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## Field Guide to the Geology of the Harlan County Lake Area, Harlan County, Nebraska – with a History of Events Leading to Construction of Harlan County Dam

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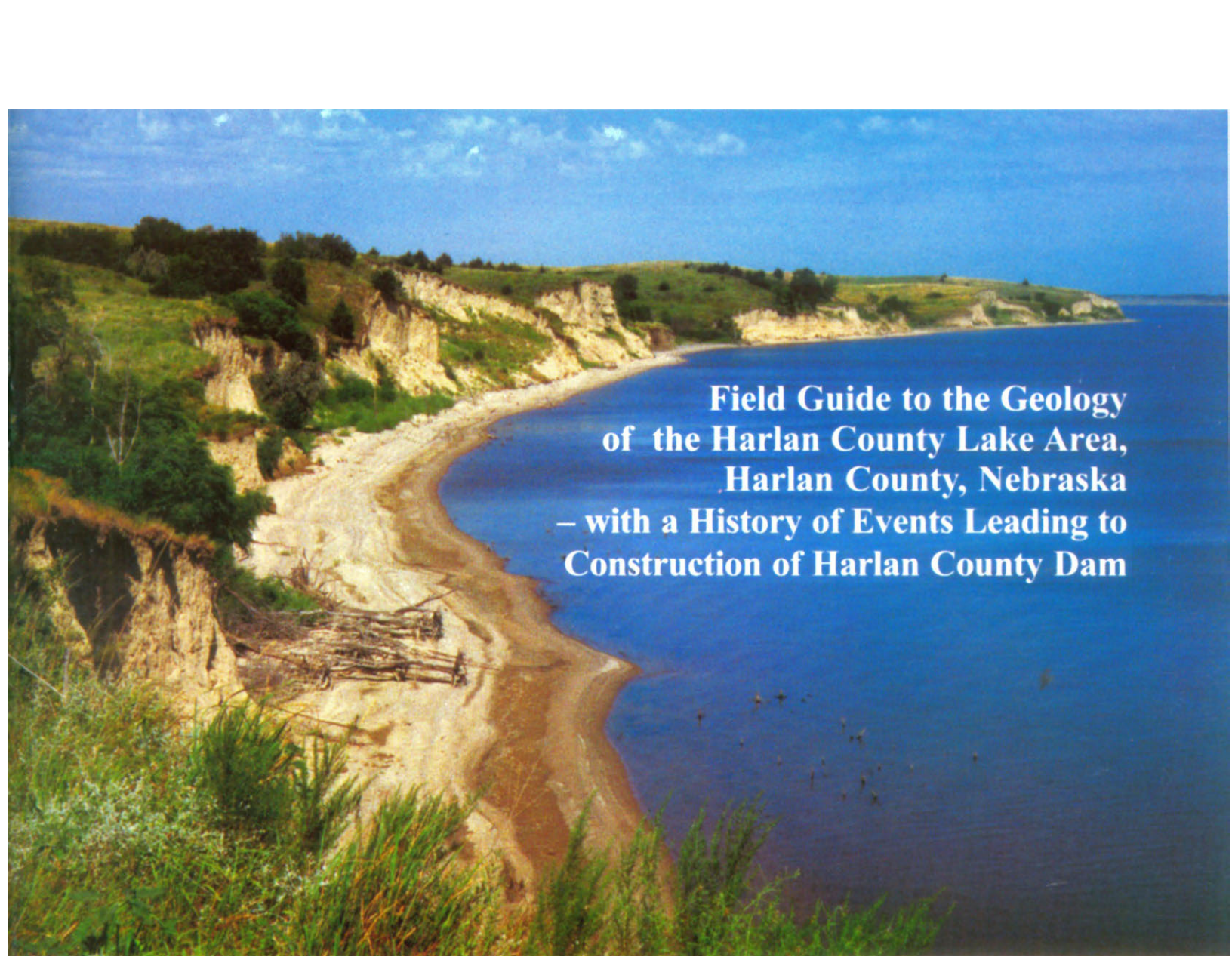
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**Educational Circular 16**

**Conservation and Survey Division  
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August 2002

### Factors for Converting English Units to the International System of Units (SI)

Multiply English units	By	To obtain SI units
	Length	
inches (in.)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres (ac)	4047	square meters (m <sup>2</sup> )
square miles (mi <sup>2</sup> )	2.590	square kilometers (km <sup>2</sup> )
	Volume	
gallons (gal)	3.785	liters (L)
acre-feet (acre-ft)	1233	cubic meters (c <sup>3</sup> )
	Flow	
gallons per minute (gpm)	.00006309	cubic meters per second (m <sup>3</sup> /s)

**Please Note:** This publication is solely the work of its authors. It does not necessarily represent the views of officials representing the State of Nebraska.



## Table of Contents

Introduction .....	1
Location .....	1
Republican River Floods .....	1
The Republican River Flood of 1935 – <i>D. R. Mohlman</i> .....	1
Cautionary Notes (sidebar) .....	1
Events After the Flood Leading to Creation of Harlan County Lake .....	9
Stormer Ford Dog Town (sidebar) .....	10
Water .....	10
Surface Water Hydrology – <i>S. Summerside</i> .....	10
Shoreline Springs and Seeps – <i>F. E. Harvey and K. J. Warren</i> .....	12
Introduction .....	12
Using Water Chemistry to Identify Spring and Seep Origin .....	12
Geology .....	15
General Conditions Leading to Good Exposures .....	15
Stratigraphy of Unconsolidated Sediments and Rock Strata .....	15
Cretaceous System - Upper Cretaceous Series .....	15
Niobrara Formation - Smoky Hill Chalk Member .....	15
Pierre Shale .....	15
Tertiary System - Miocene Series .....	16
Ogallala Group - Ash Hollow Formation .....	16
Quaternary System - Pleistocene Series .....	16
Crete (?) Formation (Sands and Gravels) .....	16
Loveland Loess .....	16
Gliman Canyon Formation .....	16
Peoria and Bignell Loesses .....	16
Quaternary System - Holocene (Recent) Series .....	16
Unnamed Fluvial, Eolian, and Colluvial Deposits .....	16
Paleontology of the Various Formations .....	16
Plants .....	16
Invertebrates – <i>R. K. Pabian</i> .....	17
Cretaceous Marine Fossils .....	17
Niobrara Formation .....	17
Foraminifers .....	17
Post-Devonian “Stromatoporoids” .....	19
Mollusks .....	19
Bivalves .....	19
Ammonites .....	19
Pierre Shale Formation .....	19
Bivalves .....	19
Ammonites .....	19
Quaternary – Pleistocene (Ice Age) Invertebrate Fossils .....	19
Vertebrate Fossils – <i>R. G. Corner</i> .....	24
Late Cretaceous Fossils .....	24
Niobrara Formation .....	24
Niobrara Fishes .....	24
Niobrara Mosasaurs .....	29
Pierre Shale Formation .....	30
“ <i>Protosphyraena</i> ” <i>gladius</i> : Giant Mystery Fish .....	30
Pierre Mosasaurs .....	32
Late Miocene Ogallala Group .....	32
Bone Cove I Fauna .....	32
Bone Cove II Fauna .....	32
Quaternary – Pleistocene (Ice Age) .....	33
Crete (?) Sands and Gravels .....	33
Gliman Canyon Formation .....	33
Peoria Loess .....	35

Late Pleistocene Fauna .....	35
Late Pleistocene Environments .....	37
Geologic Processes Affecting the Strata .....	37
Modern and Ancient Landslides .....	37
Modern Landslides – <i>D. A. Eversoll</i> .....	37
Ancient Landslides – <i>D. A. Eversoll and R. F. Diffendal, Jr.</i> .....	39
Geologic Structures .....	41
Introduction and Previous Work .....	41
Angular Unconformities .....	45
Joints .....	45
Faults and Folds .....	45
Ancient Landscapes (Paleotopography) .....	50
Quaternary River Terraces .....	50
Concluding Remarks .....	50
References Cited .....	51
Glossary .....	58

## Illustrations

### Figures

1. Location of the Harlan County Lake area .....	2
2. Area inundated during the 1935 flood .....	3
3. Republican River channel location changes, showing area to be flooded after dam construction .....	4
4. Aerial photograph of Harlan County Lake area in 1951 during construction of dam .....	5
5. Color infrared aerial photograph in 1988 of Harlan County Lake area after dam construction .....	5
6. Areas of Colorado, Kansas, and Nebraska with major precipitation events from May 30-31, 1935 .....	6
7. Playground near visitor center .....	9
8. Picnic shelter .....	9
9. Dredge clearing harbor and marina of sediment .....	9
10. Prairie dog .....	10
11. Cross section of prairie dog burrow .....	10
12. Mean daily discharge of the Republican River below Harlan County Dam, 2000 .....	11
13. Harlan County Lake end-of-month storage and average monthly discharge below Harlan County Dam, 2000. ....	11
14. Streamflow in cubic feet per second for the Republican River near Hardy, Nebraska. ....	12
15. General locations of sites with significant geologic features noted in table 2 and in the text .....	13
16. Spring flowing from the Pierre Shale at site 4 .....	14
17. Springs from Crete (?) sands and gravels at North Cove, site 35 .....	14
18. Filled animal burrows (krotovina) in Gilman Canyon Formation at site 36 .....	17
19. Foraminifers and coccoliths from the Niobrara and Pierre formations .....	18
20. Post-Devonian “stromatoporoids,” oysters and other bivalves, Niobrara Formation .....	20
21. Bivalves, Niobrara and Pierre formations, and cephalopod from the Pierre .....	21
22. Pleistocene land snails .....	23
23. Cretaceous fossils .....	30
24. Giant fish from the Pierre Formation .....	31
25. Late Miocene fossils .....	33
26. Pleistocene (Ice Age) fossils .....	34
27. Longitudinal section through an earth slump .....	39
28. Earth slump in Quaternary loess between sites 17 and 18 .....	39
29. Rock slump in Pierre Shale near site 5 .....	40
30. Complex slide at site 12 .....	40
31. Probable ancient slide in Pierre Shale at site 5 .....	41
32. Slide in Gilman Canyon Formation at site 13 .....	41
33. Block diagrams to illustrate faulting types .....	42
34. North-south cross section from south valley side along dam axis .....	42
35. Faults in bedrock beneath spillway .....	43
36. Principal joints in bedrock beneath spillway .....	43
37. Side view of core from test hole showing calcite crystal vein fill and dipping Pierre Shale .....	44

38. Angular unconformity between Niobrara Formation and Pierre Shale at site 2 .....	44
39. Angular unconformity between Niobrara Formation and Pierre Shale at site 33 .....	44
40. Angular unconformity between Niobrara Formation and Pierre Shale at site 33 .....	46
41. Three joint sets in the Niobrara Formation at low pool level at site 22 .....	46
42. View looking south at normal fault with Niobrara Formation upthrown at site 3 .....	46
43. View looking south at normal fault with Niobrara Formation upthrown at site 8 .....	46
44. View looking south at normal fault in Niobrara Formation at site 13 .....	46
45. View looking northwest along shore of lake at probable graben fault between sites 15 and 17 .....	47
46. View looking southwest at normal fault in Pierre Shale at site 19 .....	47
47. View looking south at normal faults cutting Niobrara and Pierre Shale formations at site 27 .....	47
48. View looking south at normal fault at site 29 .....	47
49. Reverse fault in Pierre Shale at site 2 .....	48
50. Locations of observed faults and either true or apparent strikes and dips of faults. ....	48
51. Structural contour map of the top of the Pennsylvanian age Lansing Formation with formations cropping out along shore of Harlan County Lake .....	49
52. Ancient hill on top of Gilman Canyon Formation at site 37. ....	51
53. Ancient hill on top of Gilman Canyon Formation at site 35. ....	51
54. Ogallala Group, Ash Hollow Formation, buried hill at site 26 .....	51
55. Cross-stratified Ogallala Group, Ash Hollow Formation, sands and gravels at site 26 .....	51
56. Ogallala Group, Ash Hollow Formation, buried hill with Ogallala landslide block and debris at site 26 .....	51

### Tables

1. Damage from Flood of 1935, southwestern Nebraska .....	7
2. Locations of geologic features at Harlan County Lake shoreline and other sites .....	13
3. Water chemistry .....	14
4. Gastropod species and their environments .....	22
5. Harlan County Lake fossil vertebrate fauna .....	25
6. Classification of landslides .....	38

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Vasek helped Mohlman with research from the newspaper archives of the Nebraska State Historical Society. Ann Mack drafted many figures, and Dee Ebbeka supplied overlays for many photographs. C. Flowerday designed the publication.



## Introduction

The year 2002 will mark the fiftieth anniversary of completion of the Harlan County Dam and Multi-Purpose Reservoir. This seems a good time to write about the history of and reasons for building the dam, the effects of the dam and reservoir on the Republican River valley, and the geologic features seen along the shores of the lake and areas nearby. As many junior authors helped produce this educational circular, they are listed in the table of contents. All other sections were written by the senior author.

## Location

The dam is located in south-central Nebraska at mile 236.2 on the Republican River in Harlan County (U.S. Army Corps of Engineers [USACE], 1951) (fig. 1). The north end of the dam is about 1 mile southeast of Republican City and about 1.2 miles south of U.S. Highway 136. The lake can be reached from the east or west from this highway and from the north or south from U.S. Highway 183. The principal cities in the area are Alma, the county seat of Harlan County, Republican City, and Orleans. The reservoir, dam and land adjacent to them are the property of the federal government.

## Republican River Floods

Floods have affected the valley of the Republican River numerous times. Major floods occurred in 1903, 1905, 1915, 1923, 1935, and 1947 (McCook Daily Gazette, 1982). Of these, the flood with the greatest magnitude in the upper part of the Republican River basin was the 1935 flood. The impact of the flood affects the lives of the citizens in the valley even today.

Some of that impact can be determined from reading the histories of the counties, cities, and villages in Nebraska in the basin of the Republican River (*see, for example*, Beezley, 1937; Bowman, 1990; Dundy County Historical Book Committee, 1988; Furnas County Genealogical Society, 1987; Kuhl and Dunlay, 1972; McCook Light and Power Company, 1935; Naponee Historical Society, 1976; and Nuckolls County Centennial, Inc., 1971). The one *big event* in all of these is The Flood of 1935, so significant that it has become a proper noun and is capitalized. In Harlan County, waters from this flood covered the entire valley floor for a time (fig. 2) and carved a new channel (fig. 3). A 1951 aerial photograph (fig. 4) and a 1988 color infrared aerial photo (fig. 5) allow comparison of the area before and after Harlan County Lake was formed.

## The Republican River Flood of 1935

During the early 1930s, Nebraska was scorched by severe drought. The spring of 1935 started out as yet another dry and dusty year. Intense dust storms raked the relatively flat landscape of southwestern Nebraska, sometimes even blocking out sunlight.

However, May 1935 finally brought heavy rain across the entire Republican River basin (U.S. Bureau of Reclamation [USBR], 2001a; Kuzelka and Flowerday, 1993) Between

## Cautionary Notes

If you visit the area, be careful. Landslides can occur along shoreline cliffs. Unpaved roads can become slippery or impassable after a rainstorm. Flies and ticks can cause illnesses. Poison ivy is common in places. Severe storms can form quickly and can produce hazardous conditions for boaters, hikers, and other people involved in outdoor activities. Collecting any plants, animals, fossils, minerals, artifacts, etc. is forbidden on public lands (USACE, 1986). If you see fossils or artifacts on the beach or anywhere else in the area, report their locations to employees of the U.S. Army Corps of Engineers, if they are on federal property, or to the property owner if on private land.

Most of the Cretaceous and Miocene bedrock and the overlying younger Quaternary sediments exposed along the shoreline of Harlan County Lake are at the ends of headlands (promontories) in nearly vertical to vertical cliffs. In rainy years and during normal high water times, the beach is very narrow or absent in front of the headlands. At these times, access to the cliffs can be gained only by walking overland or by use of a shallow-bottomed boat. The best times to view the cliffs are when the lake is low during droughts or near the end of the irrigation season from late July to early December. The cliffs are never completely safe, and pieces of bedrock and soft sediment fall periodically due to processes of undercutting and local spring sapping. Stay on the beach well back from the cliffs when viewing the exposures.

May 12 and 22, precipitation ranged from 2 to 5 inches. Between May 26 and 29, another inch or so came to northeastern Colorado, 3 or more inches to southwestern Nebraska, and 6 inches to some locations in eastern Kansas.

Farmers were starting to believe they were finally in for a bumper crop. Bernice Haskins Post, who farmed with her husband near Naponee, Nebraska, wrote of these events on July 31, 1936:

*The spring of 1935, things had never looked so rosy for us. During May we had received wonderful rains, after the worst dust storms our country had ever seen. The [Republican] valley fairly blossomed with small grain, alfalfa, and corn. It had promised to be the best crops we had ever raised.*

The newly found optimism of the Post family, along with countless other families in the region, soon would be violently swept away.

Due to the high level of precipitation in May, the soil had become nearly saturated. This would cause significant runoff from any further rains. In addition, the rivers had risen to high levels. In fact, some localized flooding had already been reported along many southern Nebraska and northern Kansas streams.

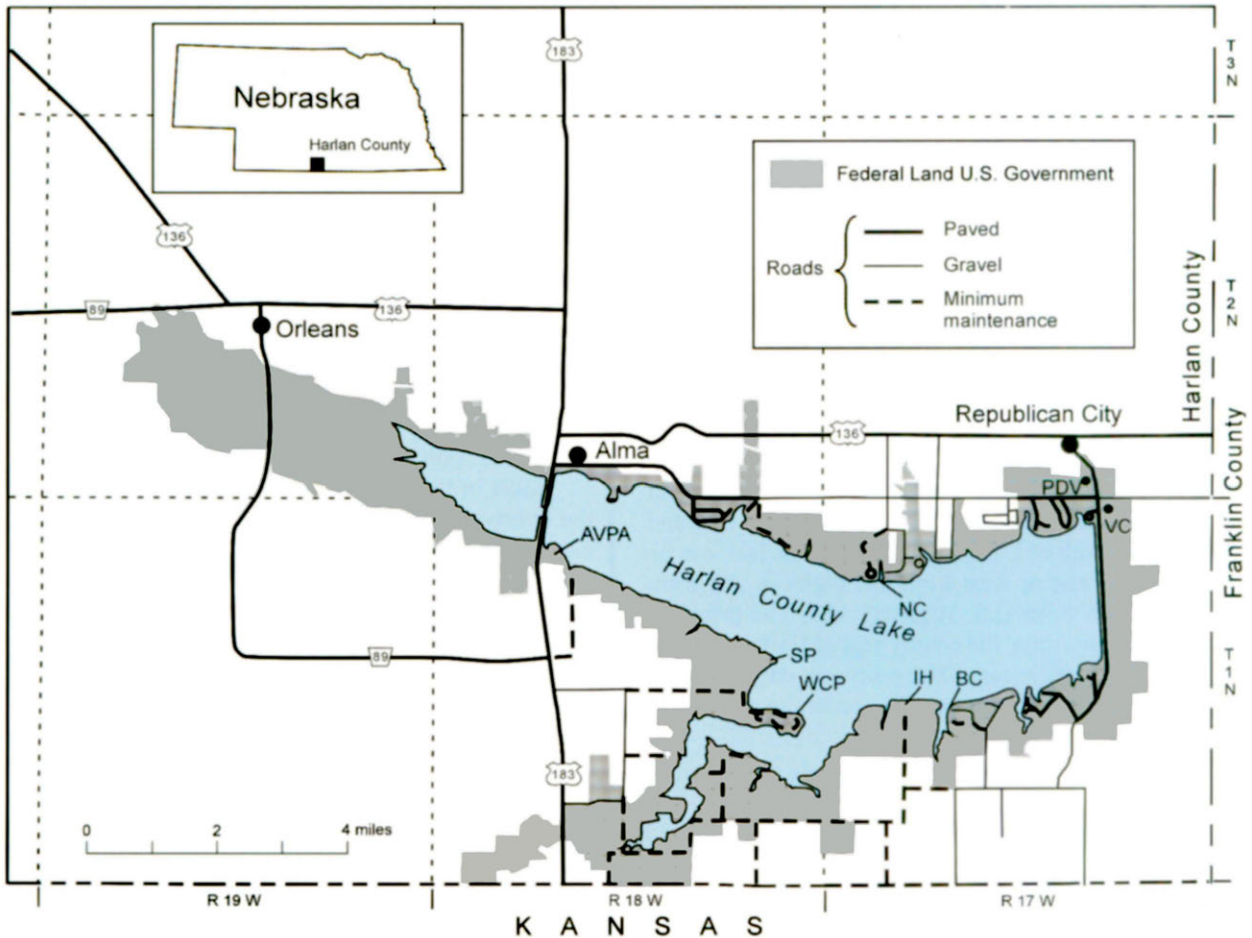


Fig. 1. Location of the Harlan County Lake area. NC-North Cove; PDV-prairie dog village; VC-visitor center; BC-Bone Cove; IH-Indian Hill; WCP-White Cat Point; SP-Sindt Point; AVPA-Alma Vista picnic area. Federal land shaded.

The primary flood-triggering event was nearing. A high pressure system, bringing a large amount of moisture from the Great Lakes with its clockwise rotation, was moving in from the northeast. At the same time, a low pressure system with a counterclockwise rotation was transporting much warm, moist Gulf air as it approached from the southwest.

On the night of May 30-31, 1935, the two weather systems, inundated with moisture, collided over the headwaters of the Republican River in northeastern Colorado, southwestern Nebraska and northwestern Kansas (fig. 6). Follansbee and Spiegel (1937, p. 25) described the resulting cloudburst:

*The storm that caused the heavy rainfall in the Republican River Basin during the night of May 30-31 began just east of the mountains in the forenoon of May 30, and in that area local residents measured, chiefly during the afternoon, as much as 20 inches (including some hail) in stock tanks. This storm followed a general northeasterly direction across the headwaters of the Republican River and ended a few miles east of Curtis, Nebraska, on May 31. The air-line distance from the head of the Republican River in northeastern Colorado to Curtis is 215 miles. Within this area the rainfall was concentrated chiefly in the basin of the South Fork of*

*the Republican River but extended along the low ridge dividing that basin from the basin of the Arikaree River nearly to Benkelman, Nebraska.*

Several reports of double-digit precipitation were made, primarily near the Colorado-Kansas border. One report of 24 inches of rainfall came from a Newton, Colorado, rancher's stock tank. Overall, the area encompassing the entire upper Republican watershed averaged 9 inches of rainfall. It should be noted that, in 1935, there were no U.S. Weather Bureau (now the National Weather Service) precipitation stations in this area of heaviest rainfall. Therefore, rainfall reports were obtained primarily from the rain gauges, stock tanks and oil or paint cans of local residents and other homemade devices.

The cloudburst of May 30-31, over an area already saturated from previous rains, would cause the worst flood in Nebraska's recorded history. To make matters even worse, the rain headed east, generally following the Republican River's drainage area. It lasted until June 2, dropping an additional 2 to 7 inches of rain over the basin. This additional rainfall along the basin meant that the flood crest traveling down the Republican River was met by extremely high flood stages of tributary streams in southwestern Nebraska and northwestern Kansas.

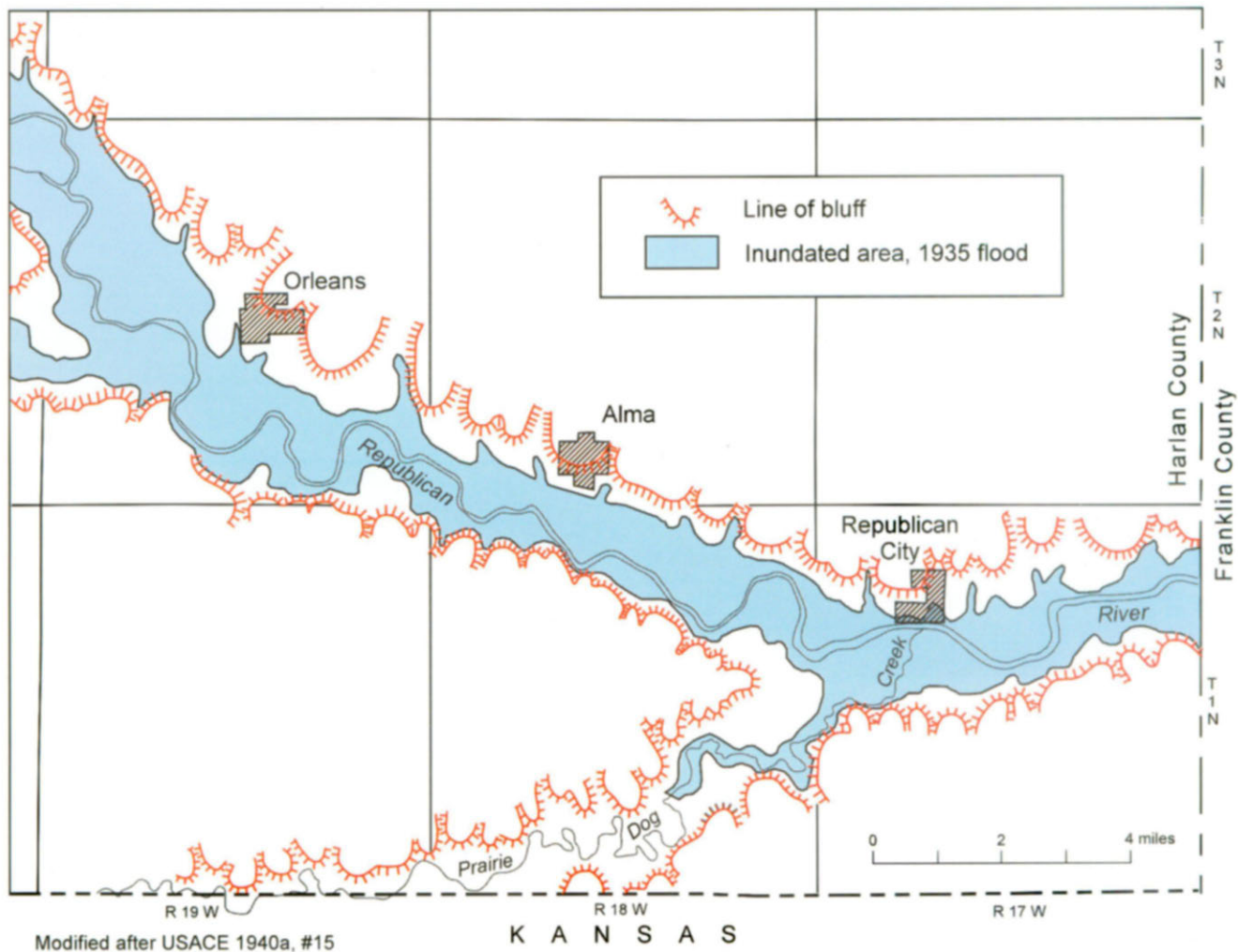


Fig. 2. Area inundated during the 1935 flood.

The resulting flood would be of epic proportions. According to Follansbee and Spiegel (1937, p. 22):

*The Republican River Valley from the eastern part of Colorado to near Junction City, Kansas, a distance of over 350 miles, was overflowed for a width ranging from three-quarters of a mile to one and one-half miles wide, with a loss of more than 100 lives, the destruction of much livestock and most of the buildings in the overflowed area, and great damage to thousands of acres of rich farm land by deposits of sand brought down by the flood waters. Nearly all the highway bridges over the river were either destroyed or rendered impassable and the highway along the valley was washed out in many places.*

A large loss of life occurred in the upper river valley in Colorado and Nebraska, where the flood advanced at night with little or no warning, but when it came, with a roar that was heard for miles. Forty lives were lost there alone. Perhaps the best first hand account of the onrushing torrent is provided by J. H. Mullison, then manager of the Southern

Nebraska Power Company near Bostwick, Nebraska. Described in Follansbee and Spiegel (1937, p. 40), his experience watching from high ground follows:

*While the flood was still several miles distant, he heard its roar, and when it appeared the advance was a mass of tumbling water and debris several feet in height, quickly filling the main channel, which at the point of observation was about 7 feet deep. Spreading out behind the advancing waves the flood quickly overflowed the bottom lands, giving the effect of an oncoming spearhead. Within a very short time the great quantity of tumbling debris blotted out the sight of the water itself. The flood made short work of bends and elbows in the old channel, taking the shortest course, which resulted in the formation of many new cut-off channels.*

Again, Bernice Haskins Post provides this vivid eyewitness account of the oncoming flood:

*We drove west of Naponee to watch the water come. We were on a hill, with the river and valley just below it.*

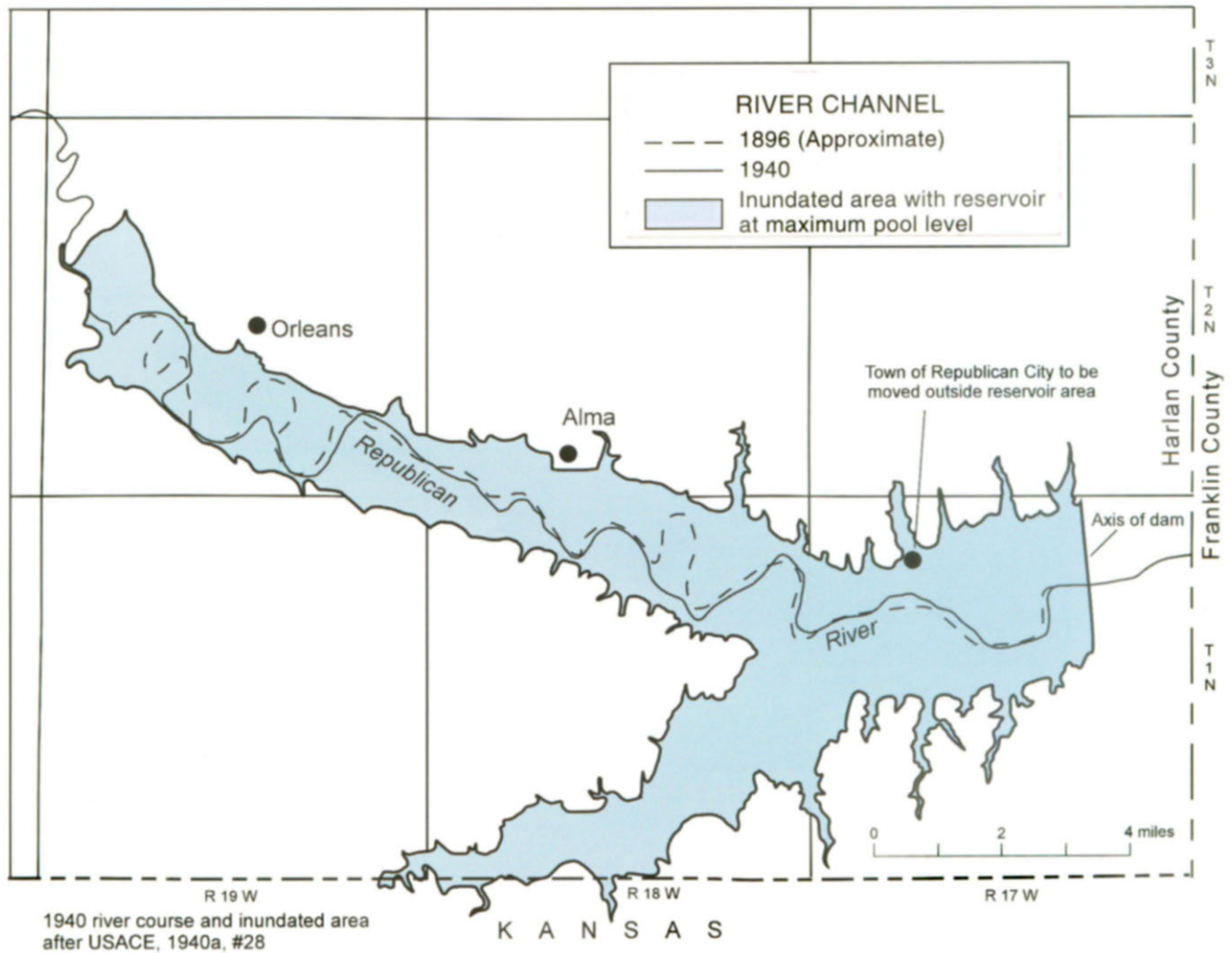


Fig. 3. Republican River channel locations in 1896 (USGS) and in 1940 (USACE, 1940a), showing area to be flooded after dam construction.

