step is taken from the old position vector [9].

Types of Information Needed to Run Simulations

To perform BD simulations, good three dimensional structures of the molecules are required. They are needed to model the detailed three dimensional shape of the molecules and for the assignments of charges to the titratable sites on the molecules. Typically, crystallographic coordinates of high resolution structures are used. Structures created from high field NMR or carefully built molecular models are also appropriate. The examples discussed in this paper include the use of crystallographic structures from the Protein Data Bank [10] and molecular models. The first step in preparing structures for BD simulations is to assign charges to each biomolecule's titratable sites. The protonation state of each titratable residue is assigned on the basis of molecular environment, pH, ionic strength and temperature; the protonation state can be estimated by performing a Tanford-Kirkwood (TK) calculation with the static-accessibility modification [11]. This method provides a quick way to estimate the net charge of each biomolecule as a function of pH, ionic strength and temperature.

How Electrostatic Fields are Determined

The nonrandom forces applied in BD simulations are electrostatic. A reasonable accurate and straightforward method for computing the electrostatic field surrounding biomolecules in aqueous electrolyte media is the numerical solution of the

Poisson-Boltzmann (PB) equation on a cubic lattice, particularly in its fully nonlinearized form. The PB technique is able to account for the detailed shape of dielectric boundaries separating biomolecule interior from bulk aqueous electrolyte media [12].

Proteins. For proteins, which do not have a high charge density at the surface, numerically solving the linearized PB (LPB) equation on a cubic lattice by the Warwicker and Watson [13] method as adapted by Klapper et al. [14] is sufficient. The electrostatic field around a protein (the target) is determined. Then the potential of interaction with an incoming diffusing protein (the nontarget) is computed by placing the rigidly rotating array of charges on the nontarget into the field of the target as a series of test charges imbedded in the high dielectric medium of water. The electrostatic potential field surrounding each isolated biomolecule is computed, each represented as an irregularly shaped cavity of low dielectric constant (ε=4) and zero internal ionic strength and having fixed imbedded charges in the crystallographic configuration [8]. Surrounding the protein cavity is a continuum dielectric with ε=78.3 for water at 298.15K [8]. The direct force between the two molecules and the torque operating on the nontarget molecule was determined at each time-step by placing the test charges of the nontarget molecule into the field around the target molecule cavity and, consulting the stored grid of forces, performing a summation over all nontarget molecule charges [9]. This procedure allows for treatment of rotation of the nontarget molecule in a field of torque generated by the target molecule [9]. The rotation of the target molecule in the field of the nontarget is included by consulting the inner and outer force lattices around the nontarget [9]. These lattices rotate in rigid-body rotation with the nontarget. A dipolar pair of charges is included on the target to serve as test charges, which interact with the field around the nontarget, and are used to compute the approximate torque on the target in the field of the nontarget [9]. This feature of two rotating molecules is essential in treating molecule pairs which are comparably sized [9].

DNA. To obtain the best accuracy of the electrostatic field molecules that have high charge densities (e.g., DNA) it is important to solve the full nonlinear PB equation (FPB). The FPB can be solved within MacroDox by first solving the LPB equation to create a test solution and then solving the FPB equation by combining a variety of techniques to gain convergence. First, iteration of the FPB can become numerically unstable if the step from one iteration to the next is too great; the instability causes the potential values oscillate or diverge to infinity. Stability can be recovered by underrelaxation; this means that each change in the potential is multiplied by a number between zero and one which is called the underrelaxation parameter; it is typically between 0.5 and 0.8 [12]. In MacroDox the underrelaxation parameter is dynamic, and the program reduces its size when it senses the onset of divergence. Second, electrostatic focusing may be used to achieve convergence. Focusing involves solving the FPB on successively smaller grids until the desired resolution is reached. For example, four separate grids were used to solve the FPB for a 103 Å piece of DNA at 1.69 Å resolution. Third, a scaling factor may be applied that phases in the FPB equation slowly by tenths; the algorithm multiplies the FPB equation by the scaling factor so that after solving the LPB, a solution is obtained using the FPB multiplied by 0.1; then a new solution is found by multiplying the FPB by the previous factor plus 0.1 until 1.0 is reached and the entire FPB is solved.

WHAT KIND OF INFORMATION CAN BE OBTAINED BY BD SIMULATIONS?

Kinetics

Traditionally, BD is used to determine bimolecular rate constants. There is considerable literature on the connection of BD trajectories to kinetics. Examples with MacroDox can be found in the references [8-9]. At UND, however, I have been exploring what other kinds of information can be obtained from BD, and these are described in sections B and C below.

Bimolecular Complexes

BD simulations of interacting biomolecules provide insights into which amino acids are important for complex formation by applying simulations that are unbiased to particular residues. For example, when experimental evidence provides a list of possible interacting residues, BD can determine if all residues suggested by experiments interact simultaneously or if only a subset interact. BD can identify residues that have not yet been identified experimentally. This is particularly useful when little experimental work has been done so that BD can assist in choosing site-directed mutagenesis experiments. BD simulations may also provide a general orientation for the interacting proteins. BD can be used as a powerful tool to generate a Boltzmann population of biomolecular conformational states.

Free Energy of Interaction and Association

Single long trajectories of interacting biomolecules provide information about the lifetime of the association between them and about the free energy curve of docking. The docking coordinate R_c can be defined as the distance between the molecules monitored specifically by choosing atoms that are known to interact or nonspecifically by choosing the center of masses or a helix axis for a helical molecule; it can be monitored throughout simulations of many steps (at least 10^7). A histogram $\rho(R_c)$ of residence times of R_c in radial concentric bins of 1 Å thickness can be tallied and converted into a potential mean force $A(R_c)$ in the R_c dimension by the statistical mechanical formula:

$$A(R_c) = -k_B T \ln(\rho(R_c)) + C \quad (4)$$

The constant C is chosen to define $A(R_c >$ some distance$) = 0$. The distance chosen to define the zero point is arbitrary, but a point beyond where the electrostatic potential of the target molecule has died out is often a good choice; for example, for Cro/DNA interactions and R_c>50 Å is appropriate. The potential of mean force essentially defines the effective radial free energy of bimolecular association, including Boltzmann statistical averaging over all orientational degrees of freedom. A parallel simulation can also be performed with zero electrostatic forces to determine the purely steric (entropic) contribution to the free energy of docking.

Using the radial free energy profile for docking obtained through BD, the mean time of association can estimated. This association-dissociation process is visualized as the one-dimensional diffusion of the protein in the radial direction toward and away from the target on the potential surface embodied in the radial potential of mean force. The mean first passage time, τ, for a particle to escape from a well is given by Szabo, Schulten, and Schulten [15].

$$\tau = \int_a^R dR_c \left[D(R_c)P_{eq}(R_c)\right]^{-1}\left[\int_{R_c}^R dy P_{eq}(y)\right]^2 \quad (5)$$

where:

$$P_{eq}(r) = \left\{\int_a^R dy\, y^{d-1} e^{-\beta A(y)}\right\}^{-1} r^{d-1} e^{-\beta A(r)} \quad (6)$$

Here $P_{eq}(R_c)$ is the equilibrium distribution in the radial coordinate R_c of complexed particles; d is the dimensionality of the diffusion, $A(R_c)$ is the potential of mean force calculated in the simulation, $D(R_c)$ is the effective diffusion constant along the radial coordinate (taken to be spatially uniform), and $\beta=(k_BT)^{-1}$. The escape distance, a, may be set to the distance at which the potential energy returns to zero. The position of the inner reflecting wall, R, will be determined by the simulation from the simulated distance of closest approach. The position of the deepest part of the well, R_{cm}, is also determined by the simulation.

SPECIFIC EXAMPLES

Cytochrome c - Cytochrome b_5

BD simulations between cytochrome c and cytochrome b_5 identified two classes of complexes. Several complexes were energy minimized several to observe more specific interactions such as hydrogen bonds. Energy miminizations were performed using 1000 steps of Adopted Basis Newton Raphson with CHARMM 22.2 (MSI, San Diego, CA) and applying distance constraints to retain the heme intact in the protein. The minimizations yielded slightly more intimate complexes (see Table 1) and indicated possible hydrogen bonds.

Using the structure of the identified complexes, the pH-dependent changes in proton binding that accompany complex formation were simulated. The pH-dependent changes in proton binding were determined by titration calculations of two different methods: (1) the TK method with the static-accessibility modification as implemented in MacroDox and (2) the single site (SS) ionization model that yields approximate charges by computing the free energy of a single highly occupied ionization state [16] available in UHBD [17]. The protonation state of each titratable site on the proteins was determined based on the protein environment, pH, ionic strength, and temperature. This provided the means to determine the net charge for the proteins. Proton uptake was determined based on the difference between the net charges of the isolated proteins and the net charge of the complex. Results agreed qualitatively with experiment showing proton release

Table 1. Close Contacts Between Loose BD Predicted Class I Complexes of Cytochrome b_5 and Cytochrome c. Cytochrome b_5 is listed first in every case.

interacting residues	atom names	unminimized distance (Å)	minimized distance (Å)
Salt Bridges			
Glu48 - Arg13	OE2 - NH1	2.49	3.26
Glu56 - Lys87	OE2 - NZ	7.03	5.06
Asp60 - Lys86	OD1 - NZ	5.26	3.13
Heme - Tml*72	O1D - NZ	4.14	4.29
Hydrogen Bonds			
Asn57 - Gly 84	HD22 - O	4.73	2.16
Asp60 - Asn70	O - HD22	3.18	2.19
Asp60 - Asn70	OD1 - HD21	4.91	2.30

*Tml is trimethyl lysine.

at acidic pH's and proton uptake at basic pH's. The TK method gave predictions that consistently underestimated release; whereas, the single site titration method consistently overestimated release (Figure 1). Repeating the proton uptake calculations for the minimized complexes improved the results predicted by the SS method significantly, but only slightly improved the results predicted by the TK method (Figure 1). The calculations using either method that most resemble experimental results are the predictions for the class I complex in the pH range of 7.5 to 8.5 (Figure 1). In this pH range, the TK method gave the best quantitative agreement with experiment (Figure 1).

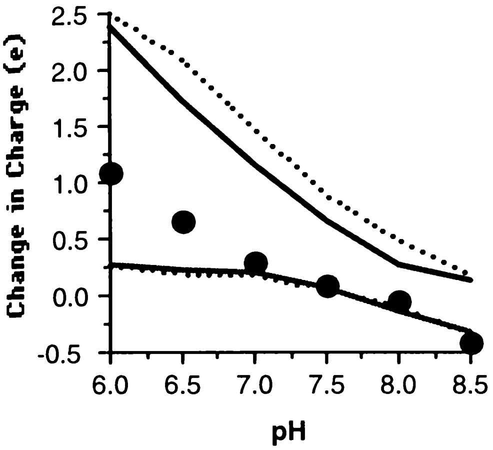

Figure 1. Predicted Proton Uptake for Class I Complexes of Cytochrome c and Cytochrome b_5 The curves below the filled circles used the TK method with the static accessibility modification. The curves above the filled circles used the single site titration method. The experimental results (filled circles) were measured by Mauk et al. [18]. Dashed curves are for unminimized complexes and solid curves are for minimized complexes.

Cro-DNA Interactions

BD has been employed to study the energetics of nonspecific binding of λ Cro repressor protein (Cro) to model B-DNA. The UND BD research team has completed the first implementation of BD to simulate protein-DNA interactions at a rigorous atomic level for an ionic strength of 0.10 M at pH = 7.0. BD simulates the diffusional collision, sliding, and hopping as the Cro repressor protein encounters the DNA surface and describes: (i) the steric effects of encounter between the irregular surfaces of the protein and DNA molecules based on crystallographic coordinates, and (ii) the electrostatic effects based on a finite difference numerical solution of the PB equation. Using BD as a means of generating a statistical ensemble of docked complexes in a Boltzmann distribution, a direct calculation of the free energy and entropy of the encounter is performed as a function of the radial distance from the DNA helix axis to the protein center. During the simulation electrostatic energies of protein interaction with DNA are taken from prior solutions of the PB equation stored on a cubic lattice. Using the FPB with periodic boundary conditions (FPBBC) for electrostatics, a free energy well-depth of -4.1 ± 0.1 kcal/mol was obtained. The LPB method yielded a well-depth of -7.6 ± 0.7 kcal/mol. Using the free energy profile of nonspecific docking predicted with FPBBC electrostatics and assuming free one-dimensional lateral diffusion (sliding) of docked pairs, the lifetime of a nonspecifically docked state was estimated to be 1 μs. The protein should be able to slide laterally approximately 46 base pairs before becoming detached.

Figure 2 shows the free energy profile of Cro interacting with B-DNA along the radial coordinate when the full PB equation with periodic boundary conditions were used. The significance of this curve is that it is Boltzmann-averaged over all mutual orientations of the protein and DNA at a range of distances. This provides novel quantitative information on the effective energy well experienced in the nonspecific binding between protein and DNA at the whole range of separations. The maximum stabilization of the Cro-DNA complex is -4.2 ± 0.1 kcal/mol occurring around R_c = 23-24 Å, which is about 4 Å larger than the closest distance in our rigid docking model. The electrostatic portion of the free energy alone gives an orientationally-averaged free energy of stabilization around -6.2 ± 0.2 kcal/mol for the free energy minimum, but this is offset by an entropy term amounting to -TS = 2 ± 0.1 kcal/

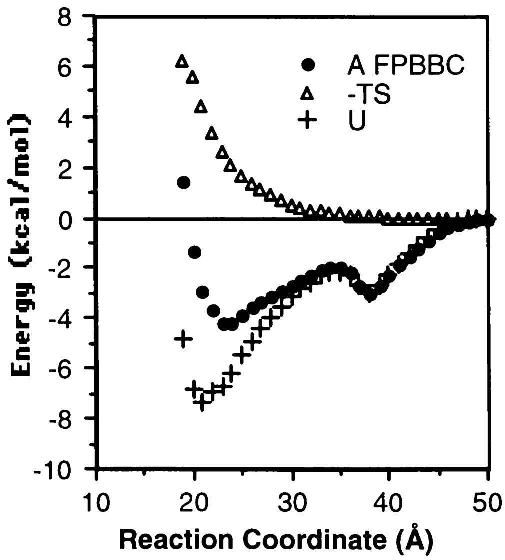

Figure 2: Free energy profile of Cro interacting with nonoperator B-DNA along the radial coordinate (Æ). Also shown are orientationally averaged electrostatic energy, U (+) and -TS, the entropic (_) component.

mol. The entropic term begins to contribute at about 33 Å separation, where the top and bottom ends of the dimer can begin to collide with the DNA along perpendicular orientations. Inside this distance the number of sterically allowed orientations becomes increasingly diminished. An interesting feature is the local minimum of -3 kcal/mol appearing in the free energy profile at separation R_c = 38 Å. This arises from a set of complexes in which the ends of the protein dimer collide with DNA in a perpendicular fashion. Although far from the most intimate arrangement, these complexes still contribute to and expand the overall region of stability of the nonspecific encounter complex. Such contributions would not appear in calculations that do not allow for a sampling of different orientations.

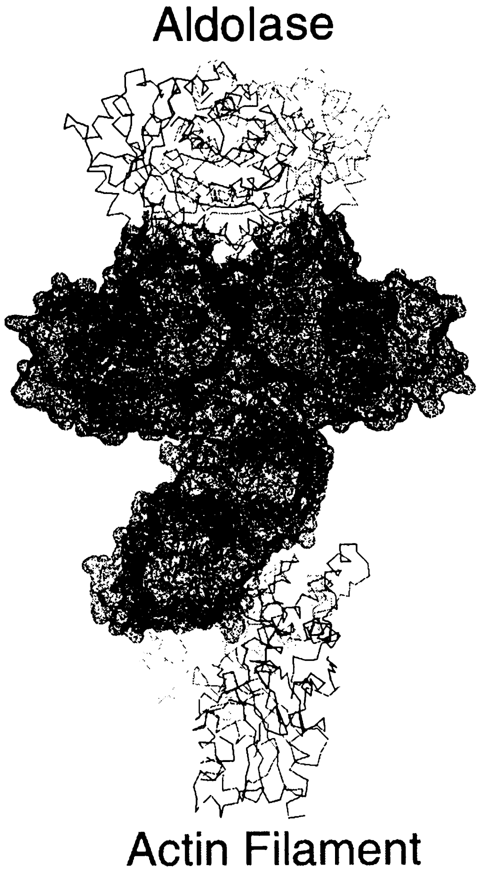

Figure 3: Connolly Surface of the Most Common Complex of F-actin with Aldolase. The Connolly surface rendering includes (left to right) subunit B and C of aldolase and immediately under the aldolase, one subunit of F-actin. The wire rendering include subunits A and D of aldolase (top) and the rest of the actin filament (bottom). F-actin is oriented so that the view is directly down the actin helix. Please note, the picture for the most common complexes of aldolase with G-actin show the same geometry.

Actin-Aldolase Interactions

Compart-mentation of proteins in cells is important to proper cell function. Interactions of F-actin and glycolytic enzymes is one mechanism by which glycolytic enzymes can compartment. BD simulation of the binding of the muscle form of the glycolytic enzyme fructose-1,6-bisphosphate aldolase (aldolase) to F- or G-actin provide first-encounter snapshots of these interactions. Using X-ray structures of aldolase, G-actin, and 3D models of F-actin, the electrostatic potential about each protein was predicted by solving the linearized Poisson-Boltzmann equation for use in BD simulations. The BD simulations provided solution complexes of aldolase with F- or G-actin. All complexes demonstrate the close contacts between oppositely charged regions of the protein surfaces. Positively charged surface regions of aldolase (residues Lys 13, 27, 288, 293, 341, Arg 257) are attracted to the negatively charged N-terminus (Asp 1 and Glu 2, 4) and other patches (Asp 24, 25, 363 and Glu 361, 364, 99, 100) of actin subunits. The electrostatic interaction energy obtained for the most stable complex with aldolase was -13.6 kcal/mol for G-actin and -15.0 for F-actin. The overall structure of the most intimate F-actin and aldolase complex was identical to the most common complex between G-actin and aldolase. Figure 3 demonstrates the most common and intimate complex. The only difference is the value of the electrostatic energy between the proteins; the electrostatic energy was lower for aldolase/F-actin interactions because aldolase experiences not only the EP of the particular actin subunit to which it is bound, but also the EP of neighboring actin subunits. For a majority of the predicted complexes, the binding of tetrameric aldolase to G- or F-actin involves close interactions of residues from two aldolase subunits with one actin monomer. According to BD results, the most important factor for aldolase binding to actin is the quaternary structure of aldolase and actin. Two pairs of adjacent aldolase subunits greatly add to the positive electrostatic potential of each other creating a region of attraction for the negatively charged subdomain 1 of the actin subunit that is exposed to solvent in the quaternary F-actin structure.

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IONIC STRENGTH DEPENDENCE OF THE FREE ENERGY OF NONSPECIFIC ASSOCIATION OF CRO REPRESSOR PROTEIN WITH B-DNA PREDICTED BY BROWNIAN DYNAMICS

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The Brownian dynamics (BD) simulation method has been employed to study the energetics of nonspecific binding of λ Cro repressor protein (Cro) to model B-DNA, the native form of DNA discovered by Watson and Crick, as a function of ionic strength. BD simulates the diffusional dynamics as Cro encounters the DNA surface including the steric effects of encounter between the irregular surfaces of the protein and DNA and the electrostatic effects based on a finite difference numerical solution of the Poisson-Boltzmann (PB) equation [1]. The free energy of a Cro-DNA encounter is determined by computing the potential of mean force versus the radial distance from the protein center to the DNA helix axis. The PB equation is solved by two approximations: the linearized form (LPB) and the full PB form (FPB); periodic boundary conditions are implemented for both solutions. The effect of the solution of the PB equation on the predicted free energy curve shows that both methods give qualitatively similar results, but statistically the best results are achieved using the full PB. Both methods show that the depth of the free energy curve dramatically decreases as ionic strength increases from 0.01M to 0.50M. For example, the full PB gives depths of the free energy curves at –7.9±0.1 and –0.34±0.06 kcal/mol for ionic strengths of 0.01 and 0.50M respectively (Figure 1). The linearized PB under the same conditions produces depths of the free energy curves at –7.6±0.3 and –0.91±0.07 kcal/mol respectively. The lifetime of a nonspecifically docked state is estimated from the free energy profile created by BD. The lifetimes of a nonspecifically docked state depend on the ionic strength and are approximately 800 and 0.04 μsec for ionic strength of 0.01 and 0.50 M respectively.

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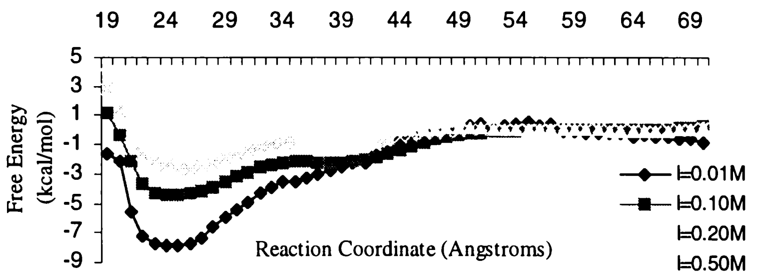
Figure 1. Free energy profiles of Cro interation with DNA as a function of a reaction coordinate using FPB electrostatics



BROWNIAN DYNAMICS SIMULATIONS OF RABBIT MUSCLE ALDOLASE BINDING RABBIT MUSCLE ACTIN, ACTIN MUTANTS AND YEAST ACTIN

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[1]Chemistry Department and [2]Department of Biochemistry and Molecular Biology,
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INTRODUCTION

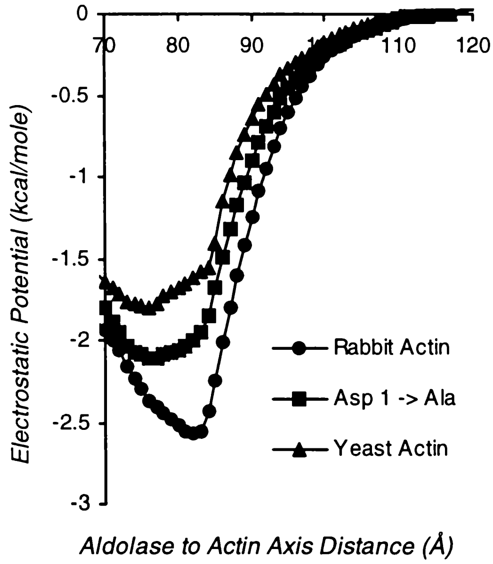
Actin microfilaments or F-actin (a polymer of G-actin) may play an important role in cellular metabolism by providing the conditions for high specificity of reactions of various metabolic pathways. Experimentally, many glycolytic enzymes bind cytoskeletal proteins reversibly; these include the muscle form of fructose 1,6-bisphosphate aldolase (aldolase). These binding processes have been extensively studied providing considerable physico-chemical information regarding the interaction of glycolytic enzymes with G- and F-actin in wild type and mutated forms. Previously, we have studied the binding mode of rabbit muscle aldolase to rabbit muscle F-actin (1). We have shown that the positively charged grooves between subunits A/D or B/C of aldolase bind to subdomain 1 of the actin monomer (1). The actin residues most frequently involved in complex formation with aldolase are from N-terminus of actin. These negatively charged residues present the source of strong attraction for positive grooves between aldolase subunits. In this work, the binding of rabbit muscle actin mutants and yeast actin to rabbit muscle aldolase are compared.

METHODS

The method of Brownian Dynamics (BD) has been applied to study the binding of aldolase to F-actin. The X-ray structure of rabbit muscle aldolase, a tetrameric structure (subunits labeled A, B, C, and D as they appeared in crystallographic coordinate file) was graciously provided by Nick Blom (2). The model of F-actin has been built based on the X-ray structure of globular actin (entry 1ATN) and model of actin filaments proposed by Holmes et al. (3). BD simulations determine the potential of mean force and average electrostatic potential of aldolase in actin electric field as a function of the distance from the aldolase center of mass to the F-actin filament axis. Free energy of binding can be estimated from average electrostatic potential. We have performed such calculations for rabbit muscle actin, rabbit muscle actin mutants (amino acid residues #1-4 of actin monomer mutated to Ala one by one and in pairs) and yeast actin. Calculations have been performed at a temperature 298 K, pH=7.0 and solution ionic strength I= 0.05M.

RESULTS

The binding energy of aldolase to rabbit muscle actin filaments determined from BD calculations is -2.6 ± 0.1 kcal/mole. Single mutations of one of first four actin residues increased the binding energy within range -2.1 to -2.3 kcal/mole; thus, the binding of aldolase to F-actin became weaker with mutation. The mutation of the first three residues caused a greater increase in the free energy of binding than did mutation of Glu 4 -> Ala. Double mutations of any pair from first four residues increases the free energy of binding by an additional 0.4 kcal/mole. The free energy of binding aldolase to yeast actin is -1.8 ± 0.1 kcal/mole. Although primary structures of yeast and rabbit muscle actin differ in more than 50 amino acids, aldolase binds yeast actin with the same affinity as mutants of rabbit actin where two of residues from N-terminus are mutated. Thus, the



dissociation constant of an aldolase/yeast actin complex should be 4 times larger than the dissociation constant of an aldolase/rabbit actin complex. This conclusion agrees with experimental data on the binding of different glycolytic enzymes to yeast and rabbit muscle actin (4).

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Symposium Agenda

THE PALEONTOLOGIC AND GEOLOGIC RECORD OF NORTH DAKOTA - IMPORTANT SITES AND CURRENT INTERPRETATIONS

April 16, 1999 (Friday)

Location - Geology Lecture Bowl (Leonard Hall)

Moderator - F.D. Holland, Jr., Professor Emeritus, University of North Dakota, Department of Geology and Geological Engineering

Convenor and Editor - Joseph H. Hartman, Energy & Environmental Research Center

Morning Session Presentations

Introduction

8:30 a.m. Joseph H. Hartman - Energy & Environmental Research Center, University of North Dakota
Paleontology in North Dakota and Its Value in Science Education

Geology of North Dakota

8:50 a.m. Clarence G. Carlson - North Dakota Industrial Commission, Oil and Gas Division
Bedrock Highlights of North Dakota

Pierre Formation

9:10 a.m. John W. Hoganson - North Dakota Geological Survey
Plioplatecarpus *(Reptilia, Mosasauridae) and Associated Vertebrate and Invertebrate Fossils from the Pierre Shale (Campanian), Cooperstown Site, Griggs County, North Dakota*

Fox Hills Formation

9:30 a.m. J. Mark Erickson - St. Lawrence University
The Dakota Isthmus - Closing the Late Cretaceous Western Interior Seaway

Hell Creek Formation Dinosaurs

9:50 a.m. Dean A. Pearson - Pioneer Trails Regional Museum
Partnerships for Productivity - Collaborative Efforts Among Amateurs and Academia

10:10 a.m. Mid-Morning Break

The K/T boundary and Plants in North Dakota

10:30 a.m. Kirk R. Johnson - Denver Museum of Natural History
Plants and the K/T Boundary - Fossil Evidence for Ecosystem Devastation and Recovery

The K/T Impact and the Radiation of Mammals

10:50 a.m. John P. Hunter - New York College of Osteopathic Medicine
The Radiation of Paleocene Mammals with the Demise of the Dinosaurs - Evidence from Southwestern North Dakota

Ludlow–Cannonball Formations

11:10 a.m. Timothy J. Kroeger - Bemidji State University
The Seas Came in and the Seas Went Out - The Use of Fossil Pollen, Spores, and Algal Bodies to Recognize Ancient Shoreline Environments in the Ludlow and Cannonball Formations (Paleocene) of Western North Dakota

Tongue River–Sentinel Butte–Golden Valley Formations

11:30 a.m. Allen J. Kihm - Minot State University
Resolving the Age Relations of North Dakota Paleocene and Eocene Strata Using Fossil Mammals

Break for Lunch (North Dakota Academy of Science Luncheon)

11:50 a.m. Morning adjournment by Moderator

Symposium Agenda, continued

THE PALEONTOLOGIC AND GEOLOGIC RECORD OF NORTH DAKOTA - IMPORTANT SITES AND CURRENT INTERPRETATIONS

April 16, 1999 (Friday)

Location - Geology Lecture Bowl (Leonard Hall)

Moderator - F.D. Holland, Jr., Professor Emeritus, University of North Dakota, Department of Geology and Geological Engineering
Convenor and Editor - Joseph H. Hartman, Energy & Environmental Research Center

Afternoon Session Presentations

Introduction
1:20 p.m. Purpose and format of afternoon symposium
Tongue River–Sentinel Butte Formations
1:30 p.m. Nels F. Forsman - University of North Dakota
Volcanism in North Dakota - The Sentinel Butte Tuff
North Dakota Sentinel Butte Volcanism
1:50 p.m. Joseph H. Hartman - Energy & Environmental Research Center, University of North Dakota
Western Exploration Along the Missouri River and the First Paleontological Studies in the Williston Basin, North Dakota and Montana
Interpreting Environments from Plants in North Dakota
2:10 p.m. Kirk R. Johnson - Denver Museum of Natural History
The Reconstruction of Ancient Landscapes - An Example from the Late Cretaceous of North Dakota
(see page 134)
2:30 p.m. Mid-Afternoon Break
North Dakota Coal Resources
3:00 p.m. Terry L. Rowland - Coteau Properties Company
What Is Solid, Black, and Worth $1.3 Billion to the North Dakota Economy?
North Dakota Oil and Gas and Horizontal Drilling
3:20 p.m. Kathy Neset - Neset Consulting Service
The Well Site Geologist's Role in Horizontal Drilling
Recent Climate Change in North Dakota
3:40 p.m. Allan C. Ashworth - North Dakota State University
Climate Change in North Dakota Since the Last Glaciation - Review of the Paleontological Record
Summary Statement and Discussion
4:00 p.m. Moderator

THE PALEONTOLOGIC AND GEOLOGIC RECORD OF NORTH DAKOTA - IMPORTANT SITES AND CURRENT INTERPRETATIONS, A SYMPOSIUM OVERVIEW AND GEOLOGIC FRAMEWORK

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The fossils and rocks found at surface exposures in North Dakota represent an important archive of biological and geological events that took place from around 95 million years ago to the present. Although the record is not complete through this interval of time, significant portions of the rock record represent a nearly continuous history and shed light on the movement of seas back and forth across North Dakota; the life present in these seas and adjacent estuaries, river systems, and terrestrial settings; and the drama of extinction of the dinosaurs and the adaptive radiation of mammals across the Cretaceous–Tertiary (K/T) boundary. These subjects are brought to life in this symposium by presentations given by researchers studying North Dakota fossils and rocks. Many aspects of the North Dakota geologic record are covered, as indicated by the speaker agenda.

Speakers are arranged more or less chronologically, so that the oldest fossils are discussed first, working upward to nearly present times. The bedrock geologic framework in Figure 1 illustrates this sequence. Ages and rock-unit nomenclature are displayed vertically by approximate (maximum) thicknesses. The estimated millions of years before present (Ma) are given in the left column at formation contacts or system boundaries. The stratigraphic nomenclature, formation thicknesses, approximate radiometric age (Ma), and chronostratigraphic information, including North American Land Mammal Ages (e.g., Puercan) are derived from various sources (1–9).

This symposium serves two related goals — to educate on matters of science and to inform specifically about the geological sciences. The membership of the North Dakota Academy of Science wishes to extend its annual meeting and other offerings to a greater public and student community. Although numerous opportunities to expand an individual's cultural context and well-being are seemingly readily available, interactions with scientists and scientific material remain somewhat less frequent for those in other fields, and scientific issues become even more mysterious as the discussion becomes more technical. By holding public-oriented symposia at Academy meetings, we hope to make the nature of science and its workings less mysterious and more enjoyable. This symposium concerning the paleontology and geology of North Dakota is meant to meet these goals by presenting current topical information in a manner that sheds light on how the information was derived. In so doing, we hope to ensure increased enthusiasm and understanding while doing away with some of the mystery of interpreting the ancient life and rock record of the Earth. As I wrote back in 1992 at an Academy symposium on *Fossils as a Resource in Research, Education, and Economics in North Dakota*, "the people of North Dakota have never been more interested in fossils. Most of this interest is associated with the rather phenomenal popularity of dinosaurs" (10). I believe this remains true and that one path to understanding scientific methods and topical subjects such as climate change is through the study of paleontology and geology.

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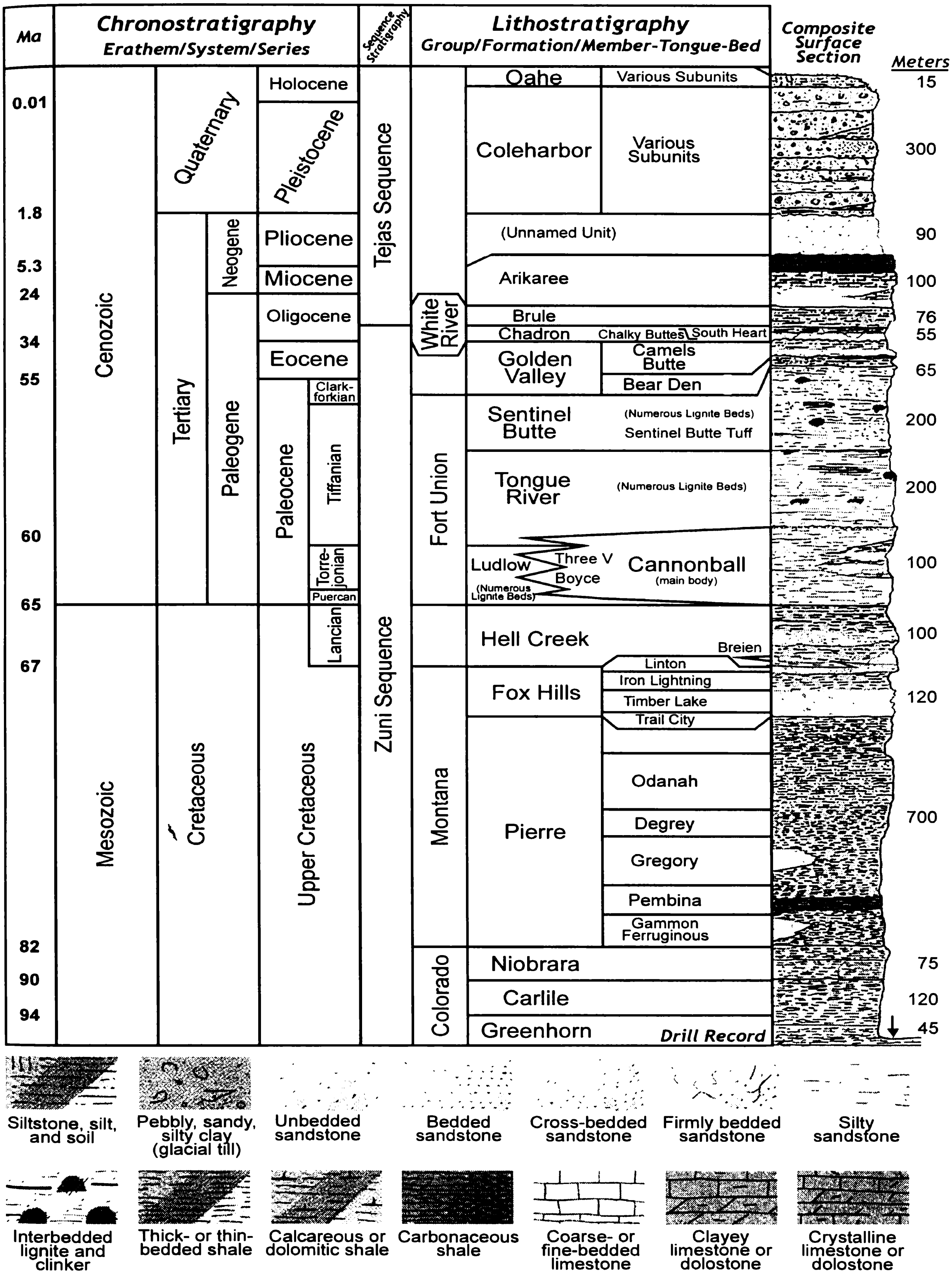

Figure 1. Geology of surface exposed rocks in North Dakota. This figure illustrates the general relationships between formations and the time they represent. The surface geologic section shown on the right gives a graphical representation of sediment types and ease of weathering (1) (see text for additional discussion).

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PLIOPLATECARPUS (REPTILIA, MOSASAURIDAE) AND ASSOCIATED VERTEBRATE AND INVERTEBRATE FOSSILS FROM THE PIERRE SHALE (CAMPANIAN), COOPERSTOWN SITE, GRIGGS COUNTY, NORTH DAKOTA

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INTRODUCTION

Few bedrock outcrops are found in eastern North Dakota because that portion of the state is covered with glacial drift. Exceptions are in areas where the drift is relatively thin and rivers have cut through the veneer of glacial deposits. In these settings, marine strata, primarily the Carlile, Niobrara, and Pierre Formations, deposited in the Western Interior Seaway during the Late Cretaceous, are exposed in isolated outcrops. One of these exposures is located 8.5 km southeast of Cooperstown, Griggs County, where erosion of the Sheyenne River has exposed a thick section of the Pierre Shale (Figure 1). The Cooperstown site encompasses an area of about 2 km^2 in a place referred to locally as "Indian Mounds." The name is derived from the haystack-shaped hills in the valley, which were thought to be Indian burial mounds. These hills, however, are erosional remnants of the once more extensive Pierre Shale. It is here that the most diverse assemblage of vertebrate and invertebrate fossils from the Pierre Shale in North Dakota is found.

Pierre Shale outcrops in eastern North Dakota are the furthest northeastern exposures of the Pierre Shale in the United States. They are, therefore, important because they provide a link between exposures of the formation in the type area of South Dakota and outcrops in Canada. The North Dakota Pierre Shale faunas provide biochronologic information about the formation and paleobiogeographic information about the eastern part of the Western Interior Seaway during the Campanian. Even though the eastern North Dakota Pierre Shale sites are important, few studies of the stratigraphy and even fewer studies of the paleontology of the Pierre Shale have been conducted in North Dakota.

The occurrence of the Pierre Shale in eastern North Dakota was first reported by Upham (1) in his monograph on Glacial Lake Agassiz. Early studies of the Pierre Shale in eastern North Dakota by North Dakota Geological Survey geologists primarily addressed the economic potential of the formation for the brick and cement industries (2–6). Kline (6) was first to suggest that at least a portion of the Pierre Shale in North Dakota is equivalent to the Gregory Member of the Pierre Shale as seen at the type area in South Dakota.

In the 1960s, the United States Geological Survey conducted several studies of the Pierre Shale. The most important of these studies in eastern North Dakota was by Gill and Cobban (7). They provided measured sections and described the stratigraphy, paleontology, and biochronology of the Pierre Shale in the Valley City and Pembina Mountain areas. They

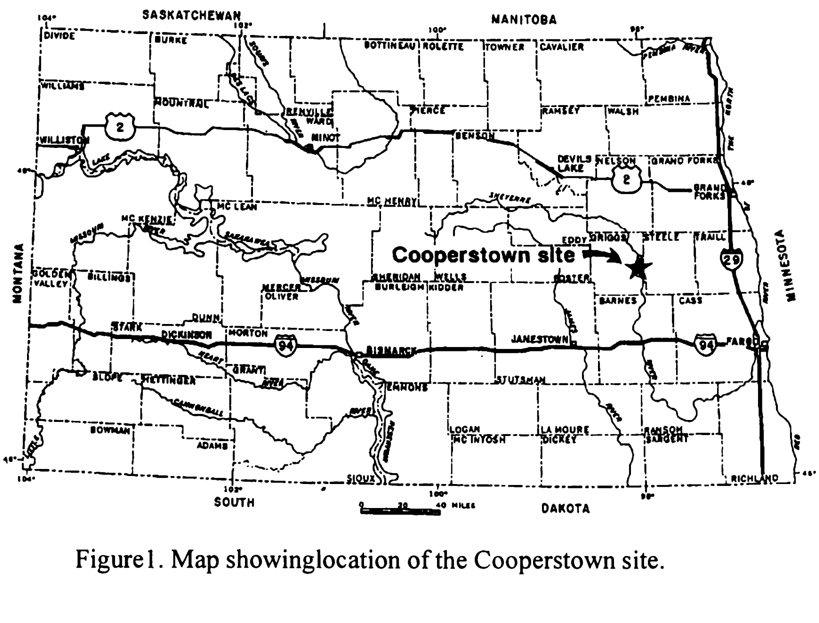

Figure1. Map showinglocation of the Cooperstown site.

applied the Manitoba names Pembina and Odanah Members to the oldest and youngest Pierre Shale units and the South Dakota names for the middle units of the formation, the Gregory and DeGrey Members. They also correlated these four members with the type Pierre Shale in south-central South Dakota.

METHODS

Standard geological and paleontological field techniques were employed during this study. Mosasaur and other vertebrate fossils in the DeGrey Member were found by prospecting during six years of field activity. Excavation of the *Plioplatecarpus* partial skeleton was accomplished using plaster jacket extraction techniques. Meter square grids were laid out at the *Plioplatecarpus* excavation site, and an excavation map was produced. Most invertebrate fossils from the Gregory Member were recovered by screen washing of matrix through window screen at the site. Small *Squalus* teeth and placoid scales were recovered from the matrix surrounding the *Plioplatecarpus* bones by screen washing matrix through 300-μm opening sieves.

STRATIGRAPHY

One of the thickest and best exposed sections of the Pierre Shale in eastern North Dakota occurs at the Cooperstown site where 40 m of the Pierre crops out (Figure 2). The lower 3 m of the section, measured from the level of the Sheyenne River, is the Gregory Member of the Pierre Shale. The Gregory Member consists of light brown to tan, calcareous claystone. Yellow-brown ironstone concretions occur in this member. A diverse assemblage of invertebrate fossils has been recovered from the Gregory. The Gregory Member is overlain by 37 m of the DeGrey Member of the Pierre Shale. The contact between the members is sharp and unconformable. The DeGrey Member is a light to dark gray noncalcareous shale. Thin layers, 1 to 15 cm thick, of very light gray bentonite occur throughout the DeGrey but are more common in the lower 7 m of the member. Black, iron-manganese carbonate and light gray, phosphatic concretions are common in the lower part of this member. These concretions are often fossiliferous, containing fragments of *Inoceramus*. The upper 18 m of the DeGrey is obscured by vegetation and thin glacial drift containing erratics. Mosasaur and remains of other marine vertebrates are found in the basal 6 m of this member.

PALEONTOLOGY

Gregory Member

A diverse assemblage of invertebrate fossils is found in the Gregory Member (8). The fossils are mostly steinkerns and are often replaced with limonite. Over 30 invertebrate taxa, including Cnidaria, Bryozoa, Brachiopoda, Bivalvia, Gastropoda, Cephalopoda, Annelida, Crustacea, Asteroidea, and Echinoidea have been identified (Table 1). Six ammonite taxa, particularly *Baculites gregoryensis*, provide useful biochronologic information. Foraminifera and ostracodes are common in the Gregory, but have not been examined for this study. Teeth of the sand-tiger shark, *Carcharias*, are rarely found with the invertebrate fossils. The Cooperstown site is the only place in North Dakota where most of these kinds of Pierre fossils have been found, although similar faunas have been reported from South Dakota and Wyoming (7, 9, 10).

DeGrey Member

Mosasaur remains and several taxa of marine fishes were recovered from the basal 6 m of the DeGrey Member (8, 11). The only invertebrate fossils that have been found in this part of the section are fragments of *Inoceramus*. Several shark taxa are represented by isolated teeth, including the sand-tiger shark, *Carcharias*; the extinct cow sharks, *Squalicorax* and *Pseudocorax*; and the dogfish shark, *Squalus* (Table 1). Teeth and vertebrae of bony fish, including the salmonlike *Enchodus*, are present. A tarso-metatarsal of the large hesperornithid bird, *Hesperornis*, was also found. The remains of twelve mosasaurs have been found in the lower part of the DeGrey from an area of about 0.5 km. Two kinds of mosasaurs, *Plioplatecarpus* and an unidentified mosasaurine, are present.

One collected *Plioplatecarpus* specimen is spectacular and consists of a partial skeleton including essentially the entire skull and lower jaws and a complete, articulated presacral vertebral column. Less than one half of the post-sacral vertebral column is present, and the rib cage is approximately one half complete. Right and left coracoids and scapulas are present, but most limb elements are missing. This *Plioplatecarpus* specimen represents a previously undescribed taxon based on its huge size (25% larger than any other known *Plioplatecarpus*), reduced vertebral count, and coracoid and skull characteristics. The specimen will be described in the near future. Scratch marks on some bones and the abundance of *Squalus* teeth and placoid scales associated with the skeleton suggest that the *Plioplatecarpus* carcass was scavenged by dogfish sharks. This skeleton is being prepared for permanent exhibit as a three-dimensional skeletal mount at the North Dakota Heritage Center in Bismarck. The restored skeleton will be 7 m long. The skull alone has a length of 1 m.

BIOCHRONOLOGY

The Gregory Member at the Cooperstown site was deposited during the time of deposition of the *Baculites gregoryensis* Western Interior Ammonite Zone as indicated by the abundance of fossils of that taxon found in the member at the site. This implies a late Campanian age for the member in eastern North Dakota, which is consistent with the age of the member as defined in its type area of south-central South Dakota. No biochronologically diagnostic fossils were

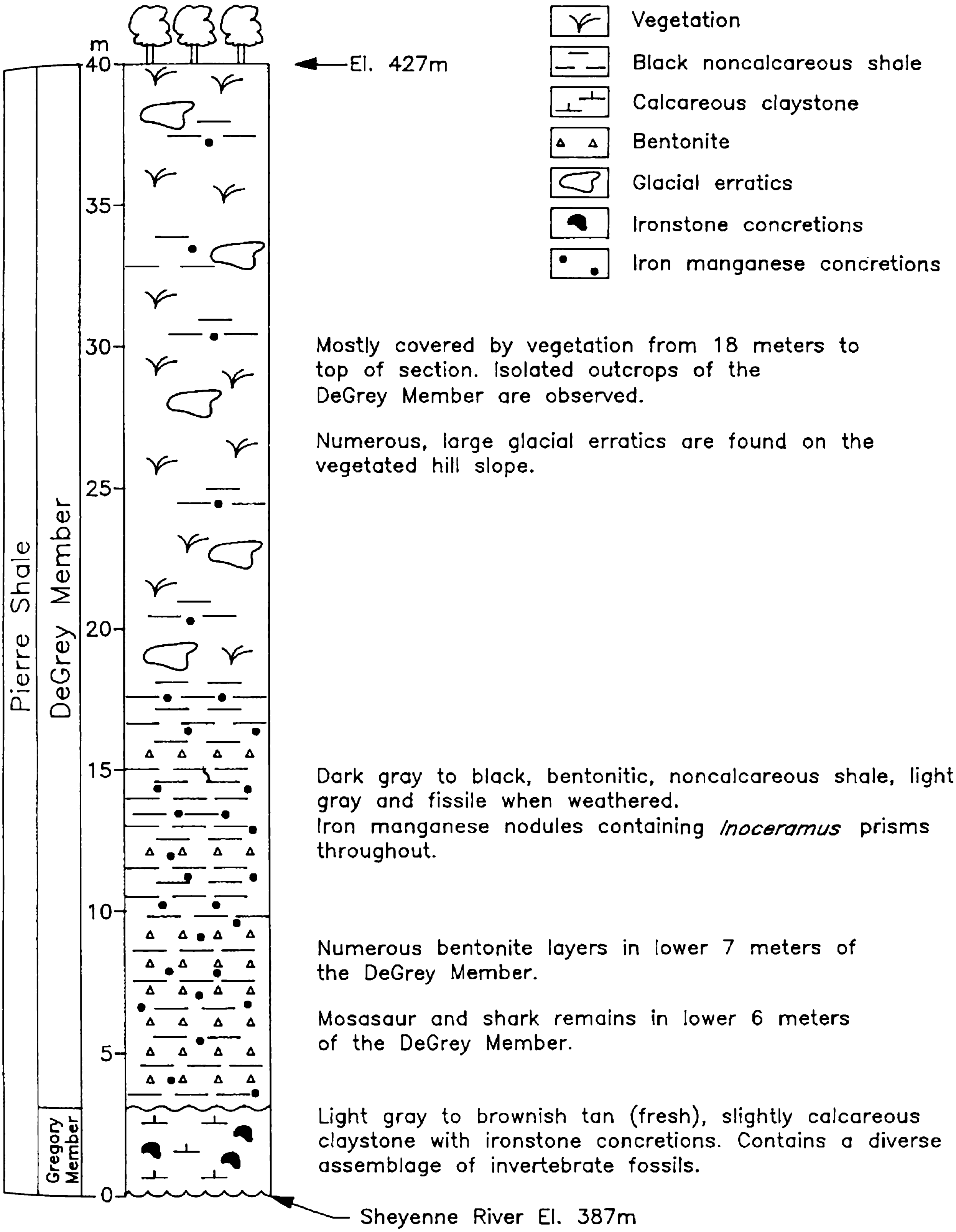

Figure 2. Measured geologic section at the Cooperstown site.

