PROCEEDINGS

of the

NORTH DAKOTA ACADEMY OF SCIENCE

(PAPERS)

Official State Academy

(Founded December, 1908)

VOLUME XXIII

1969

EDITOR

Alan M. Cvancara

EDITORIAL ADVISORY COMMITTEE

Published jointly by the University of North Dakota, North Dakota State University, Minot State College, Jamestown College and Dickinson State College.

April, 1970

GRAND FORKS, NORTH DAKOTA

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EDITOR'S NOTE

On May 2 and 3, 1969, the 61st annual meeting of the North Dakota Academy of Science was held at Minot State College, Minot, North Dakota. Presentations at that meeting were published in April, 1969 as Abstracts of the Academy Proceedings, volume XXIII. This second part of the volume includes those complete papers which were submitted in manuscript form at the time of the meeting.

Grand Forks, North Dakota — Alan M. Cvancara

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ASPECTS OF GROWTH IN THE WHITE-TAILED JACK RABBIT[1]

Ted R. James[2] *and Robert W. Seabloom*

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ABSTRACT

Growth and age characteristics of the white-tailed jack rabbit (*Lepus townsendii campanius* Hollister, 1915) were determined from 836 animals collected between April, 1964 and December, 1965, and from 24 fetuses from term females. Sexual dimorphism was observed. Females were significantly larger than males in every respect except ear length. Three distinct age classes were established on the basis of epiphyseal closure of the humerus. Age Class I individuals became Age Class II at six or seven months, and Age Class II became Age Class III at 13 or 14 months. The dry weight of the lenses of the eyes were compared with epiphyseal closure, weight, and body measurements, in rabbits up to an estimated age of 48 months.

INTRODUCTION

Elucidation of growth and other developmental phenomena in leporids has been impeded, until recently, by the lack of adequate and valid aging criteria, and by the difficulties encountered in obtaining and raising known-age animals to maturity. Investigations directed toward the development of valid techniques for studying age criteria by Hale (1949), Lechleitner (1959), Lord (1959), and Tiemeier (1965), have facilitated description of growth and developmental characteristics among several leporid species. The white-tailed jack rabbit (*Lepus townsendii campanius* Hollister, 1915) has received very little attention, and there is a paucity of information concerning these characteristics in this species. This paper shows the results of an inquiry into growth phenomena, conducted from April, 1964, through December, 1965.

MATERIALS AND METHODS

Jack rabbits were collected during 21 consecutive months, from April, 1964, through December, 1965, in 24 North Dakota counties. The majority were from a seven county study area consisting of all or parts of Adams, Billings, Bowman, Golden Valley, Hettinger, Slope, and Stark Counties. Animals were taken by shooting, usually between 1500 and 0300 hours. Occasional fresh road-kills were collected and utilized.

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[1]A contribution of the Federal Aid in Wildlife Restoration Act, North Dakota Project W-67-R. Additional support was provided by a National Defense Education Act Predoctoral Fellowship.

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Post mortem examinations were conducted within 4 hours of collection. The left humerus and eye were removed and processed according to methods developed by Lechleitner (1959) and Lord (1959) respectively, to determine whether aging techniques for other species could be applied to the white-tailed jack rabbit. In the event that either the left humerus or eye was damaged, the right was utilized.

Females collected during the breeding season were immediately examined to determine stage of pregnancy. Live fetuses were removed from any found to be full or near-full term. These young were hand reared to obtain information on growth and development. At the time of death, eyes and humeri were removed and used to determine lens growth and degree of humeral development.

RESULTS AND DISCUSSION

A total of 836 white-tailed jack rabbits were collected; 740 of these were taken in the southwestern seven county study area. The number of jack rabbits taken each month ranged from a high of 111 in June, 1964 to a low of 11 in October, 1965, or an average of 40 animals per month for the term of the study. During the spring and summer of 1964 and 1965, 24 young hares were removed as fetuses from term females. These were raised to various ages, ranging from 1 to 207 days.

TABLE I

MEAN WEIGHTS AND BODY MEASUREMENTS OF ADULT MALE AND FEMALE JACK RABBITS

Characteristic	Sex	Sample	Mean	±S.D.	Value of t[1]
Weight (oz)[2]	M	158	102	15	13.33
	F	116	122	10	
Body Length (mm)	M	138	591	26	6.23
	F	160	608	20	
Tail (mm)	M	142	101	4	4.76
	F	171	104	7	
Hind Foot (mm)	M	145	146	6	5.26
	F	177	149	4	
Ear (mm)	M	149	104	6	1.69
	F	177	105	5	

[1] $t_{.05} = 1.96$; infinite D. F.

[2] weights of pregnant females were not included

Growth characteristics.—Sexual dimorphism was observed in the weight and body size of the adult white-tailed jack rabbits (Table I). Females were generally larger and heavier than males. The mean weight for females was 122 ounces, 20 more than the mean weight for males. In order to insure that weight differences were not due to pregnancy, only the weights of non-pregnant adults were included in the sample. The difference in the mean weights of males and females was found to be significant ($t = 13.33$). The mean of all body measurements except the ear, were found to be significantly greater in females (Table I). Similar sexual dimorphism reported in the cottontail rabbit *Sylvilagus floridanus* (Elder and Sowles, 1942), and in the black-tailed jack rabbit *L. californicus* (Lechleitner, 1959; Tiemeier, 1965) indicate that this phenomenon may be characteristic of leporids.

Mean monthly weights of 274 adult jack rabbits were examined for evidence of seasonal patterns of variation. Only animals determined to be at least one year old were included in the sample.

Monthly fluctuations in weights of males suggested a seasonal pattern. These declined in March, were lowest (115 oz) in April and remained within 5 oz of the annual mean weight (102 oz) through August. They increased in September and reached a maximum of 120 oz in November. The greatest deviation above the annual mean occurred between September and March. Similar early spring weight losses among males have been reported in the cottontail rabbit (Elder and Sowles, 1942) and in white-tailed jack rabbits from Iowa (Kline, 1963).

Well-defined seasonal variations in the weights of females were not observed. However, monthly weights were close to or greater than the annual mean (122 oz) between April and September, and equal to or less than the annual mean between October and March. The lowest and highest monthly means were 115 oz in March and 132 oz in April.

The greatest increase in female weight occurred between March and April; a mean change of 17 oz. During this same period, the weights of males decreased and dropped below the annual mean for the first time since the previous August. These weight fluctuations may be a reflection of the onset of breeding activities, which have been determined to begin in late February or early March and continue into late July (James and Seabloom, 1969). The spring gain and sustained elevated mean weights during the summer months among females may be the result of increased food consumption in response to the demands of the breeding season, or the result of increased size of the reproductive tract and mammary tissue. Male weights decline in the spring and remain relatively low through the summer, possibly as a result of the stress of the breeding season.

Average hind foot and ear growth from birth to 80 days was determined from measurements obtained from 24 hand reared hares of estimable age. Growth curves were hand-fitted to the plotted measurements and extrapolated to the adult means. The hind foot and ear lengths averaged 40 and 20 mm at birth and 95 and 70 mm at 40 days respectively. If it can be assumed that maturity is reached when the hind foot and ear lengths approach the adult means, these data would indicate that adult size would be reached at approximately 115-125 and 95-105 days, respectively. These rates of growth, and the ages at which the maximum growth of hind foot and ear are attained are similar to those reported for the white-tailed jack rabbit in Colorado (Bear and Hansen, 1966) and for the black-tailed jack rabbit (Haskell and Reynolds, 1947; Tiemeier, 1965).

The average weight gain by hand reared jack rabbits was determined from birth to 80 days. Weight at birth was approximately 100 gm. There was no weight increase during the 5-7 days following birth. This is reflected in the low rate of weight gain in the first 20 days of life (5.0-6.2 gm/day). Estimated daily weight gain was relatively constant between 20 and 80 days and ranged from 8.8 to 9.4 gm per day.

The dry weights of the lenses from hand reared animals ranged from 23 mg at Day 1 to 200 mg at Day 207. The average daily lens weight gain was 1.200 mg for the first 120 days. Tiemeier (1965) estimated this value for the black-tailed jack rabbit to be 1.104 mg for the same period. The close agreement of these estimated growth rates, suggests that lens growth in the white-tailed and black-tailed jack rabbit may be quite similar; particularly during the early phase of growth.

Aging criteria.—Examination of the proximal epiphysis of white-tailed jack rabbit humeri indicates that three distinct age classes, similar to those previously reported for the black-tailed jack rabbit by Lechleitner (1959) and Tiemeier (1965), could be distinguished. Individuals in which this epiphysis was represented by a definite groove were included in Age Class I. In Age Class II individuals, the epiphyseal plate had been replaced by bone, but the bony trabeculae had not organized and a definite suture line indicating the area of closure was visible on the surface. In Age Class III individuals there was no indication of the epiphyseal line.

The time of epiphyseal-closure was determined by examining the occurrence of these age classes in the monthly collections (Figure 1). Age class I animals first appeared in May collections, and were taken through the following December. Age Class II animals were collected in all months except September and October, while Age Class III hares were taken year around. The absence of Age Class II animals in September and October indicated that the epiphyseal plate had become completely ossified and that these animals were now Age Class III. The occurrence of Age Class II animals in the November and December collections therefore indicated young-of-the-year which in previous months would have been classified as Age Class I. These

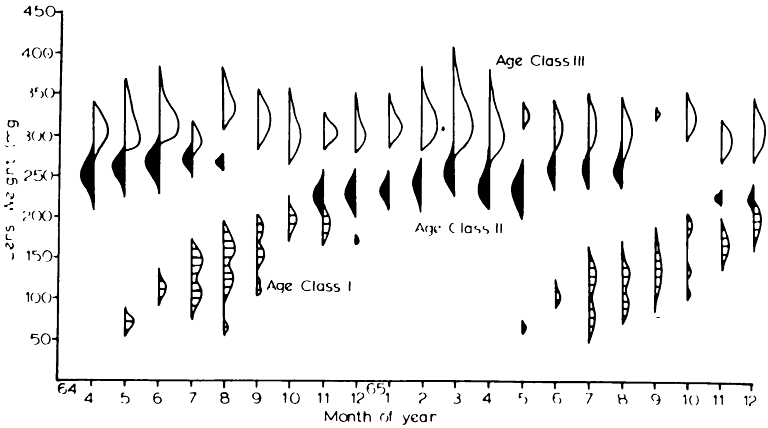

FIGURE 1—Comparison of the distribution of lens weights with the degree of epiphyseal closure of the humeri. Symbols indicate the range and relative distribution of lens weights within each age class by months, and the lens weight overlap between age classes. The time and degree of epiphyseal closure is indicated where one age class overlaps with and grades into another. Note the absence of Age Class II animals in September and October.

observations indicated that Age Class I animals became Age Class II at approximately 6 to 7 months, and Age Class II became Age Class III at approximately 13 to 14 months. These findings agree with those reported for the black-tailed jack rabbit by Lechleitner (1959) and Tiemeier (1965) and indicate that closure of the epiphysis occurs at approximately the same time in both species.

The distal epiphysis of the humerus and an atavistic epiphysis between the greater and lesser tuberculae of the humerus were found to be open in very young hares. The atavistic epiphysis closed when the humerus was between 75-80 mm in length; the distal epiphysis closed sometime before the humerus was 90 mm long. Animals in which these epiphyses were open were aged using lens weights and by comparison with data from hand raised known age animals, in order to determine when these epiphyses closed. It appeared that they closed at 80-90 days, with the atavistic epiphysis closing before the distal one.

To determine if the length of the humerus may be useful as an age criterion, measurements were taken between the proximal bicipital groove and distal notch medial to the capitulum and the trochlea. The range of humeral lengths were: Age Class I, 45-104 mm; Age Class II, 88-105 mm; Age Class III, 90-109 mm. Thus, the notch-to-notch length of the humerus was found to be an inadequate age criterion, since length is highly variable among individuals and appears to have little bearing on age except in extremely young animals.

Dry weights of 799 jack rabbit lenses were examined with regard to epiphyseal age classes (Figure 1). Lenses of Age Class I animals weighed less than 225 mg, those of Age Class II less than 295 mg, and Age Class III up to a maximum of 400 mg. The lens weights of Age Classes I and II overlap only during the months of November and December; Age Class II overlaps with Age Class III during the months of March through July. However, this overlap was not extreme and never exceeded more than 25 mg.

In order to determine if body weight could be utilized as an aging criterion, the monthly mean weights of juvenile (Age Class I) animals were compared to adult mean weight between May and December. The mean monthly juvenile weights ranged from 60-65 oz from May through July, increased to 80 oz in August, and approached the adult mean (112 oz) by September. The range of body weight and standard deviations determined from these data, overlapped to a considerable extent in September. These observations indicated that body weight is not a valid criterion for separating young-of-the-year from adult animals after August.

Certain reproductive tract characteristics of the white-tailed jack rabbit may be useful as additional age criteria. Scrotal sacs of many older Age Class III males are dark blue to black in color and covered with less hair than those of younger adults (James and Seabloom, 1969). These findings and those of Lechleitner (1959) in the black-tailed jack rabbit indicate that this condition is characteristic of an older animal.

Non-parous uteri had a smooth and compact appearance. During the first pregnancy the organ became enlarged, and a series of longitudinal striations developed in the muscular wall, a condition previously reported in the black-tailed pack rabbit (Lechleitner, 1959). These striations are apparently retained throughout life, and may be useful in distinguishing juvenile from adult females between August and February. The absence of these striations is indicative of a virgin or juvenile animal.

A summary of the developmental characteristics and aging criteria for the white-tailed jack rabbit is presented in Table II. These characteristics were estimated from the growth and aging data obtained during this study. Through the comparison of these parameters, it has been possible to estimate growth and aging characteristics from birth through 48 months. More accurate estimates may be possible after further studies of larger samples of hand reared young.

ACKNOWLEDGMENTS

We wish to acknowledge C. R. Grondahl, J. Samuelson, G. D. Kobriger, and A. W. Adams of the North Dakota Game and Fish Department, for their assistance in the field phase of this investigation; W. Cowan, for his energies during the summer of 1965; and J.

TABLE II

ESTIMATED DEVELOPMENTAL CHARACTERISTICS OF THE WHITE-TAILED JACK RABBIT

Epiphyseal age class	Est. age (months)	Lens wt. (mg)	Body wt. (oz)	Hind foot (mm)	Ear (mm)	Special characteristics
	0-1	25- 60	4-10	40- 70	20- 50	Distal and atavistic epiphysis open
	1-2	60- 90	10-25	70-100	50- 70	Distal and atavistic epiphysis open
I	2-3	90-120	25-40	100-120	70- 90	Distal and atavistic epiphysis open
(Proximal epiphysis open)	3-4	120-145	-	120-145	90-100	Distal and atavistic epiphysis closed
	4-5	145-170	-	Adult Size	Adult Size	Distal and atavistic epiphysis closed
	5-6	170-195	-	Adult Size	Adult Size	Distal and atavistic epiphysis closed
	6-7	195-220	-	Adult Size	Adult Size	Distal and atavistic epiphysis closed
II	7-10	220-260				Females: uterus is smooth; no linear striations
(Proximal epiphysis closed: line visible)	10-14	260-295				Females: uterus is smooth (non-preg nant)
III	14-20	295-325				
(No trace of	20-30	325-350				Males: scrotum dark blue to black
epiphyseal line)	30-48	350-400				

R. Reilly, for his constructive criticism and assistance in the preparation of this manuscript.

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AGE AND GROWTH OF YELLOW PERCH IN LAKE ASHTABULA

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ABSTRACT

Age and growth in length was determined from scales of 410 yellow perch, *Perca flavescens* (Mitchill), caught by angling and seining during 1967-68. Male and female yellow perch showed a general decreasing growth trend during 1961-67. Body total length (TL)-scale radius (SR) relationship of 526 male and female perch was TL=32.05+1.396 SR. Scales were magnified 35.2 times. Linearity accounted for 99.5% of regression variance. Body total length-weight relationships for 189 males and 718 females was described by the parabolic power function $W=aL^b$ with good agreement, $r_{\log Y . \log X}=0.998$. The male:female sex ratio from angling catch was 1:6 (1968); seining of young-of-the-year showed an equal sex ratio.

INTRODUCTION

This study describes the growth in length and weight of yellow perch, *Perca flavescens* (Mitchill), which is one of the most popular and abundant panfish in Lake Ashtabula, North Dakota. Data described here will be useful in future studies of environmental factors affecting population growth and size of yellow perch, particularly those which may change when irrigation waters from the Garrison Diversion Project enter the reservoir in the mid-1970's.

Lake Ashtabula is a eutrophic, 20-year-old reservoir used for flood control, fishing and boating. It is located 12.8 km northwest of Valley City, North Dakota, and is a long (43.5 km), narrow (0.96 km) reservoir with a surface area of 2197.5 ha, a mean depth of 4.0 m, and a storage capacity at normal pool of 0.0873 km^3. Water quality and primary production measurements have been reported for Lake Ashtabula by Peterka and Reid (1968).

METHODS

Yellow perch were collected by angling and seining at Camp Ritchie Conservation Center, 3.2 km north of the dam, during 1967-68. Fish collected by angling were caught with small hooks using worms or small artificial baits, and all fish caught were kept. Young-of-the-year perch were caught with a 9 m bag seine, 2 m in depth, with a mesh size of 0.64 cm^2. Measurements of total length (TL) in millimeters, wet weight to the nearest 0.2 g, and determinations of sex were made. Scales were removed from the area below the lateral line at the posterior tip of the pectoral fin. Scale impressions were made in cellulose acetate slides with a roller press (Smith, 1954).

Scale impressions were magnified 35.2 times with a slide projector and measurements of the anterior scale radius (SR), from focus to anterior scale margin, and each annulus was marked on a paper tab (Carlander and Smith, 1944). Scales were aged by both investigators and there was good agreement for the first four annuli. Where aging did not agree between investigators, scales were re-read for a third time. Back calculations of total length at annulus formation were made by the use of a nomograph (Carlander and Smith, 1944).

Statistical analyses followed the methods of Li (1964), and Snedecor and Cochran (1967). All statistics reported as significant in this paper are at the 95% confidence level.

RESULTS

Growth in length.—Two scales from each of 526 fish were measured and means of scale radii and corresponding total lengths for 10 mm intervals of scale radii were used to establish the body-scale relationship. The body-scale relationship was the same for males and females and data for sexes were combined. The relationship between fish total length (TL) and the length of the anterior scale radius (SR) magnified 35.2 times was linear, and was described by

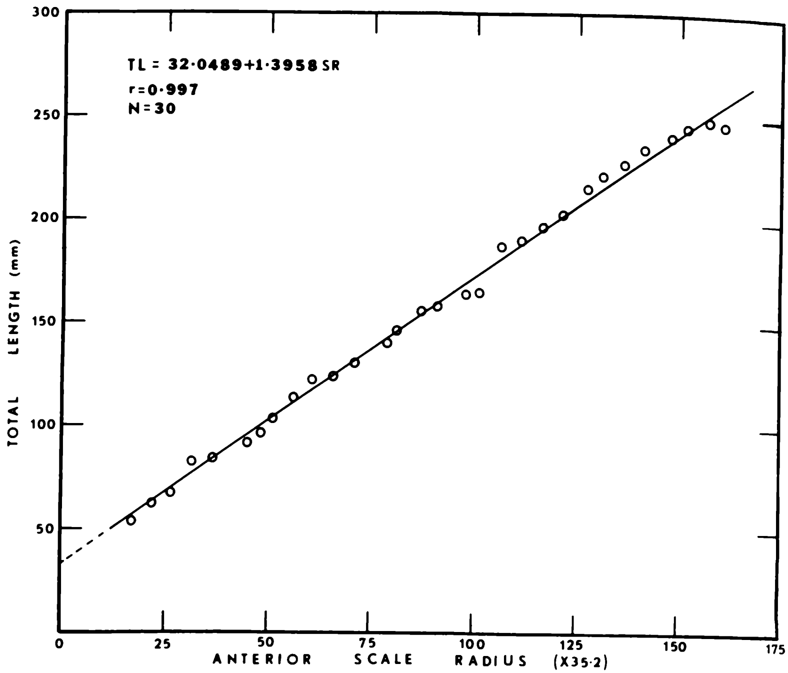

FIGURE 1—Relationship between the total length and the length of the anterior scale radius, magnified 35.2 times, of yellow perch collected from Lake Ashtabula during 1967-68.

the equation: TL=32.0489+1.3958 SR (Figure 1.) Linearity accounted for 99.5% of regression variance (r^2=0.995), and $2s_{y.x}=\pm10.8$ mm.