*The sight was such a shock. The river was not out of its bank, yet it was bank full and the center of the river seemed to be ten feet higher than the banks. In the middle of the river was a solid mat of trash. It looked as if one could walk on it without getting your feet wet. Looking west, we could see a rolling wall of water about four feet high, from bluff to bluff. We saw it hit the railroad grade and twist those rails off as if they were paper.*

Haigler, Nebraska, was spared severe damage due to its location on high ground. However, several Nebraska communities, such as Parks, Benkelman, Max, Stratton, Trenton, Culbertson, McCook, Holbrook, Edison and Naponee, were affected, some severely, by the flood. In addition to these communities, deaths were also reported in Perry, Cambridge, Arapahoe, Oxford, Orleans, Alma and Franklin. Two families, of eight and six, lost their lives at Benkelman and Culbertson, respectively. Both of the homes, along with their residents, were swept away.

Below Trenton, Nebraska, where the speed of the water decreased from 7 to 4 miles per hour, ample warning time

was given. However, the warning fell on many deaf ears. Most did not realize the unprecedented depth of the water and refused to believe their homes were in danger. When the flood arrived, once again reported by some as a deafening roar, the water rose quickly, cutting off several escape routes. In addition, it was still night. Although some did manage to barely escape, a total of sixty people lost their lives along this part of the river. The largest death toll occurred in and around Oxford, Nebraska.

The Oxford Rotary Club's historical marker on U.S. Highway 136 near Oxford describes the size and speed of the flood (Hunt, 1974):

*The rains of May 30<sup>th</sup>, concentrated in the basin of the South Fork and extending into the valleys of the Arikaree, Frenchman, Red Willow, and Medicine, poured into the main stream normally 300 to 400 feet wide, turning it into a raging torrent one to four miles wide. The flood water came as a wall, variously estimated at from three to eight feet in height. The advance of the crest was more rapid in the upper valley, reported at ten miles an hour*





*Fig. 4. Aerial photograph of Harlan County Lake area in 1951 during construction of dam (CSD photo).*



*Fig. 5. Color infrared aerial photograph of Harlan County Lake area in 1988 after dam construction. Healthy vegetation appears red; dormant areas are gray-green. Water appears blue to black (CALMIT image).*

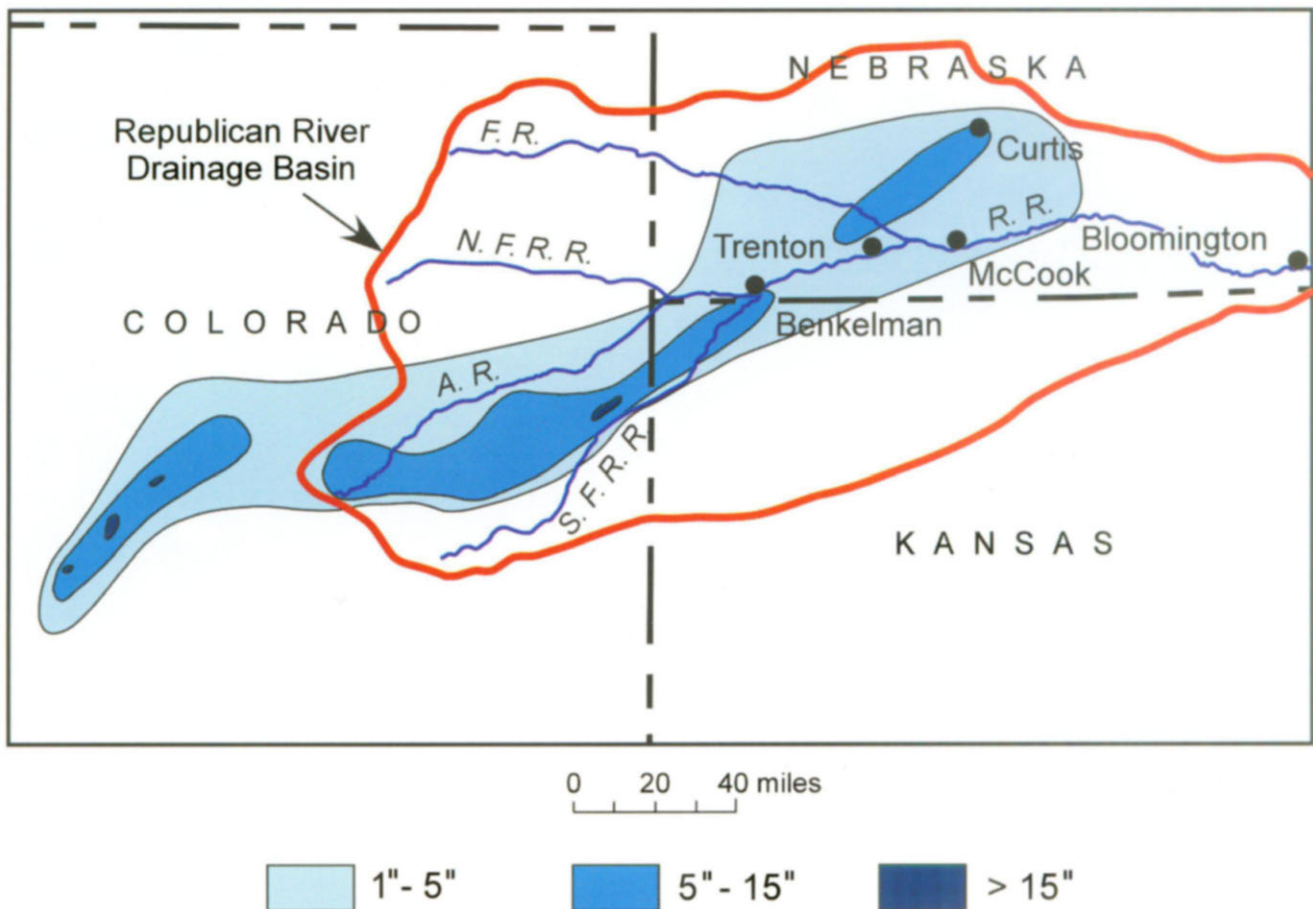


Fig. 6. Areas of Colorado, Kansas, and Nebraska with major precipitation events from May 30-31, 1935 (modified after Follansbee and Spiegel, 1937, fig. 6).

above Trenton, at five between there and Oxford, and slowing to two and one-half miles an hour upon crossing over into Kansas.

The June 6, 1935, edition of the *Oxford Standard* reported:

*Reports and warnings came to Oxford early Friday evening [May 31, 1935] that water was then five feet deep in the streets of Cambridge.*

*Several people sensing the danger had remained at the river all night. Dwellers on the low lands were warned of their danger, and in some cases trucks were waiting to take them to higher ground, but they had lived there so long and seen so-called high water so many times without trouble, that all warnings and proffered help were rejected, with perilous results.*

*When the houses began to fill up, and were finally toppled over by the force of the swift current, shrieks for help could be heard, but shrouded by darkness, nothing could be seen, [and it] presented a picture that is impossible to describe. As daylight broke, those on shore had been pushed back by the ever rising waters until the scene of the disaster was invisible except by the aid*

*of field glasses, and all sounds were hushed by the roar of the raging river.*

*Taking in the 5-mile stretch west of Oxford, the Fuchs' families suffered the heaviest fatalities. According to the survivors, as the water rose in the houses, the inmates [climbed] up into the attic, kicked in a hole in the roof, and climbed outside. Presently the houses began to float, but only went a short distance before the bottom struck trees or other objects and began to roll. Their human loads were thus dumped off into the swirling waters. Sometimes they would be successful in grabbing some objects, only to be brushed off like flies by floating debris. Thus it was a continuous fight until overcome by sheer exhaustion, rendering them an easy prey for the angry water.*

This same issue of the *Oxford Standard* described the size of the flood and resulting scene as follows:

*There was destruction and tragedy all about. Here and there could be seen the shells of what once were farm homes and barns. Telephone and electric line wires were tangled messes. Trees which for many years had given shade for tired farm families were torn from their roots.*

Some idea of how much the present flood exceeded previous high marks is exemplified in the following observation. The Clarine family had occupied the same site on the river for the past 70 years, and flood waters had never even approached the home during this time. This house had a lean-to that is more than 10 feet high. The lean-to was completely submerged when the water was at its height.

Finally,

*All buildings, horses, cattle, hogs, chickens, in fact everything movable that [was] in the main body of water [was] swept away. To give the reader some idea of the force of [the] current, heavy machinery, cement blocks, etc., brought from no-telling where, now dot the farm land three and four hundred feet from the river.*

As a result of its location on the confluence of Medicine Creek and the Republican River, the area of greatest discharge of the flood, the community of Cambridge, Nebraska, was devastated. Seventy-five percent of the homes suffered flood-related damage, and only twenty remained on their foundations. Seventy-six people were rescued by boat from the tops of nearly submerged homes.

The area between Cambridge and Arapahoe had the largest streamflow ever recorded within the borders of Nebraska: 280,000 cubic feet per second (Nebraska Department of Natural Resources, 2001a). Normally, this section of the river would not exceed 1,000 cubic feet per second. For comparison, the average flow of the Missouri River at Omaha, during the last half of the 20<sup>th</sup> century, was 29,500 cubic feet per second (U.S. Geological Survey, 1950-2000). In the Cam-

bridge to Arapahoe stretch, the river overflowed the valley for approximately 2 miles.

McCook, the largest Nebraska city on the Republican River, is situated on higher ground and experienced minor flooding. However, the city's water system was stopped when the local power plant was flooded. Forty of the power plant's employees spent a harrowing 24 hours on the roof of the plant waiting for the flood waters to recede. Only then could rescue boats safely reach them.

Adding to McCook's problems was a tornado approximately 6 miles west of the city on the afternoon of May 31. The storm's strong easterly winds caused a thick dust storm over the McCook area that lasted about 30 minutes.

The major flood waters did not arrive farther downstream until daybreak. As a result, the loss of life there was not as great. Those lives lost were due mainly to lost time trying to save personal property and livestock.

Trees along the river banks helped prevent the loss of additional lives. All along the flood route, there were reports of families climbing trees to safety. Near Culbertson, Nebraska, a family of twelve saved themselves in this manner. Occasionally, families who sought safety in the trees found they had another challenge besides the raging water. Many of the riverbank trees were already harboring wildlife also seeking safety, such as snakes, rats and other animals. Already fatigued, the families had to make a great effort to keep the wildlife at a safe distance.

The damage in the three-state basin – Nebraska, Colorado and Kansas – was staggering (table 1): 110 people killed; 20,593 head of livestock killed; nearly 275,000 acres of farmland damaged (most of it growing crops); about 1,000 miles

**Table 1. Damage from Flood of 1935, Southwestern Nebraska**  
(from: U.S. Geological Survey Water Supply Paper 796-B)

	Nebraska	Kansas	Colorado	Total
<b>Persons killed</b>	94	10	6	110
<b>Livestock killed</b>	8,100	12,193	300	20,593
<b>Poultry killed</b>	46,500	NA	NA	-----
<b>Highways damaged (miles)</b>	341	484	5	830
<b>Highway bridges</b>	307	202	6	515
<b>Crops damaged (acres)</b>	42,000	221,507	NA	-----
<b>Farmland damaged (acres)</b>	57,000	202,615	15,000	274,615
<b>Railroads (miles)</b>	NA	171	NA	-----
<b>Railroad bridges</b>	NA	83	NA	-----

NA - not available

of highways and railroad tracks damaged or destroyed; and close to 600 highway and railroad bridges damaged or destroyed.

Nebraska's share of the storm damage was severe: 94 people killed; 8,100 head of livestock killed; 46,500 poultry killed; 341 miles of highway damaged or destroyed; 307 highway bridges damaged or destroyed; and 57,000 acres of farmland damaged (42,000 acres in crops). The storm also caused havoc in northwestern Kansas, where 1,485 homes and 1,552 other buildings were flooded.

With 94 Nebraska fatalities, this flood was the most deadly weather-related event on record in the Hastings (Nebraska) County Warning Area (CWA) during the 1900s (National Weather Service, 2001). The Hastings CWA comprises a 24-county area in south-central Nebraska and six counties in north-central Kansas.

Bernice Haskins Post, in her 1936 account of the flood, gives the following description of the losses she and her family endured. Her experience undoubtedly reflects those of many others who lived in the region. In describing her farm, she wrote:

*Everything was gone but the house, barn and upright silo; and what a condition it left them in. It was at this time that we realized that our dreams of a permanent home were washed up. Both tile ends were out of the barn; all floor supports gone; looked as though the floor would fall any minute. About 150 young chickens were saved; the rest had flown down to the water to their grave. The crop loss was total: killed all the 50 acres of alfalfa. The machinery loss heavy. The land was not washed badly. Perhaps the alfalfa roots and hay helped hold it. Our total was estimated at \$5,000. The house didn't look as though we could ever live in it again. The water had been 40 inches deep and the mud was 12 inches deep. All windows broken, porches washed off. Even one interior wall moved.*

The Chicago, Burlington and Quincy Railroad lost more than 40 miles of roadbed, with several more miles rendered unusable because ballast and fills were swept away. The line did not operate from May 31 to June 23. On June 23, service was restored on temporary tracks. Reports stated that the force of the water was so great that rails were actually twisted. The *Oxford Standard* mentions one report that the tracks near Arapahoe were turned into a corkscrew and that some of the ties were standing on end. Other reports detailed how some sections of track were uplifted and resembled a picket fence. The Chicago, Burlington and Quincy Railroad alone suffered \$1.5 million in flood-related damage.

The total property value lost in Nebraska was estimated at between \$8.7 and \$13 million. In year 2000 dollars, this would equal between \$109.4 and \$163.4 million.

The huge numbers of livestock killed in the flood were a serious health hazard. This was especially true near Bartley, Nebraska, where a tree-lined bank in the bend of the river captured numerous carcasses. Adding to the health menace

was the problem that such "log jams" also caught great numbers of live rattlesnakes. The day after the flood, the local newspaper reported that forty rattlesnakes were killed in the area.

After the flood, the destruction of the carcasses was a top priority. Along the river lay dead cattle, horses, mules, hogs, sheep and chickens. To assist local workers, the federal government deployed 1,600 Civilian Conservation Corps and other emergency and relief workers. When this task was complete, attention turned to the massive clean-up of the landscape and emergency restoration of public works. For this, the federal government extended \$434,000 in aid to Nebraska.

Later in June 1935, the clean-up and reconstruction efforts would suffer a setback. The June 20, 1935, edition of the *Oxford Standard* summarized it best:

*A precipitation of 3.10 inches of rain at Oxford Sunday [June 16, 1935] night, and of equal proportion covering wide territory, put every creek from Alma to McCook at flood stage, and sent the Republican river on another rampage. Turkey creek is said to have been the highest ever known, running over the railroad track, and taking away much of the new fill at the bridge.*

*The Republican river was spread out all over the bottom all day Monday [June 17, 1935], as a result of local rains Sunday night. A cloud burst north of Trenton and Culbertson put two feet of water in the streets of those two towns in almost a twinkling of an eye, and the low lands at McCook were soon again under water, and the city light plant was again out of commission. Bartley, Cambridge, Holbrook, Arapahoe, and Edison were in turn inundated as the crest of the new flood swept eastward.*

*Reconstruction and rehabilitation programs received a set back, and many fields will have to be replanted a third time as the water inundated thousands of acres of land. It did not seem possible that water could do any further damage in the Republican valley since the ravages of the high water of May 31, but it did.*

This additional flooding in mid-June swept away and/or destroyed many of the few remaining buildings spared by the main flood of late May and early June.

To prevent this type of disaster from happening again, the federal government, as part of the 1944 Flood Control Act (commonly referred to as *The Pick-Sloan Act*), authorized and constructed a series of dams on the Nebraska section of the Republican River and its tributaries. Not only have these dams helped to prevent another such flood, they also have provided sources of irrigation and recreation. Some of the resulting reservoirs built in Nebraska include: Swanson Lake (1953) and Harlan County Lake (1952) on the Republican, Enders Reservoir (1951) on Frenchman Creek, Harry Strunk Lake (1949) on Medicine Creek, and Hugh Butler Lake (1962) on Red Willow Creek. In the process, numerous farm ponds on smaller tributaries were also created.

## Events After the Flood Leading to Creation of Harlan County Dam and Lake

After The Flood of 1935, the federal government granted authority for a preliminary examination and survey of the Republican River in Nebraska and Kansas in the Flood Control Act of 1936 (USACE, 1940c). The survey was assigned to the USACE District Engineer in Kansas City, Missouri, on December 19, 1939. The report of the survey, together with six appendices, was completed and published on February 27, 1940. Plans for flood control in the Republican River basin were the main purposes of the survey, even though opinions of citizens at meetings held in parts of the upper basin put irrigation first in importance and flood control second (USACE, 1940c, p. 94-95). The potentials for irrigation, development of hydroelectric power, improvement of navigation, and for recreation, wildlife conservation, and abatement of stream pollution were also addressed. Eighteen potential sites on the main stem and tributaries of the river were studied for flood control, and ten were also considered for multiple-purpose use. Of these, the Harlan County site was deemed best and economically most justified. It was assigned a cost/benefit ratio of 1:2.35 (USACE, 1940c, p. 145), which projected that the cost of the dam would result in returns of 2.35 times the original cost over the estimated life of the dam.

The report (USACE, 1940c) and three of the six appendices (USACE, 1940a, b) are currently in the collections of the University of Nebraska libraries. They include detailed statistical and map data related to The Flood of 1935 (and earlier ones), the geology of the potential reservoir sites, rainfall in the basin, and related information. Maps of inundated areas along the Republican River and its tributaries in The Flood of 1935 (fig. 2), inundated area of the proposed Harlan County Lake (fig. 3), and cross sections across the valley at all proposed dam sites, including the one at Harlan County Lake, are included in Appendix I of the USACE report (1940a). Descriptions of the unconsolidated sediments and the rock strata at each site are included in parts of Appendix V (USACE, 1940b).

According to written information given to the public at the Harlan County Lake visitors center (USACE, 1951), construction of the dam and reservoir was authorized by Congress in the Flood Control Act of August 18, 1941. The project was later revised and approved in the Flood Control Act of December 22, 1944. Construction of the earthen dam was started on August 1, 1946 (USACE, 1951), and completed in 1952 (USACE, 1999). Republican City was relocated to a site higher on the valley side about 2 miles to the northeast during the construction period.

The completed Harlan County Dam is 11,830 feet long and 107 feet high. The top of the multi-purpose pool has an area of 13,250 acres, the flood-control pool 23,100 acres, and the total land and water, 31,000 acres (USACE, 1999). In keeping with its multi-purpose nature, the lake area has excellent hunting and fishing, boating, and other outdoor activities. Several excellent play, camping and picnicking areas, as well as marinas, are maintained around the lake (figs. 7-9). An area



*Fig. 7. Playground near visitor center.*



*Fig. 8. Picnic shelter.*



*Fig. 9. Dredge clearing harbor and marina of sediment*

with a protected prairie dog village is located along the road north of the visitor center and south of the relocated Republican City (figs. 1, 10-11). The dam has served its purposes since it was completed. No major flood has hit the area east of the dam with waters that fell west of the dam since 1952. Irrigation of land downstream of the dam is accomplished by diverting water during the irrigation season into the Franklin and Napone irrigation canals (USACE, 1951). Normal water levels fluctuate about 9 feet annually (USACE, 1951).

## Stormer Ford Dog Town

This prairie dog town is just south of the main entrance to the land controlled by the U.S. Army Corps of Engineers on the road leading south to Harlan County Dam from Republican City. The town (also called a *colony* or *village*) covers parts of the NE and SE, NW SW, sec. 35, T.2N., R.17W. (fig. 1) generally west of the road. Black-tailed prairie dogs (*Cynomys ludovicianus*; fig. 10) have established a town of about 15 acres. Meriwether Lewis was the first Euro-American to record a description of prairie dogs. His description is recorded in journal entries of April 7, 1804, during his trip up the Missouri River in Nebraska with William Clark and others making the famous Corps of Discovery expedition.

According to the information posted at the site and from other sources (Gunderson, 1966; Booth, 1961), adults of this species reach maximum weights of about 3 pounds

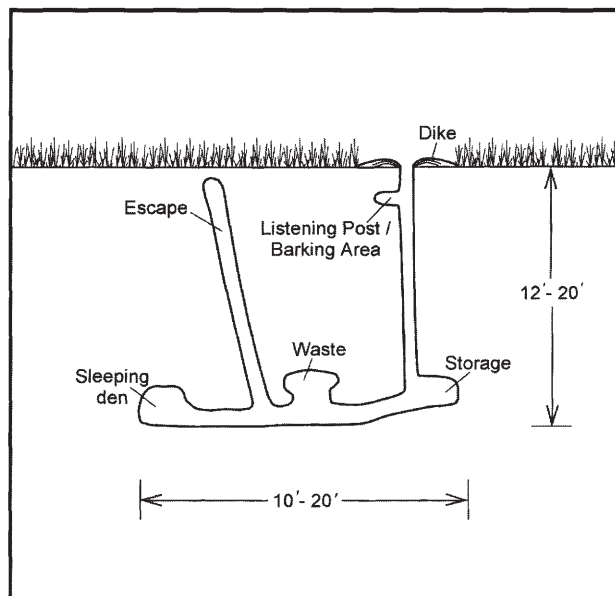


Fig. 11. Cross section of prairie dog burrow (after U.S. Army Corps of Engineers display at site).



Fig. 10. Prairie dog.

and lengths of about 16 inches. They have yellow-gray to brown fur, a short, flat tail, and pouched cheeks. Their colonies can contain from twenty to more than 10,000 individuals (one account from Texas in 1852 notes a village with about 50 million individuals!). Prairie dogs usually are less active during cold seasons. They are known for their barking signals when alarmed.

Family units consist of one male, several females, and their young. The prairie dogs reproduce in the spring of the year. After 28 days gestation they give birth to a litter with two to nine offspring. The young stay in the burrow for about 5-6 weeks before coming out to the surface (fig. 11). Prairie dogs eat woody plants, grasses, and some insects. Their enemies include humans, owls, hawks, eagles, coyotes, foxes, minks, weasels, and snakes, all of whom can eat or kill prairie dogs.

Much has been said about the damage done by prairie dogs that can actually or potentially affect humans in one way or another, but the positive impacts of these animals have often been overlooked. Two of these are related to burrowing. The burrows provide conduits for water running off the land surface, to recharge water in the unsaturated zone above the water table and to feed groundwater. Secondly, the burrows aid soils aeration. Both of these are important contributions to plains ecosystems.

## Water

### Surface Water Hydrology

Because the primary purpose of the Harlan County Dam was to provide flood control and supply water for downstream irrigation districts, it is important to have a general understanding of the surface water system in the area. The drainage area upstream from Harlan County Lake is approximately 20,750 square miles, but only about 13,530 square miles contribute directly to surface runoff (Engel, 2001). Streamflow in the basin can be highly inconsistent due to the variable climate of the region. Location and intensity of individual storm events, as well as variable weather patterns, contribute

to streamflow variations on a daily and seasonal basis.

Reservoirs are useful for irrigation purposes because they can store water at times when streamflow is abundant and release it any time it is needed. For the Harlan County Lake, the top of the conservation pool is at 1,946 feet above MSL. The lake at this level stores about 150,000 acre-feet of water (an acre of water one foot deep) and has about 75 miles of shoreline. At this level, the surface of the lake is approximately 13,250 acres. For flood-control purposes, the dam can store 809,700 acre-feet of water to an elevation of about 1,973.5 feet (at the top of flood-control pool). At this level, the surface of the lake would cover about 23,100 acres.

The reservoir releases water below the dam to the Franklin and Naponee canals, as well as to the Republican

River, which in turn supply water for irrigation purposes to the Franklin Irrigation Unit and Superior-Courtland Irrigation Unit in Nebraska and the Courtland Unit in Kansas (USBR, 2001b). These units are all part of the Bostwick Division of the Bureau of Reclamation irrigation projects. Figure 12 shows the mean daily discharge for the Republican River for water year 2000 (October 1, 1999-September 30, 2000) at a stream gauge located 2.8 miles below Harlan County Dam. It provides a graphical one-year example of how flows in the Republican River in this area are completely regulated by Harlan County Dam. During January and February, 10 cubic feet per second of water was released as part of

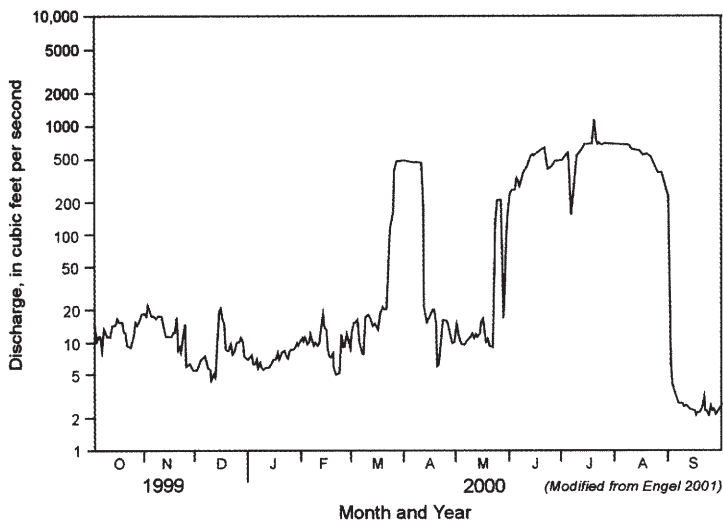


Fig. 12. Mean daily discharge of the Republican River 2.8 miles below Harlan County Dam, water year 2000.

the USBR environmental plan (USBR, 2001b). During March and April, excess water from the flood control pool was released at a nearly constant rate of about 500 cubic feet per second. Water was then held back again until releases for irrigation purposes began on May 22, 2000. Releases terminated on September 1 with the end of the irrigation season.

Harlan County Lake levels follow a typical seasonal pattern of decline during the irrigation season and rise during the rest of the year, with the magnitude of the fluctuations primarily influenced by climate in the drainage basin. Figure 13 shows for water year 2000 how the volume in Harlan County Lake rose through the fall, winter, and spring months and then dropped in the summer with the irrigation season releases to the Republican River and Franklin and Naponee canals.

Bentall (1991) explains that the Republican's average annual discharge is dominated by the surface runoff component of flow; for instance, the Republican River has much less groundwater contributing to its discharge, compared to the Loup and Niobrara rivers in Nebraska. Also, despite having a much larger drainage basin than the Loup and Niobrara rivers, the Republican River average discharge is much less than those and other rivers in the state. For example, the

Republican River at Hardy discharged an average of 898 cubic feet per second during 1933-1952. This compares to an average discharge of 1,584 cubic feet per second for the Niobrara River near Verdel during the period 1959-1989.

Flooding on the Republican River, including the 1935 flood, was discussed in an earlier section of this circular. The high flow of the 1935 flood is in sharp contrast to historical flow data for the river. According to Engel (2001), the annual mean discharge for water years 1958-2000 is 353 cubic feet per second. It is interesting to note that the highest flood of historical record occurred during the drought of the 1930s. In fact, about a year earlier, on August 9, 1934, no flow was

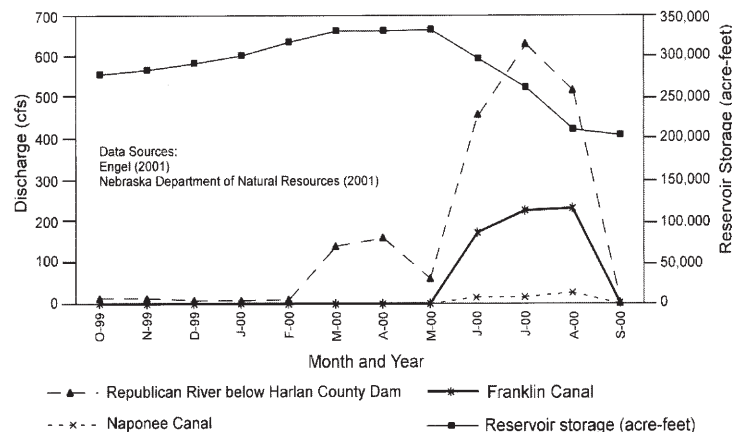


Fig. 13. Harlan County Lake end-of-month storage and average monthly discharge for gauges below Harlan County Dam, water year 2000 (Engel, 2001; Nebraska Department of Natural Resources, 2001b).

recorded for the Republican River at Hardy. According to Bentall (1991), only the gauging station near Hardy has a record long enough to provide evidence of the Republican River's discharge before major irrigation and flood-control facilities were constructed in the basin. To compare and contrast, the Republican River had an average annual discharge of 898 cubic feet per second during the 1933-1952 period, while during the period 1953-1989 after the Harlan County Dam was completed, the Republican River had an average discharge of 346 cubic feet per second.

Regulation by dams in the basin, including Harlan County Dam, has significantly affected the size and frequency of floods on the Republican River. Figure 14 indicates how regulation has resulted in much less variability in flow in the Republican River after Harlan County Dam was constructed. The dam's effect on controlling floods is evident by the lack of high values for annual peak streamflow at the Hardy gauge after the dam was constructed.

Szilagyi (1999) identified a trend of decreasing streamflow over the past 40 to 50 years at many locations in the Republican River basin. Because much of the streamflow in the Republican basin is derived from the upper parts of the wa-

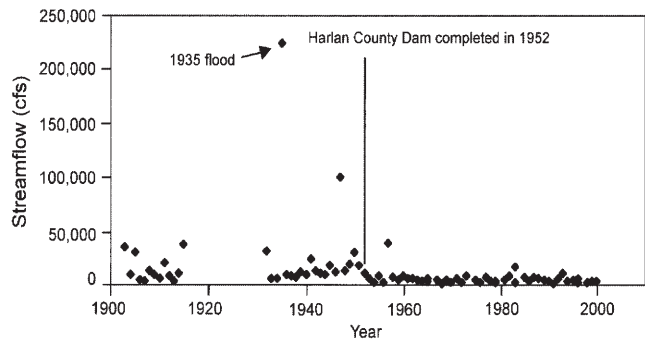


Fig. 14. Streamflow in cubic feet per second (cfs) for the Republican River near Hardy, Nebraska.

tershed, which lie outside of Nebraska in Kansas and Colorado, flow measured near Hardy where the Republican River flows from Nebraska into Kansas is consequently affected by activities outside of Nebraska. A greater percentage of streamflow at Hardy is now generated in Nebraska than used to be due to greater declines in streamflow outside of Nebraska – in Colorado and Kansas in the upper reaches of the watershed.

According to Szilagyi (2001), decline in basin runoff, observed in recent decades in streamflow records from the Hardy gauge, are not due to changes in climate; that is, there has been no observed trend of declining precipitation in the basin. Instead, the declining flows are due to a combination of factors, including the construction of reservoirs and ponds in the basin, increased crop irrigation (center-pivot technology bringing more land into production), changes in vegetative cover on the landscape, and the introduction of water-conservation practices. Most of these changes are the result of human activities and have increased the amount of water lost to evaporation over the basin and decreased the amount of water available to runoff to the rivers and streams.

Beyond their effects on flood control, Earth scientists are gaining an increasing understanding of the downstream effects of dams. Information is available to the general public from recent studies done on such high profile rivers as the Snake, Colorado and Platte (Collier and others, 2000). Like these rivers, the Republican has had its natural character altered by the regulation of its flow. Williams and Wolman (1984) documented changes in vegetation and channel morphology in the Republican River valley below Harlan County Dam. In 1949, prior to construction of the dam, the Republican was a typical braided river with active islands and bars consisting of clean sand separated by broad channels of open water. By 1956, it had changed to a system of thin, narrow channels of water around islands fixed with dense willow vegetation. In fact, they observed a 60 to 80 percent increase in area covered by vegetation along a 19.88-mile reach of the Republican River below Harlan County Dam for the period 1949-1956. From 1956 to 1980, there was an observed change in vegetative area by 85 to 95 percent. They attributed these changes primarily to the decrease in peak flows that resulted from the construction of the dam in 1952. Similar changes were observed below Trenton Dam in Hitchcock County as well.

Another well-documented downstream effect of dams on alluvial streams is the process of streambed degradation. Dams tend to trap most of the incoming sediment of a river. This adversely changes the nature of the river flow and channel downstream of the dam. Without the sediment load, the river will tend to scour its bed and banks below the dam. The increased erosive power is due to the river not having to use energy to transport the sediment trapped by the reservoir (Williams and Wolman, 1984). This lowering of the channel bed below a dam has been observed in Nebraska at several locations. According to Chen and others (1999), the channel of the Republican River just below the Harlan County Dam degraded at a rate of 0.279 feet per decade over the period 1952-1992; however, the maximum possible degradation is probably restricted by the presence of bedrock at shallow depth. Examination of test-hole records located 0.5 mile upstream and downstream of the gauging station indicate that the bedrock is probably less than 10 feet below the datum of the gauge (Burchett and Summerside, 1997). Emergence of such bedrock is one control that can limit the progression of streambed degradation (Williams and Wolman, 1984).

