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Geologic History of Ash Hollow State Historical Park, Nebraska

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Educational Circular 5a

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February 1996

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Illustrations

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

Multiply English Units	By	To obtain IS units
	Length	
inches (in)	25.4	millimeters (mm)
feet or foot (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	4047	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
acre-feet (acre-ft)	1233	cubic meters (m^3)
	Flow	
gallons per minute (gpm)	.00006309	cubic meters per second (m^3/s)

Introduction

The acquisition of the land for Ash Hollow State Historical Park, now administered by the Nebraska Game and Parks Commission, began in 1962 with an initial purchase of 312 acres. Since then the park has been expanded to include more than 1,000 acres.

The park's visitor center is located on the east side of U.S. Highway 26 about 2 miles south and 1 mile east of Lewellen, in Garden County (figs. 1 and 2). Travelers on Interstate 80 can reach the park by taking exit 106 at Big Springs and following a paved county road north to U.S. Highway 26. Nebraska Highway 92 also leads to the park from north of the North Platte River. U.S. Highway 26 leads to the park from points east and west.

Ash Hollow, one of several historically important areas along the North Platte River in Nebraska, has been the site of human activity for about 9,000 years. Native Americans used this sheltered area first. About 1830, settlers began to come through the valley on their way to Oregon and other parts of the west. The name *Ash Hollow* was given to the area because of the ash trees growing in the valley at that time.

The geologic history of the rocks exposed in the park goes back about 30 million years. Derived from the Rocky Mountains and areas farther west, sediments deposited in the Ash Hollow area contain the remains of horses, land turtles, camels, proboscidians (elephants), rhinoceroses, grasses, sedges, trees, and many other species of plants and animals. Some of these forms became extinct; but others such as bison migrated in and out of the area from time to time. Episodes of erosion have removed some of the sedimentary rocks along with their fossils, but enough of them remain to enable geologists to interpret the history of past landscapes and of the organisms that lived upon them.

In this publication, we have explained many technical terms with short definitions in parentheses. We have also placed longer definitions in a glossary (appendix I) at the end of the text.

Acknowledgments

Many people contributed originally to this educational circular. Karen Messenger, John Boellstorff, formerly of the University of Nebraska-Lincoln Conservation and Survey Division (CSD), H. M. DeGraw, M. P. Carlson, and Vernon Souders, CSD, and Sherrill Daniels, formerly of the Nebraska State Historical Society, gave many helpful comments. Michael Voorhies, Thomas Myers, and R. George Corner, of the University of Nebraska State Museum, deserve special praise for their fine suggestions and aid in finding specimens for illustration. Steve Holen, formerly of the Nebraska State Historical Society archaeological staff, located and provided John Champe's specimens for our use. The Nebraska Game and Parks Commission provided the cover photograph. Parts of this work were supported by grants to J.R. Thomasson from the National Geographic Society (nos. 1883 and 2197-80) and the National Science Foundation (nos. DEB-7809150, -8002281, and CDP-8000918). The authors thank Marvin Grace, Vern Kallsen, Norman Rochlitz, Oren Clary, the Orr family, Ellis Countryman, and all other landowners in the Ash Hollow area who have allowed studies on their properties. We also thank J. Gottula, S. Goodwin, S. Fuerniss, D. McBride, L. Rice, J. Swinton, and R. Thomasson for assistance in the field and Dennis Shimmin, superintendent at Ash Hollow Park, for help in matters relating to the park. The herbarium and scanning electron microscope at Black Hills State College were used in preparing a part of this report. Charles A. Flowerday edited the revised manuscript.

Cautions

Ash Hollow is a beautifully scenic place, but it can also be dangerous. Some animals found in the park are potentially harmful. These include rattlesnakes, common throughout western Nebraska, of which one should be mindful even in open and apparently safe areas such as campgrounds. Because these snakes can cause serious injury or even death, anyone walking overland should wear good high-topped boots and should avoid wearing canvas shoes or sandals. Bees, wasps, ticks, and mosquitoes are common either locally or generally at certain times of the year or after periods of wetter-than-normal weather. Bees and wasps are venomous insects that may produce severe allergic reactions in some people. Wood ticks carry Rocky Mountain spotted fever. Deer ticks, smaller than wood ticks, can carry Lyme disease, and some mosquitoes carry encephalitis. Ants are very common and can bite fiercely when disturbed. Also, numerous species of plants with spines can harm the unwary individual. Yucca, prickly pear, and other cacti spines can easily penetrate jeans, canvas shoes, and even boots. Sand burrs await the palms of hands, poison ivy threatens any exposed parts of one's body, and even rock exposures are potentially dangerous. For your own safety, therefore, do not stand or work under overhanging ledges or in places where you can fall and hurt yourself. We want you to have fun and to learn about the natural history in the Ash Hollow area, but we want you to be cautious and safe at the same time.