Total lengths at the end of each year of life of 107 male and 303 female yellow perch were determined (Table I). Mean calculated growth in total length of males and females was similar at the end of the first year of life, but in the second and later years females grew faster than males (Table I, Figure 2). Females of age 2 were 3.7 mm longer, and those of age 7 were 24.0 mm longer than males of the same age. Females increased from 81.8 mm at the end of the first year to 255.0 mm at the end of the seventh year of life; males increased from 81.3 to 231.0 mm. Annual length increments decreased with each succeeding year of life for both sexes (Table I, Figure 2).

The predicted ultimate length of male and female yellow perch was estimated using the method described by Walford (1946). Mean calculated total lengths at the end of one year (l_t) were plotted against those at the end of the next year (l_{t+1}) (Figure 3). The 45° diagonal line indicates the point at which there would be no increase in growth in a year's time; the two intersecting lines indicate predicted ultimate lengths for males of 248 mm and for females 275 mm. The largest male perch caught was 256 mm and the largest female caught was 282 mm.

TABLE I

AVERAGE CALCULATED TOTAL LENGTHS (MM) AT THE END OF EACH YEAR OF LIFE OF MALE AND FEMALE PERCH IN LAKE ASHTABULA FOR 1967-68

Females

Year Class	No. of Fish	Years of Life 1	2	3	4	5	6	7
1967	6	68.3						
1966	61	81.5	135.0					
1965	69	78.3	140.9	183.2				
1964	37	80.6	140.4	180.9	203.8			
1963	41	81.8	141.7	175.2	198.8	218.0		
1962	70	84.9	150.1	186.9	209.8	228.2	242.3	
1961	19	90.6	154.0	193.2	218.1	231.3	244.9	255.0
Total no.	303	303	257	184	152	98	60	8
Weighted Mean Length		81.8	144.0	183.4	207.0	228.1	243.2	255.0
Length Increments*		81.8	63.0	38.6	23.6	20.5	14.1	10.1

Males

Year Class	No. of Fish	1	2	3	4	5	6	7
1967	11	69.6						
1966	50	81.4	125.3					
1965	17	81.1	144.5	171.7				
1964	6	86.3	137.7	180.5	200.0			
1963	9	83.3	145.6	175.1	195.2	209.3		
1962	11	86.6	147.8	177.8	198.5	213.5	228.3	
1961	3	88.0	138.3	172.0	196.0	214.3	225.3	231.0
Total no.	107	107	58	38	24	18	11	2
Weighted Mean Length		81.3	140.3	177.3	197.0	212.7	227.5	231.0
Length Increments*		81.3	57.6	33.0	18.0	15.9	13.7	5.7

*Average increments of fish from the same year classes

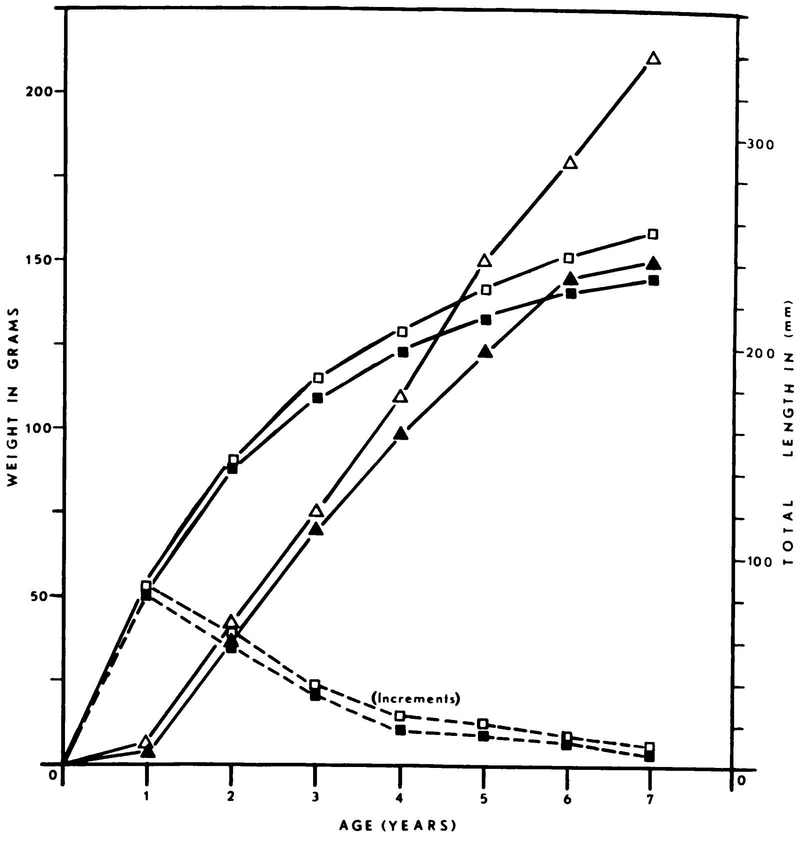

FIGURE 2—Growth in length and weight of male and female yellow perch collected from Lake Ashtabula during 1967-68. Open figures represent females; closed figures represent males. The broken lines represent increments of growth in length between successive years of life. Squares represent length; triangles represent weight.

Growth in length of yellow perch generally declined from 1961-67 (Table I, Figure 4). This decrease in growth was most evident at all ages for females and for ages 1 and 2 for males. The small sample size of 107 fish for males may have obscured decreasing growth for ages 3 to 6 or males may have different growth characteristics than females. Growth at the end of the first year of life generally decreased about 2 mm/year from 1961 to 1967 (Figure 5).

Growth of yellow perch from Lake Ashtabula was above average for the first three years and average (females) to below average

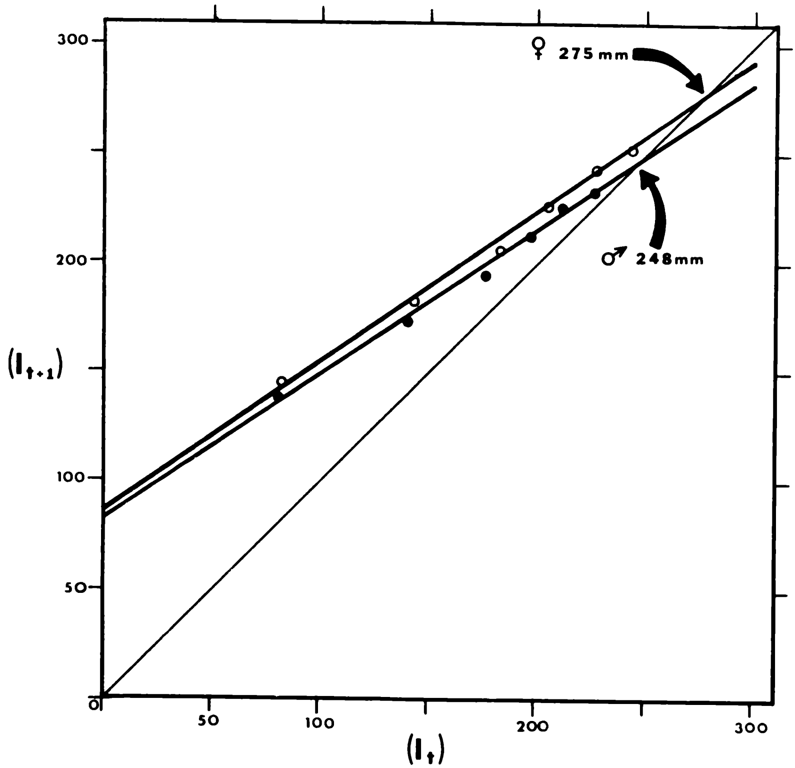

FIGURE 3—Average calculated total length at the end of one year (l_t) against the average calculated total length at the end of the next year (l_{t+1}) for male (closed circles) and female (open circles) yellow perch collected from Lake Ashtabula during 1967-68. The 45° diagonal indicates the point at which there would be no increase in length from one year to the next.

(males) for later years of life when compared with growth of perch from other lakes in the midwest (Figure 6).

Growth in weight.—The relationship between the average total length in millimeters and average weight in grams of 807 yellow perch grouped into 10 mm length intervals was: $W = 16.63 \times 10^{-6}\ TL^{3.1104}$ (Figure 7). The fish were captured during spring and summer of 1967-68 and sexes were combined into the above equation. This equation explained 99.6% of regression variance ($r^2 = 0.996$) and $2s_{\log Y . \log X} = \pm 0.059$ g. The largest yellow perch was 282 mm and weighed 320 g.

Weights of males increased from 4.9 g at the end of the first year

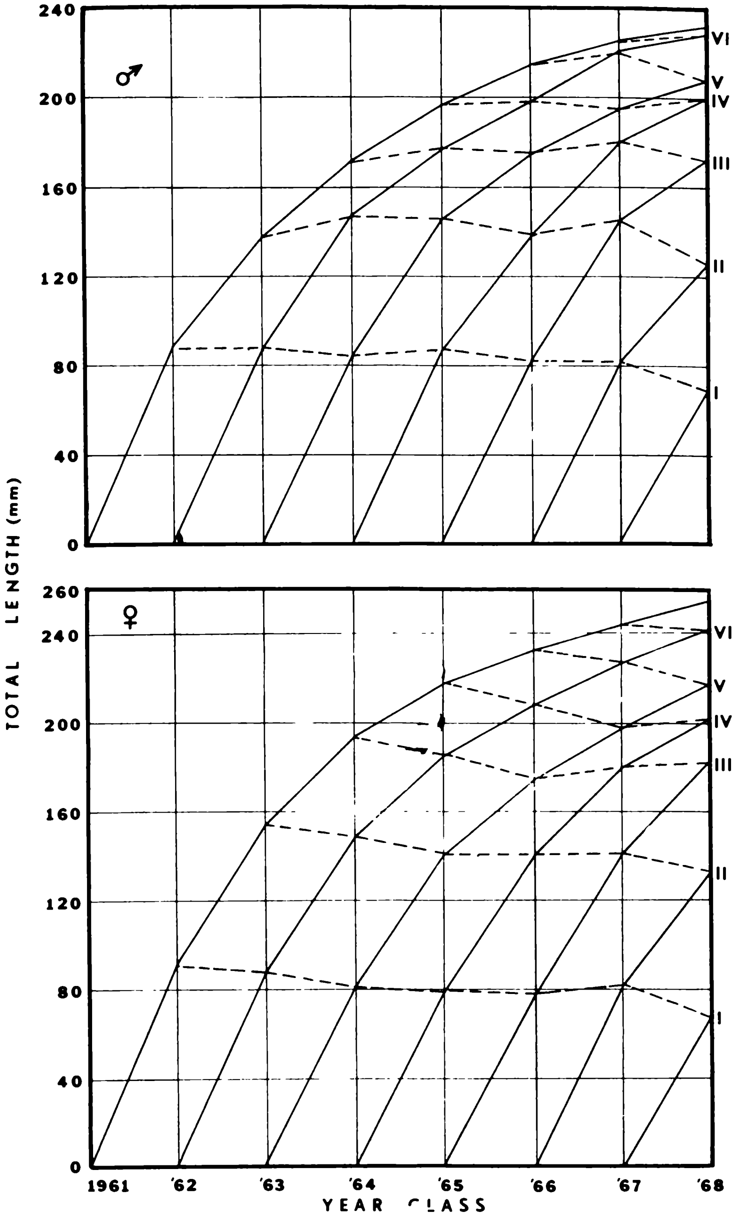

FIGURE 4—Calculated growth in length of the 1961-67 year classes of male and female yellow perch from Lake Ashtabula. Calculated lengths at the end of years of life (age-groups) have been connected by broken lines.

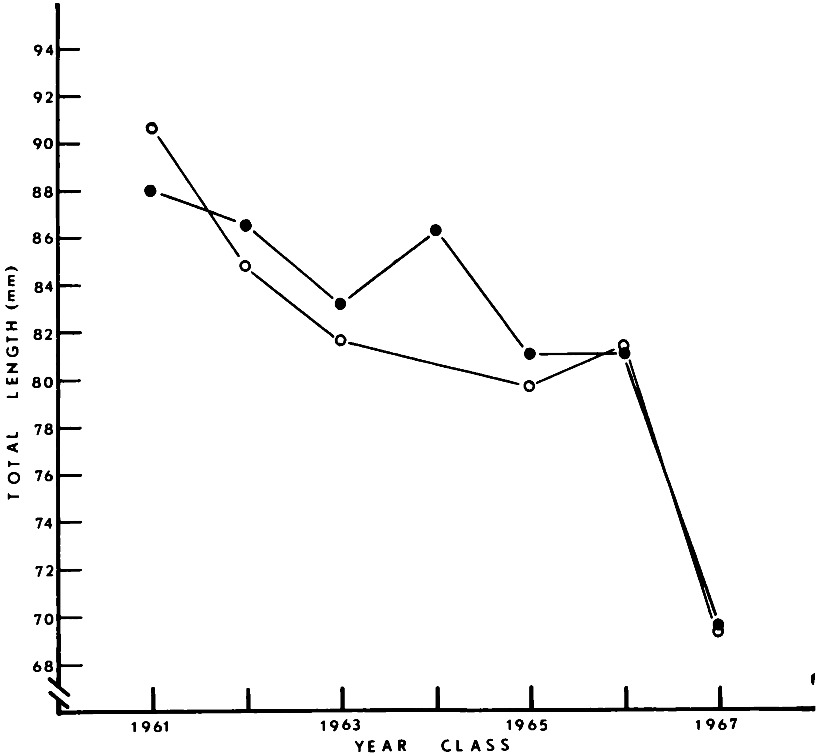

FIGURE 5—Growth in length at the end of one year of life of male and female yellow perch for year classes from Lake Ashtabula. Open circles represent females; closed circles represent males.

to 150.0 g at the end of the seventh year of life; females from 5.1 g a the end of the first year to 210.0 g at the end of the seventh year (Figure 2). Since females in the second and later years of life grew faster in length than males and the length-weight relationships was the same for the sexes, then females also grew faster in weight than males. Females increased 35 g/year after the end of the first year to the end of the seventh year of life. Males increased about 28 g/year from the end of the first year to the end of the sixth year of life, and only increased about 5 g from the end of year 6 to year 7.

Sex Ratio.—Seined yellow perch less than 100 mm in length, caught in 1968, showed an equal male:female sex ratio of 41:38; those greater than 100 mm showed a ratio of 18:35. The male:female sex ratio of fish greater than 100 mm caught by angling in 1968 was 28:166.

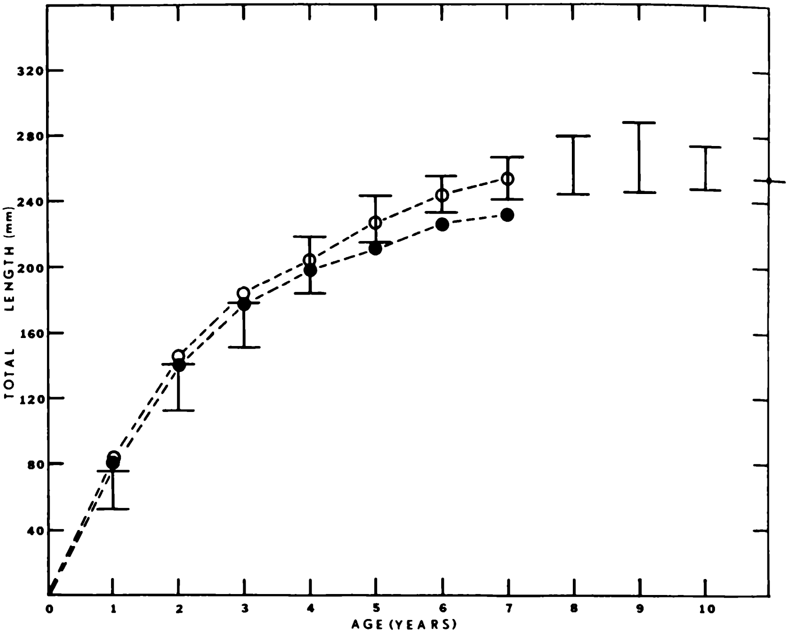

FIGURE 6—Comparison of growth in length of yellow perch, sexes combined, from other midwestern lakes with growth of male and female perch collected from Lake Ashtabula during 1967-68. Open circles represent females, closed circles represent males for Lake Ashtabula. Vertical bars represent ranges of growth in length of yellow perch from Oahe Reservoir (Fogle, 1963), Red Lakes (Heyerdahl, 1968), and various Minnesota Lakes (Carlander, 1953).

DISCUSSION

The general decrease in growth rate of yellow perch in Lake Ashtabula from 1961-67 probably reflects an increase in numbers and consequent overcrowding of the yellow perch population.

The above average growth of yellow perch in Lake Ashtabula during their first three years of life as compared with growth of yellow perch from other midwestern lakes is not easily explained. The average growth of females and the poor growth of males during later years of life is equally puzzling. Lack of adequate sizes or quantities of food organisms to supply the needs of the larger perch is a possible contributing factor.

In the angling catch for 1968, females were six times more abundant than males. Angling is, apparently, very selective for females, since in seine hauls fish of similar sizes to those caught by angling had twice as many females as males. For fish 100 mm or less col-

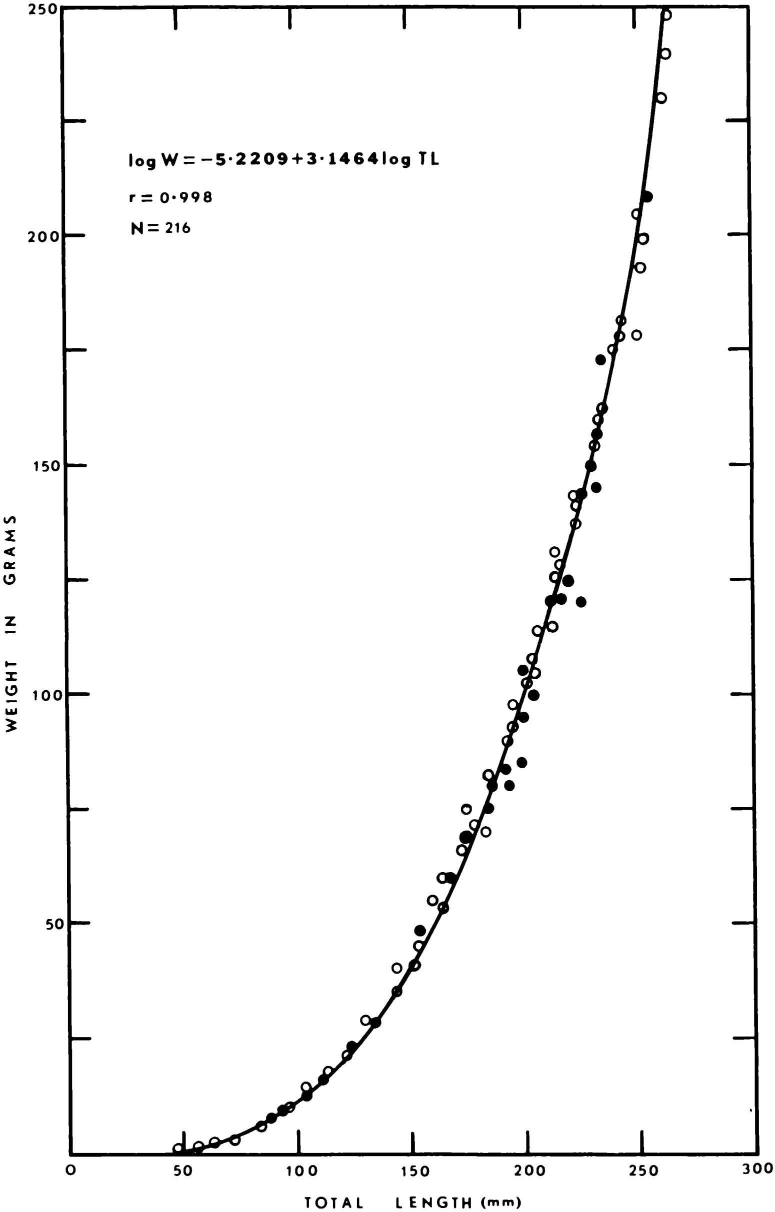

FIGURE 7—Relationship between total length and weight of male and female yellow perch collected from Lake Ashtabula during 1967-68. One-third of the grouped data are plotted for ease of reading the figure. Open circles represent females; closed circles represent males.

lected with a seine, sex ratios were equal. Extreme variations of sex ratios in collections of yellow perch have been reported in other studies as summarized by El-Zarka (1959). He found in his study of yellow perch in Lake Huron that males comprised from 26 to 87% of the total yellow perch catch in different years.