## Shoreline Springs and Seeps

### Introduction

During periods of lower lake level, the observant explorer will find springs and seeps issuing from some of the outcrops along the shorelines surrounding the lake. Most of the springs are typically the seepage points of waters that have moved downward from the surface through very permeable material, or through vertical fractures in the rock. Then at some depth below ground they have encountered a less permeable geologic unit such as a clay layer, or shale (called *aquitards* by Earth scientists). These aquitards force the water to turn and flow laterally above the contact, or through a more permeable overlying bed until it seeps out at the surface of an outcrop. Because their origin is from waters moving down from the surface, these seepage springs are usually more active and have greater flow volumes following a rain storm or during prolonged wet periods. Another type of spring that occurs in the area is a groundwater discharge spring. It may result from the outflow of more regional groundwater that moves laterally toward the lake through the various geologic units (called *aquifers*) over much longer periods. These springs tend to flow more consistently throughout the year, as their flow is not directly dependent on local rainfall events.

### Using Water Chemistry to Identify Spring and Seep Origin

One way to identify the potential source or sources of the water from the springs is to evaluate the chemistry of the water flowing from the spring. Regional groundwater discharge springs will likely have a higher concentration of dissolved ions because their waters have been in contact with the rocks or sediments of the aquifer for longer periods of time, having flowed over longer flow paths. In contrast, seepage springs will have lower concentrations of dissolved ions



because they originate as very dilute rain-water and because they have not been in contact with the rock or sediment for extended periods of time, having flowed over shorter paths.

To illustrate this relationship, water samples were collected from two springs near the lakeshore, one believed to be a seepage type and one a discharge type (figs. 1, 15; table 2, sites 4, 35). The waters from both springs were analyzed for major ion chemistry and the results of these analyses appear in table 3.

The first water sample (table 3, no. 1) was collected from a spring flowing from the Pierre Shale at site 4 about 0.8 mile east of the Alma Vista Picnic Area (figs. 15, 16) along the southern shoreline. It is high in calcium, magnesium, sodium, and chloride ions, as well as extremely high in sulfate ions. These elevated concentrations imply that the water has been dissolving minerals for a long time. These concentrations may

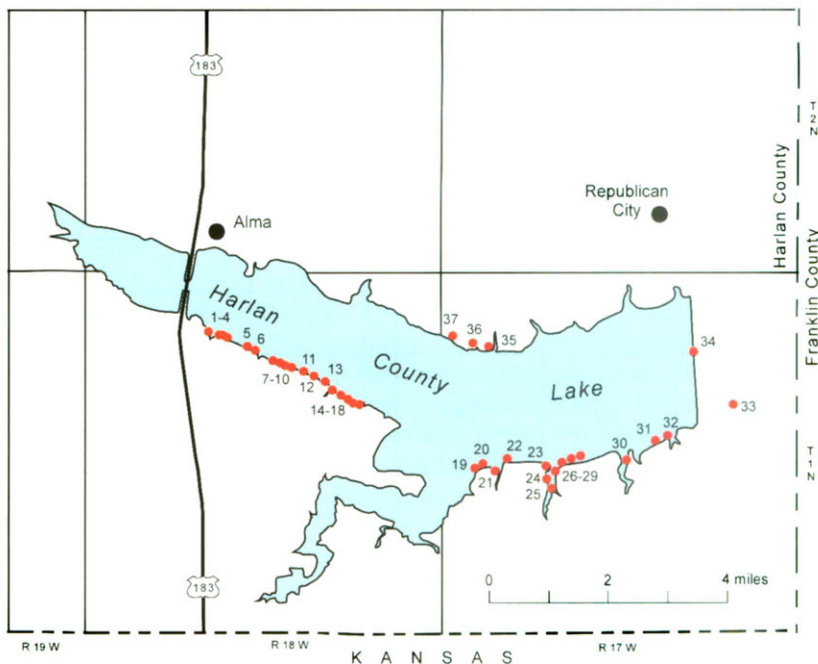


Fig. 15. General locations of sites with significant geologic features noted in table 2 and in the text.

**Table 2. Locations of Geologic Features at Harlan County Lake Shoreline and Other Sites**

Site No. (see fig. 15) - Geologic Feature(s)

1. Pierre Shale covered by Quaternary loesses and other deposits — to west only Quaternary present to low pool level. Paleosols in these deposits dated by Martin (1992 a, b). Pierre with two small normal faults.
2. Angular unconformity between Niobrara Formation and Pierre Shale; Pierre nearly horizontally bedded; Niobrara strikes about N45° E and dips at about 3° NW. Also two reverse faults in Pierre Shale.
3. Normal fault upthrown on west.
4. Pierre Shale with local apparent dips of 5° E; local seeps of highly mineralized groundwater from within Pierre.
5. Ancient landslide or brecciation associated with faulting in the Pierre Shale.
6. Normal fault.
7. Pierre Shale at low pool level.
8. Normal fault. Down on east.
9. Normal fault.
10. Central keystone block in Pierre Shale uplifted along opposing reverse faults.
11. Beds dip about 4° NE.
12. Ogallala Group, Ash Hollow Formation, sandstones and conglomerates (manganese oxide stained) in paleovalley in Pierre Shale. Thick Quaternary loesses overlie Ogallala and Pierre. Many landslides with considerable scarp retreat in this area.
13. Ancient landslide in Quaternary Gilman Canyon Formation.
14. Normal fault. Down on east.
15. Normal fault(?) with Niobrara up on west.
16. Monocline in Pierre Shale with apparent dip of about 6° NE.
17. Niobrara Formation cliff probably up along a hidden fault to west beneath thick Quaternary deposits.
18. Very thick Quaternary loess deposits from here east to Sindt Point; Quaternary fluvial terrace at White Cat Point.

**Table 2 (continued).**

Site No. (see fig. 15) - Geologic Feature(s)

19. Normal fault in Pierre Shale. Fault may extend into overlying Quaternary.
20. Normal fault in Pierre Shale.
21. Pierre Shale exposure with dipping beds.
22. Well-developed joints in Niobrara Formation exposed along shore at low pool stand. Three sets present? E-W, NE, and NW striking.
23. Ogallala Group blocks along shore below high pool strand line.
24. Ancient landslide in Quaternary Gilman Canyon Formation (see Johnson, 1996; Miller and Steeples, 1996).
25. Niobrara Formation forms core of island in Bone Cove.
26. Ogallala Group, Ash Hollow Formation, paleohill covered by Quaternary deposits including Ash Hollow landslide blocks in Quaternary deposits on slope of hill.
27. Normal faults dipping eastward.
28. Pierre and Niobrara with apparent 11° SW dip.
29. Normal fault dipping westward.
30. Recent landslide near housing development.
31. Pierre Shale with apparent 4° E dip.
32. Normal fault in Pierre Shale downthrown to the northwest.
33. Angular unconformity between Pierre Shale and Niobrara Formation (Souders and Miguez, 1990).
34. Harlan County Dam spillway (Numerous faults found during excavation for spillway; also across entire valley floor beneath alluvium during excavation; USACE, 1977).
35. North Cove—paleotopography on top of Quaternary Gilman Canyon Formation; springs at the Crete (?) sands and gravels/ Pierre Shale contact. Pierre Shale dips at about 10° SW. Piping in the Quaternary. Dates on Gilman Canyon paleosols by Martin (1993).
36. Krotovina in the Quaternary Gilman Canyon Formation exposed at low pool level.
37. Rapid scarp retreat with “hanging fence”; piping in Quaternary.

**Table 3. Water Chemistry** (Shale - a spring flowing from within the Pierre Shale; Contact - a seep flowing from contact between the Pierre Shale and overlying sand and gravel; Alma groundwater - a groundwater sample collected from a municipal well in Alma; Harlan Co. Lake - sample collected from Harlan County Lake). Concentrations in parts per million (ppm).

Samples	Ions (ppm)							
	Ca	Mg	Na	K	HCO <sub>3</sub>	SO <sub>4</sub>	Cl	NO <sub>3</sub>
Shale (1)	511	142	279	16	11	2290	371	15
Contact (2)	85	15	14	6	313	26	26	6
Alma ground-water	68	14	10	9	288	18	9	17
Harlan Co. Lake	81	23	44	16	328	81	31	10

be further increased by the evaporation of some of the water as it flows from the rock. As the water evaporates, it becomes supersaturated with the mineral gypsum ( $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ), which will precipitate as a white deposit on rock faces below the spring. The high sulfate concentrations found in the water probably occur as a result of the oxidation of the iron-bearing mineral pyrite ( $\text{FeS}_2$ ) found in the shale. This oxidation forms the sulfate ( $\text{SO}_4$ ) ion, which is carried away in the water along with iron ( $\text{Fe}^{II}$ ) as the water flows through the shale.

The second sample (table 3, no. 2) was collected at site 35, along the north shore just west of North Cove (figs. 15, 17; table 3) from a spring flowing at the contact between the

upper surface of the Pierre Shale and the overlying sand and gravel (capped by *loesses* – windblown silt). This water is much more dilute than sample 1 and contains primarily calcium and bicarbonate as the dominant ions. Its chemistry is similar to the chemistry of water samples from Harlan County Lake and of local groundwater (*see table 3*) collected as part of a previous study in the region conducted by Schellpeper and Harvey (1999). This similarity suggests that this seepage spring originates as rainfall or shallow groundwater derived from rainfall that has moved downward through the soil and loess and then laterally above the top of the shale aquitard to seep out at the face of the outcrop. As the water moves downward vertically through the overlying sediments, it dissolves the mineral calcite ( $\text{CaCO}_3$ ) present in the sediments and acquires its reported concentrations. All of the samples collected in the area contain elevated levels of nitrate ions ( $\text{NO}_3$ ). Elevated nitrate concentrations are typically associated with agricultural practices across a region. Fertilizers applied to area fields are leached by percolating soil water, which transports the nitrate down to the groundwater in the underlying aquifer.

Fig. 16. Spring flowing from the Pierre Shale at site 4. Note salt crusts along base of exposure.

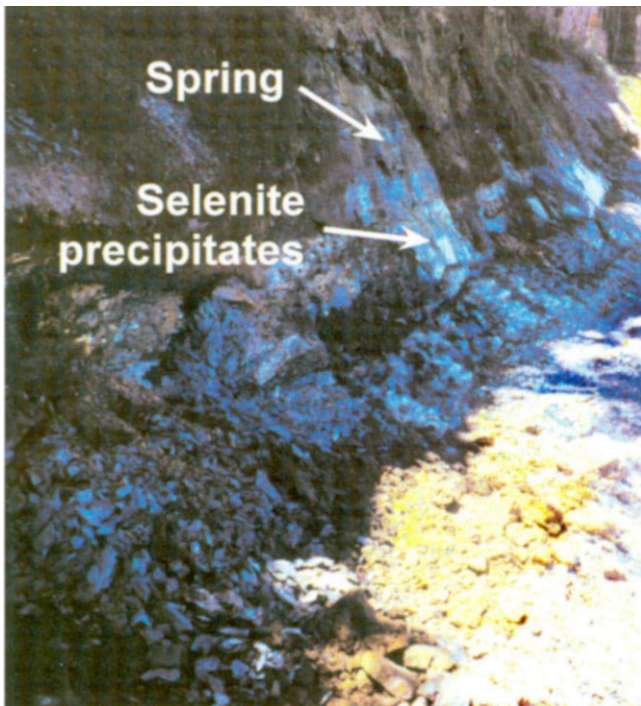


Fig. 17. Springs from the Crete (?) sands and gravels at North Cove, site 35. Pierre Shale is in the foreground.



## Geology

### General Conditions Leading to Good Exposures

What effects other than those in the original plans, detailed in the sources cited above, resulted from completion of the dam? Three that come to mind, certainly, are the delta forming at the head of the lake, the filling of the lake basin with stream- and wind-borne deposits, the headland (promontory) retreats due to wave erosion, landslides, and the erosional effects of prop wash from boats. Headland retreat has been especially good for geologists and people who like to look at well-exposed, interesting geologic formations and features. But this effect, and other shoreline erosion, is not as good for those owning shoreline property where it occurs. Other effects may also be taking place.

### Stratigraphy of Unconsolidated Sediments and Rock Strata

Natural exposures of unconsolidated sediments and poorly cemented bedrock are geologically short lived and generally rare in south-central Nebraska. Where not farmed, the land is mostly covered with vegetation. Human-made exposures along roads, canals, and excavations, unless actively maintained, rapidly are covered by debris from weathering and erosion and by vegetation. Under normal conditions, good natural exposures occur only in stream cuts and where harder rock layers come to the surface.

However, conditions at Harlan County Lake have produced excellent exposures of unconsolidated sediments and the underlying poorly consolidated bedrock. When pool level is high, wind-generated waves break against headlands and actively erode and undermine them. Propeller wash from boats at high pool level may also produce wave erosion of headlands. Some erosion is also due to ice masses being pushed against the bases of cliffs by wind during ice break up. When the headlands are eroded, vertical and near-vertical fractures or joints running in several directions through the bedrock and some of the overlying soft sediments contribute to landslides into the lake. Waves then erode the landslide masses and redistribute the rock and sediment debris along the shore and offshore on the bottom of the lake. Headland exposures in this way are always changing but are also always fresh or relatively fresh. When pool levels are low, either during the annual irrigation season or during droughts, waves do not break on the headlands and natural landslide debris is not removed rapidly. Debris builds up at the feet of cliffs on headlands covering parts or all of the exposures. Only when high water levels return are the exposures cleaned off once again. At these times, bedrock strata and overlying younger unconsolidated sediments are well exposed.

Bedrock strata of Late Cretaceous and Miocene age crop out along parts of the lake's shoreline. The Cretaceous rocks are mostly soft limestones (chalks) and shales, while the Miocene rocks are mostly conglomerates and sandstones (Dreeszen and others, 1973; Eversoll and others, 1998; Waite and others, 1944). Quaternary deposits of sand and gravel, silt and silty clay overlie the bedrock. On the land owned by the federal government, all but one of the older bedrock ex-

posures found during field reconnaissance done for this report are confined to the south side of the lake. This is south of the Republican River, except for one small exposure along the shore just west of North Cove on the north side of the lake. General locations of key exposures studied by Diffendal in 2001 are shown on figure 15 and listed with brief descriptions in table 2.

About 3,500-4,000 feet of older rock strata, mostly of marine origin, are buried beneath the surface exposures (Burchett, 1986). These overlie the ancient, Precambrian crystalline basement rocks. Burchett (1986) showed some folding affecting the lower parts of the older rock strata south of Harlan County Dam in a general way in his cross section along the Kansas-Nebraska border. His Harlan County structural contour map of the top of the Lansing Group shows the effects of this folding in more detail (Burchett, 1995).

### Cretaceous System-Upper Cretaceous Series

#### Niobrara Formation-Smoky Hill Chalk Member

The Smoky Hill Chalk Member is about 420 feet thick in the Harlan-Franklin counties area (Miller and others, 1964). The thickest exposures along the south shoreline southeast of Alma are on the order of 10-20 feet. Much thicker exposures can be seen in roadcuts along the county road on the south side of the Republican River south of Bloomington in Franklin County and about 9 miles east of Harlan County Dam. The chalk is almost exclusively composed of calcium carbonate (calcite). The rock is soft, light to dark gray, and weathers white to light orange on exposure to air. Fossils are very abundant in the chalk, but most are so tiny that they cannot be seen without the use of very powerful microscopes. Most of the fine-grained calcite is composed of biologically secreted structures called *coccoliths* produced by tiny floating (planktonic) haptomonad protists (Margulis and Swartz, 1998) that lived in the former ocean that covered the area in the Late Cretaceous Period (Watkins and others, 1990; Liu, 1994). Fine sand- to silt-sized particles are mostly tests (tiny multi-chambered shells) of foraminifera, a type of protozoan (Loetlerle, 1937). These and other microscopic and macroscopic fossils in the Smoky Hill Chalk will be discussed in a later section of this report. Brown to light tan chert nodules occur near the top of the Smoky Hill where it is weathered and overlain by rocks of the Ogallala Group or by Quaternary sand and gravel.

#### Pierre Shale

The Pierre Shale overlies the Niobrara Formation's Smoky Hill Chalk Member. The contact between the Pierre and Niobrara is sharp, rather than gradational. The Pierre exposures along the south side of the lake range from a few inches to about 20 feet, but in other parts of western Nebraska it is several hundred feet thick where buried. The thickest Pierre Shale in the Harlan-Franklin counties area is about 200 feet in northwestern Franklin County (Miller and others, 1964, p. 13). Pierre Shale is soft, brownish-gray to black in color, fissile (splits along thin planes), and weathers rapidly back to its constituent clays upon exposure to air and water.

Several thin layers of soft, cream-colored bentonite (decomposed volcanic ash) and limestone with coccoliths and foraminifers are interbedded with the thicker shale units of the Pierre. Marcasite ( $\text{FeS}_2$ ) occurs in local nodules that weather to iron oxide and other decay products when the mineral is exposed to air and moisture. Single and intergrown crystals of selenite ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) occur in the shale and along joints cutting across the shale in different directions.

### ***Tertiary System-Miocene Series***

#### **Ogallala Group-Ash Hollow Formation**

Two exposures of the Ash Hollow Formation occur along the south shore of Harlan County Lake at low pool level, one on the east side of Bone Cove near and at its mouth and the second about 0.2 miles northwest of the mouth of Coyote Canyon (fig. 15, sites 12, 26). In the area, the Ogallala Group, including the Ash Hollow Formation, has been well described by Miller and others (1964), so only a brief description will be given here.

At the exposure at Bone Cove, the Ash Hollow Formation consists of light tan to brown unconsolidated sands, some sands with small pebbles, sands weakly cemented with calcium carbonate ( $\text{CaCO}_3$ ), silty sands, and pale green to tan, hard silica-cemented quartzite. Lower limb bones of a Miocene fossil horse and fossil roots (rhizoliths) of plants have been found in the sands here. The exposure northwest of Coyote Canyon is composed of a sand and gravel cemented by manganese oxide (conglomerate), a type of rock known from the formation farther west but not reported previously from Harlan County.

All of the rocks of the Ash Hollow seen at the two sites were originally deposited as unconsolidated sediments principally by streams and rivers originating to the west of Harlan County in the Colorado Rocky Mountains. Some of these strata have cross stratification preserved that is typical of deposition in stream- or riverbeds. Other strata have been modified after deposition by burrowing animals and by soil-forming processes and lack original stratification.

### ***Quaternary System-Pleistocene Series***

#### **Crete (?) Formation (Sands and Gravels)**

Uncemented sands and gravels are locally present above bedrock on the south side of the lake. These discontinuous sands and gravels were deposited by a river that flowed across the area. The gravels include pebbles of granite and other rocks larger than the largest distantly derived pebbles in the Ash Hollow Formation. Johnson (1996) discussed this unit and its possible reassignment to another Quaternary formation. Johnson decided to continue with the name, Crete Formation, for these sediments because their geologic age in the area is still questionable. We have added a parenthetical question mark (?) behind the name to give a note of caution to anyone who uses the name uncritically.

### **Loveland Loess**

The Loveland Loess is a moderate yellowish-brown clayey to sandy silt and fine sand, primarily deposited by wind. It is massive and usually lacks obvious stratification but may be stratified locally (Bradley and Johnson, 1957). The Loveland is present discontinuously in a few spots along the south shore of the lake. It rests unconformably upon either bedrock or, at some sites, the Pleistocene Crete (?) sands and gravels.

### **Gilman Canyon Formation**

Gray to light brown sands to sandy silts with several paleosols (ancient soils) make up this formation. The Gilman Canyon Formation is widespread beneath the Peoria Loess on the south (and north) side of the lake. It may rest upon the Loveland, the older Crete (?) sands and gravels, or the Pierre Shale or Niobrara Formation. It usually blankets pre-existing paleotopography (ancient landscapes) and has deformation and slip planes in places that indicate ancient landslides in the formation after it was deposited. West of North Cove on the north side of the lake, there are numerous nearly horizontal back-filled mammal burrows (krotovina) preserved in the formation (fig. 18). These are mostly visible when the pool level is at 1,936 feet or lower or about 10 or more feet below normal pool level.

### **Peoria and Bignell Loesses**

These loesses unconformably overlie the Loveland or older units and generally form a blanket-like deposit over much of the area. They were also deposited by wind. The Peoria and Bignell loesses are light brown silts to fine sands. They are stable in nearly vertical faces and are typically cut by vertical or nearly vertical sets of joints. The two loesses are separated from one another by a paleosol. Well-preserved fossil land snails occur in these formations.

### ***Quaternary System-Holocene (Recent) Series***

#### **Unnamed Fluvial, Eolian, and Colluvial Deposits**

Many of the cliff faces have sediments exposed above the older Quaternary or bedrock units that were deposited in ancient valleys. These sediments include obvious fluvial (stream) deposits, unstratified or weakly stratified wind-deposited silts and sands, or accumulations of sediments on ancient hill slopes (colluvium). Several ancient soils have been reported in these deposits by C. W. Martin (1990a, b, 1992a, b, 1993).

### **Paleontology of the Various Formations**

#### ***Plants***

There are relatively few reports of fossil plants found in the Harlan County Lake area or in nearby areas, even though they are relatively common when searched for with diligence. Coccoliths, which lived in the Cretaceous seas, make up a major part of the Niobrara Formation, as noted above (Watkins 1997; Watkins and others, 1990).



Fig. 18. Filled animal burrows (*krotovina*) in Gilman Canyon Formation at site 36. Hammer is 1.3 feet long.

The oldest land plant fossils reported from the formations that crop out around the lake include grasses, borages (flowering plants), and trees like hackberry from the Ogallala Group (Thomasson, 1990). Siliceous fossil root traces are also common in parts of the Ogallala, as are opal phytoliths (microscopic silica coverings on the stems of grasses and other plants).

Phytoliths are also common in some of the Quaternary deposits in the area (Twiss and others, 1969). Fossil spruce needles have also been reported from older Quaternary deposits at North Cove by Johnson (1989).

### **Invertebrates**

There are two distinct groups of invertebrate fossils one can observe in the vicinity of Harlan County Lake. The oldest of these fossils are the marine animals that lived in the shallow seas that covered the North American Midcontinent during parts of the Late Cretaceous Period. The youngest of these fossils are aquatic and terrestrial mollusks, the fossils of which are found in fluvial (continental stream), lacustrine (lake or pond), and eolian (windblown) deposits of the Pleistocene age of the Quaternary Period. No invertebrate fossils have been recovered from the Ogallala Group of Miocene age in the study area through 2002, although fossil snails and bivalves have been found in these deposits elsewhere in Nebraska and other states to the south.

Paleontological research along the Republican River goes back to 1858 at least, when B. F. Shumard (1858), M.D., of St. Louis, Missouri, appended descriptions of three ammonoids, one snail, one oyster, six clams, and some fish remains to H. Engelmann's report. W. N. Logan described and illustrated many macro-invertebrate fossils from the Niobrara Formation in western Kansas, and these works served as a standard for the invertebrate paleontology of the Niobrara Formation for many years. Later researchers of invertebrate fossils from the Niobrara Formation described fossil pearls (Brown, 1940); cephalopods (Fischer and Fay, 1953; Jeletzky, 1955, 1961; Miller, 1957a, b, 1968; and Morrow, 1934, 1934); algae (Johnson and Howell, 1948); and crinoids (Miller and others, 1957). Miller (1969), Hattin (1975, 1977,

1982) and Hattin and Siemers (1987) have also reported and illustrated many Late Cretaceous fossils from Kansas. Some of the fossils found in Harlan County are listed in the above publications.

### **Cretaceous Marine Fossils**

#### ***Niobrara Formation***

The Smoky Hill Chalk Member of the Niobrara Formation consists almost exclusively of highly calcareous marine-deposited siltstone. These deposits were laid down as sediment on the floor of an ancient, shallow sea – sometimes called the Kansas-Nebraska Sea or the Western Interior Seaway – that extended between the areas we now know as the Gulf of Mexico and the Arctic Ocean but left the eastern and western parts of North America dry. In the past, geologists loosely referred to these deposits as *limestone* or *chalk*. Most of these rocks are the products of lithified (compacted and cemented) sediments composed of calcareous ooze that settled on the sea floor. These sediments are largely composed of tests, that is, shells of foraminifers (fig. 19, a-o), and coccoliths (fig. 19, p, q), fecal material (pellets) of marine animals, and inorganic clay- and silt-sized particles that were eroded from higher lands bordering the shallow sea. Over a broad area, these rocks contain the fossils of the coccoliths and foraminifers (Liu, 1994), the lower end of the food chain, as well as clams, snails, ammonites, crustaceans, fish, and reptiles. Fossils of some of the above animals have been found in the study area and may be present in the rocks along the shores of Harlan County Lake. The marine sedimentary rocks of Late Cretaceous age that are exposed along the entire length of the Republican River generally have not been targeted for extensive paleontological research. The future may provide many more examples of marine life from Harlan County that are not known to us today.

#### **Foraminifers**

In his work on Cretaceous microfossils from Nebraska, Loetterle (1937) recorded only six species of foraminifers from the Smoky Hill Chalk Member of the Niobrara Formation. Only two species were found at the outcrop at the south end of the Republican River bridge at Alma, *Gumbelina globulosa* (Ehrenberg) (fig. 19, a, b) and *Globigerina cretacea* d'Orbigny (fig. 19, c-f). *G. globulosa* (Ehrenberg) is the most common and a very long-surviving species. In addition to recording this species at two sites in Harlan County, Loetterle recorded this species at forty-five other localities covering much of Nebraska. *G. cretacea* d'Orbigny also ranges throughout the Cretaceous, and Loetterle found this species in forty-five Nebraska localities too.

Loetterle (1937) recorded six species of foraminifers from the Smoky Hill Chalk from an outcrop in sec. 19, T.1N., R.17W. near the confluence of Prairie Dog Creek and the Republican River (now shown as Prairie Dog Bay on the U.S. Geological Survey 7.5-minute topographic maps). He included the two species above and *Bolivina crenulata* Loetterle (fig. 19, g, h) from the upper Smoky Hill Chalk, as it had a short geologic and a broad geographic range.

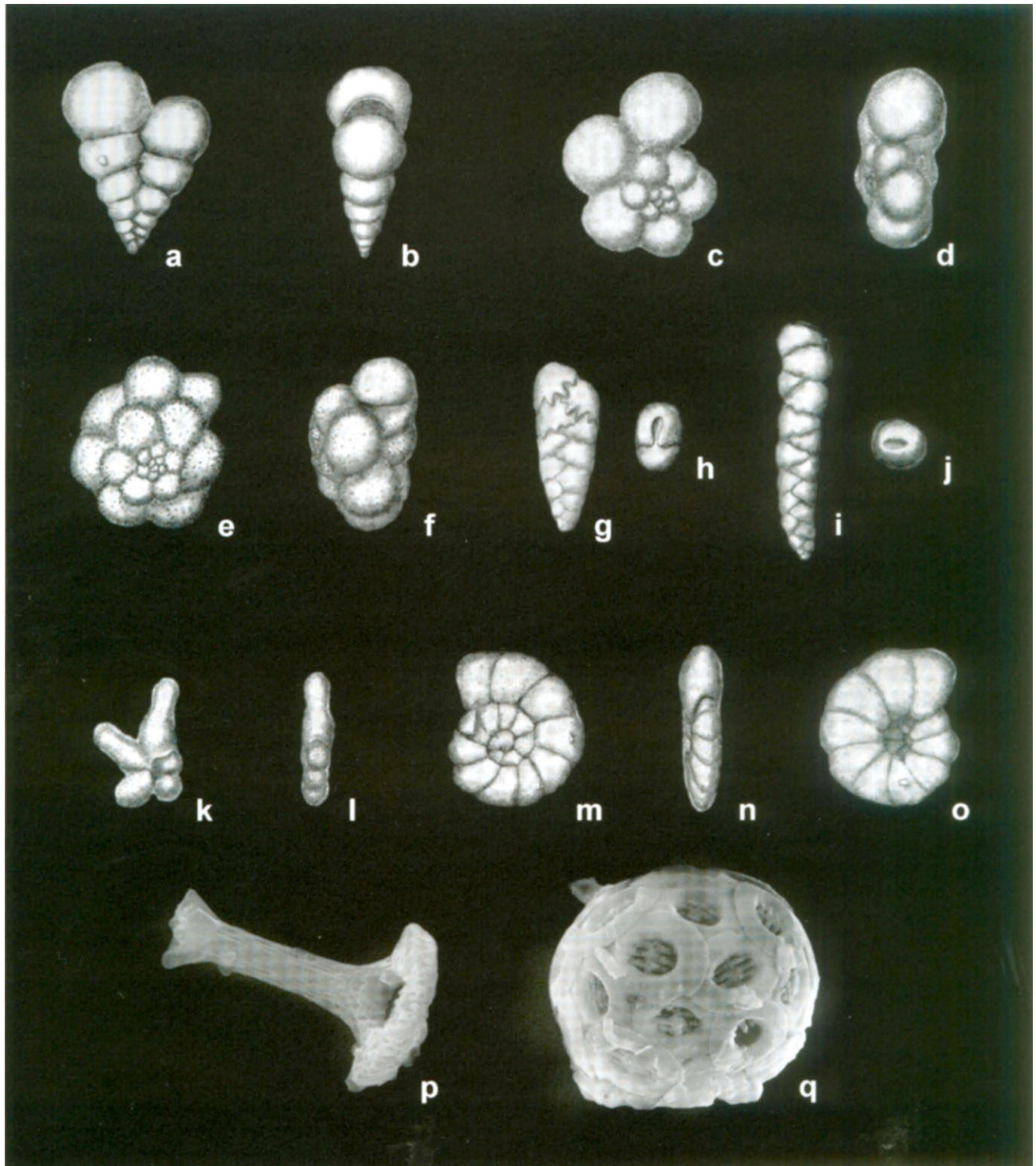


Fig. 19. Foraminifera (a-o) and coccoliths (p, q) from the Niobrara and Pierre formations. a, b) *Gumbelina globulosa* (Ehrenberg), lateral and peripheral views, x 90; c, d) *Globigerina cetacea* d'Orbigny, dorsal and peripheral views, x 60; e, f) *G. cretacea* d'Orbigny, gerontic form, x 60; g, h) *Bolivina crenulata* Loetterle, lateral and apertural views, x 40; i, j) *Loxostoma applinae* (Plummer), lateral and apertural views, x 40; k, l) *Hastigerinella watersi* Cushman, lateral and peripheral views, x 40; m-o) *Planulina kansasensis* Morrow, dorsal, peripheral, and ventral views, x 100; p, q) coccoliths (courtesy of D. Watkins).

*Loxostoma applinae* (Plummer) (fig. 19, i, j) is also found in abundance in the upper few feet of the Smoky Hill Chalk and extends into the lower few feet of the Pierre Shale, according to Loetterle. He suggested that *Hastigerinella watersi* Cushman (fig. 19, k, l) ranges throughout the Cretaceous, but it is rare and not found in every locality. Loetterle also recognized rare specimens of *Planulina kansasensis* (fig. 19, m-o) from the Smoky Hill Chalk, but he suggested the species was more common in the Older Fort Hays Member of the Niobrara Formation and it was found in only about twenty-six localities in Nebraska. Loetterle recognized no ostracods from outcrops in Harlan County.

#### Post-Devonian “Stromatoporoids”

Two unusual fossils of colonial organisms from the Niobrara Formation in the vicinity of Harlan County Lake are assigned to post-Devonian stromatoporoids, a term used by Stock (2001, p. 1083). It is uncertain whether these organisms are stromatoporoids or sponges, hydrozoans, or bryozoans. Each of the two examples found thus far have a smooth, central, semicircular indentation from which the colony appears to rise vertically (fig. 20, a-c). The larger of the two examples appears to have several shells of the commensal oyster *Pseudoperma congesta* (Conrad) attached to it.

Stock (2001, p. 1085) suggested that the paleoecology of post-Devonian stromatoporoids dealt “with their role in environments of deposition, particularly reefs.” Since there are no reefs or even evidence of a hard substrate (ocean bottom) that could have supported colonial organisms in the Harlan County area, the presence of these organisms is puzzling.

#### Mollusks

Two classes of mollusks, the bivalves (clams) and cephalopods (ammonites and baculites) have been found in the Smoky Hill Chalk Member of the Niobrara Formation in Harlan County. Macro-invertebrate fossils are somewhat scarce in the Cretaceous in Harlan County, and collections made by Roger Pabian and R. F. Diffendal, Jr. over several years and existing collections in the University of Nebraska State Museum (UNSM) have yielded a sparse fauna.