Table 1

List of taxa from the Pierre Shale Cooperstown site

*=collected from the Gregory Member. +=collected from the DeGrey Member.

Invertebrates

- Phylum Protozoa
  - Class Sarcodina
    - Foraminifera spp. indet.*
- Phylum Cnidaria
  - Class Anthozoa
    - *Micrabacia americana**
    - Anthozoa sp. indet.*
- Phylum Bryozoa
  - Bryozoa sp. indet.*
- Phylum Brachiopoda
  - Class Inarticulata
    - *Lingula subspatulata**
- Phylum Mollusca
  - Class Bivalvia
    - *Inoceramus* sp.+
    - *Nucula cancellata*?*
    - *Nuculana* sp.*
    - *Pteria* sp.*
    - ?*Nemodon* sp.*
    - Ostreidae sp. indet.*
    - Bivalvia spp. indet.*
  - Class Gastropoda
    - *Margaritella flexistriata**
    - *Trachytriton vinculum* *
    - *Atira* sp.*
    - *Oligoptycha* sp.*
    - *Graphidula*? sp.*
    - Trochidae sp. indet.*
    - Patellina sp. indet.*
    - Gastropoda spp. indet.*
  - Class Cephalopoda
    - *Baculites gregoryensis**
    - *Didymoceras cochleatum**
    - *Didymoceras* sp.*
    - *Solenoceras mortoni**
    - *Trachyscaphites* cf. *T. spiniger**

Invertebrates, continued

- Phylum Annelida
  - Annelida sp. indet.*
- Phylum Arthropoda
  - Class Crustacea
    - *Dakoticancer* sp.*
    - *Callianassa* sp.*
    - *Hoploparia* sp.*
    - Ostacoda spp. indet.*
- Phylum Enchinoderma
  - Class Asteroidea
    - Asteroidea sp. indet.*
  - Class Echinoidea
    - *Eurysalenia minima**

Vertebrates

- Phylum Chordata
  - Class Chondrichthyes
    - *Squalicorax pristodontus*+
    - *Cretolamna appendiculata*+
    - *Carcharias* sp.*+
    - *Pseudocorax* sp.+
    - *Squalus* sp.+
    - Pristiophoridae sp. indet.+
  - Class Osteichthyes
    - *Enchodus* sp.+
  - Class Reptilia
    - Order Chelonia
      - Chelonia sp. indet.+
    - Order Squamata
      - *Plioplatecarpus* n. sp.+
      - Mosasaurinae sp. indet.+
  - Class Aves
    - *Hesperornis regalis*+

recovered from the DeGrey Member at the Cooperstown site. Gill and Cobban (7) suggested that the DeGrey Member in eastern North Dakota was deposited during the late Campanian ammonite range zone of *Didymoceras nebrascensis*.

PALEOECOLOGY AND PALEOBIOGEOGRAPHY

Lithologic similarity, stratigraphic position, and faunal similarity indicate that the Gregory Member at the Cooperstown site is, at least in part, equivalent to the Gregory Member in south-central South Dakota and the Red Bird Silty Member of the Pierre Shale in eastern Wyoming. Gregory Member invertebrate taxa found at the Cooperstown site, such as the gastropod genera *Oligoptycha* and *Margaritella*, also occur in Campanian beds in the U.S. Gulf Coastal Plain. The presence of the brachiopod *Lingula*, the bivalves *Pteria* and oysters, gastropod genera, and other invertebrates in the Cooperstown Gregory Member fauna indicate deposition in shallow, probably subtropical, coastal waters.

The hiatus between the Gregory and DeGrey Members at the Cooperstown site may indicate subaerial exposure of the sea floor prior to deposition of the DeGrey, although additional study at the site is needed to confirm this. The DeGrey Member is lithologically and faunally similar to the DeGrey Member of the Pierre Shale in south-central South Dakota. The abundant, invertebrate shallow water indicators in the Gregory Member are not present in the DeGrey Member at the Cooperstown site. Water depths were probably deeper at the site during deposition of the DeGrey Member, although shallow, warm water conditions are indicated by the cartilaginous fish, mosasaur, and avian fauna. Water depths during deposition of the Gregory and DeGrey Members probably never exceeded about 60 m (9).

CONCLUSIONS

One of the thickest and best exposed sections of the Pierre Shale in eastern North Dakota is found at the Cooperstown site. At this site, the Gregory Member is overlain unconformably by the DeGrey Member. A diverse assemblage of invertebrate fossils is found in the Gregory Member at the site, indicating deposition during the late Campanian *Baculites gregoryensis* ammonite zone. The fauna indicates that the Pierre Sea was shallow and warm at that time. The Gregory Member at the Cooperstown site is at least in part equivalent to the Gregory Member in south-central South Dakota and the Red Bird Silty Member of the Pierre Shale in eastern Wyoming. The unconformity between the Gregory and DeGrey Members at the site implies subaerial exposure of the sea floor.

Deposition of the DeGrey Member resulted from a readvance of the Pierre Sea in the Cooperstown area. The basal portion of this member contains numerous layers of bentonite and a vertebrate fauna consisting of mosasaur, shark, bony fish, and bird remains. Deposition of the DeGrey Member at the Cooperstown site probably occurred during the late Campanian in a warm, shallow Pierre Sea. The DeGrey at the Cooperstown site correlates at least in part to the DeGrey Member in south-central South Dakota. The remains of several mosasaurs have been found in the DeGrey at the site. One specimen, a nearly complete 7-m-long skeleton, is a new species of *Plioplatecarpus*. The carcass of this mosasaur was scavenged by dogfish sharks.

ACKNOWLEDGMENTS

We gratefully acknowledge the interest and support of the Beverly and Orville Tranby and Tim Soma families who allowed us access to their properties for this study. We, and the citizens of the state of North Dakota, thank Beverly and Orville Tranby, Gloria Thompson, Jacqueline Evenson, and Susan Wilhelm for donating the *Plioplatecarpus* specimen to the state for permanent exhibit at the North Dakota Heritage Center. Gordon Bell, Jim Martin, Bill Cobban, Neil Landman, Rod Feldmann, and J. Mark Erickson examined specimens from the site. We appreciate their help. We also thank the many volunteers who helped excavate the *Plioplatecarpus* specimen, including Gene Loge, Orville Tranby, Scott Tranby, and geology students from St. Lawrence University, Canton, New York.

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THE DAKOTA ISTHMUS - CLOSING THE LATE CRETACEOUS WESTERN INTERIOR SEAWAY

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INTRODUCTION

The Dakota Isthmus

There is no land quite like it on Earth today: a muddy sand plain, its surface elevation controlled by mean sea level, complicated rarely by coarser sand rises and muddy swales, the result of hurricane-driven wave action, or by anastomosing deltaic tidal channels, draining to the north or to the south, and elongating rapidly to follow the retreating sea (1). If one were to try to walk along its margins, one would likely become mired knee- to waist-deep in unsupporting muck with no prospect of assistance.

The land is not barren, nor are the waters, but most members of the flora and fauna, familiar at the generic level, are forms only dimly reminiscent of modern species. However, it is because of the fossil remains of these organisms that we know of this place, that we may visualize it as habitat, and that we may understand its impact upon the rapidly changing environment of the planet 65.6 million years ago (Ma), give or take a hundred thousand years.

Sandy rises and sandbar islands in the larger estuary channels support a growth of *Pandanus* trees (2), their adventitious root systems suspending and buttressing trunk bases in the unconsolidated sand, while on the firmest ground palmettos with meter-wide fanlike leaves and palms, akin to the cut-leaf palms of southeastern Asia today, offer shade. The wetter lands are covered rather densely by stalks of a meter-tall species of the scouring rush *Equisetum* (3) that is somewhat salt-tolerant. The plant community is not as diverse as the warmth and humidity of the place might otherwise warrant because of the presence of the salt water.

Fossils of aquatic species inform us of the salt content. From the distributary system of a Mississippi-sized delta, whose source is to the west, come not only the fine, sandy muds that compose the plain but also vast quantities of freshwater gravitating seaward. In the hundreds of bayous, creeks, tidal channels, estuaries, and lagoons of this great plain, spanning hundreds of kilometers, freshwater mixes with seawater having salinity much like that of a modern continental shelf, 32 ppt. But the result of the mixing produces a wide range of water chemistries of varying dilutions both in surface water and in groundwater. Nerite and littorine snails and species of the brackish water oyster *Crassostrea* occur abundantly on flooded mudflats and in tidal channels and estuaries, some forming great heaps of shells both as living "reefs" and as chenier shell plains where storms have passed (4). Horseshoe crabs visit the plain to reproduce and to feed on mollusks in the lagoons (5). Bony fishes, sharks, skates, rays, and ratfish (6) are drawn to the rich molluscan food sources as well.

If one could stand in the center of this land, or better yet, perch high in a *Pandanus* tree and with a fine pair of binoculars, one could see, still visible to the north and south, arms of the Fox Hills Sea. To the north, the sea is fast retreating and will soon be out of view as deltaic progradation favors that route. To the south, beyond sight, resistant knobs of the ancient positive land, Siouxia, have trapped delta sands, preserving beyond them a remnant of the open oceans that once covered the entirety of present North Dakota and South Dakota, Saskatchewan, and Manitoba and adjacent terrain. The Dakota Isthmus thus served as a continental divide at this time. To the east lay more sand plain stretching to the high ground in present Minnesota and Wisconsin. Westward can be seen the gently rising surface of the Hell Creek delta platform, itself, at first, being only a few meters above sea level. It is vastly different floristically and faunally, however, as it is mostly "*terra firma,*" and it is primarily a freshwater regime of diverse plants (7), freshwater mollusks (8), and the hallmark latest Cretaceous characters such as *Triceratops prorsus* (9) munching on riparian foliage and *Tyrannosaurus rex*. It is the first land bridge between eastern and western land masses to exist in 30 or 40 Ma.

This was the Dakota Isthmus, a feature that no longer exists, but that surely covered north-central and eastern South Dakota and south-central and eastern North Dakota. The isthmus has been eroded from the relatively high grounds of the eastern and southern margins of the Williston Basin, the same high grounds that first trapped the isthmus-forming sediments, by some 60 Ma of subsequent stream erosion or, more recently, by glaciation. Glacial debris has covered any remainder. What is the evidence of this important isthmus? Why was it such a significant geographic feature? These are questions I will respond to in this paper.

Western Interior Seaway

Since 1966, when Gill and Cobban (10) popularized a reconstruction of the Cretaceous Western Interior Seaway

(WIS), numerous studies of Late Cretaceous sedimentation (11), paleogeography, paleozoogeography (12), and paleoceanography (13) have been modeled from it. Gradually, beginning in the 1970s, refinements of seaway paleogeography have produced more accurate, or realistic, reconstructions (14–19).

In 1978, Erickson (20) described the Dakota Isthmus, but the importance of the isthmus has not yet been recognized. Development of the K/T (Cretaceous–Tertiary) boundary meteorite impact hypothesis (21) and subsequent search for the "boundary layer" intensified interest in late Maastrichtian deposits throughout the area of the seaway (22, 23). Most recently, Roberts and Kirschbaum (24) have presented revised paleogeographic interpretations of the Maastrichtian-age Fox Hills Seaway, suggesting the existence of an isthmus without definition and clarification of the 6.5 million year timespan inferred from their Fig. 22. Kennedy and others (25) have clarified biogeographic and chronostratigraphic relationships between the Fox Hills deposits on the isthmus and those off its southern margin, as will be discussed below. With a single exception (20), neither the sequence of events surrounding the closing of the Western Interior Seaway nor the important effects produced by development of the Dakota Isthmus have been discussed to date.

EVIDENCE OF THE DAKOTA ISTHMUS

Evidence for existence of the Dakota Isthmus discussed here is derived from field studies of the Fox Hills Formation in central North Dakota. Divisions of the formation and lithologies encountered are illustrated in Figure 1 as a composite stratigraphic column.

Parsimony

I began this paper by giving a graphic verbal reconstruction of the Dakota Isthmus. It includes reference to many fragments of data that have produced the interpretation. No outcrops of Fox Hills Formation are known to exist in the area of the Sioux Arch (Siouxia) and similar highlands in Minnesota, but the positive structural nature of the Transcontinental Arch system is well known (24–26) including the presence of wave-cut shoreline features produced during the Cretaceous (28). It is also known that the Fox Hills deposits, though thin, once crossed these positive features and extended into northwestern Iowa (23, 29), but they are absent from the Sioux Arch region, presumably by erosion rather than nondeposition. If the Sioux Arch (here used as a northeastern surface expression of the geographically more extensive Transcontinental Arch) behaved during Maastrichtian time as it did earlier (27, 30) and as it is today (26), it was then a shoal in the Fox Hills Seaway. As the Maastrichtian regression occurred, it seems most parsimonious that the WIS first divided here, thereby closing the long marine connection between Arctic and Gulf Coast oceans. The divide developed where the sea was narrowest and shallowest, namely where the advancing Sheridan Delta met the southeastern margin of the Williston Basin. That shoaling began in south-central North Dakota.

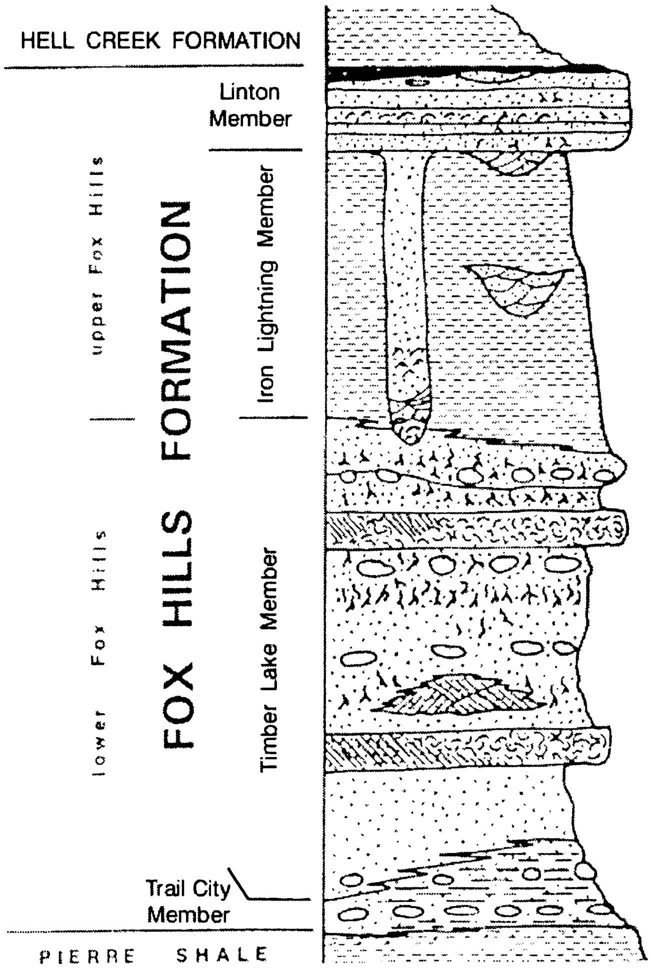

Figure 1. Stratigraphic column of the Fox Hills Formation as it occurs in western Emmons County, North Dakota.

Sheridan (Hell Creek) Delta and Fox Hills Strand

There is no issue about the existence of the massive depositional system represented by the Hell Creek Formation. Gill and Cobban (31) documented both the paleogeographic expression and increasing rate of progradation of this distributary system that originated in the area of Sheridan, Wyoming, as it swamped the Williston Basin and pushed toward its eastern and southern margin as the Fox Hills Sea retreated. The projected rate of marine regression was more than 460 km in less than 500,000 years. They called the results of the progradation the Sheridan Delta, a term I shall use herein for clarity. Figure 2 illustrates the relationship of this feature to structural and geographic elements of the region. Although their analysis stopped at the early Maastrichtian *Baculites clinolabatus* Range Zone west of the Missouri Valley of North and South Dakota, progradation represented by Fox Hills shoreline sandstone facies rapidly proceeded into southeastern North Dakota, as extrapolated from isopachous studies (1) and surface stratigraphic records. Formation of the Dakota Isthmus took place when the Fox Hills shoreface merged with shoals that surrounded and extended northwestward from the Sioux Arch and other positive tectonic features around the margin of the Williston Basin. This process was likely completed midway through the *Jeletzkytes nebrascensis* Range Zone. Rapid delivery of clastic sediments shed by Laramide orogenic pulses coupled with eustatic regression drove the delta front eastward with exceptional rapidity and formed an unusual physiographic feature in the process.

Biofacies

Above the Timber Lake Member, the last wholly marine deposits of the Fox Hills Formation, are a series of units of varying lateral extent, collectively the Iron Lightning and Linton

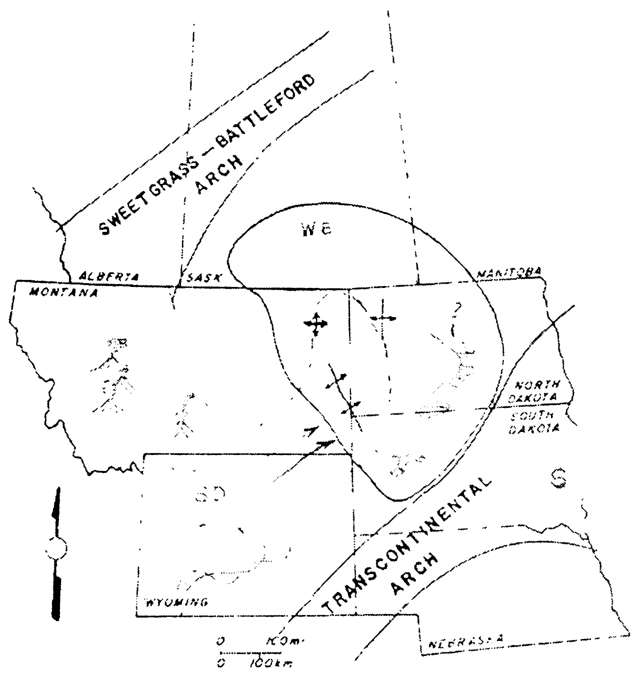

Figure 2. *Baculites clinolobatus* strandline (countershaded) of Gill and Cobban (31) modified to illustrate features of the Fox Hills strand (1) and superimposed on regional tectonic features from Shurr and others(37). **W.B.** = Williston Basin, **S** = Siouxia.

Members (3, 32, 33), that represent deposition in habitats of brackish water. This deposystem is expressed by a wide range of lithofacies from silt and clay (Bullhead lithofacies) to some of the coarsest sandstones in the formation, but all lithofacies exhibit elements of the brackish water oyster community, or biofacies, described by both Erickson (34) and Feldmann and Palubniak (4).

Two North Dakota localities provide exceptional, though limited, views of this *Crassostrea–Pachymelania* biofacies. In Logan County in sec. 26, T. 133 N., R. 23 W., a row of buttes composed of hard, dark brown, very fine, channel sandstone contains clusters of *Crassostrea glabra* in living position through more than 10 meters of section. There, meters-thick, cross-stratified, oyster biostromes lie adjacent to the *Crassostrea* channel. Known locally as Shell Buttes, these erosional remnants of the Dakota Isthmus represent an inverted topography having once been a tidal channel with a healthy fauna of oysters and associated organisms (4).

Another isolated butte system, this one to the east in Kidder County in NE¼ sec. 36, T. 141 N., R. 73 W., is capped by well-indurated, stratified, storm-deposited sandstones containing units of grain-supported *Crassostrea–Pachymelania* coquinite. The butte-capping Fox Hills Formation in this case is an ice thrust block (35) of brackish water, biofacies deposited on the Dakota Isthmus. Such tempestite cheniers once stretched over the isthmus from central South Dakota to western Minnesota. The biofacies includes *Crassostrea glabra, Corbicula cytheriformis, Pachymelania insculpta, Pachymelania wyomingensis, Neritina loganensis, Euspira subcrassa*, and *Nerita* sp.

Biogeographic Distributions

Paleontologists and biostratigraphers have paid great attention to Turonian through Campanian faunas from the standpoints of endemism and ammonite biostratigraphy (12). Close analyses of Maastrichtian faunas, particularly vertical analyses of Fox Hills organismal compositions for their probable marine thermal preferences, have not yet been completed. The rather unique provincial character of faunas in the central WIS has been generalized by Kauffman (12), and the mixing of genera having warm water preferences with those having cool water preferences has been noted specifically for Campanian-age Pierre Shale (19) and Maastrichtian-age Fox Hills Formation gastropods (17). Many other faunal elements have not yet received attention. New studies should be designed to provide evidence of the timing and behavior of the Dakota Isthmus or attempt to falsify this model in favor of another.

One example suggests that a change was occurring in marine thermal conditions and dominant ocean currents toward the top of the Timber Lake Member locally in Emmons County, North Dakota. In the section exposed in sec. 11, T. 130 N., R. 79 W., *Sphenodiscus lobatus* (=*S. lenticularis*) is present through the lower 5 or 6 m, but absent above, as it is elsewhere in North Dakota. About 7 m above its last occurrence were found in situ two double-valved specimens of a species of *Arctica* (20). This genus includes cool-temperate to arctic bivalves. They are prominent faunal elements of the Bearpaw Shale of the WIS in the Cypress Hills region of eastern Alberta, well north of the Sheridan Delta. Although similar, the Fox Hills specimens are not conspecific with the Bearpaw species, but nevertheless belong to *Arctica*. Speden's extensive review of the Fox Hills bivalves did not discover any *Arctica* in South Dakota (36). Its presence was not widespread, which is interpreted to signify that cold marine temperatures dominated the region at the close of Timber Lake deposition. Influences of currents from warmer regions were restricted. Absence of *Sphenodiscus lobatus* suggests the same. The WIS was closing.

Sedimentary Facies

Eastward from Logan and McIntosh Counties in North Dakota and the Missouri Valley in South Dakota sedimentary evidence of the Dakota Isthmus is sparse because that region lies beyond the erosional limit of the formations. Nevertheless, there are significant and distinctive facies changes evident from central Emmons County eastward (1) that signal presence of lithotopes that were atypical of Fox Hills deposition in much of its type area (32). Most notable are the presence of 1) a volcanic ash at Linton; 2) the eastward loss of the Bullhead lithofacies; 3) loss of "typical" Fox Hills concretions with rich marine faunas; 4) the rare presence of coarser sands to the east in Logan County; 5) an increase of tidal flat and oyster faunas (noted earlier); 6) and general thinning to the east and southeast of both the Fox Hills and Hell Creek Formations.

The final margin of the Sheridan Delta was not far beyond the Missouri Valley region of the Dakotas. Its interdistributary bays were heavily influenced by marine inundation (by sediment subsidence or by a minor eustatic transgression) as evidenced by the Breien Member. As the delta encroached onto the seaward edge of the eastern basin margin and began to climb toward the shoreface, delta morphologic complexity increased and became more lobate toward the coast of the eastern landmass. Distributaries were likely deflected parallel to the slope until sea level retreated farther or the platform was built to sufficient height to again evulse toward the coast. Much of this sediment distribution process took place at wave base producing a regional fine sand shoreface, yet the aerial features produced were distinctly of a river-dominated delta platform system. Marine and brackish sediments of these unusual facies (1) are still thinly preserved in Logan and McIntosh Counties and probably elsewhere.

Structural Evidence

Construction of the Dakota Isthmus relied upon rapid advance of deltaic sediments across the Williston Basin onto an existing slope and platform. The presence of the Sioux Arch as a sediment-trapping feature, perhaps even as a landmass and sediment source (24, 37), was noted earlier. Laramide tectonism had begun to effect the region by early Maastrichtian time. Shurr and others (37) have shown the existence of structural influences on pre-Fox Hills rocks in the Cretaceous of the Williston Basin, including the Missouri Valley Region, and Erickson (1) demonstrated that structural highs were present in the region during the time of the deposition of the Fox Hills Formation.

The influence of tectonism, particularly production of sediment-trapping positive features for coarse materials, impacted the southern and eastern margins of the basin throughout Fox Hills and Hell Creek deposition and fostered development of coastal plains and shoals that coalesced as the Sheridan Delta overrode them. Stoffer and others (38), Waage (32), and Shurr and others (37) have all pointed out these effects. By Fox Hills time (from at least the *Hoploscaphites nicolletii* Range Zone through the end of the Maastrichtian), there is a strong tectonic influence upon sedimentation and geomorphology along the southern rim of the Williston Basin. Tectonically active positive features served to confine that margin of the expanding Dakota Isthmus.

SIGNIFICANCE OF THE DAKOTA ISTHMUS

The geologic sciences today find themselves in a central role as collaborative cross-disciplinary research focuses on Earth systems and biogeochemical processes. Approaches to investigations of K/T boundary phenomena, Late Cretaceous climate change, endemism, extinction, and paleozoogeographic distributions of both marine and terrestrial organisms, Cretaceous–Paleocene oceanic paleocurrents and paleochemistries, and the causes of unusual biostratigraphic distributions, including formation and distribution of Fox Hills concretions, all require interdisciplinary studies. Data can only be correctly interpreted if the presence of the Dakota Isthmus is included in the basin paleogeographic and depositional model in which studies are set. Did a tsunami enter the WIS after a bolide impacting at Chixalub, Mexico? If so, it must have inundated the Dakota Isthmus! Did it leave a sedimentary record? I will close with two brief examples of the need to include the Dakota Isthmus in geographic modeling of stratigraphic work near the K/T boundary. Figure 3 suggests a geographic setting for the isthmus.

Shoreline Evolution and Mammalian Zonation

Lillegraven and Ostresh (39) in a thorough discussion of latest Cretaceous shoreline evolution of the WIS in

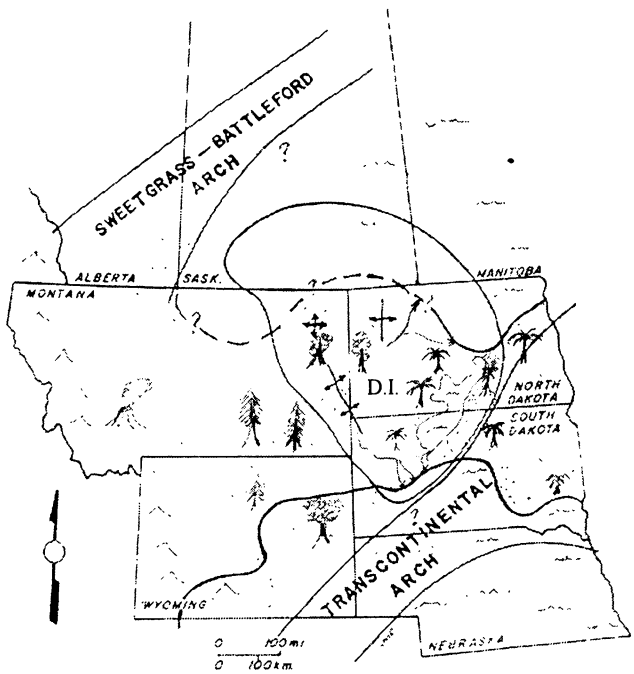

Figure 3. The Dakota Isthmus (D.I.) as it divided the Late Maastrichtian Fox Hills Seaway midway through the *Jeletzkytes nebrascensis* Range Zone. Southern margin of the isthmus in Wyoming follows the youngest strand of Gill and Cobban (32) but a shoal over most of southeastern Wyoming and neighboring South Dakota was likely present. Arms of the WIS retreated northward and southward.

relationship to mammalian faunas presented a series of shoreline graphics arranged latitudinally. Their *Discoscaphites nebrascensis* Range Zone (=*Jeletzkytes nebrascensis* Range Zone herein) indicates the Maastrichtian Fox Hills Seaway to have been restricted to the southeastern portion of North Dakota below latitude 46.5°N and to the eastern two thirds of South Dakota. No estimation of the northern shorelines is given. In their conclusions, they point out that, "Interpreted patterns of shoreline evolution during the last 20 m.y. of the Cretaceous in the Western Interior are inconsistent with (A) the existence of geologically-brief (1 to 10 m.y.) global fluctuation in sea level, and (B) the concept that the late Campanian was represented by an unusually high global sea level." Modeling the development of the Dakota Isthmus will likely help to explain some of the inconsistencies of present interpretations.

Kennedy and others (25) have recently described a "Fox Hills" fauna from siltstones in the Elk Butte Member of the Pierre Shale in southeastern South Dakota off the Sioux Arch. These faunas contain *Jeletzkytes nebrascensis,* which the authors tentatively link to fragmental ammonite material reported by Klett and Erickson (3) from the Linton Member in South Dakota and a single broken specimen (assigned to *Discoscaphites* cf *D. conradi*) from the Breien Member of the Hell Creek Formation in North Dakota, to suggest continued presence of a seaway link from the south as shown by their Figure 5.

I concur with the concept of an embayment of the Gulf Coast sea reaching into southeastern South Dakota, perhaps occasionally flooding the Missouri Valley region of South Dakota along the structural axis reported by Shurr and others (37). At this point it is not demonstrable that the Linton Member represents deposition in the *Jeletzkytes nebrascensis* Range Zone because the ammonite material of Klett and Erickson was composed of unidentifiable fragments with a strong probability that is had been reworked. The same may be true of the Breien specimen. Although it is an identifiable fragment, it remains the only ammonite specimen from these acknowledged marine rocks. Clarity of paleogeographic understanding will be crucial to future progress in interpreting late late Maastrichtian biostratigraphy, paleoceanography, and faunal endemism. I suggest that for the last half of the *Jeletzkytes nebrascensis* Range Zone in the WIS, we should consider a paleogeography such as that shown in Figure 4. It is a least a beginning point for detailed analysis of the Dakota Isthmus concept.

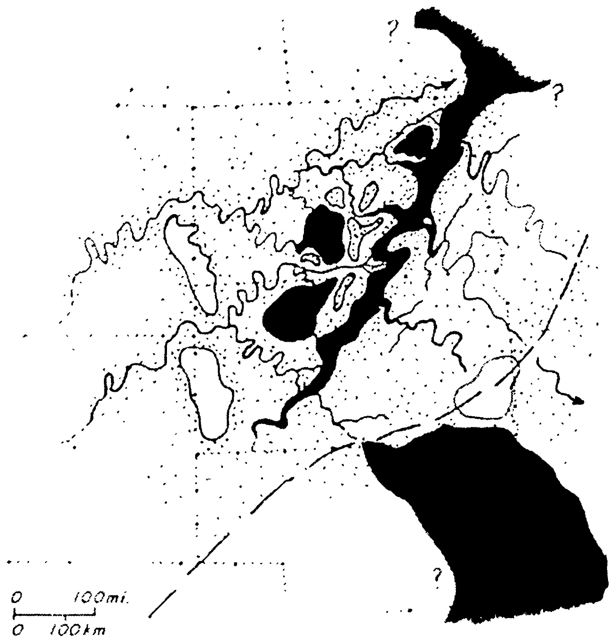

Figure 4. Paleogeographic features of the Dakota Isthmus late in the *Jeletzkytes nebrascensis* Range Zone of the late Maastrichtian in the Dakotas and adjacent area. Dashed line indicates approximate continental divide only tens of meters above sea level in many places at this time. Darkened areas indicate water.

DEDICATION

This paper is affectionately dedicated to my mother, Eleanor C. Erickson, who has always helped me to visualize distant shorelines clearly in space and time.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of numerous St. Lawrence University students who have accompanied me in the field since 1972. The present work benefitted from assistance of Timothy Woodcock and David Waugh. The manuscript was improved by the valuable criticism of F.D. Holland, Jr., and the editorial effort of Joseph Hartman. Bonnie Enslow prepared the typescript. After all the help, the errors that may be found remain my own.

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PARTNERSHIPS FOR PRODUCTIVITY – COLLABORATIVE EFFORTS AMONG AMATEURS AND ACADEMIA

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INTRODUCTION

In recent years, the renewed public interest in fossils, by young and old alike, has stimulated new research promoting insights, displays, and interpretations in the field of paleontology. This public demand for information has led to many new finds and understandings of the how and why of the ancient world. Hollywood's movies, along with educational documentaries, provide the world with continual awareness of what discoveries are being made around us. The state of North Dakota is no exception in its people's interest in fossils.

IN NORTH DAKOTA

North Dakota has several geologic formations visible at the surface, and most contain a record of ancient life. These fossiliferous horizons contain the remains of animals and plants ranging from about 25 through 80 million years old. This provides an excellent opportunity to collect and gather information about fossils within our state. However, two problems usually present themselves: not enough staffing and/ or insufficient funds to do the job. To be able to adequately collect and curate these fossil remains, one must have the time, personnel, equipment, and funding to complete the task. Obtaining the permits and establishing permission to access the fossil outcrops provide an additional challenge in time and perseverance.

This is where a collaborative partnership between amateurs and academia is so important. For most academic programs, a limited amount of time is commonly available to collect the specimens and information in the field. This is usually accompanied by a small staff because of funding constraints. These field activities may also be initially conducted in unfamiliar areas, fostering logistical nightmares. Amateurs, on the other hand, are fossil enthusiasts for the area in which they live. If a fossil outcrop is located in their home region, they probably know where it is, how to get there, and the landowners for access to the property. Most amateurs are more than willing to assist professionals with whatever needs to be done if they are given the opportunity to participate and the guidance to do so.

Therefore, additional staff, new site localities, land access, and logistical assistance are available to the professionals, while information, the ability to participate, and friendships are acquired by the amateurs (Figure 1). This can all be accomplished with a very limited funds, thus resulting a win–win situation in most cases.

THE PIONEER TRAILS REGIONAL MUSEUM

A collaborative case in point is the Pioneer Trails Regional Museum in Bowman, North Dakota, and its paleontology program. The museum is operated by the County Historical Society, which organized it in 1983 to preserve the history of the area. Since I was working on establishing a census of fossils from Bowman and Slope Counties, in 1987 the Society decided to incorporate this work into the activities of the Historical Society. To establish a reference collection of specimens and information on fossils in the area, we made contact with the State Geologist, who referred us to the North Dakota Geological Survey, which had a paleontologist on staff. We also made contacts with other institutions and museums working in the local area. Some of these initial contacts were with Yale University, the Milwaukee Public Museum, the University of California at Berkeley, the Cleveland Natural History Museum, and the University of Rhode Island.

The contacts we made and the interest we expressed in the research of these institutions and museums allowed us to participate with them, providing a "hands-on" experience. This effort ultimately led to the development of a training program under the direction of the North Dakota Geological Survey. This training program on geological and paleontological techniques allowed individuals to participate on permits assigned to the Survey, providing they completed the classes. Our local volunteers now could assist with research on state and federal lands otherwise off-limits to the amateur. This training program initially started as a 30-hour course and has grown over the years into a 60-hour course, with some classes taught for college credit through Minot State University.

The year 1989 saw the start of our participation under this newly created cooperative agreement. We began to survey and collect for the state fossil collection under the guidance of the North Dakota Geological Survey and to participate as partners with Yale University and the University of Rhode Island in paleobotanical and sedimentological studies of the local area. We were also starting to collect and curate fossils of our own with the hope that funding could soon be secured for a local museum that would house these specimens both as a reference collection and as a public display.

In 1991, two dreams were realized. The enormity of the fossil collection effort and the need for additional volunteers led to the development of a paleontological certification class. This class was developed as a result of our original training class. The certification class was developed to allow local volunteers to direct and conduct their own field operations, with the North Dakota Geological Survey paleontologist Dr. John Hoganson as technical advisor. Twenty-two local participants enrolled in the program that year, giving us a sizable crew with which to conduct our collection activities.

A MUSEUM BUILDING

The Bowman County Historical Society that year also purchased a building to remodel into a local museum. It is located one block from downtown Bowman, North Dakota, and provides 12,000 square feet (1115 m^2) of display, laboratory, and office space. The museum was named the Pioneer Trails Regional Museum. We now had our curation and storage facility from which to base our field activities.

In 1992, we held the museum's open house with a paleontological symposium and public barbecue. This activity presented the local residents and landowners the opportunity to meet the visiting professionals and gain an understanding of what research was being conducted locally and how the museum was taking part. This summer barbecue will occur for the eighth time this year. This activity provides an opportunity in which professional paleontologists can interact with the local landowners and museum volunteers during their summer field activities in southwestern North Dakota.

The displays in the Pioneer Trails Regional Museum, whether local history, archaeology, or paleontology, are established as a result of research. The museum does not collect specimens or artifacts just for display. All specimens and artifacts are collected as a result of research or for the history surrounding the object, and it is from the results of this research that the displays are developed. In this manner, all displays in the museum tell a story as well as provide the researcher with the information they need.

The museum has as its policy that fossil specimens are only collected if the collector plans to do something with them. Fossil remains, location, and geologic context are important, even if the specimen has no aesthetic display value. We also want the academics to know that we have the relevant associated data with the specimens that we have in our possession; otherwise, there is no point in establishing a reference collection. We have been fortunate to participate both as associate authors and primary investigators in the publication of the scientific literature on our findings. We would like to thank the North Dakota Academy of Science for publishing our first research data on Hell Creek Formation microsite assemblages in 1992 (Figure 2).

MUSEUM ACTIVITIES

In 1993, we were asked to participate in the Outreach Committee of the Society of Vertebrate Paleontology. This committee has the responsibility to establish working relationships between the professional community, amateurs, and the general public. Also in 1993, our paleontological certification program was one of three volunteer training programs selected nationwide that were used to establish guidelines from which amateur paleontological programs could be developed.

June 1993 saw the museum host the Marshall Lambert Symposium with the North Dakota Geological Society. A total of 18 contributors participated, producing 10 papers. The ultimate outcome was Mr. Marshall Lambert receiving the Strimple Award of the Paleontological Society, which honors the lifetime contributions of an amateur paleontologist, in New Orleans, Louisiana. A festschrift volume on area research was also produced in 1998 in his name as a result of the initial symposium. Mr. Marshall Lambert is a retired school teacher and avocational paleontologist from Ekalaka, Montana. He is the retired curator and developer of the Carter County Museum. It was through his encouragement, enthusiasm, and cooperation that relationships were established with the professional academics that led to the initial development of my interest and our paleontological program.

The professional conduct of the members of the Pioneer Trails Regional Museum has made it a partner in many different activities. The research collections have grown to number 50,000 specimens, and the museum has ongoing research collaboration with many other institutions and museums. Activities with the State University of New York at Stony Brook, the New York College of Osteopathic Medicine, the Denver Museum of Natural History, the North Dakota Geological Survey, the Energy & Environmental Research Center at the University of North Dakota, and the South Dakota School of Mines and Technology have all produced research publications. Through this collaborative work, these institutions and museums have helped us for establish our displays, filling 5800 square feet (539 m^2) in our local museum.

Some of the research we have been involved with has gained national attention. In 1992, we found and reported North Dakota's first in-place *Tyrannosaurus rex* (Figure 3). It consisted of associated skeletal remains that have to date produced 10% of the dinosaur. This find occurred coincidentally at the same time as the release of the movie Jurassic Park. This led to a massive media blitz and good

Figure 1. Preparation of the pelvic section on the associated skeletal remains of the Ceratopsian dinosaur Torosaurus. Pictured here is the large 1500-pound (680-kg) cast containing the pelvis and upper extremities. Volunteers of the museum and the landowner are seen in the photograph, which was taken in July 1992.

Figure 2. Participants from the 1998 summer field school collected the Hell Creek microsite PTRM V86002. These microsites contain many isolated specimens that were originally accumulated in ancient river channels. Volunteers crawl across the outcrop to collect the very small specimens. The buttes in the background show a "typical" Hell Creek view. The coal seam at the top of the hill delimits the horizon of the formational contact between the Hell Creek and overlying Fort Union Formations.

publicity, not only for the museum, but for North Dakota as well. The scientific findings from this site were subsequently published by the North Dakota Academy of Science in 1995.

The museum started a detailed collection in 1993 of an isolated deposit of Chadronian-age fossils (40 to 38 million years old) from south of Rhame, North Dakota (Figure 4). This site was originally reported in 1921, but no follow-up studies were subsequently conducted. The richness of this site, reported through research papers in 1993, 1995, and 1998 by our museum, indicate it is one of the oldest, if not the oldest, Chadronian site in North America. The diversity of the site averages approximately 68 taxa for every cubic meter of screened matrix. The site must be excavated "archaeological style," as it is a subsurface excavation and must be screened to separate the fossil specimens from the sand matrix. A cooperative agreement with the Royal Saskatchewan Natural History Museum in Regina, Saskatchewan, Canada, enabled our museum to borrow its rotary power screen and use it to separate the matrix. We subsequently utilized its reference collections to identify the specimens found at the site.

The volunteers of the Pioneer Trails Regional Museum have participated with Minot State University and the South Dakota School of Mines and Technology in collecting ice-age (Pleistocene) fossils at Fossil Lake, Oregon, in 1993, 1994, and 1995. We participated with the North Dakota Geological Survey in conducting a fossil inventory on the public grasslands for the U.S. Forest Service in 1995 and the same for the Bureau of Land Management in 1997. We assisted Dr. Kirk Johnson of the Denver Museum of Natural History in the collection of plants living at the time of the dinosaurs (Hell Creek Formation, uppermost Cretaceous), which led to our volunteers participating in television documentaries that have aired on the Discovery Channel, the Learning Channel, and public broadcasting networks. Insight into dinosaur extinctions and comet impacts enabled us to participate in a documentary on the Sci-Fi Channel with the University of Rhode Island. We have also collaborated with Dr. Joseph Hartman from the Energy & Environmental Research Center at the University of North Dakota, Grand Forks, in the study and collection of Cretaceous and Paleocene invertebrates in the area. In 1996, the first detailed account was published on the mammals at the end of the Cretaceous in North Dakota. This Hell Creek Formation study was jointly conducted between our museum and Dr. John Hunter, then at the State University of New York at Stony Brook.

In 1997, Terry Schaefer, a volunteer with the museum, discovered a partial skull of a Ceratopsian (a three-horned dinosaur) in the basal part of the Ludlow Member of the Fort Union Formation. This was important, in that it indicated dinosaurs were not restricted to the Hell Creek Formation and that the basal part of the Ludlow Member is older than previously thought in some areas. This Ceratopsian was also found closer to the level at which dinosaurs went extinct than any other dinosaur in the world to date. This meant the museum and North Dakota have in their possession the "geologically youngest dinosaur."

Figure 3. This is a view of the *Tyrannosaurus rex* excavation site PTRM V92068 during the summer of 1993. Notice the grid work of string used to map the various specimens found. The bones, which are visible in the foreground below the museum volunteer, were not found articulated at this site.

Figure 4. Laurie Oakland, a museum volunteer, is seen here in the "archaeological style" excavation site PTRM V89002. This Chadron Formation site produces fossils that are about 40 million years old.

By 1998, the museum had seen 52 participants go through its certification program from as far away as Mayville and Cooperstown, North Dakota. We are currently offering a summer field school that is in its second year. Last year, our field school had 38 participants and was conducted jointly with Minot State University (Dr. Allen Kihm) and the Denver Museum of Natural History (Dr. Kirk Johnson). The museum also gives public educational tours to its excavation sites to teach the general public paleontological techniques and principles. We are currently involved with a project on the fossils of the Hell Creek Formation and with the theories of dinosaur extinctions. These findings will be presented in the fall of 1998 at the Geological Society of America annual meeting in Denver, Colorado.

THE FUTURE

The results of academic and amateur collaboration are limited only by the imagination, stamina, and perseverance of the participants. Combining the efforts of all equates to a better understanding, not only of the research and fossils, but of the participants as well. We have only to look from where we have come to realize that the path to the future holds tremendous opportunities for all involved.

THE RECONSTRUCTION OF ANCIENT LANDSCAPES: AN EXAMPLE FROM THE LATE CRETACEOUS HELL CREEK FORMATION OF NORTH DAKOTA

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INTRODUCTION

In this paper, I will delineate the scientific, artistic, and practical steps that we took to conceive, research, and build the upper Hell Creek ecosystem as an immersion diorama in the *Prehistoric Journey* exhibit at the Denver Museum of Natural History.

Since the early 19th century, there have been artistic attempts to reconstruct the ecosystems of the distant past (1). Usually these undertakings were two-dimensional illustrations based on collaborations between artists and paleontologists. Some of these efforts included three-dimensional renderings known as dioramas. Many reconstructions of ancient worlds have focused on animals and have represented the ancient vegetation with a miscellany of modern plants masquerading as their ancestors. Although lifelike animal reconstructions are an admirable goal, ecosystems and landscapes are primarily characterized by their plants and topography, not their animals. The *Prehistoric Journey* exhibit at the Denver Museum of Natural History (DMNH), which opened in October 1995, took the approach of reconstructing prehistoric scenes as three-dimensional habitat dioramas using detailed studies of the sedimentology and fossil vegetation of specific fossil sites to create more realistic reconstructions of the ancient ecosystems.

The *Prehistoric Journey* exhibit was planned and built between 1989 and 1995. Each diorama was based on a specific fossil site that contained fossils of both plants and animals and sedimentary evidence of the site's original geomorphology. Between 1990 and 1994, DMNH paleontologists selected and visited the sites and collected the fossil specimens and associated data. These specimens, data, and resulting publications provided constraints and authenticity to the site-specific reconstructions (2). Work on the dioramas began in early 1991 and was completed in late 1995. The final exhibit has seven such dioramas and one additional partial diorama with skeletons mounted in front of it. The dioramas include a 600-million-year-old (Ma) shallow marine setting with vendozoan organisms from Australia (muralist: Terry Chase); a 425-Ma carbonate reef complex from Racine Wisconsin (muralist: Terry Chase); a 395-Ma estuarine shoreline with trimerophytes and lycopods from Wyoming (muralist: Deborah Vriesen); a 295-Ma coastal forest of walchian conifers, cordaites, lycopods, pteridosperms, and calamites from Kansas (muralist: Jan Vriesen); partial diorama of a 225-Ma stream bank thicket of sphenopsids, ferns, cycads, and bennititaleans from Arizona (muralist: Jeff Wrona); a 66-Ma angiosperm stream bottom forest from North Dakota (muralist: Kent Pendleton); a 50-Ma angiosperm rainforest from Wyoming (muralist: Kent Pendleton); and a 20-Ma wooded grassland from Nebraska (muralist: Jeff Wrona). This paper documents some of the decisions that were made in building the 66-Ma Cretaceous creek bed diorama.

PREVIOUS VISIONS OF THE LATE CRETACEOUS

The latest part of the Cretaceous Period has long been ecologically confusing because its flora appears "modern," with the abundance of flowering plants relative to gymnosperms and ferns. This confusion was compounded by generations of paleobotanists who used modern plant generic names to describe angiosperms that are now known to belong to extinct genera. If the paleobotanists were using names of modern plants, then it should be no surprise that the artists painted modern vegetation. Rudy Zallinger's spectacular "Age of the Reptiles" mural, painted in 1949 on the wall of the Great Hall of Dinosaurs at the Peabody Museum, Yale University, is an example of this type of reconstruction (3). Behind the classic dinosaurs of the Late Cretaceous Period are weeping willows, Virginia magnolias, Chilean monkey-puzzle trees, and flowering dogwoods, all modern trees. The effect is a Cretaceous fauna in a modern botanical garden. An additional problem has been the difficulty of rendering latest Cretaceous ground cover. Aware that grasses were an innovation of the Cenozoic, artists have routinely left bare ground in their images of the Late Cretaceous. While the omission represents an effort at accuracy, the result is the phenomenon that the animals in the images appear to be wandering around on parking lots.

PALEOENVIRONMENT AND BIOTA OF THE UPPER HELL CREEK FORMATION

The Hell Creek Formation exposed in Slope and Bowman Counties in southwestern North Dakota is a 100-m-thick unit that is well-suited for the demands of a diorama builder. The formation is well-exposed and extremely fossiliferous. These rocks have been extensively studied in the past 20 years, and the resulting papers and subsequent field work were the basis for the reconstruction at DMNH (4–8). The formation contains a fossil flora that varies throughout its thickness (6, 7) and we chose to use the biota that occurs in the uppermost 20 m of the formation. The site chosen to for reconstruction was DMNH Localiy 428, which is located near Mud Buttes in Bowman County. At this site, a megaflora of more than 50 species is associated with abundant vertebrate microsites that contain typical Lancian vertebrate assemblages. The sedimentology suggests a medium-sized meandering river setting with poorly drained but not swampy floodplains. These observations are in concordance with recent analyses of Hell Creek paleosols which indicate that soils were moderately to poorly drained and conditions were generally humid (4, 5, 9). Coal seams are rare and thin in the Hell Creek Formation, suggesting that although the area was moist, it was rarely swampy.