General Stratigraphy

The exposed and buried sediments and the rock layers of western Nebraska have been generally described by Condra and Reed (1959). Names for Cenozoic formations in this sequence, currently recognized by Diffendal (1995), are shown in the stratigraphic column (fig. 3). The oldest rocks exposed in the Nebraska Panhandle are sedimentary rocks of Cretaceous age cropping out in the extreme west-central and northwestern parts (fig. 4; *also see back cover*). We will describe the lithology, ages, and relationships of the rock layers exposed in the park above the Cretaceous after a brief review of some geologic terminology. (*Lithology* is the physical character of a rock formation described in terms of its structure, texture, color, and mineral composition.)

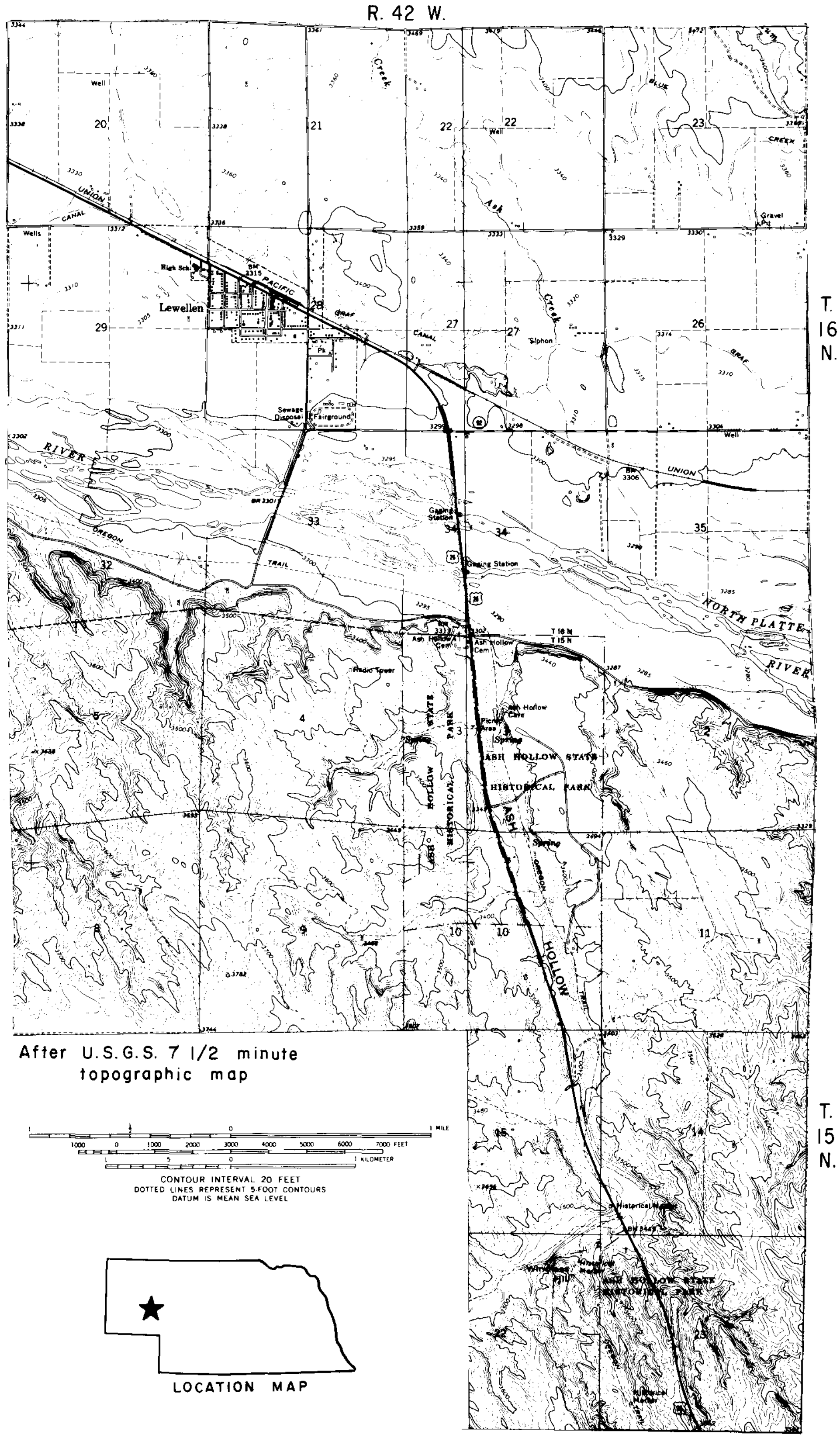

Fig. 1. *Topographic map of the Ash Hollow Park area.*

Fig. 2. *Aerial photograph of Ash Hollow and vicinity.*

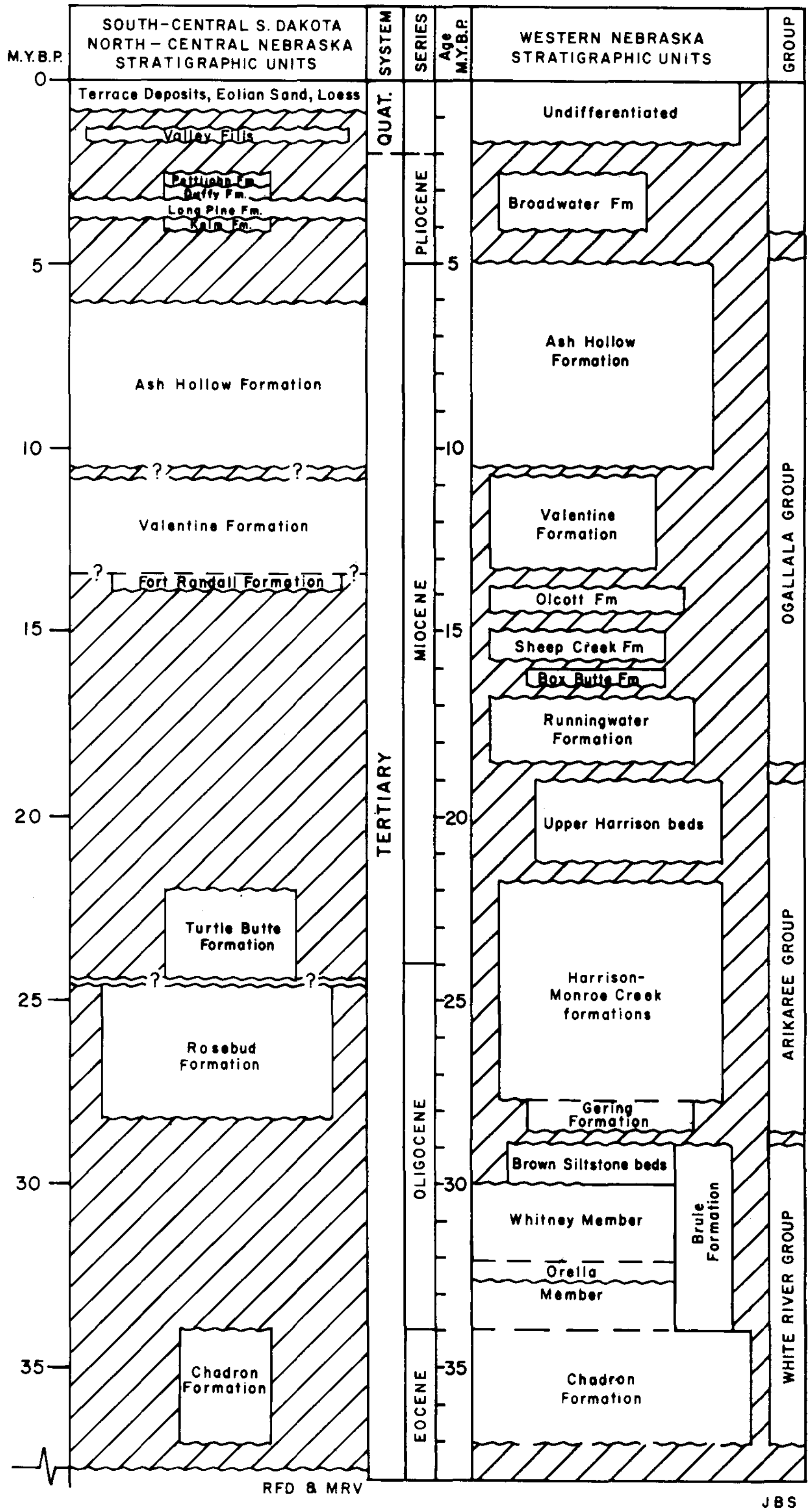

Fig. 3. *Generalized classification of Cenozoic rocks in parts of Nebraska and South Dakota (after Diffendal, 1995). This is not a complete list. Research indicates more units may need to be defined. Approximate boundary ages are in millions of years. Wavy lines indicate unconformities.*