#### Bivalves

The most common bivalve in the Smoky Hill Chalk is the small oyster, *Pseudoperma congesta* (Conrad) (figs. 20, d, e, f, g, h; 21, a, b). This species was formerly called *Ostrea congesta*, a name no longer used by paleontologists but which still commonly appears in the popular literature. *P. congesta* is what is called a commensal organism – it has found a firm substrate on the shells of the large clam *Inoceramus* (*Platyceramus*) *platinus* Logan. This appears to be a very host-specific relationship as *P. congesta* is rarely found on the shells of any other organism. *I. (Platyceramus) platinus* attains very large sizes, and some shells may approach 3 feet (about a meter) in width. We have illustrated (figs. 20, g, h; 21, a, b) two growth stages of the above clam that have attached to *P. congesta*. We have also illustrated (fig. 20, e) a

juvenile clam with a single attached specimen of *P. congesta*. This example may be a juvenile specimen of the host clam.

#### Ammonites

Ammonites are rare in the Smoky Hill Chalk and only a few fragmental remains or poor impressions of their shells have been found in it. Several fragments of what appears to be *Coahuilites* sp. cf. *C. choteauensis* (Cobban) have been found.

#### Pierre Shale Formation

Fossils are relatively scarce in the Pierre Shale in the Harlan County area. This observation may be the result of extremely fast deposition of sediments and reducing conditions of the water near the substrate. The mineral marcasite (FeS<sub>2</sub>), an iron sulfide, replaces many of the fossils that are found in the Pierre Shale. Marcasite may be very unstable once it is exposed to air. It may react with the water in the atmosphere to form iron sulfate and water. Many of the marcasite fossils quickly develop a white, powdery coating of iron sulfate. Another product of the chemical reaction of marcasite decomposing in air is sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). If the calcium ion is present, gypsum, a hydrated calcium sulfate (CaSO<sub>4</sub>•2H<sub>2</sub>O), may form. Gypsum is present in large quantities in the Pierre Shale in Harlan County, and much of it probably is a decomposition product of marcasite, some of which may have originally been fossil shells.

Loetterle reported no examples of foraminifers or ostracods from the Pierre Shale in Harlan County, and our collections include only a few partial specimens of bivalves and a single fragment of an ammonite.

#### Bivalves

Several fragmented clam shells (fig. 21, d-f) were recovered from the Pierre Shale. These are comparable to the species *Inoceramus browni* sp. cf. *browni* Cragin and *Inoceramus* (*Endocostea*) sp. cf. *balticus* Bohm.

#### Ammonites

One partial, straight ammonite shell, a baculite, *Baculites* sp. (fig. 21, g) was found in the Pierre Shale at Harlan County. The specimen is replaced with marcasite, and it had already developed a heavy iron sulfate coating within a few days of bringing it into the laboratory for photographing.

#### Quaternary-Pleistocene Invertebrate Fossils

The geologic history of the Pleistocene Epoch of the Quaternary Period along the Republican River, in part, is one of a stream cutting a valley and then later the valley filling with fluvial sediments – stream-deposited silt, sand, and gravel – as the stream’s capacity declines. Eolian sediments, specifically loess, were deposited on adjacent uplands. Each of these paleovalleys had several kinds of environments that included bogs or swamps, ponds, grasslands and woodlands. The invertebrate fossils found in the study area tell us about some of these ancient (paleo-) environments and the changing climatic conditions that existed in the Pleistocene (Leonard, 1947, 1950, 1952).

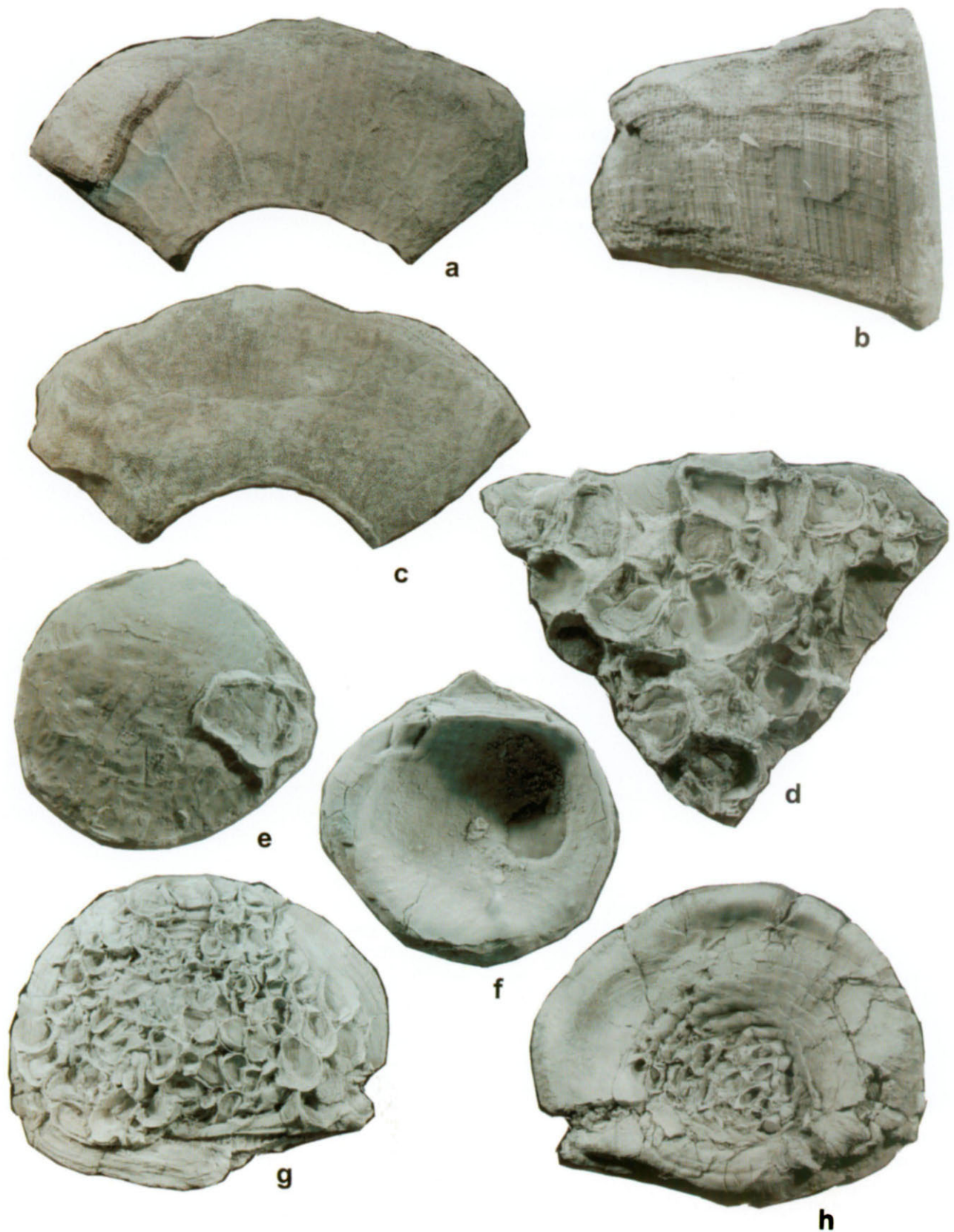


Fig. 20. Post-Devonian "stromatoporoids" (a-c). oysters and other bivalves (d-h) from the Niobrara Formation near Harlan County Lake; a-c) Post-Devonian "stromatoporoid" intact colony, x 0.33; d) *Pseudoperna congesta* (Conrad) on fragment of bivalve shell, x 1; e, f) solitary shell of *P. congesta* on immature bivalve shell, possibly a juvenile *Inoceramus* (*Platyceramus*) *platinus* Logan x 1; g, h) *Pseudoperna congesta* (Conrad) on exterior and interior of shell of *Inoceramus* (*Platyceramus*) *platinus* Logan, x 0.33.



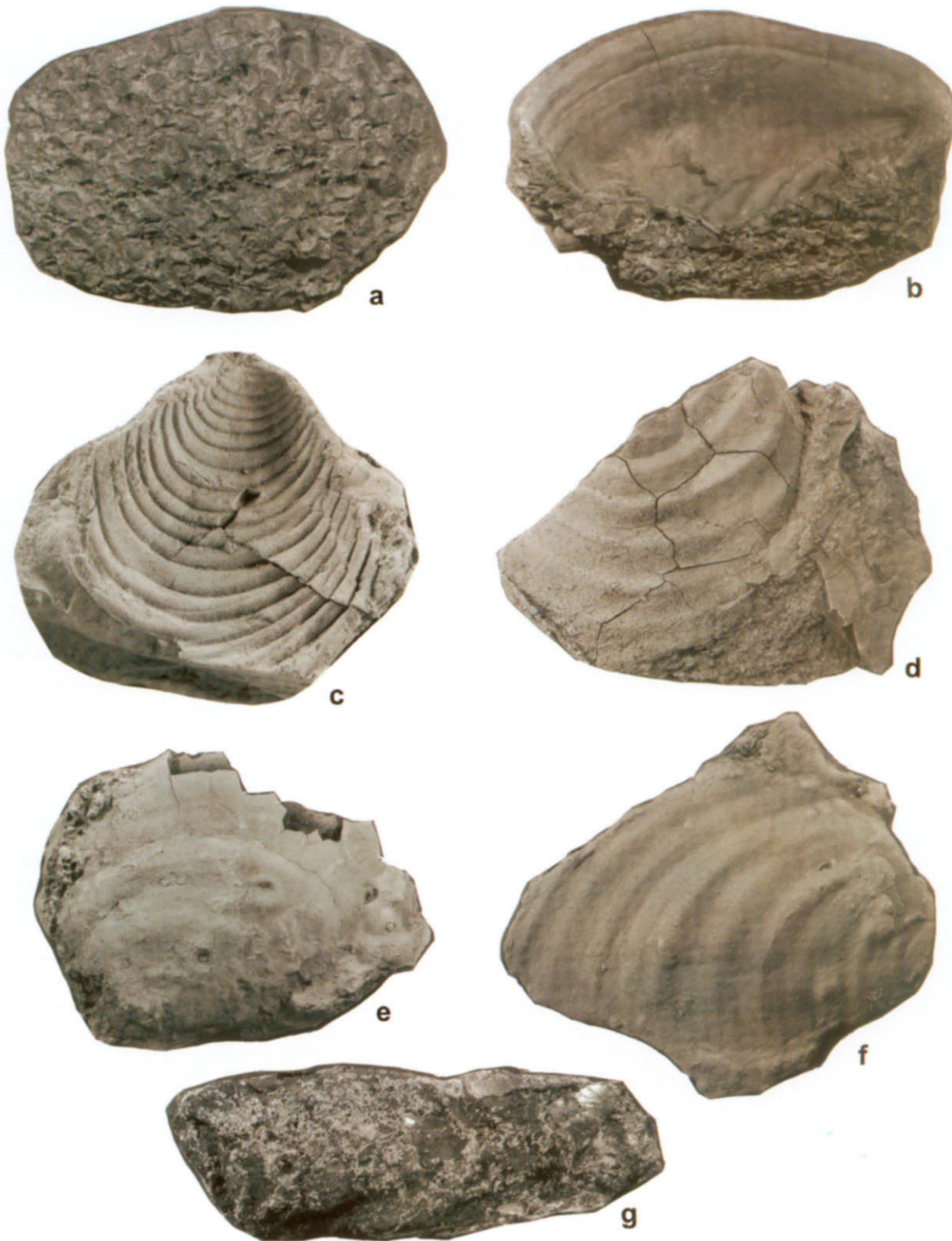


Fig. 21. Bivalves (a-c) from the Niobrara Formation; bivalves from the Pierre Shale; and cephalopod (g) from the Pierre Shale exposed in the vicinity of Harlan County Lake. a, b) *Pseudoperna congesta* (Conrad) attached to shell of large clam *Inoceramus* (*Platyceramus*) *platinus* Logan, exterior and interior views, x 1/6; c) *Anomia* sp., imprint of shell in Smoky Hill Chalk, x 1.5; d) *Inoceramus* sp. cf. *I. browni* Cragin, partial right valve, x 1; e, f) *Inoceramus* (*Endocostea*) sp. cf. *I. balticus* Bohm, e: left valve with two borings, x 1; f: right valve, x 1; g) *Baculites* sp., partial shell, x 1.

Philip Seff (1952) recorded thirty-three species of pulmonate gastropods (land snails) and bivalves (clams) from the Pleistocene loess and stream terrace deposits in Franklin, Harlan, and Frontier counties. Seff did not recover any bivalves from the two outcrops he studied in Harlan County but found a number of land snails that he interpreted to show paleoenvironments and paleoclimates in the area. Of the seven fills of the paleovalleys in these counties reported by Seff, two are exposed in the immediate vicinity of Harlan County Lake. The oldest of these fills, designated *terrace 4* (T4) by Seff, contained the fossil remains of ten species of gastropods (fig. 22, a-t). The younger of these fills, terrace 2B (T2B), contained the remains of seven species. Six of the seven species found in the T2B deposits are also found in the T4 deposits. *Pupilla blandi* Morse of T2B is one species not shared by both terraces. Some of the nine species found in the T4 deposits have not been found in the younger T2B deposits.

Seff's work showed some very interesting changes in environments and climates during the deposition of the fill in the older T4. Table 4, which follows, is based on data from Seff (1952) and shows the species of gastropods he studied, their stratigraphic positions and the environments they preferred. Environmental preferences are based on interpretations by Seff (1952) and LaRocque (1970).

It is possible to make interpretations of the environments and climates in which the above fossil gastropods have been found because all of these species are still extant – none are extinct. These species have been found in modern times by researchers such as LaRocque (1966, 1968, 1970), whose study of Pleistocene mollusks in Ohio showed that all of the species recorded by Seff were extant in such areas as Newfoundland, the Northwest Territories of Canada, and Alaska. LaRocque's works also substantiated the environmental distribution of all of the species known to Seff with the exception of *Pupilla blandi*, which had not been found in Ohio and was not discussed.

Gastropod species	Terrace 4 (T4), older	Terrace 2B (T2B), younger	Stratigraphic position in terrace	Preferred environment
* <i>Carychium exiguum</i> (Say)	X	-----	Near base	Woodland species
* <i>Discus cronkheiti</i> Newcomb	X	-----	Near base	Cool climate species
<i>Hawaiiia miniscula</i> (Binney)	X	-----	Near top of T4	Woodland species
<i>Helicodiscus singleyanus</i> Pilsbry	X	X	Near top of T4; near top of T2B.	Woodland species
<i>Pupilla blandi</i> Morse	-----	X	Lower and middle part of T2B	Cool climate species
<i>P. muscorum</i> Linnaeus	X	X	Upper part of T4; lower and middle parts of T2B	Cool climate species
<i>Succinea avara</i> Say	X	X	Upper part of T4; lower and middle parts of T2B	Floodplain species
<i>S. grosvenori</i> Lea	X	X	Upper part of T4; lower and middle parts of T2B	Cool climate species
<i>S. ovalis</i> Say	X	-----	Upper part of T4	Swampland species
<i>Vallonia gracilicosta</i> Reinhardt	X	X	Low in T4; low to middle part of T2B	Woodland species

Data from Seff (1952, plate VI).

\*Seff recorded these species in the lower units of T4 but provided no details.



Fig. 22. Pleistocene land snails. a, b) *Carychium exiguum* (Say), apertural and adapertural views, x 5; c, d) *Discus cronkheiti* Newcomb, adapertural and apertural views, x 10; e, f) *Hawaiiia miniscula* (Binney), adapertural and apertural views, x 5; g, h) *Heliodiscus singleyanus* Pilsbry, adapertural and apertural views, x 2; i, j) *Pupilla blandi* Morse, apertural and adapertural views, x 10; k, l) *P. muscorum* Linnaeus, apertural and adapertural views, x 10; m, n) *Succinea avara* Say, apertural and adapertural views, x 5; o, p) *S. grosvenori* Lea, apertural and adapertural views, x 5; q, r) *S. ovalis* Say, apertural and adapertural views, x 5 (note that the shell of *S. avara* is coiled in a left-handed spiral whereas *S. grosvenori* and *S. ovalis* are coiled in a right-handed spiral); s, t) *Vallonia gracilicosta* Reinhardt, adapertural and apertural views, x 5.

## **Vertebrate Fossils**

Many vertebrate fossils have been found throughout Nebraska. The south-central portion of the state, including Harlan County, is no exception. Down-cutting by the Republican River and its tributaries, wave action at Harlan County Lake, and road cuts have exposed Cretaceous marine rocks, late Miocene stream deposits, as well as Pleistocene silts, sands, gravels, and loess. All of the above strata yield vertebrate fossils to some extent. Some of these fossil remains are commonly found in the Great Plains, some are quite unusual and a few others are unique to the area (table 5).

Over the years an impressive vertebrate fauna has been collected from the Harlan County Lake area. The first fossil in the University of Nebraska State Museum (UNSM) collections from the vicinity of the present-day reservoir is a lower wisdom tooth from an Ice Age camel (*Camelops* sp.) found near Alma, Nebraska, sent to the museum by J. I. Wilkins of Alma in August 1905. In the summers of 1928 and 1929 Professor E. H. Barbour, director of the NU State Museum, sent C. B. Schultz and John LeMar to collect fossils in the Republican Valley. Schultz and LeMar found numerous horse, elephant, camel, and antilocaprid (antelope) bones and teeth from the late Miocene sediments at Bone Creek, as well as near the mouth of Crystal Creek on the south side of the Republican River just south of Republican City. Fifteen long-jawed mastodon bones and teeth were found in 1936 at the Brownie-Gifford Gravel Pit located at the mouth of Crystal Creek.

In 1945, Stafford C. Happ, a U.S. Army engineer, discovered that some of the preliminary test pits, dug in connection with the new proposed dam project, began to yield vertebrate fossils. In the spring of 1947 the UNSM entered into an agreement with the U.S. Army Corps of Engineers to salvage fossils from within the area of the proposed dam and reservoir. From 1947 to 1949 UNSM field crews spent several weeks in Harlan County each summer salvaging vertebrate fossils (Schultz and others, 1951). From 1983 to 1985, J. D. Stewart of the Los Angeles County Museum and associates from the University of Kansas sampled the late Pleistocene North Cove Site for vertebrates and snails (Stewart, 1987). In 1990 Steve Holen and associates researched the Prettyman Mammoth Site on the north shore of the lake (Holen and others, 1996). The fall of 1992 saw the salvaging of the highly unusual "*Protosphyraena*" skeleton from below Indian Hill by its discoverers Mary Beavers and Lisa Willett and a field crew from UNSM.

The UNSM collections at Harlan County Lake include thirty individual specimens (eight species) from the Cretaceous rocks, 110 specimens (twenty-one species) from the late Miocene sediments, 120 specimens from the late Pleistocene and 235 modern bison specimens from Holocene sediments for a total of nearly 500 specimens. The late Pleistocene North Cove Fauna housed at other institutions is estimated to contain about 500 specimens (total number of late Pleistocene species is seventy-one). More than 1,000 vertebrate fossil specimens from Harlan County Lake, consisting of at least ninety-nine species, are housed in UNSM and other institutions.

## **Late Cretaceous Fossils**

The very words "paleontology" and "fossil" conjure up thoughts of extinct, gigantic, bloodthirsty beasts called "dinosaurs." Dinosaurs are terrestrial and are only rarely found in marine rocks such as the Niobrara Formation and then only in highly unusual situations. O. C. Marsh (1872) described a hadrosaur (duckbill) from the Niobrara of the Smoky Hill River of Kansas, and Mehl (1936) described an ankylosaur (armored dinosaur) from the Niobrara of Gove County, Kansas. The world-famous Niobrara Chalk of western Kansas that produced not only a rare occasional dinosaur, but numerous marine reptiles, flying reptiles (pterosaurs), sharks and modern, bony fishes, is only 100 miles southwest of Harlan County. The same rocks of the Smoky Hill Member of the Niobrara Formation of Kansas, as well as gray shales of the younger Pierre Formation, outcrop along the shores of the lake. It is unlikely that dinosaur remains will be found at Harlan County Lake but, considering the rare Kansas finds, the possibility does exist.

The Harlan County fauna from the Late Cretaceous (table 5) consists of two sharks, four species of bony fishes and two mosasaurs. A shark, three genera of bony fishes (Class Osteichthyes) and a mosasaur have been collected from the Niobrara Formation at Harlan County Lake and a shark, a very strange primitive bony fish and a mosasaur have been located in the basal beds of the Pierre Shale Formation.

## **Niobrara Formation**

The Smoky Hill Chalk Member of the Niobrara Formation is the source of marine fishes and reptiles throughout its area of outcrop in the Midcontinent. The Kansas-Nebraska Sea must have been a dangerous place for a day at the beach, as the waters teemed with large fishes and marine lizards that possessed large mouths with sharp, pointed teeth for holding struggling prey. Remains of fishes and many other Niobrara fossils are on display regionally at the Sternberg Museum of Natural History in Hays, Kansas; the Dyche Museum of Natural History in Lawrence, Kansas; and the NU State Museum in Lincoln, as well as other museums throughout the world.

During deposition of the Smoky Hill Chalk Member, the waters were relatively deep, slightly below normal salinity and had a temperature characteristic of mild to subtropical climates. In addition, the sea floor was perfectly flat, bottom currents were weak and the bottom was mostly poorly oxygenated, making it a hostile place for many groups of marine organisms (Hattin, 1982). Vertebrate fossil remains from the Cretaceous marine chalk at Harlan County Lake, most of which were salvaged during dam construction, include a tooth, vertebrae and an occasional partially articulated skeleton (fig. 23, a-c).

## **Niobrara Fishes**

A very large shark, *Cretoxyrhina mantelli*, is known from six calcified vertebrae found during construction of Harlan County Dam. The vertebrae are 1.75 inches (45 millimeters) in diameter and are from an average-sized individual. This extinct relative of modern mako and great white sharks may have reached a length of up to 19.5 feet (6 meters) and

Table 5. Harlan County Lake Fossil Vertebrate Fauna		
<p>Abbreviations: <i>cf.</i> = "compares favorably with"; <i>Indet.</i> = Indeterminate; <i>KUVP</i> = University of Kansas Vertebrate Paleontology Collection; <i>LACM</i> = Los Angeles County Museum (Schwimmer and others, 1997); <i>NC</i> = North Cove Fauna, University of Kansas (modified after Stewart, 1987); <i>PM</i> = Prettyman Mammoth Site (Holen and others, 1996); <i>SP</i> = Sindt Point (Adair, 1987); <i>sp.</i> = species; <i>UNSM</i> = University of Nebraska State Museum.</p> <p>* = Extinct; ** = extra-limital (still present in the modern fauna but far removed from the fossil site); *** = present member of Harlan County Fauna.</p>		
Family (bold) or genus and species (italics)	Common name (in parenthesis for family)	Author/Institution
<b>Late Cretaceous Niobrara Formation</b>		
<b>Lamnidae</b>		
<i>Cretoxyrhina mantelli</i> *	Mantell's shark	UNSM
<b>Chirocentridae</b>		
<i>Xiphactinus audax</i> *	Tarpon-like bony fish	UNSM
<i>Ichthyodectes ctenodon</i> *	Large bony fish	UNSM
<b>Enchodontidae</b>		
<i>Enchodus dirus</i> *	Smaller bony fish	UNSM
<b>Mososauridae</b>		
<i>Platecarpus ictericus</i> *	Medium-sized mosasaur	LACM
<b>Late Cretaceous Pierre Formation</b>		
<b>Anacoracidae</b>		
<i>Squalicorax kaupi</i> *	Kaup's shark	UNSM
<b>Pachycormidae</b>		
<i>"Protosphyraena" gladius</i> *	Primitive bony fish	UNSM
<b>Mososauridae</b>		
<i>Tylosaurus sp.</i> *	Large mosasaur	UNSM

Table 5, continued (table 5-2). Harlan County Lake Fossil Vertebrate Fauna		
Family (bold) or genus and species (italics)	Common name (in parenthesis for family)	Author/Institution
<b>Late Miocene Ogallala Group: Bone Cove I</b>		
<b>Trionychidae</b>		
<i>Apalone sp.</i> *	Soft-shelled turtle	UNSM
<b>Testudinidae</b>		
<i>Geochelone sp.</i> *	Giant tortoise	UNSM
<b>Canidae (Dogs)</b>		
<i>?Aelurodon sp.</i> *		UNSM
<i>Carpocyon compressus</i> *		UNSM
<b>Mustelidae (Weasels, etc.)</b>		
<i>?Brachypsaloides sp.</i> *		UNSM
<b>Felidae (Cats)</b>		
<i>Pseudaelurus marshi</i> *		UNSM
<b>Gomphotheriidae (Four-tuskers)</b>		
<i>Gomphotherium osborni</i> *		UNSM
<b>Equidae (Horses)</b>		
<i>?Hypohippus sp.</i> *		UNSM
<i>Parahippus cognatus</i> *		UNSM
<i>Calippus placidus</i> *		UNSM
<i>Pseudhipparion sp.</i> *		UNSM
<i>Pliohippus mirabilis</i> *		UNSM
<b>Rhinocerotidae (Rhinos)</b>		
<i>?Aphelops sp.</i> *		UNSM
<i>Peraceras crassus</i> *		UNSM
<b>Camelidae (Camels)</b>		
<i>?Aepycamelus sp.</i> *	Giraffe camel	UNSM
<i>Procamelus occidentalis</i> *	Medium-sized camel	UNSM

Table 5, continued (table 5-3). Harlan County Lake Fossil Vertebrate Fauna		
Family (bold) or <i>genus and species (italics)</i>	Common name (in parenthesis for family)	Author/ Institu- tion
<i>Protolabis gracilis</i> *	Small camel	UNSM
<b>Dromomerycidae</b> (Horned ruminants)		
<i>Cranioceras skinneri</i> *		UNSM
<b>Antilocapridae</b> (Prongbucks)		
<i>Merycodus warreni</i> *		UNSM
<b>Late Miocene Ogallala Group: Bone Cove II</b>		
<b>Gomphotheriidae</b>		
<i>Torynobelodon loomisi</i> *	Scoop-tusker	UNSM
<b>Equidae</b> (Horses)		
<i>Pliohippus pernix</i> *		UNSM
<b>Late Pleistocene (Ice Age) Fauna</b>		
<b>Crete (?) Sands &amp; Gravels</b>		
<b>Anatidae</b>		
<i>Branta canadensis maxima</i> ***	Giant Canada goose	UNSM
<b>Mylodontidae</b>		
<i>Paramylodon harlani</i> *	Harlan's ground sloth	UNSM
<b>Castoridae</b>		
<i>Castor canadensis</i> ***	Beaver	UNSM
<b>Canidae</b>		
<i>Canis lupus</i> **	Gray wolf	UNSM
<b>Elephantidae</b>		
<i>Mammuthus columbi</i> *	Columbian mammoth	UNSM
<b>Equidae</b>		
<i>Equus sp.</i> *	Extinct horse	UNSM
<b>Camelidae</b>		
<i>Camelops sp.</i> *	Camel	UNSM

Table 5, continued (table 5-4). Harlan County Lake Fossil Vertebrate Fauna		
Family (bold) or <i>genus and species (italics)</i>	Common name	Author/ Institu- tion
<b>Cervidae</b>		
<i>Odocoileus sp.</i> ***	Deer	UNSM
<b>Bovidae</b>		
<i>Bison cf. B. antiquus</i> *	Bison	UNSM
<b>Gilman Canyon Formation</b>		
<b>Bufo</b>		
<i>Bufo sp.</i> ***	Indet. toad	UNSM
<b>Sciuridae</b>		
<i>Spermophilus richardsonii</i> **	Richardson's ground squirrel	UNSM
<i>Cynomys ludovicianus</i> ***	Black-tailed prairie dog	UNSM
<b>Geomys</b>		
<i>Thomomys talpoides</i> **	Northern pocket gopher	UNSM
<b>Heteromyidae</b>		
<i>Perognathus hispidus</i> ***	Hispid pocket mouse	UNSM
<b>Arvicolidae</b>		
<i>Pitymys cf. P. ochrogaster</i> ***	Prairie vole	UNSM
<b>Mustelidae</b>		
<i>Mustela frenata</i> ***	Long-tailed weasel	UNSM
<b>Felidae</b>		
<i>Felis atrox</i> *	North American lion	UNSM
<b>Elephantidae</b>		
<i>Mammuthus columbi</i> *	Columbian mammoth	UNSM
<b>Equidae</b>		
<i>Equus sp.</i> *	Extinct horse	UNSM

Table 5, continued (table 5-5). Harlan County Lake Fossil Vertebrate Fauna		
Family ( <b>bold</b> ) or <i>genus and species (italics)</i>	Common name (in parenthesis for family)	Author/ Institu- tion
<b>Tayassuidae</b>		
<i>Platygonus compressus</i> *	Flat-headed peccary	UNSM
<b>Antilocapridae</b>		
<i>Antilocapra americana</i> **	Prongbuck	USNM
<b>Bovidae</b>		
<i>Bison antiquus</i> *	Extinct bison	UNSM
<b>Peoria Loess</b>		
<b>Catostomidae</b> (Suckers) ***		NC
<b>Cyprinidae</b> (Minnows) ***		NC
<b>Percidae</b>		
<i>Stizostedion canadense</i> **	Sauger	UNSM
<b>Ambystomatidae</b>		
<i>Ambystoma tigrinum</i> ***	Tiger salamander	NC
<b>Bufonidae</b>		
<i>Bufo hemiophrys baxteri</i> **	Wyoming toad	
<b>Hylidae</b>		
<i>?Pseudacris sp.</i> ***	Chorus frog	NC
<b>Ranidae</b>		
<i>Rana sp.</i> ***	Leopard frog	NC
<b>Chelonian</b> (Indet. Turtle) ***		NC
<b>Colubridae</b>		
<i>Regina grahami</i> **	Graham's crayfish snake	NC
<i>Thamnophis proximus</i> ***	Western ribbon snake	NC
<i>Thamnophis radix</i> ***	Plains garter snake	NC

Table 5 (continued: table 5-6). Harlan County Lake Fossil Vertebrate Fauna		
Family ( <b>bold</b> ) or <i>genus and species (italics)</i>	Common name (in parenthesis for family)	Author/ Institu- tion
<b>Anatidae</b>		
<i>Anas discors</i> ***	Blue-winged teal	NC
<b>Phasianidae</b>		
<i>cf. Lagopus sp.</i> **	Ptarmigan	NC
<b>Tetraonine (small)</b> *** (suborder)	Grouse	NC
<b>Scolopacidae</b>		
<i>Bartramia longicauda</i> ***	Upland sandpiper	NC
<b>Columbidae</b>		
<i>Ectopistes migratorius</i> *	Passenger pigeon	NC
<b>Muscicapidae</b>		
<i>Turdus migratorius</i> ***	Robin	NC
<b>Emberizidae</b>		
<i>Sturnella sp.</i> ***	Meadowlark	NC
<b>Passeriforms</b> (Songbirds) *** (order)		NC
<b>Soricidae</b>		
<i>Sorex arcticus</i> **	Arctic shrew	NC
<i>Sorex cinereus</i> ***	Masked shrew	NC
<i>Blarina brevicauda brevicauda</i> ***	Shorttail shrew	NC
<i>Chiropteran</i> ***	Bat	NC
<b>Leporidae</b>		
<i>Lepus americanus</i> **	Snowshoe hare	NC
<b>Sciuridae</b>		
<i>Marmota cf. M. flaviventris</i> **	Yellow-bellied marmot	NC
<i>Tamiasciurus hudsonicus</i> **	Chickaree	NC

Table 5, continued (table 5-7). Harlan County Lake Fossil Vertebrate Fauna		
Family (bold) or <i>genus and species (italics)</i>	Common name	Author/ Institu- tion
<i>Tamias minimus</i> **	Least chipmunk	NC
<i>Spermophilus richardsoni</i> **	Richardson's ground squirrel	NC
<i>Spermophilus tridecemlineatus</i> ***	13-lined ground squirrel	NC
<b>Geomyidae</b>		
<i>Geomys sp.</i> ***	Gopher	NC
<i>Thomomys talpoides</i> **	Northern pocket gopher	NC
<b>Cricetidae</b>		
<i>Peromyscus cf. P. leucopus</i> ***	White-footed mouse	NC
<i>Peromyscus maniculatus</i> ***	Deer mouse	NC
<b>Arvicolidae</b>		
<i>Synaptomys borealis</i> **	Northern bog lemming	NC
<i>Ondatra zibethica</i> ***	Muskrat	NC
<i>Phenacomys intermedius</i> **	Heather vole	NC
<i>Clethrionomys gapperi</i> **	Red-backed vole	NC
<i>Microtus montanus</i> **	Montane vole	NC
<i>Microtus pennsylvanicus</i> ***	Meadow vole	NC
<i>Microtus cf. M. richardsoni</i> **	Water vole	NC
<i>Microtus xanthognathus</i> **	Yellow-cheeked vole	NC
<i>Pitymys cf. P. ochrogaster</i> ***	Prairie vole	NC

Table 5, continued (table 5-8). Harlan County Lake Fossil Vertebrate Fauna		
Family (bold) or <i>genus and species (italics)</i>	Common name	Author/ Institu- tion
<b>Zapodidae</b>		
<i>Zapus hudsonius</i> ***	Meadow jumping mouse	NC
<i>Zapus cf. Z. princeps</i> **	Western jumping mouse	NC
<b>Ursidae</b>		
<i>Ursus americanus</i> **	Black bear	UNSM
<b>Mustelidae</b>		
<i>Mustela nivalis</i> ***	Least weasel	NC
<i>Martes nobilis</i> *	Noble marten	NC
<i>Martes cf. M. pennanti</i> **	Fisher	NC
<i>Gulo gulo</i> **	Wolverine	KUVP
<b>Felidae</b>		
<i>Felis atrox</i> *	American lion	UNSM
<b>Elephantidae</b>		
<i>Mammuthus columbi</i> *	Columbian mammoth	NC, PM
<b>Tayassuidae</b>		
<i>Platygonus compressus</i> *	Flat-headed peccary	UNSM
<b>Cervidae</b>		
<i>Navahoceros fricki</i> *	Extinct mountain deer	NC
<i>Odocoileus sp.</i> ***	Deer	UNSM
<i>Rangifer tarandus</i> **	Woodland caribou	Holen, others, 1996
<b>Bovidae</b>		
<i>Bison antiquus</i> *	Extinct bison	NC, UNSM
<i>Bootherium bombifrons</i> *	Helmeted muskox	KUVP



**Table 5, continued (table 5-9)**  
**Harlan County Lake Fossil Vertebrate Fauna**

<b>Family (bold) or genus and species (italics)</b>	<b>Common name</b>	<b>Author/ Institu- tion</b>
<b>Pleistocene Beach Fauna (Unknown Stratigraphic Provenience)</b>		
<b>Castoridae</b>		
<i>Castoroides ohioensis*</i>	Giant beaver	SP
<b>Canidae</b>		
<i>Canis dirus*</i>	Dire wolf	Holen, others, 1996
<b>Mammutidae</b>		
<i>Mammut americanum*</i>	American mastodon	NC
<b>Elephantidae</b>		
<i>Mammuthus columbi*</i>	Columbian mammoth	NC, UNSM
<b>Equidae</b>		
<i>Equus sp.*</i>	Extinct horse	NC
<b>Camelidae</b>		
<i>Camelops sp.*</i>	Extinct camel	UNSM
<b>Cervidae</b>		
<i>Rangifer tarandus**</i>	Woodland caribou	Holen, others, 1996
<b>Bovidae</b>		
<i>Bison antiquus*</i>	Extinct bison	NC, UNSM

was the largest predatory shark of the late Cretaceous.