A modern analog stream system was discovered in Connecticut (6, 10). The forested floodplain of the Quinnipiac River in North Haven, Connecticut, was mapped and monitored. Channel size is similar to the upper Hell Creek channels, and observations made in the modern system helped to constrain the prehistoric reconstruction. The muralist and the primary foreground artist visited this analog site and made observations and sketches to constrain the Hell Creek reconstruction.

The known megaflora of the Hell Creek Formation (7, 10–12) consists of 190 plant morphotypes (1 bryophyte, 6 pteridophytes, 1 ginkgo, 1 cycadophyte, 9 conifers, and 172 angiosperms). Angiosperms represent about 90% of the flora both in number of species and specimens collected. Important angiosperm families include the Lauraceae, Platanaceae, Magnoliaceae, Berberidaceae, and Arecaceae (palms), but a great number of the Hell Creek leaves have yet to be assigned to families. The majority of Hell Creek angiosperms belong to extinct genera. Although it is commonly reported in textbooks and popular articles, modern plant groups such as oaks, maples, willows, and grasses are not present in the Hell Creek. Conifers are represented by members of the Taxodiaceae, Araucariaceae, and Cheirolepidiaceae (extinct). *Ginkgo* is known from only a few localities. The sole cycad, *Nilssonia*, is present throughout the formation but very rare, and ferns are extremely uncommon.

An extremely large fossil leaf collection from DMNH Locality 428 provided a reasonable assessment of the local vegetation. These were counted and calibrated with the results of studies of leaf litter in modern forest floors. Counts of the relative abundance of forest floor leaves in modern forests of known species composition and structure provide additional data about the structure of the ancient plant communities (10, 13, 14). The large sample size also provided insight into the variability within a single fossil species, allowing for realistic reconstructions of ancient plants.

Angiosperms dominate the upper Hell Creek megaflora and were clearly the primary vegetation on the landscape (Figure 1). Ferns and fern allies are extremely rare as megafossils though more abundant in the palynoflora, suggesting that ferns were present but were primarily herbaceous. Conifers are locally abundant but rarely dominate. Fossil trunks and logs are present but extremely rare. Their near-absence seems to be a function of their not being preserved, since deep rooting horizons are abundant and tree leaves are common. The few trunks that are preserved are usually carbonized rather than petrified (Figure 2). Trunk diameter is rarely larger than 30 cm. These observations suggest that the Hell Creek landscape was forested by small trees with trunks smaller than 30 cm and a height probably less than 20 m. The ground cover was probably sparse as it is in modern broad-leaved forests, but the surface was likely covered with leaf litter.

The fauna of the Hell Creek Formation has been studied for nearly a century, and a recent comprehensive review is provided by Archibald (8). Extensive fieldwork by the Pioneer Trails Regional Museum in Bowman led by Dean Pearson (15) has documented that the common elements of the Hell Creek Formation in Montana are also present in the upper Hell Creek Formation at Mud Buttes.

PRACTICALITIES OF BUILDING A CRETACEOUS DIORAMA

Exhibit designers determined the outer dimensions of the roughly oval space to be occupied by the diorama. Sculptors used a variety of materials to build a stream bed and cutbank and forest floor. The stream bed was designed to carry flowing water and was cast from an actual sandy stream bed near Denver. A cast of a *Triceratops* dinosaur skull was set in the modern stream bed, and water was allowed to flow around it for several hours. The resulting stream bottom had ripple marks that had actually formed downstream from a *Triceratops* skull.

The plant reconstructions began with a collaboration between paleobotanist Kirk Johnson and botanical illustrator Marjorie Leggitt. The seemingly straight forward task of creating leaves and plants from fossil material offered many unexpected challenges. Several factors inhibit the ready construction of ancient plants. Not only do plants usually fall apart before they are fossilized, there are also plant parts that rarely become fossilized. For example, it is extremely uncommon to find fossilized bark. Also, leaves, twigs, and cones are usually found detached from their stems or trunks, and even these parts are frequently incomplete. With extinct plants, it is not always clear which parts go with which plants unless they are found attached, a rare condition. And since the size of leaves is not necessarily proportional to the size of the plants and petrified trunks are often missing, it can be difficult to tell if the leaves grew on large trees or small shrubs.

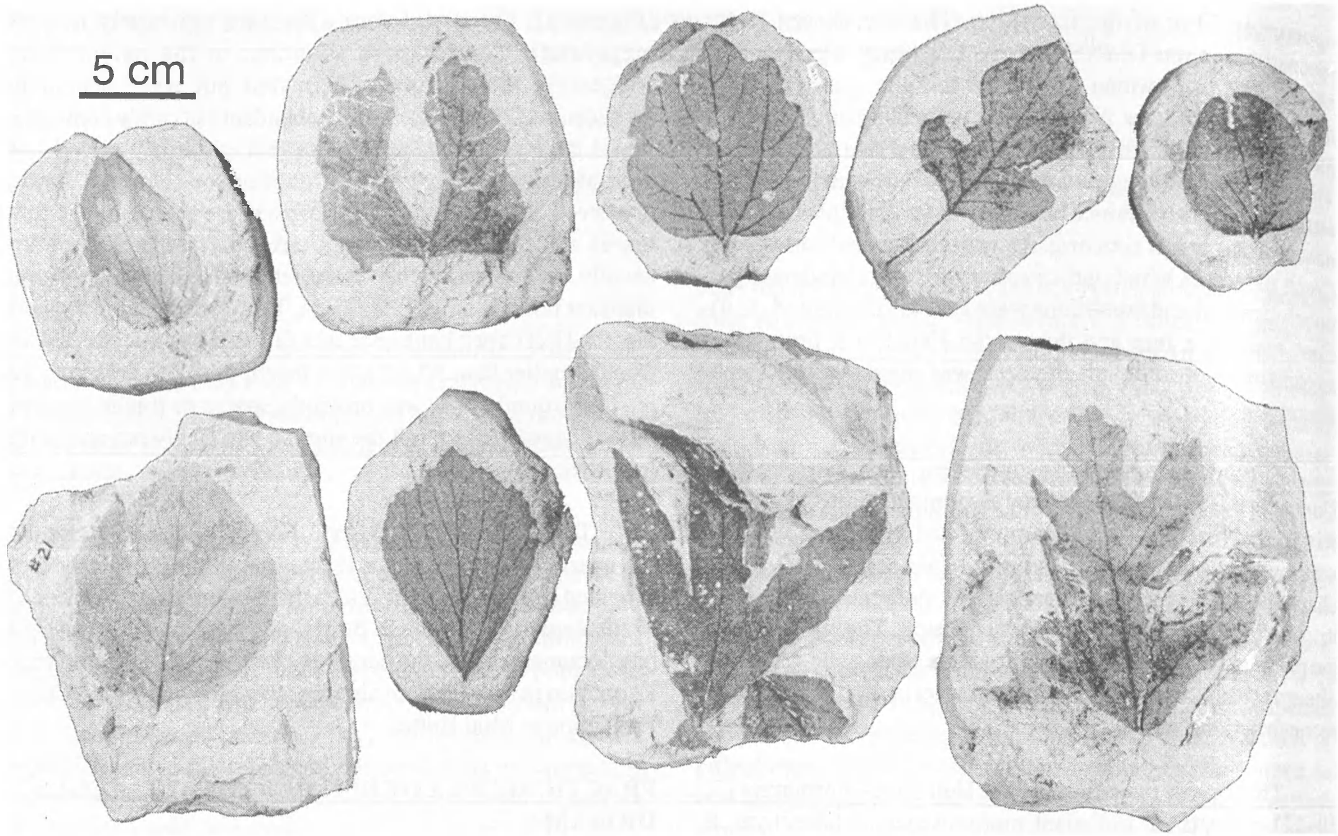

Figure 1. Examples of angiosperm leaves from the upper Hell Creek Formation, from top left to right these are *Zizyphus fibrillosus*, *Liriodendrites bradacii*, *Marmathia trivialis*, an unnamed lobed Lauraceae, an unnamed leaf, an unnamed leaf, *Platanites marginata*, *Erlingdorfia montana*, and "*Artocarpus*" *lessigiana.*

On the basis of what was discovered at the selected prehistoric sites, particular ancient plants were chosen to research and reconstruct. With fossils in hand (Figures 1, 3), the botanical illustrator rendered detailed tracings of up to 25 fossils per species to document the main features of each leaf. Many different fossil leaves were drawn to account for the variation of leaf shapes found on individual plants and within species. In some cases, 6x camera lucida illustrations were created to understand venation patterns to the highest available level of detail. In other cases, india ink renderings, drawn on acetate by laying a sheet of glass over the fossil and tracing the leaf's outline and major vein patterns, provided adequate information. Additional features such as insect herbivory damage were captured on these drawings. Next, detailed pencil renderings on tracing vellum were developed. These halftone drawings depicted the reconstructed leaves. Missing or damaged portions were speculatively reconstructed. Decisions such as whether a leaf was simple or complex were based on comparison with the plant's living relatives. The reconstruction and comparison of many variable leaves from a single source supplied enough information to establish a set of "rules" about the leaves and plants to be fabricated. At each step, the paleobotanist checked all illustrations for accuracy.

Library research and discussions with paleobotanists, specializing on specific plant groups, provided the information required to draw a reconstructed leaf-bearing branch. In some cases, the nature of the leaf attachment was known from the fossil record, in most cases it was not. In the latter situation, leaf attachment was hypothesized using common types of attachments found in the nearest living relatives of the fossil. This information was used to create a life-size pen-and-ink illustration. Finally, schematic pencil drawings of whole plants, prehistoric forest profiles, and diorama sketches were created using all available information.

A portfolio for each plant and environment, including all the tracing and outline drawings, the reconstructed leaf and branch illustrations, and the schematics, was then passed on to sculptors and muralists. Final diorama design, plant fabrication, and painted background decisions were based on this visual information. The choices of which plants and animals to include in the diorama were based on the occurrence of fossils of those organisms in the upper Hell Creek Formation with an emphasis given to fossils that we felt we could most accurately reconstruct. The resulting plants are listed in Table 1 and the animals in Table 2.

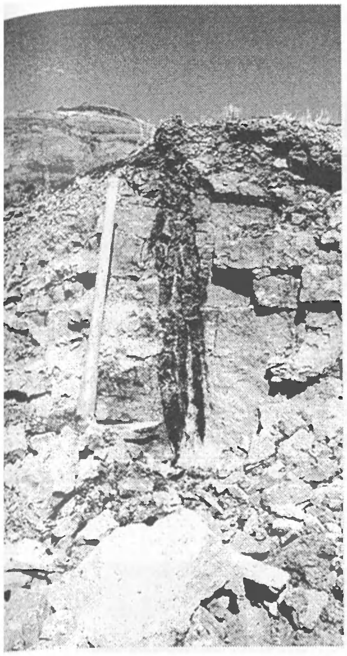

Figure 2. A fossil trunk preserved in the upper Hell Creek Formation near Mud Buttes, Bowman County, North Dakota. The trunk is replaced by organic-rich clay.

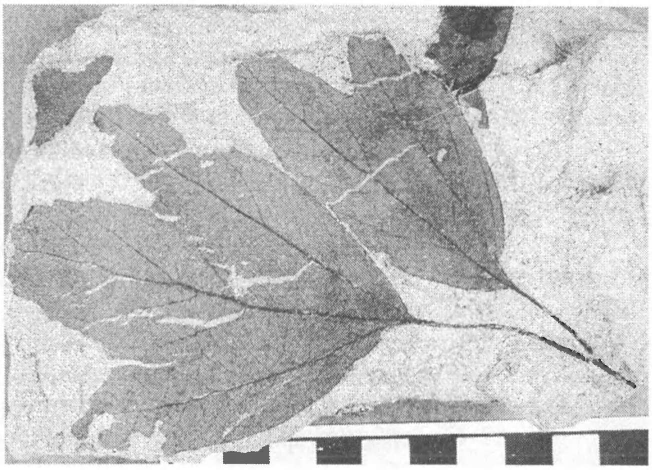

Figure 3. A fossil leaf of *Erlingdorfia montana* showing leaflet attachment.

Foreground sculptors and volunteers constructed the individual plants. Leaf molds were created by cutting modern leaves into small pieces bound by major leaf veins, then composing the pieces to match the detailed drawing of the fossil. Casting plaster, poured on the composite leaf, provided a mold that was accurate in shape, size, and major and minor venation patterns. Heated mylar sheets were vacuum-formed over the blocks (Figure 4), generating detailed plastic leaves that were cut out and painted by hand (Figure 5). Up to fifteen different leaf shapes were made for each plant. Plastic-sheathed wire, attached to each leaf, simulated the petiole (Figure 6). In the Cretaceous diorama alone, 21,467 plastic leaves were created! The finished leaves were attached to preserved or fabricated tree branches which themselves were attached to trunks modeled from fossils or cast from living trees. Finally, the completed tree was situated in the diorama. In some cases, individual plastic leaves were "distressed" and painted to mimic decaying leaf litter. These and other fabricated fallen plant parts such as fallen seed cases were added towards the end of construction. A Cretaceous poppy fruit, *Palaeoaster*, was reconstructed from several extremely well-preserved petrifactions (16). The resulting fruits were placed in the leaf litter because we had no information about the nature of the parent plant.

The portfolios of plant illustrations were also used as blueprints by Kent Pendleton, the painter who created the background mural for the diorama. By providing accurate and consistent drawings to both the foreground sculptors and the mural painter, each of the dioramas displayed an accurate and consistent final product with a smooth transition between the foreground and the background. The Hell Creek diorama required more than two years of work to install. During this time, the muralist painted from the distant background towards the foreground, integrating and blending with foreground sculptures so that the transition between the two-dimensional mural and the three-dimensional mural appeared seamless.

The animals reconstructed in the diorama were based on fossils collected in the Hell Creek Formation (8, 15). In most cases, the reconstructions were relatively straightforward because of the completeness of the known skeletal material. In the case of the feature animal, the *Stygimoloch* pachycephalosaur, the reconstruction was based on two partial skulls. This work was supervised by Ken Carpenter who used the postcranial anatomy of the Mongolian pachycephalosaur *Homocephale* as a model. Subsequent discovery of a nearly complete *Stygimoloch* skeleton from the Hell Creek Formation of northwest South Dakota did not warrant modifying this

Table 1. Plant Species Represented in the Hell Creek Diorama

Species	Habit	Rendering
Liriodendrites bradacii	small tree	3-D
Marmarthia trivialis	small tree	3-D
Marmarthia pearsonii	small tree	3-D
Platanites marginata	small tree	3-D
Cissites panduratus	small tree	3-D
Bisonia niemii	small tree	3-D
Erlingdorfia montana	small tree	3-D
Paranymphaea hastata	vine	3-D
Zizyphus fibrillosus	vine	3-D
Philodendron-like Araceae	vine	2-D
Nilssonia yukonenesis	understory cycad	3-D
Onoclea sensibilis	understory fern	3-D
Palaeoaster inquirenda	woody fruit	3-D
Parataxodium cuneatum	conifer tree	2-D

Table 2
Animal Species Represented in the Hell Creek Diorama

Species	Type of Animal	Rendering
Stygimoloch spinifer	pachycephalosaur dinosaur	3-D whole body
Triceratops horridus	horned dinosaur	3-D rotting skull
Ornithomimus sp.	ostrich dinosaur	2-D
Tyrannosaurus rex	carnivorous dinosaur	2-D body, 3-D tracks, and sound
Edmontosaurus annectens	duckbilled dinosaur	2-D bodies
Indeter. pterosaur	flying reptiles	2-D bodies
Birds	birds	2-D bodies
Neurankylus eximius	turtle	3-D whole body
Didelphodon vorax	marsupial mammal	3-D whole body
Mesodma sp	multituberculate mammal	3-D whole body
misc. insects	insects	3-D whole bodies

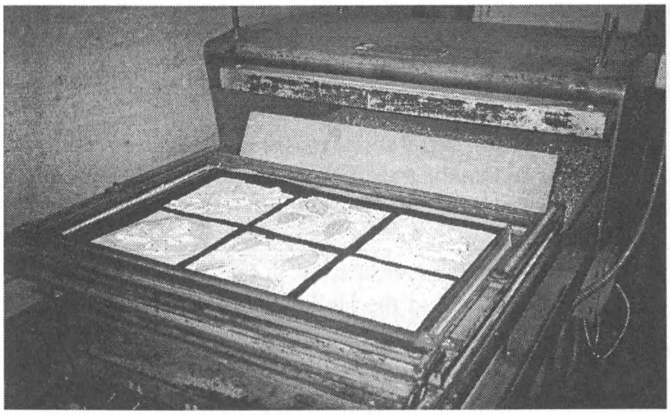

Figure 4. Vacuum press with molds of reconstructed Cretaceous leaves. Mylar sheets are sucked down on these molds and heated to conform to the molds. Then the leaves are hand-cut from the sheets by teams of volunteers.

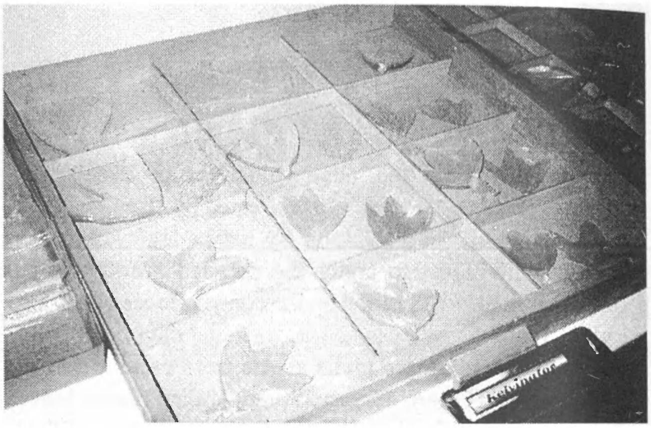

Figure 5. Unpainted mylar leaflets of *Erlingdorfia montana.*

Figure 6. After being hand cut from the sheets of mylar, the plastic leaves are glued to stems made of wire with plastic sheaths. Each leaf is painted several times.

reconstruction. The animal models were built by DMNH taxidermists who constructed clay models which were molded in latex and cast in fiberglass (Figure 7). Final coloration of the animals was based on best guesses and an acknowledgment that these were forest animals. The sole exception to this was the *Neurankylus* turtle. The same species of turtle had previously been discovered in New Mexico with a spotted coloration preserved (17, 18).

CONCLUSIONS

The goal of the Hell Creek diorama in *Prehistoric Journey* is to immerse the visitor in an accurate reconstruction of North Dakota as it was 66 million years ago (Figure 8). The diorama is realistic enough that the visitor can momentarily suspend disbelief and time-travel to a different place and time, one populated with accurately revived plants and animals (19).

The visitor descends the stairs from the mezzanine and down a steep stream bank into a lush riverside forest composed of broad-leaved trees. Across the small waterway on a sandy

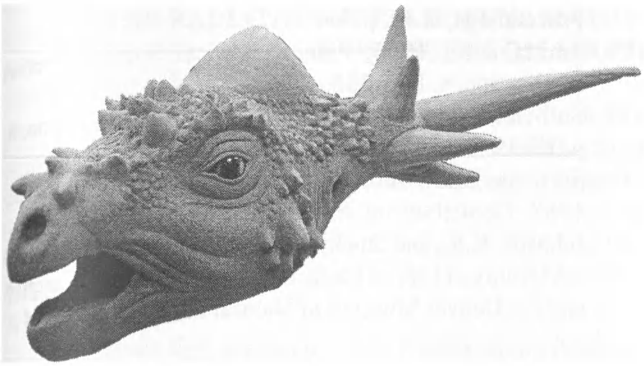

Figure 7. The clay head of *Stygimoloch spinifer*, a pachycephalosaur known from two partial skulls and one complete skeleton from the Hell Creek Formation.

point bar, two 12-ft-long (3.7 m), brightly colored male *Stygimoloch* dinosaurs challenge each other in an impressive mating ritual. With lusty fervor, they aggressively display the formidable array of bony spikes that crown their thick, bony skulls. Near their feet, a *Triceratops* skull, leaves, and woody debris lay partially buried in the sand deposited by a recent flood. Gigantic *Tyrannosaurus rex* footprints trap pools of water. Above the stream bank, small cycadlike *Nilssonia*, ground ferns, and leaf litter cover the forest floor while mushrooms emerge in sheltered niches. Bird and insect sounds are heard as a turtle's nest is invaded by two marsupials. A larger river can be seen in the background and a distant ostrichlike *Ornithomimus* dinosaur browses on *Nilssonia* leaves.

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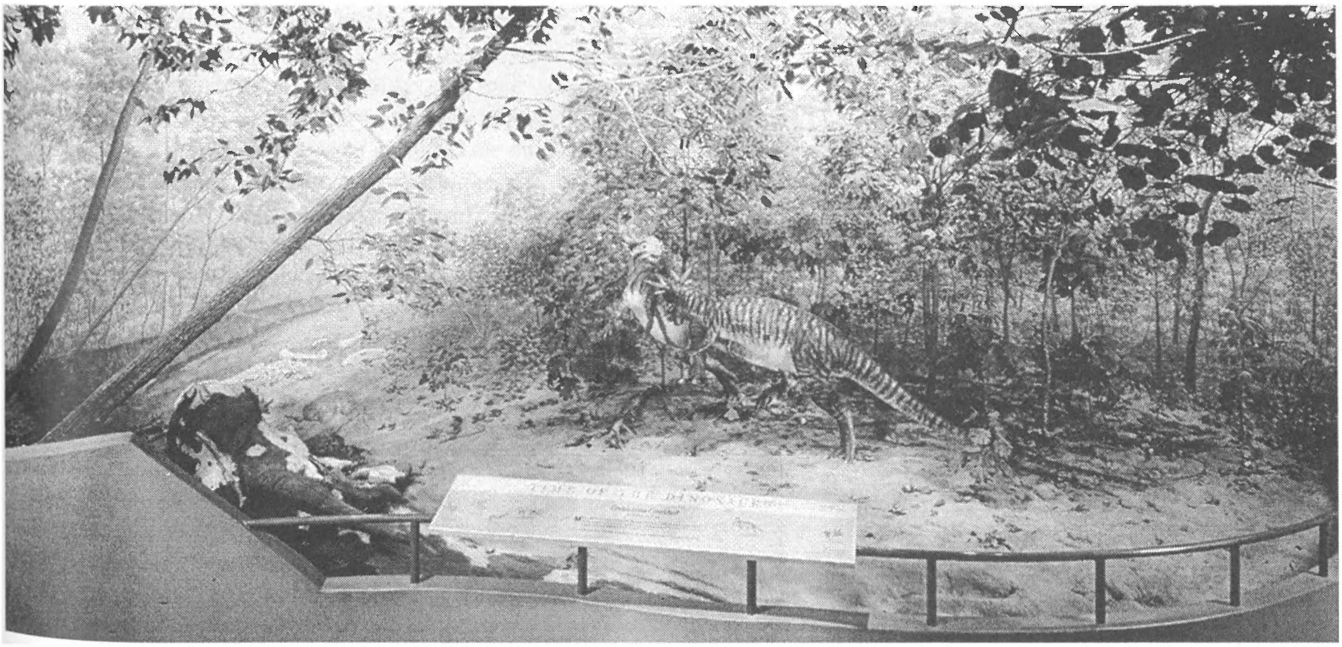

Figure 8. Diorama of the Cretaceous Hell Creek Formation

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THE RADIATION OF PALEOCENE MAMMALS WITH THE DEMISE OF THE DINOSAURS: EVIDENCE FROM SOUTHWESTERN NORTH DAKOTA

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INTRODUCTION

Mammals first appeared in the Triassic approximately 225 million years ago (1) but remained a minor and inconspicuous part of terrestrial faunas for the remainder of the Mesozoic Era (2). Although biologically distinctive during the Mesozoic, mammals did not begin to emerge as a morphologically and taxonomically diverse group until the Cenozoic Era, after the dinosaur extinction 65 million years ago. The processes by which "horses and tigers and things" evolved have operated over long timescales — millions to tens of millions of years — in order to produce the differences that characterize the orders and families of mammals. Nevertheless, to see incipient differences among the orders of mammals, one must look back to the beginning of the Cenozoic, that is, to the Paleocene mammalian radiations. The goal of this paper is to explain the significance of the Paleocene radiations in the evolutionary history of mammals and to review recent discoveries of Paleocene mammals in southwestern North Dakota from this critical interval of life's history.

THE PALEOCENE MAMMALIAN RADIATIONS

The Paleocene marked the beginning of a diversification of placental mammals that continued through much of the Cenozoic, evident in both numbers of taxa (3) and variation in morphology (4). This evolutionary radiation began during a dynamic period in earth history that included the dinosaur and ammonite extinctions, a major marine regression, climatic change, floral turnover, and intense volcanism (5). These events may have impacted on the evolutionary history of placental mammals. At the Cretaceous–Tertiary (K/T) boundary in North America, a major faunal turnover occurred among mammals in which a Paleocene mammalian community, containing diverse placental mammals, replaced a Cretaceous mammalian community, dominated by primitive marsupials and archaic multituberculates (6). Whether this change in mammalian communities occurred as a result of competition between mammalian species (5) or opportunistic replacement following mass extinction remains controversial in paleontology.

The mass extinction of the dinosaurs cleared many ecological niches and may have permitted placental mammals to diversify by releasing them from either competition with (7) or predation by (8) dinosaurs. Paleocene mammals, however, did not radiate immediately across all of the ecological niches that dinosaurs occupied during the Mesozoic. For example, there is a 10-million-year delay after dinosaur extinction before the appearance of mammals that approach dinosaurs in body mass (8–13). Nevertheless, the largest single increase in average body mass of mammals occurred at the K/T boundary (14), suggesting some sort of ecological release.

Taxonomically, the Paleocene radiations encompassed both archaic placental mammals (e.g., taeniodonts) and some of the earliest members of the extant orders of placental mammals (e.g., the earliest known Carnivora) (15). Traditionally, paleontologists have thought that the modern orders of mammals originated in a burst after the dinosaur extinction, during the Paleocene and Eocene (16). Some supraordinal groups of placental mammals (i.e., above the level of order) may have diverged during the Cretaceous as suggested, for example, by the occurrence of 80-million-year-old ungulate-like mammals in western Asia (17). Recent studies of DNA sequence divergence assuming a "molecular clock" (i.e., stochastically constant rates of nucleotide substitution through time) have yielded even older estimates for the divergence of the placental mammal orders, up to 129 million years ago (18, 19). In order for these early "molecular clock" origination times, some 64 million years older than fossil-based estimates, to be plausible, the Cretaceous record of mammalian evolution would have to be woefully incomplete. Empirical estimates of the completeness of the Late Cretaceous mammal record, however, demonstrate that this record is more complete, by at least an order of magnitude, than the maximum allowed by the "molecular clock" hypothesis, suggesting that the "molecular clock" estimates are too old (20). A more modest origination time, perhaps 70 million years ago, is more plausible (20). Sequence divergence could overestimate origination time if molecular evolution speeds up during times of evolutionary radiation. If so, then the "molecular clock" may have overestimated the origination time of other groups that diverged during a major radiation, such as the apparent deep Precambrian origins of metazoan phyla that appeared in the fossil record in a "Cambrian explosion" (21).

Finally, abundant evidence supports the Paleocene as a time of ecological, as well as taxonomic, diversification for mammals. Increases in body size (9, 14) and in variation of tooth shapes found among mammals (4, 9) indicate new dietary adaptations near the K/T boundary. For example, I have documented transformation in tooth shape in the diverse early

Paleocene condylarths (i.e., archaic ungulate mammals), showing a transition from insect-eating to more varied diets during their adaptive radiation (22). Because adaptive diversification of condylarths and other lineages of placental mammals — which serve as multiple, replicate examples (23) — did not occur until after the K/T boundary, it is likely that the Paleocene radiations are causally related to K/T boundary events, the dinosaur extinction in particular.

PALEOCENE MAMMALS OF SOUTHWESTERN NORTH DAKOTA

The most complete record of the Paleocene mammalian radiations occurs in North America, where paleontologists have found mammalian localities in sedimentary basins along the eastern flank of the Rocky Mountains (24–26). Although certain basins may preserve a remarkably continuous portion of the Paleocene mammalian record (e.g., middle to late Paleocene in the Crazy Mountains Basin, Montana), nowhere does a continuous and complete record of the entire Paleocene occur. For this reason, paleontologists have patched together a composite record of the succession of Paleocene mammals, by correlating local faunas from one basin to another (24). The resulting mammalian timescale is in relative time units: from oldest to youngest, the Puercan, Torrejonian, Tiffanian, and Clarkforkian North American land mammal ages (NALMAs), each divided into several numbered faunal zones. Eventually, as the fossil record improves, paleontologists will undoubtedly adopt a timescale based more nearly on radiometric dates then one constructed on faunal composition (27).

In North Dakota, Paleocene mammals occur at a few, widely dispersed localities of varying age. Richard C. Holtzman (28) and, more recently, Allen J. Kihm and his colleagues (29–31) have been studying several local faunas from North Dakota of Torrejonian and Tiffanian ages. Below, I report on a faunal sequence from southwestern North Dakota that includes mammals of Puercan, Torrejonian, and early Tiffanian age. This work is still very much in progress and represents a collaborative effort with Joseph H. Hartman and David W. Krause on the paleontology and stratigraphy of southwestern North Dakota. Among our goals are to correlate the terrestrial and marine fossil records and to use fossil mammals to date fluctuations of the Cannonball Sea, a major intracontinental seaway that divided North America during the Paleocene (32). Specific locality data are available to qualified researchers from either Joseph H. Hartman or me.

PITA Flats Locality (PTRM-V86005)

Dean Pearson of the Pioneer Trails Regional Museum, Bowman, North Dakota, discovered this vertebrate locality in the lower part of the Ludlow Formation (Fort Union Group) in 1986. In 1994 and 1995, field crews from the State University of New York at Stony Brook (SUNY-SB) recovered fossil mammal specimens from this site, most of which occurred in an anthill (Table 1). The most biochronologically informative taxon recovered is the condylarth *Oxyacodon priscilla* (Figure 1), known only from two faunal zones of the Puercan NALMA (early Paleocene), Pu2 and Pu3 (24). Mammalian taxa indicate that PITA Flats is early, but not earliest, Paleocene in age. PITA Flats is in superposition over vertebrate localities in the Hell Creek Formation, at which occur Cretaceous-age mammals of the Lancian NALMA (33).

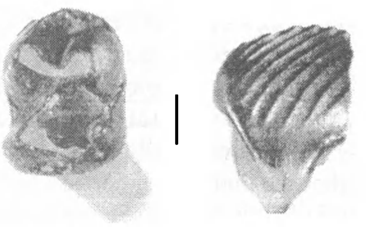

Figure 1. Mammalian Fossils, PITA Flats Locality. Lower left second molar of *Oxyacodon priscilla* in occlusal view (left) and fragment of lower left fourth premolar of *Mesodma* sp. in labial view (right). Scale bar equals 1 mm.

Table 1. Faunal List and Taxon Ranges, PITA Flats Locality

Taxon	Range
Order Multituberculata	
Mesodma sp.	Campanian–late Paleocene
Order Condylarthra	
Oxyacodon priscilla	Pu2–Pu3 (early Paleocene)
Protungulatum sp.	?Maastrichtian–early Paleocene

Brown Ranch Localities

The Brown Ranch localities were discovered in 1986 by a joint University of North Dakota (EERC)/SUNY-SB field crew. These localities occur in the upper part of the Ludlow Formation, between westward directed tongues of the Cannonball Formation (32). Four fossil mammal specimens were recovered, of which only three are identifiable to genus or species (Table 2). A taeniodont, probably *Conoryctella dragonensis*, is represented by upper and lower premolars, probably belonging to the same individual (Figure 2). *Conoryctella dragonensis* is known with certainty only from the type specimen from the middle Paleocene Dragon local fauna of Utah (34), which is from the earliest faunal zone of the Torrejonian NALMA (To1). The other identifiable mammal is the mesonychid (archaic ungulate) *Dissacus* (Figure 2), which ranges from the second faunal zone of the Torrejonian, To2, well into the Eocene (34). Mammalian taxa indicate that the Brown Ranch localities are middle Paleocene in age, specifically early Torrejonian, To1 or To2 (24).

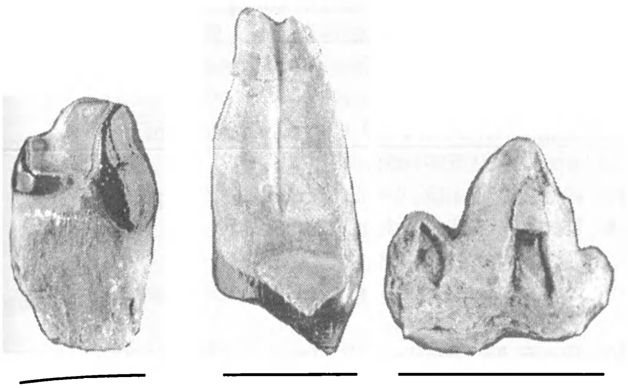

Figure 2. Mammalian Fossils, Brown Ranch Localities. *Conoryctella* cf. *C. dragonensis*, right lower fourth premolar in labial view (left) and right upper fourth premolar in distal view (center). *Dissacus* sp., right lower postcanine in labial view (right). Scale bar equals 10 mm.

Table 2. Faunal List and Taxon Ranges, Brown Ranch Localities

Taxon	Range
Order Taeniodonta	
Conoryctella cf. *C. dragonensis*	To1 (middle Paleocene)
Order Mesonychia	
Dissacus sp.	To2–Eocene

X-X Locality (L28)

The X-X Locality (L28 of Hartman) occurs in the lower part of the Tongue River Formation, above the highest tongues (Three V) of the Cannonball Formation. Because of intensive screen-washing efforts of crews from the State University of New York at Stony Brook and University of North Dakota (EERC) in 1990–1992, the mammalian fauna of X-X is better known than that of the other localities (Table 3). Mammals indicate a late Paleocene age (Tiffanian NALMA) for this locality, probably faunal zone Ti2 (24). Of the mammalian taxa recovered, the most informative biochronologically is *Plesiadapis anceps* (Figure 3) because of Gingerich's (35) well-documented biostratigraphic zonation of plesiadapiforms with tightly constrained ranges of plesiadapiform species. *Plesiadapis anceps* is known only from Ti2 (35). Other taxa have observed ranges that are consistent with a Ti2 age, including an occurrence of the condylarth *Ectocion* (Figure 3), usually considered an "index fossil" for the Tiffanian (36).

DISCUSSION

The succession of Paleocene mammals of southwestern North Dakota, outlined above, spans the early Paleocene through the early part of the late Paleocene, but this sequence is far from continuous. Gaps in time exist between each of these local faunas, and samples are still small. As a result, only a few of all of the mammalian lineages known to have existed during the Paleocene are represented in these local faunas. Nevertheless, the sequence of Paleocene mammals in southwestern North Dakota expands current knowledge of the Paleocene mammalian radiations geographically, to include mammals of the coastal plain along the Paleocene Cannonball Sea. Future fieldwork in southwestern North Dakota should result in new insights into geographic, ecological, and temporal aspects of the Paleocene mammalian radiations.

Table 3. Faunal List and Taxon Ranges, X-X Locality

Taxon	Range
Order Multituberculata	
Ptilodus sp. C	Ti2–Ti3
Neoplagiaulax hunteri	Ti1–Ti4
Microcosmodon sp.	Paleocene–Eocene
Order Marsupialia	
Peradectes sp.	Paleocene–Eocene
Order Plesiadapiformes	
Plesiadapis anceps	Ti2
Order Proteutheria	
Propalaeosinopa diluculi	Torrejonian–Tiffanian
Palaeotomus cf. *P. senior*	Ti1–Ti2
Order Condylarthra	
Ectocion collinus	Ti1–Ti2

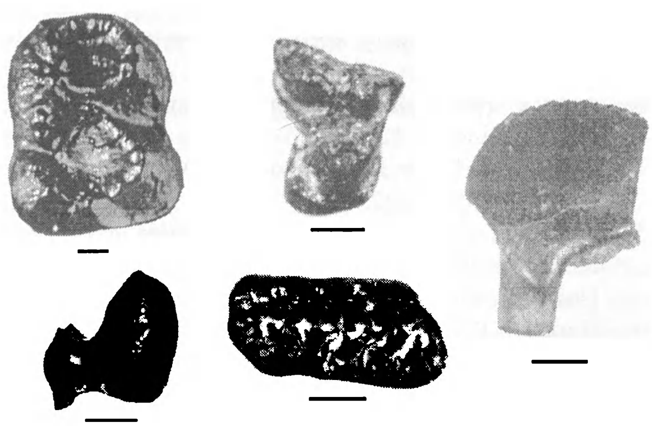

Figure 3. Mammalian Fossils, X-X Locality. *Ectocion collinus*, right lower first molar in occlusal view (upper left); *Plesiadapis anceps*, right lower fourth premolar in labial view (lower left); *Propalaeosinopa diluculi*, right upper first molar in occlusal view (upper center); *Ptilodus* sp. C, left lower first molar (lower center); and *Neoplagiaulax hunteri*, fragment of left lower fourth premolar (right). Scale bar equals 1 mm.

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THE SEAS CAME IN AND THE SEAS WENT OUT: THE USE OF FOSSIL POLLEN, SPORES, AND ALGAL BODIES TO RECOGNIZE ANCIENT SHORELINE ENVIRONMENTS IN THE LUDLOW AND CANNONBALL FORMATIONS (PALEOCENE) OF WESTERN NORTH DAKOTA

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INTRODUCTION

Pollen, spores, and other acid-resistant microfossils (collectively termed palynomorphs) are the most abundant and diverse group of fossils known from the Ludlow and Cannonball Formations of southwestern North Dakota. These fossils are present in nearly every stratum and, therefore, provide a paleontological record from nearly all paleoenvironments, including the shoreline and nearshore depositional settings. However, because of the ease with which palynomorphs may be transported by wind or water, care must be utilized if the paleoecology of the ancient organisms is interpreted based upon their paleoenvironmental distribution.

Within modern environments, recurring palynomorph assemblages have been associated with some shoreline settings (1–3). A similar relationship between palynomorph assemblages and depositional environment has also been recognized in ancient shoreline and fluvial deposits (4–8).

Objectives

The primary objectives of this study are to determine if distinctive associations of fossil palynomorphs are present within ancient shoreline environments and to recognize palynomorph taxa that are characteristic of any of the depositional environments. Once identified, distinctive palynomorph associations can be used to help sedimentologists interpret depositional environments, especially in areas of poor outcrop or from well core or cutting samples.

Location of Study Area

The shoreline strata within the Ludlow and Cannonball Formations are exposed in the badland terrain within the valleys of the Little Missouri River and its tributaries within northern Slope County, North Dakota. The sampling sites referred to in this report, M1721a-b, M2187, and M1720, are located within T. 135 N., R. 105 W (Figure 1).

GEOLOGIC SETTING

Stratigraphy

The strata exposed within the study area are assigned to the Ludlow and Cannonball Formations. The Cannonball Formation is present as two relatively thin beds that are intercalated with the Ludlow Formation. The Cannonball beds are interpreted as tongues, extending westward from the main body of the Cannonball Formation, which is located in south-central North Dakota. Recently, these tongues were designated as the Boyce (lower bed) and Three V (upper bed) Tongues of the Cannonball Formation (9). With the exception of the Boyce and Three V Tongues, the strata above the top of the Hell Creek Formation (Upper Cretaceous) through the base of the Bullion Creek or Tongue River Formation (Paleocene) are assigned to the Ludlow Formation. This usage of the Ludlow is similar to that of Moore (10) and Belt and others (11).

Lithology

The Ludlow Formation consists of interbedded sequences of coal, claystone, siltstone, mudstone, and sandstone that are dominantly dark brown, gray, and black, although some sandstone beds are yellow to tan. In general, the strata are relatively well bedded and laterally persistent; many distinctive beds can be traced for some distance in the badland exposures. The Boyce and Three V Tongues of the Cannonball Formation are dark brown, gray to black claystone and mudstone.

Paleoenvironments

The marginal marine, brackish water depositional environment of the Boyce and Three V Tongues has long been recognized by to the presence of a distinctive bivalve fauna, including *Crassostrea*, *Ostrea*, *Corbicula*, and *Corbula* (12). The Ludlow Formation is recognized as fluvio-deltaic in origin, representing the deposits of rivers that were prograding eastward into the Cannonball Sea. Within this setting, the deposits of a number of deltaic subenvironments can be identified, including distributary channels, natural levees, crevasse splays, freshwater lakes, marshes, swamps, and bays or inter delta-lobe basins (7, 11). Evidence that the Boyce Tongue paleoenvironment was initially a freshwater lake that increased in salinity over time is present at one locality (M1721a). The basal part of the tongue bears freshwater bivalve and gastropod fossils, overlain by a bed containing bivalves that are characteristic of brackish water.

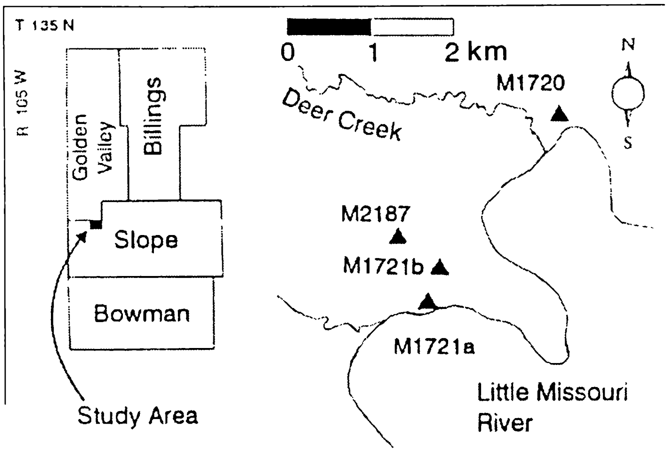

Figure 1. Location of study area in southwestern North Dakota.

METHODS

Unweathered samples for palynologic analysis were collected during the process of making detailed measurements and descriptions of the strata. Each paleoenvironment is represented by many samples, providing a large database from which paleoenvironmental trends in palynomorph distribution were identified. The detailed lithologic descriptions were compared with published sedimentologic models and descriptions of deposits in modern depositional environments to identify the conditions under which the strata were deposited. Acid maceration techniques described by Doher (13) were used to prepare the palynomorphs for microscopic study.

The abundance of palynomorph taxa in each sample was determined by counting all identifiable palynomorphs along randomly selected traverses of the microscope slides. Nearly all samples are dominated by pollen grains produced by the conifer families Taxodiaceae, Cupressaceae, and Taxaceae (TCT), potentially masking paleoenvironmentally significant occurrences of less abundant palynomorph types. For this reason, the TCT pollen were excluded from the paleoenvironmental analysis. At least 250 non-TCT palynomorphs were counted from each productive sample. The non-TCT palynomorph abundances were normalized to yield the relative abundance data used in the paleoenvironmental analysis.

The normalized data were analyzed by two methods, subjective analysis of pollen diagrams and objective analysis through ordination, a multivariate statistical technique. In addition, the ecologic requirements of the modern descendants of the organisms that produced the palynomorphs were evaluated. In many cases, especially for algal and spore taxa, there appears to be relatively good association between the paleoenvironments determined from sedimentologic data and the presumed paleoautecology of a palynomorph based on the ecology of its modern descendant taxa. This method is used conservatively and was not applied to angiosperm or gymnosperm taxa.

RESULTS

One hundred and thirty-three palynomorph taxa, or groups of morphologically similar taxa, are present in sufficient abundance (very rare taxa are excluded) within 112 palynomorph-bearing samples. These palynomorphs can be classified into several palynological groups: 1) angiosperm pollen; 2) gymnosperm pollen (dominated by conifers, but other gymnosperms are present); 3) spores of ferns, mosses, and microphyllous vascular plants; 4) cysts of unicellular algae, predominantly dinoflagellates; 5) spore bodies produced by green algae; and 6) preserved algal colonies.

Numerous palynomorph taxa characterize the marginal marine, brackish water strata of the Boyce and Three V Tongues. Included are the dinoflagellate cysts *Williamsidinium* sp., *Senegalinium* spp., *Spinidium? pilatum*, and an unnamed taxon referred to as "dinoflagellate sp. 1." In addition, several other algal palynomorphs are common, especially *Micrhystridium* type 1 and acritarch type 4. Several spore and pollen taxa also have their most conspicuous occurrences in the brackish beds, including *Triporopollenites granilabratus*, *Nyssapollenites* sp., and *Stereisporites* spp.

Deposits interpreted to represent slightly brackish water environments are characterized by a number of algal palynomorphs, including *Botryococcus* sp., *Cymatiosphaera*, *Micrystridium* type 1, *Ovoidites* cf *O. ligneolus*, *Pediastrum* sp., *Pterospermella australis*, and acritarch types 1, 2, and 3. Associated lacustrine deposits are characterized by *Micrhystridium* type 2, *Ovoidites* cf. *O. ligneolus*, *Pediastrum* sp., *Polyoporina* sp., and acritarch type 2, all of which are algal in origin. The sedimentologic evidence for increasing salinity over time during deposition of the brackish water beds is supported by the palynomorph distribution patterns, not only in the Boyce Tongue, but also in the Three V Tongue. In both tongues, the basal samples tend to bear relatively high percentages of the freshwater colonial alga *Pediastrum* and *Ovoidites* cf. *O. ligneolus*, a spore probably produced by freshwater, zynemataceous algae (Figure 2). These freshwater indicators diminish in abundance upward through both tongues, and dinoflagellate cysts, considered to represent more marine conditions, become more abundant.

The strata directly overlying the Boyce and Three V Tongues contain considerably more silt and fine-grained sand, representing the infilling of the marine/brackish water bay environment, probably due to crevassing of the distributary channels into the bay setting. Although based on sedimentologic character these strata still appear to represent

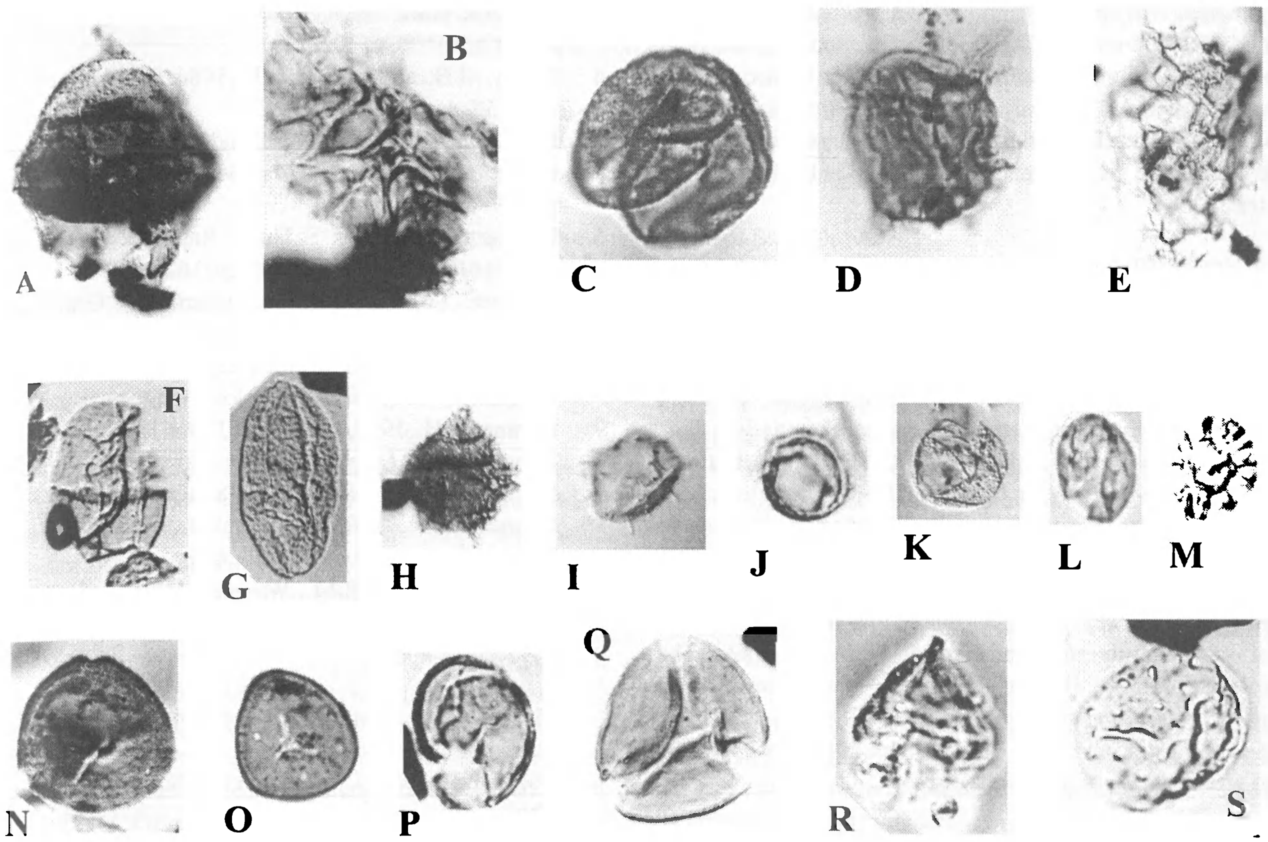

Figure 2. Palynomorphs typifying shoreline deposits: A) *Williamsidinium* sp. (400x); B) *Botryococcus* sp. (1000x); C Acritarch type 1 (1000x); D) *Cymatiosphaeara* sp. (1000x); E) *Pediastrum* sp. (400x); F) Dinoflagellate sp. 1 (400x); G) *Ovoidites* cf. *O. ligneolus* (400x); H) *Spinidium*? *pilatum* (400x); I) *Micrystridium* type 1 (1000x); J) *Micrhystridium* type 2 (1000x); K) Acritarch type 4 (400x); L Acritarch type 2 (400x); M) *Pterospermella australis* (400x); N) *Triporopollenites granilabratus* (1000x); O) *Stereisporites* sp. (1000x); P) Acritarch type 3 (1000x); Q) *Nyssapollenites* sp. (1000x); R) *Senegalinium* sp. (400x); and S) *Polyoporina* sp. (1000x).

subaqueous deposition, their palynomorph assemblages are completely dominated by pollen and spores that originated in terrigenous environments. Presumably these palynomorphs were transported by water with the coarser-grained clastic sediments.