Angling was largely restricted to shallow water and the ratio of six females to one male in our angling catch may have been, in part, the result of a behavioral difference in feeding. Eschmeyer (1938) reported that female yellow perch fed near the surface and in shallow water, whereas males fed in deeper water in a study done in Michigan.

ACKNOWLEDGMENTS

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INSECTS ASSOCIATED WITH ERGOT-INFECTED MALE STERILE BARLEY[1]

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INTRODUCTION

Claviceps purpurea (Fr.) Tul., the causal fungus of ergot, occurs frequently on cereal grains and on cultivated and native grasses in North Dakota. The disease is recognized by ovarial infections which result in the copious production of a sticky, sweet exudate followed by conspicuous clerotia that replace kernels in the spikes. Upon maturity of the host, the sclerotia fall to the ground and germinate in the spring to produce stromata which bear perithecia and ascospores. It is believed that primary infections develop from wind or insect-borne ascospores and secondary infections result almost exclusively from conidia disseminated by insects that feed upon the exudate. Numerous observations of insects considered as possible vectors of ergot have been made (1, 2, 3). In the lists of insects compiled, only circumstantial evidence exists that the insect species act as true vectors of ergot. Experimental proof of vector relationships is lacking for most insects.

Among economic cereals, ergot is most important on rye, but it also occurs on other cereal grains and on numerous cultivated and native grasses. The disease is important not only because it reduces yields of grain, but also because the sclerotia contain poisonous alkaloids which are harmful when ingested by man or animal. Hybrid barley is extremely susceptible due to a delay in pollination which prolongs the period when ovaries remain infective. Increased interest in hybrid barley production in recent years has prompted investigation of insects associated with ergot-infected male sterile barley to determine which insects are most prevalent and which are most likely vectors of the fungus.

METHODS

Two male sterile barley lines were grown adjacent to brome grass headlands at Fargo to provide a favorable location for the natural spread of the pathogen to the field. Tanglefoot traps made of white plastic discs 4 inches in diameter were mounted horizontally at barley head level and were distributed throughout the barley plots. Tanglefoot trap treatments were control, ergot exudate or water in wells on the trap surface and infected barley heads placed close to the

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[1]Journal Paper No. 204, North Dakota Agricultural Experiment Station.

surface to determine whether ergot exudate attracts certain insects. Insects were collected daily from traps before 8 a.m. during the period July 10-21, 1968. Insects actually feeding on ergot exudate from infected florets were observed at various times during the day and night.

RESULTS AND DISCUSSION

Ergot developed in nearly every head of both male sterile barley lines. The number of sclerotia and hybrid seed obtained from equivalent lengths of rows of two male sterile lines are presented in Table I.

TABLE I

NUMBER OF SCLEROTIA AND HYBRID SEED IN EQUIVALENT ROWS OF TWO MALE STERILE BARLEY LINES GROWN NEAR BROME GRASS HEADLANDS, FARGO, 1968

Barley[1] Line	Number of Sclerotia	Number of Hybrid Seed	Percent Sclerotia
Cumalt(msms)XCumalt(MsMs)	444	167	73
Traill(msms)X2670-66-25(MsMs)	194	394	33

[1]Barley lines obtained from Earl Foster, Associate Professor of Agronomy, NDSU.

Differences in percent sclerotia between the two lines probably do not indicate differences in susceptibility. Differences in environmental conditions suitable for dissemination of conidia or infection probably account for these differences in infection.

Sixty-seven different species of insects from 8 orders were collected. They were: 27 species of Diptera, 1 of Neuroptera, 3 of Hymenoptera, 8 of Coleoptera, 2 of Hemiptera, 2 of Homoptera, 1 of Thysanoptera and 23 of Lepidoptera. Most insects found on the traps were also observed to feed on ergot exudate. During daylight hours the most prevalent feeders were various Diptera (flies). Eleven species of Diptera, 1 of Hymenoptera, 5 of Coleoptera, 1 of Hemiptera and 1 of Neuroptera were observed. During darkness, species from 5 families in 4 orders were observed feeding on ergot exudate. They were: 17 species of Lepidoptera, 1 of Diptera, 2 of Coleoptera and 1 of Neuroptera (Table II).

No significant differences in numbers or species of insects were found on trap controls, traps treated with ergot exudate or water and infected barley heads.

The importance of insects in ergot transmission should be considered not only in relation to the numbers of species collected and observed, but also in relation to the structure of mouth parts and feeding habits. Based upon numbers of insects observed and trapped, species from three orders were initially considered important. In

TABLE II

INSECTS COLLECTED FROM TANGLEFOOT TRAPS AND OBSERVED FEEDING ON ERGOT EXUDATE IN INFECTED HYBRID BARLEY FLORETS

No.	Order	Family	Species	Trapped	Observed
1	Diptera	Calliphoridae	*Calliphora erythrocephala*	+	+
2	Diptera	Calliphoridae	*Calliphora vomitoria*	+	+
3	Diptera	Calliphoridae	*Phormia regina*	+	+
4	Diptera	Calliphoridae	*Lucilia illustris*	+	
5	Diptera	?	Unidentified species	+	+
6	Diptera	Calliphoridae	*Cynomyopsis cadaverina*	+	+
7	Diptera	Sarcophagidae	*Sarcophaga bullata*		+
8	Diptera	Tetanoceratidae	*Tetanocera* sp.	+	+
9	Diptera	Muscidae	*Muscina stabulans*	+	+
10	Diptera	?	Unidentified species	+	
11	Diptera	Anthomyidae	*Hylemya testacea*	+	
12	Diptera	Anthomyidae	*Hylemya cilicrura*	+	+
13	Diptera	Lauxaniidae	*Camptoprosopella* sp.	+	+
14	Diptera	Dolichopididae	*Dolichopus distraetus*	+	
15	Diptera	Sepsidae	*Sepsis punctum*	+	
16	Diptera	Culicidae	*Culex dorsalis*	+	+
17	Diptera	Chloropidae	*Thaumatomyia bistriata*	+	
18	Diptera	Chloropidae	*Oscinis frit*	+	
19	Diptera	?	Unidentified species	+	
20	Diptera	Stratiomyiidae	*Stratiomyia unilimbata*	+	
21	Diptera	Tabanidae	*Chrysophs aestuans*	+	
22	Diptera	Syrphidae	*Eristalis latifrons*	+	
23	Diptera	Syrphidae	*Eristalis tenax*	+	

TABLE II (Continued)

INSECTS COLLECTED FROM TANGLEFOOT TRAPS AND OBSERVED FEEDING ON ERGOT EXUDATE IN INFECTED HYBRID BARLEY FLORETS

No.	Order	Family	Species	Trapped	Observed
24	Diptera	Syrpidae	*Mesogramma marginata*	+	
25	Diptera	Syrpidae	*Syrphus opinator*	+	
26	Diptera	Syrpidae	*Metasyrphus wiedemanni*	+	
27	Diptera	Syrpidae	*Melannostoma pietipes*	+	
28	Neuroptera	Chrysopidae	*Chrysopa* sp.	+	
29	Hymenoptera	Ichneumonidae	Unidentified species	+	
30	Hymenoptera	Vespidae	Unidentified species	+	+
31	Hymenoptera	Vespidae	Unidentified species	+	
32	Coleoptera	Elateridae	*Melanotus fissilis*	+	+
33	Coleoptera	Phalacridae	Unidentified species	+	+
34	Coleoptera	Coccinellidae	*Hippodamia convergens*	+	+
35	Coleoptera	Mordellidae	*Mordellistena pustulata*	+	+
36	Coleoptera	Cleridae	Unidentified species	+	
37	Coleoptera	Cleridae	Unidentified species	+	
38	Coleoptera	Nitidulidae	*Glischrochilus quadrisignatls*		+
39	Coleoptera	Nitidulidae	Unidentified species	+	
40	Hemiptera	Miridae	*Trigonotylus* sp.	+	
41	Hemiptera	Miridae	*Lygus lineolaris*	+	+
42	Homoptera	Cicadellidae	*Macrosteles fascifrons*	+	
43	Homoptera	Aphididae	*Rhopalosiphum maidis*	+	
44	Thysanoptera	Thripidae	*Limothrips denticornis*	+	
45	Lepidoptera	Hesperidae	*Atrytone logan*	+	
46	Lepidoptera	?	Unidentified species	+	

TABLE II (Continued)

INSECTS COLLECTED FROM TANGLEFOOT TRAPS AND OBSERVED FEEDING ON ERGOT EXUDATE IN INFECTED HYBRID BARLEY FLORETS

No.	Order	Family	Species	Trapped	Observed
47	Lepidoptera	Noctuidae	*Pseudoletia unipuncta*	+	+
48	Lepidoptera	Noctuidae	*Leucania multilinea*	+	+
49	Lepidoptera	Noctuidae	*Hypocoena defecta*	+	
50	Lepidoptera	?	Unidentified species	+	
51	Lepidoptera	?	Unidentified species	+	
52	Lepidoptera	?	Unidentified species	+	
53	Lepidoptera	Noctuidae	*Chorizagrotis auxilaris*	+	+
54	Lepidoptera	Noctuidae	*Caenurginia crassiuscula*		+
55	Lepidoptera	Noctuidae	*Heliotropha reniformis*		+
56	Lepidoptera	Noctuidae	*Agrotis ipsilon*		+
57	Lepidoptera	Noctuidae	*Crymodes devastator*		+
58	Lepidoptera	Noctuidae	10 unidentified species		+

order of numerical abundance, they were the lace winged flies or *Chrysopa* sp. (Neuroptera), flies (Diptera) and moths (Lepidoptera). *Chrysopa* sp. were found to feed on ergot exudate by day and night. Although the population of *Chrysopa* sp. was very high, predatory habits of this species appeared to preclude the potential for efficient dissemination of conidia.

Most flies that were associated with ergot exudate had sponging-lapping type mouth parts. Closely observed, none of these flies appeared to extend their proboscises into the barley florets. Among the various species of Diptera observed or collected, there appeared to be no single predominant species (Table II).

Various species of noctuid moths appeared best adapted for transmission of *Claviceps* conidia. Upon approaching barley heads, moths uncoiled their proboscises and moved about searching for exudate. During this process they moved their proboscises from side to side, forward and backward, and probed rapidly into almost all the open florets as they passed along the heads. After finding an infected floret with exudate the moths would settle down and actively feed. They emerged from the brome grass headlands at the onset of darkness and actively fed upon ergot exudate and probed healthy florets until dawn. Most of the moths are the adults of cutworms and army worms which have long been known as serious pests of many economic plants.

In the laboratory moths were observed to feet on ergot exudate, both *in vivo* and *in vitro*. They also located readily dried drops of exudate on leaves of barley. When the head of a moth was approached with a stick dipped in sucrose, it would not respond, but when approached with exudate, it would become agitated, flutter its wings rapidly and immediately uncoil its proboscis and follow the stick as it was withdrawn.

Among all insects observed and collected in this investigation, moths are believed to be the most important disseminators of ergot. The manner, time of feeding and structure of mouth parts of moths appear to be suitable characteristics for dissemination of conidia of the fungus.

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NORTH DAKOTA FLEAS. II. RECORDS FROM MAN AND OTHER MAMMALS

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INTRODUCTION

In an earlier paper, Larson and Peterson (1969) attempted to summarize all published flea records for North Dakota. In the intervening year since that manuscript was submitted, we have found two additional papers which contain North Dakota records. In one of these (Jellison, 1945), the state's distribution of *Oropsylla rupestris* on *Citellus richardsoni* was extended to Barnes, Benson, McHenry, and Pierce Counties. The same flea was also reported from *Citellus* sp. in McHenry County. In the other paper, Johnson and Traub (1954) reported subspecific intergrades between *Peromyscopsylla hesperomys hesperomys* and *P. h. adelpha* taken from *Microtus pennsylvanicus* in Morton County. It thus appears that only 12 species have been reported previously. With this paper that number is increased to 27 with the addition of 15 species.

Although we were initially interested in the fleas of man and his domestic pets, this coverage expanded to include specimens taken from all mammals. Such collected material dates from June 1932 through December 1968. Many of the older specimens were deposited in the University of North Dakota entomology collection by Dr. G. C. Wheeler, Professor Emeritus of Biology. More recent specimens have many contributors, although much of the 1968 material was collected and processed by the senior author.

METHODS

All fleas collected were preserved in 70 per cent ethanol. These, plus the old bottled specimens, were then processed by conventional methods. This involved bleaching for one to several days in 10 per cent potassium hydroxide, followed by dehydration in ethanol, clearing in xylol, and mounting in Canada balsam. A number of old and poorly mounted specimens were also remounted.

All flea slides retained by the Biology Department were transferred from the entomology collection to the University of North Dakota Parasitology Collection with accession numbers. These are the numbers referred to in the body of this paper.

Most of our identifications are based on the descriptions and keys found in Fox (1940), Eping and Fox (1943), Hubbard (1947), and Holland (1949). Of these, the last is by far the most useful for North Dakota fleas.

A number of specimens were identified in the early 1960's by Dr. James Beer, Department of Entomology, Fisheries and Wildlife, University of Minnesota. Several other specimens were examined in March 1969 by Dr. William Jellison, retired medical entomologist at the Rocky Mountain Laboratory, Hamilton, Montana. Under Acknowledgements are noted the accession numbers of the specimens examined by these authorities.

RESULTS AND DISCUSSION

Each of the 15 species of fleas new to North Dakota is considered herein, as are new host and county records for seven of the 12 species previously known from the state. Unfortunately, several species were either identified on the basis of a single specimen, or from several specimens all of the same sex. Neither situation leads to total confidence in the determination of difficult species. All specimens have host and locality records, but a few lack collection dates. The parasites are considered alphabetically by family.

Family Ceratophyllidae

Ceratophyllus garei Roths.

No. 473 from man, Grand Forks Co., 30 May 1949, 1 female.

C. garei must be considered an accidental human parasite since it is a Holarctic species normally associated with ground-nesting birds. Although we have only a single female specimen, Dr. Jellison believes we are correct in our identification. This is a new report for North Dakota.

Foxella ignota (Baker)

No. 138 from cat, Grand Forks Co., October 1932, 1 female; No. 168-169 from *Mustela frenata*, Grand Forks Co., November 1932, 2 males, 2 females; No. 170 from *M. frenata*, Grand Forks Co., 6 December 1933, 1 male, 1 female; No. 191-192 from *Geomys bursarius*, Grand Forks Co., 25 May 1947, 2 males, 2 females; No. 193-194 from *G. bursarius*, Grand Forks Co., October 1963, 2 males; No. 225-226 from *Microtus pennsylvanicus*, Grand Forks Co., 16 April 1965, 1 male, 1 female; No. 227 from *Microtus* sp., Grand Forks Co., 20 September 1965, 1 male, 1 female; No. 228 from *G. bursarius*, Grand Forks Co., 24 September 1965, 1 male; No. 332 from *G. bursarius*, Grand Forks Co., 9 September 1966, 1 female; No. 333-334 from *G. bursarius*, Grand Forks Co., 10 October 1966, 2 males; No. 335-338 from *M. frenata*, McHenry Co., 13 November 1966, 3 males, 5 females.

F. ignota is a polymorphic species split by various authors into 8 or 10 subspecies. One of these, *F. i. albertensis*, appears to range southeastward from the Canadian Rockies into Saskatchewan, Montana, Wyoming and north-central North Dakota, thus accompanying its major host, *Thomomys talpoides*. This flea was reported from McHenry and Ward Counties by Jordan (1937) and Hubbard (1947), respectively. The only other subspecies to extend out of the Rockies into the Great Plains is *F. i. ignota*. It is known from Colorado, Nebraska, Iowa, Minnesota, and Illinois, mainly from the other species of pocket gopher, *Geomys bursarius.* It is noteworthy that in the UND Parasitology Collection we appear to have both subspecies. All specimens from Grand Forks County fit the descriptions for *F. i. ignota.* All those from McHenry County seem to be valid *F. i. albertensis.* We have not had these identifications verified but we believe them to be correct. It would be interesting to see what subspecies span the 150 miles between Grand Forks and McHenry Counies, *i.e.,* do the ranges overlap and do the subspecies hybridize.

Megabothris asio megacolpus (Jordan)

No. 425 from *Microtus pennsylvanicus,* Grand Forks Co., 8 November 1966, 1 female.

This subspecies of flea is well known from small rodents in central and western Canada. Dr. Jellison agrees with our identification as based on a single female. This is a new record for the state and apparently a new extension of the southern range noted in Manitoba by Buckner (1964).

Megabothris quirini (Roths.)

No. 330 from *Zapus hudsonius,* Grand Forks Co., 9 May 1959, 1 female; No. 383 from *Clethrionomys gapperi,* Bottineau Co., date ?, 1 male; No. 384 from *Eutamias minimus borealis,* Bottineau Co., date ?, 1 male; No. 387 from *Microtus pennsylvanicus,* Bottineau Co., date ?, 1 female; No. 390 from *C. gapperi,* Grand Forks Co., 21 October 1967, 1 male.

M. quirini is a common and widely distributed flea on small rodents throughout Canada and the northern portions of the United States. This is the first report from North Dakota, although *Z. hudsonius* from East Grand Forks, Minnesota, was listed as a host (Jordan, 1937).

Monopsyllus eumolpi eumolpi (Roths.)

No. 196 from *Eutamias minimus pallidus,* Slope Co., date ?, 1 male, 1 female.

This exteremely dark flea is typically parasitic on chipmunks of the genus *Eutamias* throughout the host's range. The occurrence of only one record from North Dakota undoubtedly reflects a lack of collecting, rather than a scarcity of the parasite. One of us (O.R.L.) has examined a lengthy series of fleas from *E. minimus* collected in north-central Minnesota, and in that sample *M. e. eumolpi* was found on nearly every chipmunk examined.

Monopsyllus vison (Baker)

No. 474 from *Tamiasciurus hudsonicus,* Grand Forks Co., 26 September 1968, 1 male, 1 female; No. 481-482 from *T. hudsonicus,* Grand Forks Co., 30 October 1968, 2 males, 2 females; No. 502 from *Sciurus* *carolinensis,* Grand Forks Co., 24 November 1968, 1 female; No. 509 from *T. hudsonicus,* Cavalier Co., 14 December 1968, 1 female.

M. vison is a common parasite of red squirrels throughout most of the host's North American range. Infrequently it may also parasitize other squirrels, pikas, and mustelids.

Monopsyllus wagneri (Baker)

No. 427-428 from *Mus musculus,* Divide Co., 20 June 1936, 1 male, 4 females; No. 495-496 from *Peromyscus maniculatus,* Grand Forks Co., 21 November 1965, 1 male, 5 females.

There appear to be two closely related subspecies of *M. wagneri* extending eastward from the Rockies into the prairie states. These are *M. w. wagneri* and *M. w. systaltus.* Both subspecies were reported from deer mice in Nebraska (Rapp and Gates, 1957), and without subspecific designation from various rodents in Illinois (Verts, 1961). However, in Canada, *M. w. systaltus* is said to be the only subspecies east of the Rockies (Holland, 1949). We also believe the North Dakota specimens to be *systaltus,* but this has not been verified. In any event, this species is a new record for the state.

Nosopsyllus fasciatus (Bosc)

No. 388 from "rat", Grand Forks Co., 30 October, 1941, 1 female.

The introduction of *N. fasciatus,* the European rat flea, into North America parallels the arrival of rats from Europe and Asia aboard ships. *Rattus norvegicus* in particular has carried this flea out of the seapors into the interior of the continent. Wherever here are grain storage facilities or garbage dumps, one can expect to find the host and its potentially dangerous flea. *N. fasciatus* is considered an effective vector of plague bacilli.

We are aware of *N. fasciatus* collected within 10 miles of the North Dakota border near Estevan, Saskatchewan, but this is the first report of *N. fasciatus* from the state. It is unfortunate that the species of rat from Grand Forks was not noted by its collector.