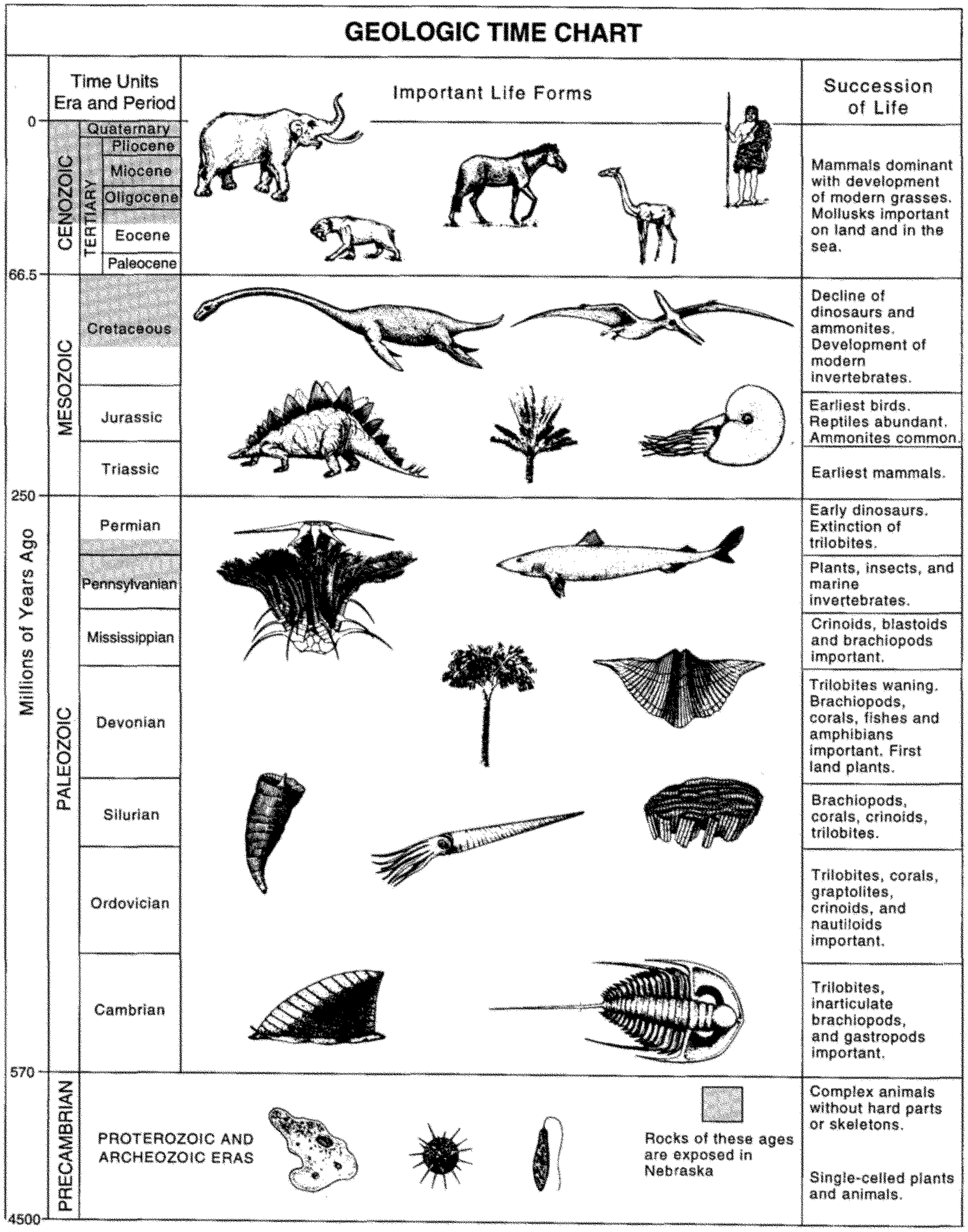

Fig. 4. Geologic time chart. Shaded parts of the time units indicate the age of rocks exposed in Nebraska.