DISCUSSION

Interpretation of the palynological assemblages from the shoreline deposits requires integration of data from several sources, including physical sedimentology, invertebrate paleontology, palynomorph transport, and the paleoautecology of the organisms that produced the palynomorphs. Using these data sources, the palynomorph assemblages allow recognition of nearshore and shoreline deposits within the Ludlow and Boyce and Three V Tongues of the Cannonball Formation.

Typically, paleoenvironmentally sensitive algal palynomorphs are present within the deposits that originated in marine, marginal marine, and freshwater environments. However, many pollen grains and spores that are common in the riverine environments are also found in the shoreline sediments. These terrestrial palynomorphs were transported into the marginal marine environment by wind or water. Typically, their relative abundance increases as the silt-sized, terrigenous clastic content of the deposit increases. Since spores and pollen tend to have the hydrodynamic properties of silt-sized particles, most of them were probably transported into the brackish water settings by water, although airborne transport of the pollen from the coastal and inland floras certainly did occur.

The utility of paleoenvironmentally distinctive palynomorph assemblages has been demonstrated by confirming the presence of the Boyce or Three V Tongues in measured Section M1720 and in the stratigraphic test well M2187 (unpublished studies, 12). On the basis of the presence of marine ichnofossils, shoreline deposits of similar age to the

Boyce and Three V Tongues have been recognized in southeastern Montana (14). Somewhat younger shoreline deposits within southwestern North Dakota have also recently been identified (15). Analysis of palynomorph assemblages could confirm marine influence within these strata and would help recognize additional shoreline deposits that may be present.

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THE DISCOVERY AND PRELIMINARY RECORD OF NORTH DAKOTA PALEOCENE MAMMALS FROM THE LLOYD AND HARES LOCALITIES

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INTRODUCTION

Mammalian local faunas represent a significant means to interpret the chronostratigraphy of Paleocene nonmarine and marine strata in North Dakota (1). The Lloyd and Hares Localities may provide a key piece of information to interpreting the timing of the regression of the Cannonball Sea, as contemporaneous localities in fluvial channels occur within a few meters of the top of the Cannonball Formation. This report provides documentation of the original Lloyd and Hares Locality and a preliminary chronostratigraphic assessment of the newly discovered Lloyd and Hares II Locality, representing vertebrate-bearing deposits at the base of the Tongue River Formation in Grant County, south-central North Dakota.

THE ORIGINAL LLOYD AND HARES LOCALITY

Background

The simple discovery in 1913 of a new mammalian locality in North Dakota belies a history of confused locality data and notices of taxa based on specimens that have apparently been lost for some time. As part of an effort to relocate reported North Dakota mammalian localities, the authors investigated the report of mammals (Hartman Locality L5384) first given by Lloyd and Hares in 1915 (2) and determined its original geographic location. In the process, we discovered specimens from a contemporaneous new locality (Lloyd and Hares II Locality).

Lloyd and Hares (2) gave a somewhat disconnected account of the discovery of two mammalian teeth from "the north bank of Heart River in Tp. 136 N., R. 88 W." in "an erosion channel from 30 to 50 feet [9.1 to 15.2 m] deep in the Cannonball member [Formation] filled with the channel deposits of a Fort Union [Group] stream." U.S. National Museum paleontologist J.W. Gidley identified the two mammalian specimens as *Euprotogonia* sp. (second lower molar of the left jaw) and *Pantolambda cavirictus* Cope (upper premolar), and the crocodile *Champsosaurus* and turtle *Lepisosteus* (2). We report this collection as from the Lloyd and Hares Locality. Lloyd and Hares (1) noted that lenses of conglomerate are found at this and other localities near the base of the Fort Union along the Heart River, representing an unconformity "such as would be expected in a transition from marine to continental sedimentation." Gidley's identifications were used by Thom and Dobbin (3) to indicate an age equivalence from these basal Tongue River channel deposits with that of the Lebo Formation of south-central Montana.

Simpson (4) reported on the Lloyd and Hares fossil occurrence, adding "Billings County" to the locality data on the basis of a misinterpretation of the township and range (see Holtzman [5]), and retained *Euprotogonia* as a junior synonym of *Tetraclaenodon*. Note that reference to Billings County was in error, as the township and range given by Lloyd and Hares (2) clearly places the locality in Grant County (in Morton County at the time of collection). Jepsen (6) followed the Billings County reference and added that this genus "is also reported from the Rock Bench [Quarry and] from the lower part of the Melville [Formation]" suggesting that the 'Tongue River' of North Dakota might be correlated with the Lebo (and the Torrejon), in contradiction to the more general belief that the Lebo [Formation] is older than and below the Tongue River." Simons (7) continues the "Billings County" referent for *Pantolambda cavirictus*. Sloan (8) stated that "Jepsen (1940) reported a faunule of late Torrejonian age, collected many years earlier near Heart Butte." The names, Heart River, as used by Sloan (8) in a locality correlation diagram, and Heart Butte have more or less stuck with the use of the faunule first noted by Lloyd and Hares (below see also West [9]). The subsequent use of Heart Butte (10) is unfortunate in that Sloan only used the butte as a general reference (it is located 16 km to the northwest of the locality), while the locality is associated with a meander bend of the Heart River, a potentially meaningful locality name. Holtzman (5) referred to the Lloyd and Hares (2) mammalian faunule as from the Lloyd and Hares Locality and the Heart River Locality. Holtzman (5) commented, "a channel that matches the Heart River locality of Lloyd and Hares can be found in NW¼ sec[.] 18, T136N, R88W, Grant County, North Dakota." Holtzman added that he found no vertebrates at this locality but that they may have been removed by subsequent erosion.

Present Studies

The Lloyd and Hares Locality, as used herein, represents the names Heart Butte and Heart River. We found that the discovery of the mammals from the Lloyd and Hares Locality was made by the crew of E.R. Lloyd in 1913 in the "north bluff of Heart River in sec. 23, T. 136 N., R 88 W." (Figure 1). The bluff consisted of "buff and gray sandstones containing lenses of conglomerate from which were collected, mammal teeth, fish and turtle remains, etc." This information was obtained from a photo (11) (Figure 2a). A second Lloyd photo (12) of the same bluff, viewed to the north, shows an "apparent angular unconformity of sandstone and conglomerate upon light gray shales. All of the material, however, is probably Fort Union and the exposures are in the channel of an ancient river" (Figure 2b). Unfortunately, no record of this locality or collection can be found in Lloyd's field notes (13). In 1990, we examined the exposures in sec. 23, T. 136 N., R. 88 W., Crown Butte Creek SW Quadrangle, and found a remarkable set of slump blocks from just north of Heart River to the meander-shaped headwall cliff (again in imminent danger of slumping) (Figures 1, 2c, 2d). There is little reason to doubt that the NE¼ SE¼ of sec. 23 represents the area where the mammals of the Lloyd and Hares Locality were collected and the precise location is now lost to slumping and likely covered.

Fossil Mammals

After J.W. Gidley identified the specimens in 1915, they were incorporated into the U.S. National Museum (USNM) vertebrate collections as Specimen 7949 (Accession 56248). From that time on, although the taxa have been mentioned a number of times, no one has given evidence of actually examining the specimens. For example, Simons (7) stated,

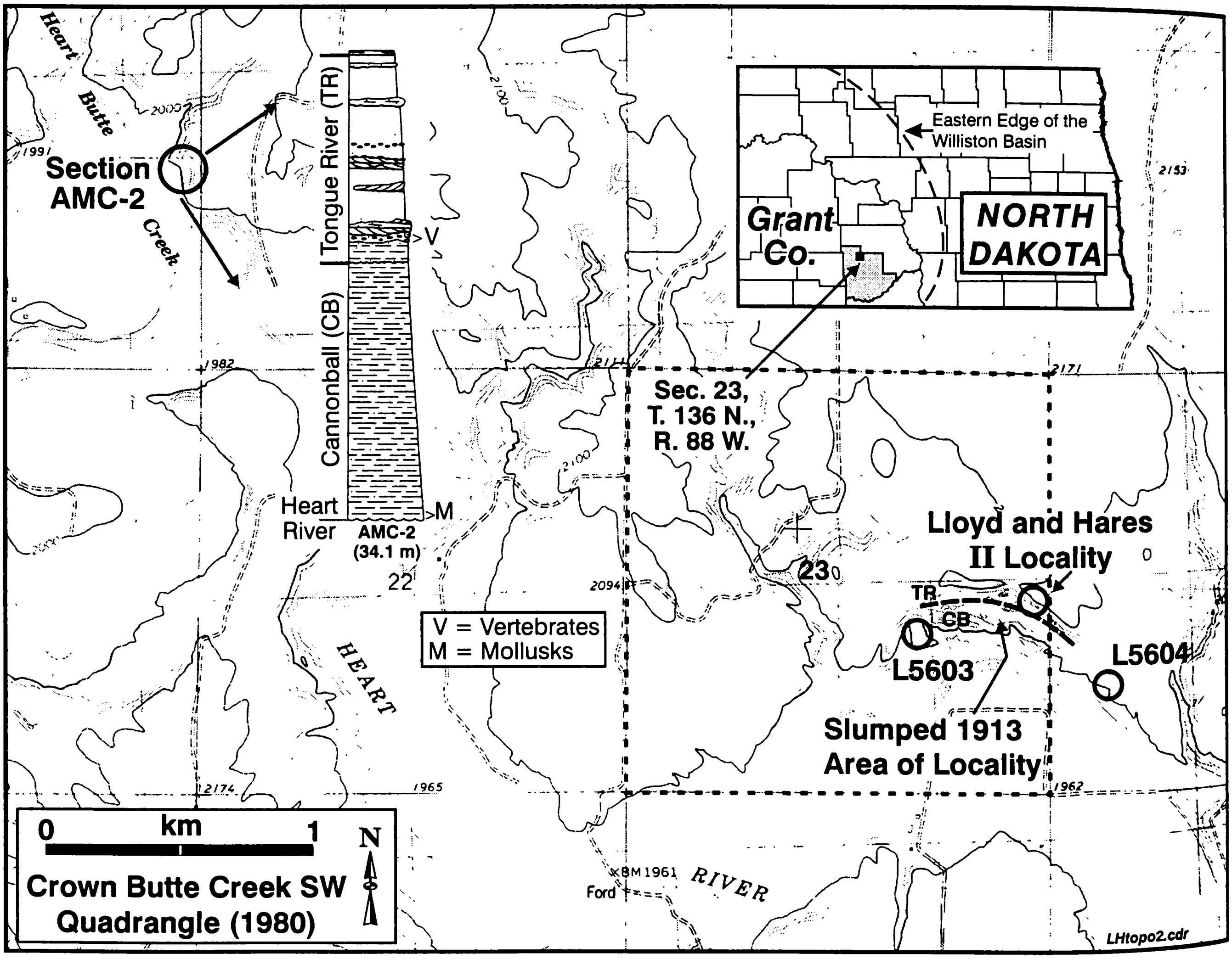

Figure 1. Study area of the Lloyd and Hares Localities. "Slumped 1913 area of locality" = original Lloyd and Hares Locality. Section AMC-2 slightly modified from Cvancara (19).

under the heading "Horizon and Locality" of referred specimens of *Pantolambda caviryctus*, that the specimen was from the "Fort Union formation, Billings Co., North Dakota," but his list of referred specimens does not include USNM 7949, and nothing in the following three pages of discussion includes reference or comment on the North Dakota specimen. He did state (much later in the paper) under the heading of "Geologic and Geographic Occurrence," that "specimens referable to the genus *Pantolambda* have not been found outside the localities discussed above except for a single upper premolar identified as *P. caviryctus* by Gidley, and recovered from the Fort Union formation of Billings, County, North Dakota." Our reading of this is that Simons did not actually see the specimen. Later, West (9) stated that "the easternmost occurrence of *Tetraclaenodon* is along the Heart River in Billings County, North Dakota (T. 136 N., R. 88 W.). A single tooth was reported by Lloyd and Hares . . . , and the pantodont *Pantolambda bathmodon* has also been found there . . . . This poor assemblage is here designated the Heart River local fauna." This report is interesting in that 1) this is the first identification of *P. bathmodon* Cope rather than *P. caviryctus* from the Lloyd and Hares Locality and 2) Jepsen (6), in his reference to *Pantolambda*, did not refer the specimen to species and gives no evidence of actually seeing the specimens. In reference to

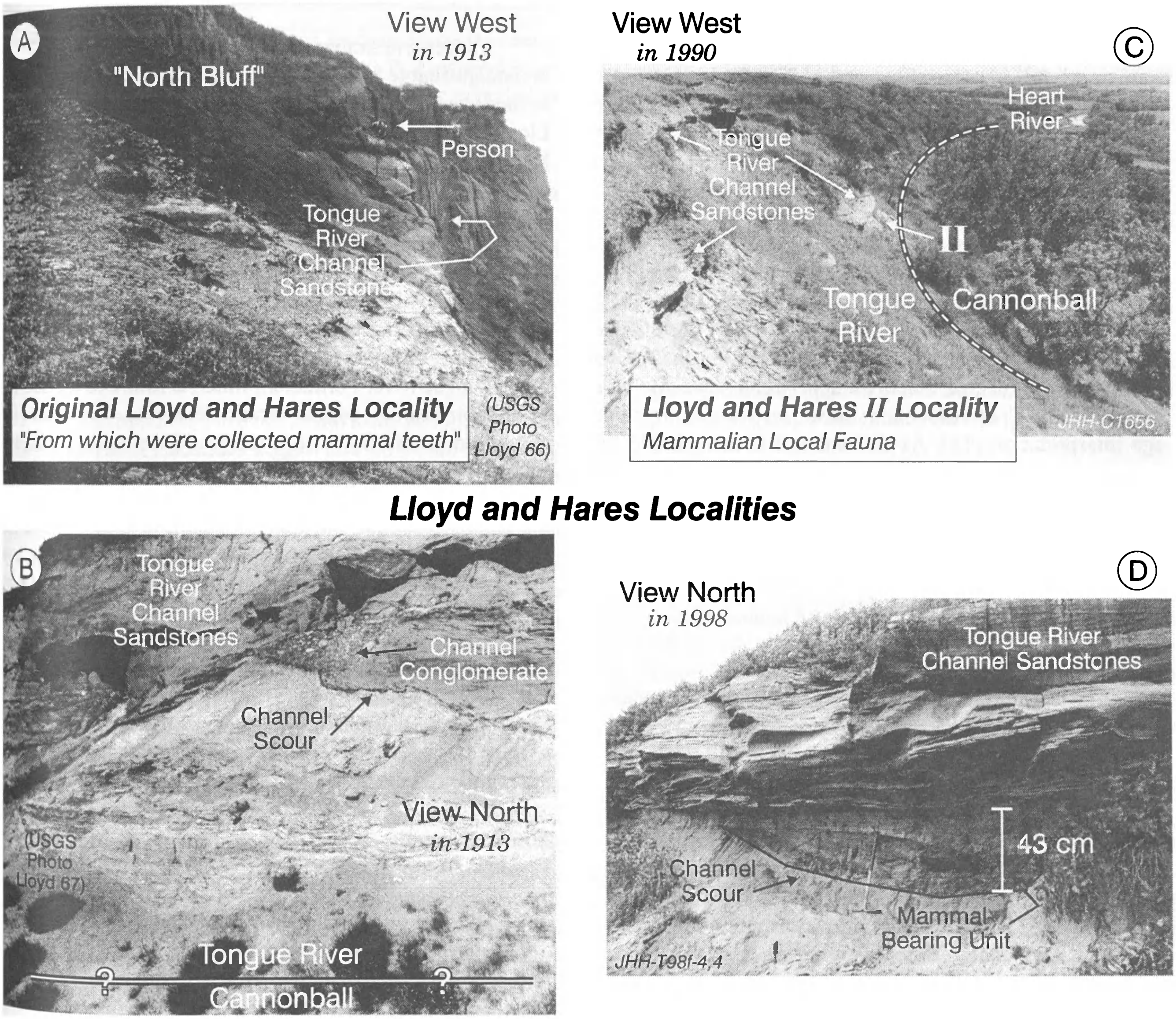

Figure 2. Lloyd and Hares Localities. A. Original Lloyd and Hares Locality in 1913. The quote is from photo caption (10). B. Channel deposits at the Lloyd and Hares Locality (11). C. View of north bluff of Lloyd and Hares II Locality in 1990. D. View of mammal-bearing Lloyd and Hares II Locality.

Tetraclaenodon, West (14) stated that "the other specimens from assorted localities in Wyoming, Montana, North Dakota and California fit easily into *T. puercensis*." Note that West did not list specimen numbers of referred specimens in this paper, but he stated "I am sure I actually looked at the specimens, most likely in Washington, but they might have made their way to the Milwaukee Public Museum [MPM] (where I did most of that phenacodont work)" (15). Neither MPM nor USNM has a record of such a loan transaction. Holtzman (5) stated "both of the specimens must now be considered lost . . . attempts by the [USNM] museum staff and me to locate them have been fruitless." And finally, Thewissen (16) stated "phenacodontids have been reported from a Torrejonian locality . . . ; a single specimen [was] identified by Gidley as '*Euprotogonia* sp.' (now *Tetraclaenodon*)." In this case as well, there is no evidence to suggest the specimens were examined (17). Our efforts at the USNM, which included going through all of the drawers with Paleocene of North America specimens, proved to confirm Holtzman's assessment.

Age Interpretation

If the original identification of the specimens is correct, *Pantolambda* is known only from the late Torrejonian (To3) and questionably from the earliest Tiffanian (Ti1). *Tetraclaenodon* is known from the middle to late Torrejonian (To2–To3). Therefore, the locality is late Torrejonian (To3) in age. Jepsen's (6) comparison to the upper Lebo–lower Melville portion of the Crazy Mountains Basin section confirms this age interpretation (18). As the material is unavailable for examination, this age assessment must be considered tentative. A recent compilation (10) gave a Torrejonian or Tiffanian age to the locality.

LLOYD AND HARES II LOCALITY

Introduction

The relocation of the area of the Lloyd and Hares Locality prompted a search of current exposures. Specimens reported here were collected from a new but associated locality here referred to as Lloyd and Hares II. The names Heart River and Heart Butte are considered unacceptable because Heart Butte was never actually assigned with the intent to be a locality name and Heart River has the drawback as a name of potentially representing any number of fossil localities along the length of the Heart River through exposures of the Fort Union Group. Besides mammals discussed below, the Lloyd and Hares II material includes a vertebrate fauna characteristic of Paleocene clayball conglomerates and includes fish similar to *Lepisosteus*-type and "alligator gar," crocodiles and true alligators, and different species of turtle. These fossils presently provide no information about the age of the deposits, although the turtles have some limited potential for age corroboration if enough diagnostic material is collected.

Location

Like the Lloyd and Hares Locality, Lloyd and Hares II occurs in the NE¼ SE¼ of sec. 23, but is more precisely placed on southwest-facing exposures in the S½ NE¼ NE¼ SE¼, sec. 23, T. 136 N., R. 88 W., Crown Butte Creek SW Quadrangle (1980), Grant County, North Dakota, at an elevation of about 2079 ft (632 m) above mean sea level (Hartman Locality L5639) (Figures 1, 2c, 2d).

Geologic Context

The relative stratigraphic position of this locality is likely indistinguishable from the original Lloyd and Hares Locality in the lowermost strata of the Tongue River Formation. The Lloyd and Hares II Locality consists of inclined beds of a point bar, having an erosional base with the underlying sandstone, and truncated by the overlying horizontal rippled cross beds. Vertebrates were found from the conglomeratic base through irregularly bedded sandstone (representing a maximum thickness of 43 cm). A similar geologic section was described by Cvancara (19, AMC-16; 20, AMC-2) 8 km west in SE¼ sec. 16, T. 136 N., R. 88 W. The dark gray mudstone of the Cannonball Formation is unconformably overlain by silty shale of the Tongue River Formation, which is followed up-section by nodular-bearing, conglomeratic sandstone. Cvancara (19) also noted ganoid fish scales, shark and crocodile teeth, and bone fragments. In the Lloyd and Hares II Locality section, marine invertebrates were found at about 14.9 and 21.0 m below the mammal-bearing horizon. Cvancara (19) found marine mollusks at a similar horizon in the Cannonball, 18.7 m below the base of his Cannonball–Tongue River formational contact. In his section, the marine mollusks are about 20.3 m below the vertebrate-bearing beds (see Figure 1 inset Section AMC-2). Although the exact placement of the Lloyd and Hares Localities relative to the Cannonball–Tongue River formational contact cannot be precisely determined, comparisons to Section AMC-2 suggest that the localities are between 1.2 to 1.7 m above the base of the Cannonball.

Fossil Mammals

The mammals at the Lloyd and Hares II Locality provide an important opportunity to assess the age of the basal strata of this portion of the Tongue River Formation, following the retreat of the Cannonball Sea. This report represents the first specimens collected in 1998 from about 100 kg of screen matrix. Collections made in 1998 include a probable *Chriacus orthogonius* (Figure 3a), a tentatively identified neoplagiaulacid *Leptacodon* (Figure 3b), a second neoplagiaulacid (Figure 3c), a probable insectivoran similar

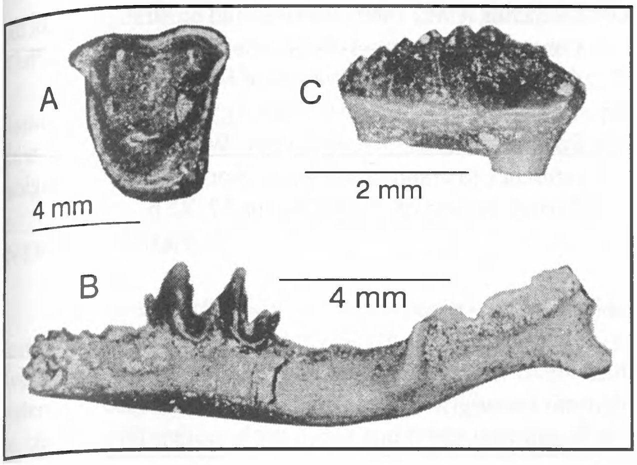

Figure 3. Mammal specimens from Lloyd and Hares II Locality. A. *Chriacus orthogonius*, occlusal view. B. *Leptacodon* sp., external view (see text). C. Neoplagiaulacid sp., external view.

to the *Litocherines*, and a plesiadapiform. *C. orthogonius* is a widespread late Torrejonian (To3) species, but it may also occur in earliest Tiffanian (Ti1). Because the remainder of the fauna cannot yet be identified to species, an age assessment is limited. Nothing in the fauna, however, excludes its consideration as late Torrejonian or earliest Tiffanian.

CONCLUSIONS

In combination, the mammalian identifications from the Lloyd and Hares Localities suggest that the fluvial channels in the lowermost Tongue River Formation are late Torrejonian (To3) in age, but an earliest Tiffanian (Ti1) age cannot at this time be rejected. Clearly, additional specimens and further study will provide a more definitive age interpretation. This age, however, delimits more precisely the maximum age of the regression of the Cannonball Sea from North Dakota from about 61 to 60 Ma.

ACKNOWLEDGMENTS

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VOLCANISM IN NORTH DAKOTA - THE SENTINEL BUTTE TUFF

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INTRODUCTION

A Paleocene volcanic airfall unit is preserved over a wide portion of McKenzie County, North Dakota (Figure 1). Everywhere it is found, it is associated with over- and underlying clay layers. These clay layers originated through the chemical alteration of the upper and lower portions of the once much thicker volcanic tuff unit. Thus they are bentonites, in this case composed of quite pure montmorillonite. This unusual occurrence of progenitor tuff still associated with its alteration products makes the Sentinel Butte Tuff a world-class unit for scientific study.

HISTORY OF DISCOVERY

Royse (1967) had noted the tripartite character of a distinctive bench-forming clay unit in the North Unit of Theodore Roosevelt National Park; two clay layers were commonly separated by a gray-white silt layer. The lower clay layer was generally regarded as bentonite because of its swelling character; the clay swells when wet, producing a popcorn-like surface exposure. A volcanic origin for this clay was suspected by some, and Forsman and Karner (1975) presented some preliminary evidence for this at the 1975 North Dakota Academy of Science meeting. The silt layer overlying this bentonite was first formally recognized as tuff by Forsman (1982). There have been several subsequent reports of this unit (Forsman, 1983; 1984; 1992; Forsman and LeFever, 1994).

EXTENT AND FIELD EXPRESSION OF OUTCROPS

Mapping of this tuff has been conducted by Forsman (1985) and by Larsen (1988). It extends over an area of nearly hundreds of square kilometers within McKenzie County, North Dakota. Very good exposures of the tuff and its enclosing bentonites occur within the North Unit of Theodore Roosevelt National Park, where special Park Service permission is required for study. Additional exposures occur primarily north and west of the park. Outcrops are of course plentiful within the Little Missouri Badlands, but only a few flatland outcrops occur, south of the town of Arnegard.

In the badlands, the lower bentonite commonly forms a prominent bench that can be stood upon. Because the clay is cohesive, it resists erosion better than mudstones, siltstones, sandstones, and lignites that comprise the Paleocene Sentinel Butte Formation. Thus the bentonite forms a local capping material, protecting underlying portions of cliffs from slope retreat (Figure 2). Overlying portions of the cliff at such sites have worn back, leaving the bentonite prominently exposed. Where preserved, the overlying gray-white tuff is recessed to the rear of the bentonite bench and is overlain by a second much less prominent minor bench formed by an overlying bentonite.

This bentonite-tuff-bentonite sequence ranges up to 7.5 m thick; the lower bentonite is up to 3.7 m thick, the tuff ranges from 0.6 to 2.4 m thick, and the upper bentonite ranges from 0.6 to 1.5 m thick. The unit occurs within the lower one-third of the stratigraphic section represented by the Sentinel Butte Formation. The lower bentonite is normally underlain by silty sandy mudstone but locally occurs a very short distance above what is referred to as the "basal sand" of the Sentinel Butte Formation. The upper bentonite commonly grades upward to carbonaceous shale, in turn overlain over a broad region by the "lower yellow bed" of the Sentinel Butte Formation.

PETROGRAPHY OF THE TUFF AND BENTONITE

The tuff is fine grained, consisting predominantly of <30-μm silt grains. A very small proportion of grains up to 60 μm in size also occurs. This silt fraction normally consists of 75% volcanic glass shards (Figures 3a, b). About 16% of the silt consists of volcanic phenocrysts and admixed detrital grains. Because of the lack of rounding of nearly all sedimentary grains of fine silt size, it is quite difficult to distinguish with confidence between the phenocrysts and admixed detrital silt grains in this tuff. Some crystals in the tuff are seen attached to glass and these are certainly phenocrysts. These are primarily plagioclase feldspars (Forsman, 1985).

Vesicles are common within the larger glass grains, giving a resemblance to minute pumice fragments. Microscopic examination reveals that enclosed vesicles are superhydrated, which is, of course, to be expected for glass of great age. But most grains show no modification other than this. Some grains host authigenic montmorillonite growths (Figure 3b), in a physical manner, suggesting clay growth in situ from glass grain surfaces rather than as strictly a mineralogic precipitate from groundwater. Authigenic clay comprises only 9% of any sample taken from central portions of the tuff layer (75% glass, 16% nonclay minerals, 9% clay). The <2-μm clay fraction of the tuff, as well as of the bentonites, consists of virtually pure montmorillonite, determined by x-ray diffraction. A chemical

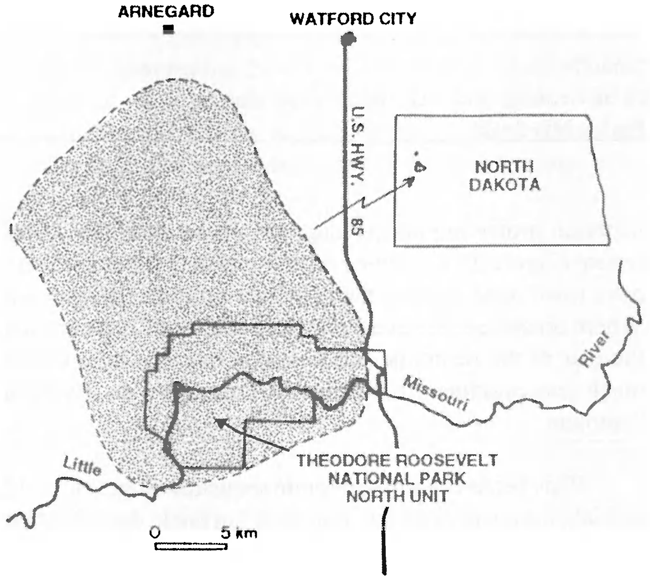


Figure 1. Areal extent of the Sentinel Butte Tuff exposures in western North Dakota.

and x-ray comparison of this clay with other clay layers of the Sentinel Butte Formation has been conducted (Forsman, 1985), distinguishing this clay as the only known bentonite within the formation.

Glass grains also occur within the upper and lower bentonites: 11% glass in the lower bentonite, and 4.5% glass in the upper bentonite. The glass is identical in composition to glass grains within the tuff. Microprobe analyses indicate a rhyolitic composition, 78.8% Si.

A MODEL FOR PRESERVATION OF THE TUFF

There are no nonvolcanic partings between the tuff and its enclosing bentonites. There are thin transition zones at the top and bottom of the tuff, within which clay content gradually increases toward the bentonites. This transition from tuff to bentonite is complete over a distance of only a few centimeters. A chemical examination of the glass-to-clay transition (Forsman, 1985) reveals that Mg and Fe must be introduced. Without magnesium, montmorillonite apparently will not form from glass in this geologic setting.

This tuff was undoubtedly beneath the groundwater table for most of its existence. Thus hypotheses requiring it to be dry in order to be preserved are untenable. Instead, the preservation of this tuff is probably based on a nonavailability of necessary elements for the conversion of rhyolitic glass to clay. If Fe and Mg were contributed from overlying and underlying sediments by groundwater flow following burial of the tuff, alteration of the tuff to clay would be expected to begin where the tuff contacts those sediments. Once the margins of the tuff altered to clay, a selective ion exclusion process may have operated. That is, clay layers may have acted as semipermeable membranes, allowing water to pass through, but restricting the further passage of crucial ions into the enclosed ash. This explanation remains untested. The groundwater causing alteration of the tuff is no longer available for study. And thus far, laboratory simulations would appear to supply only equivocal results because of the absence of geologically long periods of time for the experiment. The ion-exclusion hypothesis seems attractive in that it does not require the tuff to remain dry in order to be preserved. It also seems to fit the observation that wherever it is seen, the Sentinel Butte tuff is sandwiched between bentonites.

It should also be noted that the original volcanic ash for this unit was apparently deposited in a lake. The original ash accumulation was up to 7.5 m thick. Fossilized current ripples are preserved at the top of the rock unit immediately below the lower bentonite at several locations. Such ripples are common along shorelines of lakes. It is suggested that a much wider mantle of volcanic ash was rinsed into a lake, enabling incorporation of this interesting unit into the rock record.

IMPORTANCE OF THE SENTINEL BUTTE TUFF

The Sentinel Butte tuff provides solid evidence that significant volcanism occurred during the Paleocene Epoch in the Western Interior of North America. The tuff and possibly even its enclosing bentonites provide opportunities for petrographic fingerprinting, of use in checking for regional correlations with tuffs in other regions. The tuff also provides an opportunity for radiometric age determinations. This has

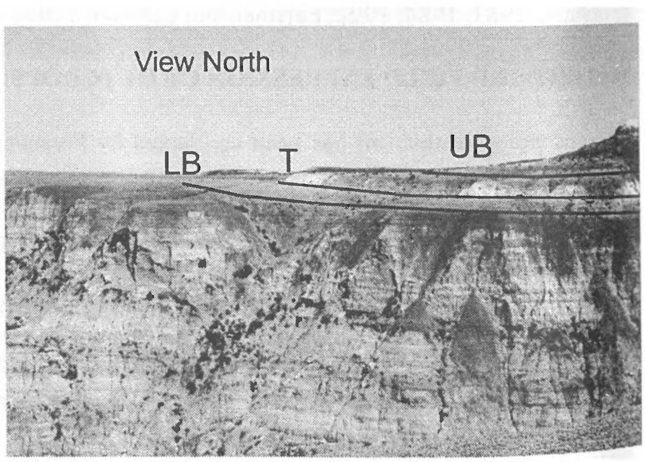
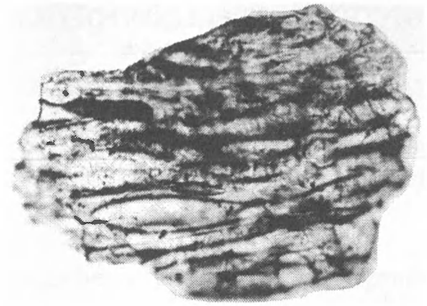
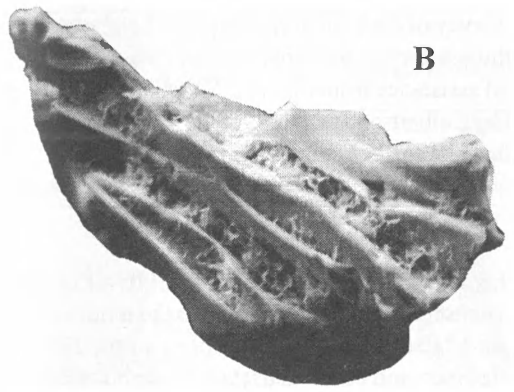


Figure 2. Field expression of the Sentinel Butte Tuff. View north of east flank of Squaw Creek valley in the North Unit of Theodore Roosevelt National Park, Billings County, North Dakota. LB (lower bench, T (Sentinel Butte Tuff), UB (upper bench).

A





B

Figure 3. Glass shards from the Sentinel Butte Tuff. A. Petrographic (plane light) view (40 mm maximum length). B. Scanning electron microscope view, incluling authigenic clay in elongate vesicles (65 mm maximum length).

thus far been problematic because of the very fine grain size of constituents in the tuff, but this problem will eventually be overcome as techniques for extraction of minute phenocrysts are developed. Dating this tuff would be of great value to geologists. Paleontologists continually desire absolute ages to assist them in developing the time-stratigraphic utility of fossils.

This tuff with its enclosing bentonites is a world-class deposit. The presence of well-preserved tuff in this Paleocene formation prevails over notions that glass cannot be geologically old. The bentonite, together with its progenitor ash, provides nearly unparalleled opportunity for evaluation of the formative process of bentonite. And because the progenitor ash and secondary bentonite are present over such a wide area, a comparison of the formative process from site to site can be conducted.

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WESTERN EXPLORATION ALONG THE MISSOURI RIVER AND THE FIRST PALEONTOLOGICAL STUDIES IN THE WILLISTON BASIN, NORTH DAKOTA AND MONTANA

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INTRODUCTION

Outside the esoteric field of nonmarine paleontology, few people know of the significant role the rocks and fossils along the Missouri River had in shaping the subsequent geological and paleontological exploration throughout western North America, serving as the foundation for subsequent research. This contribution highlights the discovery and record of the "classic" Paleocene-age freshwater and terrestrial molluscan fauna in the Williston Basin of western North Dakota and adjacent Montana. The table and figures presented here summarize and illustrate the location of type localities, taxonomy changes, and primary type material of the Meek and Hayden species described in the initial years of western exploration. Recent studies (1) have shown that this fauna actually represents a relatively brief interval of time in the late Paleocene, approximately 56–59 million years old (Ma), which much improves the value of the fauna for its chronostratigraphic correlation throughout the Western Interior.

A DISCOVERY AT FORT UNION - 1843

The first scientific recognition of fossil nonmarine mollusks (L3842a-b) from west of the 100th meridian resulted from the collections made by Edward Harris (2) and John J. Audubon in the spring of 1843. The collection was made in the vicinity of Fort Union near the Yellowstone–Missouri River confluence near what is now the Montana–North Dakota state line. The collections and stratigraphic information were analyzed by a committee formed by the Academy of Natural Sciences of Philadelphia, which included Henry D. Rogers, Samuel G. Morton, and Walter R. Johnson (3). They concluded that on the basis of "proofs thus afforded . . . [there is] probably widely diffused freshwater formation in the region of the Upper Missouri, reposing upon cretaceous strata, and imbedding remains of a tertiary age." The Philadelphia Academy's report foreshadows the more intensive investigations in this area by F.V. Hayden nearly 10 years later.

HAYDEN ON THE MISSOURI RIVER - 1855–1860

Hayden on His Own

After paleontological studies in the Big Badlands area of what is now South Dakota with Fielding Bradford Meek in 1853, Ferdinand Vandiveer Hayden returned to the upper Missouri country in the spring of 1854 and examined strata and collected fossils into 1855. He "conducted under very adverse conditions a single-handed geological and natural history survey of the vast, newly organized Nebraska Territory" (4). Although for the most part on his own, Hayden received logistical assistance from Col. A.J. Vaughan, Indian Agent, and Alexander Culbertson and others of the American Fur Company (6). In fact, the earliest collections received by the Smithsonian Institution from Hayden were sent from Vaughan and Hayden (6).

Hayden ". . . explored the Missouri River to the vicinity of Fort Benton, and the Yellowstone to the mouth of Big Horn River" and "also considerable portions of the Bad Lands of the White river, and other districts not immediately bordering the Missouri" (5). The exact whereabouts of Hayden at any given time, however, is difficult to document in the absence of his field journals. Some idea of the nature of his travels can be determined from a report he submitted, on request, to Lt. G.K. Warren (7), from his correspondence (8), and from terse locality data published with new species descriptions (9) (Figure 1). Unfortunately, in this heyday of exploration, because of confused ownership of fossils and the lack of standardized specimen management to logically reposit specimens, about half of the species described by Meek and Hayden (9) are not now represented by type specimens from the original published localities (10). This problem is summarized in Table 1, where locality and nomenclatural information are given on the species named by Meek and Hayden (9) from the Hayden collections of 1854 or 1855, as well as Meek's changed type locality. Meek's subsequent use of new localities and thus different specimens makes all of the specimens now designated as holotypes actually neotypes. The presumption must be that the specimens from the original collections are lost or unavailable.

Hayden with G.K. Warren

In 1856, Lt. G.K. Warren of the topographic engineers asked Hayden to participate in his expedition to the upper Missouri country for the purposes of mapping the Missouri River. Hayden's experience in the region thus resulted in his first solo job opportunity as a professional geologist and made him a desirable participant. The expedition traveled by steamer up the Missouri to 60 mi (96 km) beyond Fort Union and connected with the earlier exploration of I.I. Stevens in 1853. From Fort Union, Warren's party traveled up the Yellowstone

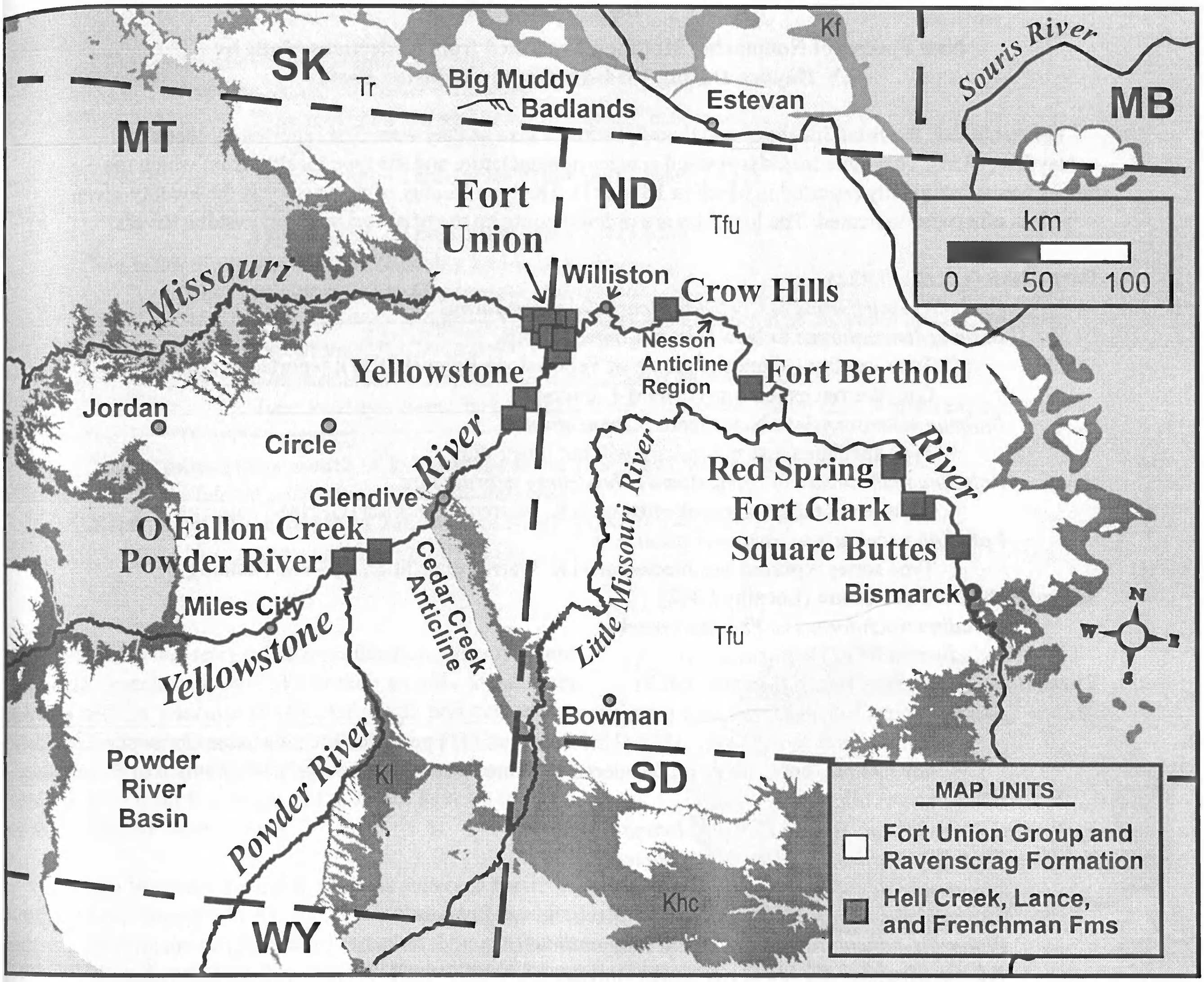

Figure 1. Hayden's geologic and paleontologic study localities in the Williston Basin (modified from Hartman and Kihm [1]). All of the species of nonmarine mollusks described by Meek and Hayden at the beginning of their collaborative careers were collected at the locations indicated by squares in what Hayden called the Great Lignite Tertiary Basin or Fort Union Group. No collections where made from the underlying uppermost Cretaceous Hell Creek Formation.

by land to within about 20 mi (32 km) of the mouth of the Powder River and from here a contingent journeyed to its mouth. From Fort Union, they made a "leisurely" (15) trip down the Missouri, stopping 2 to 3 days at points of interest. From all accounts (15, 16), Hayden was an insatiable collector. He produced a catalog (15) of some of his collecting sites, but it is difficult to use as a reference to extant collections. The catalog includes localities that were not visited by the Warren expedition. I believe he included his earlier work out of a desire to gain support and credibility for his western studies and thus gave credit to Warren freely. Thus the history resulting in the collection of some type specimens is, in the absence of Hayden's field notes, nearly impossible to interpret.

Almost all of the species reported by Meek and Hayden (9) were later illustrated and redescribed by Meek (11), and it appears plausible that in many cases, Meek chose new, probably "better" specimens to represent already named taxa (Plates 1–3). Note that almost all of the locality data for Meek and Hayden type specimens reported in the U.S. National Museum invertebrate (USNM-I) catalogs (17, 18) follow data cited by Meek (11). Because of the curatorial policies during the early part of Meek and Hayden's career, some of Hayden's 1854 and 1855 specimens that were no longer recognized as types were not cataloged by the Smithsonian Institution when it began its current system in 1859. Joseph Henry, then Secretary of the Smithsonian, "viewed collections as research tools. Principal

Table 1

New Species of Nonmarine Mollusca Described from Collections Made by F.V. Hayden During 1854–1855 in the Williston Basin

This table lists the fossil localities and their constituent taxa as they were first reported by Meek and Hayden (1856). This table includes revised species nomenclature and the type locality from which the species was subsequently reported in Meek in 1876 (11). The type locality of the species is the locality given unless otherwise indicated. The localities are ordered going up the Missouri and Yellowstone Rivers.