Orchopeas caedens (Jordan)

No. 380-382 from *Tamiasciurus hudsonicus,* Grand Forks Co., June 1932. 2 males, 2 females; No. 459 from *Sciurus niger,* Grand Forks Co., 3 February 1968, 2 females; No. 460-472 from *T. hudsonicus,* Grand Forks Co., 2 and 10 March 1968, 9 males. 16 females; No. 489 from *T. hudsonicus,* Grand Forks Co., 18 September 1968, 1 male, 1 female; No. 494 from *T. hudsonicus,* Grand Forks Co., 30 October 1968, 1 male, 1 female; No. 503-505 from *S. carolinensis,* Grand Forks Co., 24 November 1968, 2 males, 4 females; No. 507-508 from *T. hudsonicus,* Cavalier Co., 14 December 1968, 2 males 2 females.

O. caedens along with *Monopsyllus vison* are typically the fleas of red squirrels. *O. caedens* is split into two subspecies, *caedens* and *durus* based on the 7th sternite of females. The subspecific males cannot be separated. We have not attempted to make subspecific identifications although Dr. Jellison considers the two females he examined to be *O. c. caedens.*

Orchopeas leucopus (Baker)

No. 426 from *Citellus tridecemlineatus,* Grand Forks Co., 31 May 1968, 1 female.

This first and only record of *O. leucopus* from North Dakota appears very meager when compared to the incidence in the eastern half of North America. In one study, nearly 69% of the fleas removed from *Peromyscus* in the state of New York where *O. leucopus* (Benton and Altmann, 1964). Although Poorbaugh and Gier (1961) also reported this flea as common on small mammals in Kansas, generally *O. leucopus* becomes somewhat of a rarity west of the 100th meridian (Hubbard, 1947). Whether this parasite is truly scarce in North Dakota cannot be determined until further collections of *Peromyscus* and other small rodents are made.

Oropsylla arctomys (Baker)

No. 340 from *Vulpes vulpes,* Grand Forks Co., 16 September 1961, 1 female; No. 370-378 from *Marmota monax,* Grand Forks Co., 23 May 1968, 3 males, 12 females; No. 488 from *Taxidea taxus,* Ward Co., 15 July 1968, 1 female.

Although a new record for North Dakota, this rather large flea is commonly found on woodchucks throughout the host's North American range. Both red fox and badger have been reported as infrequent hosts for *O. arctomys* in the USA (Fox, 1940) and in Canada (Holland, 1949). Such hosts probably acquire the flea during predation on woodchucks. A range map by Hall and Kelson (1959) indicates that *M. monax* does not reach the central and western portions of North Dakota, hence one might question if badgers could acquire *O. arctomys* from woodchucks in Ward County. The University of North Dakota mammal collection contains a woodchuck taken at Riverdale, some 55 miles due south of Minot. It thus appears that woodchucks (and their fleas) are farther west in the state than is generally known.

Opisocrostis bruneri (Baker)

No. 339 from *Citellus richardsoni,* Dickey Co., 2 July 1932, 1 male, 1 female; No. 341 from *C. tridecemlineatus.* Grand Forks Co., 7 October 1932, 1 male, 1 female; No. 379 from *C. tridecemlineatus,* Grand Forks Co., 7 October 1936, 1 male; No. 385-386 from *Microtus pennsylvanicus.* Bottineau Co., date ?, 1 male, 2 females; No. 389 from man, Grand Forks Co., 1942, 1 male; No. 420-423 from *C. tridecemlineatus,* Grand Forks Co., May 1943, 4 males, 4 females; No. 430 from human dwelling, Grand Forks Co., 5 July 1944. 1 female; No. 431 from human dwelling, Grand Forks Co., 14 September 1948, 1 male; No. 432 from man, Grand Forks Co., 14 July 1949, 1 male; No. 433-434 from *C. richardsoni*, Grand Forks Co., 9 August 1953, 2 males; No. 435-436 from *C. richardsoni*, Grand Forks Co., 15 October 1964, 3 males, 1 female; No. 437 from *Microtus* sp., Grand Forks Co., 10 October 1966, 1 male; No. 439 from *C. tridecemlineatus*, Nelson Co., 28 April 1968, 1 female; No. 441-445 from *C. tridecemlineatus*, Grand Forks Co., 31 May 1968, 5 males, 5 females.

A partial list of recorded localities for *O. bruneri* includes every state and province bordering North Dakota (Holland, 1952). This paper thus constitutes the first report from the state. The parasite's prevalence on *Citellus* is well known, but the North Dakota records from man and his dwellings are disturbingly frequent in view of this flea's potential role as a vector of plague.

Opisocrostis tuberculatus tuberculatus (Baker)

No. 490-492 from *Citellus richardsoni*, Nelson Co., 28 April 1968, 2 males, 3 females; No. 493 from *C. tridecemlineatus*, Nelson Co., 28 April 1968, 1 male.

Thrassis bacchi (Roths.)

No. 137 from *Citellus richardsoni*, Dickey Co., 2 July 1932, 1 male, 1 female; No. 391 from *C. richardsoni*, Grand Forks Co., 8 April 1961, 1 male.

Both *O. t. tuberculatus* and *T. bacchi* are of historical importance in North Dakota since they and two other species (*Opisocrostis labis* and *Oropsylla rupestris*) were incriminated as vectors of sylvatic plague in Divide County (Prince, 1943).

Family Hystrichopsyllidae

Epitedia wenmanni (Roths.)

No. 343 from *Mustela frenata*, McHenry Co., 13 November 1966, 1 male; No. 344 from "squirrel," Grand Forks Co.. 14 January 1967, 1 male.

E. wenmanni spans the continent on a variety of rodents, although *Peromyscus* is considered to be the most typical host. Our two records augment an earlier report of this flea from a North Dakota long-tailed weasel (Jordan, 1937).

Neopsylla inopina (Roths.)

No. 136 from *Citellus tridecemlineatus*, Dickey Co., 2 July 1932, 1 female.

N. inopina closely resembles *Epitedia wenmanni*, but is quite specific to ground squirrels, especially Richardson's. The only previous record of *N. inopina* for the state was from *C. franklini* (Jordan. 1937).

Family Leptopsyllidae

Peromyscopsylla hamifer (Roths.)

No. 342 from *Mustela frenata,* McHenry Co., 13 November 1966, 2 females.

Dr. Jellison has examined these specimens and believes them to be *P. hamifer* ssp. The lack of a visible genal process above the upper genal tooth and the contour of the 7th sternite support this identification. However, the frontal spiniforms on the head are three in number, while descriptions emphasize only two. Also troublesome is the number of antepygidial bristles. There are said to be four on a side in females of the genus, but our specimens possess five. Additional specimens (especially males) from McHenry County might resolve these inconsistencies.

Family Pulicidae

Ctenocephalides canis (Curtis)

No. 345 from dog, Grand Forks Co., 11 January 1941, 1 female; No. 346 from human dwelling, Grand Forks Co., winter of 1947-48, 1 female.

Ctenocephalides felis (Buche)

No. 347 from cat, Grand Forks Co., 9 December 1937, 1 female; No. 348 from man, Grand Forks Co., July 1941, 1 female; No. 349-352 from man, Grand Forks Co., 1942, 2 males, 2 females; No. 353 from dog, Grand Forks Co., 23 December 1944, 1 male, 1 female; No. 354 from human dwelling, McLean Co., November 1951, 1 male, 1 female; No. 355 from dog, Grand Forks Co., 25 July 1953, 1 female; No. 356 from cat, Grand Forks Co., 5 January 1965, 1 male; No. 357 from cat, Grand Forks Co., 15 November 1965, 2 females; No. 497-501 from cat, Grand Forks Co., 15 November 1968, 5 females.

Although we suspect that North Dakota veterinarians and pet owners have many times seen dog and cat fleas, apparently neither parasite has been reported from the state. A rounded head plus a short first genal tooth easily separates *C. canis* from *C. felis.* Typical cat fleas have a longer, pointed head, with the first genal tooth nearly as long as the second. However, the 10-20% of *Ctenocephalides* which are atypical constitute a problem for the taxonomist. Such interspecific morphology suggests hybridization between the two species.

Based on host distribution presented in this and other surveys, there appears to be little host specificity. One is as apt to find cat fleas on dogs as *C. canis* on dogs. Man can also be a frequent and suitable host for both species when his pets are infested.

Hoplopsyllus affinis (Baker)

No. 506 from *Sylvilagus floridanus,* McHenry Co., 3 July 1968, 1 female; No. 510-520 from *S. floridanus*, McHenry Co., 9-11 July 1968, 10 males. 11 females; No. 526 from *S. floridanus*, Ward Co., 17 July 1968, 2 females.

H. affinis is a common flea on hares and rabbits in the Rocky Mountains and midwestern prairies. This is the first report of *H. affinis* from North Dakota cottontails, although Voth and James (1966) found this flea on white-tailed jackrabbits in an area mostly within Slope and Bowman Counties.

Pulex irritans Linn.

No. 190 from *Vulpes vulpes*, Grand Forks Co., 16 September 1961, 1 male, 1 female; No. 195 from "jackrabbit." Ward Co., 30 December 1963, 1 male; No. 359-360 from dog, Nelson Co., 7 April 1968, 2 females; No. 575 from *Taxidea taxus*, Mountrail Co., 14 July 1968, 1 female; No. 576 from *T. taxus*, Ward Co., 15 July 1968, 1 female; No. 577 from *T. taxus*, McLean Co., 28 July 1968, 2 males; No. 578 from *T. taxus*, Ward Co., 29 July 1968, 1 male, 1 female; No. 595-596 from *V. vulpes*, Nelson Co., 9 August 1968, 2 males, 2 females.

P. irritans, the "human flea" has a Holarctic distribution. Although Smit (1958) argued for the restoration of *P. simulans* as a valid and distinct species from *P. irritans*, we are less than convinced. When compared with Smit's illustrations of the male genitalia, most of our specimens are distinctly *irritans*, with a few showing morphologies weakly tending toward *simulans*.

With one exception (*Oropsylla arctomys*), *P. irritans* is the only species of flea we have from North Dakota badgers. Since *P. irritans* is commonly found on prairie-dogs, this may be a prey-predator type of dispersal. The human flea was reported previously from white-tailed jackrabbits in the extreme southwestern portion of the state (Voth and James, 1966).

Family Vermipsyllidae

Chaetopsylla lotoris (Stewart)

No. 479-480 from *Procyon lotor*, Grand Forks Co., 30 October 1968, 2 males, 2 females.

C. lotoris is considered a true parasite of raccoons, although it is not uncommon on the grey fox. On either host the distribution is sparse, erratic, and generally restricted to the eastern half of North America. This is the first report of *C. lotoris* in the state and one of the more westward records in the continent.

SUMMARY

This paper presents new information on the host and geographic distribution of 22 species of North Dakota fleas, 15 of which were previously unknown from the state. Verified records are now known from 17 of the state's counties, but much survey work remains to be

done. As yet, whole groups such as bats and birds await examination. In addition, there are interesting aspects of host and flea biogeography and potential hybridization of overlapping taxa which deserve future study.

ACKNOWLEDGMENTS

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THE FLUID FLOW PATTERNS NEAR A ROTATIONAL OSCILLATING CYLINDER

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INTRODUCTION

In recent years many fields have been confronted with the problems of heat transfer in an oscillating flow. It can be observed in the nuclear rocket or other similar combustion devices. The main idea in such cases is to control the heat transfer rate. Much experimental work has been done in this area but only limited analytical results are available. It is then important to obtain the velocity distribution near a solid boundary. The purpose of this paper is to to find the steady-state velocity profiles near an oscillating circular cylinder. Since the flow is incompressible, it is immaterial whether the cylinder oscillates in a stagnant fluid or the cylinder is fixed while the fluid oscillates. Graphical representation is made to illustrate the nature of the velocity profiles. As the dimensionless radius of the cylinder is increased to infinity, the velocity profiles should become identical to those obtained by G. G. Stokes (1) for the flow near an oscillating flat plate. It is also well known as Stokes' 2nd problem. This comparison is shown graphically. The transient component in the solution is not given more consideration in this paper since its effect is up to the first half-cycle of oscillation. Hence, this transient component plays a less important role in the total solution. This work is applicable in some of the problems concerning the free convective heat transfer area. Also, with the help of information on the depth of penetration and the boundary layer thickness, the viscosity of the fluid can be estimated.

MATHEMATICAL FORMULATION

Consider a single cylinder, infinite in length and placed in an infinite fluid, oscillating in the form of a cosine function along an axis perpendicular to its generators. The fluid velocity must satisfy the following dimensionless diffusion equation. It is presented in the cylindrical coordinates as

$$\frac{\delta \theta}{\delta \Lambda} = \frac{\delta^2 \theta}{\delta \eta^2} + \frac{1}{\eta} \cdot \frac{\delta \theta}{\delta \eta} - \frac{\theta}{\eta^2} \qquad (1)$$

The initial and boundary conditions are

$$\theta(\eta, 0) = 0 \qquad (2)$$

$$\theta(\eta_1, \Lambda) = \cos \Lambda, \quad \Lambda > 0 \qquad (3)$$

$$\theta(\infty, \Lambda) = 0 \qquad (4)$$

where

$$\theta = \frac{U}{U_0}, \qquad \eta = r\left(\frac{\omega}{\lambda}\right)^{1/2}, \qquad \Lambda = \omega t$$

To obtain a steady-state solution for the above differential equation the method of the complex variable introduced by Arpaci (2) is used. First, the supplementary differential system would be constructed and then multiplied by an imaginary number i. The resulting system is added to the original system described by Eq. (1) and Eq. (4). The complex differential system thus obtained can be shown as

$$\frac{\delta \psi}{\delta \Lambda} = \frac{\delta^2 \psi}{\delta \eta^2} + \frac{1}{\eta} \frac{\delta \psi}{\delta \eta} - \frac{\psi}{\eta^2} \qquad (5)$$

$$\psi(\eta, 0) = 0 \qquad (6)$$

$$\psi(\eta_1, \Lambda) = e^{i\Lambda} \qquad (7)$$

$$\psi(\infty, 0) = 0 \qquad (8)$$

It should be pointed out the supplementary system would represent the case in which the cylinder oscillates in the form of a sine function. Let the solution of Eq. (5) be

$$\psi(\eta,\Lambda) = \phi(\eta)e^{i\Lambda} \quad (9)$$

Introducting Eq. (9) into the complex differential system would lead to

$$\eta^2\frac{d^2\phi}{d\eta^2} + \eta\frac{d\phi}{d\eta} - (i\eta^2 + 1)\phi = 0 \quad (10)$$

$$\phi(\eta_1,\Lambda) = 1 \quad (11)$$

$$\phi(\infty,\Lambda) = 0 \quad (12)$$

The solution of the above differential system, after McLachlan (5), described by Eq. (10), Eq. (11) and Eq. (12) can be shown as

$$\phi(n) = A + iB \quad (13)$$

where

$$A = \frac{Kei_1(n)\ Kei_1(n_1) + Ker_1(n)\ Ker_1(n_1)}{Kei_1^2(n_1) + Ker_1^2(n_1)}$$

$$B = \frac{Kei_1(n)\ Ker_1(n_1) - Ker_1(n)\ Kei_1(n_1)}{Kei_1^2(n_1) + Ker_1^2(n_1)}$$

Putting Eq. (13) into Eq. (9) yields

$$\psi(\eta,\Lambda) = a\cos(\Lambda+\beta) + i\,a\sin(\Lambda+\beta) \quad (14)$$

where

$$a = (A^2+B^2)^{1/2} \quad (15)$$

$$\beta = \arctan(B/A) \quad (16)$$

The real part of Eq. (14) represents the steady-state solution for the case in which the cylinder oscillates in the form of a cosine function. The imaginary part of Eq. (14) would represent the steady-state solution for the case in which the cylinder oscillates in the form of a sine function. It is seen that the amplitude of oscillations, a, and the phase angle, β, do not depend on the type of oscillatory function imposed at the surface of the cylinder. The detailed deviation of Eq. (14) could be seen in Marfatia (3).

RESULTS

Numerical calculations have been carried out with the help of the computer IBM 360/50. To facilitate the discussion later, some of the results are presented in Figures 1 to 4. Figure 1 indicates the velocity profiles generated by the oscillating cylinder at the various moments.

It is seen that the steady-state velocities at the surface of the cylinder remain the same as the oscillations of the cylinder. Figure 2 represents the effect of the dimensionless radius of the cylinder on the steady-state velocity profiles. As the dimensionless radius of the cylinder increases, the velocity profiles would become identical to

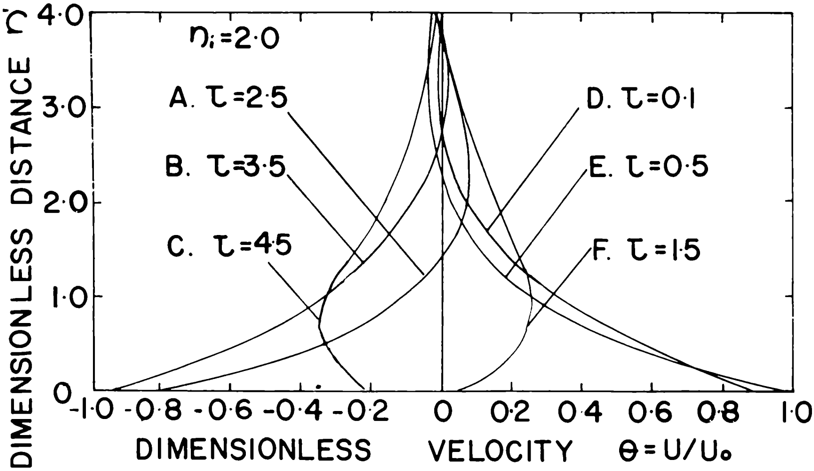

FIGURE 1—The steady-state velocity profiles for the case when the cylinder oscillates in the form of cos τ.

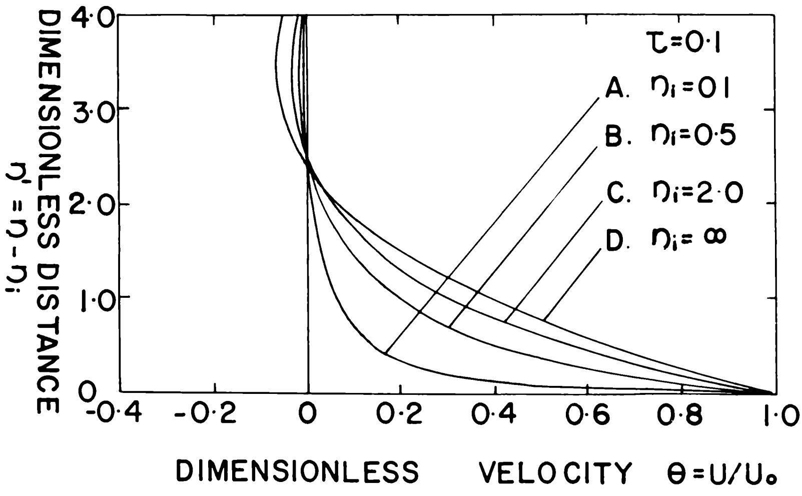

FIGURE 2—The effect of the dimensionless radius of the cylinder on the steady-state velocity profiles.