	Rocks formed during span of geologic time	Span of geologic time	Rock masses*
Main division	Erathem	Era	Group Formation Member
Smaller subdivision	System Series Stage	Period Epoch Age	

*Because the terms below do not always correlate with terms in the columns to the left, they are entered at an angle to show that continuous rock masses may be of different ages and may cross geologic time lines.

Fig. 5. Relationships between geologic ages.

Geologic units

Geologists have developed a series of terms to designate spans of time, masses of rock formed during specific spans of time, and masses of rock having unifying characteristics, such as common lithology and fossils (remains of past life), so they can more easily communicate with one another as they seek to interpret the sequence of events that has produced the earth as we now see it. These purposes often have not been realized because not all geologists agree with the definitions for each time period or each rock unit and because the relationships between the different units of time and rock are often complex and so difficult to understand that even some geologists have trouble keeping them straight. Relationships of time and rock units are shown in figure 5.

Some of the earliest attempts to subdivide and decipher the events recorded in the geologic record were made by European geologists tracing rocks containing certain kinds of fossils. Subdivisions of erathems, systems, series, and stages (defined in the next paragraph) were originally based on two established principles. First, in a sequence of undisturbed sedimentary rock, the oldest layer is at the bottom. Second, unique assemblages of fossils occur only in certain rock layers and not in higher or lower layers in the sequence. *See Berry (1968) for a more complete historical account.*

The work of geologists in Europe and North America led to piecemeal designations of the various systems. Eventually, geologists grouped these systems into an orderly sequence and began to establish a chronologically arranged geologic column to which rocks around the world could be compared. Geologic time--the time from the origin of the earth to the present--is divided into principal subdivisions of unequal length called *eras* (fig. 5), which in turn are subdivided into successively smaller units of time called *periods, epochs,* and *ages.* These time terms are equivalent to the subdivisions of rocks formed during a span of geologic time described in the last paragraph (*see* fig. 5). Parallel usage of time and rock terms occurs when a geologist speaks about the Quaternary Period as a time unit and then speaks of the Quaternary System as the rocks that formed during the Quaternary Period.

North American geologists have developed a third, less abstract series of terms to subdivide masses of rock. The fundamental unit of rock subdivision, the formation, is defined as a mappable unit with some uniform characteristics. A formation can be either a homogeneous mass of rock or various kinds of rock layers in one cycle of a repetitive sequence. Two or more formations may be placed collectively in a group. A formation may be divided into two or more distinctive members.

Groups, formations, and members are usually named for a standard reference section, called a *type section*, that serves as a standard of comparison to determine rocks of similar ages. For example, the type locality of the Ash Hollow Formation is the bluffs along the valley of Ash Hollow Creek.

Originally, sedimentary rock units that underlie broad regions were thought to have been deposited everywhere during the same span of geologic time. One of the unfortunate things that complicates the usages described above, however, is that continuous masses of rock sometimes having uniform lithologic characteristics were not necessarily formed everywhere during the same span of geologic time. For example, a blanket of beach sand could have been deposited over a broad area of new sea floor as sea level gradually rose through time after a period of glaciation. If we consider the beach sand in this example as a formation, then it is not everywhere the same age but, instead, becomes younger toward the land. A rock unit, then, may be one age in one place and another age somewhere else, even though it is a continuous mass between those two places.

Let's now examine the rock and sediment sequence cropping out in Ash Hollow, while keeping in mind the units described above.

Oligocene Series-White River Group-Brule Formation-Whitney Member

The oldest rocks exposed in the park belong to the Whitney Member of the Brule Formation of Oligocene age (fig. 3). The Whitney is exposed along the bluffs that face the North Platte River on either side of the mouth of Ash Hollow and for a short distance south from the mouth of Ash Hollow Creek on both sides of the valley. Its distribution is shown on the geologic map of the park and adjacent area (fig. 6).