Fort Clark (Locality L422)
- *Corbula mactriformis* to *Corbula (Bicorbula) mactriformis*
- *Bulimus limneaformis* to New Genus A *limneaformis*
  - Type locality - Opposite mouth of Yellowstone River (L3951); reported as collected on G.K. Warren expedition (USNM-I catalog)
- *Bulimus nebrascensis* to New Genus A *limneaformis*
  - Type specimen lost and species without illustration
- *Paludina multilineata* to *Campeloma nebrascense nebrascense*
  - Type series reported as collected on G.K. Warren expedition (USNM-I catalog)
- *Paludina peculiaris* to *Viviparus peculiaris*
  - Type series reported as collected on G.K. Warren expedition (USNM-I catalog)

Ten miles below Fort Union (Locality L432)
- *Paludina trochiformis* to *Viviparus meeki*
- *Paludina leidyi* to *Viviparus leidyi*

Three miles below Fort Union (Locality L429)
- *Bulimus? teres* to *Pseudocolumna vermicula*
  - Not *Bulimus teres* Olivier 1801 (12); Cockerell (13) proposed the new name *Columna haydeniana*, but *C. teres* is considered by some to be a junior subjective synonym of *P. vermicula*.
- *Bulimus? vermiculus* to *Pseudocolumna vermicula*
- *Limnaea tenuicosta* to *Pleurolimnaea tenuicosta*
- *Physa nebrascensis*
  - Name apparently abandoned by Meek; *nomen dubium*
- *Planorbis subumbilicatus* to *Valvata subumbilicata*
- *Velletia (Ancylus) minuta* to *Acroloxus minutus*
- *Paludina retusa* to *Viviparus retusus*
  - Type locality - Mouth of Yellowstone River (L435); reported as collected on G.K. Warren expedition (USNM-I catalog)
- *Valvata parvula*, not *V. subparvula* Cossmann 1921 (14); *nomen dubium*
- *Melania minutula* to *Micropyrgus minutulus*
  - Type series reported as collected on G.K. Warren expedition (USNM-I catalog)

Fort Union (Locality L431)
- *Paludina leai* to *Viviparus leai*
  - Type locality - Three miles below Fort Clark (L2305)

Three miles above Fort Union (Locality L427; 5 km)
- *Cyclas formosa* to *Eupera formosa*
  - Type locality - Ten miles below Fort Union (L432); reported as collected on G.K. Warren expedition (USNM-I catalog)
- *Cyclas fragilis* to *Eupera formosa*
  - Type locality - Ten miles below Fort Union (L432)
- *Cyclas subellipticus* to *Sphaerium subellipticum*
  - Type locality - Ten miles below Fort Union (L432); reported as collected on G.K. Warren expedition (USNM-I catalog)

Table 1, continued

Three miles above Fort Union, continued
Pupa helicoides to *Pupa*? *helicoides*
Type specimen lost and never illustrated; *nomen dubium*
Physa longiuscula
Type locality – Three miles below Fort Union (L429)
Physa rhomboidea
Type locality – Three miles below Fort Union (L429)
Ten miles above Fort Union (Locality L434; 16 km)
Melania multistriata to *Lioplacodes multistriata*
Type locality – Mouth of Yellowstone (L435); reported as collected on G.K. Warren expedition (USNM-I catalog)
Melania nebrascensis to *Lioplacodes nebrascensis nebrascensis*
Type locality – Fort Clark (L422); reported as collected on G.K. Warren expedition (USNM-I catalog)
Thirty miles above mouth of Yellowstone River (Locality L433; 48 km)
Melania anthonyi to *Hydrobia anthonyi*
Forty miles above mouth of Yellowstone River (Locality L430; 64 km)
Unio priscus to *Plesielliptio priscus*

type specimens were retained after publication; other type and 'duplicate' specimens were distributed as aids to museum curators and in education" (4). Although undated in the Paleobiology invertebrate catalog, the collections of the Warren Expedition (as prepared by Meek and Hayden) commence with USNM-I 176, from the mouth of the Judith River, a location not visited by the Warren party.

On the Warren expedition, Hayden collected fossils in North Dakota (presented here as ascending the Missouri; Figures 1, 2) from the Tongue River Formation at Square Buttes [Hills] (L421), the valley of the Missouri River 3 mi (4.8 km) below Fort Clark (L2305), Oliver County, along the bluffs at Fort Clark (L422); from the Sentinel Butte Formation near Red Spring (L420), Mercer County, in the Fort Berthold area (L4279), McLean or Mercer County, in the valley of the Missouri about 150 mi (240 km) downstream from Fort Union (L3823), Mountrail–Dunn County line; and from the Tongue River and Sentinel Butte Formations in Crow Hills (L423), Williams County, and in the area of Fort Union near the Yellowstone–Missouri confluence (L424, L2306b, L3951) in the vicinity of the Montana–North Dakota state line. In Montana, Hayden collected from the Fort Union Formation in the valley of the Yellowstone River at O'Fallon Creek (L426) and at the mouth of the Powder River (L3812), both in Prairie County.

As a geologist, Hayden extended the earlier stratigraphic observations made with Meek in South Dakota and constructed a geologic map and cross section (19; Figure 2) illustrating the Great Lignite Tertiary Basin, now known as the Williston Basin. Meek and Hayden (20) would

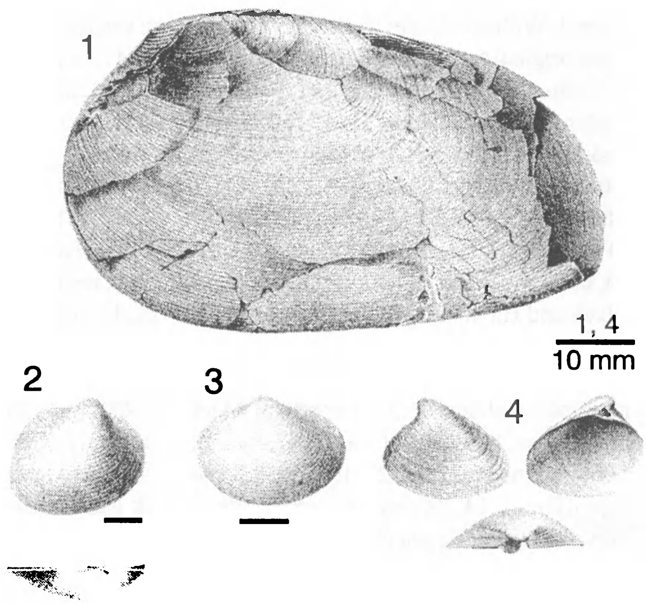

Plate 1. Williston Basin freshwater bivalves described by Meek and Hayden in the 1850s. Type specimen figures are from original figure illustrations drawn by Meek (11) (see also Table 1). Letters (e.g., 1a, b), although not shown on the plate, refer to specimens from left to right, and bar scales for Figures 2 and 3 represent actual specimen size. **Unionoida**. 1. *Plesielliptio priscus* (Meek and Hayden); holotype, left valve, external (pl. 43, fig. 8d). **Veneroida**. 2. *Eupera formosa* (Meek and Hayden); neotype, right valve, external (pl. 43, figs. 4b–c). 3. *Sphaerium subellipticum* (Meek and Hayden); neotype, left valve, external (pl. 43, fig. 5b). **Myoida**. 4. *Corbula* (*Bicorbula*) *mactriformis* Meek and Hayden; holotype, left valve, a) exterior, b) dorsal, c) interior (pl. 43, figs. 7a–c).

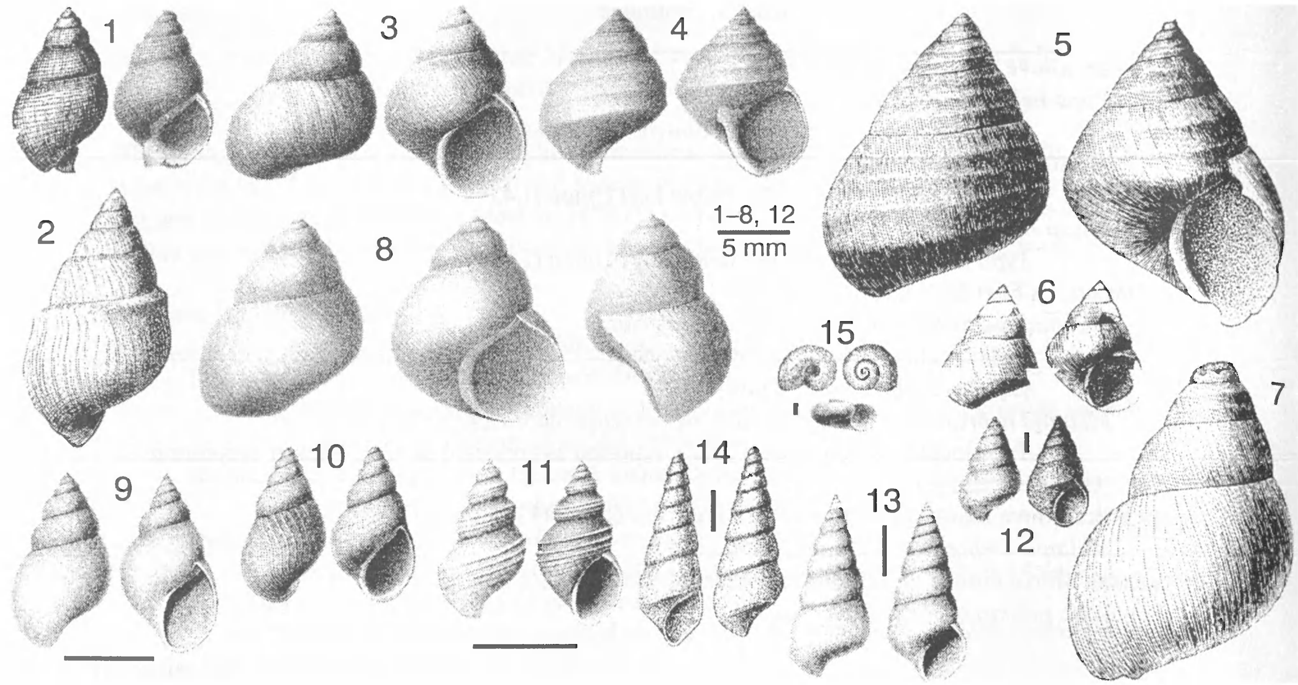

Plate 2. Williston Basin freshwater prosobranch gastropods described by Meek and Hayden in the 1850s. Type specimen figures are from original figure illustrations drawn by Meek (11) or are from copies of Meek's figures or redrawn illustrations made under White's (22) direction (see also Table 1). Letters (e.g., 1a, b), although not shown on the plate, refer to specimens from left to right and bar scales for Figures 9 and 11–15 represent actual specimen size. **Mesogastropoda**. 1. *Campeloma nebrascense nebrascense* (Meek and Hayden), holotype; a) abapertural, b) apertural (11, pl. 44, figs. 1a, b; 22, pl. 27, fig. 1). 2. *Campeloma nebrascense whitei* Russell, holotype; abapertural (22, pl. 27, fig. 5; this subspecies was originally included in the concept of C. *n. nebrascense*). 3. *Viviparus leai* (Meek and Hayden); neotype, a)Êabapertural, b) apertural (11, pl. 44, figs. 6a, b). 4. *Viviparus meeki* Wenz; holotype; a) abapertural, b) apertural (11, pl. 44, figs. 2a, b). 5. *Viviparus formosus* Meek; holotype, a) abapertural, b) apertural (11, pl. 44, figs. 3a, b). 6. *Viviparus peculiaris* (Meek and Hayden); neotype, a) abapertural, b) apertural (22, pl. 24, figs. 23, 24). 7. *Viviparus leidyi* Meek and Hayden; holotype, abapertural (11, pl. 44, fig. 4). 8. *Viviparus retusus* (Meek and Hayden); neotype, a) abapertural and c) right lateral; topotype from neotype locality, b) abapertural (11, pl. 44, figs. 5a–c). 9. *Lioplacodes multistriata* (Meek and Hayden); holotype, a) abapertural, b) apertural (11, pl. 44, figs. 15c, d). 10. *Lioplacodes nebrascensis nebrascensis* (Meek and Hayden); neotype, a) abapertural, b) apertural Meek (pl. 43, figs. 12a, b). 11. *Lioplacodes tenuicarinata* (Meek and Hayden); holotype, a) abapertural, b) apertural (11, pl. 43, figs. 14a, b). 12. *Hydrobia anthonyi* (Meek and Hayden); holotype, a) abapertural (11, pl. 43, fig. 10b), apertural (22, pl. 27, fig. 39). 13. *Hydrobia warrenana* (Meek and Hayden); holotype, a) abapertural, b) apertural (11, pl. 43, figs. 11b, c). 14. *Micropyrgus minutulus* (Meek and Hayden); holotype, a) abapertural, b) apertural (11, pl. 43, figs. 18a, b). 15. *Valvata subumbilicata* (Meek and Hayden); holotype, a) abapical, b) apical, c) apertural (11, pl. 43, figs. 13a–c).

go on to name much of the standard reference geologic section for the northern Great Plains.

Hayden with W.F. Raynolds

In 1859–1860, Hayden participated in the last major expedition conducted by the topographical engineers in the West, which was referred to as the Yellowstone expedition. Led by Capt. William F. Raynolds, partaking in his first western exploration, the exploring party was frequently split into two forces, one under the command of Raynolds and the other under Lt. H.E. Maynadier. These parties covered an impressive amount of ground, extending along the upper Missouri River from Fort Benton to Fort Union, as far south as the North Fork of the Platte River near Fort Laramie, west to Jackson Hole, Wyoming, and Virginia City, Montana. The routes taken by Raynolds and Maynadier are shown on the 1867 "Map of the Yellowstone and Missouri Rivers and their tributaries." Nonmarine mollusks were collected only from the Powder River Basin, Wyoming, from "Clear Fork" (L2173, L2175, L2177) and "Lower Fork" of the Powder River. Meek and Hayden described *Viviparus raynoldsanus*, *V. wyomingensis*, and *Hydrobia eulimoides* from the Tongue River Member of the Fort Union Formation and from the "Wasatch" Formation. Although recorded as collected by Hayden, these fossils were probably collected by Maynadier's party, which traveled up

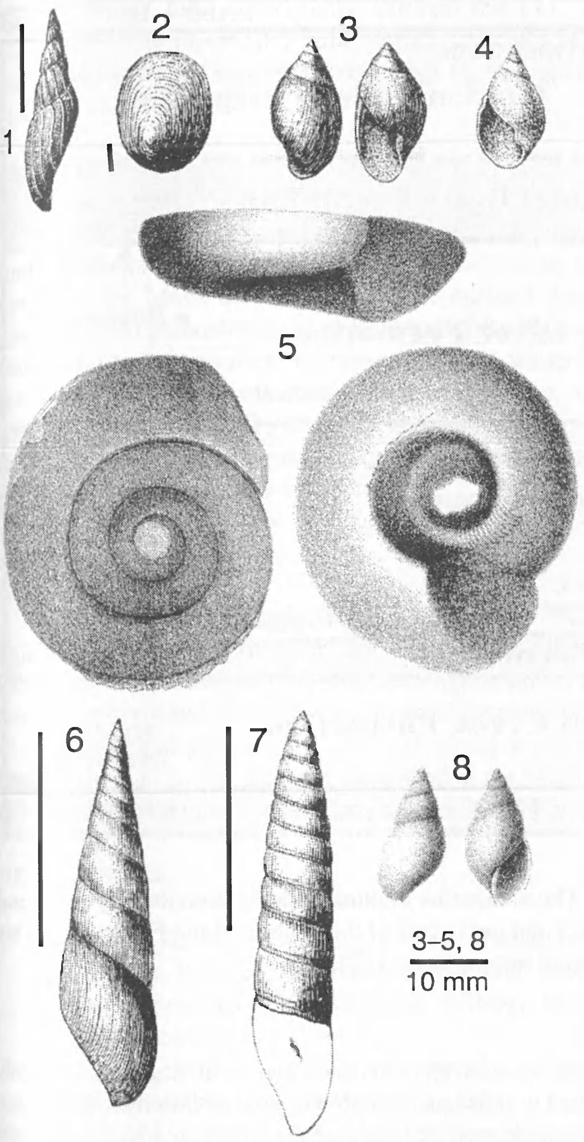

Plate 3. Williston Basin freshwater and terrestrial pulmonate gastropods described by Meek and Hayden in the 1850s. Type specimen figures are from original figure illustrations drawn by Meek (11) (see also Table 1). Letters (e.g., 1a, b), although not shown on the plate, refer to specimens from left to right, and bar scales for Figures 1, 2, 6, and 7 represent actual specimen size. **Archaeopulmonata**. 1. *Pleurolimnaea tenuicosta* (Meek and Hayden); holotype, a) apertural (pl. 44, fig. 13b). Basommatophora. 2. *Acroloxus minutus* (Meek and Hayden); holotype, a) apical, (pl. 44, fig. 10). 3. *Physa longiuscula* (Meek and Hayden); neotype, a) abapertural, b) apertural (pl. 43, figs. 16a, b). 4. *Physa rhomboidea* (Meek and Hayden); neotype, a) apertural (pl. 44, fig. 17). **Stylommatophora**. 5. New Genus T *planoconvexa* (Meek and Hayden); holotype, a) apertural, b) apical, c) abapical. 6. *Pseudocolumna vermicula* (Meek and Hayden); holotype of *Bulimus*? *teres* = new name P. *haydeniana* Cockerell; a) abapertural (pl. 44, fig. 11b). 7. *Pseudocolumna vermicula* (Meek and Hayden); holotype of *Bulimus*? *vermiculus*; a) abapertural (pl. 44, fig. 12b). ***Incertae sedis***. 8. New Genus A *limneaformis* (Meek and Hayden); neotype, a) abapertural, b) apertural.

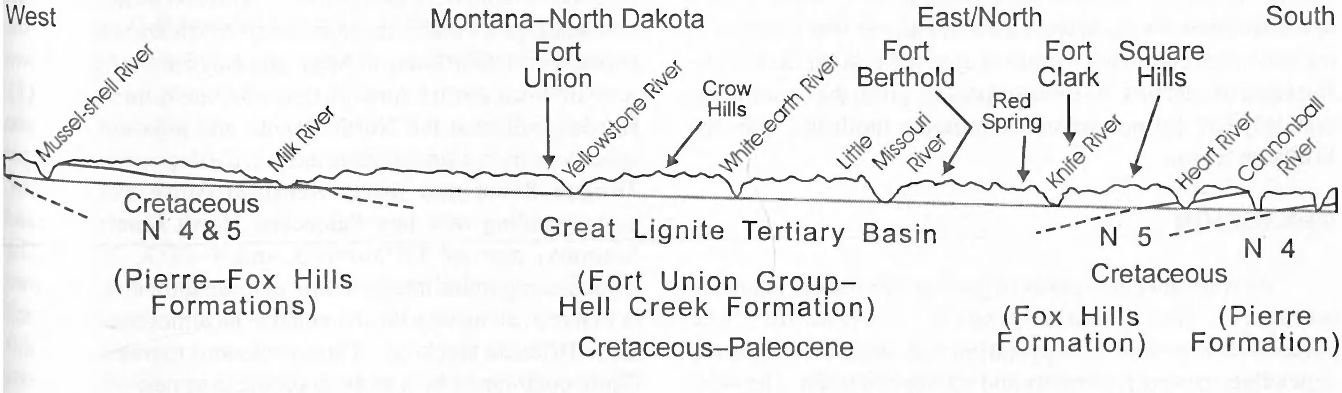

Figure 2. Hayden's geologic and topographic profile of the Great Lignite Tertiary Basin This figure was redrawn and slightly modified from Hayden (16). The labeling is that of Hayden, except with the addition of Fort Union, Crow Hills, and Red Spring. The figure also includes current lithostratigraphic units, which, except for the Hell Creek Formation, where introduced by Meek and Hayden in 1862 (17).

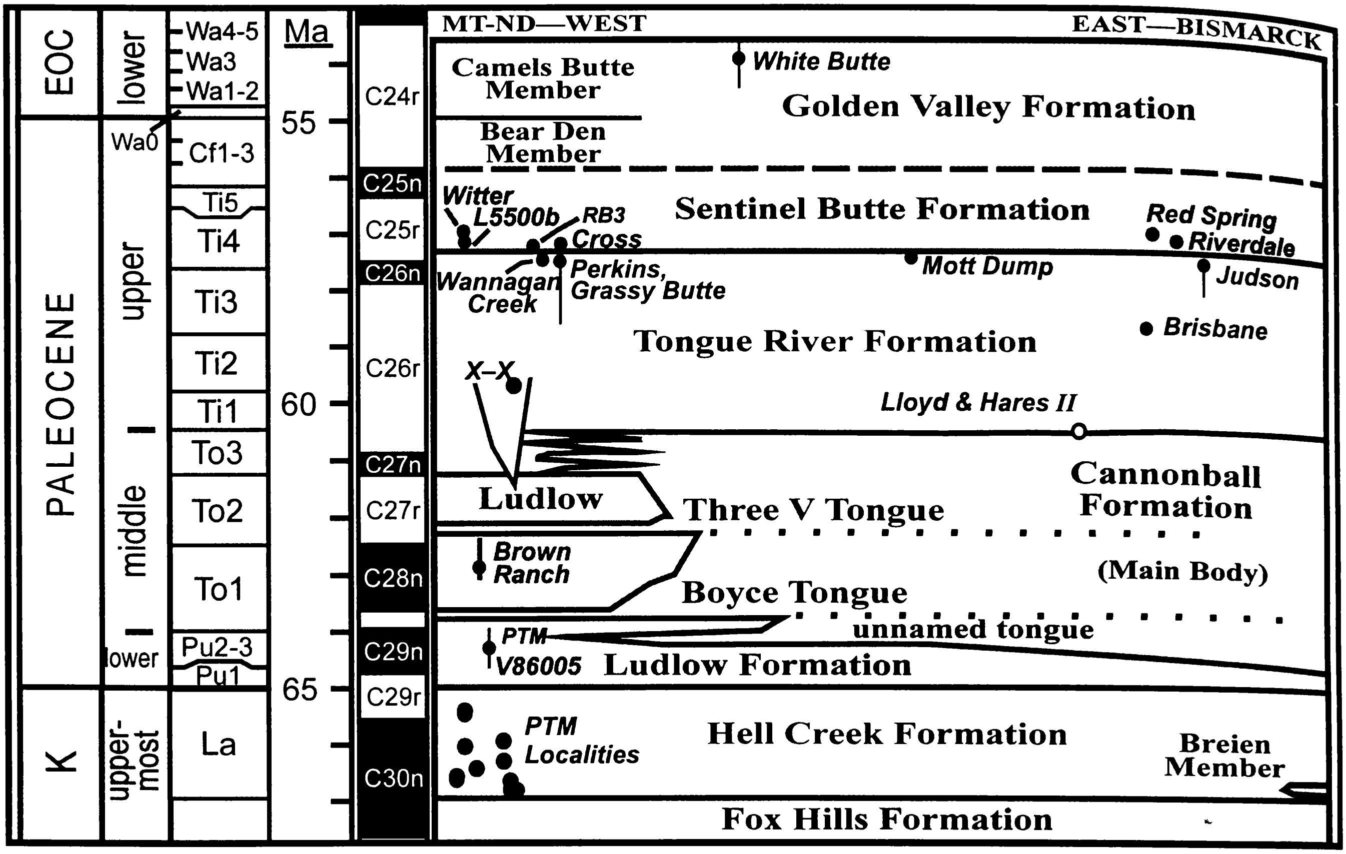

Figure 3. Chronostratigraphy of western North Dakota bedrock strata. The nonmarine molluscan fauna described by Meek and Hayden coincides with the interval of the upper part of the Tongue River and lower part of the Sentinel Butte Formations. This drawing is modified from Hartman and Kihm (21) and incorporates recent interpretations (23, 24).

the Tongue River to near the mouth of Prairie Dog Creek, crossing the divide to Clear Creek ("Clear Fork") near the mouth of Lone Tree Creek in Sheridan County, Wyoming. From here, they went downstream to the mouth of Clear Creek and then up the main channel of the Powder River ("Lower Fork") to the mouth of Crazy Woman Creek. Hayden was attached to the Raynolds command, which skirted the eastern base of the Big Horn Mountains. It seems surprising, given the opportunity, that Hayden did not collect nonmarine mollusks from the Williston Basin.

DISCUSSION

As with other disciplines of geology, the use of nonmarine mollusks for biostratigraphic correlation and paleoenvironmental interpretation has waxed and waned depending on perceived utility and scholarly interest. The work of Meek and Hayden in the Williston Basin was used extensively from the 1870s to 1930s for the correlation of the Paleocene-age Fort Union Formation/Group throughout the Western Interior of North America. The perceived limited use of these fossils in more finely divided biostratigraphy ultimately resulted in subsequently more limited attention paid them and the expanded use of land mammals as their fossil record and evolution became much better understood. With litho- and chronostratigraphic reassessment of Williston Basin Paleocene mammals, particularly those found in North Dakota (21), the classic Fort Union fauna of Meek and Hayden has been shown to be of much shorter duration than previously interpreted (1). Hayden collected the North Dakota and adjacent Montana specimens from a stratigraphic interval that represents the upper Tongue River and lower Sentinel Butte Formations, corresponding to a late Paleocene North American Land Mammal age of Tiffanian 3 and 4 (Ti3, Ti4). The chronostratigraphic interpretation of these formations is shown in Figure 3, along with the mammalian localities used to delimit these Tiffanian biochrons. The correlations represented in this figure continue to be a work in progress as new observations continue to refine movements of the Cannonball Sea (Cannonball Formation) and other formational contacts. This illustration presents the latest interpretation of the age of the Lloyd and Hares II Locality (24) which shows an older, lower

Tongue River than previously interpreted (1). This interpretation is in conflict with marine invertebrate and vertebrate fossils that suggest a younger age for the upper part of the Cannonball Formation.

SUMMARY

This paper provides a concise summary of the taxonomy and chronostratigraphy of the nonmarine molluscan fauna described by Meek and Hayden in the earliest days of geological and paleontological exploration of the West. This fauna can continue to play an important role in interpreting geologic history in the nonmarine strata of the West, as the time interval represented by the fauna is considerably less (10 to 2.5 Ma) than previously considered, and thus of value for refined chronostratigraphic correlation.

ACKNOWLEDGMENTS

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WHAT IS SOLID, BLACK, AND WORTH $1.3 BILLION TO THE NORTH DAKOTA ECONOMY?

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INTRODUCTION

Western North Dakota geology is predominantly of the Cenozoic Era (65 million years – present), Tertiary Period (65 million years – 2.5 million years), and Paleocene age (65 million years – 55 million years), plus Pleistocene (2.5 million years – 10,000 years) sediment overlies the north one third of western bedrock geology. Pre-Pleistocene rocks consist predominantly of clays, sands, till, and lignite. Lignite is the lowest-rank coal and is defined as a brown to black combustible rock formed over millions of years by the partial decomposition of plant material, subject to increased pressure and temperature in an airless environment.

WILLISTON BASIN

Most of North Dakota is in the Williston Basin, an intracratonic basin (a basin which developed on top of a very stable part of the Earth's crust), whose center is south and east of the city of Williston. At its center, the sediments are more than 15,000 feet thick. The basin extends northward into Canada, westward into Montana, and southward into South Dakota. The eastern limit is in eastern North Dakota approximately at the top of the Fall River Formation (Cretaceous).

The portion of the Williston Basin in North Dakota contains close to 1500 ft (457 m) of lignite-bearing rocks in the Fort Union Group (Paleocene). The Fort Union is a clastic (siltstone, mudstone, sandstone, claystone, and lignite) wedge that gets thinner from eastern Montana into central North Dakota. The Fort Union Group is made up of the Ludlow, Cannonball, Slope, Bullion Creek, and Sentinel Butte Formations (Figure 1). All these formations are nonmarine coal-bearing strata except the Cannonball. The Coleharbor Formation (Pleistocene) overlies the lignite-bearing rocks to the north and east of the Missouri River and appears as patchy remnants and erratics south of the river. The Coleharbor is made up of glacial deposits. These deposits consist mainly of till, outwash gravel and sand, and lake sediment. Erosion has exposed the lignite-bearing rocks to their present-day appearance.

THE ORIGIN OF LIGNITE

A number of possible depositional environments have been proposed for the Paleocene sediments in the Williston Basin. This geologic feature is a large depression in the earth's surface in which sediments from an ancient mountain range to the west accumulated. There are two popular depositional scenarios. The first and more widely held proposal is that the lignite was deposited in areas dominated by fluvial river channel and fluvial lake facies. These would be environmentally low, flat areas covered mostly by peat swamps and swampy areas. These peat swamps would be cut by well-established river channels, and in some places, freshwater shallow lakes, drained by slow-moving rivers, would exist within the swamps. The closest modern-day environment to this would be the Okefenokee Swamp in southern Georgia and northern Florida. This swamp would be a very stable environment over many, many years. Periodically the rivers would overflow their natural levee and cover all or part of the swamp. When the swamp was entirely covered, it may have been drowned out and start

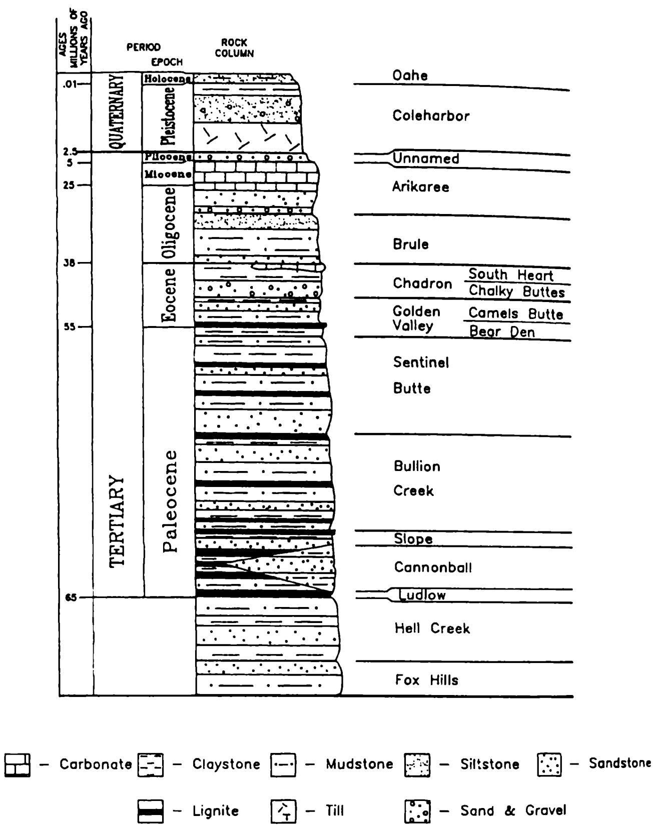

Figure 1. Generalized stratigraphic cloumn of the coal-bearing rocks in North Dakota.

a period of clay and sand sedimentation, followed by the start of a new swamp on top of the clay or sand. This cycle would repeat itself a number of times.

The second popular type of depositional environment is lacustrine (lake)-dominated. Again, this would be a very stable area of low relief along the edge of a very large freshwater lake. There would be only small rivers feeding into the environment. The fluctuating water level of the lake would regulate the growth and extent of the peat swamp. Sediments would carry up and over the peat swamps in periods of high water and off the swamps in periods of low water, thus promoting the growth of the peat swamp again.

LIGNITE IN NORTH DAKOTA

These types of depositional environments and the time that these environments existed in North Dakota (Paleocene) are what help make our coal "lignite." It is classified as lignite on the basis of its chemical and physical properties. Lignitic coals are high in moisture and volatile matter and low in fixed carbon and caloric value. Lignitic coals also slack easily (lose their moisture) and are subject to spontaneous combustion when exposed to air. These physical and chemical properties, in main part, are due to their young age. Not as much heat and pressure have been applied to the lignite because of its young age. This is also responsible for the high volatile matter and low fixed carbon. North Dakota lignite has an average "as-received" quality as given in the following table:

Moisture	= 36.40%
Ash	= 6.70%
Volatile Matter	= 26.60%
Fixed Carbon	= 30.20%
Sulfur	= 0.70%
Caloric Value	= 6990 Btu/lb (16 million J/kg)

The state's coal is classified as Lignite A, which is based on the caloric value it has (6300–8300 Btu/lb [14,653,800–19,305,800 J/kg]). These qualities make lignite poor for generating heat but very good for gasification, liquefaction, and carbonization as compared to higher-ranked coals.

The promoters of the two depositional theories believe these types of environments can allow the peat to become thick and cover large areas. The compaction rate of peat to lignite is 1.5 ft: 1 ft. For example, if you have a 20-ft (6 m)-thick lignite seam, you would have to have 30 ft (9 m) of peat. The lignite-bearing formations with mineable thicknesses within North Dakota cover an area of 28,000 mi^2 (72,520 km^2) (Figure 2). This area has the largest amount of lignite in the United States. North Dakota has approximately 351 billion tons (318 billion metric tons) of lignite. At our present annual rate of mining (30 million tons [27 million metric tons]), North Dakota alone has 1000 years of lignite to mine.

Lignite Stratigraphy in North Dakota

Lignite seams in western North Dakota are usually 5 ft (1.5 m) or less in thickness, but a few of the seams have an average thickness in excess of 20 ft (6 m) for several hundred square miles. The thickest coals tend to occur in either the upper Bullion Creek or lower Sentinel Butte Formations. These two formations each have maximum thickness of about 600 ft (183 m) in western North Dakota and thin to about 300 ft (91 m) in central North Dakota. The Fort Union Group is overlain by the Golden Valley Formation (Paleocene–Eocene). The upper member of the Golden Valley Formation contains lignite, but the seams are typically thin. Any given place in western North Dakota stands a good chance of being underlain by a dozen or more lignite seams. Although the majority of these seams tend to be thin, occasionally a very thick seam of lignite will exist. This abundance of lignite seams, and lack of trees, made the mining of lignite inevitable.

The Lignite Industry

The first recorded mention of lignite in North Dakota was contained in the journals of Lewis and Clark, they commented on the abundant deposits of lignite that they saw as they traversed the Missouri River. Since that first mention, approximately 2000 books, maps, and articles have been printed about all North Dakota geology. In the fall of 1873, a mine near the old town of Sims was started to supply "soft coal" to the growing village of Bismarck. The Sims mine was abandoned after several months because of attacks by Indians.

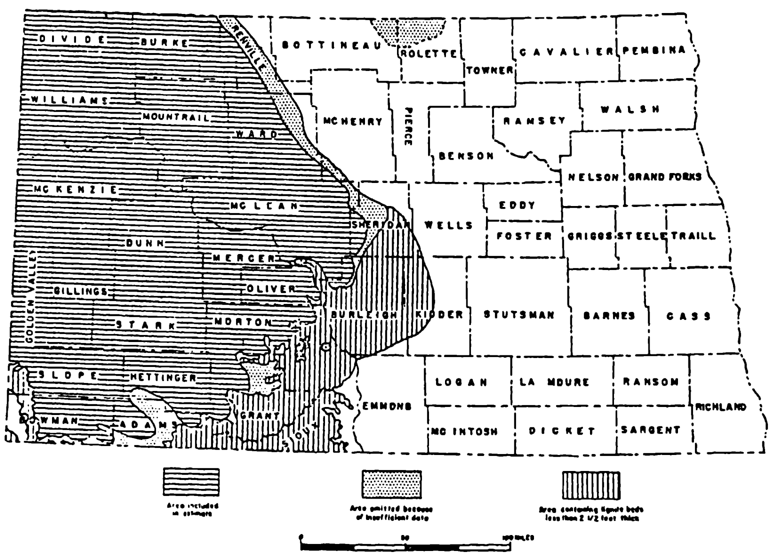

Figure 2. Map of North Dakota showing lignite-bearing areas.

The very next year, 1884, the reported production in North Dakota was 35,000 tons (32,000 metric tons).

So, from that first small step, the present-day lignite industry has blossomed. The state has gone from having 320 predominately underground mines producing at the peak approximately 2.2 million tons (2 million metric tons) annually to just four surface mines producing approximately 30 million tons (27 million metric tons) annually. This production went from mostly supplying lignite for domestic use to almost exclusively supplying lignite for commercial use. There are at present 3075 people directly employed by the lignite industry and 15,725 people indirectly employed providing goods and services to the lignite industry. This industry has annual expenditures $450 million. These expenditures generate more than $1.3 billion in business activity for North Dakota. In addition $60 million annually in state tax revenue were generated from all sources in the lignite industry. This is all attributable to the presence of lignite-bearing rocks in western North Dakota.

THE WELL SITE GEOLOGIST'S ROLE IN HORIZONTAL DRILLING

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INTRODUCTION

Horizontal drilling has had a significant impact on the petroleum industry in the Williston Basin. In the past five years, we have seen an increase in the number of horizontal wells being drilled relative to vertical wells. This can be attributed to both the advancements in the technology available today, and the adaptability of horizontal drilling methods to our regional geology. This newest trend in petroleum exploration has created new fields of research and has resulted in expanded and different roles for petroleum geologists and engineers.

HORIZONTAL AND DIRECTIONAL DRILLING – METHODS AND APPLICATIONS

Directional drilling encompasses many different techniques, with new methods being introduced and expanded as the need increases to reach deeper and more complex remote targets. Some of the techniques available allow for the drilling of single and multilateral horizontal legs, and sidetracks of original laterals. In addition to conventional medium-radius technology, methods are now available for short-radius and extended-reach targets.

Most horizontal wells in the Williston Basin are drilled using a medium-radius plan which allows the well bore to gradually curve from the vertical to the horizontal plane. With the continued advancements in directional drilling methods, short radius technology now allows for the radius length of the curve in horizontal wells to range in length from 143 ft (44 m) down to 40 ft (12 m). This compares to the radius of conventional medium radius technology averaging 400 ft (122 m). This shorter-radius drilling is more difficult and requires special tools and techniques but is more desirable for many applications. It allows for the isolation of production zones without the use of setting and cementing a liner, drilling the curve below problem formations, and working within lease restrictions more successfully. Extended reach drilling provides technology to drill lateral extensions as long as 8 to 9 mi (13-15 km). Standard lateral extensions usually reach a maximum length of approximately 5000 ft (1524 m).

All of the directional drilling methods use various arrangements of nonmagnetic drill collars, mud motors, bent housings, survey tools, and drill bits. It is the arrangement, settings, and drilling parameters utilized by the directional driller that allows for the creation of the build section of the well bore and the lateral legs.

The ability to drill horizontally in a target formation has allowed for the development of formations that would be uneconomical if drilled vertically. By increasing the area of the productive formation open to the well bore, the well more effectively produces from a formation. This is especially effective in low-permeability zones where a vertical well bore cannot effectively drain a spacing unit. The North Dakota Industrial Commission regulates how many wells can be drilled within a section. The number of wells per section is referred to as a spacing unit and varies for different areas and for different types of reservoirs and formations.

With only a moderate increase in drilling costs, horizontal drilling can greatly increase the productivity of a well. The Mission Canyon formation in North Dakota is a major oil-producing formation and is approximately 9000 ft (2743 m) deep. A vertical well drilled to this depth may cost $600,000. Drilling horizontally to this same formation may increase operating costs by 50 to 60 percent, bringing total costs to near $1,000,000. Although this increase is substantial, the production of a horizontally drilled well may be as much as 400% greater than the production of a vertically drilled well, resulting in a more favorable return on the investment dollar.

Technological advances in directional drilling have led to new and much more critical roles for the well site geologist. Wells drilled vertically require the well site geologist to be able to evaluate the structural position of a well bore relative to other wells in a field and to identify and evaluate potentially productive zones in a well. With the advent and success of technological advances to horizontal drilling, the well site geologist's role and the importance of evaluating target formations have also increased and expanded.

Vertical well bores are drilled straight down and designed to intersect mapped formations at estimated depths. Correlations to existing well bores are made to determine position on a structure and to calculate intersection with a productive formation. Once a productive zone is encountered, the reservoir potential is directly related to the area or thickness of the well bore that is exposed to the productive zone. This has been the method of oil and gas exploration in the Williston Basin since oil was discovered in 1951 and as vertical drilling continues today.

In the past several years, rapid advances have been made in technology and tools required for directional drilling, thereby creating new ways to explore for and develop the oil fields of the world and the Williston Basin, in particular.

TARGET GEOLOGY

Defining a target formation for horizontal drilling is similar to that for vertical drilling. There are several factors needed for a formation to be proven productive. First, a formation must have reservoir potential, which is the ability of the rock to hold a large volume of hydrocarbons. The fluid-holding capacity of rocks is studied by a reservoir engineer. The formation must also exhibit porosity, which is the pore space within a rock unit that holds the oil and gas. Permeability is the ability to move the fluid through the rock and is necessary for the recovery of hydrocarbons. Of course, in order for a formation to be productive, it must contain large quantities of oil and gas. Horizontal drilling expands the possibilities available, by making remote targets reachable and low-permeability zones economically feasible.

One method used to justify drilling horizontally in a formation is to first establish a productive zone by drilling a vertical well bore. After the depth and presence of hydrocarbons are ascertained, a horizontal leg is then drilled in this zone. This vertical well bore is referred to as the pilot hole.

While drilling the pilot hole, the well site geologist's duties include evaluating of drill cuttings, graphing rate of penetration to aid in identifying structural markers, and evaluating of gases present. A total hydrocarbon detector, or hotwire, is used to detect the presence of gases. A chromatograph is used to break the gas down into its components. After the pilot hole is evaluated, the well is plugged back, or cemented, to a kick-off point. This is the depth at which directional drilling begins.

Once it is determined that a formation warrants horizontal drilling, a directional plan is fine-tuned to the exact formation depth as established in the pilot hole. Calculations are made to account for the anticipated dip of the formation. These calculations adjust for the depth of the formation at the point where the well bore will intersect the target zone at the end of the build section. These calculations involve basic and in-depth trigonometry principles and formulas. This gives the well site geologist the day-to-day opportunity to combine interpretive geology with math concepts. It is another direct use of classroom knowledge and how it is applied in a particular field.

GEOLOGY DURING DRILLING

With the expansion of horizontal drilling has come the additional responsibilities of the well site geologist and new terms to address these procedures. One such term is geosteering. Geosteering refers to the use of geologic information obtained while drilling as an aid to guide the direction a horizontal well bore should follow.

In order to drill horizontally, the well bore must change from the vertical to a horizontal direction. This is attained by the curve, or build section. While drilling the build, the geologist must first identify marker formations above the zone of interest. The depth of these markers is then used to update the exact depth that the well bore will intersect the target formation. Once again, trigonometric formulas are used in these calculations. It is necessary to intersect the target formation at or near 90E in order to stay in or to drill in the producing zone. The exact angle of inclination is adjusted to follow the dip of the formation. Failure to enter the zone at the proper angle results in either drilling through the formation and out the bottom or attaining 90E above the zone and not penetrating the desired formation.

Once the well bore intersects and is drilling in the producing zone, it is the work of the well site geologist that helps maintain this course. This is done by the interpretation of data obtained while drilling. While drilling in the zone, rate of penetration is very fast, gas readings are high, and drill cuttings exhibit formation lithology with oil shows. These parameters diminish or are absent if the well bore drills out of zone. This is the most critical phase of geosteering. First it must be determined if the well bore is out of zone, and if so, the direction. The geologist evaluates the drill cuttings and compares them to the information obtained in the pilot hole to determine if the drill string is exiting the formation toward the top or bottom of the zone. Once it is determined which direction the drill string has exited, then the proper adjustments are made to the directional plan to correct the path of the well bore and resume drilling in zone. This phase of the horizontal drilling requires close communication between the drilling and geology personnel.

The importance of the proper determinations made by the geologist is critical in horizontal drilling. Incorrect interpretations result in drilling out of zone and lost production for the life of the well. By not reacting correctly to well bore changes, it may take several hundred feet to recover and resume drilling in zone. By quickly realizing the structural position and making proper geosteering recommendations, the well site geologist becomes an integral part in the success of a horizontal well.

CLIMATE CHANGE IN NORTH DAKOTA SINCE THE LAST GLACIATION - REVIEW OF THE PALEONTOLOGICAL RECORD

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INTRODUCTION

The terms "global change" and "global warming" have entered our everyday language. We are forced to concede that our activities have already contributed to the degradation of landscapes and the loss of biodiversity and are probably contributing to climate change. With the record-setting floods in the Red River and Missouri River valleys in 1997, Devils Lake at its highest level in historical time, and farmland being lost to coalescing lakes in the southeastern counties, North Dakotans know only too well the effects of climate change. From 1988 to 1992, the state experienced drought conditions, but since then, North Dakota has been in a wet cycle. North Dakotans are stoical when it comes to weather, but even so, there is a concern about what the future will bring. Most of our knowledge of climate change comes from an instrumental record that is only 100 years in length. This record has been extended by dendroclimatology and by high-resolution paleontological and geochemical studies of lake sediments. What these studies are showing is that 100 years is far too short a time to show the natural variability in the climate record.

In recent years, our knowledge about climate change in North Dakota, especially since the last glaciation, has grown considerably. In winter, the frozen surfaces of North Dakota's lakes provide a perfect platform for coring lake sediments. The use of casing and the application of stronger and lighter alloys in coring rods now make it possible to obtain longer and more complete cores than ever before. Accelerator mass spectroscopy (AMS) has revolutionized radiocarbon dating so that now only small amounts of carbon are needed for high-quality dates. This makes it possible to calculate rates of processes with greater accuracy. In this review of the late Quaternary climate history, ^{14}C Ka refers to thousands of radiocarbon years before present.

THE LAST GLACIATION

North Dakota comprises both glaciated and nonglaciated terrains. During the last glacial maximum, the northern and eastern parts of the state were ice-covered, with flow directed generally southward, following the James and Red River drainages. The western boundary of the ice sheet across North Dakota was east of the Missouri River (1). Only the southwestern part of the state was ice-free (Figure 1). Fossil polygons, remnants of patterned ground, are widespread (2) indicating cold and, possibly, arid conditions. The age of the polygons is uncertain and may predate the last glaciation (3). Are they indicators of a polar desert? What was the vegetation and fauna of the ice-marginal zone? Sediments from shallow depressions in the unglaciated region are unfossiliferous. There are no pollen records for the polygons, but on the basis of a profile from a site close to the Rocky Mountains (4), we can speculate that vegetation of the Great Plains before 15 ^{14}C Ka was dominated by *Artemisia* (sage), herbs, and Poaceae (grasses). The vegetation was probably what has been referred to as "mammoth steppe" (5). Certainly, the molars of many mammoths have been found in gravel deposits in western North Dakota but for the majority of the specimens, stratigraphic context is either unknown or uncertain. None of the teeth have been dated so it is not known whether they are from the last or earlier glaciations. We do know that the Woolly Mammoth, *Mammuthus primigeneus,* inhabited the western shore of Lake Agassiz about 11 ^{14}C Ka, and, presumably, it was from an ancestral population in the Southwest (6). What other large animals roamed the ice margin? Teeth and bones of bison, including partial skulls of *Bison latifrons* and *Bison antiquus* (*Bison bison antiquus*), are also found in alluvium, but as with the mammoth teeth, their age is uncertain.

Perhaps, the best insight about the megafauna is from the Hot Springs site in the southern Black Hills, South Dakota. This site was located about 200 km south of the ice margin in North Dakota, a distance within the migratory range of several of the large animals. At Hot Springs, mammoths and other large animals were trapped in the sediments of a sink hole lake about 26 ^{14}C Ka. The most prominent fossils are those of *Mammuthus columbi* (Columbian mammoth) and *M. primigenius* (woolly mammoth) (7). The fauna also included the herbivores *Camelops hesternus* (yesterday's camel), *Hemiauchenia macrocephalus* (large headed llama), *Antilocapra americana* (pronghorn), and cf. *Euceratherium collinum* (shrub ox). The carnivores and scavengers on these animals were *Canis lupus* (gray wolf), *Canis latrans* (coyote), and the largest of the late Pleistocene predators, *Arctodus simus* (giant short-faced bear).

THE LATE GLACIAL

By 12 ^{14}C Ka, the margin of the Laurentide ice sheet stretched across central North Dakota from the northwest to the southeast corners of the state. Ice from the Des Moines

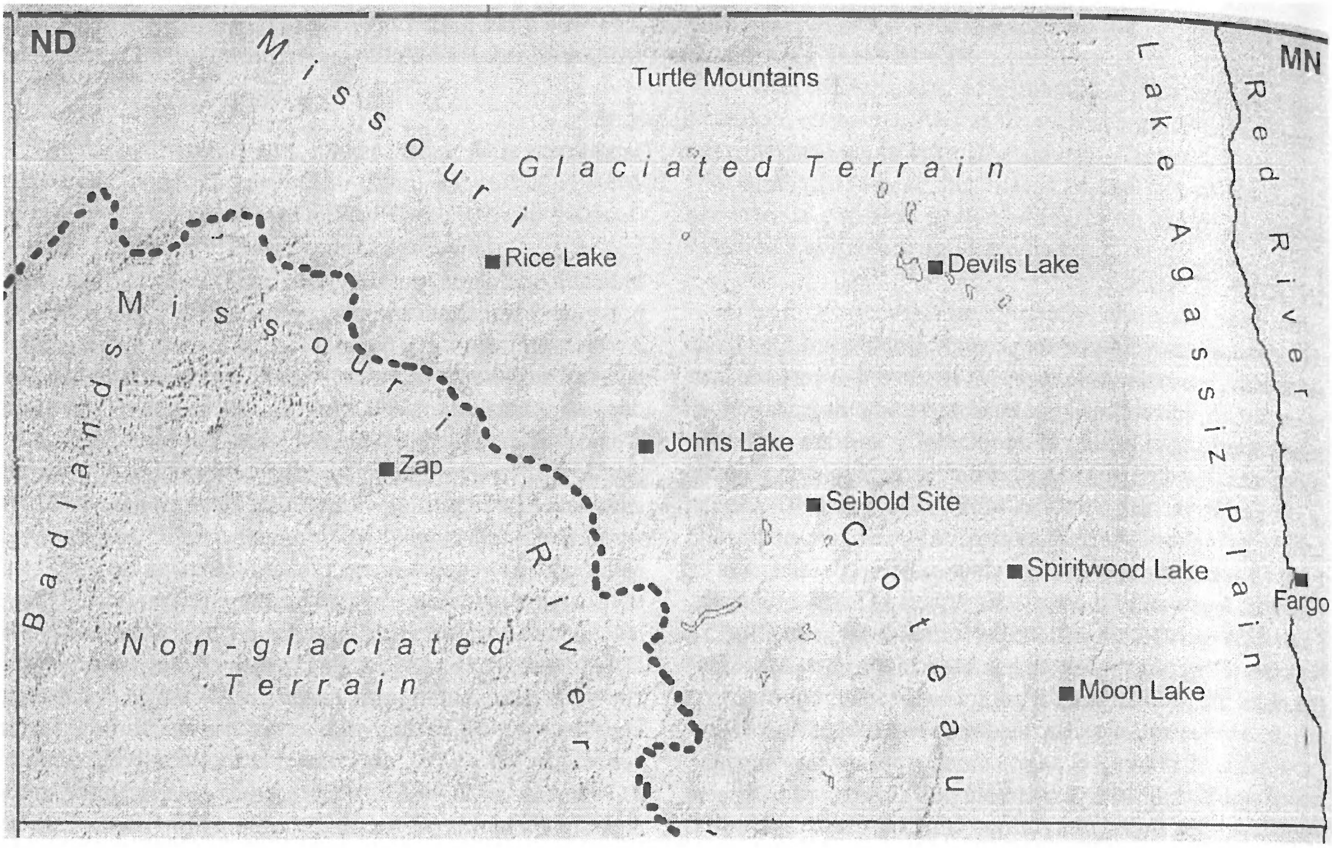

Figure 1. Quaternary paleontological sites in North Dakota. The dotted line marks the western margin of the Laurentide ice sheet during the last glaciation (base map from Color Landform Atlas of the United States [30]).