*Xiphactinus*, *Ichthyodectes* and *Enchodus* are genera of bony fishes commonly found in the Smoky Hill Chalk Member throughout its outcrop extent in the Midcontinent. *Xiphactinus* at Harlan County Lake is known from a single, large isolated tooth; *Ichthyodectes ctenodon* is known from isolated vertebrae and one body section that includes twelve vertebrae and articulated ribs; and *Enchodus dirus* remains include three jaws and a partial skull. *Xiphactinus* and *Ichthyodectes* are members of the same extinct family of

fishes, the chirocentrids. Both genera possessed strong, up-turned, bulldog-like lower mandibles (lower jaw) with a single row of teeth and had large crests on the rear of their skulls. *Xiphactinus* was much larger with a body length of up to 20 feet (Stewart, 1900), which rivaled the size of small mosasaurs, while *Ichthyodectes* was about 6 feet in length (Lane, 1944). At one time *Xiphactinus* was thought to be one of the longest-bodied teleosts (modern, or climax, bony fishes), exceeding in length the living swordfishes (Bardack, 1965), but now it can be shown that some of the pachycormids (see “*Protosphyraena*” discussion later in this report) were larger. *Xiphactinus* is easily distinguished from *Ichthyodectes* in that the former had several large, downward-projecting fang-like premaxillary (front upper) teeth as well as variable-sized mandibular (lower) teeth, while the latter retained a similar-sized tooth row throughout its length. *Xiphactinus* was undoubtedly a voracious predator and must have preyed on numerous large species of fishes, including *Ichthyodectes*. One of the most unusual fossil fish specimens ever found is the “fish-within-a-fish” that features a 14-foot *Xiphactinus* skeleton with a 6-foot *Gillicus* skeleton in its gut (Liggett, 2002). In 1952 George Sternberg collected this fabulous specimen, which is on display at the Sternberg Museum in Hays, Kansas.

*Enchodus* is another of the highly predaceous Niobrara fishes. The body is elongate and fusiform; the skull is triangular; and the body and skull are laterally compressed. The mandibles have an inner row of large teeth and an outer row of smaller teeth. Some species of *Enchodus* may be as much as 7 feet in length (Lane, 1944).

#### **Niobrara Mosasaurs**

Mosasaurs are closely related to living monitor lizards but had huge paddle-like limbs that propelled them through the Cretaceous waters and were rivaled only by giant short-necked plesiosaurs as the top predators of the Kansas-Nebraska Sea. Three genera of mosasaurs, *Clidastes*, *Tylosaurus* and *Platecarpus* are often found in the Smoky Hill Chalk. A partial skeleton of *Platecarpus ictericus*, the largest species of the genus, was recovered from the Niobrara Formation at Harlan County Lake. The *Platecarpus* skeleton revealed numerous cuts on the ribs, most of which were caused by serrated teeth attributed to the shark, *Squalicorax* (Schwimmer and others, 1997).

*Platecarpus* (“flat wrist”) was 20 to 25 feet in length with a short trunk and a long tail. It is thought that since necrotic (dead) tissue is found in numerous *Platecarpus* vertebrae, most individuals, because of diving to depths, may have suffered from decompression syndrome, or “the bends” (Martin and Rothschild, 1989), much like modern Beluga whales. It was once thought that, based on geographic distribution of the three Niobrara genera of mosasaurs, *Clidastes* inhabited the near-shore environment and *Tylosaurus* and *Platecarpus* frequented deeper waters (Russell, 1967). Sheldon (1997), however, found that the microstructure of the ribs of *Platecarpus* correlates with life in the shallower zones and *Clidastes* and *Tylosaurus* were more at home in

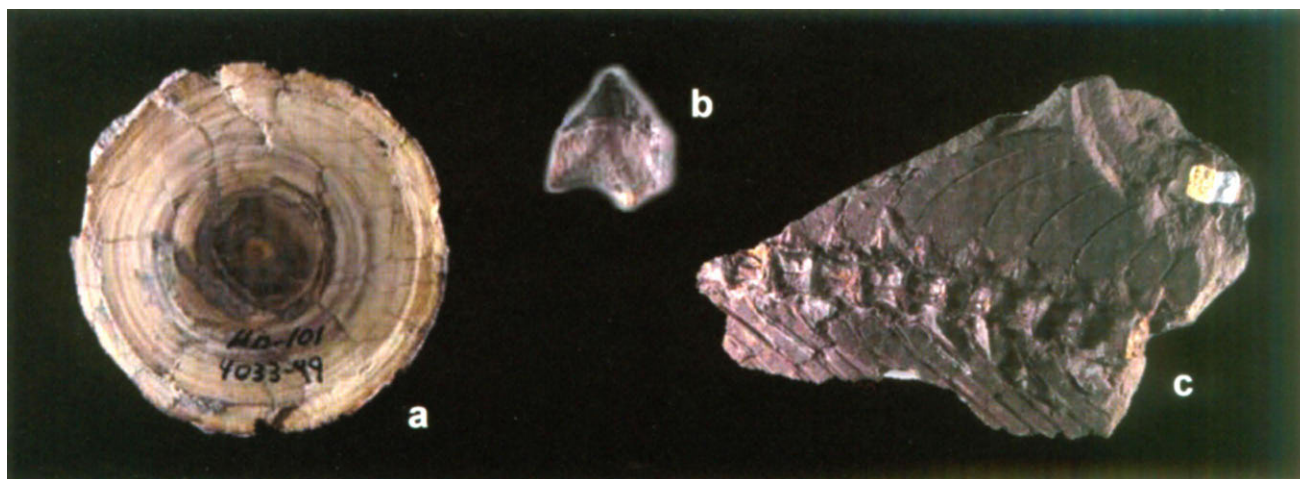


Fig. 23. Cretaceous fossils. a) *Cretoxyrhina mantelli*, shark vertebra, Niobrara Formation, x 1.0; b) *Squalicorax kaupi*, shark tooth, Pierre Formation, x 1.30; c) *Ichthyodectes sp.*, bony fish, Niobrara Formation, x 0.25.

the greater depths. Kiernan (2002) had an intermediate view and showed *Platecarpus* and *Tylosaurus* at home in shallower water and *Clidastes* as a denizen of the deep. A favorite delicacy of *Platecarpus* was the coiled squid-like ammonites. Many ammonite individual shells bear tooth damage from *Platecarpus* teeth.

#### Pierre Shale Formation

##### “*Protosphyraena*” *gladius*: Giant Mystery Fish

The most unusual fish skeleton ever found in Nebraska sediments was discovered by sisters Lisa Willett and Mary Beavers and their families of Hastings, Nebraska. They found it in July of 1992 at Harlan County Lake during a period of low water levels (fig. 24, a-d). Through the concerted efforts of these amateur fossil hunters, an unusual and rare fossil specimen was preserved for scientific study. UNSM personnel applied for permission to dig from the U.S. Army Corps of Engineers, and the skeleton was salvaged in the fall of 1992. The remains, recovered from the base of the Pierre Formation at the Niobrara contact, included four partial and two complete fins (including a pectoral and a probable dorsal), dozens of fin rays, some as long as 4.6 feet (1.4 meters), and parts of the shoulder girdle. The fish, identified as “*Protosphyraena*” *gladius*, is the last and largest of the genus of “snout-fish.” The exact placement of each of the recovered fins as to body position can only be estimated at this writing. Apparently only pectoral fins and skull remains of “*Protosphyraena*” have been described and figured in the literature (Stewart, 1988) and a caudal fin remains undescribed. Even though we have much of the skeleton, this strange gigantic fish still remains a mystery.

The generic name, “*Protosphyraena*,” is included in quotes as no distinctive snouts, upper or lower jaws or even teeth are known for “*P.*” *gladius*. A nearly complete individual, such as the Harlan County specimen, might suggest that “*P.*” *gladius* not only possessed a partially cartilaginous skeleton (the reason no vertebrae or ribs were found), as in

all other members of the family Pachycormidae, but also may have had a cartilaginous skull as no teeth or skull parts were recovered. This might indicate that “*P.*” *gladius* was a filter feeder as with the giant, Middle-Jurassic, European pachycormid, *Leedsichthys*, which is the world’s largest bony fish (Martill, 1985, 1988). However, there is no evidence of the diagnostic gill rakers that are found in filter feeders in the Harlan County specimen. The tail fin of *Leedsichthys* (Martill, 1988) measures 5.75 feet (1.75 meters) for each lobe and was probably more than 9.8 feet (3 meters) long, while individual fin rays of the Harlan County monster measure 4.6 feet (1.4 meters). If indeed the latter are tail fin rays, the tail fin of the UNSM individual may have been an incredible 8.2 feet (2.5 meters) in length. Martill (1988), on only partial material, estimated the total body length (using *Asthenocormus* as a model) of *Leedsichthys* at between 44 to 91 feet (13.5 and 27.6 meters) with the lower end of the estimate being very conservative.

The fin tentatively identified as the dorsal appears to be of major interest as well. This triangular-shaped fin measures 2.6 feet (80 centimeters) along the straight rear edge, 0.8 feet (26 centimeters) at the base and is 0.6 inches (1.5 centimeters) thick along its leading edge. The dorsal, apparently like all of the fins in “*P.*” *gladius*, has a knife-like, unserrated forward edge. The large triangular dorsal fin and a very strong tail fin compare grossly to the living swordfish (*Xiphias*). Gregory and Conrad (1937) suggest that marlins and swordfishes, possessing large triangular dorsal fins and large strong caudal fins, cruise slowly at the surface, sound when encountering a school of fish and rise from below, striking and thrashing, and then turn to gobble up the dead or mangled fish. The large erect dorsal fin is also necessary to meet the thrusts of the enormous caudal fin. If *Xiphias* is shown to be the closest model for our puzzling fish, then we might expect to find a relatively large anal fin and a lack of pelvic fins.

“*Protosphyraena*” is worldwide in distribution and is known from Late Cretaceous marine rocks of Europe, Asia, North America, and South America. “*Protosphyraena*”

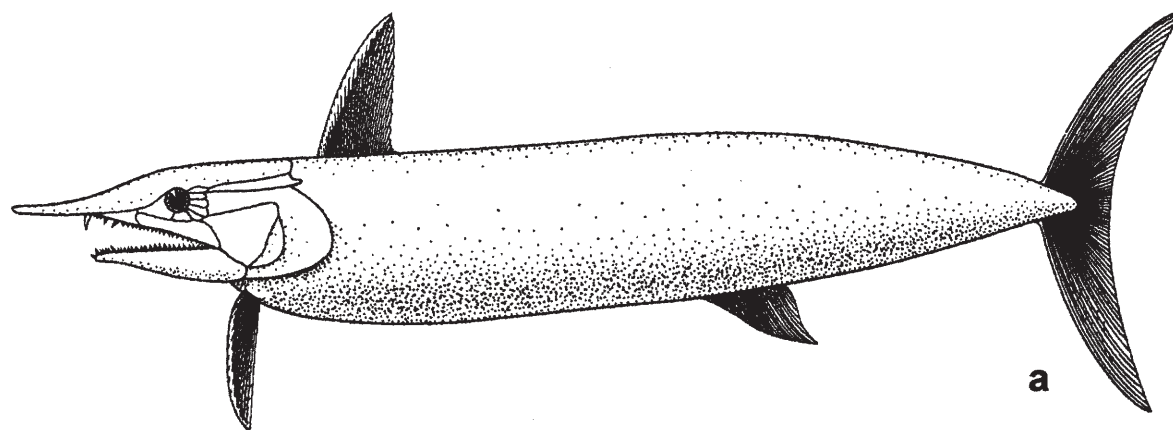


Fig. 24. Giant fish from Pierre Formation. a) conjectured reconstruction of “Protosphyraena” gladius; caudal (tail) fin is more than 8 feet tall with an estimated total length of 22 feet. Skull (after Gregory, 1951, fig. 9.25) is based on other known members of the genus. Life position of the dorsal fin is unknown and exact shape and placement of the anal fin is unknown; b) the discovery site, 1992. Sisters Mary Beavers (left) and Lisa Willett found the specimen and reported it to UNSM; c) pectoral fin as found in the field with isolated caudal fin rays shown below the brush, x 0.08. d) dorsal fin ray in its field jacket, x 0.10.

*gladius* remains have been found in Kansas, Wyoming, South Dakota, Texas, Mississippi, Alabama, New Jersey and Nebraska. This is the first Nebraska record! Needless to say, the state's largest fish came from Harlan County and if encountered in life would have been an awesome sight and the cause of much trepidation. Even if "*P.*" *gladius* is shown to be a filter feeder, the huge knife-armed fins (including the tail) would have been reason enough not to enter the water when it was near.

Associated with "*P.*" *gladius* at Harlan County Lake were several teeth of the anacoracid shark, *Squalicorax*, which has been found to be a common predator or scavenger of various large-bodied marine vertebrates (Schwimmer and others, 1997).

Much of the deeper, quiet-water deposition that took place in the Pierre sea was probably poorly oxygenated and may actually have been poisonous to most marine life. The giant fish may actually have inhabited shallower, well-oxygenated waters, and the carcass drifted downward into the depths.

### **Pierre Mosasaurs**

A fourth genus of North American Late Cretaceous mosasaur is from the Mobridge Member of the upper part of the Pierre Formation of northeast Nebraska. A nearly complete skull and front paddle of a very large *Mosasaurus missouriensis* was recovered from a roadcut at Niobrara State Park (Bailey, 1997). As yet, no *Mosasaurus* has been found in the Pierre Formation at Harlan County Lake, but a partial skull and skeleton of *Tylosaurus* sp. was recovered. *Tylosaurus* was longer-bodied than *Platecarpus* with a total length of up to 30 feet, but it was apparently smaller than *Mosasaurus*, which had an estimated length of more than 33 feet. *Tylosaurus* may have on occasion preyed on smaller mosasaurs like *Clidastes*, as there is one skeleton of *Tylosaurus* with a *Clidastes* skeleton in its stomach (Martin [L.D.], 1990). In *Tylosaurus* the premaxilla extends much beyond the front teeth, and it may have used this knob-like structure as a battering ram, as do porpoises today.

### **Late Miocene Ogallala Group**

Based on paleontological evidence, there are two distinct ages of late Miocene fossils from Ogallala Group sediments at Harlan County Lake. There is a late Barstovian Fauna about 13 million years old (Bone Cove I) and a younger late Clarendonian or early Hemphillian Fauna, about 10 million years old (Bone Cove II) (fig. 25, a-e; table 5). No attempt has been made as yet to systematically recover microvertebrate fossils using a screening process, which, potentially, could add numerous species to the faunal list and further help to define the exact temporal settings of the Bone Cove faunas.

### **Bone Cove I Fauna**

All of the 120 identified vertebrate fossils that make up the Bone Cove I and II faunas are from the south side of the lake (table 5), and most were found in the Bone Creek drain-

age. A few scattered specimens were collected on Patterson Creek, Crystal Creek, Coyote Canyon and near Alma Vista. Throughout most of the extent of the Republican River's course through Nebraska, only rarely do outcrops of the Ogallala occur on the north side of the valley. The Bone Cove I fauna is comparable in age to other vertebrate fossil sites from the Republican Valley near Red Cloud in Webster County, in southern Franklin County and on Driftwood Creek in Hitchcock County. The Bone Cove I Fauna consists of a soft-shelled turtle, a tortoise, two dogs, a weasel, a cat, a four-tusked mastodont, five three-toed horses, two rhinos, three camels, a deer-like ruminant and a prongbuck (antelope). Not only do the Bone Cove I fossils compare well with other material from the Republican Valley, but all classifications are similar to those from late Barstovian sites near the type section of the Valentine Formation in north-central Nebraska (Voorhies, 1990). The Bone Cove Fauna is a typical bone assemblage from Ogallala sediments in that the material consists of broken limb bones, isolated teeth, occasional jaws and no articulated specimens. Probably the most distinctive characteristic of the Bone Cove I Fauna is its diversity, even though only 120 specimens have been cataloged. The fauna consists of twenty distinct species in eleven families of vertebrates, in spite of the fact that no systematic recovery of microvertebrate fossils using the screening process has been attempted in the Ogallala sand units at Bone Cove.

A few of the Bone Cove taxa are worthy of additional comment. Felids (cats) are extremely rare in the late Barstovian. The bobcat-sized felid from Bone Cove, *Pseudaelurus marshi*, is only known from an isolated calcaneum (heel bone). The horse assemblage consists of five three-toed horses, two with short-crowned teeth that were browsers (?*Hypohippus* and *Parahippus*) and three with higher crowned teeth that grazed on prairie grasses (*Calippus*, *Pseudhipparion* and *Pliohippus*). Of the two rhinos, *Peraceras* was a big brute, about the size of the living white rhino, and *Aphelops* had distinctive thin tusks and approached the size of a Hereford bull.

The three camels are present in nearly every large late Barstovian Fauna. *Aepycamelus*, was the size of a young giraffe and had a similar long neck and limbs and was capable of browsing from the treetops. *Procamelus* was intermediate in size between a dromedary camel and a llama, and *Protolabis* was llama-sized with gracile limbs. The typical late Barstovian four-tusked mastodont is *Gomphotherium osborni*. These proboscideans possessed extremely long, heavy lower jaws with two peg-like tusks at their tips. *G. osborni* was about the height of an Indian elephant, but the males were probably much bulkier. Evidence from the Valentine Quarries indicates that the females of *G. osborni* may have been much smaller than the males.

### **Bone Cove II Fauna**

Two taxa have been assigned to the Bone Cove II Fauna: a three-toed horse, *Pliohippus pernix*, and a scoop-tusked mastodont, *Torynobelodon loomisi*. *Pliohippus pernix*, with

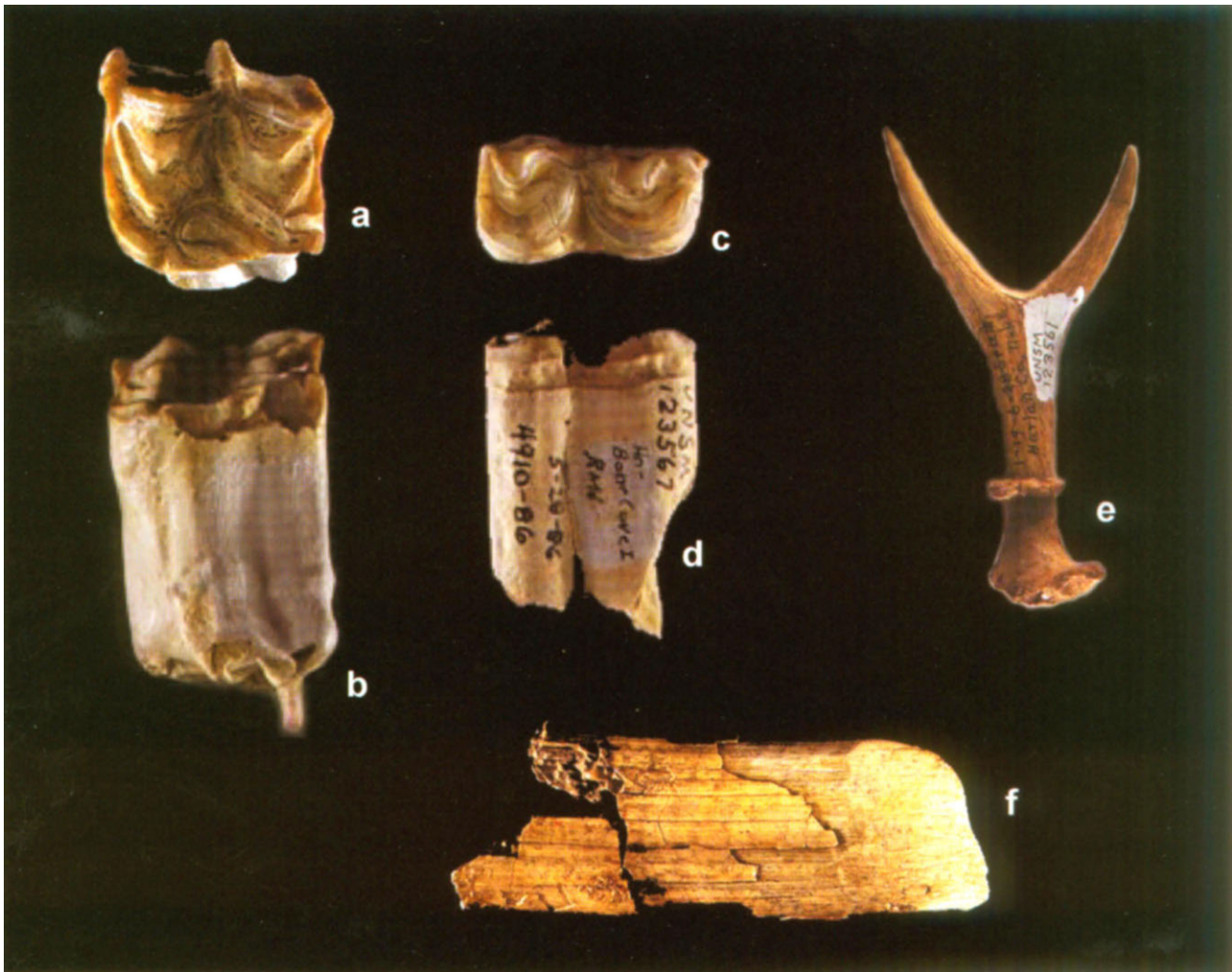


Fig. 25. Late Miocene fossils. (a-d) *Pliohippus mirabilis* teeth (horse), Ogallala Group, x 1; a-b) upper cheek tooth, c-d) lower cheek tooth; a and c are occlusal views; b, lingual view; d, labial view; e) *Merycodus warreni* (prongbuck) horn, Ogallala Group, x 0.57; f) *Torynobelodon loomisi* (four-tusked elephant) lower tusk, Ogallala Group, x 0.22.

larger, higher crowned teeth, is more advanced than *P. mirabilis* from Bone Cove I (table 5). The most unusual late Miocene specimen is the partial lower tusk of *Torynobelodon loomisi* (fig. 25, f). *T. loomisi*, a relative of the highly unusual *Platybelodon* of northern Nebraska and Mongolia, is known only from this single specimen (Barbour, 1929). This tusk was collected just east of Indian Hill in what C.B. Schultz called "Sand Canyon" on the south side of the lake by Charles McPherson of Republican City, and donated to UNSM in 1928. It is allied to the platybelodonts because the core of the tusk is composed of long dentine rods that are only known in this strange group of proboscideans. The presence of the above two species indicates the presence of a second, younger channel at Bone Cove as well.

#### Quaternary-Pleistocene (Ice Age)

An extremely diverse and interesting array of vertebrates has been found in various stratigraphic units of late Pleistocene age (fig. 26). Seventy-one species of vertebrate fossils (three fishes, five amphibians, four reptiles, nine birds

and fifty mammals) in thirty-nine families are known to scientists from Ice Age sediments at Harlan County Lake (table 5). Ice Age mammals are found in the Crete (?) sands and gravels, the Gilman Canyon Formation, the Peoria Loess and from unknown Pleistocene sources that washed onto the local beaches.

#### Crete (?) Sands and Gravels

The Crete (?) sands and gravels are a source of mostly large mammal remains, including horse, bison, camel, mammoth, deer, ground sloth, beaver and wolf. These sediments may be the same that Souders and Kuzila (1990) described as poorly sorted sand at the base of the Gilman Canyon Formation in Franklin County, Nebraska.

#### Gilman Canyon Formation

Soils within the Gilman Canyon Formation, equal in part to the "Citellus Zone" (Schultz and Martin, 1970), have produced associated rodent skeletons, including *Spermophilus richardsonii* (Richardson's ground squirrel), *Thomomys*

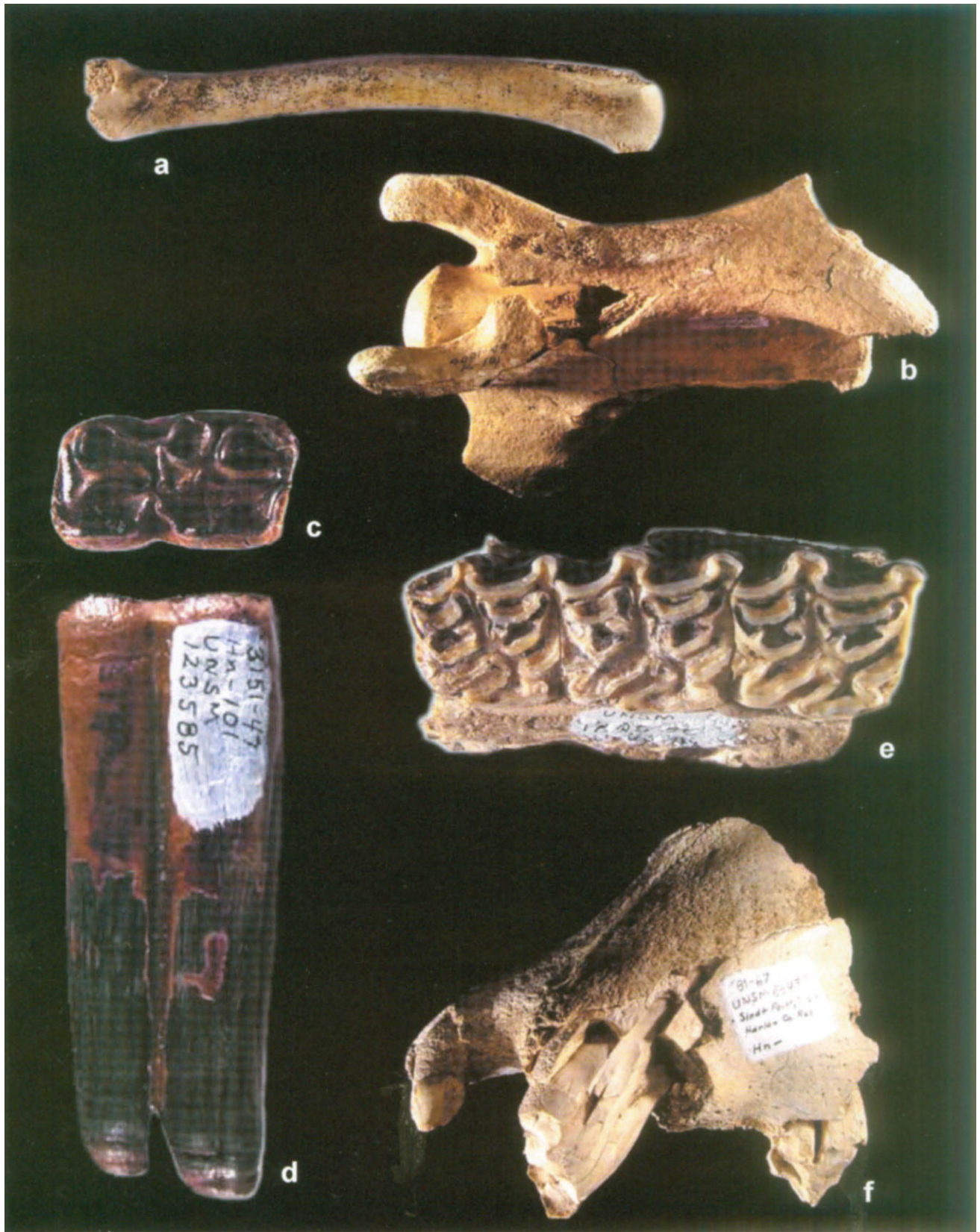


Fig. 26. Pleistocene (Ice Age) fossils. a) *Branta canadensis maxima* (giant Canada goose) humerus, Crete (?) sands and gravels, x 0.60; b) *Camelops* sp. (extinct camel) cervical vertebra, Crete (?) sands and gravels, x 0.40; c-e) *Equus* sp. (extinct horse) lower cheek tooth, Crete (?) sands and gravels (c-d) with occlusal view (c) and labial view (d); and (e) labial view of maxillary fragment with P3/ - M1/, x 0.82; f) *Felis atrox* (American lion) skull fragment with I3/, C/, alv. P2/ and P3/, Peoria Loess, x 0.62.

*talpoides* (northern pocket gopher), *Perognathus hispidus* (hispid pocket mouse), and *Pitymys ochrogaster* (prairie vole). In addition, occasional large mammal bones have been found at Harlan County Lake from sediments of the Gilman Canyon Formation: longtail weasel, horse, peccary, prongbuck, and bison. The Gilman Canyon deposits in the Republican River basin range in age from approximately 30,000 to 21,000 yr B.P. (Holen and others, 1996)

### Peoria Loess

Under the direction of J. D. Stewart of the Los Angeles County Museum, a project was undertaken on the north side of the lake at North Cove from 1983 to 1985 to systematically collect a vertebrate fossil site from a paleochannel cut in the Peoria Loess (Stewart, 1987) and ranging in age from 14,800 B.C. to 11,070 B.P. Other fossils from the base of the Peoria may range up to 20,000 yr B.P.

### Late Pleistocene Fauna

The late Pleistocene fauna at any North American locality consists of only a limited number of extinct forms, but many extra-limital species – still present in the modern fauna but far removed from the fossil site. The Ice Age fauna at Harlan County is made up of fourteen extinct species (20 percent), twenty-six extra-limital species (37 percent) and thirty-one species (43 percent) present in the fauna of modern south-central Nebraska.