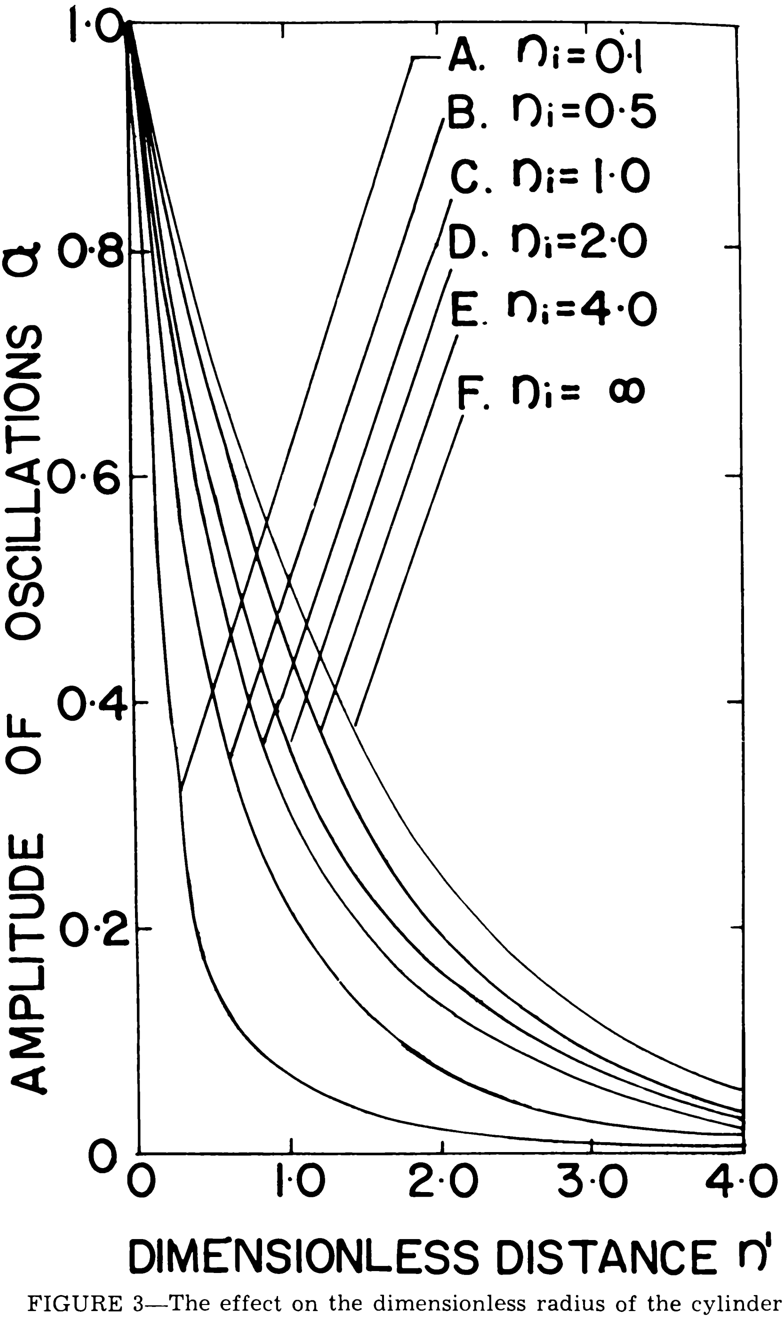

FIGURE 3—The effect on the dimensionless radius of the cylinder on the amplitude of oscillations, a.

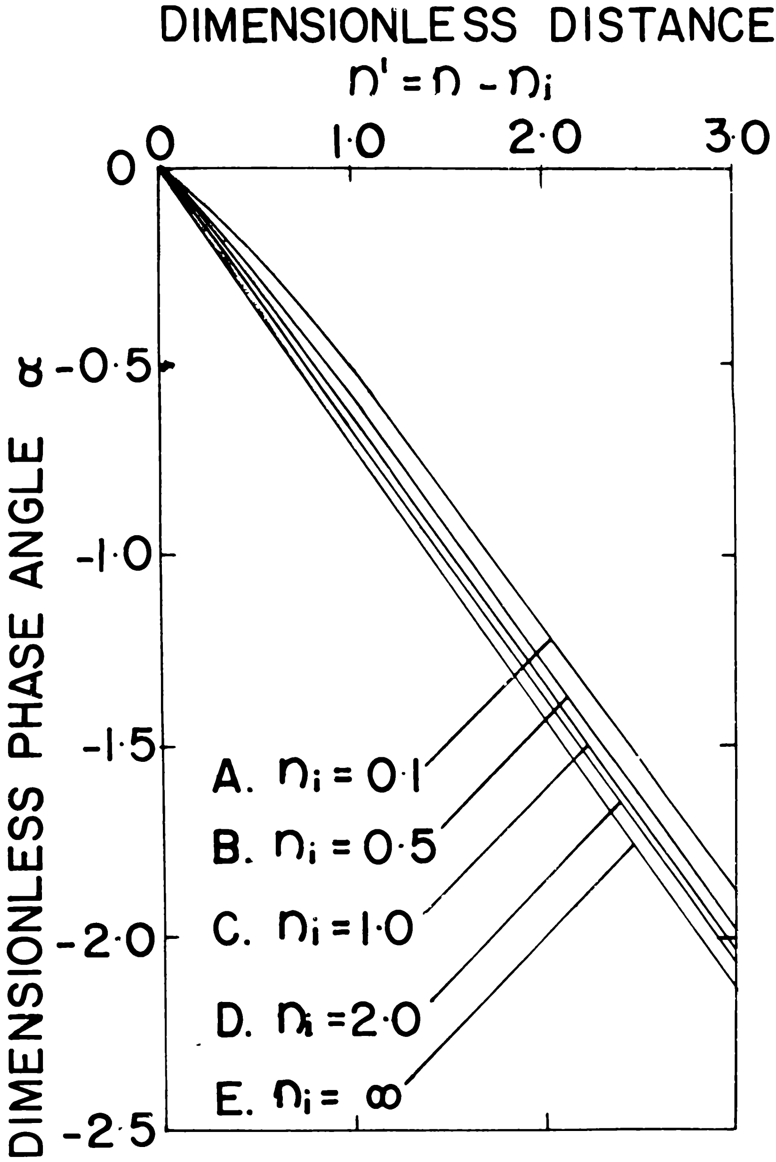

FIGURE 4—The effect of the dimensionless radius of the cylinder on the phase angle, α.

those in Stokes' 2nd problem as it is expected. The amplitude of oscillations, a, and the phase angle, β, are plotted in Figures 3 and 4, respectively. Here also, the effect of dimensionless radius of the cylinder is studied. As the dimensionless radius of the cylinder increases, the amplitude of oscillations and the phase angle approach those obtained in Stokes' 2nd problem. Similar observations could be made for the case in which the cylinder oscillates in the form of a sine function.

The distance between two fluid layers oscillating in the same phase is known as the depth of penetration. It can be regarded as a kind of wave length of the viscous wave motion. As the period of oscillation is 2π, the depth of penetration could be obtained from the relation

$$\beta = 2\pi \tag{17}$$

Making use of Eq. (16) into Eq. (17) and arranging it algebraically, it would lead to

$$r_a = c \left(\frac{\omega}{\lambda} \right)^{1/2}$$

where the term c would depend on the dimensionless radius of the cylinder, n_1. It should be pointed out that to find the term c for the different large values of n_1, the computer time required is quite large. It was observed that as the dimensionless radius of the cylinder increased, term c approached that obtained in Stokes' 2nd problem. This value found was approximately equal to 8.89.

It is obvious the boundary layer would form at the surface of the oscillating cylinder due to the influence of viscosity. In this thin layer the velocity of the fluid decreases asymptotically from the maximum value at the surface of the cylinder to zero. The depth of this thin layer is defined as the thickness of the boundary layer. The approximate value of this boundary layer can be found by equating Eq. (14) to 0.01. That is

$$a \cos (\Lambda + \beta) = 0.01 \tag{18}$$

Making use of Eq. (15) and Eq. (16) into Eq. (18) and arranging it algebraically would yield

$$r_t = \text{constant} \left(\frac{\lambda}{\omega} \right)^{1/2}$$

It is seen that the thickness of the boundary layer depends on the kinematic viscosity and the frequency of oscillations. It decreases with the decreasing kinematic viscosity and increasing frequency.

DISCUSSION

In this paper the steady-state velocity profiles for the flow near an oscillating cylinder are obtained by the method of complex variable. The method of complex variable can be easily applied also in determining the velocity profiles for the flow between two concentric oscillating cylinders. The problem considered in the paper was also solved by the technique of Laplace transformation (3). The results obtained were identical to those mentioned in this paper.

The fact that the initial condition was not saitsfied by the steady-state solution indicates the transient solution must be added. The transient effect is negligible for the case when the cylinder oscillates in the form of a cosine function since it dies out within the first half cycle of the oscillations. The same phenomenon could be observed for the case when the cylinder oscillates in the form of a sine function. for the same reason the transient solution was not included in this paper. Those interested in the transient solution are referred to Marfatia's work (3). Panton (4) obtained he transient solution in closed form for Stokes' 2nd problem. He also found the transient solution would die out within the first cycle of oscillations.

Because of the linearity of the differential system, the method of complex variable can also be used with the help of the superposition technique in determining the velocity profiles when the oscillations of the cylinder are in the form of some other function rather than the sine or cosine function. The function for the oscillation of the cylinder is expressed by the Fourier Series. Corresponding to each term in the Fourier Series, there is one oscillating differential sub-system similar to the one solved in this paper. The solution for the system considered is the sum of solutions for these sub-systems.

LIST OF NOMENCLATURE

Symbol	Description	Units
U	The velocity of the fluid	LT^{-1}
U_o	The maximum velocity of the fluid at the surface of the cylinder	LT^{-1}
θ	The dimensionless velocity of the fluid	
ψ	The dimensionless complex velocity	
r	The radial distance	L
r_a	The depth of penetration	L
r_t	The thickness of boundary layer	L
n	The dimensionless radial distance	
r_1	The radius of the cylinder	L
n_1	The dimensionless radius of the cylinder	
t	Time of oscillation	T
Λ	The dimensionless time	
ω	Frequency of oscillations	T^{-1}
a	Amplitude of oscillations	
β	Phase angle	

λ	Kinematic viscosity of the fluid	L^2T^{-1}
$Kei_1(n)$	Kelvin imaginary function of the first order with the argument n	
$Ker_1(n)$	Kelvin real function of the first order with the argument n	

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TEMPERATURE RESPONSES IN A RADIATIVE AND CONVECTIVE CYLINDER

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INTRODUCTION

Numerous studies of the transient heat conduction in a solid body have appeared in the literature. The motivation for this effect is apparent when one considers the usefulness of these studies in areas such as auxiliary power systems for satellites or space vehicles, design of nuclear reactors and cryogenics. As indicated in the survey (1), the boundary condition usually taken in these investigations is either convective or radiative. In other words, is is assumed that the solid body would lose heat to its environment either by convective heat transfer or by radiative heat transfer at its surface. The most recent work in this area was done by Ayers (2). Ayers calculated the temperature responses in a cylindrical body which, initially at a uniform temperature, loses heat to its environment by radiative heat transfer at the surface. It is believed that the convective heat loss from the surface is significant and would affect temperature responses. Therefore, this paper is intended to present the numerical results for the temperature responses in a cylindrical body. This body is assumed to lose heat to its environment both by convection and radiation at the surface. It is hoped the results presented here are more accurate than previous results.

MATHEMATICAL METHOD

The solid body to be considered is an infinitely long cylinder which, initially at a uniform temperature, is exposed to the environment at a lower temperature. This cylinder would lose heat in the radial direction to the environment both by convective and radiative heat transfer at the surface. The governing equation for one-dimensional transient heat conduction can be expressed in the cylindrical coordinates as

$$\frac{\delta^2 t}{\delta r^2} + \frac{1}{r}\frac{\delta t}{\delta r} = \frac{1}{\alpha}\frac{\delta t}{\delta \Lambda} \tag{1}$$

with the initial and boundary conditions, respectively, as

$$t(r,0) = t_{ii} \,, \qquad 0 \leq r \leq R \tag{2}$$

$$\frac{\delta t(0,\Lambda)}{\delta r} = 0 \tag{3}$$

$$-K\,\frac{\delta t(R,\Lambda)}{\delta r} = \lambda F(t_R^4 - t_S^4) + h(t_R - t_e) \tag{4}$$

The above differential system is based upon the assumption that the material of the cylindrical body is homogeneous and opaque, it contains no heat source or heat sink, and the thermal properties of material are independent of the temperature. To calculate the temperature responses in this cylindrical body the method of finite difference is used.

First, the cylinder is divided into concentric, cylindrical shells and each shell is assumed to be isothermal at any moment. Let the thickness of the typical shell be Δr and the thickness of the shell at the center and the surface of the cylinder be $\Delta r/2$. To obtain the equation of finite difference for the typical interior shell, say the shell i, the first derivative, the second derivative and the time derivative could be approximated, respectively, as

$$\left(\frac{\delta t}{\delta r}\right)_i = \frac{t_{i+1} - t_{i-1}}{2\Delta r} \tag{5}$$

$$\left(\frac{\delta^2 t}{\delta r^2}\right)_i = \frac{t_{i+1} + t_{i-1} - 2t_i}{\Delta r^2} \tag{6}$$

$$\left(\frac{\delta t}{\delta \Lambda}\right)_i = \frac{t'_i - t_i}{\Delta \Lambda} \tag{7}$$

Substituting these equations into Eq. (1) and rearranging it, one could easily obtain the equation of finite difference in the dimensionless form as

$$T'_i = T_i + (N\text{-}1)^2 N_f \left[T_{i+1} + T_{i-1} - 2T_i + \frac{\Delta r}{2r_i}(T_{i+1} - T_{i-1})\right] \tag{8}$$

To obtain the equation of finite difference for the shell at the surface of the cylinder, the heat balance should be taken on that shell. It gives

$$T'_N = T_N + \frac{2(N\text{-}1)N_f}{\left[1 - \frac{1}{4(N\text{-}1)}\right]}\left[(N\text{-}1)\left(1 - \frac{1}{2(N\text{-}1)}\right)(T_{N-1} - T_N) + N_c(T_e - T_N) + \frac{1}{N_R}(T^4_S - T^4_N) \right] \tag{9}$$

Similarly, the heat balance on the shell at the center of the cylinder would lead to

$$T'_1 = T_1 + 2N_f(N\text{-}1)^2(T_2 - T_1) \tag{10}$$

Eq. (8), Eq. (9) and Eq. (10) are the equations of finite difference for the differential system in consideration. It is seen that the "Future" temperature in the typical shell would depend on the "Present" temperatures at the same shell as well as the neighboring shells. On the outer shell, the "Future" temperature would also depend on the present temperatures on that shell and the neighboring shells. In addition, this temperature on the dimensionless convective parameter, N_c, the dimensionless radiative parameter, N_R, the dimentionless environment temperature, T_e, and the dimensionless sink temperature, T_S.

RESULTS

The numerical calculations have been carried out through the computer IBM 360/50. The temperature responses in three different locations (the center, the midpoint of radius and the surface of the cylinder) are presented here. They are shown in Figures 1 to 6. The first three figures indicate the effect of the dimensionless convective parameter, N_c, on the temperature responses. As this parameter approaches zero, the heat loss due to convection at the surface would become negligible as compared with the heat loss due to radiation. It is found that the results in this limiting case are identical to those obtained by Ayers (2). The last three figures would indicate the effect of the dimensionless radiative parameter, N_R, on the temperature responses. As this parameter approaches an infinity, physically it means the cylindrical body in consideration would lose heat only by

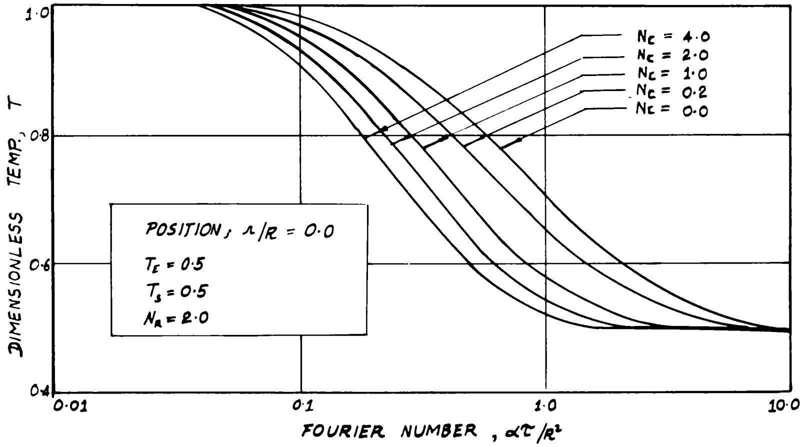

FIGURE 1—Temperature responses of a radiating and convecting cylinder (position r/R=0.0).

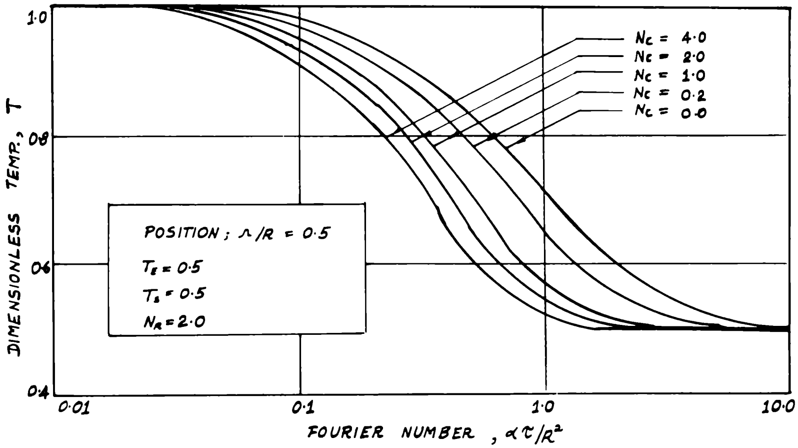

FIGURE 2—Temperature responses of a radiating and convecting cylinder (position r/R=0.5).

the convective heat transfer at the surface. In this limiting case the results presented here are also in good agreement with those available in the literature (3). Other results in these numerical calculations were determined by Munshi (1).

DISCUSSION

It should be pointed out that the sink temperature of the environment to which the heat from the cylindrical body would be radiated is generally different from the temperature in the environment. In fact, the sink temperature would depend on the geometrical conditions between the solid body in consideration and other nearby bodies. In addition, the sink temperature also depends on the surface emissivity, the temperature in the environment and some other factors. The equality of these two temperatures taken here is just an arbitrary choice. In the calculations done for this study, the number of shells was also arbitrarily chosen as 21. The truncation error thus involved has been found and is less than five percent. For the present investigation the stability analysis has also been made. The stability criteria which must be satisfied could be expressed as

$$N_f \leqq 0.5(N-1)^{-1} \left[(N-1) + N_C + \frac{1}{N_R} \right]^{-1} \qquad (11)$$

This equation indicates that the value of the time interval, $\Delta\tau$ (which is contained in the term of N_f), is related to the number of shells taken for the calculation. In other words, the more shells that are taken, the smaller the time interval, $\Delta\tau$, will be and the longer computer time it will take for calculations. Once the number of shells is chosen, the time interval, $\Delta\tau$, must be determined according to

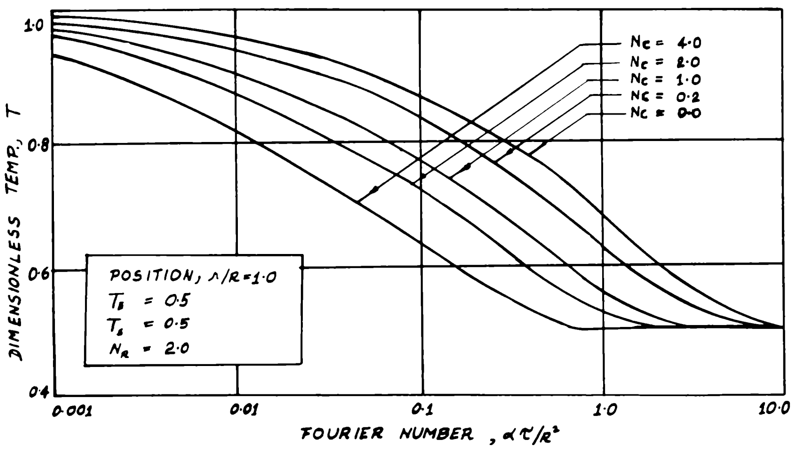

FIGURE 3—Temperature responses of a radiating and convecting cylinder (position r/R=1.0).

Eq. (11). The details of derivation for Eq. (11) are available in Munshi (1).

The present study indicates that when the internal thermal resistence in the solid body is negligible as compared to the surface thermal resistance, the temperatures responses do not depend on the spatial coordinates. In other words, the temperature change of the

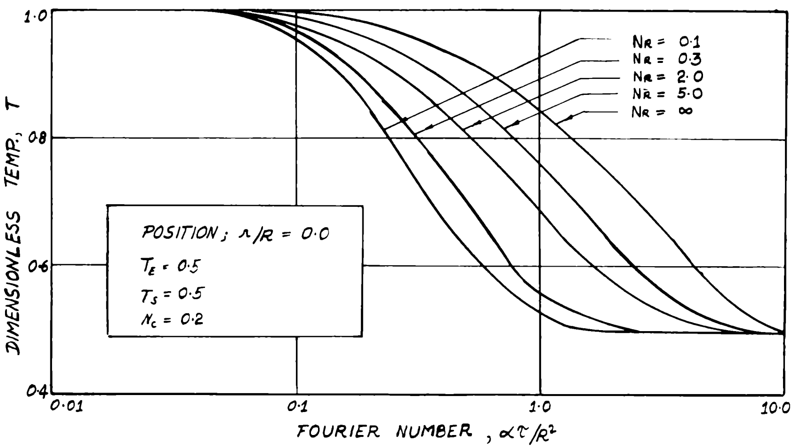

FIGURE 4—Temperature responses of a radiating and convecting cylinder (position r/R=0.0).