Lobe still occupied the Red River Valley. By 11 ^{14}C Ka, however, the margin of the ice sheet was north of Winnipeg. Large segments of the ice sheet stagnated along the margin of the Missouri Escarpment, and proglacial lakes formed along the actively retreating ice margin. Meltwater flowed southeastward across the state and accumulated in low areas to form large lakes, including Lake Dakota, Lake Agassiz, and Lake Souris (8). The pollen from Moon Lake, Barnes County, North Dakota, indicates that the initial vegetation was *Picea* (spruce)-dominated forest (9). This forest persisted from about 11.8 to 10.3 ^{14}C Ka (Figure 2). Other regional pollen sites have a basal zone that is dominated by spruce pollen (10, 11).

Lake Agassiz formed on the eastern margin of the state as the ice margin retreated northward. At 11 ^{14}C Ka, *M. primigenius* (woolly mammoth) inhabited the strandlines. Grasses were probably the main diet of *M. primigeneus*, and a grassland, not a spruce forest, was probably the preferred habitat. Wind and cold surface waters of the lake may have favored a narrow zone of open vegetation around the shorelines (6). Further, the mammoths, isolated by their ecology into a narrow zone between spruce forest to the west and the lake to the east, may have been preyed on by paleoindian hunters who entered North Dakota about this time (6). Mammoth became extinct in North America about 11 ^{14}C Ka.

The southern basin of Lake Agassiz was colonized by plants when the waters drained to the Atlantic Ocean during the Moorhead Phase, between 10.9 to about 10.3 ^{14}C Ka (12). Deposits from a cut bank on the Red River, Fargo, with an age of 10.3 ^{14}C Ka, contain pollen, macroscopic plant remains, fossil beetles, gastropods, and bivalves (13). The fossil assemblages are dominated by aquatic organisms. Most of the wood preserved at the site is *Populus*, probably *P. tremuloides* (aspen), but there is also a cone of *Alnus* (alder) and a few, poorly preserved leaves of *Picea* (spruce). The macroscopic fossils indicate eutrophic conditions in a shallow, lagoonal environment. The climate was probably similar to that in northern Minnesota of the present day (13). The pollen assemblage from the Seminary site, about 1 km to the south, at a similar stratigraphic position and with an age of 9.9 ^{14}C Ka, was dominated by *Picea* (14). This pollen, however, could have been reworked and redeposited from older sediments.

Further to the west, two late-glacial (late Pleistocene) and early Holocene fossil assemblages have been examined from the area of the stagnant moraines of the Missouri Coteau.

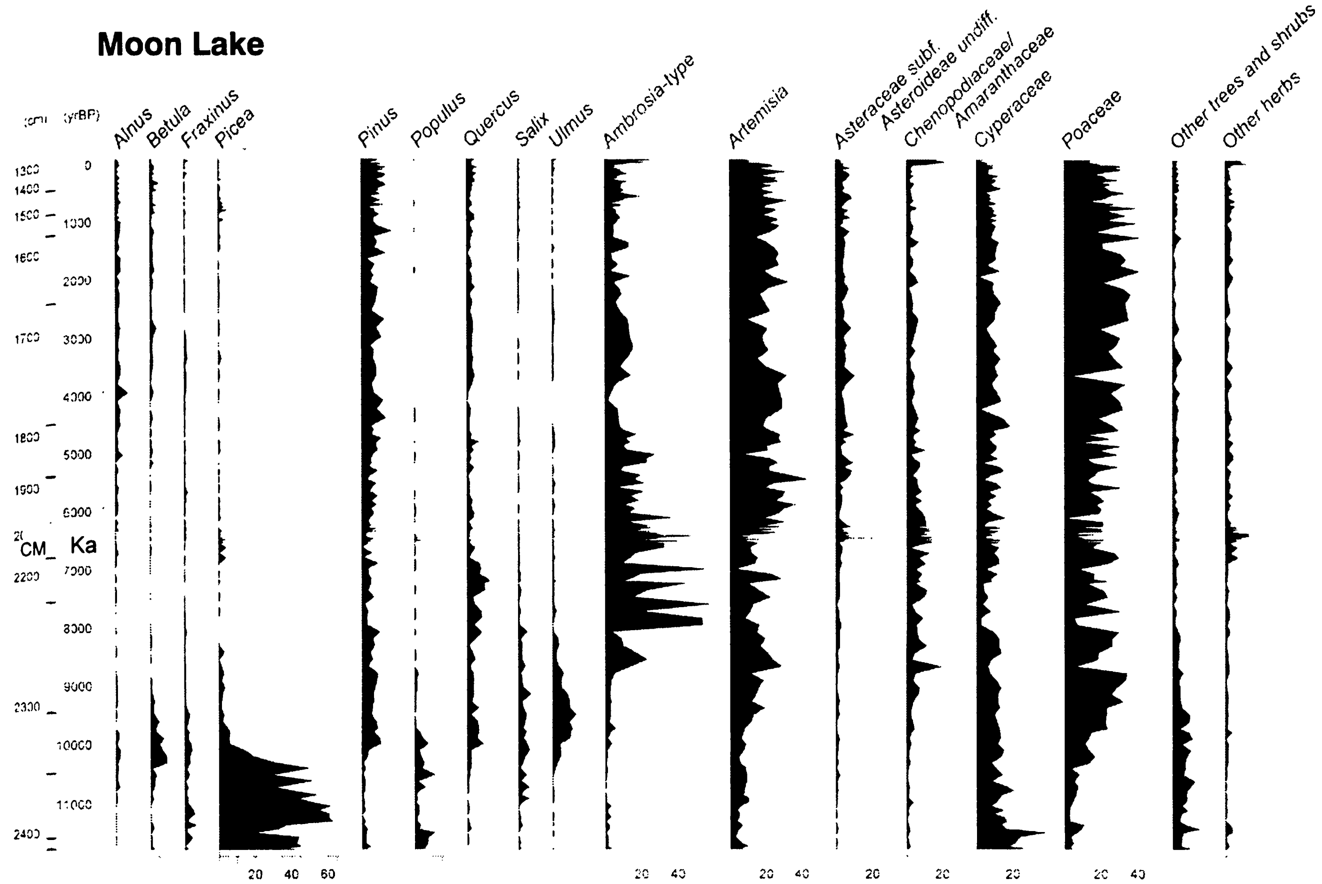

Figure 2. Summary pollen diagram for Moon Lake, Barnes County, North Dakota (9). Reprinted from the North American Pollen Database using Siteseer.

The sediments of Johns Lake, with an age of 10.8 ^{14}C Ka, contain abundant cones and leaves of *Picea*. This site also has a rich fossil beetle fauna, including several species of Scolytidae (bark beetles) associated with *Picea* (15). A few of the beetle species are those typically found in prairie habitats, suggesting that the forest was open and possibly more like the southern margins of the boreal forest today. On the basis of macrofossils from the Seibold site, *Picea* persisted until about 9.3 ^{14}C Ka on the Missouri Coteau (16). In addition to *Picea*, the Seibold sediments contain exceptionally well-preserved fossils, including complete leaves of *Populus* (cottonwood), complete skeletons of fish and frogs, bones of muskrat, coprolites of beaver, exoskeletons of amphipods, insect larvae, aquatic bugs, and beetles. The beetles, like those of the Johns Lake site, represent some species associated with spruce forest and others associated with prairie (17).

THE HOLOCENE

At 9.9 ^{14} C Ka, an ice advance in Canada blocked the northeastern drainage outlets of Lake Agassiz and the lake rose for the final time, flooding the southern part of the basin. Shortly afterwards, the ice retreated and Lake Agassiz drained for the last time. The lake may have persisted in North Dakota until about 8.2 ^{14}C Ka (12). Further west on the Missouri Coteau, buried ice had melted out by 9 ^{14}C Ka.

Isolated spruce populations persisted in North Dakota until the early Holocene. At Moon Lake, the spruce forest was replaced at about 10.3 ^{14}C Ka by a parkland of mixed deciduous forest and prairie. This vegetational change is attributed to an increase in summer temperatures (9). A climate change to progressively drier summers is thought to have caused the demise of *Ulmus* (elm) and finally *Quercus* (oak). By 7 ^{14}C Ka, the vegetation surrounding Moon Lake was a prairie (9). At Rice Lake in northwestern North Dakota, prairie replaced earlier parkland vegetation by 9.4 ^{14}C Ka (Eric Grimm, pers. comm., 1999).

At Moon Lake, there is continuous prairie from about 7 ^{14}C Ka to the present. The pollen of *Ambrosia* and other weedy species is more abundant than that of grasses until about 5 ^{14}C Ka. The increased representation of grass pollen during the last 5 ^{14}C Ka is also recorded in the pollen diagram for Rice

Lake. The maximum drought conditions during the mid-Holocene occurred between 7-6 ^{14}C Ka. At Moon Lake, between 6.6 to 6.3 ^{14}C Ka, pollen of *Iva annua* (marsh elder), *Ruppia* (ditchgrass) and *Picea*, all show small increases. *Ruppia* is an aquatic, and the presence of its pollen is believed to indicate a shallowing of the lake (9). The modern range of *Iva* does not extend north of Nebraska, and its presence is thought to represent warmer conditions. The spruce pollen is believed to be reworked from older sediments eroded along the margins of the lake as the water surface was lowered by intense evaporation (10). In one of the best dated records in the region, maximum drought conditions at Elk Lake, Itasca Park, Minnesota, occurred between 6.2 to 6 ^{14}C Ka (18).

Fossil diatom assemblages have been studied from several closed-basin lakes in North Dakota and provide one of the best indicators of salinity changes (9, 19–22). The general assumption is that significant changes in lake levels are the result of climatic change. At Moon Lake, the water until 10 ^{14}C Ka was fresh, from 10 to 7.3 ^{14}C Ka it was moderately saline, and from 7.3 to about 2 ^{14}C Ka it was highly saline (9). At Devils Lake, the change from fresh water to highly saline conditions occurred at about 8 ^{14}C Ka, about two thousand years later than at Moon Lake. The very high salinity at Devils Lake persisted until about 5 ^{14}C Ka, but during this time the lake was flushed periodically with freshwater. From about 5 ^{14}C Ka to about about 2 ^{14}C Ka ,the lake was moderately saline (20). Variations in the timing of salinity events in prairie lakes varies and has been attributed to a number of causes, including differences in hydrological sensitivity of lake basins to climatic change, poor chronological controls, and sensitivity differences between different proxy indicators. Even so, most lakes in North Dakota and the surrounding prairie region record intense episodes of drought during the mid-Holocene from 8 to 4 ^{14}C Ka.

During the mid-Holocene, evaporation was so intense that shallower lakes completely dried up (23). At these times, wind erosion removed older sediments from many shallow lake basins. Ages of basal sediments in those basins date only to about 3 ^{14}C Ka. At Spiritwood Lake, near Jamestown, North Dakota, divers from Northwest Divers, Moorhead, Minnesota, found bison skulls and bones scattered across a shelf at about a 6-m depth. The bones could have been from individuals drowned as they broke through the ice during an early freeze or a late thaw. The horn core dimensions of a skull, however, are most similar to those of *Bison bison occidentalis,* the typical mid-Holocene form. This led me to conclude that the bones were more probably from bison that died on the margins of the mid-Holocene lake. Large bison skulls, initially reported as *Bison crassicornis*, but revised to *B. bison occidentalis*, were also described from the base of an alluvial fill at a 6-m depth on Spring Creek, near Zap, North Dakota. Beaver-gnawed wood associated with those specimens had an age of 5.4 ^{14}C Ka (24, 25).

Holocene climate was the topic of symposia at the 1998 meetings of the Geological Society of America and the American Quaternary Association. The causes of mid-Holocene drought have been hotly debated. In the northern Great Plains, regional drought is generally associated with stronger westerly zonal airflow. One hypothesis suggests that stronger circulation was initiated by Milankovitch-driven insolation changes. A lag of 3 ^{14}C Ka, following the insolation maximum at 9 ^{14}C Ka, is attributed to a rapidly disintegrating ice sheet cooling the atmosphere and delaying the effects of heating (26). A second hypothesis, suggests that the increased strength in the westerlies was associated with increased solar geomagnetic disturbances (27). Using spectral analyses, it was determined that cycles of 200, 100, 50, 22, and 20 years in duration were represented in the varve record of Elk Lake. During the mid-Holocene it was further determined that there was an inverse relationship between varve thickness and the 200-year cycle in ^{14}C production determined from tree rings. During this same period, the Earth's dipole moment was at its lowest during the Holocene, suggesting a link between an increase in solar geomagnetic disturbance and the strength of the circulation.

The late Holocene pollen record for Moon Lake indicates an increase in grasses and a decrease in *Ambrosia* for the last 4 ^{14}C Ka (9). There were also several small increases in *Ruppia* pollen during this time that are believed to be associated with drawdowns of the water level. The diatom-inferred salinity at Moon Lake remained high until about 2.2 ^{14}C Ka, after which the frequency of droughts increased (9).

North Dakota does not have any long-lived trees, but *Pinus ponderosa* and *Juniperus scopulorum* in the North Dakota badlands have records that extend back to about AD 1600 (29). Instrumental records for climate change in North Dakota are about 100 years old. Comparison of the tree ring records with the instrumental climate records indicates that the tree ring record is sensitive to drought. All the trees have thinner rings during the drought of the 1930s. Individual records show a lot of variation, but there appears to be a cyclicity to drought, with intense droughts occurring on a frequency of 40-60 years. What is particularly striking in the Moon Lake salinity record is the magnitude of a series of droughts prior to AD 1200: at AD 200-370, AD 700-850 and AD 1000 -1200 (28). These droughts were all of a greater magnitude than the intense drought of the 1930s. They have been correlated with intense episodes of drought in western North America, suggesting that their cause lies in changes to atmospheric circulation over the Pacific Ocean (28).

CONCLUSIONS

Studies in Quaternary paleontology have contributed significantly to our knowledge of climate change on the northern Great Plains. Future studies will be directed at filling gaps in the knowledge base and in "fine-tuning" methods to improve the quality of interpretation.

The climate along the ice margin during the last glacial is still poorly known. The semiarid climate of the southwestern part of the state, and the depth of oxidation, is not conducive to the preservation of organic sediments. Nevertheless, the sediments of shallow basins should continue to be examined for pollen. Future fossil discoveries will probably continue to be vertebrate remains. Radiocarbon dating of bone has been unreliable, but new techniques promise to change that situation. Also, it may be possible to infer vegetation from isotopic studies of tooth enamel.

Late-glacial and early Holocene sediments on the Missouri Coteau need to be more completely examined. The Seibold site, with its incredible preservation, is probably not unique. Ancient DNA could well be preserved in these fossils. Future studies in molecular genetics could provide a real link between populations of the past and those of today that would enable detailed reconstructions of dispersal routes of organisms in response to climate change.

Micropaleontological studies of lacustrine sediments during the last 10 years have made a significant contribution to our knowledge of Holocene climate. Historically, the terms altithermal and hysithermal were used to describe a peak of warmth in the mid-Holocene. The high resolution records of pollen, diatoms, ostracods, and geochemistry that are now being studied indicate that that classical concept was an oversimplification. The latest records indicate much more complexity. The modal changes which seem to be part of the Holocene record are especially intriguing, as they imply major reorganizations of the Pacific oceanic-atmospheric circulation.

The opportunities for future paleontological research in lacustrine sediments are great. There is a need to find out more about the relationships between specific organisms and their responses to climate parameters and water chemistry. There is also a need to resolve the complex relationships between climatic parameters and hydrology in such a way that it can be taken into account in paleoclimatic interpretation. In a vicious pun, paleontology has been referred to as the "dead science." Nothing could be further from the truth. Quaternary paleontology, with its links to global change and climate change, is very much alive and a significant contributor to evaluating the extent and scale of prehistoric changes in climate and their importance in present-day climate change concerns.

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Symposium Agenda

SCIENCE EDUCATION REFORM - REVISING PEDAGOGY TO PROMOTE INQUIRY IN THE SPIRIT OF THE NATIONAL SCIENCE EDUCATION STANDARDS

April 16, 1999 (Friday Morning)

Location - Memorial Union

Convenor and Moderator - Mark D. Guy, University of North Dakota, Department of Teaching and Learning

Participants

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SCIENCE EDUCATION REFORM - REVISING PEDAGOGY TO PROMOTE INQUIRY IN THE SPIRIT OF THE NATIONAL SCIENCE EDUCATION STANDARDS

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INTRODUCTION

A recent national initiative has been developed in response to numerous national reports recommending science education reform in the United States. The *National Science Education Standards* (National Research Council, 1996), establishes broad frameworks to guide comprehensive science education reform efforts. The *Standards* encompass not only teaching and science content in K-12 classrooms but also addresses teacher education, assessment, program, and system standards related to science learning in our schools. "Founded on exemplary practice and research, the *Standards* describe a vision of the scientifically literate person and present criteria for science education that will allow that vision to become a reality" (p. 11). A major goal of this initiative is therefore to help all students attain better science skills and understandings through more conceptually organized, inquiry-based methods of instruction.

The purpose of this symposium is to further the professional dialogue among scientists, educators, and community leaders regarding science education practices that promote conceptual understanding as well as an interest to pursue science related careers. Symposium presenters represent various levels of science instruction, from elementary aged children through college and adult learning. A common theme for all the presentations will focus on practical strategies and ideas for promoting science inquiry experiences among learners

The symposium is designed to be highly interactive with presenters showcasing their programs and innovative ideas at hands-on centers located around the room. Time will also be allotted for discussion and questions related to the activities presented and teaching more meaningful science to students.

SYMPOSIUM PRESENTERS AND TOPICS

Roger Palmer: Chemistry Teacher, Red River High School, Grand Forks

The Red River Valley Geographic Information Systems (GIS) in Education project: This presentation describes a currently designed summer and school year science club activities that offer Grand Forks students opportunities to pilot new and innovative uses of technology. Students to continue to build and maintain a regional dynamic database of water quality information that will be available to others through a server at Red River High School. Teachers and students will have access to this information via the World Wide Web. Plans call for a Web site for Red River wide basin projects and links to collaborating sites or additional resources on the Internet. A goal for the project is to become a regional training center for teachers to learn technologies such as GIS so that they might be able to implement it in their classrooms. These units of study can be integrated into courses such as: chemistry, biology, geography, economics, computer-aided drafting, and marketing during the school year.

Dexter Perkins: Professor, Geology and Geological Engineering, UND

Revitalizing Science Education: Recent studies have shown that most Americans are scared of science and think it is a mysterious something they will never be able to understand. Yet, just as many studies have shown the need for a science-literate society. This contradiction has led many to question the way in which science is taught in the classroom. Their conclusions are unanimous: science education needs to be done differently. There are several keys to a successful reform of science teaching, and we will discuss them all. As a first step, science educators must reevaluate and clearly identify the goals of their teaching. As a second step, they must understand the ways students learn and what works best in the classroom. Finally, science educators must be willing to sacrifice coverage for process. The needed changes are not trivial, and require time to implement, but fortunately there are a number of excellent reports and other references available to aid the process.

A focus in the presentation will be placed on identifying course goals and purposes that contribute to meaningful learning and manageable ways to implement theses objectives. Actual classroom examples will be offered and illuminated for discussion.

Vera Uyehara: Director, Dakota Science Center

Inquiry and Technology: The Dakota Science Center embraces inquiry in all its programs and exhibits. Participants will be introduced to the range of Dakota Science Center programs, and experience how hands-on, standards-based, inquiry approaches to science, math, and technology can be incorporated into a new model for science education. At the break out session participants will explore the NatureShift! web site and directly experience the Exploration model. This unique learning cycle combines Internet tools with real world hands-on experiences, culminating in interdisciplinary projects of a variety of forms. Participants will be able to choose one of three areas: environmental science, history, or American Indian culture.

Carol Zito: Chemist, Human Nutrition Research Center, Grand Forks

Science Safari: Participants will take a safari through science trunks available from a range of federal, state, and private organizations. All of the materials are consistent with the *National Science Education Standards* in terms of emphasis on inquiry and investigation. Participants can see first hand how water flows under ground using the North Dakota Groundwater Trunk from *Project WET* or they can take an animal safari using the materials in the Wild Trunk from *Project Wild.* There will also be experiments with soybean products using the Soybean Science Kit: Polymers and Oil from the North Dakota Soybean Council. Sample curriculum materials from many other programs will be available for review.

Jerry Wenzel: Life Science Teacher, Central Middle School, East Grand Forks

Red River Valley of the North Project (RRVN): An overview of this award winning middle school curriculum will be presented as a model of interdisciplinary instruction appropriate for middle grades. Students in grades 6, 7, and 8 at Central Middle School explore the Red River Valley through all subjects with a strong foundation of science inquiry. Not only is the project interdisciplinary offering multiple perspectives of learning about the valley, but each grade takes a different time period: 6th graders explore the present valley conditions; 7th graders look back into the past; 8th graders delve into what the future might hold for the valley. Science inquiry is at the heart of the project through investigations of water quality, soil analysis, and biotic community comparisons. Emphasis throughout the curriculum is placed on helping students connect with their local environment and community. Video clips and supporting materials will be offered to further explain the project.

REFERENCE

1. National Research Council., 1996, National Science Education Standards: Washington, DC, National Academy Press.

Symposium Agenda

CONCENTRATED ANIMAL-FEEDING OPERATIONS (CAFOs) AND ENVIRONMENTAL QUALITY IN NORTH DAKOTA

April 16, 1999 (Friday Afternoon)

Location – Memorial Union

Convenor and Moderator – David Rush, Research Associate, Energy & Environmental Research Center

Symposium contributions and discussion to be published as a supplement to this volume.

INTRODUCTION TO CAFOs

Background on CAFOs

1:00 p.m. Greg Lardy – North Dakota State University Extension Service
CAFOs in the United States: Where Are We At and How Did We Get Here?

1:25 p.m. Dakota Resource Council
The Hidden Costs of Factory Farming

Regulation of CAFOs

1:50 p.m. Gary Haberstroh – North Dakota State Health Department
State and Federal Regulations for CAFOs

ENVIRONMENTAL ISSUES ASSOCIATED WITH CAFOs

Natural Resource Concerns

2:20 p.m. Dexter Perkins – University of North Dakota; Sierra Club, Dakota Chapter
Environmental Problems Associated with CAFOs

2:40 p.m. Mike Ell – North Dakota State Health Department
The Effects of Concentrated Livestock Feeding Operations on Water Quality in North Dakota

Human Health Concerns

3:00 p.m. Charlie Stoltenow – North Dakota State University Extension Service
Antibiotic Resistance

TECHNIQUES, BEST MANAGEMENT PRACTICES (BMPs), AND TECHNOLOGIES FOR OPERATING CAFOs

Waste Handling and Nutrient Management

3:20 p.m. Scott Birchall – Carrington Research Extension Center
Manure Management Practices in North Dakota

Engineering Designs

3:45 p.m. Dan Stepan – Energy & Environmental Research Center
What's the Stink? Odor Control Technology Demonstration at a Hog-Farrowing Facility

4:00 p.m. Shane Kjellberg – South Central Dakota Regional Council, BMP Engineering Team
Agricultural Waste BMP Design and Operation

4:20 p.m. Mark Bauer – North Dakota State University Extension Service
Nutritional Implications on Livestock Waste

PANEL DISCUSSION

4:45 p.m. Moderator – David Rush

Panel Members –
Greg Lardy, North Dakota State University Extension Service
Dexter Perkins, University of North Dakota; Sierra Club
Mike Ell, North Dakota State Health Department
Shane Kjellberg, Resource Conservation & Development Council
Mark Bauer, North Dakota State University Extension Service, North Dakota Farm Bureau
Gary Haberstroh, North Dakota State Health Department
Charlie Stoltenow, North Dakota State University Extension Service
Scott Birchall, North Dakota State University Extension Service
Dan Stepan, Energy & Environmental Research Center
Dakota Resource Council
Roger Johnson, North Dakota Agricultural Commissioner

COMMUNICATIONS

UNDERGRADUATE

ESTROGEN RECEPTORS AND SIZE OF UTERINE ARTERIOLES IN OVARIECTOMIZED, STEROID-TREATED EWES

Holly R. Berginski*, Dale A. Redmer, Mary L. Johnson, Kim C. Kraft, Lawrence P. Reynolds
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INTRODUCTION

The ovarian steriods, such as estrogens and progesterone, are the primary uterotropic hormones, and their effects are reflected by the cyclic patterns of uterine cell proliferation, vascular growth, and blood flow that occur throughout the nonpregnant cycle (1, 3, 5). These uterotropic effects of ovarian steroids are thought to serve primarily to prepare the uterus for implantation and subsequent placentation (1, 4). The uterine arterioles are the primary resistance vessels that regulate blood flow to the uterus and to the maternal portion of the placenta and thus determine the rates of transplacental exchange and fetal growth (1, 3, 5). This experiment was conducted to determine the effects of estradiol and progesterone on size and estrogen receptor levels of uterine arterioles.

METHODS

Thirty- two ewes were ovariectomized (Ovx) on Day 10-12 after estrus, allowed to recover for 30 days, and then treated with ovarian steroids as follows: no hormone (Control), estradiol (E, 2 days), progesterone (P8, 8 days; P30, 30 days; P60, 60 days), or E plus P (E+P). In addition, two groups of intact ewes that were in estrus (EST, period of estrogen dominance) or luteal (LUT, period of progesterone dominance) stages of the estrous cycle were used (2). Ewes were slaughtered, and a cross-section of the whole uterus was fixed in formalin for immunohistochemical evaluation of size of and estrogen receptor levels (E2R) in uterine arterioles (2, 6). Tissue sections (6 μm thick) were stained using mouse monoclonal E2R antibody and a biotinylated peroxidase complex system. For control staining, sections were incubated with normal horse serum or mouse ascites fluid. All tissues were counterstained with Harris' hematoxylin (1, 2, 6). Each section was evaluated by using an image analysis system (6) to determine arteriolar size and percentage of arteriolar nuclear area containing estrogen receptors. All data were analyzed by ANOVA and Duncan's test and differences were determined as significant at $P<0.05$.

RESULTS

Uterine arteriole vessel area (VA, μm^2) was greater ($P<0.05$) for EST compared with LUT or Ovx ewes, which were similar. Although estradiol had no effect, treatment of Ovx ewes with progesterone for 8 days (P8) or 30 days (P30) increased ($P<0.05$) VA. VA of E+P ewes was similar to VA of Controls. The percentage of nuclear area containing estrogen receptors (%E2R) also was greater ($P<0.05$) for EST compared with LUT. Treatment of Ovx ewes with estradiol (E) increased ($P<0.05$) %E2R by 1.5 to 2-fold. Addition of progesterone (E+P) blocked the stimulatory effects of estradiol on %E2R. Although progesterone had no effect when administered by 8 or 30 days, when given for 60 days (P60) it decreased ($P<0.05$) %E2R.

DISCUSSION

These data demonstate that estrogen has a marked effect on increasing uterine arteriolar estrogen receptors. This observation may explain the dramatic effects of estrogen on uterine blood flow and vascular growth (angiogenesis) in ewes (3, 4, 7). In addition, treatment with progesterone for 60 days resulted in a decrease in estrogen receptors in uterine arterioles, which may explain the detrimental effects of long-term progesterone treatment on the uterine vasculature (8).

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FOLLICULAR DEVELOPMENT AND OOCYTE RETRIEVAL IN NON-TREATED AND FSH-TREATED EWES

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INTRODUCTION. In recent years, assisted reproductive technologies (ART) for the creation, advancement and preservation of animal genetics as well as for the continued improvement of animal reproductive efficiency have been introduced and improved (3). In sheep reproduction, ART have been used to obtain multiple embryos *in vivo* or *in vitro* from follicle stimulating hormone (FSH)-treated sheep and to obtain transgenic or cloned animals (2,3). This experiment was conducted to determine the effects of in vivo FSH administration on the number of follicles and recovery of oocytes.

METHODS. Ewes (n=29) were implanted with Synchro-Mate-B (SMB; norgestomet) for 14 days to synchronize estrus. The sheep were randomly distributed into three groups, non-treated (control, n=10), or treated with FSH for two days (FSH-2day; n=9) or three days (FSH-3day; n=10). Beginning on the morning of Day 12 or Day 13 of SMB treatment, ewes received twice daily (morning and evening) intramuscular injections of FSH as follows: Day 1, 5 units/injection; Day 2, 4 units/injection; Day 3, 3 units/injection. For all treatments laparotomy was performed on day 15 to count the number of small (<3 mm), medium (3-8 mm), and large (>8 mm) follicles and to retrieve oocytes. For each ovary, the number of follicles and their surface diameter was determined before oocyte collection, and oocytes were collected from all visible follicles. Oocytes were evaluated as healthy or atretic on the basis of morphology.

RESULTS.

Table 1. Number of small, medium, and large follicles, and number of oocytes recovered from small, medium and large follicles in non-treated or FSH-treated ewes

Treatment	Number of Follicles				Number of Oocytes Recovered			
	<3mm	3-8mm	> 8mm	Total	<3mm	3-8mm	>8mm	Total
No-treatment	3.3±0.8	4.6±0.7 [a]	0.3±0.2	8.2 ±1.0 [a]	3.1±0.6 [d]	3.9 ±0.7 [d]	0.2±0.1	6.4 ±0.5 [d]
FSH-2day	2.0±0.9	13.4 ±1.7 [b]	0.7±0.3	16.2 ±2.1 [b]	1.1 ±0.6 [e]	9.2 ±1.4 [e]	0.2±0.2	10.1 ±1.6 [d,e]
FSH-3day	1.3±0.6	19.3 ±2.1 [c]	0.8±0.4	21.4 ±2.0 [c]	0.7 ±0.4 [e]	13.2 ±1.8 [e]	0.5±0.4	14.4 ±1.9 [e]

[a,b,c] p<0.01 means ± SEM differ within a column. [d,e] p<0.02 means ± SEM differ within a column.

Table 2. Recovery rate and the proportion of healthy and atretic oocytes for non-treated and FSH-treated ewes

Treatment	Total recovery (%)*	% of healthy oocytes	% of atretic oocytes
No-treatment	76.1±5.5	67.7±5.9 [a]	32.3±5.9
FSH-2 day	62.1±6.1	87.3±5.6 [b]	12.7±5.6
FSH-3 day	61.0±7.1	95.1±2.3 [b]	4.9±2.3

[a,b] p<0.05, *Total recovery was calculated on the basis of number of follicles used for oocyte collection and the number of oocytes collected.

DISCUSSION. In the present study, FSH increased the number of follicles, the number of oocytes recovered, and the proportion of healthy oocytes, but oocyte recovery rate was similar for all treatments. Other experiments also demonstrated a greater number of follicles in FSH-treated ewes (2-4). In FSH-treated ewes with synchronized estrus, Baldassarre et al. (1) showed that recovery rate of oocytes by laparoscopy was 82% and was similar for follicles <5mm and >5mm. Quality of oocytes was similar for both follicle sizes (1). Thus, laparotomy is an efficient method to retrieve oocytes from sheep ovaries, and FSH treatment provides a good method for obtaining a large number of healthy oocytes.

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HEIGHT AND SOCIO-ECONOMIC STATUS OF MEN: THE EFFECTS ON ATTRACTION AND DATING PREFERENCES

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INTRODUCTION

For many years there has been research on the role that height plays in the perceived physical attractiveness of a person. Women not only look at the height, but at socio-economic status (SES) in evaluation of a man. It was hypothesized that a man of tall height and high SES would be found most attractive and the short, low status man the least attractive.

METHOD

Participants

Sixty Moorhead State University female students participated. They may have received extra credit for participation.

Materials

Each participant received one descriptive paragraph of a man named John based on the biodata used by Hensley (1). Each description pertained to a man of short (5'7") or tall (6'2") height and low ($15K), medium ($22K) or high ($80K) socio-economic status exemplified by occupations of bank teller, video store rental manager, or businessmen respectively based on Singh's (2) with six statements following, describing different types of relationships, and a 15 question version of the Interpersonal Attraction Scale (IAS) rated on a 5- point Likert scale used by McCroskey & McCain (3).

Procedure

The study was a 2 x 3 design. Participants were tested in groups with randomly distributed surveys. Each was told the purpose was to assess how people choose partners for dating and marriage. Each participant received an envelope with one description of the man followed by six relationship types and the IAS. Each scored the 6 types of relationships, with 0 being not willing and 9 being willing to engage in the relationship type. The IAS was also completed. Subjects had 20 minutes to complete the task, and then they were debriefed and given a research credit card.

RESULTS

A 2 (height) x 3 (SES) ANOVA was performed on each of the six types of relationships and the IAS, which was analyzed by type of attraction (social, task and physical). There was no main effect for height for any of the dependent variables. A main effect was found for income and a significant interaction effect in several of the dependent variables. A significant effect was found for income for willingness to have coffee and conversation, $p<0.001$. There was an interaction between height and income, $p<0.05$. A significant effect was found for women's willingness to go on a date with the target person for income, $p<0.01$. A significant interaction was found for willingness to be in a non-romantic friendship, $p<0.01$. There was no significant effect on willingness to be involved in a short term relationship. A significant main effect was found for income in the long term relationship, $p<0.001$. A main effect was found for income in the participants willingness to marry, $p<0.001$ and a significant effect for height when all types of romantic relationships were combined, $p<0.001$. A significant effect was found for the target person's rating on the social attraction subscale of the IAS, $p<0.03$. There was a main effect for income on the task attraction subscale, $p<0.002$. There was no significant effect for the target person's rating of physical attractiveness.

DISCUSSION

Consistent with evolutionary theory on mate selection, the results show that income has a clear impact on a man's perceived attraction level, but the impact is not clear for height. A medium height target person may have changed the results. The interactions could have been affected by the job title and there should be a consistent title in future research. Participants outside of the college population would also make the results more generalizable.

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DEVELOPING AND USING PHYLOGENIES: AN EXAMPLE USING DNA SEQUENCES AND BLACKBIRDS

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INTRODUCTION

The taxonomic group that comprises blackbirds, orioles, grackles, and relatives, (tribe Icterini) is perhaps the best studied bird group. The many studies of these species have yielded a wealth of data that could be analyzed in conjunction with a phylogeny. Icterines have been widely used to study the evolution of nest parasitism (1), plumage variation (2), and the importance of characteristics such as body size in evolutionary history (3).

Through estimating a phylogeny, one can study the evolution of traits. Today, most phylogenies are estimated from analysis of variation in DNA sequences. Microsatellite loci are repetitive DNA sequences that vary greatly within species. They are valuable tools for population and heritability studies. The DNA sequence data used in this project comes from the flanking regions of five microsatellite loci originally characterized in the great-tailed grackle (4). The purpose of this study is to generate an independent phylogeny of the icterines that can be compared to others based on DNA sequence data or morphology. In addition we will be able to trace the evolution of microsatellite sequences.

METHODS

DNA was extracted from breast muscle or blood by digesting the tissue sample with Proteinase K and SDS, NaCl precipitation, phenol-chloroform extraction, and alcohol precipitation of nucleic acids. Following resuspension, DNA concentration was measured with a spectrophotometer.

DNA amplification followed standard conditions. Each reaction (10µl) contained about 10ng DNA, 50mM KCl, 10mM Tris/Cl pH8.3, 1.5mM Mg^{2+}, 0.1% NP40, 250µM each dNTP, 500nM each primer. Using the tube control function of a Hybaid thermal cycler (which measures reaction mix components with a thermistor inserted into a dummy tube), reactions were cycled through a series of: 92 C 90s, then 55 C 5s, 72 C 5s, 92 C 0s, thirty times, and finally 72 C 90s. Reaction mixes were then loaded onto a 6% acrylamide gel and ran for app. 2 hrs at 120 volts.

Gels were stained with ethidium bromide, and photographed. Bands of DNA were cut out, divided into four tubes, and then used as template for sequencing. Sequencing was performed using an Amersham Pharmica Biotech ^{33}P radiolabled terminator cycle sequencing kit Thermosequenase. The product was run on a sequencing gel for 2800 vhr at 50 C, dried, then exposed to film overnight. The sequences were analyzed using Paup 3.1.01 (5).

RESULTS

A total of twenty-one species were used for this project. Not all primers would amplify in all birds. Therefore four phylogenies were produced from the data each with separate requirements as to which birds and which sequences were used in the analysis. There were several important findings. First, in the four phylogenies there existed poor resolution between the genus *Quiscalus* and morphologically similar genera. Second, the monophyly of the genus *Icterus* was strongly supported. Third, the monotypic genus, *Amblycercus holosericeus,* was found to be most closely related to the genus *Cacicus.* Five microsatellite loci were also sequenced in all study species and mapped across the phylogeny of Lanyon and Omland (6).

DISCUSSION

The poor resolution of the genus *Quiscalus* is indicative of a relatively recent speciation event. Lanyon and Omland (6) found five distinct lineages of blackbirds, but little support for any relationships between them. The second conclusion supports the finding of a distinct monophyletic *Icterus* lineage. Also, microsatellites mapped across the phylogeny were grouped according to the five blackbird lineages. The third result differs from their conclusions by showing the monotypic bird lineage is closely related to the genus *Cacicus.*

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COLONIZATION OF GIBBRELLA ZEAE IN SENESCENT WHEAT PLANTS

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INTRODUCTION

In recent years Fusarium head blight (FHB) has caused tremendous damage to wheat in various locations around the world, including North Dakota. The disease is favored when the weather is wet during flowering. Populations of the causal fungus, *Gibbrella zeae* (anamorph: *Fusarium graminearum*), are affected by availability of nearby hosts and infested residue. This study was done to understand on what location of the wheat plant *G. zeae* survives after harvest.

METHODS

Prior to harvest in 1998, 120 wheat plants that showed 100% FHB severity were labeled in a small field on NDSU's campus. For nine weeks, beginning at harvest, five complete labeled plants were removed from the field at one week intervals. These plants were dissected into 11 parts consisting of the entire kernel, glume, and lemma, and 1 cm pieces of the middle rachis, proximal rachis, peduncle, first, second, and third node, and first and second internode. The samples were surface sterilized and placed on Komada's selective medium (1) for one week. All colonies were categorized by color and type of growth on Komada's medium. Sample colonies of each type were transferred to PDA slants to obtain pure cultures, and then to carrot agar for colony identification of species by asexual spores or observation of perithecia (1,2). The number of colonies in a specific category was multiplied by the percentage identified as *G. zeae* in each category to derive the population of *G. zeae*.

RESULTS

Regression analysis of the colony data against time revealed a trend of increasing colonization in the glume, kernel, peduncle, and first node For example, *G. zeae* colonization of the first node increased by 373%. The rest of the plant parts showed little or no increase in colonization frequency over time. The lemma and rachis showed a steady rate of high infection, averaging more than three colonies of *G. zeae* per five pieces sampled. Further down the plant in the second and third node and first and second internode, a much lower amount of colonization was observed. The second and third nodes averaged slightly over one colony of *G. zeae* per five sampled, and the internodes averaged less then one colony of *G. zeae* per five sampled.

DISCUSSION

Since FHB is a disease of the head, we expected more colonization in parts of the spike such as the rachis, glume and lemma than lower plant portions. The trend of increasing colonization observed in the kernel may suggest the fungus takes slightly more time to spread into the mature seed. The dramatic increase of infection in the peduncle and the first node suggest the fungus may colonize down from the head into the senescent tissue after harvest. The path taken by the fungus to colonize the lower plant parts was not determined. These results indicate the *G. zeae* may survive in both head and stem parts of the wheat plant.

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SEXUAL REPRODUCTION IN LEAFY SPURGE (*Euphorbia esula*)

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INTRODUCTION

Leafy spurge (*Euphorbia esula*) is a herbaceous perennial that has flourished as a weed of economic and ecological importance. This plant was introduced to North America from continental Europe and Asia in the early nineteenth century as a contaminant in seed grain (4). Since that time, it has become widespread and now infests over 5 million acres in the north central United States and Canada (2). Most of the current research on this invasive plant is concentrated on its eradication. Methods involving chemical, mechanical and biological control are in the forefront of most leafy spurge studies (1,3). Unfortunately, little has been known about the events of sexual reproduction.

Given this lack of reproductive information, an analysis of the breeding system of leafy spurge was conducted. This study examined the sexual reproductive biology of leafy spurge, including breeding strategies and floral structures involved in sexual reproduction. This study is the first to provide preliminary evidence of apomixis in leafy spurge.

METHODS

Breeding System Analysis. Treatments were carried out to test for self compatibility and apomixis. Controlled pollinations were maintained by bagging flowers with nylon mesh before anthesis. Hand pollinations were performed roughly a week after bagging. Plants to be tested for apomixis were emasculated. All treatments were observed for seed development daily and mature seeds were collected 6-8 weeks later.

Fluorescence Microscopy of Pollen Tubes. Flowers from outcrossed and selfed plants were collected 12, 24, 48 and 72 hours after pollination, prepared for pollen tube fluorescence and observed with UV epifluorescence for the presence of pollen tubes.

Brightfield Microscopy. Ovaries collected for observation were chemically fixed, embedded in glycol methacrylate, serially sectioned and mounted on microscope slides for observation.

RESULTS AND DISCUSSION

Leafy spurge was found to be self compatible, with 29% of the selfed flowers (n = 90) and 63% of the outcrossed flowers (n = 122) producing seeds. Unpollinated flowers (n = 112) failed to set seed and thus preliminary tests for apomixis were negative.

Microscopy results of both the selfed and outcrossed samples revealed that multiple pollen grains germinate on the stigmatic surface and that pollen tubes initiate growth into the style. Interestingly, pollen tubes were never observed to grow past the upper one-third of the style. Nevertheless, embryos were consistently found in pollinated flowers.

Although pollination is a prerequisite for seed set, we were unable to track pollen tubes to the ovule. It is therefore plausible that leafy spurge is a psuedogamous apomict and that pollen is only needed to trigger apomictic development of embryos and seeds. As an invasive plant, self compatibility and apomixis may, in part, be responsible for the rapid and widespread infestations of leafy spurge across America. Further studies using molecular techniques are needed to verify apomixis in leafy spurge.

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REGULATION OF SCLERAL PROTEOGLYCAN GENE EXPRESSION BY TGF-β1

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INTRODUCTION

Changes in proteoglycan synthesis and accumulation within the posterior sclera are associated with alterations in ocular length and subsequent changes in refractive error in a variety of animal species. Although the regulation ofproteoglycan synthesis has been studied in a variety of tissues, the mechanisms by which proteoglycan synthesis are regulated within the human sclera are largely unknown. Transforming growth factor-β (TGF-β) is a potent growth factor that has been implicated in the regulation of extracellular matrix formation and has been shown to modulate the synthesis of proteoglycans. Specifically, studies have shown that TGF-β increases the synthesis of large and small chondroitin/dermatan sulfate proteoglycans in several different type of cells. In the present study, we utilized cultures of human scleral fibroblasts to examine the effects of TGFβ-1 on the expression of aggrecan, a large chondroitin sulfate/keratan sulfate proteoglycan and on biglycan, a small chondroitin/dermatan sulfate proteoglycan.

METHODS

Human scleral fibroblasts (P6 - P10) were plated in a high serum-containing medium (DMEM + 15% FBS) and grown to confluence. Medium was replaced with a low serum-containing medium (F-12/HBSS + 0.1% plate poor horse serum; PPHS) and cells were cultured for two additional days to convert the cells to a phenotype which is more representative of the in vivo state. Media was then changed to media containing TGF-β1 (5 ng/ml) or control PPHS media, and the cells were incubated for an additional 48 hrs. The media was harvested and total RNA was extracted from the cell layers using a standard protocol. Total RNA (10 μg) was separated by denaturing gel electrophoresis and transferred to nitrocellulose for Northern blotting. Digoxigenin-labelled cDNA probes were generated using PCR and were used to detect steady state levels of biglycan and aggrecan mRNA using a kit (Genius 7, Roche Inc.). Additionally, a digoxigenin-labelled cRNA probe was generated to a region of the human 18s rRNA transcript and was used as a control probe on the same Northern blots to standardize for loading differences between the samples. Northern blot results were quantified by scanning densitometry using NIH Image software.

RESULTS

The aggrecan and biglycan transcripts from human scleral fibroblasts were detected on Northern blots as ≈ 9.0 kB and 2.6 kB bands, respectively. Treatment of scleral fibroblasts with TGF-β1 reduced the amount of aggrecan mRNA to undetectable levels. In contrast, TGF-β1 treatment increased the level of biglycan mRNA by ≈ 105% over that of controls ($P = 0.02$, ANOVA).

CONCLUSIONS

These results indicate that TGF-β1 has opposite effects on the transcription of aggrecan and biglycan by scleral fibroblasts. The finding that TGF-β1 results in a dramatic decrease in aggrecan expression by scleral fibroblasts suggests a new role of this growth factor in extracellular matrix remodeling.

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HYDRODESULFURIZATION OF THIOPHENE IN PETROLEUM: THE ROLE OF NOVEL IRIDIUM COMPLEXES AS PRECURSORS

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Hydrodesulfurization (HDS), the removal of sulfur from sulfur-containing residues of petroleum, is a reaction that must occur daily to meet standards set to lower sulfur's contamination to the world. The most difficult to desulfurize sulfur-containing residue of petroleum is thiophene, thus the mechanism(s) of catalytic thiophene HDS has been under scrutiny (1). Angelici (1) proposed that the first step to understand this mechanism(s) is the synthesis of transition metal complexes of thiophene that serve as models of thiophene adsorption at metal sites on the HDS catalyst surface. Some novel complexes of iridium have recently been uncovered because of these studies and the desire for new, more active HDS catalysts (2, 3). Under base catalysis, Cp*Ir (η^4-2,5-Me_2T) (1), where Cp* = η^5-C_5Me_5 and 2,5-Me_2T = 2,5-dimethylthiophene, undergoes rearrangement to the more stable Cp*Ir (η^2-2,5-Me_2T) (2). It has been reported that both (1) and (2) react with BH_3 to give the η^4-BH_3 adduct (3) and with H_2 to give the dihydride (4) (Figure 1).

1 2 3 4

Figure 1. Novel complexes of iridium uncovered by thiophene HDS studies (2, 3).

The purpose of this research is to theoretically study characteristics and reactions of (1) and (2) to model experimental results and show that (1) and (2) and their reactions may be precursors to a new mechanism(s) for thiophene HDS.

Structures of (1) and (2) were modified with hydrogen substituted for methyl groups on the Cp* or thiophene portions to decrease complications caused by rotation. The molecular drawing program MacMolPlot was used to position BH_3 or H_2 on modified (1) or (2) and then to recover the 3-D coordinates. Coordinates (assumed gas-phase) were submitted to the quantum chemical computation program GAMESS and optimized until equilibrium geometry was located according to a set gradient convergence tolerance. Hessians were run on equilibrium structures to confirm that they were indeed equilibrium states. MacMolPlot was also used to generate molecular orbitals and electrostatic potentials for modified (1) and (2).