Bird bones are uncommon in the fossil record because of the very nature of their adaptation to flight: the long bones are thin-walled and hollow. A somewhat diverse list of nine bird species has been recovered from Ice Age sediments at Harlan County Lake. Most interesting are the occurrences of giant Canada goose, ptarmigan and extinct passenger pigeon. The giant Canada goose (*Branta canadensis maxima*) averages much larger than other Canada goose subspecies and approaches a small swan in size. The giant Canada was once a common breeder from the Dakotas to Kansas but is now relegated to captive flocks on game refuges (Johnsgard, 1975). A humerus of the giant Canada goose was collected from the gravels of the Crete (?) sands and gravels.

Ptarmigan and passenger pigeon bones were recovered at North Cove (Stewart, 1987) in the Peoria Loess. The three species of North American ptarmigans (*Lagopus* spp.) are only found in boreal, taiga and tundra situations in Canada and Alaska, or in high alpine conditions as far south as central Colorado (Johnsgard, 1973), and so are another good indicator of extremely different climatic conditions for the central Great Plains in the late Ice Age. The passenger pigeon became extinct in 1914, only a century after it was estimated that one flock in the Ohio Valley contained more than an incredible 2 billion individual birds (Balouet, 1990)! This is the second record for fossil passenger pigeon in Nebraska and the first from the late Pleistocene.

Harlan's ground sloth (*Paramylodon harlani*), a large extinct cousin of the tree sloths of South America, was about the size of a grizzly bear and was never a common component of any Pleistocene fauna. But no other group of larger mammals (family Mylodontidae) native to the South Ameri-

can continent ranged over so vast a territory during the Pleistocene (Stock, 1925). *Paramylodon*'s huge feet were armed with large claws that were undoubtedly used in pulling down branches during its browsing forays, but may also have been used as defensive weapons against large Pleistocene predators such as sabertooth cats, American lions, and packs of dire wolves (Kurten and Anderson, 1980). A metacarpal (front foot bone) of *Paramylodon harlani* was found by Charles Osborne in 1943 in the Crete (?) sands and gravels.

The largest of the North American rodents is the beaver (*Castor canadensis*), of which a femur was found in the Crete (?) sands and gravels during dam construction. The largest extinct beaver was the giant beaver (*Castoroides ohioensis*), a relatively common fossil in the eastern deciduous forest areas just south of the Great Lakes. Giant beavers are present but not common on the Great Plains. *Castoroides* was about the size of a black bear, though the largest individuals approached 8 feet in length and 400 pounds in weight. The giant beaver's blunt, rounded incisor teeth were much different from the chisel-shaped incisors of *Castor* and it probably did not build dams or fell trees. *Castoroides* was an inhabitant of lakes and ponds and Kurten and Anderson (1980) suggest it was more similar in habits to the muskrat than to the existing beaver. Adair (1987) reported *Castoroides* from the beach near Sindt Point.

Two species of wolves have been found in the late Pleistocene deposits at Harlan County Lake: the modern gray wolf (*Canis lupus*) and the giant extinct dire wolf (*Canis dirus*). *Canis lupus* is known from a complete humerus from the Crete (?) sands and gravels; *Canis dirus* was reported from beach deposits of unknown stratigraphic position (Holen and others, 1996). The world-famous Rancho La Brea Tar Pits of southern California have produced a minimum of more than 1,640 *Canis dirus* individuals (Kurten and Anderson, 1980), but it can be shown that individuals from the Midcontinent of North America averaged much larger than the southwestern form. It was estimated by Voorhies and Corner (1988) that a big male *Canis dirus* from the Great Plains may have weighed in at an incredible 300 pounds, 100 pounds heavier than the Rancho La Brea individuals, and twice as heavy as the largest modern gray wolf. This size difference is undoubtedly a result of the Great Plains individuals being closer to the cold glacial front than their counterparts.

Mustelids (weasels and their kin) are represented in the Harlan County Ice Age Fauna by five species: two of which are found in the area today, *Mustela nivalis* (least weasel) and *Mustela frenata* (long-tailed weasel), two of which are no longer found on the Midcontinent, *Gulo gulo* (wolverine) and *Martes pennanti* (fisher), and one of which is extinct, *Martes nobilis* (noble marten). The least weasel is usually found in open grasslands and meadows and the long-tailed weasel in wooded areas where the least weasel is not likely to be found (Jones and others, 1983). The noble marten was intermediate in size between the fisher and pine marten and all other records but this one from Harlan County and a skull from Red Willow County are from the Yukon, the Rocky Mountain West or the Appalachians (Graham and Graham, 1994).

A wolverine mandibular ramus, reported by Burrell (1992) from Peoria Loess at Harlan County Lake, was the size of the largest individuals of the extensive fossil wolverine sample from Fairbanks, Alaska (Anderson, 1977). The Ice Age *Gulo* was larger than most examples of modern wolverines. Three other examples of wolverine from the late Pleistocene have been reported for Nebraska (Corner and Voorhies, 1987).

Late Pleistocene records of the fisher (*Martes pennanti*) are from lower latitudes and altitudes than the modern fisher, and all are from the southeastern United States with the closest occurrence to Nebraska in northern Illinois (Graham and Graham, 1994). The North Cove occurrence is the first Nebraska record and the only Great Plains record for the species. The fisher is larger than the marten, about the size of a red fox and semi-arboreal in habits. Today the fisher is more often found in hardwood or mixed forest situations than in strictly coniferous woods and relishes feasting on porcupines (Jones and others, 1983).

The rarest of all mammalian species recovered at vertebrate fossil sites are the top carnivores: bears and great cats. An upper molar and a lower jaw fragment of the black bear (*Ursus americanus*) were found in the base of the Peoria Loess, 2 feet above the paleosol at the top of the Gilman Canyon at Bone Cove in 1945. Because of its denning habits, the black bear is common as a fossil in eastern and western North American caves but is rarely found in the Great Plains Pleistocene (Kurten and Anderson, 1980). This is the first and only occurrence of *Ursus americanus* in the Nebraska fossil record. In the early 18<sup>th</sup> century, the black bear was once commonly found along the Missouri River and westward on the Loup and Niobrara rivers (Jones and others, 1983). The upper second molar measures 1.14 inches (28.4 millimeters) in length, which is too small to be referred to the grizzly bear (*Ursus arctos*) but lies within the range of the black bear (Graham, 1991).

A partial maxillary of the great American Lion, *Felis atrox*, was found at Harlan County Lake from Peoria Loess deposits by Merle Stevens of Sutton, Nebraska. This large cat was the largest of all North American cats, about 20 percent larger (Voorhies and Corner, 1982) than the African lion (*Panthera leo*) and apparently only second in size to the cave lions (*Panthera spelaea*) of Eurasia. Turner (1996) states that the American lion likely belongs to the same taxon as its Eurasian and African relatives, whereas Martin and Gilbert (1978) show that it can easily be distinguished from the African species. The American lion was a highly cursorial (specialized for running) animal, very much at home on the Great Plains, preying on large ungulates, ground sloths and perhaps even infant elephants.

Both mastodont and mammoth remains have been found at Harlan County Lake. The American mastodon (*Mammuthus americanus*) is only known from a single cervical vertebra that was found on the beach at North Cove (Stewart, 1987) and probably came from the Peoria Loess. Mammoth teeth and bones outnumber mastodont remains in Nebraska by a ratio of about ten to one. This ratio is indicative of open grassland areas throughout the Ice Age in Nebraska, whereas in

states to the east, the ratio more nearly approaches one, and eastward into the Ohio Valley and upper New York state, mastodont remains outnumber mammoths. *Mammuthus americanus* was a browser and was at home in hardwood as well as evergreen forests.

Mammoths are one of the commonest and most easily recognized of Nebraska fossils, so much so that the official state fossil was deemed by the state legislature to be "the mammoth." Nearly all of the isolated teeth and postcranial bones have been referred to the southern or Columbian mammoth, *Mammuthus columbi*. These were extremely large animals that reached a maximum height of more than 13 feet at the shoulder and a weight of about 10 tons, so large that they must have spent the better part of the day just grazing on the tough prairie grasses that covered the plains. Isolated *Mammuthus* teeth and fragmented limb bones have been found in the Crete (?) sands and gravels, the Gilman Canyon Formation, Peoria Loess and in beach deposits at the lake. Associated bones of three distinct mammoth skeletons have been found on the north side of the lake.

Ice Age horse remains are extremely common in the fossil record. Numerous species have been described, and a tremendous over-splitting of described species exists. More complete material such as skulls and complete limb bones are needed to begin to speciate Pleistocene horses. Horse teeth, toe bones and broken limb bones have been found in the Crete (?) sands and gravels, Gilman Canyon Formation and in beach deposits at the lake.

Several species of extinct peccaries, cousins of the living javelinas, are known from the Pleistocene of Nebraska. The commonest, and the species present at Harlan County Lake, is the flat-headed peccary, *Platygonus progressus*. Williston (1894) described a family group of flat-headed peccaries consisting of nine individuals that was buried in late Pleistocene sediments at Goodland, Kansas, 100 miles southwest of Harlan County Lake. Several completely articulated (fully or mostly jointed) *Platygonus* skeletons have also been found in neighboring Franklin County, 20 miles east of the lake. These complete peccary individuals were probably victims of a storm or blizzard. A peccary canine tooth was found during dam construction from a soil in the Gilman Canyon, and a mandible was found by Steve Holen from Peoria Loess.

The common camel of the late Pleistocene of Nebraska is *Camelops*. This camel, about the size of the modern dromedary camel, is second only to *Equus* (horses and related extant and extinct species) in the number of identifiable bones and teeth from any of UNSM's numerous Pleistocene localities. Commercial pits using late Pleistocene gravels on the Republican River near McCook, Nebraska, 60 miles west of Harlan County Lake, have produced more than 950 identifiable *Camelops* bones from at least sixty-two individuals (Corner, 1989). *Camelops* remains from Harlan County Lake in the UNSM collections consist of a complete cervical vertebra and tibia from the Crete (?) sands and gravels and several broken metapodial (foot) bones from beach sediments.



Fossil cervids (deer and relatives) are often found in Ice Age faunas. Three cervid species appear to be present at Harlan County Lake: *Odocoileus* sp. (white-tailed or mule deer), *Navahoceros fricki* (Frick's extinct mountain deer), and *Rangifer tarandus* (woodland caribou). The latter two species are intermediate in size between *Cervus elaphus* (elk) and *Odocoileus* (deer) and can be extremely difficult to identify based on fragmental material so far discovered; likewise the *Odocoileus* species are nearly impossible to separate without antlers. Numerous skeletons of *Navahoceros* are found in the caves of western United States and Mexico, and the Harlan County report is one of the few occurrences from the Great Plains. *Navahoceros* possesses short, plump limbs, as in other montane species of ungulates, and was estimated to be very much at home in mountainous regions (Kurten, 1975). It seems likely that *Navahoceros*, like the extinct mountain sheep (*Ovis catclawensis*) and extinct marten (*Martes nobilis*), was evicted from its montane habitat by late Pleistocene alpine glaciers in the Front Range and forced onto the High Plains. A fourth genus of Pleistocene cervid is the stilt-legged deer, *Sangamona fugitiva*, which also is intermediate in size between elk and mule deer (Kurten, 1979) and must be considered as a possible member of the Harlan County Ice Age Fauna. The problem with differentiating the Harlan County intermediate-sized deer is that only the ends of long bones are present in most cases and we must await the retrieval of complete long bones or antlers to be confident about identifications of *Rangifer*, *Navahoceros* and *Sangamona*.

The fossil bison discussed in this report from Harlan County Lake refers to *Bison antiquus*, which includes the subspecies *B. a. antiquus* and *B. a. occidentalis* of McDonald (1981). *B. a. antiquus* horn cores are the shorter, smaller forms, and *B. a. occidentalis* usually had long, slender and less curved horn cores. Since no horn cores were found, no determination of subspecies could be made. The extinct species probably lived in great herds and would probably average 10 to 15 percent larger than the modern species, *Bison bison*. Extinct *Bison* remains have been found in the lower gravels, the Gilman Canyon, Peoria Loess and in beach sediments at Harlan County Lake.

Neas (1985) described a partial skull and horn cores of the muskox, *Bootherium bombifrons*, from the north side of the lake west of North Cove. Spruce wood from the muskox site is dated at 15,000 years B.P., placing it within the time span of Peoria Loess sedimentation. For years it was thought that two distinct genera of muskoxen were present in the Pleistocene of North America, *Symbos* and *Bootherium*. McDonald and Ray (1989) reasonably showed that only one species is represented by the grossly different skulls and horn cores of *Symbos* and *Bootherium*, and that differences can easily be explained away by sexual variation. *Bootherium* has not been found in warm-weather faunas and might be an indicator of cool-weather situations. In other Republican Valley late Pleistocene faunas in Red Willow County, *Bootherium* is associated with the woodland caribou, *Rangifer tarandus* (Corner, 1977).

## Late Pleistocene Environments

Many of the Harlan County extra-limital mammals are boreal or western high-altitude species, the ranges of which do not extend into southern Nebraska. Some of these species include: *Lagopus* sp. (ptarmigan), *Sorex arcticus* (Arctic shrew), *Lepus americanus* (snowshoe hare), *Marmota flaviventris* (yellow-bellied marmot), *Tamiasciurus hudsonicus* (chickaree), *Tamias minimus* (least chipmunk), *Spermophilus richardsonii* (Richardson's ground squirrel), *Thomomys talpoides* (northern pocket gopher), *Synaptomys borealis* (northern bog lemming), *Phenacomys intermedius* (heather vole), *Clethrionomys gapperi* (red-backed vole), *Microtus montanus* (montane vole), *Microtus richardsonii* (Richardson's vole), *Microtus xanthognathus* (yellow-cheeked vole), *Zapus princeps* (western jumping mouse), *Mustela nivalis* (least weasel), *Gulo gulo* (wolverine), and *Rangifer tarandus* (woodland caribou). The above species indicate a cooler overall climate in southern Nebraska in the late Pleistocene about 15,000 years ago.

In addition, some of the above species are found in association with spruce woods, indicating the presence of stands of evergreen trees and much less open short-grass prairie than one sees today. Fredlund (1987) also showed a much different landscape from today's Harlan County, as he found abundant pollen from the open, mixed spruce-deciduous forest of the late Pleistocene from the fossil horizons at North Cove, including white spruce, pine, juniper, aspen, boxelder, oak, alder, hazel, willow, hickory, walnut, birch and others. C.W. Martin (1990a) found spruce charcoal from near the base of the Peoria Loess in Coyote Canyon on the south side of the lake, and indeed spruce charcoal is common in the lower 3 feet (about a meter) of the Peoria Loess (May and Holen, 1993). Even though there is much evidence for stands of spruces and other north woods trees, the forests were not deep and extensive, but a parkland was present that allowed for stands of conifers, as well as open prairie situations during the late Ice Age. Thus an extremely large and varied fauna for the late Pleistocene is evident at numerous Great Plains fossil sites, including the Harlan County Lake area.

## Geologic Processes Affecting the Strata

Having outlined the stratigraphy and paleontology of the Cretaceous to Holocene deposits at Harlan County Lake and vicinity, let's turn our attention to geologic processes that have affected or are continuing to affect the strata of the area. These include landslides, development of unconformities, jointing, faulting and folding.

## Modern and Ancient Landslides

### Modern Landslides

Nebraska is not widely known by the public as a landslide-prone state. However, a recent study included records of more than 200 landslides in the state (Eversoll, 1991), and Eversoll (personal communication, 2002) now reports that more than 300 exist. Although most of these are located in

the eastern and northeastern parts, landslides do occur in the vicinity of Harlan County Lake.

Landslides are downward and outward movements of earth materials. Three conditions are required before landslides occur. First, the geologic formations (unconsolidated sediments or bedrock) must have a history of land sliding. Second, the land surface usually must be sloping at certain critical angles that vary with the nature of the formations. And third, excessive amounts of water must be present, whether from precipitation, springs, seeps, or human application.

All three of these conditions exist naturally in the vicinity of Harlan County Lake. The Pierre Shale and Niobrara Formation, found in this area, have a history of producing landslides, the Pierre more so than the underlying and older Niobrara. The Pierre Shale is well known across the Great Plains for development of landslides even on fairly low slopes. The second necessary condition, slopes at critical angles, is present on many of the steeper slopes in the area, especially along the steeper southern banks of the lake. Erosion has caused the banks to become steeper than normal and thus more susceptible to landsliding. The third necessary condition, presence of excessive water, occurs not only from precipitation, springs and seeps, but also from wetting by lake waves breaking on the shore. Excessive water causes an increase in pore pressures (build up of pressure in soil or permeable rock due to addition of water in pore spaces), and it adds weight to the sediments. Wave erosion can also undermine banks, increasing slopes and making the banks unstable.

There are four type of landslides recognized by geomorphologists and engineering geologists (Varnes, 1978 – see table 6) that are found in the Harlan County Lake area. These are earth slumps, rock slumps, rock falls, and complex slides.

Earth slumps are movements of unconsolidated sediments due to forces that cause a rotation or a turning movement in these sediments. The surface of rupture is concave

upward (fig. 27). Examples can be observed along the shore and banks of the lake (fig. 28) in the Pleistocene formations described above.

Rock slumps are movements of bedrock downward and outward due to forces that cause the rock to rotate or turn. Examples occur mostly along the southern shore of the lake and mostly in the Pierre Shale (fig. 29).

Rock falls are free-falling rocks from a cliff or from cliffs undercut by wave erosion. Examples are found all along the southern shore of the lake and mainly involve the Pierre and Niobrara formations but also include some Ogallala Group rocks.

Complex slides are combinations of two or more of the various other types of landslides (fig. 30). At Harlan County Lake, complex slides are a combination of earth slumps and either rock slumps or rock falls. The latter type occurs where overlying Pleistocene deposits form an earth slump over shales (Pierre or Niobrara) with steep slopes, adding weight to the shales and making them fall. All of this debris comes to rest at the bottom of the steep banks, where wave action eventually breaks them up and moves them into the lake. Many examples of this kind of slide can be seen along the south side of the lake.

Most landslides are slow moving, except for rock falls, which are usually sudden, unexpected events. Rock falls along Harlan County Lake shorelines are dangerous and could be classified as a geologic hazard to those people who use the lake to fish, swim, picnic, or boat.

There are few reported landslides away from the shores of Harlan County Lake, but the Pierre Shale does crop out in the area and probably does have some landslides that are currently unrecognized and mapped. Some small earth slumps in Pleistocene deposits can be found along roads and railroad cuts in the area. These are mainly in silts and sands of the Gilman Canyon and Peoria Loess formations that overlie the uplands bordering the lake. These slides are usually small

Table 6. Classification of landslides (after Varne, 1978). Shaded areas indicate those seen near Harlan County Lake.

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational	few units	Rock slump	Debris slump	Earth slump
		— — —	Rock block slide	Debris block slide	Earth block slide
	Translational	many units	Rock slide	Debris slide	Earth slide
Lateral spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
Complex			Combination of two or more principal types of movement		

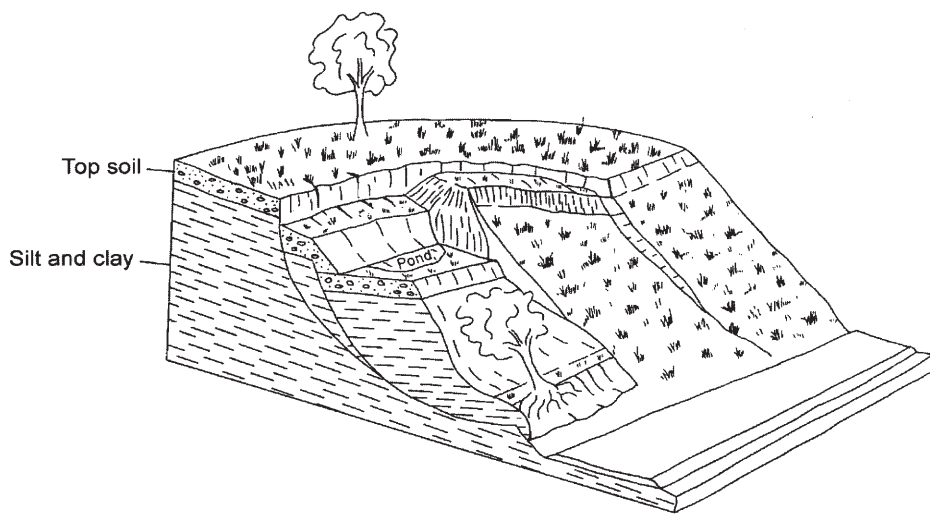


Fig. 27. Longitudinal section through an earth slump.



Fig. 28. Earth slump in Quaternary loesses between sites 17 and 18.

but provide a more-or-less constant rain of debris off exposed cliffs. They do cause maintenance problems for road- and railroad-repair crews.

### ***Ancient Landslides***

Three sites on the south side of the lake and one on the north side have been found where ancient landslide deposits occur (fig. 15; table 2). One affects the Pierre Shale (fig. 31). An eastward-dipping slip plane separates slightly deformed shale on the west from a chaotic jumble of shale blocks on the east. The landslide could have formed along a fault plane intersecting the former land surface or formed along a shallow slip plane. To date, no geophysical studies have been done here so we do not know which of these explanations is

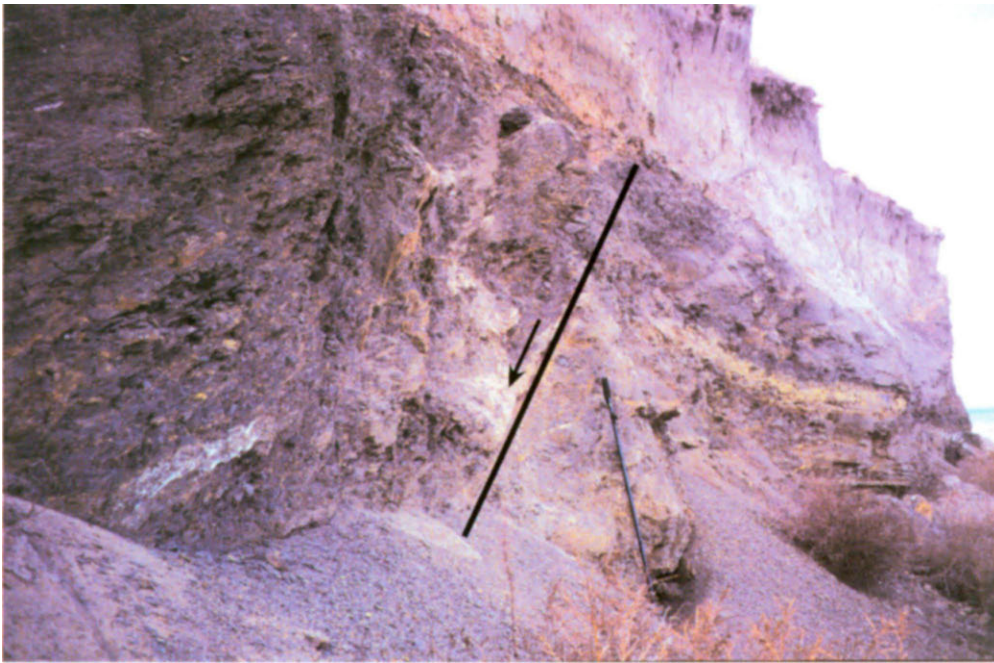
correct. The Pierre is overlain by undeformed Pleistocene loess, so the slide is pre-Peorian in age. Two other sites involve slides in the Pleistocene section. The earliest report of one of these is from a site on the west side of Bone Cove that is above normal high pool level. First reports listed the site as one where late Pleistocene faulting had occurred (Johnson, 1996). Subsequent studies by Johnson (1996), Miller and Steeples (1996), and Machette and others (1998) have found that the planes become less steeply sloping with depth and only affect the Pleistocene section, indicating that offsets are along southward-dipping slip planes on landslide blocks. The slip planes at this site extend up into the Peoria Loess, indicating that the slide took place after at least part of the Peoria was deposited.



*Fig. 29. Rock slump in Pierre Shale near site 5. Man is about 5.5 feet tall.*



*Fig. 30. Complex slide at site 12. Man is about 5.5 feet tall.*



*Fig. 31. Probable ancient slide in Pierre Shale at site 5. Walking stick is 4.4 feet long.*

The second site of an old slide in the Pleistocene section was discovered by Diffendal in 2001. It occurs at the mouth of Coyote Canyon on the west side of the canyon. The exposure is visible only at low pool level in a small area. Slip planes cut the Gilman Canyon Formation and appear to cut part of the overlying Peoria Loess (fig. 32). This slide apparently is a post-Peorian one. Machette and others (1998) also report that Johnson told them about a slide of similar type at a site on the west side of North Cove, on the north side of the lake. In 2001 the exposures there were partly covered with recently deposited landslide debris and with vegetation, and the location of the slide could not be verified.

## **Geologic Structures**

### ***Introduction and Previous Work***

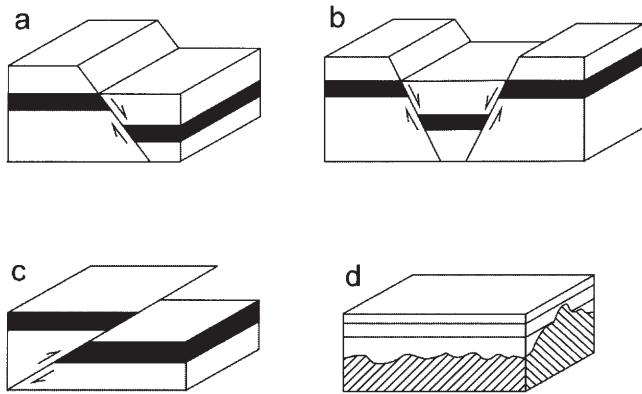
Angular unconformities, joints, and earthquake faults cut the bedrock at sites along the shoreline of Harlan County Lake. The faults are of three types: normal, graben, and reverse (fig. 33, a-c). A fault is a fracture along which rocks on either side have slid past one another. The relative motion of rock masses on either side of normal and graben faults is opposite to the relative motion of the rock masses on either side of a reverse fault. All three types are high-angle faults. An unconformity is a surface of erosion or non-deposition separating rocks of different geologic ages from one another. In an angular unconformity, the rock layers below the erosion surface are inclined at an angle to the layers above the erosion surface (fig. 33, d). This angular relationship indicates that the older underlying rock layers were deformed after deposition and were subsequently eroded before the geologically younger layers were deposited above the unconformity.

Geologic structures affecting bedrock were first observed by geologists in the area in the 1940s. Faults were first noted

*Fig. 32. Slide in Gilman Canyon Formation at site 13. Hammer is 1.3 feet long.*



Fig. 33. Block diagrams to illustrate faulting types (a-c) and an angular unconformity (d); a) normal fault; b) two opposing normal faults with central down-dropped graben; c) reverse fault.



in the area by S.C. Happ (1945, 1948), a U.S. Army Corps of Engineers geologist working at the dam site. Happ (1945) drew a north-south cross section showing high-angle faults offsetting strata in the Niobrara Formation and in one case also cutting the overlying Pierre Shale (fig. 34). Maps and cross sections of the spillway and south abutment areas published later show the distributions and orientations of faults and joints cutting bedrock at sites along the dam axis (figs. 35, 36; USACE, 1977). Some cores from holes drilled into bedrock beneath the valley floor along the dam axis have faults with slickensides (a polished, striped rock surface caused by one faulted rock sliding over another) and vein calcite preserved in them (fig. 37).

There are a few other written and oral reports of faults cutting the Cretaceous rocks of south-central Nebraska. Two inferred faults in Franklin County, just to the east of Harlan County Dam in the SW sec. 15, T.1N., R.16W., were mapped and discussed by Miller and others (1964). Pabian (personal communication, 2001) discovered a normal fault in the Cretaceous strata at a site along the south side of Harlan County Lake south of Alma, Nebraska, in the 1970s. No information about this fault was published until Souders and Migues

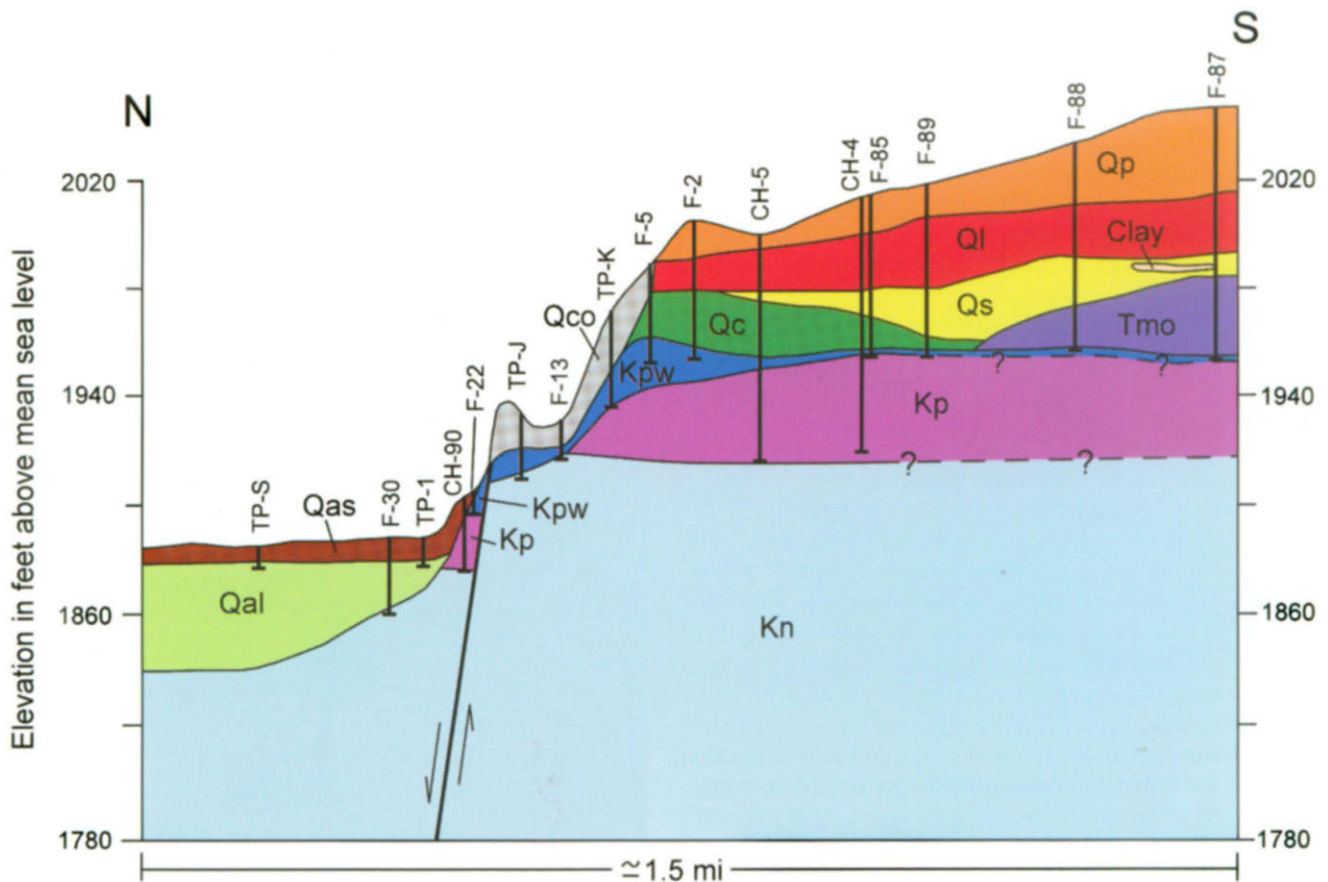


Fig. 34. North-south cross section from south valley side along dam axis (modified from Happ, 1945). Kn - Niobrara Formation; Kp - Pierre Shale; Kpw - weathered Pierre Shale; Tmo - Ogallala Group, Ash Hollow Formation; Qc - Crete (?) Formation; Qs - unnamed Quaternary silt; Ql - Gilman Canyon and Loveland Formations; Qp - Peoria Loess; Qco - Quaternary colluvium; Qal- Quaternary alluvium; Qas- Quaternary sandy alluvium.