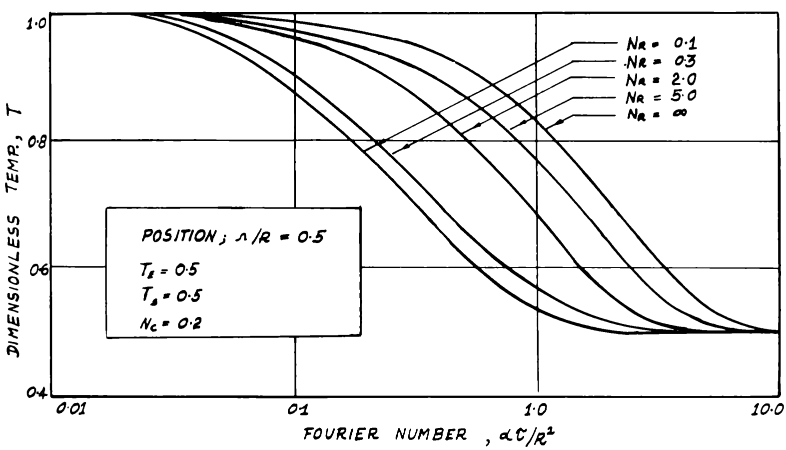

FIGURE 5—Temperature responses of a radiating and convecting cylinder (position r/R=0.5).

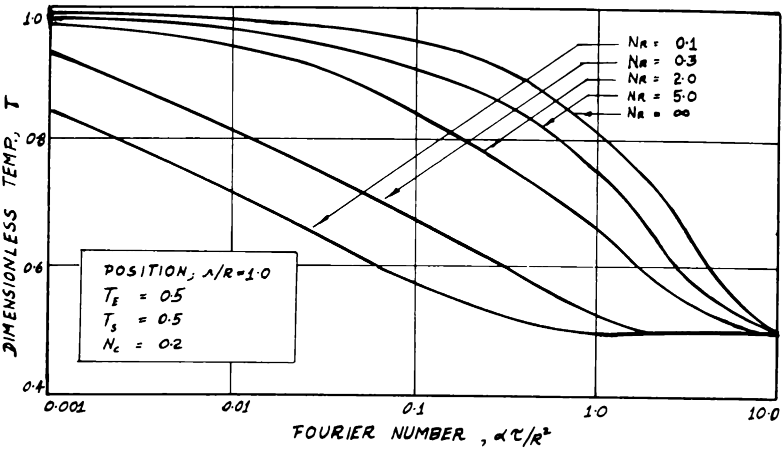

FIGURE 6—Temperature responses of a radiating and convecting cylinder (position r/R=1.0).

body is a function of the time variable only. It has been found that the lumped formulation could be taken without causing more than a five percent error.

The inclusion of radiative and convective losses into consideration is of obvious importance. At the presence of temperature difference between the solid body and its environment these two losses would exist simultaneously. However, in some special cases in which the temperature of solid body is much higher than the temperature in its environment, the convective loss would be very small as compared with the radiative loss and thus can be neglected in calculation. Similarily, in the cases in which the temperature of solid body is not much higher than the temperature in the environment, the radiative loss would be then small as compared with the convective loss and therefore can be neglected. In the present investigation both heat losses were taken into consideration.

In summary, the method of finite difference presented here is quite useful in solving the transient heat conduction problems with the radiative and convective boundary conditions. The results obtained in this present study should be more accurate than the previous ones because both radiation and convection losses are taken into consideration at the same time. Even though attention is only given to the cylinder-shaped body in this paper, the method used here is still applicable in cases involving the bodies of irregular shapes.

LIST OF NOMENCLATURE

F = Radiation interchange factor
h = Convective heat transfer coefficient
K = Thermal conductivity
N = Number of shells
N_C = Dimensionless convective parameter and defined by hR/K
N_t = Dimensionless time variable and defined by $\frac{\alpha\Delta\Lambda}{R^2}$
N_R = Dimensionless radiative parameter and defined by K/λF T_{ij}R
r = Radial distance
R = Radius of cylinder
t = Temperature
t_e = Temperature in the environment
t_R = Temperature at the surface of cylinder
t_S = Radiative sink temperature in the environment
t_{ij} = Initial temperature of the cylinder
t' = Future temperature
T = Dimensionless temperature and defined by t/t_{ij}
T_e = Dimensionless temperature in the environment and defined by t_e/t_{ij}
T_R = Dimensionless temperature at the surface of cylinder and defined by t_R/t_{ij}
T_S = Dimensionless radiative sink temperature and defined by t_S/t_{ij}
T' = Dimensionless future temperature and defined by t'/t_{ij}
α = Thermal diffusivity
λ = Stefan - Boltzmann's constant
Λ = Time variable

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EVOLUTION OF CAVES IN BADLAND DEBRIS

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ABSTRACT

Caves with chambers up to 200 feet in length, 50 feet in width, and 25 feet in height can be observed in most badland areas. Many caves, located in gully bottoms, have two or more distinct levels, separated by mudstone debris. Mass movements of claystone from oversteepened valley walls first fill gully floors. Rain then forms an impermeable seal on the surface of the loose debris. After drying this seal forms an adobe crust. Additional claystone is washed down from adjacent valley walls thickening the cover. Water percolates through the debris, frequently along bedrock-debris contacts. Unsupported loose material collapses into these pipes and is washed away, leaving a large chamber. Channel meandering may further exlarge the chamber. Repeated mass movements may bury an existing adobe roof. If a pipe, possibly originating from a blocked tributary, can form through the fresh material, a second higher level may be formed.

INTRODUCTION

Badlands, although striking topographic features, have received surprisingly little serious geomorphic study. The most extensive publication on badland topography (Schumm, 1956) dealt mainly with artificial fill undergoing erosion in the humid climate of Perth Amboy, New Jersey. Other geomorphologists have largely selected well known badland areas of easy accessibility, as in national monuments. Vertebrate paleontologists have done considerable work in significant fossil localities and on stratigraphic problems; however, they have seldom commented on the landforms.

The badland surfaces generally have a mantle of debris ranging from a few inches to many feet in thickness covering the bedrock. The surface crust of this mantle is composed of a baked adobe which when dry often contains desiccation cracks. Where the montmorillonite content is high the surface has a "bread crumb" appearance. When wetted, the clays composing the mudstone swell, closing the cracks and forming an impermeable seal. Drying of these clays results in the hard adobe crust and the surface cracking.

Mass movements along the narrow valleys are common, especially when the mudstones become saturated for some reason (e.g., repeated freeze-thaw conditions and melting of snow may greatly increase water penetration). Some scars along the valley walls indicate recent slides. The best evidence of the frequency of the slides is found in the numerous debris piles appearing to block the narrow valleys. Major channels in many badland regions, unlike their tributaries, are U-shaped, perhaps having been backfilled since their original cutting.

Hypotheses for the origin of the flat floored or U-shaped valleys have been discussed by Rubey (1928, p. 417). "Fenneman (1922) concluded that gullies and 'draws' with this shape are caused primarily by the predominance of the action of percolating water over that of run-off. He suggested that percolating water undercuts or saps at the base of the gully walls and thus causes them to retreat as nearly vertical scarps. Evans (1927) regarded this sapping as only a secondary process and lateral cutting during rare floods as the most important factor in maintaining the level valley floor. Davis (1927, p. 272) considered the plains as simply normal stream channels that are exposed by the prevailing low water stage."

Rubey found numerous depressions or sinks associated with flat floored valleys. Trying to relate the depressions to the U-shaped valleys he developed a hypothesis of gully formation by *ground sinking* (p. 421). "Some . . . process of washing out of material seems . . . the best explanation of the elliptical depressions and perhaps of the vertical scarps also. In loose sandy soils with a low water table and in soils deeply cracked by repeated droughts, percolating water would carry with it the finer clay and silt particles and eventually develop small passageways. Miniature tunnels would form just below the temporary ground water level of the rainy season and, once started the effects would be cumulative. As these small passageways grew, more vigorous subterranean erosion and transportation would be possible. Subsidence of the roofs over the tunnels would develop surface depressions which would concentrate rain water and intensify percolation and erosion. Loose wet soil would gradually move in from both sides to fill the tunnels and the ground would sink, perhaps as a flat gully floor. That is, the soil would creep toward the middle of the gullies to fill the tunnels, thus causing the sod at the margins of the moving mass to crack and the ground inside the marginal cracks might sink evenly. In turn, cracks formed by soil creep would localize percolation and thus start new tunneling."

Buckham and Cockfield (1950, p. 139) proposed that "the silts have a certain amount of permeability, apparently quite variable from place to place. Water, at times of spring melting and after infrequent storms, percolates into the silts and travels downward until it reaches a temporary water table, where it travels more nearly horizontally until it reaches a point on the gully wall or otherwise returns to the ground surface at a lower level. This forms a body of saturated silt; from the lower end of which water carrying silt emerges. Commonly a block of silt suddenly slides out, and a tunnel is formed running back into the silt body. It appears that a "free face" of some sort is necessary to initiate the process. Of course, once the underground passageway has formed it itself provides a free face throughout its length."

"We have, then, the surface water tending to disappear underground and travel some distance below the land surface, at first dropping steeply and then travelling more nearly horizontally. At a free face, blocks of saturated silt drop out forming the beginning of underground channels which rapidly work their way inward from the point where the water discharges from the back or steep gully face. Once a passageway is opened up, water flows through it as a stream, much more freely than when it was percolating through the silt. The silt, because of its extremely fine grained character, is readily carried in suspension by the stream. The stream greatly increases the rate of erosion and the underground channel is thus enlarged until the roof can no longer support the load and parts of it fall in. There are thus formed one or more funnel shaped depressions, which in turn serve to collect more water from the surrounding area and pass it into the underground system. As the process continues the rims between adjacent sink-holes collapse, thus forming a continuous gully."

The Madden, Wyoming, area was visited in this study and "ground sinking" or "pseudo-karst" (Parker *et al.*, 1964, p. 393) was prevalent. Unlike the areas in which Rubey (1928) and Buckham and Cockfield (1950) worked, the "caves" in the Madden area were of sufficient size to permit easy human entrance and observation. Several of these caves are described below with reference to their origin and future development.

DESCRIPTION OF STUDY AREA

The Madden area is a fourth order drainage basin (contour crenulations on the 1:24,000 Madden, Wyoming, topographic sheet are considered first order channels) located about four miles southwest of the Madden station on the Chicago, Burlington, and Quincy Railroad and about three miles north of U.S. highway 20-26 in the NE¼NE¼ Sec. 15, T. 37N., R. 90W. Access is from the Humble Oil Frenchie Draw Unit #2.

The north scarp in the Madden area is approximately two and one half miles long and about 350 feet high. From the foot of the scarp streams extend across a dissected pediment surface to Alkali Creek some 200 feet lower and three miles to the north. The scarp is on the north face of an inselberg carved in the Wind River Formation with a width of approximately one mile. The south-facing scarp of the inselberg is only about 100 feet in height, with what appears to be a southward-sloping pediment surface at its foot leading to Poison Creek and Merrian Meadows three miles to the south. All faces of the inselberg form badlands; however, those on the north are most pronounced. Caves or pipes are abundant on the north, but rare on the other faces, where relief is less.

Except for alluvial deposits the entire region is underlain by the nearly horizontal beds of the Early Eocene Wind River Formation which here is several thousand feet thick (Thompson and White, 1952, p. 8). The upper 150 feet in the sampling unit contain the typical red banded mudstones of the Wind River Formation while the lower 200 feet of the scarp are cut in light gray to greenish gray tuffaceous, mudstones interbedded with discontinuous siltstone and yellow-orange sandstone lenses.

The north face of the inselberg is cut by numerous U- and V-shaped valleys. The walls of these valleys can become vertical with the sandstone ledges supporting the cliffs. Cliffs of 100 feet or more are common along many of the valleys.

THE CAVES

The two major types of caves observed were the meander-type and the gully type. They apparently differ more in form than in origin. Meander type caves, formed along the sides of the U-shaped valleys, are relatively rare in the sampling unit. The caves are found behind what appears to be steep talus cones at the foot of cliffs with vertical elevations of 50 to 100 feet.

The maximum dimensions of the largest observed cave of the meander type are 80 feet in length, 30 feet in width, and 20 feet in height. Of the 30-foot width some 20 feet were cut into bedrock.

Undercutting in the bedrock indicates that the cave is migrating downstream behind the talus debris. Upstream, short abandoned passages at two higher levels indicate that the cave has existed for some time and has migrated downstream to its present position as badland dissection of the scarp proceeded.

At present there are four openings to this largest meander cave providing adequate lighting of the main chamber. These openings are the swallow hole, the downstream channel exit, and two windows or sinks in the talus roof. Each of these is large enough to permit human entrance. The two windows probably started as small holes adjacent to the bedrock-adobe contact and have been enlarged by repeated rainwash. A few small rills will further widen the window. Thus the cave apparently is near its maximal size, although it is not in danger of collapse. There is abundant evidence that the cave has been used by deer, antelope, bats, and various birds for shelter.

The floor of this cave like those of many others shows silt benches roughly two feet above the present channel level. This evidence suggests backfilling and later trenching along the stream channels in this basin.

The upper part of the cave is cut in green-gray tuffaceous mudstones while the lower six feet are cut in siltstones. The siltstones support much of the bedrock overhang.

Enlargement of the cave chamber is probably the result of undercutting by the intermittent stream followed by collapse of the well fractured bedrock (Figure 1). Under the adobe roof enlargement is probably the result of flaking off and collapse into the stream channel of unsupported pieces of debris not adequately cemented to the roof.

The adobe cone has probably been built up in thickness (up to 8 feet) by wash and slump debris from the mudstone on the cliff above. Windows may be the result of collapse of weakly cemented sections when underlying material is removed and/or the result of water penetration through the clay seals at the bedrock-adobe contacts, turning the adobe locally into mud.

The cave may have initiated as a meander cut into the steep valley wall. Collapse of the outer portion of the overhanging bedrock, where undercutting was greatest at the center of the meander, would not have blocked the stream channel, but instead would have permitted the establishment of the chamber.

A gully-type cave (Figure 2) was formed in a relatively minor valley which has been filled by mudstone debris from the steep

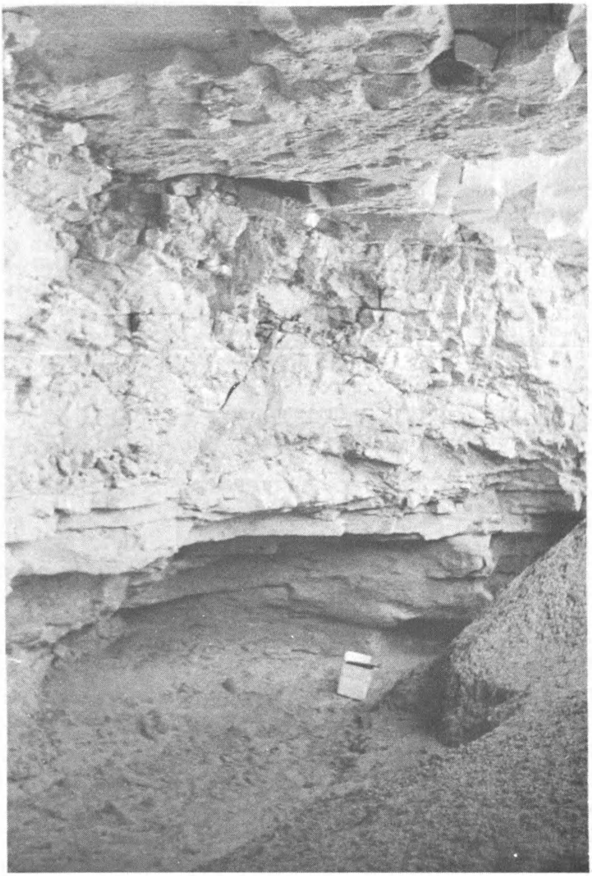

FIGURE 1—Interior of a meander type cave.

valley walls above. With the exception of one window which permits access there are no openings for a distance of over 150 feet along the gully (Figure 2). The window opens to a chamber 80 feet by 25 feet by 15 feet. Passage beyond this chamber into other chambers may be possible both up and downstream.

The north wall and about half of the roof are cut into the mudstone bedrock while the remainder of the cave is cut in adobe material. Rills leading into the cave from the window suggest that the opening is being enlarged. The relatively small size of the window would probably permit closing of the cave should the adobe roof be able to support the weight of a landslide when the overhang in the bedrock above the opening collapses.

Another cave, through which one can easily walk along the graded stream channel floor, has a straight line distance from portal to portal of only 40 feet, although the meandering stream channel is well over 80 feet long between portals. The maximum height is approximately 10 feet. The width at the portals is only about 5 feet although inside it increases to 15 feet.

Inside this cave again is evidence of backfilling and more recent trenching. The debris pillar contains stratified silt, sands, and fine conglomerates up to five feet above the present channel floor. Benches along the present channel with excellent mudcracks suggest recent trenching of 2½ feet. The present channel floor is cut in a sandstone layer.

FIGURE 2—Interior of a gully type cave.

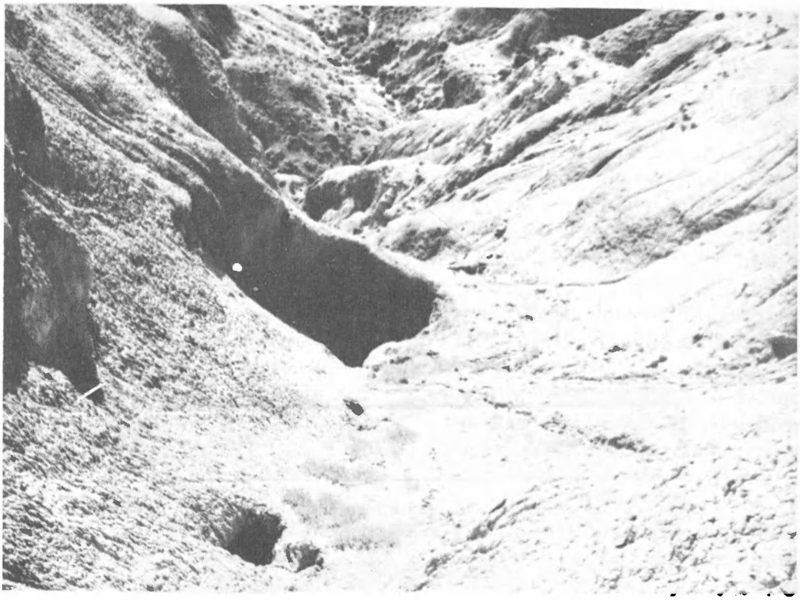

FIGURE 3—Hollow debris piles appearing to block a badland gully.

SUMMARY

In all, some 22 large pipes were observed in the one basin studied. Many "smaller" caves were also observed to which entrance was not possible. Several of these smaller ones could potentially contain chambers as large or larger than the chambers observed in the "large" systems. There is no reason to believe that windows (which served as the only means of access to 12 of the "large" caves) have penetrated to even a significant minority of the subsurface chambers in the basin. They have probably penetrated only the very largest chambers. Many other debris piles and talus cones exist which could easily be hollow (Figure 3).

In most of the caves two or more levels of chambers were observed. In several, backfilling and later trenching along stream channels existed. Others showed only evidence of recent trenching. The various cave levels are thus thought to have resulted from minor climatic fluctuations causing periods of aggradation and periods of degradation. The recent trenching may have resulted from the exceptionally wet spring of 1967.

In most of the caves the adobe walls and parts of the roof are found on the south and west walls, while bedrock is exposed on the north and east walls. This preferred orientation may result from a greater number of landslides and slumps on the south and west facing valley walls. These landslides would occur if there was increased water penetration on these slopes during winter freeze-thaw conditions.

The location of all the caves in this sampling unit along or near bedrock-debris contacts and the fact that the windows are usually developed along these contacts indicates that the contacts are more susceptible to water penetration and piping than the bedrock or adobe mantle alone. The absence of any cave systems cut entirely in bedrock forces rejection of the hypothesis that piping is associated with fracturing in the claystones in this particular sampling unit. The existence of parts of cave systems cut only in debris indicates that under proper conditions caves can develop without any bedrock support.