BH_3 was initially positioned 5.0 A from the sulfur of both modified (1) and (2); in both cases, BH_3 was rejected, indicating a bonding barrier. Trials then positioned BH_3 within bonding distance of sulfur (~2.0 A) and, since iridium has a negative charge, to iridium (~1.7 A) of both modified (1) and (2). H_2 was positioned within bonding distance of iridium (~1.6 A) of modified (1). BH_3 and H_2 were positioned at various places that appeared to have optimum bonding conditions due to electronegativities and steric hindrances.

Trials did uncover positions BH_3 and H_2 might attack modified (1) to give (3) and (4), respectively (Table 1).

Trial to give (3)	Equilibrium	Trial to give (4)	Equilibrium

Table 1. Trials that produced experimental structures of modified (3) and (4), respectively.

Trials also gave unexpected products, many of which showed C-S bond cleavage/thiophene ring opening which is a precursor to thiophene HDS; it is unsure if any of these structures are experimentally significant. Molecular orbitals showed both modified (1) and (2) might have an element of symmetry not previously noted. Electrostatic potentials showed regions of modified (1) and (2) where positively charged ligands would tend to attack. Future goals of this research are to find transition states between modified (1) and (2) and equilibrium geometries to better understand the reactions with BH_3 and H_2 that may be precursors to a new mechanism(s) for thiophene HDS.

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REACTION OF *exo*-GLUCAL WITH ARYLSULPHENYL CHLORIDE ADDUCT OF 1-METHOXY-2-METHYLPROPENE

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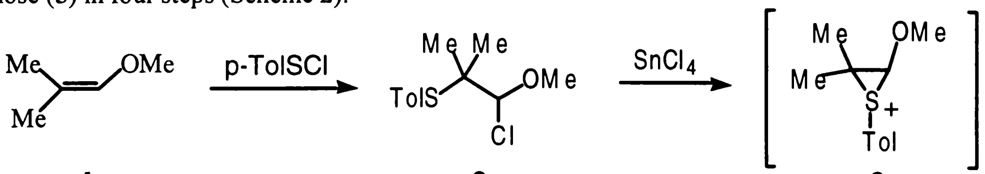
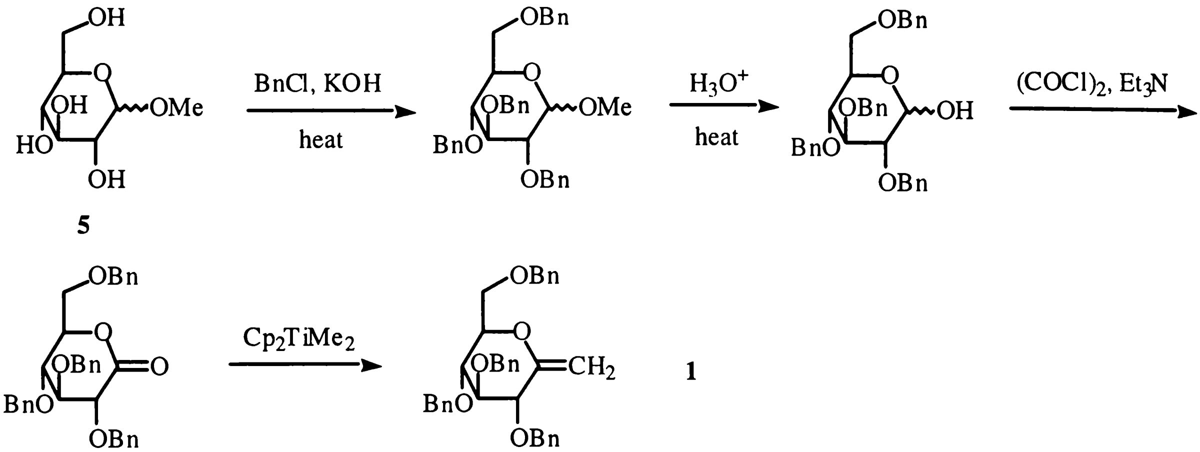
Recently the synthesis of *C*-glycosides have attracted a lot of attention. *C*-Glycosides are naturally occurring compounds possessing a variety of physiological activities. As non-hydrolyzable analogs of *O*-glucosides, *C*-glycosides have been used as enzyme inhibitors and substrates for carbohydrate-binding proteins. Here we would like to report our preliminary results on the synthesis of *C*-glucosides using the reaction of 2,6-anhydro-3,4,5,7-tetra-*O*-benzyl-1-deoxy-D-*gluca*hept-1-enitol (*exo*-glucal, **1**) with episulfonium ions.

In the present work, the episulfonium ion (**2**) was synthesized by the action of $SnCl_4$ on p-tolylsulfenyl chloride (p-TolSCl) adduct (**3**) of 1-methoxy-2-methylpropene (**4**, Scheme 1). *exo*-Glucal, **1**, was prepared from 2,3,4,6-tetra-*O*-benzyl-α-D-*O*-methyl*gluco*pyranose (**5**) in four steps (Scheme 2).



4 **3** **2**

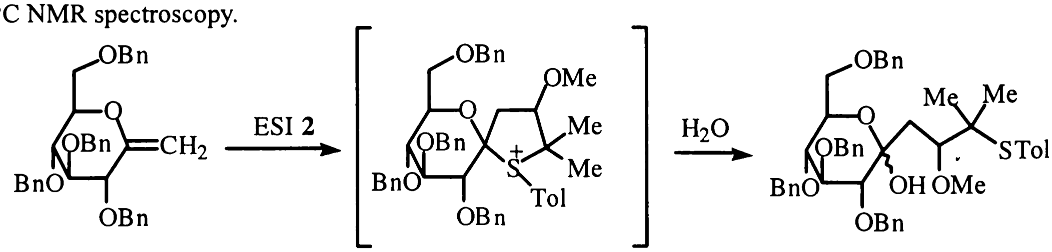
Scheme 1 an episulfonium ion (ESI)



5 **1**

Scheme 2

We have found that the episulfonium ion **2** readily reacts with *exo*-glucal to give an intermediate, the five-membered sulfonium salt **6**. Upon quenching with H_2O, this intermediate was converted to a mixture of two isomeric *C*-glucosides, α-gluco and β-gluco in a ratio of 3.4 : 1 (**7a,b**, Scheme 3). The structures of the two isomers have been determined by mass spectrometry, ^{1}H NMR and ^{13}C NMR spectroscopy.



1 **6** **7a,b**

Scheme 3

Currently we are working on the use of other episulfonium ions in the reaction with *exo*-glucal.

BISON HABITAT USE AND HERD COMPOSITION IN THEODORE ROOSEVELT NATIONAL PARK IN THE NORTH DAKOTA BADLANDS

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INTRODUCTION

Bison (*Bison bison*) no longer roam the open prairies in the United States. Bison herds now exist only within the confines of parks, preserves, and private pastures. Bison were re-established in Theodore Roosevelt National Park (TRNP) in 1956. A portion of the herd is periodically removed from TRNP during a fall roundup to prevent overpopulation. In the early 1980's, Norland and others (1) studied habitat use and devised models to determine optimum stocking rate in TRNP. Since that time, however, few studies have been done on the bison herd. Park personnel are interested in how the bison now use TRNP and the current herd composition in light of past herd culling practices. The purpose of our study was to investigate bison habitat use, space use, and herd composition in the South Unit of Theodore Roosevelt National Park in the Badlands near Medora, ND, during the summer of 1998.

METHODS

Bison were observed from various vantage points with binoculars and spotting scopes from vehicles driven over the park roads during mid-May, July, and August 1998. Locations of bison and other ungulates were recorded on maps and on a Global Positioning System. Gender and age class (adult, subadult, and juvenile) of bison were recorded when possible.

RESULTS

In May, before the breeding season, i.e., rut, many lone bulls were scattered throughout the park in various habitats while females were not readily visible from the park roads. As the rut progressed in July, bison from all over the park congregated in the black-tailed prairie dog (*Cynomys ludovicianus*) town areas and used these areas heavily. The most bison for which we could account on any particular day with accuracy occurred on 16 July 1998. On this day, we located 10 lone bulls scattered throughout the park and one large herd of 273 animals congregated on a single prairie dog town. Repeated counts of the 273 animals indicated there were at least 58 calves, and approximately 77 adult cows, 65 adult bulls, 11 subadult females (based on smaller size and/or absence of calf), 30 subadult males, 28 subadults for which the gender was undetermined, and 4 animals of unknown age or gender. Counts 2 days later indicated that there might be as many as 102 cows, most of which were probably included in the totals above as either subadult females or subadults of undetermined gender. Although it was easy to determine gender by body features and genitalia (if the animal was standing), it was sometimes difficult to determine female age if no calf was present. By late August, the rut was nearly finished, and the bison had again dispersed into smaller cow/calf bands with only a few bulls associated with these bands. Many bulls were again solitary or in small male bands. Movements of other ungulates in the park appeared to be independent of those of the bison.

DISCUSSION

Past studies in TRNP have indicated that bison use all areas of the park over the course of the year (1). Our study was conducted only during the summer months and centered primarily around the breeding season. We found that the prairie dog habitats and the large open areas they offered were used extensively, nearly exclusively, during the rut. Most of the movements we noted during July were from dog town to dog town, with occasional forays to the river or watering holes to drink. Our observations indicated that the dirt offered by the mounds around the prairie dog burrow entrances was frequently used for wallowing, pawing, and various displays that seemed to be associated with the rut. In future studies, we plan to observe reproductive behavior and evaluate current bull to cow ratios, e.g., "does the bison herd have too many bulls?" It would also be interesting to compare the rut activities of the bison herd in the North Unit of TRNP with those of the South Unit because the North Unit has less acreage associated with prairie dog towns than does the South Unit. Our hope is that the information we collect on the TRNP bison herd can be used to enhance herd management.

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INVENTORY OF EPHEMEROPTERA (CLASS INSECTA) OF THE MIDDLE SHEYENNE RIVER

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INTRODUCTION

During the spring and fall of 1997 and 1998 macroinvertebrate samples were collected from the middle Sheyenne River and its tributaries in the eastern portion of central North Dakota. The purpose of the macroinvertebrate sampling was to 1) document taxa of macroinvertebrates in the Sheyenne, and 2) to establish bioassessment criteria for macroinvertebrate sampling. One of the main taxa we are interested in documenting are the mayflies, Ephemeroptera. Pollution sensitive, Ephemeroptera larvae are good indicators of water quality.

METHODS

Basic sampling techniques were adapted from the 1997 draft revision of Rapid Bioassessment Protocols for Use in Streams and Rivers (1). D-frame nets were used for collecting from riffle, shoreline and /or aquatic vegetation, leaf pack, snags, and open water. In addition, Hester-Dandy plate samplers were placed in one section of the river, and removed two weeks later. Samples were preserved in 70% ethyl alcohol. A total of eleven sites were sampled in the two years, eight on the river, and three tributaries of the Sheyenne.

RESULTS

Currently our results show a total of 12 genera of Ephemeroptera. Eight of these genera were found in 1997, and 11 were found in 1998. Of the eight sites sampled in 1997, one site, a tributary to the Sheyenne, showed no Ephemeroptera larva. The highest abundance of genera was three, and this occurred in four sites. Genus *Stenacron* was the most widespread, appearing in six of the eight sites. This is interesting because to our knowledge genus Stenacron has not been reported west of the Mississippi River basin. Genus *Epheron* and, *Caenis* each were identified in only one site.

Of the seven sites sampled in 1998, *Stenacron* again was the most widespread, appearing in six of the seven sites. The highest abundance of genera was five in one site, followed by three sites with four genera. Five genera were identified in only one site. The genus *Leptophlebidae* was found above Bald Hill dam, but not in the river below the dam. One genus, *Isonychiidae*, was only found in the Hester-Dandy plate sampler

DISCUSSION

To our knowledge no in-depth survey of Ephemeroptera larva in the Sheyenne River has been conducted. We have established a reference collection for the middle Sheyenne River. This knowledge gives us a benchmark to document changes in the macroinvertebrate community that may be caused by major impacts, such as the proposed Devils Lake outlet, on the Sheyenne River.

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GENE FREQUENCIES OF DOMESTIC CATS IN THE RED RIVER VALLEY

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INTRODUCTION

Over the past 30 years populations of cats have been scored for mutant alleles at up to 11 genes, based on coat color traits. These studies have been conducted in the United Kingdom, France, Canada, and northeastern United States (1, 2, 3). Only one study has examined Midwestern cats in Chicago (4). Our survey is an attempt to add to the worldwide information about cat population genetics and to fill this gap. There were no domestic cats in the New World before Europeans settled; therefore the first cats to arrive left a genetic imprint which is visible today in allele frequencies. This imprint is characteristic of cats from the source of human immigrants. Therefore, from cat coat color genetic studies, inferences can be made about human migration patterns. Such data also contribute to the understanding of population dynamics of cats. We have surveyed cats since October 1997.

METHODS

Cats in our survey were from Grand Forks, ND, East Grand Forks, MN, and the surrounding areas. Cats were scored for presence of mutant alleles at nine genes in two ways. One by direct examination of the cats, of which a large proportion were from the Humane Society, and the other by information provided by people from a survey. Gender was determined for the great majority of cats. We avoided litter bias by choosing only one cat at random from a litter and omitting "fancy" cats such as Siamese. From this, we determined genotypes for the following mutant alleles: sex-linked orange (O) and autosomal mutants nonagouti (a), blotched tabby (t^b), dilute color (d), long hair (l), piebald spotting (S), dominant white (W), polydactyly (Pd), and lethal Manx (M). Proportions of dominant and recessive alleles for each gene were estimated using Hardy-Weinberg frequencies (5).

RESULTS AND DISCUSSION

A total of 362 cats were scored, 263 were directly observed, 99 were from returned surveys. Results from the two methods are shown in Table 1.

Table 1. Frequencies of the mutant alleles

Total N=362	O	a	t^b	d	l	S	W
Cats we scored N=263	0.29±0.03	0.72±0.03	0.29±0.04	0.57±0.03	0.48±0.03	0.52±0.03	0.01±0.03
Cats from survey N=99	0.25±0.05	0.72±0.03	0.52±0.04	0.63±0.04	0.46±0.04	0.50±0.04	0.00±0.05

Based on our data, the most common cats found in Grand Forks are gray (rather than orange), longhaired, striped tabbies, many with some white spotting usually on their feet. Polydactyly (Pd) and Manx (M) mutants are extremely rare.

Hypotheses of human migration routes into Grand Forks area must await additional cat surveys in the northern Great Plains. However, we can use our data to test for the effects of both human and natural selection on domestic cats in this region. The direct observation data are from abandoned or stray cats taken to the Humane Society, but the survey data is from pets. The allele with the greatest frequency difference between these two populations is the blotched tabby allele (t^b). This is found almost twice as frequently among pet cats than among stray cats, indicating a human preference for the swirled tabby pattern over the striped tabby pattern. Many other surveyed populations in North America have lower frequencies of the longhaired (l) allele (3). Our data suggest that longhaired cats have greater survivorship in the North Dakota climate due to selection.

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METABOLIC AND CARDIORESPIRATORY CHANGES RESULTING FROM A SERIES OF SUPRA-MAXIMAL LABORATORY TESTS

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INTRODUCTION. Physiological demands for alpine skiing are provided by both aerobic and anaerobic energy production. However, due to the intermittent, high-intensity nature of skiing and specifically ski training, energy production depends greatly on anaerobic energy sources. Glycogen is the primary source of energy during skiing; a 50% depletion of muscle glycogen stores has been shown after a day of repetitive skiing. Ski training of elite level skiers in preparation for the winter season takes place on glaciers at moderate altitude (2800 m-3200 m) with temperatures well below 0° C. On-snow ski training usually consists of 8-12 repeated runs that are 30 to 45 sec. in duration depending on the event. It has been reported that the rate of energy expenditure during slalom training run at moderate altitude is on the order of 1.5-2.0 times VO_2 max. Thus, energy requirement per hour can be quite high, given that racers cover four to five runs per hour. Low glycogen levels have a detrimental effect on skiing performance because skiing depends greatly on anaerobic energy production. It has been reported that the ability to produce lactate is markedly reduced when muscle glycogen is voided.

PURPOSE. The purpose of this study was to measure metabolic and cardiorespiratory changes in elite alpine competitors in Graz, Austria during simulated supra-maximal training session in laboratory setting. Ten highly trained alpine skiers from Austria competing in International Competition races (mean age 17.9±1.7 yrs, weight 75.1±8.4, height 178±6.8) volunteered to participated in this investigation.

METHODS. All participants were subjected to a single maximal oxygen uptake test (VO_2max) on an electronically braked cycle ergometer and eight consecutive modified Wingate tests (WAnT) on a mechanically braked cycle ergometer. Subjects conducted 8 - 40s WAnT with 12-min recovery between each WAnT. WAnT resistance was set at 5% of the individual body weight (BW) or 0.005 kg. kg^{-1} BW. During all WAnT we measured heart rate (HR), oxygen consumption (VO_2), leg muscle power output expressed as peak, mean, and minimum power, and fatigue index (FI). Muscle leg power was measured via SMI software package. VO_2 was measured with Jäger Industries, open air spirometry. Blood samples from hyperemic ear lobe in the amount of 180 µl were drawn immediately after each WAnT test and 6-min of recovery and analyzed for partial pressure of oxygen (PO_2), partial pressure of carbon dioxide (PCO_2), oxygen saturation (SaO_2), hemoglobin (Hb), hematocrit (Hct), pH, bicarbonate (HCO_3^-), blood osmolality (Osmol), base excess (BE), and blood glucose (Glu). Lactic acid (LA) was measured immediately after each WAnT, and 3, 6 and 12 min of each tests. All blood variables with the exception of LA were measured utilizing the AVL Omni 9 automatic analyzer. Lactic acid concentration was analyzed with the enzymatic amperometric method (Eppendorf, Hamburg, Germany). All subjects completed all tests.

RESULTS. Statistical analysis (ANOVA and Tukey post-hoc tests) revealed the following results. There were no statistically significant differences ($p>0.05$) for any of the absolute or relative leg power measures nor were there any differences in FI. There were statistically significant differences for SaO_2, PO_2, PCO_2, pH, Osmol, LA, HR, HCO_3^-, and BE ($p<0.001$). However, there were no statistically significant differences for Glu, Hb, and Hct ($p>0.05$).

CONCLUSION. The results of this investigation suggest that the metabolic demand of simulated alpine skiing session in the laboratory impose very high demands on the young elite alpine competitors. The most striking changes were observed in LA production where LA in some individuals exceeded 22.0 mmol.l^{-1} (mean LA for WAnT # 8 of 16.1±3.1). Blood acidity of pH was measured below 7.0 in some individuals (mean pH for WAnT # 8 of 7.1±0.09) and drop in HCO_3^- from mean 23.5±0.8 at the beginning of the first WAnT to a mean of 8.3±2.4 during 6 min recovery after the WAnT # 8. This data suggest that the internal (cellular) environment has dramatically changed and may and will interfere with various intracellular processes required for muscular contraction. This type of tests of short duration and high intensity, depend heavily on glycolysis and produce large amounts of LA and H^+ within the muscles. However, the cells and body fluids possess buffers, such as bicarbonate (HCO_3^-) that minimize the disrupting influence of the H^+. Without these buffers H^+ would lower the pH to about 1.5 killing the cells. Because of the body's buffering capacity, the H^+ concentration remains low even during the most severe exercise, allowing muscle pH to fall from a resting value of about 7.1 to no lower than 6.6 to 6.4 at exhaustion. However, the pH changes of this magnitude adversely effect production and muscle contraction. An intracellular pH below 6.9 inhibits the action of phosphofructokinase (PFK), an important glycolytic enzyme, slowing the rate of glycolysis and ATP production. At a pH of 6.4, the influence of H^+ stops any further glycogen breakdown, causing a rapid decrease in ATP and ultimately exhaustion. In addition, H^+ may displace Ca^{++} within the fiber. Most researchers agree that low muscle pH is the major limiting factor of performance and the primary cause of fatigue during maximal short-term exercise. In our study we did not observe a significant decline in leg muscle power and there were no significant changes in fatigue index for the eight 40s modified Wingate tests with 12 min recovery. This may suggest that perhaps the training specificity of the event, 12-min recovery and high tolerance for lactic acid and low intracellular pH may have played a role in these highly trained alpine competitors.

MACROINVERTEBRATE ASSESSMENT ON THE SHEYENNE RIVER NEAR VALLEY CITY

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INTRODUCTION

The Sheyenne River Invertebrate Assessment Project was initiated in 1997 in order to establish effective aquatic invertebrate sampling techniques as well as to inventory the macroinvertebrate community residing in the river near the Valley City area. Another focus of the project is to determine the relative health of the Sheyenne River through the use of macroinvertebrate bioassay procedures as well as by comparing the Sheyenne's macroinvertebrate composition and populations to river systems with similar characteristics. We also are attempting to establish a multimetric index of biological integrity (MIBI) for our sampling sites. The Sheyenne begins about 15 miles North of McClusky in central North Dakota and winds its way south through Valley City and Lisbon before it eventually drains into the Red River near Fargo. Due to the lack of information regarding the biological integrity of the River, the information gathered here should become a valuable resource in the near future considering of the international nature of the Sheyenne River and the proposed Devils Lake outlet, which would drain into it.

METHODS

Five sites along the Sheyenne were sampled in the late summer and fall of 1997. These five sites, along with three new sites, were sampled during the same time period in 1998. In addition, three sites located on tributary streams to the Sheyenne were sampled during each of these years. Sampling was done primarily with aquatic D-framed nets and to a lesser extent with a Hester-Dendy sampler. Macroinvertebrates were also collected from various snags and other debris. The macroinvertebrates collected were placed in 70% ethanol. The samples were labeled in the field and brought back to the lab for identification and storage. Identification was done to the lowest taxon possible. In most cases this was the genus level.

RESULTS

Although the identification of our 1998 samples is still in progress, we do have results for a number of sites. The Taxa Richness metric for three of the nine sampling sites ranged from 25-28 with an average of 26.3. The number of species of Ephemeroptera, Plecoptera, and Trichoptera (EPT index) ranged from 6-9 with an average of 7.0. These results contrast with our 1997 data, which, for the same sites, had a Taxa Richness ranging from 9-16 with an average of 11.0 and an EPT index ranging from 4-5 with an average of 4.4.

DISCUSSION

As mentioned earlier, the primary goals of the Sheyenne River Invertebrate Assessment Project are to establish a reference collection of aquatic invertebrates of the Sheyenne River, establish effective aquatic invertebrate sampling techniques, determine the relative health of the river through macroinvertebrate biomonitoring, and to establish a multimetric index of biological integrity for our study sites. The first of these goals is relatively simple to attain, and we do have quite a good reference collection established. We have also established efficient and thorough aquatic invertebrate sampling methods. The other two goals have proven more difficult. In order to establish a multimetric system and to determine the health of a river system one must be able to establish a reference site. To due this one must have consistent, accurate data. Our 1998 data conflicts greatly with our 1997 data, as well as data supplied from a similar study conducted in 1995 by the North Dakota Department of Health. Interestingly, the 1995 and 1997 data show similar ranges for these indexes. Thus far, our 1998 data has shown an increase in Taxa Richness of 239% over our 1997 data and an increase in EPT index of 159% over our 1997 data. We are not quite sure how to explain this. Part of it may be due to the implementation of more effective sampling techniques, but this does not fully account for the discrepancy. Our goal now is to obtain consistent data and/or explain the inconsistency in our results so we will be able to establish an accurate biomonitoring program and a MIBI.

INVENTORY OF THE AQUATIC HEMIPTERA OF THE MIDDLE SHEYENNE RIVER

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INTRODUCTION

The purpose of this study was to inventory the Aquatic Hemiptera of the middle Sheyenne. Hemiptera are common components of aquatic ecosystems, and serve many ecological roles. This inventory of aquatic Hemiptera was established because of the need for a reference collection to aid the Sheyenne River Invertebrate Assessment Project. This reference collection will serve as a baseline to monitor possible changes in the macroinvertebrate populations of the Sheyenne River.

METHODS

We sampled six sights along the Sheyenne River ranging from north of Lake Ashtabula to Kathryn, ND. We also sampled three tributaries along the river. We used several methods to collect the macroinvertebrates. Aquatic D-frame nets were used to dislodge and retrieve the invertebrates from the vegetation along the shoreline. The aquatic D-frame nets were also used to collect the macroinvertebrates from the bottom of the river. We also collected insects embedded in the mud by placing the mud on a screen and filtering water over it. The invertebrates were placed into 70% ethanol, in plastic jars that were labeled in the field. They were then transported back to the lab for identification to the lowest possible taxa, which was usually genus.

RESULTS

Our sampling of the middle Sheyenne found 7 families and 14 genera of Hemiptera. The families and number of genera were as follows: Gerridae (3 genera) Nepidae (1 genus) Belsotomatidae (2 genera), Mesoveliidae (1 genus), Pleidae (1 genus), Notonectidae (1 genus), and Corixidae (5 genera). The family Gerridae, the water striders, was found at the majority of sampling sights along the Sheyenne River. Family Nepidae, the predatory water scorpion, was found at four sampling sights, including all three tributaries and only one directly on the river. The other large predator, Family Belostomatidae, the giant water bugs, was found in all three tributaries plus three sites on the river. The Mesoveliidae was found at two sights, both within the Valley City city limits. The Family Corixidae, the water boatman was by far the most abundant of the Hemiptera families. It was found at every sampling sight on and off the Sheyenne River. In a casual observation we noticed an increase in the Corixidae population on the Sheyenne River as winter got closer.

DISCUSSION

There has never been an in-depth study of the Hemiptera on the middle Sheyenne River. The only study of Hemiptera in North Dakota we know of, Jacobson (1), lists 10 families common to North Dakota. We found 7 of these families on the middle Sheyenne and its tributaries. The information gathered in this study will become part of a large reference collection at Valley City State University to enable us to conduct further studies on the life histories of the aquatic Hemiptera.

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COMMUNICATIONS

GRADUATE

OVULATION RATE AND IN VITRO FERTILIZATION (IVF) IN NON-TREATED AND FSH-TREATED EWES

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INTRODUCTION. Follicle stimulating hormone (FSH) is widely used for induction of follicular growth in sheep (1,2). To use this method for artificial insemination or in vitro fertilization it is important to determine when these follicles ovulate and whether oocytes from these follicles can be used for IVF. This study was designed to determine the fertilization rate of oocytes collected from non-treated and FSH-treated ewes, and to determine when follicles ovulate in FSH-treated ewes with synchronized estrus.

METHODS. Ewes implanted with Synchro-Mate-B (SMB; norgestomet) for 14 days were treated with FSH for 2 days (2D), 3 days (3D), 4 days (4D), or no FSH (control). Starting on day 12 (3D and 4D ewes; day 0 = day of SMB implantation) or day 13 (2D ewes), ewes received twice daily intramuscular injections of FSH (2). Fifteen hours after SMB removal, oocytes collected from the control, 2D, and 3D groups were matured and then classified as healthy or atretic based on morphology. The healthy oocytes were used for IVF, and two days later the number of cleaved oocytes was determined. The 4D ewes were examined laparoscopically 36, 48, and 60 hours after SMB removal to determine the number of recently ovulated follicles (corpora hemorrhagica; CH), and six days later ewes were subjected to a laparotomy to determine the total number of ovulations (corpora lutea; CL) for each ovary.

RESULTS.

Table 1: Number and cleavage rate for oocytes used for IVF

Treatement	n	# of healthy oocytes	% of healthy oocytes*	# of oocytes cleaved	Rate of cleavage (%)**
None	5	4.4±1.3[a]	63.8±12.6	3.0±1.0	67.6±9.6[c]
2D FSH	4	10.5±2.6[b]	84.4±4.7	6.5±1.5	70.5±13.7[c]
3D FSH	7	10.4±2.0[b]	85.3±6.1	4.7±1.3	42.3±5.9[d]

Table 2: Number of CH and ovulation rate

Time	n	# of CH	Ovulation Rate (%)***
36 Hours	16	0.63±0.26[a]	3.99±1.7[a]
48 Hours	13	8.69±1.74[b]	53.6±7.7[b]
60 Hours	16	10.69±1.59[c]	66.8±6.2[c]

[a,b,c,d] means ± SEM differ within a column, $p<0.02$; n - number of ewes.
*Calculated by dividing the number of healthy oocytes used for IVF by the total number of oocytes recovered.
**Calculated by dividing the number of oocytes cleaved by the number of oocytes used for IVF.
***Calculated by dividing the number of CH at laparoscopy by the total number of CL at laparotomy

DISCUSSION. Determining how FSH treatment affects the quality of oocytes can improve success rates of IVF. The number of oocytes used for IVF was greater in FSH-treated than in non-treated ewes, however the percent of healthy oocytes after maturation was similar among treatment groups. The percent of oocytes cleaved was higher in the non-treated and 2D ewes than 3D ewes. Other investigations have reported similar cleavage rates of 68-80% (3,4). Increasing cleavage rates through the use of appropriate follicular induction techniques may prove to be a key factor in the overall efficiency of IVF. In the present study, 4D ewes showed 33% of the follicles were not ovulated at 60 hours. Previous studies show that the optimal time to inseminate is between 54 and 60 hours after progestin removal (5). These observations suggest that ovulation in ewes synchronized with SMB and treated with FSH occurs later than in ewes synchronized by other means. The results of this study will ultimately lead to improved efficiency of methods for obtaining large numbers of high quality oocytes and embryos. Improvement in these techniques will enhance the overall efficiencies of assisted reproductive technologies, such as in vitro fertilization, embryo transfer, and artificial insemination in sheep.

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COMMUNICATIONS

PROFESSIONAL

PROPERTIES OF A BRYANT SERIES PEDON AFTER 25 YEARS OF RECOVERY FROM COMPACTION

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Many studies can be found in the literature that address various aspects of soil compaction. However, few of those studies address long term, natural recovery of the soil from compaction. Those that do usually address recovery over time periods of less than 20 years, and usually conclude that recovery was probably not complete. Therefore, studies addressing longer time periods are needed.

This study investigates natural soil recovery from compaction over a 25-year period by comparing a number of soil morphological properties in a compacted (wheel tracks) versus an uncompacted (control) pedon of the Bryant series (Fine-silty, mixed, superactive, frigid Typic Haplustolls). The study site is an abandoned farmyard in Emmons County, North Dakota. The Bryant series are deep, well drained, moderately permeable soils on loess covered uplands (1). The local geology is characterized by an undulating to rolling till surface of low to moderate relief that is veneered to covered by loess (2). This area averages between 100 and 120 days a year that the high is above and the low below freezing (i.e. freeze-thaw cycles) (3).

The properties compared between pedons include soil color, depth to carbonates, structure, bulk density, carbon content, nitrogen content, the C/N ratio, water content at the time of sampling, and texture. Both pedons show the same colors within their profiles, but the darker colors (indicating higher organic matter) extend deeper in the uncompacted pedon. Similarly, carbonates are deeper in the uncompacted pedon, and the compacted pedon has a zone of platy structure that is not present in the uncompacted pedon. Bulk density is lower in the uncompacted pedon (Figure 1). Organic carbon is higher in the uncompacted pedon, nitrogen content is about the same in both pedons, and the C/N ratio is higher in the uncompacted pedon (Figure 2). Water content tended to be higher in the compacted pedon at the time of sampling.

These results were interpreted as indicating that this soil has not recovered from compaction after 25 years of recovery time. This is consistent with two recent studies on long-term soil recovery from compaction, one involving 110 years (4) and the other 145 years (5) of recovery time. It is therefore concluded that studies involving longer recovery periods (>100 years) are needed. It also seems that over the years compaction has lead to a change in the type of organic matter present in the soil (Figure 2). Therefore, studies addressing the effect of compaction on soil organic matter over long time periods are needed.

Figure 1 - Bulk Density in the Wheel Tracks versus the Control Section

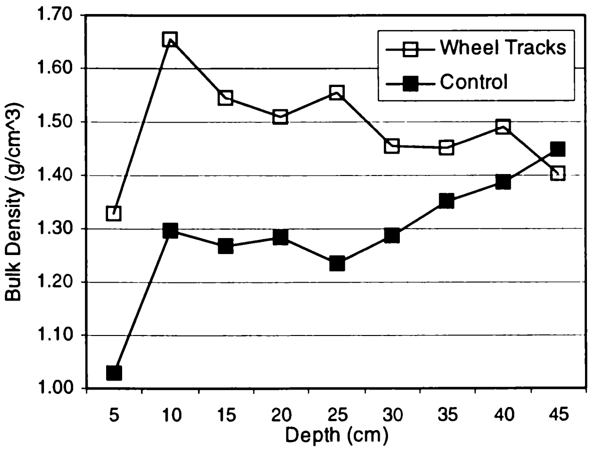
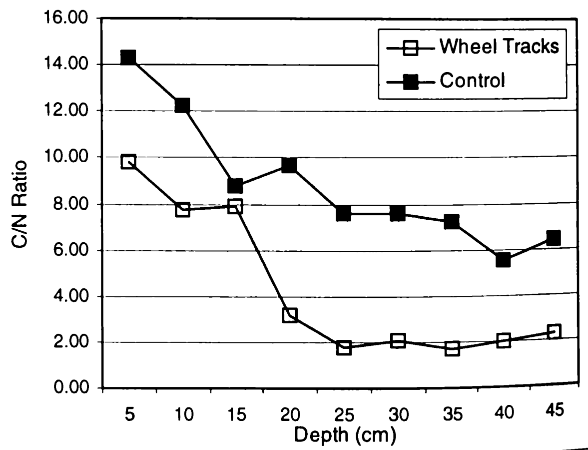


Figure 2 - C/N Ratio in the Wheel Tracks versus the Control Section



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STUDY OF THE *MULTIPLE ARCHESPORIAL CELLS1 (MAC1)* MUTATION IN *MAIZE*

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Analysis of mutations and their phenotypic effect is useful because they identify genes that are required for the normal developmental processes of an organism. *Maize* is an excellent plant for mutational analysis because of several favorable biological properties. For instance a single *maize* plant can produce up to 500 progeny from a single pollination. Also, there is a large amount of information already known about *maize* genetics, and because male and female flowers are located separately in the plant and it is therefore easy to perform controlled pollinations. Due to the ease of controlled pollinations, and hence control of sexual reproduction, an investigator can have confidence in the allelic constitution for the gene of interest, such as a gene controlling fertility. A mutation in such a gene can then be used to analyze the genetic control of that process.

This study focuses on the *multiple archesporial cells1 (mac1)* mutation, which results in male sterility of homozygous recessive mutant plants. By studying this mutation we aim to learn more about the genetic control of meiosis and normal development of *maize* ovules and anthers. This analysis is being performed with mutant and normal anthers collected during early stages of development. The anthers are fixed in glutaraldehyde and osmium tetroxide, dehydrated, and embedded in Spurr's epoxy resin. The plastic blocks are then cut with a microtome, the resulting sections are stained, and examined and photographed under a light microscope. The results of this microscopic analysis of anther development will be reported.

THE CHANGING DEMOGRAPHIC IN NORTH DAKOTA: IMPLICATIONS FOR FUTURE DEVELOPMENT

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The demographic structure of North Dakota has changed in several important ways during the 20[th] century. These changes have far-reaching consequences for the state's future development policies. North Dakota is in the last stages of the demographic transition, the epidemiologic transition, and the mobility transition theories. In this century, the fertility rate, the infant mortality rate, and the population natural growth rate have all declined significantly. The causes of death have shifted from predominantly infectious diseases to mostly degenerating diseases such as heart disease, cancer, and diabetes. Finally, because of persistent rural to urban migration, more North Dakota residents now live in cities rather than in rural areas, and the gap in gender spatial mobility is narrowing rapidly. Consequently, the demographic structure of the population has changed from a "youthful" one with a median age of 21.6 in 1910 to a "maturer" population with a median age of 35.4 in 1997. The national median age is 34.9. We tend to think of a population, such as North Dakota's, growing older as people live longer, but it is when fertility declines, which results in fewer births, that a population begins to age. Improvements in life expectancy resulting from improved health conditions can have an impact on the aging of a population, but mortality reductions tend to occur at all ages. Migration may also affect the age distribution, but this impact will depend on the age of the immigrants and their fertility and mortality characteristics. This study focuses on trends in North Dakota's population age structure and its implications for future development policies. The age-sex structure of a population is an important feature thaι population specialists, planners, and policy advocates consider when assessing a state's demographic situation.

Figure 1 is a combined age pyramid of North Dakota population in 1910 and 1990. The shape of the age structure is the direct result of the state's recent demographic history and is closely tied to its social and economic change. It is the interrelationship between past fertility, mortality, and migration that produce the current age structure. Crude birth rates declined continuously from more than thirty-five per thousand to about fifteen in 1990, with a temporary increase during the post World War II period that created the well-known baby boom generation. During the same period, the crude death rate shows a slight increase from about five per thousand in 1910 to more than eight per thousand in 1990. However, the state recorded a significant decrease in the infant mortality rate between 1900 to 1990. The natural growth rate has also been less than one per thousand since the 1970s. The net migration rate has been negative since 1930, when the population of North Dakota reached its highest number at 680,845. Among all the above factors, fertility affects the population age structure the most. The left side of the pyramid (1910) portrays a demographic structure with nearly 38% of the population less than fourteen years of age (13.3% of which were less than five years), but only 2.6% are more than sixty-five years of age. These percentages are characteristics of a youthful population with high fertility and low mortality. The situation is notably different on the right side of the pyramid (1990). Here more than 14.3% of the residents are over sixty-five years, that is 5.5 times more than the same age group on the left side. On the other hand, the proportion of "youth" has dropped precipitously to 23.3% in 1990 and is continuing to decline. Only 8 percent of the population is less than five years of age.

Figure 2 shows the trends in age structure of North Dakota for almost a century. The "labor force" potential population (15-64) has hovered at about 60% during the entire period. On the contrary, the percentage of population from age 0-14 shows a general downward trend. An optimistic population projection to the year 2010 points to a very slow growing population and a much older age structure. It is also important to note that these age structural traits are not uniformly found throughout the state. In Sioux and Rolette counties, where most native Americans in the state live, the population pyramid has a much wider base and narrower top than the state pyramid. On the other hand, most of the remaining rural counties depict a narrow base and a wide top. Fertility rates of the former counties are twice that of the latter.

The knowledge of a state's age structure can be important in decision-making processes relating to social, political, and economic policy. An older population structure may lead to a sharp drop in school enrollment at all educational levels, closure of youth-oriented sport clubs, as well as a greater need for nursing homes, hospitals, and other health-related institutions. In the long term, it may cause labor shortages, influence business types, and the commodities marketed in a community. A recent wave of consolidations of many school districts, and even disappearances of many rural and small towns stems from these demographic changes. Without major changes in the social, cultural, and economic situation, we expect this trend in aging to continue well into the next century.

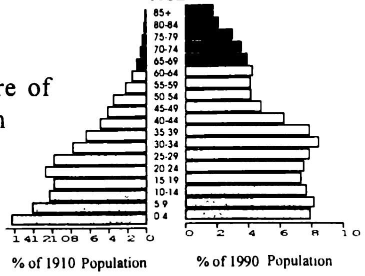

Figure 1. Age Structure of North Dakota Population

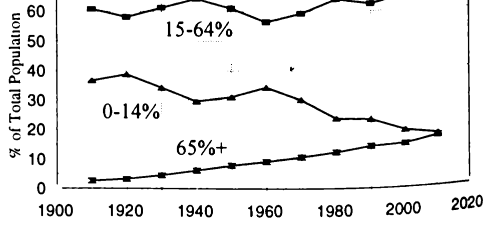

Figure 2. Trends in North Dakota's Population Age Structure, 1910-2010

OCCURRENCE OF TRACE-ELEMENT-RICH SOILS NEAR THE PEMBINA ESCARPMENT, CAVALIER COUNTY, NORTH DAKOTA

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Many trace metals (Cd, Cr, Cu, Ni, Mo, V, etc.) are found in relatively high concentrations in marine shales, such as those which underlie all of eastern North Dakota, and have been incorporated into glacial drift to varying degrees. From an agricultural perspective, the rationale for trace metal studies of soils is often to assess the need for micronutrient fertilizers, but recently issues of food quality have become important also. Cadmium (Cd) is one of the trace elements which is not an essential plant nutrient, but is of interest because it is sometimes present in seeds and grains at levels that can exceed regulatory limits on Cd in human foods (1). This issue is of interest to growers in the northern Great Plains of the United States and Canada, where crops such as durum wheat, sunflower, and flax may occasionally accumulate levels of Cd which approach or exceed present or proposed limits.

Geochemical data on trace element distribution in North Dakota soils are rather limited. In a recent study of prairie soil A horizons, Garrett (2) reported that the mean total Cd concentration of 1273 soils from the prairie provinces of Canada and adjoining areas in the United States was 0.28 ppm, and he suggested an environmental baseline of 0.3 ppm. Analyses of trace elements in 167 samples of agricultural soils from our detailed survey of northwestern North Dakota have shown similar concentrations of Cd, with a mean, median, and range of 0.34 ppm, 0.32 ppm, and 0.20 to 0.72 ppm. These concentrations are within the normal range for Cd in soils (3).

In Cavalier County, certain locations show anomalously high concentrations of total Cd and several other trace elements. The A horizon concentrations of several elements, including Cd, in these soils are 10 to 20 times higher than the concentrations typical of other soils of the region (2, 3). In these soils, which formed in clay-rich till or colluvium derived from shale, several samples exceeded 5 ppm and one reached 15 ppm. Concentrations of chelate-extractable Cd (a measure of plant-available Cd) were unusually high also, and remained high in the subsoils. The presumed source of these trace metals is the Pierre Shale, which lies beneath Cavalier County and is exposed at the surface in the Pembina Escarpment, in areas not covered by a veneer of drift.

The degree of enrichment of these soils in Cd, Cu, Ni, V, and Zn is shown below. Also shown is the Zn/Cd ratio, often used to quantify Cd enrichment relative to Zn in geologic materials. The average Zn/Cd ratio for crustal rocks is about 270 (4). Comparison of these enriched soils and nearby colluvium from local shales suggests that either these soils developed from other parent materials or that Cd has been concentrated in some manner. Soils west of the Pembina Escarpment have Zn/Cd ratios that are about 5 times higher than those of the enriched soils. Other chalcophile elements, and several rare earth elements, are present also at unusually high levels in the enriched soils.

Table 1. Trace metal concentrations (ppm) in soils and parent materials near the Pembina Escarpment

Material	Cd	Cu	Ni	V	Zn	Zn/Cd
Soil 1	6.8	63	91	467	228	34
Soil 2	8.9	56	73	428	230	26
Soil 3	7.5	55	62	381	231	31
Colluvium (n=4)	2	34	53	227	146	85
Soils west of Escarpment (n=50)	0.5	16	22	104	75	151

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COMPLETE DELETION OF CHROMOSOME 11 FROM THYMIC LYMPHOMAS INDUCED IN P53 HEMIZYGOUS MICE BY PHENOLPHTHALEIN

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INTRODUCTION

In August of 1997 the Food and Drug Administration proposed to ban phenolphthalein (3,3-bis(4-hydroxyphenyl)-(3H)-isobenzofuranone) from use as an active ingredient in over-the-counter laxatives. The action was taken in response to reports that phenolphthalein induces a variety of carcinogenic effects in $B6C3F_1$ mice and Fisher 344 rats after a two year dose period (1). Toward characterizing the mechanisms of phenolphthalein-induced carcinogenesis, and toward defining the potential to more rapidly identify carcinogenic effects, hemizygous p53-deficient mice were also dosed with phenolphthalein. These mice developed carcinogenic effects within four months. As in $B6C3F_1$ mice, a treatment-related increase in the occurrence of thymic lymphomas was observed (2).

METHODS AND RESULTS

DNA isolates from spontaneous and phenolphthalein-induced thymic lymphomas (T) were compared to DNA from surrounding normal tissues (N) for alterations at *p53* and at 57 mapped simple repeat sequences. While present in spontaneous tumors and normal tissues, the wildtype p53 allele was completely deleted from each induced lymphoma.

The initial screening of 28 short repeat sequences revealed interesting results from only chromosome 11. Subsequent genotyping of chromosome 11 showed heterozygosity for C57Bl/6 and 129Sv over about 35% of chromosome 11. Analyses of DNA from the phenolphthalein-induced thymic lymphomas showed treatment-related loss of heterozygosity at each informative loci. However, the specific polymorphism, either C57Bl/6 or 129Sv, lost from each tumor varied.

DISCUSSION

From the patterns of loss of heterozygosity at the mapped short repeat sequences we deduced crossover events that likely occurred as a result of phenolphthalein treatment. The data suggest each induced tumor lost a recombined chromosome 11 including a region of C57Bl/6 polymorphism that is linked with the wildtype p53 allele. Although loss of p53 function is most likely the cause of tumorigenesis, loss of C57Bl/6-specific resistance elements, or loss of monoallelic expressed genes can not be ruled out as having a role in the mechanism of thymic lymphomagenesis induced in hemizygous p53 mice by phenolphthalein.

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MULTIPLE INTEGRATED MEMBRANE (MIM) TREATMENT FOR POTABLE WATER IN GRAND FORKS

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INTRODUCTION

The Grand Forks Water Treatment Plant (GFWTP) is faced with the challenge of treating the relatively low quality and highly variable Red Lake River and Red River waters to meet the stringent disinfection, disinfection by-product, and filtration requirements of the Surface Water Treatment Rule (SWTR) and the Enhanced Surface Water Treatment Rule (ESWTR). The operation of a pilot-scale, series arrangement of microfiltration (MF) and nanofiltration (NF) membranes was studied at three locations in the existing GFWTP process train (1,2): 1) Stage 1- immediately post pre-sedimentation, 2) Stage 2- immediately post clarification, and 3) Stage 3- post softening recarbonation. The MF unit ability to remove particles and the NF unit ability to remove natural organic carbon precursors of carcinogenic disinfection byproducts and dissolved ions were evaluated at the three locations. Successful membrane system application required meeting established water quality goals while maintaining acceptable flux rates, permeability, and cycle times between chemical cleanings.

METHODS

The parameters monitored for the membrane skids were: the feed pressure; filtrate/permeate (product water) flow; feed temperature; flux corrected to 20 degrees C for MF and 25 degrees C for NF (gallons per day per square foot, gpd/ft^2); temperature-corrected permeability (gpd/ft^2 per pound per square inch differential pressure, gpd/ft^2*psid); hours of operation; backwash cycles; and the number of chemical cleanings required. The water quality parameters monitored in the product water were turbidity, total organic carbon (TOC), total hardness, and simulated distribution system (SDS) total trihalomethanes (TTHM) and haloacetic acids (HAA5). Water quality analyses were performed using *Standard Methods for the Examination of Water and Wastewater* and Environmental Protection Agency-approved methods..

RESULTS AND DISCUSSION

The water quality treatment objectives and study results for each of the stages are shown in Table 1. Microfiltration at the Stage 1and Stage 2 locations was observed to require unacceptably high levels of maintenance and cleaning. Only the Stage 3 operations resulted in both acceptable maintenance requirements and product water quality.

Table 1. MIM Study Summary

	Goal	Stage 1	Stage 2	Stage 3
MF Flux, gpd/ft^2 Cleaning Frequency	40 to 100 typical	64 4 times/972 hours	52 4 times/1560 hours	60 Once/1082 hours
NF Flux, gpd/ft^2	8 to 18 typical	29.8 (short duration)	13.8	16.9
MF Turbidity	<0.1	0.10 avg./0.49 max.	0.12 avg./0.35 max.	0.10 avg./0.43 max.
NF TOC	<1.0	No Data	0.80 avg./2.24 max.	0.43 avg./0.81 max.
NF Total Hardness	120 mg/l as $CaCO_3$	No Data	42 avg./90 max.	42 avg./62 max.
NF SDS TTHM	<40 mg/l	No Data	6.4 avg./8.7 max.	6.8 avg./10.8 max.
NF SDS HAA5	<30 mg/l	No Data	10.0 avg./12.5 max.	8.1 avg./15.5 max.

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THE ROLE OF COURSEWORK IN THE HISTORY OF GEOGRAPHIC THOUGHT FOR A GRADUATE GEOGRAPHY PROGRAM

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INTRODUCTION

Most graduate geography programs have coursework in the history of geographic thought (1), and the University of North Dakota's Department of Geography is no exception. Considering geography's wide-ranging diversity of sub-fields, having such coursework is especially crucial if a graduate student is to recognize the unity of geography as a discipline. Since the mid-1990s, GEOG 501 (Geographic Thought and Philosophy) has been a de facto introduction to graduate studies in geography plus its content emphasizes the period of 1859 to the present far more than it did two decades ago. Because of recent academic restructuring on the Grand Forks campus, it is time to review the history of geographic thought as part of geography graduate studies at the University of North Dakota.