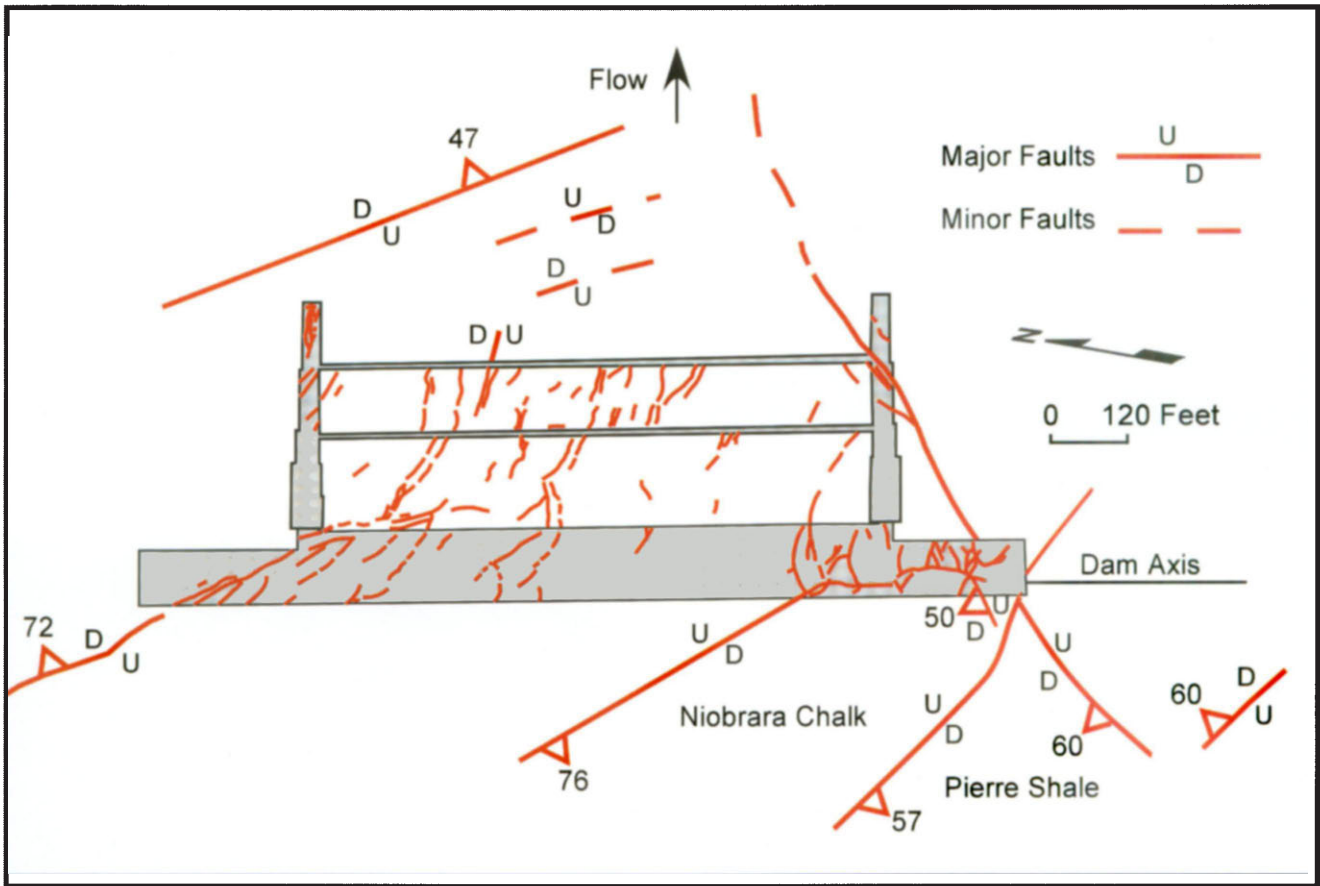


Fig. 35. Faults in bedrock beneath spillway (modified after USACE, 1977, plates 51 and 52).

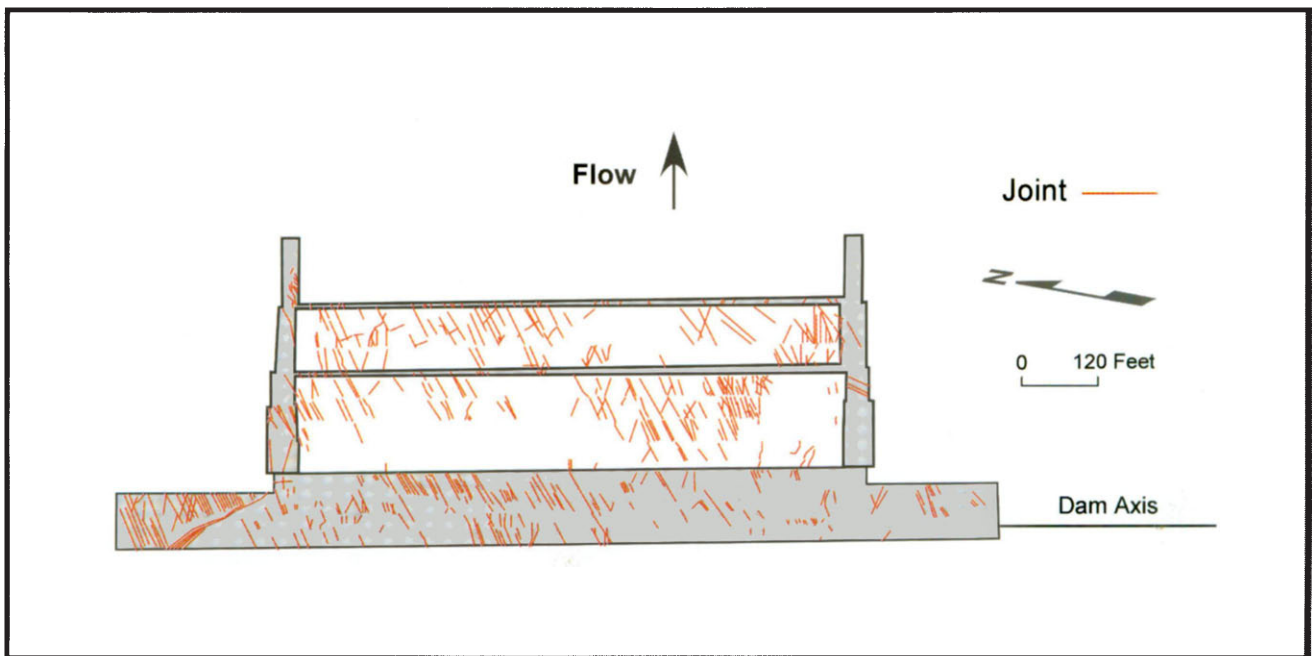


Fig. 36. Principal joints in bedrock beneath spillway (modified after USACE, 1977, plates 51 and 52).

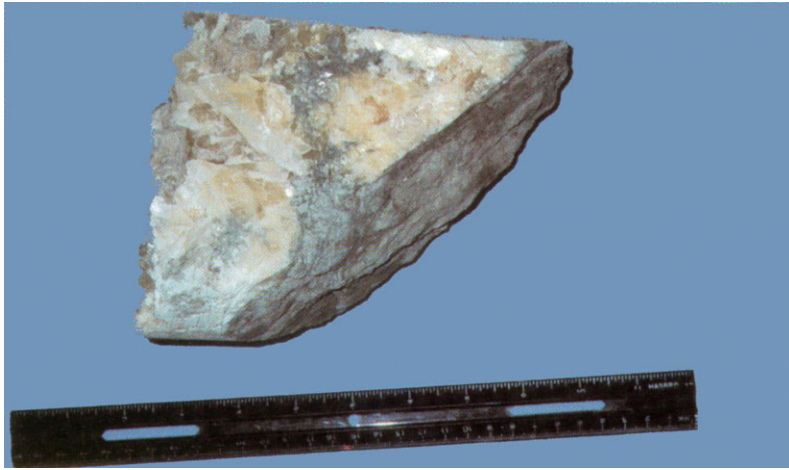


Fig. 37. Side view of core from test hole showing calcite crystal vein fill and dipping Pierre Shale with slickensides on fault surface. Ruler is 1 foot long.

Fig. 38. Angular unconformity between Niobrara Formation and Pierre Shale at site 2. Man is about 5.5 feet tall (courtesy of D. Eversoll).

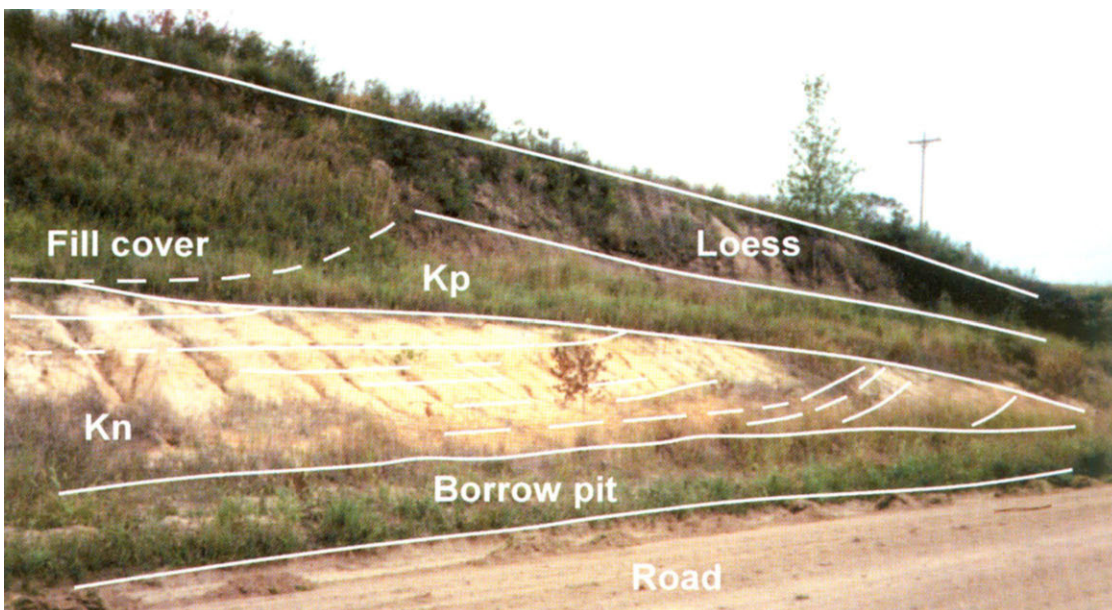
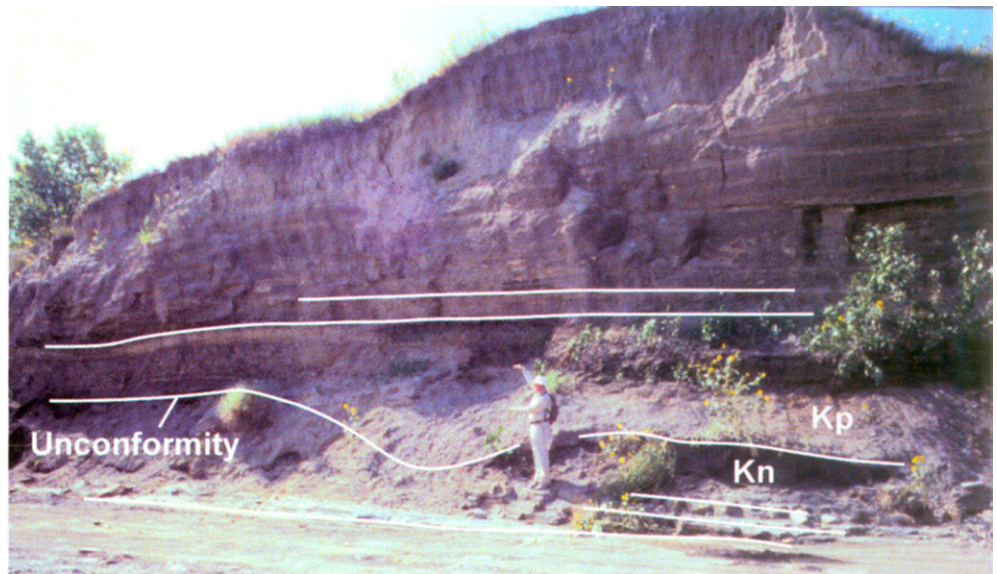


Fig. 39. Angular unconformity between Niobrara Formation and Pierre Shale at site 33 (courtesy of V. Souders).



(1990) noted its location. They also reported observing an angular unconformity between dipping beds of the Niobrara Formation and beds of the overlying horizontally stratified Pierre Shale at a site on the south side of the Republican River valley about 0.8 mile east of Harlan County Dam (center, NW NW, sec. 13, T.1N., R.17W.). Souders and Miguez (1990) also noted the locations of two normal faults in the Niobrara Formation in Franklin County and the location of one normal fault in Webster County. Pabian (1987) illustrated a fault cutting the Niobrara Formation in Franklin County at a site just west of Riverton, but this is no longer exposed.

Geophysical studies by Miller and Steeples (1996) demonstrated that faulting affected the bedrock at Bone Cove on the south side of the lake (fig. 15; table 2). These investigators ran a single north-south, high-resolution seismic reflection survey from the lake shore to south of the Pleistocene landslide area on the west side of Bone Cove that was discussed earlier. The faulting did not affect the Pleistocene deposits, but it did cut through the Cretaceous deposits and extended down through older bedrock. Miller and Steeples (1996) said that the faults they detected could be primarily normal or reverse, but favored the latter. The work done by the Army Corps of Engineers geologists noted earlier and the observations made by Diffendal in 2001 indicate that most faults are normal and that Miller and Steeples could be incorrect in favoring reverse faulting at Bone Cove. Future seismic surveys, coupled with additional data obtained by more comprehensive surficial geologic mapping and test-hole drilling at carefully selected sites, could probably determine which of these two fault types are present at the site.

Wave erosion and landslides have exposed unconformities, joints, gentle folds, and high-angle faults along the shoreline bluffs bordering Harlan County Lake. These features include an angular unconformity between the Niobrara Formation and the overlying Pierre Shale, several high-angle faults and numerous closely spaced joints cutting both formations, as well as gentle folds (fig. 15, table 2). Only one of the faults had been reported previously.

### **Angular Unconformities**

Wave erosion has exposed an angular unconformity between the Niobrara Formation and the overlying Pierre Shale along the south shore of Harlan County Lake southeast of Alma, Nebraska. The angular unconformity is nearly horizontal and separates beds of the Niobrara Formation dipping about 3 degrees northwest and striking at about north 70 degrees east from horizontally bedded, overlying Pierre Shale (fig. 38). (*Strike and dip are characterized differently from one another. See the glossary for explanations of strike and dip and how they are characterized.*)

Souders and Miguez (1990) reported another angular unconformity between the Niobrara and the Pierre just east of the Harlan County Dam on the south side of the Republican River valley (fig. 39). The Niobrara beneath the unconformity has an increasingly steep dip to the east as one moves westward, while the overlying Pierre is nearly horizontal (fig. 40). The relationships at both of these sites indi-

cate that there was deformation in the area after deposition of the Niobrara and before deposition of the Pierre.

### **Joints**

Joints in bedrock are exposed in cliff faces and on wave-cut bedrock shores primarily on the south side of the lake. All joints are vertical or nearly vertical. Three principal sets of shallow joints were observable at several exposures along the lake shore. One joint set is usually parallel or nearly parallel to cliff faces, while the other two sets are usually perpendicular or at a high angle to the cliff faces (fig. 41). During excavation for the spillway and stilling basin of the dam, the Army Corps of Engineers (1977) showed three sets of joints in the bedrock beneath the valley floor (fig. 36). The dominant set strikes northeast. Two much less frequently developed sets strike east-northeast and northwest. In contrast to the closely spaced shallow surface joints, with a spacing of 1-2 feet, the deeper joints mapped by the Corps appear from the map to have spacings of 2-10 feet or more. This difference may be due to the origins of the joints. The shallower ones may be in part tectonically controlled and in part developed by wave and ice stresses, while the deeper ones beneath the spillway may be entirely tectonically controlled.

### **Faults and Folds**

Seventeen and possibly eighteen or nineteen faults have been found cutting the Cretaceous bedrock on the south side of Harlan County Lake. Other faults may also affect the area, but have not been identified yet because they are covered by vegetation and/or by undeformed Quaternary sediments. All but four of the faults with exposed fault planes are either high-angle normal faults or grabens (figs. 42-48). The westernmost normal fault at site 2 has a strike of about north 50 degrees west and dips about 45 degrees northeast. Two faults within the Pierre (fig. 49) are reverse faults that dip to the northwest. Locations of these and other faults exposed along the shoreline are shown in figure 50. Faults in part may have controlled the direction of erosion of the valley sides. The faults with observable fault planes at the western end of the lake mostly strike northwest, and the valley side is elongate in a northwest-southeast direction.

The bedrock exposed in the cliffs along the shore is either nearly horizontally bedded or has dips up to 11 degrees locally. A small local anticline (a convex-upward fold) is presently exposed along the shore in about the center of the NE SW sec. 10, T.1N., R.18W. An eastward-dipping monocline (dipping in one direction only) is exposed in the cliff face along the shore in the NE NW sec. 14, T.1N., R.18W.

The geologic ages of the above noted faults and folds are uncertain but most likely are older than the Ogallala Group of Miocene age. All but one (at site 19) are certainly older than the Quaternary deposits overlying all of the bedrock exposures because the structures do not extend into the Quaternary deposits. The faulting has had an impact on the thickness and geometry of the Quaternary deposits in the area and also probably has had an impact on the geomorphic develop-

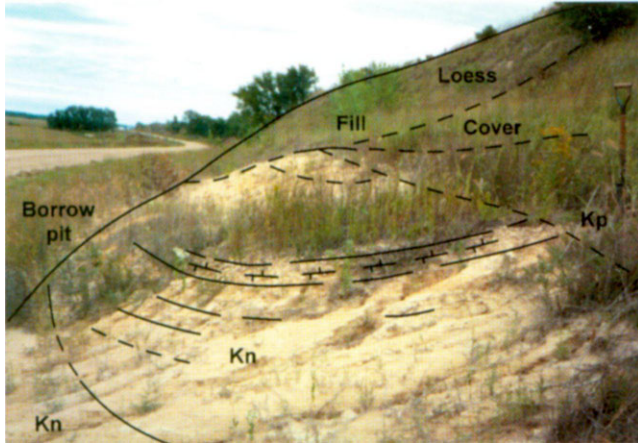


Fig. 40. Angular unconformity between Niobrara Formation and Pierre Shale at site 33. Shovel is about 4 feet long (courtesy of V. Souders).



Fig. 42. View looking south at normal fault with Niobrara Formation (right side) upthrown at site 3. Stick is 3.9 feet long.

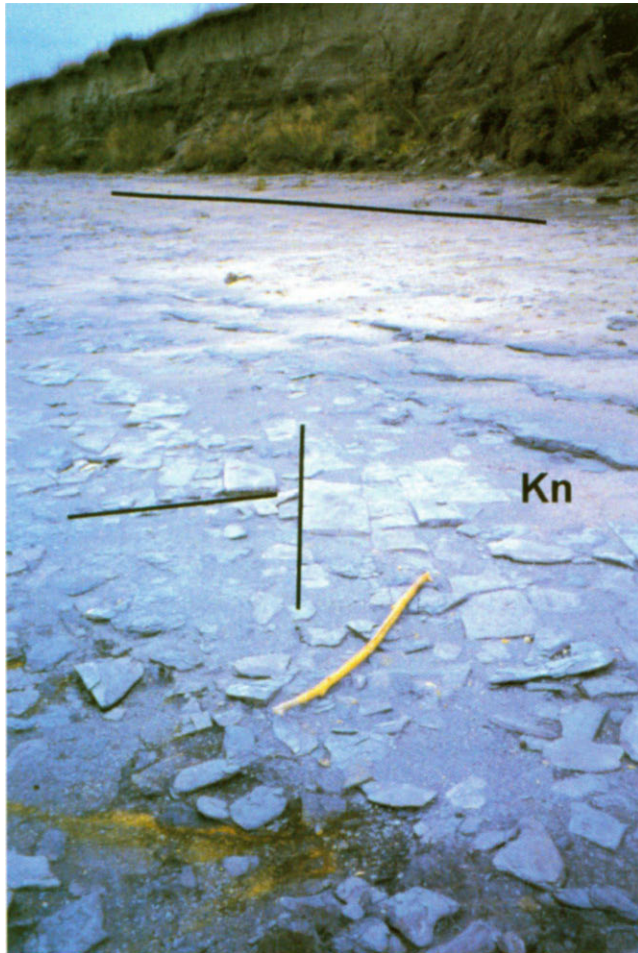


Fig. 41. Three joint sets in the Niobrara Formation at low pool level at site 22. Stick is 3.9 feet long.

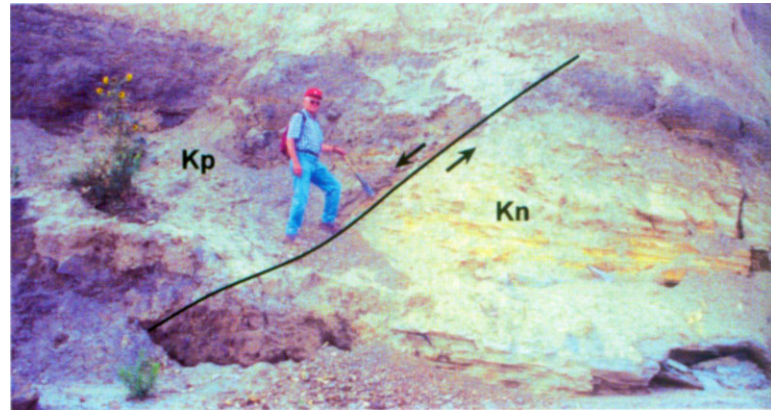


Fig. 43. View looking south at normal fault with Niobrara Formation (right side) upthrown at site 8. Man is 5.9 feet tall.



Fig. 44. View looking south at normal fault in Niobrara Formation at site 13.



Fig. 45. Left: view looking northwest along shore of lake at probable graben between sites 15 and 17.

Fig. 46. Right: view looking southwest at normal fault in Pierre Shale at site 19. Quaternary deposits above Pierre may be faulted. Stick is 3.9 feet long.

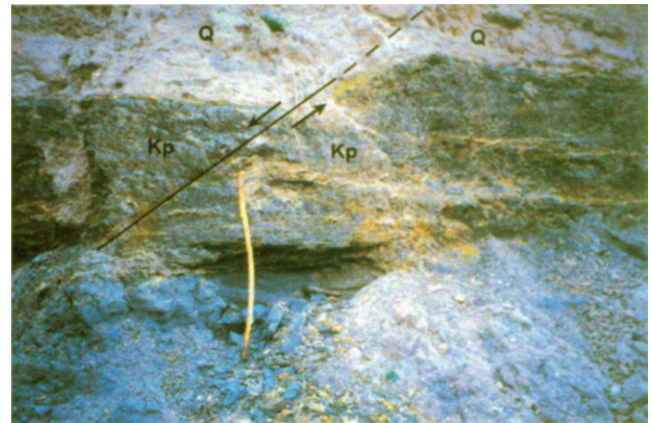


Fig. 47. Below: view looking south at normal faults cutting Niobrara and Pierre Shale formations at site 27.

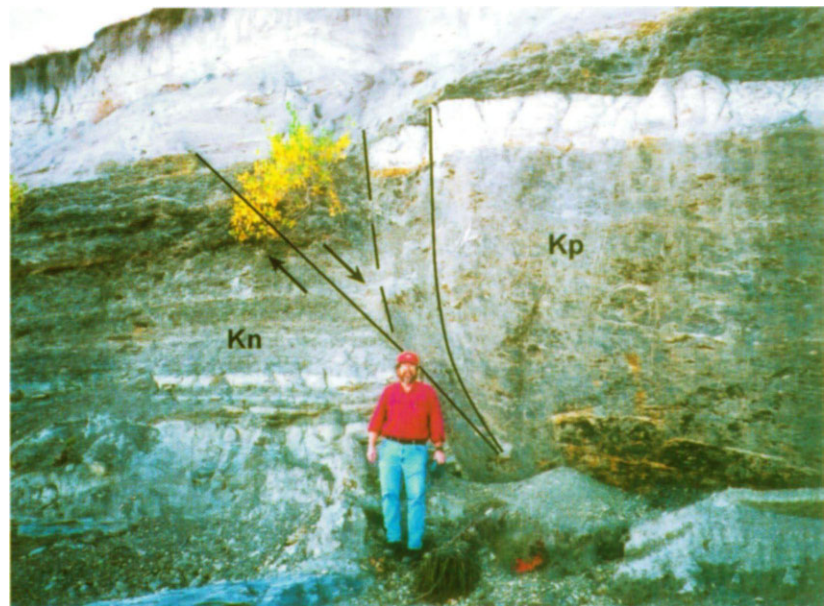
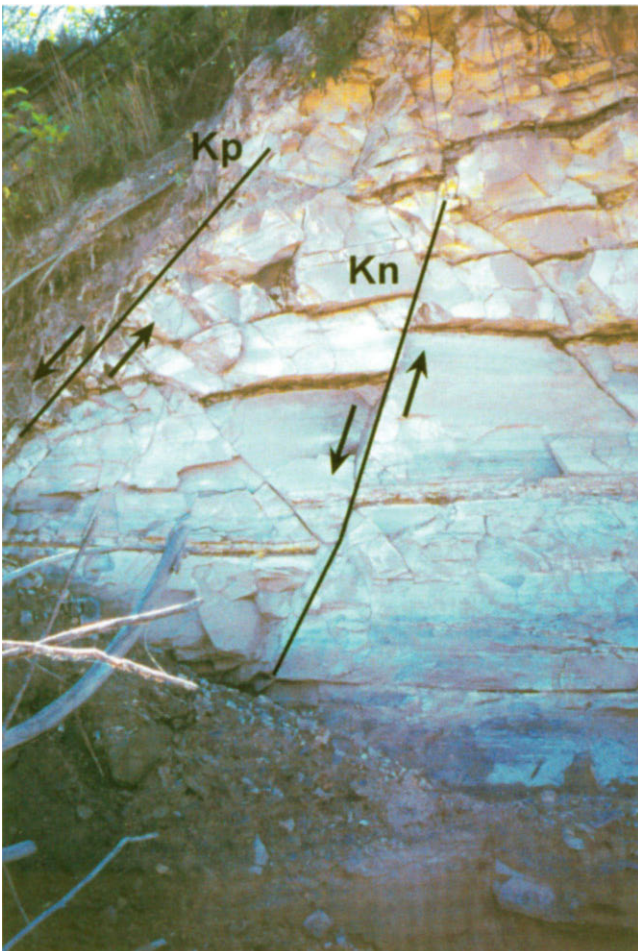


Fig. 48. View looking south at normal fault at site 29. Man is about 5.5 feet tall.

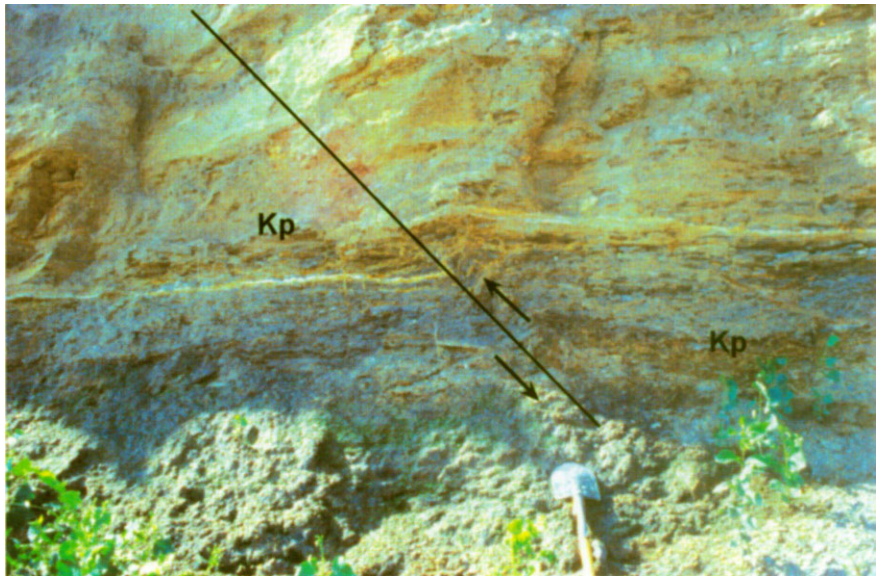
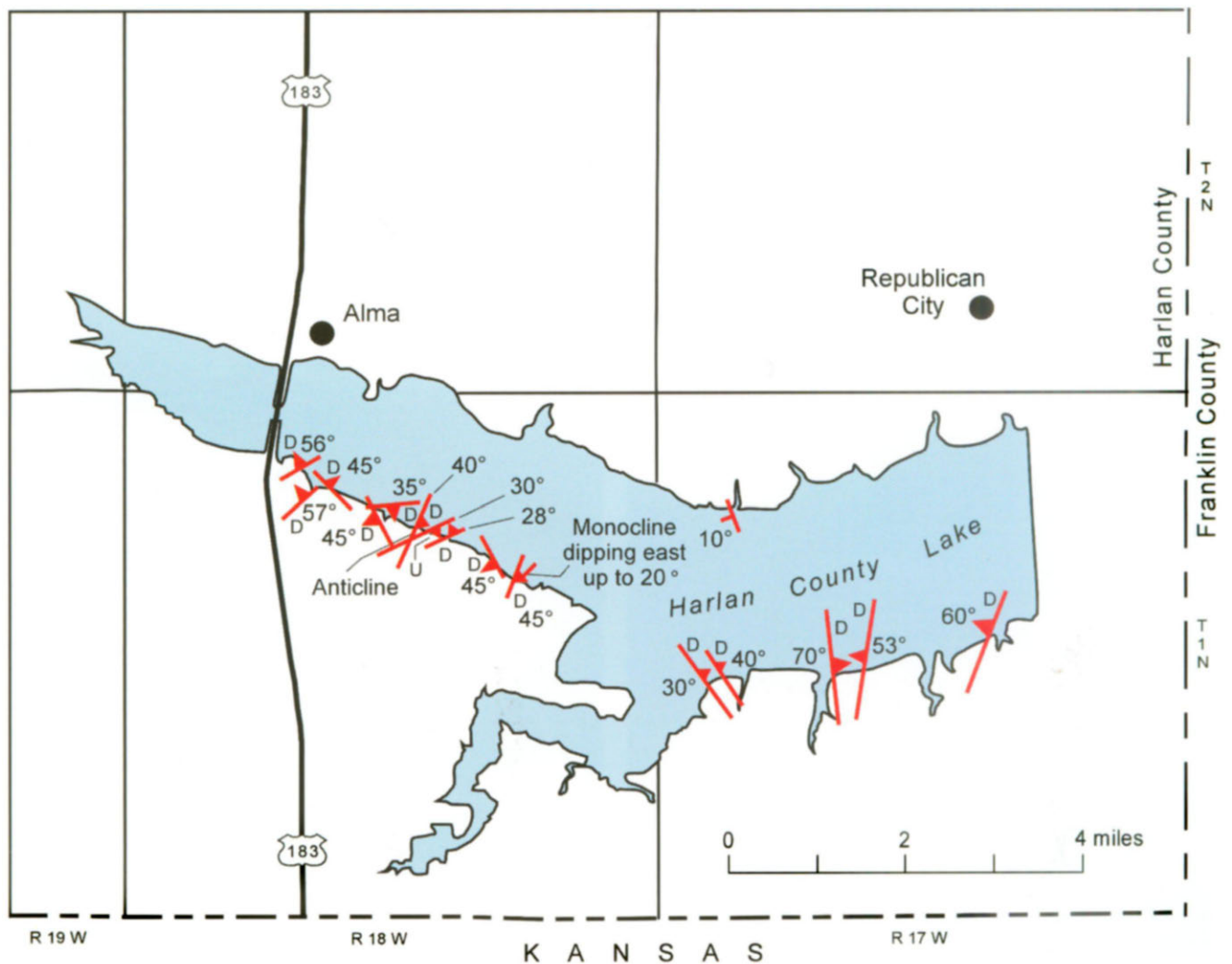


Fig. 49. Reverse fault in Pierre Shale at site 2. Shovel is about 4 feet long.

Fig. 50. Locations of observed faults and either true or (where taking exact measurements was too dangerous due to landslide potential) apparent strikes and dips of faults. U - upthrown side; D - downthrown side.