The sandstone and siltstone floors of many of the caves may mean that a lower impermeable layer aids the development of these pipes. The multiple chamber levels, some cut only in debris, and several caves with mudstone floors provide notable exceptions.

Once the cave or pipe is formed, it will grow to a point where the walls and roof are unable to support themselves and windows begin to penterate to the chambers. In time this process results in the collapse of the debris roofs and the gully is reformed often at a deeper level than before. This new gully is again filled with landslide debris and new caves or pipes are formed.

ACKNOWLEDGMENTS

I thank Professor B. Mears, Jr., of the University of Wyoming Department of Geology for his many helpful suggestions during this project. The Department of Geology also provided financial assistance and employment during the conduct of this project. Field assistance during the summer of 1968 from Lee C. Pigage greatly aided the project.

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PRELIMINARY CLASSIFICATION OF CONCRETIONS AND NODULES IN THE CRETACEOUS HELL CREEK FORMATION, NORTH DAKOTA[1]

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ABSTRACT

The following classification of concretions and nodules was developed after initial investigation of field occurrence, structure, texture and composition:

I. Concretions; A. Calcareous sandstone types, 1. lenses, 2. "logs", 3. irregular masses; B. Sideritic types, 1. lenses, 2. sandstone lenses, 3. irregular masses; C. Lignitic sandstone lenses, 1. calcareous, 2. sideritic; D. Others, 1. bone-cored rounded masses, 2. jarosite spheroids, 3. septarian types, 4. barite lenses.

II. Nodules; A. Sideritic types, 1. structureless-smooth surface, 2. structureless-spiny, 3. calcite-veined; B. Pyrite spheres.

Relationships to primary sedimentary structures indicate that most of these features are post-depositional. Gradations between types suggest that relatively few factors were important in their origin. These include the channels of migrating aqueous fluids, their calcium, iron and carbonate contents and the distribution of organic material within the sediments.

INTRODUCTION

Concretions and nodules are common in the sedimentary geologic record in rocks of widely varying age, but few detailed studies of these structures have been made. The term "concretion" is used here for structures mineralogically similar to, but more resistant than the enclosing sedimentary rock and developed by selective deposition of cementing materials from solution in the pores of a sediment. "Nodule" is used for structures consisting of mineral matter unlike and more resistant than the enclosing sedimentary material.

The Hell Creek Formation (Cretaceous) in southwestern North

[1]Supported by U.N.D. Faculty Research Grant 4522.

TABLE I

PRELIMINARY CLASSIFICATION AND CHARACTERISTICS OF CONCRETIONS AND NODULES OF THE HELL CREEK FORMATION, NORTH DAKOTA

Type	Abundance	Size Range	Relation to Bedding	Enclosing Sediment	Composition (parts per ten) (M=minor, T=trace) Clay*	Quartz	K-feldspar	Plagioclase	Calcite	Siderite	Fe oxides*	Organic	Other**
Concretions													
Calcareous ss types													
lens	Abundant	1-10m in diam. 0.1-2m thick	Randomly distributed; bedding undisturbed	Sandstone	1	2	1	1	5				M(D,H)
"log"	Common	1-3m in diam. 5-15m in length	Randomly distributed; bedding undisturbed	Sandstone	1	2	M	1	6				
irregular mass	Abundant	0.5-1m in diam.	Concentrated in layers; bedding disturbed	Sandstone	M	2	1	1	6		T		
Sideritic types													
lens	Rare	1-2m in diam. 3-15cm thick	Concentrated in layers; bedding undisturbed	Sandy bentonite		1				9	M		
ss lens	Rare	1-3m in diam. 0.2-1m thick	Randomly distributed; bedding undisturbed	Sandstone	M	2	1	1		6	M		
irregular mass	Common	0.5-1m in diam.	Randomly distributed; bedding undisturbed	Sandstone	M	2	1	1	2	4	T		

*clay dominantly montmorillonite; iron oxides dominantly goethite

**D=dolomite, H=heulandite, A=apatite, J=jarosite, B=barite, P=pyrite-marcasite

TABLE I (Continued)

PRELIMINARY CLASSIFICATION AND CHARACTERISTICS OF CONCRETIONS AND NODULES OF THE HELL CREEK FORMATION, NORTH DAKOTA

Type	Abundance	Size Range	Relation to Bedding	Enclosing Sediment	Composition (parts per ten) (M=minor, T=trace) Clay*	Quartz	K-feldspar	Plagioclase	Calcite	Siderite	Fe oxides*	Organic	Other**
Lignitic ss lenses													
calcareous	Rare	1-5m in diam. 0.5-1m thick	Randomly distributed; bedding undisturbed	Lignitic sandstone	1	1	1	1	5			1	
sideritic	Abundant	5-20m in diam. 0.5-2m thick	Concentrated in layers; bedding disturbed	Lignitic, bentonitic shale		1		M	3	2	3	1	
Others													
bone-cored mass	Common	5-20cm in diam.	Randomly distributed; bedding disturbed	Lignitic, bentonitic shale	M	1	M	M	1		T	M	8(A)
jarosite sphere	Abundant	10-30cm in diam.	Randomly distributed; bedding disturbed	Sandstone	2	4	1	2			T		1(J)
septarian type	Rare	1m in diam. 0.3m thick	Concentrated in layers; bedding undisturbed	Sandstone	1	2	1	1	5				
baritic ss lens	Rare	0.5-1m in diam. 5-10cm thick	Randomly distributed; bedding undisturbed	Sandy bentonite		2	1	1				M	6(B)

*clay dominantly montmorillonite; iron oxides dominantly goethite

**D=dolomite A=apatite B=barite
H=heulandite J=jarosite P=pyrite-marcasite

TABLE I (Continued)

PRELIMINARY CLASSIFICATION AND CHARACTERISTICS OF CONCRETIONS AND NODULES OF THE HELL CREEK FORMATION, NORTH DAKOTA

Type	Abundance	Size Range	Relation to Bedding	Enclosing Sediment	Composition (parts per ten) (M=minor, T=trace) Clay*	Quartz	K-feldspar	Plagioclase	Calcite	Siderite	Fe oxides*	Organic	Other**
Nodules													
Sideritic types													
structureless-smooth surface	Abundant	0.1-0.2m in diam.	Concentrated in layers; bedding deflected	Bentonitic sandstone		1				9	M		
structureless-spiny	Rare	0.1-0.5m in diam.	Concentrated in layers; bedding deflected	Bentonitic sandstone		1				1	8		
calcite-veined	Common	0.5-1m in diam.	Concentrated in layers; bedding deflected	Sandstone		1			1	3	5		
Pyrite sphere	Rare	2-4cm in diam.	Randomly distributed; bedding deflected	Sandstone	M	2	1	1					6(P)
Enclosing Rocks													
Sandstone					M	5	2	3	T		T	T	
Bentonitic sandstone					2	4		4	T		T	T	
Lignitic bentonitic sandstone					4	3	1	1	T		T	1	

*clay dominantly montmorillonite; iron oxides dominantly goethite

**D=dolomite, H=heulandite, A=apatite, J=jarosite, B=barite, P=pyrite-marcasite

Dakota, described by Frye (1964, 1967, and 1969) contains abundant concretions and nodules of varying types. Five members of the Hell Creek are recognized in the study area in Slope and Bowman Counties, southwestern North Dakota (Frye, 1969). They are, from youngest to oldest:

Pretty Butte Member—bentonite and bentonitic shales with small sandstone channels, 9 meters thick.

Huff Member—thick sandstone channel deposits with a few thin bentonites and bentonitic shales, 26 meters thick.

Bacon Creek Member—bentonitic shales, bentonites, lignitic lenses, and occasional sandstone channels, 36 meters thick.

Marmarth Member—two thick sandstone channel deposits seperated by a thin sequence of bentonites and bentonitic shales, 23 meters thick.

Little Beaver Creek Member—generally lignitic sediments and shales as well as some sandstone bodies, 32 meters thick.

The purpose of this paper is to present the preliminary results of a detailed study of the concretions and nodules of the Hell Creek Formation.

METHODS

Field study primarily involved the collection of typical specimens of all concretion and nodule types, as well as the enclosing sediments,

FIGURE 1—Calcareous sandstone lenses randomly distributed in sandstone in the Marmarth Member, Sec. 25, T. 133N., R. 106W., Slope County, North Dakota.

from the study area in Slope and Bowman Counties in southwestern North Dakota. Size, shape, stratigraphic location and relation to sedimentary structures were noted, as well as the composition of the enclosing sedimentary material.

Mineralogical composition was determined semiquantitatively by standard methods described in detail by Groenewold (M.S. Thesis, Univ. of N. Dak., in preparation) and by Karner (1968, p. 44-51).

RESULTS AND DISCUSSION

A preliminary classification based on shape and composition of the Hell Creek concretions and nodules with a summary of their characteristics is given in Table I. Mineralogical compositions are for typical specimens. Important features are illustrated in Figures 1-8.

As a result of this initial study the following relationships are judged to be the most significant in the consideration of the origin and history of the concretions and nodules:

(1) Abundance of both concretions and nodules. Concretions are post-depositional and appear to be most simply interpreted as localized areas of rock cementation. Nodules indicate either complete replacement of original material or formation during deposition of the enclosing sediments.

(2) Orientation parallel to bedding. Most types are inequidimensional and oriented with the longest dimensions parallel to bedding planes of the enclosing sediment (Figure 1). This suggests an origin directly related to the formation of beds or to the physical environment produced by bedded layers each with different properties.

(3) Concentration along bedding planes. Some types, particularly sideritic nodules and concretions, are most abundant along certain bedding planes (Figure 2) supporting observation (2) above and providing a means of testing the possible conclusions of (2).

(4) Relation to sedimentary structures. Certain types (Table I) preserve structures such as cross bedding (Figure 3) and normal bedding while other types disturb or deflect such structures, allowing sequential events to be determined.

(5) Occurrence of calcareous concretions in sandstones. Concretions appear to be deposited by solutions moving through permeable materials and may represent the initial stages of lithification of some sandstones (Figures 1-3, 7).

(6) Occurrence of sideritic structures in bentonitic materials. Availability of iron may have been controlled by volcanic activity either by providing a source for iron or by modifying chemical conditions so as to cause its precipitation (Figures 5, 6, 8).

(7) Common association with organic materials. Some of the structures, particularly the sideritic types, may be formed as a result of chemical reactions involving organic compounds (Figures 4, 7, 8).

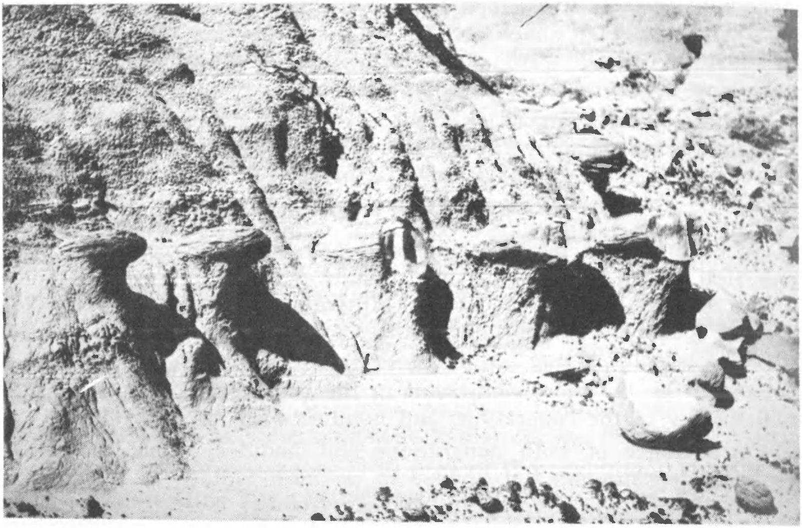

FIGURE 2—Calcareous sandstone lenses concentrated along a bedding plane in sandstone in the Pretty Butte Member, Sec. 8, T. 134N., R. 106W., Slope County, North Dakota.

FIGURE 3—Calcareous sandstone lens enclosing undisturbed bedding in sandstone in the Marmarth Member, Sec. 26, T. 133N., R. 106W., Slope County, North Dakota.

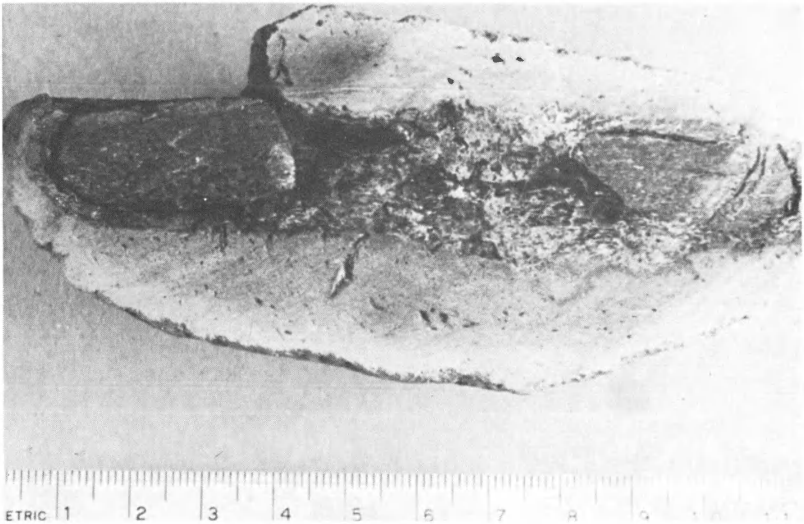

FIGURE 4—Bone-cored, apatite-rich concretion; from Bacon Creek Member, Sec. 23, T. 133N., R. 106W., Slope County, North Dakota.

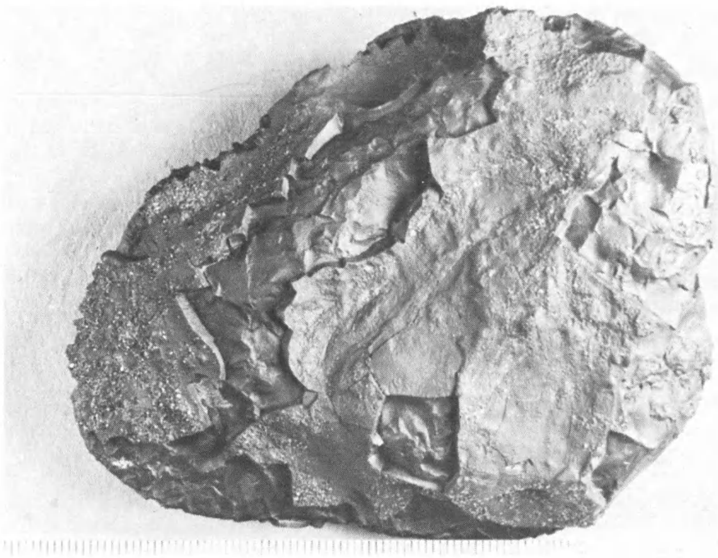

FIGURE 5—Sideritic nodule with weathered, limonitic, outer zone containing embedded sand grains; from Marmarth Member, Sec. 26, T. 133N., R. 106W., Slope County, North Dakota.

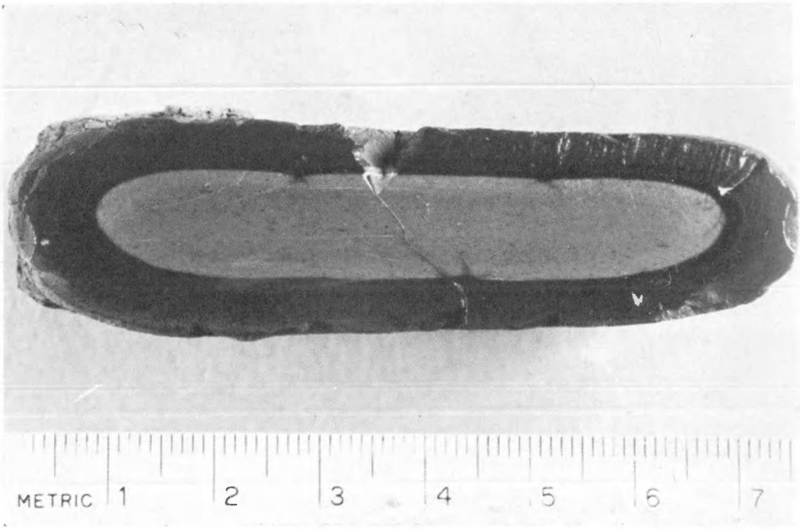

FIGURE 6—Sideritic nodule in cross-section showing limonitic weathering zones; from Bacon Creek Member, Sec. 23, T. 133N., R. 106W., Slope County, North Dakota.

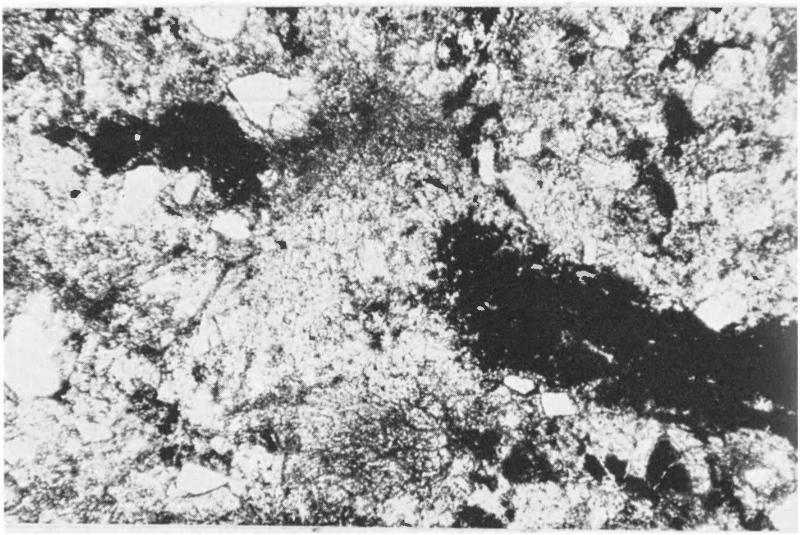

FIGURE 7—Thin section of lignitic, calcareous sandstone lens showing dark organic fragments and clear detrital quartz and feldspar grains in calcite-cemented matrix; from Huff Member, Sec. 16, T. 134 N., R., 106W., Slope County, North Dakota (50X).

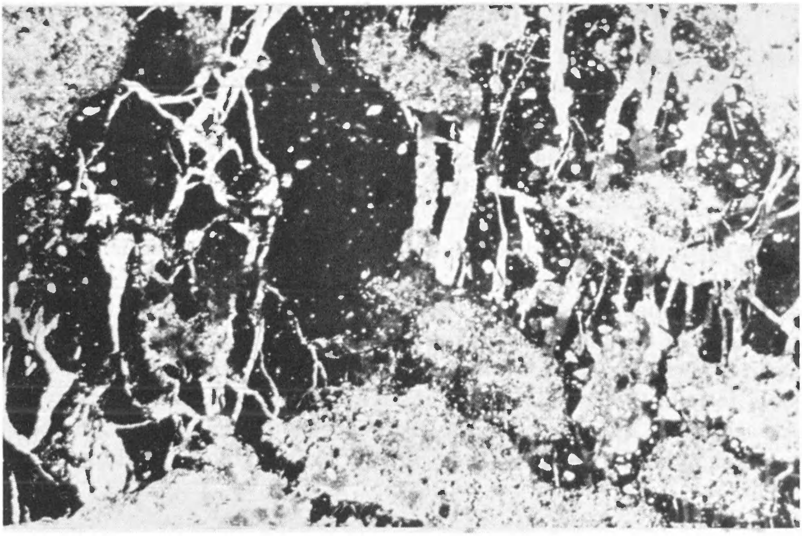

FIGURE 8—Thin section of a lignitic, sideritic, sandstone lens showing a complex history. Clear detrital quartz and feldspar grains within dark areas of siderite cement with fractures filled with calcite spar; from Huff Member, Sec. 16, T. 134N., R. 106W., Slope County, North Dakota (50X).

(8) Common gradational relationships. Many of the types are gradational suggesting a small number of possible origins as opposed to a separate origin for each type.

(9) Specimens with complex histories. Several stages or possibly continuous concretion and nodule formation over a long period of time are suggested (Figure 8).