BACKGROUND TO THE DISCUSSION

Established as a separate department at the University of North Dakota in 1946, coursework in the history of geographic thought has been available frequently in the Department of Geography (2). The geography graduate program is at the master's level, and for over 25 years one of the degree's two required courses has been GEOG 501 (Geographic Thought and Philosophy). During the 1970s, 1980s, and 1990s, the course was offered yearly each Spring Semester. It became a Fall Semester course in the mid-1990s. Prior to that time, the course had been highly traditional with its core based upon *All Possible Worlds* (3).

As a Fall Semester course, it became one of the first courses for entering geography graduate students at the Grand Forks campus. The course gradually began to incorporate helping graduate students acculturate to academe at this level plus dealing with the Graduate School's rules and regulations as well as policies and procedures within the Department of Geography. Less reliance was made upon *All Possible Worlds* with greater attention given to a more contemporary disciplinary study of geography, *Geography's Inner Worlds* (4). Furthermore, all members of that geography department were invited each semester to make at least one presentation on their respective sub-field.

DISCUSSION AND CONCLUSION

Although paperwork was submitted in the Fall Semester of 1998 to drop the number of credits from three to two and to transform the course to be even more an introduction to graduate studies in geography, this effort was suspended in January of 1999. Helping entering geography graduate students acculturate to academe will not be solved by tinkering with this course. Rather than continue to chip away at the base of the course in the history of geographic thought, that course needs to resume focusing upon the evolution of the discipline and to reinforce the premise that geography is a set of evolving fields of studies with deep roots in the past from which to grow.

Too often in an academic setting undergoing major restructuring there is a tendency to seek a "quick-fix" solution which frequently is counter-productive in actuality. If an individual is going to be able to understand one's place in the field of geography today and prepare for being a geographer in the future, it is imperative that more, not less, attention be given to emphasizing the period prior to 1859, especially that of the 11th-17th centuries. Earth system science resembles geographic study of centuries ago, but today the tools are remote sensing satellites, computer cartography, and geographic information systems. The past indeed is prologue to the future.

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DEVELOPING SCHOOL-UNIVERSITY PARTNERSHIPS TO IMPROVE UNDERGRADUATE TEACHER EDUCATION IN GEOGRAPHY

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INTRODUCTION

Since the mid-1980s, geography in grades K-12 has been transformed (1). This renaissance in geographic education has emphasized retraining in-service educators in up-to-date concepts, content, pedogogy, and technology from the discipline. Attention now is shifting to preparing pre-service educators using school-university partnerships. Such a school-university partnership has existed between the Grand Forks (ND) Public School District and the University of North Dakota for almost two decades with plans to expand it.

EVOLUTION OF THE SCHOOL-UNIVERSITY PARTNERSHIP

Teacher education in geography has been ongoing at the University of North Dakota since 1929 and especially under the direction of Dr. Bernt L. Wills offering a geographic education methods course in the 1950s through mid-1970s (2). By the late 1970s teacher preparation in geography was altered significantly on that campus with grant money from the U.S. Department of Education and National Science Foundation. One major spinoff of these programs was the stimulus for a school-university partnership.

That relationship began in the early 1980s when junior high school teachers from the Grand Forks (ND) Public School District accepted invitations to not only be guest presenters but to help shape the geographic education curriculum. In the 1980s and 1990s, additional local high school and elementary teachers also began to be involved in GEOG 319 (Geography for Teachers). Accelerating the interest of K-12 teachers in improving the teaching of geography was the development of national standards in geography, but a driving force also was the concern of these K-12 teachers for teacher trainees to have the best possible student teaching experience and to be able to make a smoother transition for those undergraduates to go from being pre-service educators to in-service educators after graduation with the baccalaureate degree.

The course is fine-tuned each semester with changes being made to make it the most thorough and effective methods in geographic education course possible in a weekly two-hour block. Presently, almost half of the course uses input each semester from eight-to-ten K-12 teachers in topics ranging from children's literature to applications of geographic information systems. A major feature of the course is that the undergraduates travel to local school sites when the topics are presented by the K-12 teachers. During the Fall Semester of 1998, Viking Elementary, Schroeder Middle School, and Red River High School hosted the teacher trainees on a total of seven occasions. Not just social studies and geography teachers are engaged in GEOG 319 (Geography for Teachers); two librarians, a high school chemistry instructor (a state-recognized specialist in geographic information systems applications in earth science/physical science), and an associate high school principal are major contributors to the bi-yearly planning of the course.

Overall, the undergraduates have responded enthusiatically to this approach and so have the master teachers who have been helping with the course. Introducing the teacher trainees to the pre-collegiate geography classroom well before the student teaching experience is showing positive benefits with more effective experiences when student teaching does occur.

TAKING THE SCHOOL-UNIVERSITY PARTNERSHIP BEYOND THE YEAR 2000

Future plans for the teacher education course in geography are being geared toward an entirely school-based approach. Gradually, the course will be offered wholely off-campus with an even higher percentage of input from K-12 teachers in it. Ultimately, an Advanced Placement (AP) course in geography will be developed at Red River High School which would make this partnership even more cutting edge (3). The ultimate future benefactors of this program will be the citizens of North Dakota.

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GROWTH OF *ESOX TIEMANI* AND A NEW SPECIES OF *JOFFRICHTHYS* OF THE SENTINEL BUTTE FORMATION (PALEOCENE) NEAR ALMONT, NORTH DAKOTA

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Since 1994, we have been examining what appears to be the littoral zone of an ancient lake in the Sentinel Butte Formation (Paleocene), near Almont, North Dakota to assess the fish fauna of the site. The site is known primarily for semitropical terrestrial plant fossils (1). We have previously presented a detailed account of the fish assemblage of the Almont site which has at least five species including *Esox tiemani* and a new species of *Joffrichthys*. While much emphasis has been placed on identifying new species, taxonomy, and paleozoography; little work has been done to assess fish growth in the fossil record. The objective of this study was to assess the growth patterns and life history characteristics of these two fish species and help elucidate ecological processes occurring in the Almont lake system.

Joffrichthys and *Esox tiemani* were originally described from the Paskapoo Formation in Alberta, Canada (2 and 3). *Joffrichthys* is represented from the Sentinel Butte Formation by two complete and two partial specimens, and individual scales. The pike (*Esox tiemani*) is known from the Sentinel Butte Formation by three complete and four partial specimens, and individual scales. We used individual fish scales to construct growth curves for both species; and we determined the age of each scale by counting annuli. Because scales grow in proportion to body size, we then measured the dorsal/ventral distance of the scale and used it to assess growth. Maximum size values for each age were used in the von Bertalanffy growth formula to construct a growth curve.

Based on 166 *Joffrichthys* scales, ages ranged from 0 through 9 years old including four scale-covered skeletons of ages 0, 0, 1, and 4 years. The growth curve indicated that growth in *Joffrichthys* was rapid in the first three years of life, attaining >70% of their adult size and then reaching an asymptote.

Based on 16 *Esox tiemani* scales, ages of individuals ranged from 0 through 9 years old including three complete and four partial pike skeletons, ages 0, 0, 0, 0, 2, 5, and 6 years. *Esox tiemani* growth was also rapid with fish attaining >90% of their maximum size by age 5, then reaching an asymptote. This asymptotic age is similar to the growth patterns of extant pike. *Esox masquinongy* and *E. lucius* were reported to reach an asymptote about five to seven years of age, respectively (4). The total lengths of *Esox tiemani* are similar to living *Esox lucius* at ages 0 and 5 years.

These data provide a unique snapshot of the population dynamics of this ancient lake system. *Joffrichthys* lived to at least age 9 and reached an asymptote in growth after age 3. The extinct pike (*Esox tiemani*) lived to at least age 9 and reached an asymptote in growth near age 5. Further comparative research into the life history characteristics of the *Joffrichthys symmetropterus* and *Esox tiemani* from Alberta may elucidate additional information on life history and population dynamics of Paleocene lake systems in north-central North America.

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IRON SUPPLEMENTATION REDUCES IRON ABSORPTION FROM FOOD

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INTRODUCTION

There is evidence that humans have the ability to adapt iron (Fe) absorption in response to a wide range of Fe intakes and requirements. It is not clear, however, if this adaptation is different for heme versus nonheme Fe. Also, it is thought that changes in Fe absorption occur to protect a pre-determined "set point" in Fe stores [1]. This randomized, placebo-controlled supplementation trial was designed to test for a) adaptation of heme and nonheme Fe absorption, and b) to evaluate changes in Fe stores, as indicated by serum ferritin, with Fe supplementation and after it was stopped.

METHODS

Healthy men and women (n = 57; age, 22 to 58 y; serum ferritin, 10 to 230 µg/L) were recruited from the community to receive either a daily supplement of 50 mg Fe (as ferrous sulfate) or placebo for 12 wk. Serum ferritin was monitored an additional 24 wk after supplementation was stopped. Heme and nonheme Fe absorption from a test meal were measured with Fe-59 (as $FeCl_3$) and Fe-55 (as rabbit hemoglobin) radiotracers by using whole body scintillation counting and the ratio of Fe-55/Fe59 in blood after two wk. The meal (ground beef, french fries, and milk shake) contained 5.1 mg total Fe and 1.2 mg heme Fe and was consumed on two consecutive days before and after 12 wk of supplementation.

RESULTS AND DISCUSSION

Daily Fe supplementation for 12 wk resulted in a significant decrease of about 36% in nonheme Fe absorption ($p<0.001$). A slight reduction in heme Fe absorption with time was not significantly related to Fe supplementation. There was a small, but significant, increase in serum ferritin after 12 wk of Fe supplementation. The increase in serum ferritin at wk 36 of the study, 6 months after supplementation stopped, was so slight as to be detectable only as % change from baseline compared with the placebo group. At all times tested, this change in serum ferritin was positive and higher in the Fe supplemented, as compared to the placebo group in which serum ferritin declined probably because of phlebotomy (see data below).

Effects of Iron Supplementation on Heme and Nonheme Iron Absorption:

Iron Absorption	Placebo, wk 0	Placebo, wk 12	Iron, wk 0	Iron, wk 12
Heme, %	25 (22, 28)	23 (21, 26)	22 (20, 25)	19 (17, 22)
Nonheme, %	5.2 (4.4, 6.0)	5.0 (4.3, 5.8)	5.0 (4.4, 5.8)	3.2 (2.8, 3.7)*

Changes in Serum Ferritin with and after Supplementation with Iron:

Iron	wk 0	wk 12	wk 18	wk 24	wk 36
Ferritin, µg/L	51 (38,69)	60 (44,81)*	52 (39,71)	55(41,74)	56 (42,76)
% change	0	+19.8*†	+5.8†	+9.5†	+12.3†
Placebo					
Ferritin, µg/L	60 (44,83) 0	53 (39,73)	49 (36,67)	51 (37,70)	53 (39,73)
% change	0	-10.8	-16.7	-12.2	-8.5

Note: Data from an analysis of variance are expressed as least square geometric means (-2SE, +2SE). Data followed by '' are significantly different than wk 0 in each treatment group and those followed by '†' are significantly different than the placebo group for each time period (p<0.05). Only data from wk 12 and 36 were compared to wk 0 in each treatment group.*

In conclusion, with daily Fe supplementation, healthy individuals adapted to decrease their efficiency of nonheme, but not heme, Fe absorption from food. There was a small increase in Fe stores, as indicated by serum ferritin, which tended to persist 6 months after Fe supplementation was stopped.

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FIELD VERIFICATION OF CONSPECIFIC AVOIDANCE OF INJURY-RELEASED CHEMICAL CUES BY *GAMMARUS LACUSTRIS* (CRUSTACEA: AMPHIPODA) AND CORRESPONDING ATTRACTION BY THEIR PREDATORS *DINA PARVA* (ANNELIDA: HIRUDINEA)

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Predation is a powerful agent of selection shaping animal behavior. Risk assessment is therefore an integral part of behavioral decision making (1). Physical and chemical properties of an animal's environment constrain the sensory modalities that most reliably inform about predation risk. Aquatic environments are ideal for the solution and dispersal of chemical cues. Chemical cues from conspecifics released upon injury are reliable indicators of risk in aquatic environments. These cues are typically released only during a predation event. Conspecifics that detect these cues adopt antipredator behaviors such as area avoidance, reduction in activity and hiding (2,3). A number of amphibians, fish, and recently, invertebrates, have been shown to exhibit this response (4). *Gammarus* are small invertebrates commonly found in local streams, ponds and lakes. Studies conducted in the laboratory indicate that *Gammarus* respond to chemical cues from injured conspecifics with an antipredator response (5-7). In this experiment, we sought field verification of these laboratory findings. Small traps were constructed from jars fitted with a large funnel leading into the jar. A block of cellulose sponge was added to each jar. Sponges were soaked in a solution of either extract of injured *Gammarus* or water (control). Thirty traps (15 *Gammarus* cue, 15 control) were set in a local pot-hole lake for one hour each then removed. Traps scented with injured *Gammarus* cue caught significantly fewer *Gammarus* than traps baited with control sponges (P = 0.026), indicating avoidance of the cue. The median (and 25 percentiles) of the number of *Gammarus* caught per trap was 40 (30 - 66.5) and 90 (50 - 117.5) in *Gammarus*-scented and control traps respectively. Leeches (*Dina parva*) prey on *Gammarus*. Traps scented with injured *Gammarus* cue caught significantly more leeches than control traps (P = 0.005). The median (and 25 percentiles) of the number of leeches caught per trap was 2 (0.5 - 3) and 0 (0 - 1) in *Gammarus*-scented and control traps respectively. Thus, these data confirm that chemical cues from injured *Gammarus* indicate risk to conspecific *Gammarus* in their natural habitat. Moreover, these cues serve as an attractant for predators. Chemical cues appear to mediate the predator-prey interactions between *Gammarus* and leeches.

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THE EFFECT OF RATION AND SHOALMATE FAMILIARITY ON THE PROLIFERATION OF ALARM SUBSTANCE CELLS IN AN OSTARIOPHYSAN FISH

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Ostariophysan fishes have specialized epidermal alarm substance cells (ASCs)(1). To date, work on this system has concentrated testing for fitness benefits. In this study we demonstrate a metabolic cost to the production and maintenance of these cells. Individual fathead minnows *Pimephales promelas* were maintained on high (n=20) or low food (n=20) rations and, to test for the effect of social context on the number of ASCs, they were held with either no shoal-mates or two shoal-mates. Shoal-mates were familiar (from the focal fish's shoal), or unfamiliar (from a shoal separated by 1 km from the focal fish's shoal). In the high food treatment, seven, seven and six fish were assigned to the familiar, non-familiar and no shoalmate treatments respectively. In the low food treatment, sample sizes were 6, 7, and 7 respectively. After 16 days, epidermal thickness was 0.0489 ± 0.0089mm in the high food group and 0.0370 ± 0.0064 mm in the low food group (ANOVA $F_{1,34}$ = 20.1, $P < 0.001$), the number of mucus cells per unit epidermal area was 4.79 ± 1.23 in the high food group and 4.08 ± 0.86 in the low food group (ANOVA $F_{1,34}$ = 4.5, $P = 0.041$) and the number of ASCs per unit epidermal area in the high food group was 6.05 ± 1.74 and 4.79 ± 1.50 in the low food group (ANOVA $F_{1,34}$ = 6.0, $P = 0.02$). Within the high ration group, physical condition was positively correlated with epidermal thickness ($r^2 = 0.39$, $P = 0.003$) and ASC number ($r^2 = 0.21$, $P = 0.04$) but not the number of mucus cells ($r^2 < 0.001$, $P = 0.905$). There was no relationship between condition and epidermal quality in the low food group ($P > 0.1$). Therefore food availability determines investment into ASCs, inferring a tradeoff between the cost of ASCs and the fitness benefits they accrue (2).

The shoalmate treatment showed that fathead minnows adjust investment into ASCs facultatively based upon the level of perceived risk. Antipedator behavior is most effective among familiar shoalmates (3). When placed into a container with non-familiar shoalmates (relatively high risk) ASC production increased (ANCOVA $F_{2,16}$ = 3.61, $P = 0.05$). ASCs allow these individuals to better attract a secondary predator (4, 5). When placed into a container with familiar shoalmates (relatively low risk) ASC production decreased. This may reflect increased effectiveness of a group antipredator response by familiar individuals, and/or the cost to inclusive fitness of attracting additional predators to the vicinity of their kin (6).

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AN INNOVATIVE PILOT BIOLOGICAL WASTEWATER TREATMENT SYSTEM

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INTRODUCTION

The ENVISION wastewater treatment process is an integrated fixed-film biotower, suspended biological culture contact tank, and biomass sedimentation basin system (1). The pilot is an innovative configuration of the trickling filter/solids contact (TF/SC) process in use at some full-scale wastewater treatment plants. The biological contact tank's compressed air supply provides the mixing and oxygen for the suspended growth biological culture and subsequently serves as the forced-draft oxygen supply for the fixed-film biotower. The system configuration has potential for lower construction costs, higher energy efficiency, and lower air pollutant emissions.

METHODS

A timer-controlled solenoid valve was used to dose a concentrated sugar (carbon, C) solution into the treatment system influent water flow. Ammonium hydroxide (Nitrogen, N), phosphoric acid (Phosphorus, P), and sulfuric acid (Sulfur, S) were dosed into the treatment system influent flow in order to provide nutrients equivalent to a 20 C: 5 N: 1 P: 2 S ratio. The strength of a wastewater is measured as biochemical oxygen demand (BOD), which is the oxygen required by microorganisms as they degrade the organic contaminants in a water. The unit was operated from August 1997 through February 1998 at average soluble biochemical oxygen demand (SBOD) biotower loadings of 79 lb./1000 ft^3 and contact tank loadings of 53 lb./ 1000 ft^3. Water samples were obtained from the top of the biotower (TBT), the bottom of the biotower (BBT), and the settled effluent (SE). The BOD tests were performed on the water samples using a HACH BODTRAK instrument. Total BOD (TBOD) was differentiated from the SBOD by filtration of the SBOD water samples through a 0.45 um filter prior to the incubation. Suspended solids (SS), pH, and dissolved oxygen (D.O.) tests were performed using methods from *Standard Methods for the Examination of Water and Wastewater.*

RESULTS AND DISCUSSION

The pilot study results are summarized in Tables 1 and 2 (handouts 2). Biotower SBOD loadings were near the upper end of the normal TF/SC range. The biological contact tank SBOD loading was about two times the loading that most full-scale TF/SC aeration basins would receive. Efficiency of SBOD removal in the biotower was lower than expected. Yet, overall system SBOD removal was 69.5 percent, which was comparable to some reported efficiencies of full-scale TF/SC processes (3,4,5,6). Better results would be expected by reducing system SBOD loading or increasing biotower efficiency.

The sedimentation efficiency of 67 percent was unacceptable. The loss of biomass in the sedimentation basin effluent adversely affected the SBOD removal of the system by preventing recirculation of adequate biomass populations back into the biological contact tank. System biomass loss was caused by floc flotation in the sedimentation basin due to air bubble attachment to the sedimentation influent biomass and attachment of anaerobic decomposition biogas produced by settled solids. Settled biomass was recycled from the sedimentation basin at timed pumping intervals, resulting in solids detentions which contributed to biogas formation.

Sedimentation process re-design is in progress to enable continuous recirculation of settled biomass to the aerated biological contact tank without pumping, i.e., using baffled quiescent settling zones within a common aeration/clarifier tank. The new configuration will maximize retention of mixed liquor biosolids concentrations, minimize pumping energy requirements, facilitate gaseous emissions collection, reduce hazardous air pollutant emissions, and reduce hydraulic loading fluctuations and disturbances.

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CONSTITUTION of the NORTH DAKOTA ACADEMY OF SCIENCE

Founded 1908, Official State Academy 1958

ARTICLE I - *Name and Purpose*

Section 1. This association shall be called the NORTH DAKOTA ACADEMY OF SCIENCE.
Section 2. The purpose of this association shall be to promote and conduct scientific research and to diffuse scientific knowledge.

ARTICLE II - *Membership*

Membership in the Academy shall be composed of persons who share the stated purpose of the Academy and who are active or interested in some field of scientific endeavor.

ARTICLE III - *Council*

The officers of the Academy shall be a President, a President-Elect, and a Secretary-Treasurer. The Council, consisting of the officers, the retiring President, and three elected Councilors, shall be responsible for the fulfillment of the scientific and business obligations of the Academy.

ARTICLE V - *Dissolution and Limits of Action*

Section 1. In the event of dissolution of the Academy, any remaining assets shall be distributed to organizations organized and operated exclusively for education and scientific purposes as shall at the time qualify as exempt organizations under Section 501(c) (3) of the Internal Revenue Code of 1954.

Section 2. No substantial part of the activities of the Academy shall be the carrying on of propaganda, or otherwise attempting to influence legislation, and the Academy shall not participate in or intervene in, any political campaign on behalf of any candidate for public office.

Section 3. No part of any net earnings shall inure to the benefit of, or be distributable to, Academy members or officers, or other private persons, except that the Academy may authorize the payment of reasonable compensation for services rendered.

ARTICLE VI - *Amendments*

Section 1. This Constitution may be amended at any annual Business Meeting of the Academy by a two-thirds vote. Proposed amendments shall be submitted in writing to the Secretary -Treasurer who shall send them to the members at least two weeks before the meeting at which such amendments are to be considered.

Section 2. Bylaws may be adopted or repealed at any regular business meeting by a two-thirds vote.

BYLAWS

BYLAW 1. *Meetings*

Section 1. *Scientific Meetings.* The Academy shall hold at least one annual scientific meeting each year at a time and place determined by the Council. Other scientific meetings, regional, state, or local, may be held at times and places determined by the Council. The Council shall establish regulations governing the presentation of papers at Academy sessions. Such regulations shall be made available to members at least three months before any meeting at which they are to apply.

Section 2. *Business Meetings.* A Business Meeting of the membership shall be scheduled at the regular, annual scientific meeting of the Academy. Ten percent of the active members shall constitute a quorum at the annual business meeting.

Section 3. *Special Meetings.* Special meetings shall be called by the President upon the request of ten percent of the active members and require twenty percent of the active members for a quorum. Notice of the time and place of such meetings shall be sent to all members of the Academy at least four weeks in advance of the meeting. Only matters specified in the call can be transacted at a special meeting.

Section 4. *Procedure.* Parliamentary procedures to be followed in all business meetings shall be those specified in "Standard Code of Parliamentary Procedure" by Alice F. Sturgis.

BYLAW 2. *Financial*

Section 1. *Dues and Assessments.* The annual dues and assessments may be changed from time to time by the Council, subject to approval by a two-thirds vote of the members at an annual Business Meeting. The student member dues shall be one-third (to nearest dollar) of the regular member dues. These dues are payable 1 December of each year.

Section 2. *Supporting Members.* Council shall maintain a program to encourage members to voluntarily contribute funds over and above the regular dues and assessments for the support of activities of the Society.

Section 3. *Sustaining Members.* Any association, corporation, institution, or individual desiring to support the Society with funds or services valued at $50 or greater may be invited by the President or designee to become a Sustaining Associate.

Section 4. *Audit and Reports.* The Nominating Committee shall appoint on a yearly basis one member who is not a member of Council to conduct at least one internal audit per year. The Secretary-Treasurer shall report on the financial affairs of the Society, including the results of an annual audit, as may be requested by the Council.

BYLAW 3. *Membership*

Section 1. *Membership Categories.* Classes of membership shall include the following: (a) Regular, (b) Student, (c) Emeritus, (d) Honorary, (e) Supporting, (f) Sustaining, and (g) Lifetime Members.

Section 2. *Eligibility and Procedure for Membership.* Candidates for membership, except Sustaining Member, may be proposed by any regular or emeritus member of the Academy by submitting the candidate's name to the chairman of the Membership Committee.

(a) *Regular Members.* Any person who is active or interested in some field of scientific endeavor shall be eligible for regular membership. A majority vote of Council shall elect to regular membership.

(b) *Student Members.* Any student who is an undergraduate or graduate student in some field of science shall be eligible for student membership. A majority vote of Council shall elect to regular membership.

(c) *Emeritus Members.* Any member in good standing upon formal retirement is eligible for emeritus membership. A majority vote of Council shall elect to emeritus membership.

(d) *Honorary Members.* The Academy may recognize, by awarding honorary membership, any person (nonmember or member) who has in any way made an outstanding contribution to science. It shall be the responsibility of the Membership Committee to be aware of individuals whom it would be fitting for the Academy to honor in this fashion. A two-thirds vote of members attending the annual business meeting shall elect to honorary membership.

(e) *Supporting Members.* Regular or student members may voluntarily contribute funds over and above the regular dues and assessments for the support of activities of the Society.

(f) *Sustaining Associates.* Any association, corporation, institution, or individual desiring to support the Society with funds or services valued at $50 or greater may be invited by the President or designee to become a Sustaining Associate.

(g) *Lifetime Members.* Any regular member in current good standing for at least one year may become a Lifetime Member by paying an assessment equal to 18 times the current annual dues in one lump sum or in two equal payments over the current and following year.

Section 3. *Privileges of Membership.*

(a) Voting at the annual business meeting is permitted of regular and emeritus members.

(b) Members of all categories may attend business meetings of the Academy.

(c) The Secretary-Treasurer and members of Council must be regular members in good standing.

(d) Regular, student, and emeritus members may submit abstracts or communications for scientific meetings of the Academy.

(e) Emeritus and Honorary Members shall be exempt from payment of dues.

(f) A Sustaining Member is provided a display area at the annual scientific meeting of five linear feet per $50 donation up to a maximum of 20 linear feet.

(g) Every member in good standing shall receive a printed copy or an electronic copy (if available and of equal or lesser cost than the printed copy) of the annual *Proceedings of the North Dakota Academy of Science*, the form to be determined by the member.

(h) Special offices such as Historian may be created by the unanimous vote of the regular members at the annual Business Meeting.

(i) All student research participants shall receive a properly inscribed certificate.

Section 4. *Forfeiture of Membership.*

(a) *Nonpayment of dues.* Members shall be dropped from the active list on 31 November following the nonpayment of dues during the membership year commencing the previous 1 December. A member may return to the active list by paying the current year dues.

(b) *Expulsion for Cause.* Membership may be terminated for conduct injurious to the Academy or contrary to the best interests of the Academy. The accused member shall be given an opportunity for a hearing before the Council. If a majority of the Council votes to expel the member, the action must be ratified by at least two-thirds of the members present at the next annual business meeting of the Academy. An expelled member shall forfeit all paid dues and assessments.

BYLAW 4. *Duties and Responsibilities of the Council and Council Members*

Section 1. *Council.* The Council shall meet, at the call of the President, at least twice a year. The Council shall:

(a) be the governing board of the Academy, responsible only to the membership.

(b) arrange for programs, approve committee appointments, be responsible for the fiscal affairs of the Academy, an transact such business as necessary and desirable for function and growth of the Academy.

(c) determine the location of the annual meeting three years in advance.

(d) annually appoint an Academy representative to the National Association of Academies of Science and to Section X (General) of the American Association for the Advancement of Science.

(e) shall appoint and may compensate a Secretary-Treasurer.

(f) shall appoint and may compensate an Editor of the PROCEEDINGS and other publications.

(g) shall be empowered to charge a publication fee of authors on a per page basis.

(h) shall control all activities of the Academy including grant applications.

Section 2. *President.* The President shall preside at meetings of the Council and over the annual business meeting of the Academy at the close of the regular term of office. The President shall vote only to break a tie. Unless otherwise specified, the President shall, with the approval of the Council, appoint members to serve on Standing Committees and *ad hoc* Committees, designate the chair of each Committee, and appoint representatives to other organizations. The President serves as Coordinator of the Local Arrangements Committee for the annual meeting that occurs at the end of the President's term.

Section 3. *President-Elect.* The President-elect shall be considered a vice president and shall serve as such in the absence of the President.

Section 4. *Past-President.* The retiring President shall serve as Past-President and chair of the Nominating Committee. The Past President shall serve ex officio on those committees designated by the President and shall serve in the absence of the President and President-elect.

Section 5. *Secretary-Treasurer.* The Secretary-Treasurer shall:

(1) Assist Council in carrying on the functions of the Academy including the receipt and disbursement of funds under the direction of Council.

(2) Manage the Academy Offices under Council's general supervision.

(3) Serve as Managing Editor of the *Proceedings of the North Dakota Academy of Science.*

(4) Prepare a summary of the most recent audit and a report of the Academy's current financial status. This information shall be shared with the membership at the annual business meeting and published in the PROCEEDINGS following the business meeting.

(5) Perform all other duties of the Secretary-Treasurer listed in the Bylaws.

(6) Serve as archivist and be responsible for all official records, archives, and historic material which shall be in reposit with the Secretary-Treasurer.

BYLAW 5. *Appointment, Nomination and Election of Members of Council*

Section 1. *Eligibility for Office.* All candidates for election or appointment to the Council must be regular members in good standing. Nominees for President-elect must be members who reside within easy commuting distance of the site of the annual meeting selected by the Council that occurs when the President-elect serves as President.

Section 2. *Nomination Procedures.* The Nominating Committee shall be responsible for all nominations to elective office, shall determine the eligibility of nominees, shall ascertain that nominees are willing to stand for office, and shall be required to advance to the Secretary-Treasurer at least two names for each open position as needed. Academy members shall have been encouraged to suggest nominees to the committee prior to the Committee submitting its report.

Section 3. *Election Procedures.* Election shall be by secret mail ballot. The Secretary-Treasurer shall prepare a printed ballot that bears all names submitted by the Nominating Committee, that contains a brief biography of each candidate, and that has space for write-in candidates for each office. This ballot is to be mailed to all members no later than 1 November. Each member wishing to vote must return the marked ballot in a sealed signed envelope to the Secretary-Treasurer postmarked not more than thirty days after the ballots were mailed out to members. The President shall appoint tellers who shall count the ballots which have been received by the Secretary-Treasurer and the tellers shall present the results in writing to the President. A plurality of the votes cast shall be necessary to elect and in the case of a tie vote, the President shall cast the deciding vote. The results of the election shall be announced at the annual Business Meeting.

Section 4. *Term of Office.* A President-Elect shall be elected annually by the membership and the following years shall succeed automatically to President and Past President to constitute a three year nonrenewable term. Three Councilors shall be elected by the membership to three-year, non-renewable terms on a rotating basis. All elected Council members shall take office at the end of the next annual Business Meeting following election and shall continue until relieved by their successors. Council is empowered to appoint and compensate a Secretary-Treasurer to successive three-year terms that commence with the beginning of the fiscal year.

Section 5. *Removal from office or position* If for any reason any elected member of Council is unable to fulfill his/her duties, the Council member may be removed from office by two-thirds vote of Council. If for any reason the Secretary-Treasurer is unable to fulfill his/her duties, the Secretary-Treasurer may be relieved of all duties by a majority vote of Council.

Section 6. *Interim vacancies.* Should a vacancy occur in the Presidency, the Council by a majority vote shall appoint a member of the Academy able to coordinate the next annual meeting to fill the unexpired term. A retiring interim President shall succeed automatically to Past President. Should a vacancy occur in the Presidency-elect, the Council shall reassess and change the location of the coinciding annual meeting as necessary and then call for a special election by mail ballot. An interim vacancy in the Past-Presidency shall be filled by the most recently retired Past-President able to fill the duties of the Past-President. Persons appointed to fill the unexpired term of Secretary-Treasurer are expected to remain in the position for a minimum of three years. A vacancy in the office of Councilor shall be filled by a majority vote of Council until the following election at which time the interim Councilor may stand for a full three year nonrenewable term.

BYLAW 6. *Committees*

Section 1. Standing Committees. Standing committees shall include but not be limited to, the following: Editorial, Education, Denison Award, Necrology, Nominating, Resolution, Membership, and Audit Committees. The President shall appoint members of committees other than the Nominating and Audit Committees.

Section 2. *Editorial Committee.* The Editorial Committee shall consist of three regular members appointed to three year terms. The duties are explained in BYLAW 7 (Publications).

Section 3. *Education Committee.* The Education Committee shall consist of five regular members and two high school teachers appointed to five year terms. The Education Committee shall work with high school students and teachers in the state, in visitation programs, Science Talent Search programs, and other programs to stimulate an interest in science by the youth of the state. It shall operate the Junior Academy of Science program and administer the AAAS high school research program.

Section 4. *Denison Awards Committee.* The Denison Awards Committee shall consist of six regular members appointed to three year terms. The Denison Awards Committee shall have as its prime duty the judging of student research and paper competitions, both undergraduate and graduate, and any other similar competitions. The committee shall also maintain the criteria to be used in the judging and selection of papers, such criteria to be circulated to prospective competitors.

Section 5. *Necrology Committee.* The Necrology Committee shall consist of three regular members appointed to three year terms. The Necrology Committee shall report to the annual meeting on those deceased during the preceding year. Obituaries may be included in the minutes of the annual meeting and/or published in the Proceedings.

Section 6. *Nominating Committee.* The Nominating Committee shall consist of the five most recent past-presidents. The major duties of the Nominating Committee are listed in BYLAW 5 (*Appointment, Nomination and Election of Members of Council*). The Nominating Committee will also administer the selection process, develop a separate funding source for a monetary award, and develop, for Executive Committee approval, the criteria for the North Dakota Academy of Science Achievement Award.

Section 7. *Resolution Committee.* The Resolution Committee shall consist of three regular members appointed to three year terms. The Resolution Committee shall prepare such resolutions of recognition and thanks as appropriate for the annual meeting. Further, the Committee shall receive suggested resolutions for the membership and transmit such resolutions and the Committee recommendation to the membership.

Section 8. *Membership Committee.* The Membership Committee shall consist of unlimited numbers of regular members appointed annually.

Section 9. *Audit Committee.* The Nominating Committee shall appoint on a yearly basis one member who is not a member of Council to conduct at least one internal audit per year.

Section 10. *State Science Advisory Committee.* The State Science Advisory Committee (SSAC) shall consist of five regular or emeritus members appointed to four year terms. The SSAC shall serve to direct questions of a scientific nature to the appropriate expert as requested, shall inform regional granting agencies and state and national science policymakers of its expertise and availability and shall counsel those agencies and persons upon their request. The SSAC shall adhere in particular to the guidelines described in Article V, Section 2 of the Constitution.

Section 11. *Ad hoc Committees.* The President may appoint such additional committees as may be needed to carry out the functions of the Academy. Ad hoc committees serve only during the tenure of the president who appointed them. Reports of ad hoc committees shall be presented to Council or to the annual meeting.

BYLAW 7. *Publications*

Section 1. *Editorial Committee.* Three regular members are appointed to the Editorial Committee for renewable three year terms. The Editorial Committee shall develop and recommend the Academy publication program and policies to the Council. It will assist the Editors of each official publication in reviewing manuscripts for those publications that include the *Proceedings* . Chairs of symposia will review manuscripts written for relevant symposia.

Section 2. *Managing Editor.* The Secretary-Treasurer shall serve as the Managing Editor of all Academy publications and as such shall oversee each Editor.

Section 3. *Editor.* Editors shall serve three year terms. The Editors shall edit all official publications of the Academy including the *Proceedings.*

BYLAW 8. *Memorial Fund*

The Council of the Academy shall establish a J. Donald Henderson Memorial Fund and administer this fund so that the proceeds will be used to promote science in North Dakota.

BYLAW 9. *Fiscal Year*

The fiscal year of the North Dakota Academy of Science, for the purpose of financial business, shall be 1 January to 31 December.

BYLAW 10. *Achievement Award*

The Academy establishes the North Dakota Academy of Science Achievement Award to be given periodically to an Academy member in recognition of excellence in one or more of the following:

a. Nationally recognized scientific research.

b. Science education.

c. Service to the Academy in advancing its goals.

The Nominating Committee will administer the selection process, will develop a separate funding source for a monetary award, and will develop, for Council approval, the criteria for the award.

BYLAW 11. *Research Foundation*

The **North Dakota Science Research Foundation** is established as an operating arm of the Academy. The purposes of the Foundation are:

(1) to receive funds from grants, gifts, bequests, and contributions from organizations and individuals, and

(2) to use the income solely for the making of grants in support of scientific research in the State of North Dakota.

Not less than 50% of the eligible monies received shall be placed in an endowment from which only the accrued interest shall be granted.

The foundation shall be responsible for soliciting the funds for the purposes described. The Foundation funds shall be in the custody of the Secretary-Treasurer of the Academy and shall be separately accounted for annually.

The Foundation Board of Directors shall be comprised of five members of the Academy , representing different disciplines. Members shall be appointed by the President of staggered five year terms. The chairperson of the Board shall be appointed annually by the President. The Board shall be responsible for developing operating procedures, guidelines for proposals, evaluation criteria, granting policies, monitoring procedures, and reporting requirements, all of which shall be submitted to the Executive Committee for ratification before implementation.

The Foundation shall present a written and oral report to the membership of the Academy at each annual meeting, and the Secretary-Treasurer shall present an accompanying financial report.

BYLAW 12. *Affiliations*

The Academy may affiliate itself with other organizations which have purposes consistent with the purposes of the Academy. Such affiliations must be approved by the Council and by a majority of those attending a regularly scheduled business meeting of the membership.

BYLAW 13. *Indemnification*

Section 1. Every member of the Council or employee of the North Dakota Academy of Science shall be indemnified by the Academy against all expenses and liabilities, including counsel fees, reasonably incurred or imposed upon him/her in connection with any proceedings to which he or she may be made part, or in which he or she may become involved, by reason of being or having been a member of the Council, or employee at the time such expenses are incurred, except in such cases wherein the member of the Council or employee is adjudged guilty of willful misfeasance or malfeasance in the performance of his or her duties. Provide, however, that in the event of a settlement of the indemnification herein shall apply only when the Council approves such settlement and reimbursement as being for the best interests of the Academy.

The foregoing right of indemnification shall be in addition to and not exclusive of all other rights to which such members of the Council or employee may be entitled.

Minutes (Unapproved) of the North Dakota Academy of Science Business Meeting
1:00 p.m., Best Western International Inn, Minot ND, April 3, 1998

36 members were in attendance.

After an introduction and presentation of a Denison award by President Allen Kihm the first order of business was to approve the minutes from the September 1997 business meeting. The minutes were approved as presented.

A financial report was presented by Secretary-Treasurer Uthus. A copy of that report will be printed in the 1998 Proceedings of the North Dakota Academy of Science. The Academy at present is financially sound. This in part is the result of the Bremer/Bush grant obtained by Curtiss Hunt for the 1997 meeting. The main expense that the Academy has is the printing of the Proceedings. This year the projected cost is $1500. Next year, when the meeting is in Grand Forks the projected cost is $6000. Outside funding will be sought to help underwrite the cost of printing the Proceedings next year. This year, Minot State University has pledged $500 towards the cost of printing the Proceedings. This year, the Proceedings will be published after the meeting. As soon as they are completed, copies will be mailed to all members.

A necrology report was given by Uthus. Two members passed away since the last annual meeting; Dennis Disrud from Minot State University and Theodore Auyong from the University of North Dakota. Their obituaries will be published in the 1998 Proceedings. Members stood in a moment of silence in remembrance of these two members.

Applications for the North Dakota Research Foundation grant have not yet been reviewed. The Research Foundation Committee will get the applications from the Secretary-Treasurer shortly for review.

Meeting statistics: Fifty-two registered attendees, 2 symposia with 4 presentations in each along with moderated discussion periods, 14 professional talks 2 of which were posters, and 1 Denison (undergraduate) presentation.

The Denison award winner was Ched Phillips from Valley City State University. His presentation entitled "Initiation of a long term invertebrate sampling project on the Sheyenne River" was coauthored by Brian Tangen and Andre DeLorme.

The Academy usually presents awards to two State Science Fair winners. This year, Eileen Starr and Om Madhok will select the awardees.

Kim Michelsen (Grand Forks) has been in charge of the Jr. Academy. This year it will be held in Minot in April following the annual meeting. Shiloh Schnabel is the local coordinator form Minot. In the future, the Academy will try arrange the Jr. Acadmey to coincide with the annual meeting as is traditional.

There was discussion on lack of elections this year. The Nominating Committee has had difficulty finding someone to run for President-elect. This person should be from Fargo as that is where the 1999 meeting (when he/she is President) will take place. We also need to fill one vacant councilor position. As soon as nominations have closed, ballots will be sent to all eligible members. The election will be official not less than 30 days after the declared due date of ballots. Our Constitution now provides this mechanism of election. Normally the ballots would be finalized and counted the day of our business meeting at the annual meeting. Results would be announced then).

President Kihm opened the floor for discussion of allowing an open competition for the Denison awards - that is allowing students from schools other than those from North Dakota institutions of higher education to participate. This could only be done if the original Denison endowment allows (or does not prohibit) non-North Dakota students to participate. A motion was made to allow open competition if not prohibited by the Denison endowment. The motion carried without any descending votes. Secretary-Treasurer Uthus will research the Denison endowment to see if there are prohibitions tied to the awards.

A certificate of appreciation was presented to Past-president Hunt. This certificate, which was supposed to have been presented during last year's annual meeting, thanked him for his work as President of the Academy. A certificate of appreciation was then given to Allen Kihm by Curtiss Hunt, thanking Allen for his work as President of the Academy.

Allen Kihm officially ended his duties as President by introducing Joseph Hartman (UND, EERC). President Hartman discussed next year's meeting which will be held in Grand Forks on April 15 and 16, 1999.

Meeting adjourned 1:45 PM

ACADEMY OFFICERS AND COMMITTEES

Executive Committee
Membership:
- Past-President
- President
- President-Elect
- Secretary-Treasurer
- Councilors (three-year terms)

President
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Editorial Committee

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Denison Awards Committee

Necrology Committee

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1983	Virgil I Stenberg	Grand Forks
1984	Gary Clambey	Fargo
1985	Michael Thompson	Minot
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1987	William Barker	Fargo
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1989	Forrest Nielsen	Grand Forks
1990	David Davis	Fargo
1991	Clark Markell	Minot
1992	John Brauner (elect)	Grand Forks
1993	John Brauner	Jamestown
1994	Glen Statler	Fargo
1995	Carolyn Godfread	Bismarck
1996	Eileen Starr	Valley City
1997	Curtiss Hunt	Grand Forks
1998	Allen Kihm	Minot
1999	Joseph Hartman	Grand Forks

Financial Statement, 12/31/98

	1995	1996	1997	1998
ASSETS				
Operating Accounts				
Checking	23.89	-424.21	1707.61	3771.27
Trust Accounts				
Scholarship	23206.92	23700.57	29592.49	27850.12
Research Foundation	12060.19	13372.85	13573.57	13797.48
Total	$35,291.00	$36,649.21	$44,873.67	$45,418.87
LIABILITIES				
Advanced Dues Payments	78.00			
Restricted Purpose Funds				
Scholarship Principal	23206.92	23700.57	29592.49	27850.12
Research Foundation	12060.19	13372.85	13573.57	13797.48
Total	$35,345.11	$37,073.42	$43,166.06	$41,647.60
Accumulated Surplus	-54.11	-424.21	1707.61	3771.27
Change in Surplus		-370.10	2131.82	2063.66
DUES				
Reinstatements				
Current year	1673.00		1345.00	3077.00
Future years	78.00			
Sponsor/Patron	599.00			
Total	$2,350.00	$1,069.50	$1,345.00	$3,077.00
INSTITUTIONAL SUPPORT				
UND		1000.00		1000.00
Minot State University				500.00
Valley City State University		250.00		
NDAS Research Foundation	1200.00			
Total	1200.00	1250.00		1500.00
ANNUAL MEETING				
Registration fees	1005.00	4148.00	6408.32	564.00
Banquet	526.00			
Luncheon				
Sigma Xi - Minot	50.00			
Sigma Xi - UND	50.00			
Bremer/Bush Grant			5400.00	
Total	$1,631.00	$4,148.00	$11,808.32	$564.00
AWARDS PROGRAM				
Scholarship Dividends	829.45	832.20	832.20	901.80
NDAS Research Foundation	456.00	500.00		
Total	$1,285.45	$1,332.20	$832.20	$901.80

	1995	1996	1997	1998
PUBLICATION SALES	112.50		444.50	154.50
MISCELLANEOUS INCOME				
Donations		240.40	170.00	537.00
Dividend Income				14.32
Total		$240.40	$170.00	$551.32
TOTAL INCOME	$6,578.95	$8,040.10	$14,600.02	$6,748.62
MEMBERSHIP				
Emeritus	52	58	56	47
Students	41	53	42	36
Professional	161	178	141	144
Delinquent	140	83*	141**	
Dropped	88	3		
Other	19			
Total	501	375	380	
Member Count	413	289	239	227
	*1995 or before			
	**1996 or before			
ANNUAL MEETING				
Speakers Expenses				140.00
Meals/Refreshments	2504.71	1915.55	2511.23	521.32
Printing				
General Expenses				
Registration Refund			868.00	
Total	$2,504.71	$1,915.55	$3,379.23	$661.32
AWARD PROGRAMS				
ND Science/Engineering Fair	50.00	50.00	50.00	50.00
Denison	400.00	400.00	400.00	100.00
ND Junior Academy	350.00	397.50	350.00	937.83
Research Foundation Grant	500.00	500.00	500.00	500.00
Total	$1,300.00	$1,347.50	$1,300.00	$1,587.83
PUBLICATION				
Proceedings	2507.00	3699.00	4820.23	1792.46
Supplement			1473.73	
Total	$2,507.00	$3,699.00	$6,293.96	$1,792.46
OFFICE EXPENSES				
Postage	268.74	652.38	965.96	455.03
Post Office Box Rental	58.00		39.00	39.00

	1995	1996	1997	1998
Duplication	283.21	84.60	635.94	303.84
Supplies	63.66		243.73	179.33
Clerical Assistance				
Phone	2.96			
Other		501.46	593.73	131.85
Bank Fees			24.70	9.30
Total	$676.57	$1,238.44	$2,503.06	$1,118.35
MISCELLANEOUS				
Fidelity Bond	26.00	26.00	26.00	26.00
NAAS Dues	70.00	70.00	64.75	
Other	1403.00	23.20		
Research Foundation Loan interest		168.00	238.70	
Total	$1,499.00	$287.20	$329.45	$26.00
Total Disbursements	$8,487.28	$8,487.69	$13,805.70	$5,185.96
SCIENCE RESEARCH FOUNDATION				
CASH INCOME				
Donations from Members	212.00	110.00		
Allocations from Dues	244.00	298.00	235.00	
Interest Accrued	425.08	1012.50	675.00	741.91
Sponsors/Patrons				
Total	$881.08	$1,420.50	$910.00	$741.91
CASH EXPENSE				
Grants	500.00	500.00	500.00	500.00
Interest Compounding	425.08	1012.50	675.00	675.00
Other Disbursements	18.00			
Bank Fees			47.52	18.00
Total	$943.08	$1,512.50	$1,222.52	$1,193.00
Net Change	($ 62.00)	($ 92.00)	($ 312.52)	($451.09)
ASSETS				
Pass Book Savings, 31 Dec	2060.19	3372.85	3573.57	3797.48
T-Note, book value	10000.00	10000.00	10000.00	10000.00
Investment Total	$12,060.19	$13,372.85	$13,573.57	$13,797.48
Change		$1,312.66	$200.72	$223.91
SCHOLARSHIP FUND				
CASH INCOME				
ENOVA (SDGE)	426.25	429.00	429.00	429.00
IES Industries	403.20	403.20	403.20	472.80
Total	$829.45	$832.20	$832.20	$901.80

	1995	1996	1997	1998
CASH EXPENSE				
Denison Awards	400.00	400.00	400.00	100.00
Junior Academy Awards	400.00	375.00	350.00	400.00
ND Science and Engineering Fair	50.00	50.00	50.00	50.00
Other Expenses		22.50		
TOTAL	$850.00	$847.50	$800.00	$550.00
Net Change	($ 20.55)	($ 15.30)	$32.20	$351.80
ASSETS				
ENOVA Shares (1983, 250 shares)	758.86	792.83	836.18	853.52
Price 18.50	23.75	22.66	26.94	25.38
Value 4625.00	18022.92	17965.53	22524.49	21658.12
IES Industries (1990, 120 shares)	192	192	192	192
Price 31.63	27.00	29.87	36.81	32.25
Value 3795.60	5184.00	5735.04	7068.00	6192.00
Total Investment Value	$23,206.92	$23,700.57	$29,592.49	$27,850.12
	Change	$493.64	$5,891.92	($1,742.37)

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