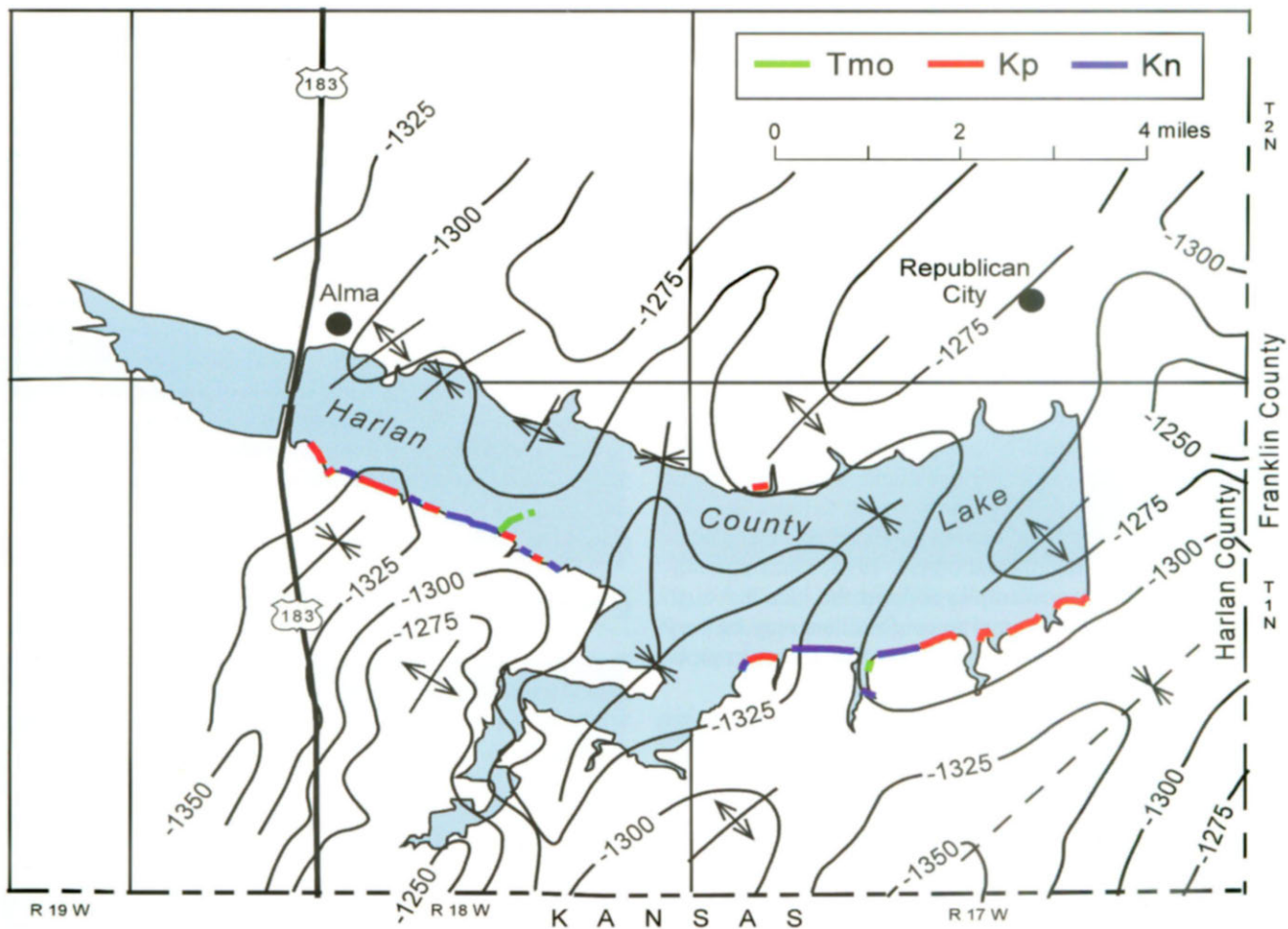


Fig. 51. Structural contour of the top of the Pennsylvanian age Lansing Formation (modified after Burchett, 1995) with formations cropping out along shore of Harlan County Lake at low pool level superimposed. Contour interval 25 feet. Negative contour values indicate altitudes below mean sea level. Kn - Niobrara Formation; Kp - Pierre Shale; Tmo - Ogallala Group, Ash Hollow Formation.

ment too. The thickest Quaternary loesses are deposited on the down-dropped sides of faults. David Thompson (personal communication, 2001) of HWS, Inc. in Lincoln, Nebraska, has observed that a normal fault cutting the Niobrara and Pierre formations near Long Island, Kansas, just south of Harlan County, does not cut across the overlying Ogallala and thus must be older than the Ogallala.

Another uncertainty at this time is whether or not the faults continue downward and cut older Phanerozoic bedrock or even Precambrian basement. The work of Miller and Steeples (1996) certainly supports the idea that at least some of the faults extend deeply beneath the surface and cut older bedrock. But additional lines of seismic survey around the lake would likely yield data supporting the idea that most, if not all, of the faults cutting bedrock in the area extend deeply beneath the surface. Interestingly, a structural contour map drawn on the top of the Lansing Group of Pennsylvanian age in Harlan County by Burchett (1995) shows apparent highs and lows that correspond to some of the surface faults (fig. 51). Lows on the surface also seem to correspond to areas

covered by thicker loess, particularly where the loess is exposed down to the shoreline and where no bedrock is visible. Since loess is wind deposited and often blankets older topography, the thickness increases may indicate where structurally produced ancient topographic lows formed on the top of the bedrock. Carlson (2001) reported that Precambrian structural features in the U.S. Midcontinent, including Nebraska, had been reactivated throughout geologic time. The faults in the Harlan County Lake area may continue down into the Precambrian rocks and may have been active a number of times during the geologic development of the area.

A further uncertainty centers on how far from Harlan County these kinds of structures extend. A few similar faults and folds have been noted and mapped in northwestern Phillips County, Kansas, the county bordering Harlan County to the south (Landes and Kroker, 1942; Frye and Leonard, 1949; Johnson, 1993), including a fault noted earlier just east of Long Island, Kansas, in the NE, sec. 24, T. 1S., R. 20W. Unfortunately, these structures have not been located and shown by symbols on any geologic map of Phillips County,

including the most recent map by Johnson and Arbogast (1993). Strikes and dips of the beds and the fault planes have not been published either, although a strike of about north 11 degrees east can be estimated for the Long Island normal fault, assuming the contact line between the Niobrara and Pierre shown on the geologic map of the area by Frye and Leonard (1949) is correctly drawn. However, David Thompson (personal communication, 2001) of HWS, Inc. has recorded a preliminary strike of north 20-25 degrees east and an apparent dip to the southeast at about 50 degrees on the Long Island normal fault. Thompson believes this fault can be traced into Nebraska just east of Orleans along Rope Creek, but no accurate comparison between Harlan and Phillips counties' structures can be made at this time because of the lack of good structural data from Phillips County and areas to the north in Nebraska. Farther afield, in South Dakota, faults with trends and relationships similar to those exposed at the lake have been noted cutting the Pierre Shale and older Cretaceous units (Nichols and others, 1994; Shurr and others, 1994). These two examples support the idea that such faulting, folding, and internal unconformities may be very common across the north-central plains. Surface cover probably has obscured this fact.

There is also a question about how geologically stable Harlan County is, given the ample evidence of previous deformation there. At this time most of the evidence points to stability. Only one fault has been found that possibly cuts Quaternary deposits. No earthquakes have been reported from Harlan County through 1990 according to data in Burchett (1990). Small quakes noted in Red Willow County, two counties to the west, were probably caused by water flooding an oil field there (Burchett, 1990). Still, Carlson (2001, p. 16) has reported suture zones in the ancient Precambrian rocks of Nebraska that have been "reactivated repeatedly during our more recent geologic history and controlled the structural activity now present in our younger rocks." If Carlson is correct, prudence would dictate that careful monitoring for earthquakes in Harlan County be continued.

Finally, there is a question about how much faulting there is in the area. It is likely that there is much more present, perhaps hidden by the Quaternary cover and beneath the lake, than has been found along shoreline exposures and during excavations. Johnson (1996), for example, proposed a valley-axis fault based on the occurrence of Pierre Shale on the north side of the lake at North Cove and the Niobrara Formation to the south across the lake at Bone Cove. Certainly the large number of closely spaced faults identified by the Army Corps of Engineers (1977) beneath the dam site would argue for many additional faults in the area. It is possible that many or most all of the valleys tributary to the Republican River in the area around the Harlan County Lake have been developed along fault zones, but Quaternary deposits cover the bedrock so that those faults cannot be verified without expensive excavations. Detailed seismic studies of the area, as suggested previously, would expand the number of faults and greatly increase our understanding of the structural complexities of the area.

## **Ancient Landscapes (Paleotopography)**

After at least some of the faulting affected the Cretaceous strata and before deposition of the Ogallala Group and younger formations noted above, hills and valleys were carved into the Cretaceous strata by rivers draining the land. Faulting also produced some hills and valleys. Sediments of the Ogallala Group were deposited in both of these types of valleys by rivers and streams flowing there. Subsequent cycles of river erosion and deposition produced other younger valley fills. At times loess was deposited over both hills and valleys as a blanket deposit. Buried hills of Cretaceous shale and sedimentary strata of the Ash Hollow Formation have been partly uncovered by wave erosion of the headlands along the south side of Harlan County Lake and by road construction and maintenance crews who made local road cuts (figs. 52-55). Masses of colluvium and sediments from ancient landslides are preserved on the sides of these buried hills in some places (fig. 56).

## **Quaternary River Terraces**

Seff (1952) reported on the terrace fills in parts of the Republican Valley. More recently, three river (fluvial) terrace fills have been recognized around Harlan County Lake, T0-T2 of the T0-T5 sequence described in earlier publications to be found along rivers and streams in Nebraska (Cornwell, 1987; Holen and others, 1996). Cornwell mapped the distributions of the fills and drew cross-valley profiles with the fill surfaces labeled. Radiocarbon dates on paleosols from these fills and from older Quaternary deposits noted above have been published (Johnson, 1989, 1996; Martin [C.W.], 1990a, b, 1992a, b, 1993). Souders and Kuzila (1990) also published some radiocarbon dates from some of the same units in Franklin County, Nebraska. All of these dates have helped to refine the time correlations made between these Quaternary deposits.

In at least some places around the shores of Harlan County Lake, the terrace sequence revealed by wave erosion of the shoreline promontories is far more complex than the pattern shown in the simple terrace-fill model noted above. At North Cove, for example, multiple cuts and fills of Crete (?) sands and gravels, Gilman Canyon Formation, Peoria Loess and younger Holocene deposits are exposed in one place. Each has little or no obvious surface expression, yet each could be considered a separate terrace-fill deposit using the model. Given these observations, careful attention needs to be paid to understanding the developmental sequence at any supposed terrace site along the Republican River valley.

## **Concluding Remarks**

The geologic history of the Harlan County Lake area can be better discerned than in other areas nearby, either upstream or downstream, thanks to the active erosion of the valley sides along the shores of the reservoir. The U.S. Army Corps of Engineers has done a great service to those of us interested in this history by building the Harlan County Dam.

Fossils have been found, structural relationships and paleogeographic development have been elucidated as a result.

And the lake provides outstanding recreational and avocational opportunities for the citizens.



Fig. 52. Ancient hill on top of Gilman Canyon Formation at site 37.



Fig. 53. Ancient hill on top of Gilman Canyon Formation at site 35.

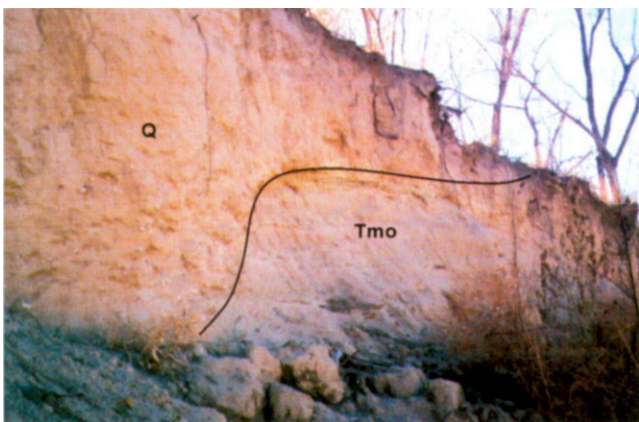


Fig. 54. Ogallala Group, Ash Hollow Formation, buried hill at site 26

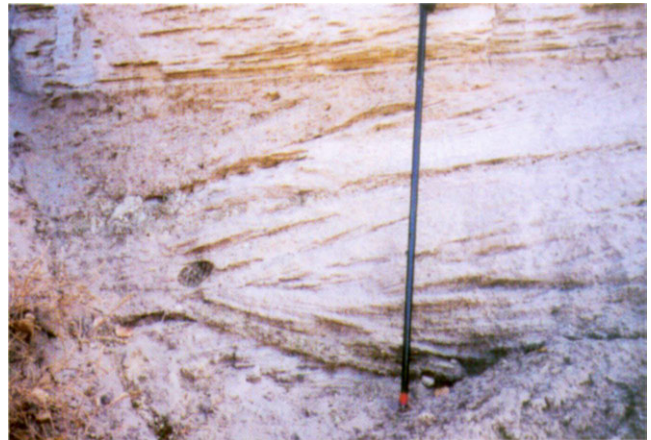


Fig. 55. Cross-stratified Ogallala Group, Ash Hollow Formation, sands and gravels at site 26. Walking stick is 4.4 feet long.

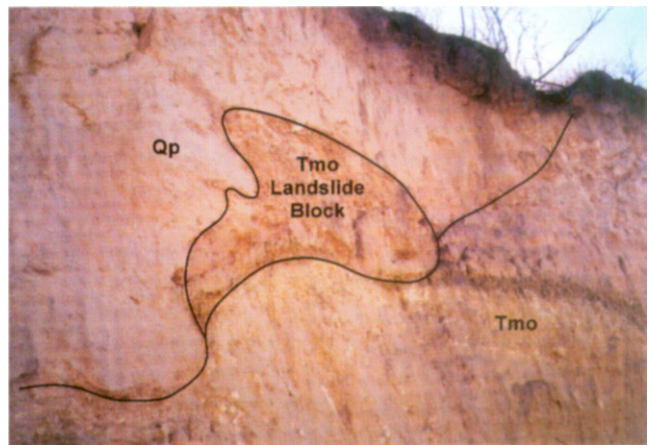


Fig. 56. Ogallala Group, Ash Hollow Formation, buried hill with Ogallala landslide block and debris included in overlying Quaternary Peoria Loess at site 26.

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## Glossary

aeration - in soil, the supplying of air and other gases to the pore spaces (voids).

alga (algae) - singular (and plural, respectively) for any of various primitive, chiefly aquatic, one-celled or multi-cellular plants that lack true stems, roots, and leaves but usually contain chlorophyll. Included are kelps and other seaweed, as well as diatoms.

alluvium (alluvial) - sediment deposited by flowing water (or pertaining to same, respectively), as in a riverbed, a floodplain or a delta.

ammonite - a usually coiled, flat, chambered shell of any of various extinct mollusks of the class Cephalopoda, characterized by a thin, ornamented shell with complex sutures (seams) that have finely divided, sometimes pointed, lobes with saddles between them.

anacoracid - a member of an extinct family of worldwide sharks, called "crow" sharks, that ranged from Late Jurassic to Late Cretaceous.

ankylosaur - any of a suborder (Ankylosauria) of heavily armored Cretaceous-age dinosaurs that are flattish and wide and might resemble a horned toad.

anticline - a fold in rocks, the core of which contains the stratigraphically older rocks, that is convex upward and in which the limbs dip away from each other; to be contrasted with a *syncline*, in which the fold is *concave* upward.

antilocaprid - a genus of ruminants (hoofed, even-toed grazing or browsing mammals such as cattle, goats, sheep, deer, *antelopes*, etc.) consisting of the pronghorn.

aquifer - water-bearing sediments with sufficient space between the grains to store quantities of water that are economical to pump; also igneous, metamorphic, or hardened sedimentary rocks with fracture zones or other voids offering the same properties.

aquitard - water-bearing sediments permeable enough to transmit water slowly and in small quantities, sufficient to be significant in analysis of groundwater flow but not for production wells.

articulated - jointed, consisting of segments united by joints.

baculite - a straight-shelled ammonoid of the genus *Baculites*.

bentonite - two principally aluminum-silicate clays, also

containing some magnesium and iron, that are distinguished by sodium or calcium content with corresponding high or low swelling capacity.

bivalve - a class of mollusks (Bivalvia), including clams and oysters, with shells consisting of two hinged parts.

borage - a plant, native to southern Europe and northern Africa, having star-shaped flowers and hairy leaves sometimes used as seasoning.

boreal - pertaining to the forest areas and tundras of the northern temperate zone and Arctic Circle.

bryozoan - a phylum of aquatic animals that reproduce by budding, that usually form branching, flat, or mosslike colonies permanently attached on stones or seaweed.

calcaneum - the quadrangular bone at the back of the foot (the heel bone).

calcareous - consisting of or containing calcium carbonate (*see below*).

calcium carbonate - a colorless or white crystalline compound ( $\text{CaCO}_3$ ), occurring naturally as calcite, chalk, limestone, marble and other forms; used in wide variety of manufacturing processes.

cartilaginous - composed of or relating to cartilage; in this report, especially with regard to some fishes, such as sharks.

caudal - constituting, belonging to or relating to a tail.

cephalopod - any of various mollusks of the class Cephalopoda, such as an octopus, squid, cuttlefish, ammonoids or nautiloids, having a definite head, an internal shell in some species and prehensile tentacles. Some are extinct and valuable as index fossils.

cervid - one of the Cervidae family: deer, elk, moose.

coccolith - various microscopic calcium-rich structures or button-like plates having various shapes and constituting the outer skeletal remains of a coccolithophore. Coccoliths are found in chalk and deep-sea oozes of the temperate and tropical oceans and were probably not common before the Jurassic.

colluvium - a general term applied to any loose, mixed, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.

commensal - one who eats at the same table as others; in

biology, living in commensalism, a relation in which one organism obtains food, protection or other benefits without damaging or benefitting the other.

crinoid - any of various invertebrates of the class Crinoidea, including sea lilies and perhaps feather stars, characterized by feathery, radiating arms and usually a stalk by which they are attached to a surface. Cretaceous crinoids are unstalked free swimmers.

cursorial - adapted to or specialized for running.

decompression syndrome - aeroembolism; in humans: Cassion's disease, "the bends"; gas bubbles forming in tissues, causing intense pain in muscles and other tissues.

dip - the maximum angle that a structural surface, for example, a bedding or fault plane, makes with the horizontal; measured perpendicular to the strike of the structure and in the vertical plane. A dip is characterized in terms of degrees from a direction (30 degrees northeast), as contrasted with a strike (*see strike*).

dorsal - belonging to or situated near or on the back of an animal.

eolian - transported by wind.

extant - still in existence, not destroyed, lost or extinct.

extra-limital - still present in the modern fauna but far removed from the fossil site.

felid - of the family Felidae, including lions, tigers, jaguars, panthers, mountain lions and other wild and domestic cats.

fissile - capable of being split.

filter feeder - an animal that obtains its food by filtering organic matter or minute organisms from a current of water that passes through some part of its system.

fluvial - pertaining to a river or a stream.

foraminifer - a one-celled microorganism belonging to the order Foraminifera characterized by a calcareous, external shell with perforations through which many false "feet" protrude. Most are marine, but freshwater forms do exist.

fusiform - shaped like a spindle, tapering toward each end.

gastropod - a mollusk of the class Gastropoda, such as a snail, slug, cowry, or limpet, characterized by a single or double, usually coiled shell(s) and a muscular mass on the bottom for locomotion.

geomorphology(ist) - science (or scientist, respectively) that deals with the land and submarine relief features of the Earth's surface and seeks a genetic interpretation of them by using principles of physiography in its descriptive aspects and dynamic and structural geology in its explanatory aspects.

gill raker - one of the bony processes on the inside of the branchial (gill-related) arches of fishes that help to prevent solid substances from being carried out through the branchial clefts.

graben fault - a depressed segment of the Earth's crust bounded on at least two sides by faults and generally of considerable length relative to its width.

hadrosaur - a heavy, plant-eating, duck-billed dinosaur; of the genus *Hadrosaurus*, the type of the family Hadrosauridae, found in the Cretaceous of North America; attained a length of more than 30 feet with a large head.

haptomonad protoctist - a tiny, planktonic, one-celled organism characterized by a haptone, a thread used as a holdfast or stabilizer, scales and coccoliths, that is, microscopic disc-like calcium carbonate structures.

headland - a point of land, usually high and with a sheer drop, extending out into a body of water; promontory.

high-angle fault - a fault, the dip of which is greater than 45 degrees.

horn core - the bony inner shaft of a typical horn.

humerus - the long bone of the upper part of the arm, extending from the shoulder to the elbow.

hydrozoan - a class of coelenterates that includes various simple and compound polyps and jellyfishes having no stomodaeum (the first part of the alimentary, or food-digesting, canal) or gastric tentacles and differing widely in appearance, structure and habits; some are attached polyps that have no free-swimming stage, others always free-swimming and the majority alternating between a free-swimming sexual generation and an attached asexual generation.

javelina - a peccary, a wild pig.

krotovina - horizontal, back-filled mammal burrows.

lacustrine - pertaining to lakes.

lithified - pertaining to sediments, once unconsolidated, that are now compacted and cemented.

loess - windblown silt - larger than clay-sized but smaller

than sand-sized particles – that has the capacity to form relatively high, unstratified vertical faces.

manganese oxide - a dark brown or gray-black insoluble compound ( $MnO_2$ , manganese dioxide) used as an oxidizing agent in dry cells, in glass making and ceramics, as a pigment, and as a starter for other manganese compounds.

marcasite - a mineral of iron disulfide ( $FeS_2$ ) having the same composition as pyrite but differing in crystalline structure.

marten - any of several, slender-bodied carnivorous mammals that are larger than weasels and of somewhat arboreal habits, characterized by a rather long tail and fine, soft fur that is light-colored below and brown or gray above.

metacarpal - pertaining to the metacarpus – the part of the hand or forefoot that contains the five bones connecting (in humans) the fingers to the bones of the wrist.

metapodial - a metacarpal (*see above*) or metatarsal (forming the instep in humans) bone.

monitor lizard - any of various tropical Old World pleurodont lizards closely related to iguanas and constituting the genus *Varanus* and the family Varanidae; so-called from the belief that such lizards give warning of the approach of crocodiles.

monocline - strata all dipping in the same direction at the same angle.

morphology - a branch of geology and evolutionary biology that deals with the form and structure of plants and animals; a study of the forms, relations, changes and phylogenetic development of organs apart from their functions; also, the features comprised in the form and structure of an organism or any of its parts.

mustelid - fur-bearing mammals of the family Mustelidae, which includes the badger, fisher, mink, otter, skunk, weasel and wolverine.

necrotic - pertaining to the death of living tissue, sometimes only on part of a plant or animal.

normal fault - a fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45-90 degrees.

pachycormids - a long-ranging (-surviving) family of primitive bony fishes that lived from the Late Triassic to the Late Cretaceous; includes the enigmatic snout-fish.

paleosol - fossil or ancient soil, almost always buried.

paleotopography - ancient landscape with an emphasis on contours.

paleovalley - ancient valleys, often buried by younger sediments.

parkland - an area of grassy land with scattered groups of trees and shrubs.

peccary - either of two wild, piglike, hoofed mammals of southern North, Central and South America having dense, long, dark bristles (*see javelina*).

pellet - in this report, a small, firm, somewhat cylindrical mass of dung dropped by a small mammal; can refer to worm pellets in marine environments.

phytolith - a silica-based part of a living plant that secretes mineral matter.

planktonic - pertaining to generally microscopic, floating organisms that drift in fresh or salt water.

platybelodont - scoop-tusked, long-jawed elephant-like animals found only in the late Miocene of North American and China.

plesiosaur - marine reptiles (suborder Plesiosauria) of the Mesozoic of Europe and North American having a very long neck, a small head and limbs developed as paddles for swimming.

postcranial - behind the head.

predaceous - predatory, often highly so.

premaxilla - either of two bones located in the front of and between the maxillary bone (jawbone) in the upper jaw of vertebrates

proboscidean - a mammal of the order Proboscidea, animals comprising elephants and extinct related forms that typically have some of the front teeth enlarged into tusks, that have a nose drawn out into a trunk and that formerly were widespread but now are native only to Africa and parts of Asia.

ptarmigan - any of various grouses of the genus *Lagopus* of the northern regions having completely feathered feet, winter plumage that is chiefly or wholly white, except in the British red grouse, and summer plumage that is chiefly grayish, brownish or blackish and variously barred.

pterosaur - flying reptiles flourishing from the Jurassic to Late Cretaceous ages and including pterodactyls and related forms.



pulmonate - having lungs or similar organs; includes many gastropods found in the Harlan County Lake area.

ramus - the posterior (back) more or less vertical part of the lower jaw on each side that articulates with the skull; also, the entire right or left half of the jaw, used when the jaw has no plainly distinguishable vertical part.

reducing (agent) - an element or compound that donates electrons or a share of its electrons to another element or compound.

reverse fault (or thrust fault) - a fault in which the hanging wall has moved upward relative to the footwall. Horizontal compression, rather than vertical displacement, is its characteristic feature.

rhizolith - fossil root or its trace(s).

seismic reflection survey - in geophysical surveys, a digitized or magnetic record of reflected, artificially induced seismic (percussion-based) waves; the *reflection* is the return of this wave from the subsurface area it has hit to a recording medium; used to profile sequences of rock.

selenite - clear, colorless variety of gypsum, hydrated calcium sulfide ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) occurring, especially in clays, in distinct, transparent crystals or in large crystalline masses that easily break into broad, thin layers.

silica (siliceous) - a chemically resistant dioxide of silicon ( $\text{SiO}_2$ ) occurring naturally in five crystalline forms (or pertaining to same, respectively): quartz, tridymite, cristobalite, coesite, and stishovite, in crypto(hidden)-crystalline form as chalcedony, in amorphous and hydrated forms as opal, and in less pure forms such as sand, diatomite, tripoli, chert, and flint; also combined in silicates as an essential constituent of many minerals.

slickensides - a polished, striated (scratched or striped) rock surface caused by one faulted rock sliding over another.

slip plane (or slip surface) - a land displacement surface, often in a crystalline substance and slickensided (*see above*), striated, and below the plane of its original surface.

speciate - to produce new species of organisms from existing ones in evolution.

strike - (noun) the direction or trend taken by a structural surface, for example, a bedding or fault plane, as it intersects the horizontal; (verb) to be aligned or to trend in a direction at right angles to the line of dip. A strike is characterized in terms of degrees between two directions (north 70 degrees west), as contrasted with dip (*see dip*).

stromatoporoid - any of a group of colonial invertebrates of uncertain classification included with hydrozoans, characterized by a calcareous skeleton and massive, sheet-like, or dendritic growth. The stromatoporoids have been variously classified as algae, foraminifers, sponges, hydrozoans, other cnidarians, and bryozoans. Range is Cambrian to Cretaceous or perhaps Holocene (Recent).

substrate - in biology, a surface on which a plant or animal grows; in geology (sometimes *substratum* or the plural *substrata*), an underlying layer of rock or sediments, or, occasionally, a subsoil.

surficial - pertaining to near or on the surface of the Earth

taiga - the subarctic evergreen forest of Siberia and similar regions in Eurasia and North America.

teleost - belonging to the infraclass Teleostei; modern bony fishes also characterized by rayed fins.

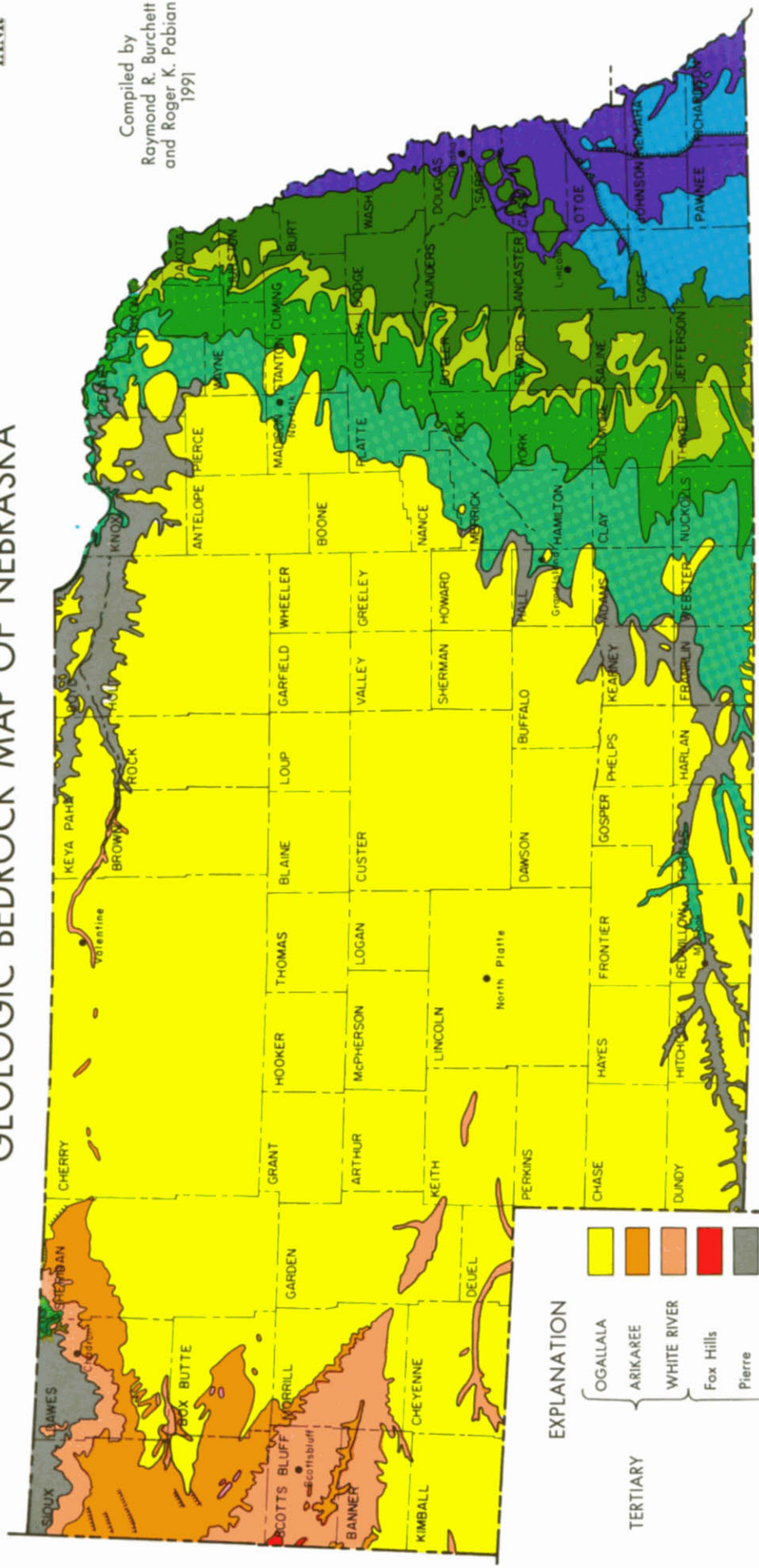
test - a hard, external covering, as with certain foraminifers, insects and invertebrates; a shell.

tibia - the inner and larger of the two bones in the human lower leg or similar structure in animals.

unconformity - a substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as the interruption in the depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary strata. It results from a change that caused deposition to cease for a considerable span of time, and it normally implies uplift and erosion and loss of the previously formed record.

# GEOLOGIC BEDROCK MAP OF NEBRASKA

Compiled by  
Raymond R. Burchett  
and Roger K. Pabian  
1991



Drafted by Jerry P. Leach

**EXPLANATION**

	OGALLALA
	ARIKAREE
	WHITE RIVER
	Fox Hills
	Pierre
	Niobrara
	Carlile
	Greenhorn-Graneros
	DAKOTA
	JURASSIC
	PERMIAN
	PENNSYLVANIAN
	MISSISSIPPIAN
	DEVONIAN
	SILURIAN
	ORDOVICIAN
	CAMBRIAN
	PRECAMBRIAN

Fault



GEOLOGIC CROSS SECTION ALONG SOUTHERN NEBRASKA BORDER



Conservation & Survey Division  
Institute of Agriculture and Natural Resources  
University of Nebraska—Lincoln

NOTE: Unconsolidated sediments of Recent and Pleistocene age cover the bedrock throughout much of the State and are not shown.

## ADDENDUM TO

<http://digitalcommons.unl.edu/natrespapers/77>



After field work was completed and this publication went to press the senior author, R. F. Diffendal, Jr., returned to Harlan County Lake. The reservoir level had continued to fall as a result of ongoing drought in Nebraska and Kansas. On the south side of the reservoir the lake bottom in many areas where faults were noted earlier was exposed and bed rock could be seen out onto the exposed lake bottom for considerable distances.

Where faults were exposed on the south valley side, the traces of these faults continued across the newly exposed lake bottom.

The three images taken in 2005 show the fault traces of three of these faults. The Dodge Ram pickup in one of the images gives you, the reader, a general scale of the exposure. The Cretaceous Niobrara Chalk Formation underlies the lighter colored shores; the younger Pierre Shale underlies the darker gray colored area of the shores.