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SAMPLING AREA AND LIVER VITAMIN A

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INTRODUCTION

In cattle nutrition research, data on carcass excellence is obtained routinely at the close of an experiment. At slaughter, the livers are sampled to measure the stores of hepatic Vitamin A, one of the better measures of the adequacy of the Vitamin A of the ruminant. During several such samplings it was observed that it was not always possible to take the sample from similar areas or locations on all livers. Abscesses on livers, scar tissue from previous damage, etc., necessitated samplings from other areas. Use of liver biopsy techniques as described by Whitehair *et al.* (1952) also leaves doubt as to area sampled.

Anderson *et al.* (1962) sampled four sites on 98 livers from cattle and sheep at slaughter and found coefficients of variation from 22 to 29% when the mean hepatic Vitamin A was less than 30 μg/g. It appeared that the lower the Vitamin A content in the livers, the greater the coefficient of variation. Because of these situations, which could arise during sampling, an experiment was designed to obtain an estimate of reliance on hepatic Vitamin A values when sampled at slaughter.

MATERIALS AND METHODS

When steers from Experiment C-15 were slaughtered, five livers were selected at random from the 12 steers on one treatment. The results of gains, feed efficiency and other pertinent data from this experiment have been published elsewhere (Dinusson *et al.*, 1968). The steers sampled for location variation had received 12,000 I.U. of Vitamin A palmitate per head daily in the supplement plus whatever amount of precurser (carotene) present in one-half pound of suncured and one-half pound of dehydrated alfalfa.

Five areas or locations were selected for sampling: Site 1) papillary lobe adjacent to portal vein; 2) caudate lobe (right lateral lobe) close to edge; 3) ventral border (midway between left central and left lateral lobes); 4) right central lobe (dorsal to gall bladder) and 5) center lobe (close to posterior vena cava). Site 1 is the usual location of routine sampling. A slice of liver was taken at each location, placed in a plastic bag, identified and quick frozen for storage until analyzed. The hepatic Vitamin A was estimated by the method of Gallup and Hoefer (1946).

TABLE I

HEPATIC VITAMIN A VALUES AND VARIATIONS BY STEERS

Steer No.	Vitamin A Average μg/g wet liver	Standard Deviation	Coefficient of Variation %
35	23.8	2.56	10.8
34	17.6	4.05	23.0
38	7.6	2.22	29.2
47	7.8	1.64	21.1
45	18.2	3.40	18.7

TABLE II

HEPATIC VITAMIN A VALUES AND VARIATIONS BY LOCATION

Site No.	Vitamin A Average μg/g wet liver	Standard Deviation	Coefficient[1] of Variation %
1	14.8	7.5	50.7
2	14.2	7.6	53.5
3	12.0	5.7	47.7
4	17.8	7.6	42.7
5	16.2	8.0	49.3

[1]Includes variation due to steers

RESULTS AND DISCUSSION

The summary of results is presented in Tables I and II. The average liver Vitamin A content per steer averaged from 7.6 to 23.8 μg/g of wet liver (there are approximately 3.3 I.U./μg of Vitamin A alchohol). These amounts were apparently adequate since no gross symptoms of Vitamin A deficiency were evident. The coefficient of variation in Vitamin A content between steers (5 samples/steer) ranged from 10.8% to 29.2% with the steers having the lower levels showing the greatest variation. All the steers so sampled had received the same ration and levels of Vitamin A in the supplement. Thus, this variation between steers was either a reflection of variation in requirement, efficiency of use or possible stores in the liver at the start of the experiment. The yearling cattle purchased for the experiment had been "warmed up" and it was likely they had been given high levels of Vitamin A during this "warm up" period. No biopsies were taken at the beginning of the experiment so these conjectures are based on limited knowledge of treatment prior to purchase.

In Table II, where the five sites (locations) of sampling are considered, there was less variation between locations of sampling than between steers. Since these measures of variation also include the variation due to steers, they appear to be very high. From the components of variance, 86% of the variation was explained by differences between the steers, 7% by locations of sampling, and unexplained variation, 7%.

TABLE III

ANALYSIS OF VARIANCE: 5 STEERS, 5 LOCATIONS

Source	df[1]	ms[1]	F[1]
Total	24	——	——
Between Steers	4	251.3	57.9*
Between Sites	4	23.7	5.46**
Within (error)	16	4.34	

[1]df=degrees of freedom; ms= mean square; F=variance ratio.
*Significant at the 5% level; **Significant at the 1% level

Table III shows results of analysis of variance. Both sources of variation, steers and locations, were highly significantly different ($P<0.01$). However, the variation between steers was about 12 times larger than between sites, indicating that even though exact site sampling is not possible in all cases, it is a useful measurement in establishing the Vitamin A status of animals or treatments.

The values from the hepatic Vitamin A determinations for the entire group of cattle on experiment are summarized in Table IV. Thirty-six yearlings were put on experiment, six per lot, 12 per treatment. The average values per lot are quite similar by replicates (lots 1 and 4, 2 and 5, etc.). The standard deviation for the entire experiment was 10.61, which is about half of the mean value for the experiment and resulted in a coefficient of variation of 49%. Thus, there is tremendous variation from steer to steer within treatment and this variation also includes that due to location of sample, although effort was made to sample from site 1 (papillary lobe) whenever possible. Even with this large variation, the differences between rations used were significant at the 1.0% level. Apparently the extra one-half pound of either suncured alfalfa (lots 1 and 4) or dehydrated alfalfa (lots 3 and 6) received by the steers contributed an appreciable amount of the precursor, and it appears that the suncured alfalfa may have contributed even more than the dehydrated alfalfa.

Correlations were run between hepatic Vitamin A levels and average daily gain within treatments. No relationship was evident even if the average gains were significantly different between the treatments at the 1% level (Table V). In two of the treatments the "r" value (correlation coefficient) was positive but non-significant.

TABLE IV

SUMMARY HEPATIC VITAMIN A AND AVERAGE DAILY GAINS BY TREATMENT EXP. C-15. VALUES FOR A IN μG/G OF WET LIVER (6 STEERS PER LOT)

Lot No.	Hepatic Vitamin A Average	Standard Deviation	Coefficient of Variation %	ADG[1] lb.
1	29.67	10.98	37.0	2.27
4	30.41	15.88	52.2	2.25
Ave. (treatment)	30.04	13.02		2.26±0.47
2	16.08	7.96	49.5	2.50
5	13.50	5.26	39.0	2.57
Ave. (treatment)	14.79	6.57		2.54±0.29
3	19.00	12.88	67.8	2.47
6	20.83	6.81	32.7	2.49
Ave. (treatment)	19.92	9.85		2.48±0.34
Ave. Experiment	21.58	10.61	49.2	

[1]Average daily gain with standard deviation

TABLE V

ANALYSIS OF VARIANCE BY TREATMENT EXP. C-15

Source	df[1]	ms[1]	F[1]
Total	35	——	——
Rations	2	722.67	6.41**
Replications	1	——	——
Interactions	2	15.9	——
Within (error)	30	112.68	

[1]df=degrees of freedom; ms=mean square; F=variance ratio
**Significant at the 1% level.

In one treatment the "r" value was negative. Therefore, the levels of Vitamin A in the rations must have been adequate, at least as measured by lack of gross signs and apparent lack of effect on gain.

CONCLUSIONS

Sample site from the liver can have a significant influence on the apparent level of hepatic Vitamin A. However, it appears that differences between animals are usually larger than differences between areas of liver. To increase reliance on estimates of hepatic Vitamin A, all livers should be sampled from similar locations. Small differences between animals for hepatic Vitamin A values could be masked by variation in the Vitamin A content between location or areas of liver.

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THE CONCENTRATION OF T3 AND T4 IN THE NORMAL, PINEALECTOMIZED AND HYPOTHALAMUS LESIONED ALBINO RAT

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INTRODUCTION

The serum concentration of FT4 (free thyroxine) is the most accurate indicator of true thyroid activity state (1). It is unaffected by pregnancy or estrogen therapy which increase TBP (thyroxine binding protein) and decrease RT3 (liothyronine I^{131} uptake), androgen or anabolic steriod therapy which decrease TBP and increase RT3, or chronic disease which lowers TBP. It is unreliably increased only during acute illness in the euthyroid patient.

FT4 concentration is too small (less than 0.1% of the total T4) to be measured directly and must be extrapolated from the following equilibrium formula (2):

$$FT4 + FTBP \leftrightarrows T4 \,.\, TBP$$

$$\frac{(FT4)(FTBP)}{T4 \,.\, TBP} = k$$

where FTBP designates the unoccupied binding sites on TBP, T4 . TBP the protein-bound T4 and k the dissociation constant.

Equating these terms with more familiar ones, T4 . TBP is largely represented by PBI while FTBP is proportional to the resin uptake of liothyronine I^{131} or triiodothyronine I^{131}.

From the above it is obvious that determining either T4 . TBP (T) or RT3 (T3) alone may give fallacious results, but both provide an accurate index of thyroid function. Normal values of these were not available for the rat, so they were determined and measured in the surgically-lesioned animal. Unfortunately k had not been determined in the rat making it impossible to extrapolate the values to obtain FT4.

METHODS

Adult rats housed under usual laboratory conditions and fed Purina Lab Chow were used. All experiments were done on animals over five months of age. Blood was drawn per cariac puncture into a plastic syringe from pentobarbital-anaesthetized animals and allowed to clot in glass tubes and the serum drawn off the following day. T3 and T4 levels were measured on each rat by the commercial methods of the Curtis Nuclear Corporation who very kindly supplied all the chemicals used in these tests. The T3 is measured by the serum uptake of radioactive triiodothyronine and is reported as percent uptake. T4 is measured by holding the thyroxine to a strong exchange resin, releasing it selectively by concentrated acetic acid, then releasing the iodine from the thyroxine to combine with arsenous acid. This combination reduces the yellow color of ceric ammonium sulfate in a manner proportional to the iodine present. T4 is here reported as micrograms per 100 ml of serum (μg/100 ml).

Pineal glands were removed from four-day-old rat pups comprising one half of the litter and the other half was sham operated. The animals receiving electrolytic brain lesions were anaesthetized with pentobarbital, placed in a Stoelting Stereotactic machine for the rat and given 2 ma for 20 seconds at AP 7.0, H $\pm$ O, V+1 (3) from a lesion producing device. Blood was drawn two weeks later. All data are handled as means and standard deviations and significant differences determined by the student "t" test.

RESULTS

Data are reported in Table I. The males are tabulated separately from the females except for the lesioned animals where equal numbers of males and females were used. The males have significantly greater T3 values ($P<.01$) than the females in all groups while the animals lesioned at these specific coordinates have significantly ($P<.01$) smaller T3 values, compared to the mean of 58 $\pm$ 3.6% found in 39 male and female animals lesioned and bled in a similar way in other areas of the hypothalamus. No significant differences were present in the T4 values.

DISCUSSION

Comparing our values for the rat with those accepted for the human indicates the human has two to three times as much bound thyroxine (3.2-6.4 mcg%) and about half as much unsaturated thyroid-binding globulin (24-36% uptake), so the product of these two parameters is about the same in each species. No difference between

TABLE I*

	Normal Rats	PND Rats	Sham Operated	Lesioned Rats
Male				
T3 % uptake	59.0±3.1 (94)	59.6±3.4 (26)	58.0±3.6 (23)	
T4 μg%	1.26±0.6 (59)	1.61±0.8 (16)	1.56±0.6 (15)	
Female				
T3 % uptake	55.2±4.7 (22)	56.4±3.1 (28)	55.7±3.5 (22)	
T4 μg%	1.28±0.8 (9)	1.14±0.7 (19)	1.14±0.6 (16)	
Male & Female				
T3 % uptake				49.6±2.1 (18)
T4 μg%				1.58±0.4 (12)

*The males have significantly greater T3 values than the females in all groups. The control animals for the lesioned rats are described in the text. The number of animals is shown in parentheses.

males and females in the human has been reported, thus the rat may be unique.

Finding no change in T3 or T4 in the pinealectomized rat was rather surprising as recent work suggested a relationship between the pineal and thryroid glands. Baschieri *et al.* (4) found melatonin, the specific amine produced by the pineal, depressed thyroid growth. Ishibashi *et al.* (5) found pinealectomy to increase food consumption and thyroid hormone secretion rate and melatonin to depress these, while Csaba *et al.* (6) found the uptake of radioactive iodine by the thyroid to increase by almost 50% after pinealectomy in the adult rat. However, they found no increase in iodine uptake in animals pinealectomizd in the neonatal period, indicating the timing of the operation may be critical.

The idea of testing the particular portion of the brain for thyrotropic activity arose when lowered T3 values were found in rats carrying brain cannulae. It appears this area of the brain does exert an effect on thyroid-binding globulin but whether through a direct action on the thyroid gland or indirectly on protein formation is moot and more work is required here to answer this question.

ACKNOWLEDGMENT

We thank Mr. William Christianson for his excellent technical work in measuring the T3 and T4 levels.

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COPPER SENSITIVE AREA IN THE RAT HYPOTHALAMUS

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INTRODUCTION

We have shown previously that the pituitary-adrenal axis has some regulatory activity on the plasma copper level (1). Since the hypothalamus regulates the pituitary-adrenal axis (2), it appeared promising to look for a regulatory action on plasma copper as well.

Five hypothalamic areas were selected which bracket this part of the brain, the pre-optic area (POA) anteriorly, the mammillary bodies (MM) posteriorly, the lateral hypothalamic area (LHA) laterally, the paraventricular nucleus (PVH) medically and superiorly, and the arcuate nucleus (ARH) medially and interiorly (Figure 1). Into each of these areas copper was placed and subsequently plasma copper was measured, to see if a feed-back control mechanism was active.

Further reasons for selecting some of these areas are as follows: The POA is concerned with the temperature cycle (3) which follows a circadian rhythm as does the plasma copper (4). The LHA has an effect on thirst (5) and appetite (6) and thus may have some controlling action on copper absorption. Both the ARH and the PVH are integrated into the pituitary-adrenal feed-back loop. The ARH manufactures a corticotrophin releasing factor (2) and the PVH mediates the stress response (7). Since copper is affected by the pituitary-adrenal hormones, both these areas may have at least an indirect effect.

METHODS

White rats of the Wistar strain were purchased from C. B. Schettle of Clearwater, Minn., and allowed to grow to age four months when either plain Dowex cationic resin, 200-300 mesh (control animals) or this resin saturated with copper sulfate, ferrous phosphate or calcium chloride (experimental animals), was placed stereotactically in one of the five hypothalamic areas according to DeGroot's Atlas (8). These resins (9) were tamped into the end of a 20 guage spinal needle by pushing the needle into the resin five times then positioned and the resin deposited by seating the stylet. Trial runs showed the needle would gather an average of 0.9 mg of resin with five pushes and analysis showed this amount of resin to hold about 20 μg of elemental copper. We did not analyze the resins containing iron or calcium. Blood was drawn from the surviving animals under intraperitoneal pentobarbital anaesthesia from the heart on the fifth day after lesioning. One group of rats had a second blood sample drawn 30 days

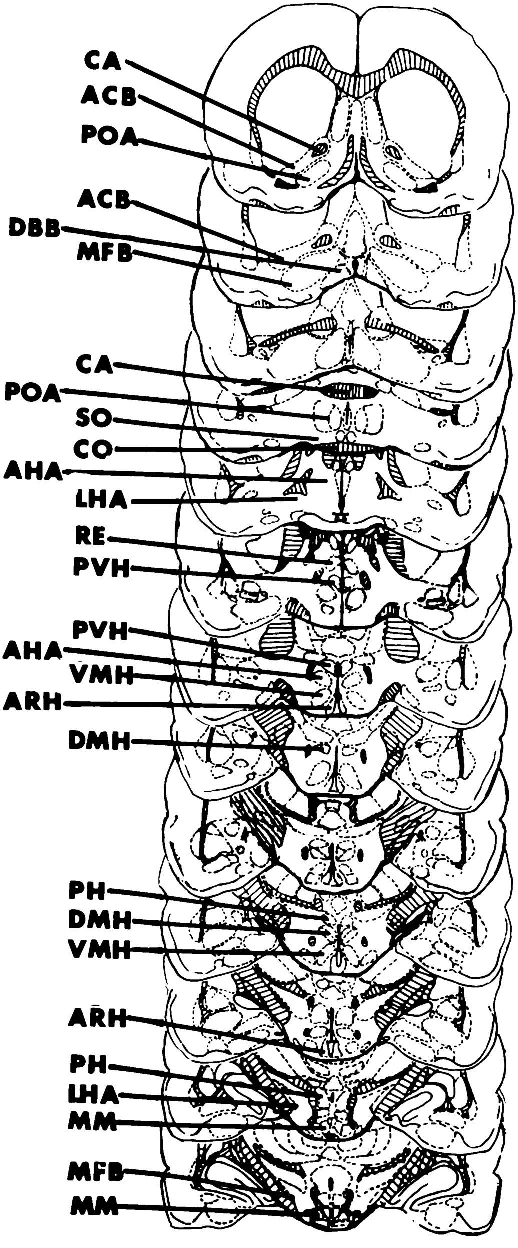

FIGURE 1—Illustrations from DeGroot's Atlas that show the areas of the brain where lesions were made.

after lesioning. The blood was heparinized, centrifuged, 1 ml of the plasma removed, digested and the copper read (10). Calcium was measured on all of these specimens as well but since no significant differences were present, they are not recorded here. The position of the resin boluses has been confirmed by examining coronal sections of a few brains.

TABLE I

DETAILS FOR THE ANIMALS LESIONED IN THE HYPOTHALAMUS*

	No. of animals measured for Cu	Death rate	Five days Cu μg/100ml	Thirty days Cu μg/100ml
POA: 7.6, ± 2, -1.5				
Resin	20	10%	152±34*	103±12*
Cu Resin	11	76%	168±56	
Fe Resin	8	0%	155±47	
Ca Resin	7	12.5%	135±11	
8.6, ± 2, -1.5				
Resin	6	0%	209±46	
Cu Resin	6	0%	169±43	
7.6, ± 0, -1.5				
Resin	6	10%	153±35	
Cu Resin	6	0%	142±25	
PVH: 6.6, ± 0, -1.5				
Resin	4	11%	138±21	
Cu Resin	4	11%	168±51	
ARH: 6.2, ± 0, -3.5				
Resin	5	11%	136±18	
Cu Resin	8	11%	144±23	
MM: 3.8, ± 0, -3.5				
Resin	11	12%	158±21	
Cu Resin	7	12%	175±33	
LHA: 6.6, ± 1.5, -2.5				
Resin	7	12.5%	155±11	
Cu Resin	9	12.5%	141±19	

*The first column indicates the number of animals surviving the lesioning. The difference between the asterisked means and standard deviations is significant beyond the 1% level of confidence. The numbers in the stub indicate millimeter readings on the three coordinate planes. The first number is the distance in front of the ear in the anterior-posterior direction. The second is the distance to either side of the sagittal sinus and the third the distance above (positive) or below (negative) an arbitrarily defined zero vertical point. The death rate is determined as the number of animals dead by the fifth day after lesioning.

RESULTS

All of the plasma copper values from blood drawn five and thirty days post lesioning are listed in Table I. There is no significant difference between any of these with one exception; the values obtained at five days are significantly larger than the values obtained twenty-five days later from the same animals. These rats were lesioned with resin in the POA. Turning to the death rate in this table it is seen to be about 10%, which is equal to the mortality from pentobarbital alone, and all of the groups fall in this range except the animals receiving copper resin in the particular areas of the POA where the death rate is 76%.

DISCUSSION

These data illustrate the general response to stress shown by the white rat with elevation of the plasma copper mostly in the ceruloplasmin compartment. While we did not measure copper in this particular group of animals before lesioning because of the plasma copper elevation following blood drawing, we have in others and find a normal value of around 100 μg/100 ml. As Table I shows, the increased values following lesioning are returned to normal after 30 days. The cause of this stress-associated copper rise is not clear. ACTH injections in the intact animal will decrease the plasma copper while cortisone increases it, but only after several months of injections. Adrenalectomy leads to a prolonged rise in plasma copper lasting about a year. In view of these facts it would seem the increases we have found would indicate an adrenal insufficiency state. Whatever the cause, the lesions we produced did not alter the copper response in a significant manner.

The POA site that is copper sensitive is quite constant, specific and rather small. It was found repeatedly at the 7.6, $\pm$ 2, -1.5 coordinates. Neither iron nor calcium, both divalent ions, proved lethal in this area nor was copper itself when placed 1 mm rostral, 2 mm medial or a little more than a millimeter caudal (LHA, Table I) to this point. What this means is not at all clear but it opens many avenues for further work.

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