In this area, the Whitney Member is a light brown, massive siltstone with clay coating the silt and very fine sand grains. The uniformly massive nature of the Whitney has been observed many times before. Perhaps the earliest recorded geological observations on the Whitney were made by Stansbury (1852) during his expedition to the Great Salt Lake. On July 5, 1849, Stansbury (1852, p. 44) observed after turning west from Ash Hollow along the North Platte:

> The road winds along the bottom under the bluffs. The lower stratum consists of yellow clay, capped by cliffs of sandstone and silicious limestone, about two hundred feet in height.

Later, Engelmann (1876, p. 260-62), reporting on his observations while part of the J. H. Simpson expedition of 1858 and 1859, also described the geology of Ash Hollow. He stated (p. 262):

> At the mouth of Ash Hollow the lowest 30 feet are occupied by a stratum of buff-colored, finely arenaceous material, with no visible cement, but rather compact, capped by the calcareous sandstones.

Other studies relating to the Whitney and geology of the Ash Hollow area include those of Darton (1903), Lueninghoener (1934), Schultz and Stout (1955, 1961, 1980), and Stout (1971).

More recently, Swinehart (1979, 1980), Pabian and Swinehart (1979), Stanley and Benson (1979), and Swinehart and others (1985) reported on the mineralogy, source rock, and environmental conditions at the site of Whitney deposition. Swinehart (1979, p. 27) cleaned off the clay coatings of very fine sand grains from the Whitney and reported a minimum of 75 percent of the grains were of volcanic origin. He noted also that volcanic glass shards are the dominant constituent. The first two authors cited above concluded that the sediments constituting the Whitney were transported to Nebraska by winds from volcanic sources far to the west. Considering that the Whitney Member is minimally 250 feet thick and blankets much of western Nèbraska, the volcanic eruptions to the west must have been of immense scale.

Well-developed features that you can see in the Whitney above the base of the bluff just north of Ash Hollow Cave are possible ancient soil horizons called *paleosols* (figs. 7 and 8 [*in pocket on inside back cover*] and appendix II). Stout (1971, p. 40) described two dark bands about 15 feet above the valley floor and said these were paleosols. They are likely weathered zones in the Whitney and probably represent times of much slower deposition of volcanic ash.

Common features occurring in the uppermost Whitney at this spot are calcite (calcium-carbonate) cemented, vertically elongated, potato-shaped concretions (figs. 7c and 8).These concretions, common near the top of the Whitney, are often found along vertical fractures in the siltstone. They are probably due to downward percolation of calcite-rich water and precipitation of calcite in the siltstone along fractures during a long period of soil development and erosion of the overlying Whitney and possibly younger rocks.

Stout (1971, p. 40) suggested that this concretion zone may be part of the younger Gering Formation of the Arikaree Group. Diffendal, Pabian, and Thomasson (1982) thought that the beds in the zone probably belong to the Whitney because, excluding the presence of the concretions, the rock is mineralogically similar to the Whitney. There is a clear difference, however, in weathering behavior (fig. 7), and the irregular lower surface of the concretion zone may even be an unconformity (or erosion surface). This uppermost unit may be part of the Brown Siltstone beds of Swinehart and others (1985), the youngest unit of the Brule Formation recognized by them in western Nebraska. At present, this latter suggestion is most probably correct, but we cannot be certain because no radiometrically datable sediments or correlatable fossils have been recovered from these strata as yet.

Miocene Series-Ogallala Group-Ash Hollow Formation

The Ash Hollow Formation of the Ogallala Group was assigned a Miocene age by Boellstorff (1978, p. 46) on the basis of dates obtained from a study of fission tracks in volcanic ash shards. The Ash Hollow is composed primarily of stream-transported and stream-deposited sediments. At Ash Hollow and other places in Nebraska, the Ogallala was subdivided into the Valentine, Ash Hollow, and Kimball formations by Stout (1971). Lueninghoener (1934), Diffendal (1980a), and Diffendal, Pabian, and Thomasson (1982) simply placed all of these strata in an unsubdivided Ogallala Formation or Group, in the latter two cases because the Ogallala classification was in a state of flux due to disagreement among workers on the reality of the Kimball Formation. Finally, Swinehart and others (1985) defined an expanded Ash Hollow Formation, including all strata previously placed in the Kimball Formation. This expanded definition has been accepted by most workers at this time.

The basal Ash Hollow is generally a cross-bedded conglomerate of variable thickness resting on an eroded surface (an unconformity) developed on top of the concretion zone in the Whitney Member of the Brule Formation (figs. 7 and 8). Virtually all the larger grains in the conglomerate are partially rounded concretions derived from the underlying

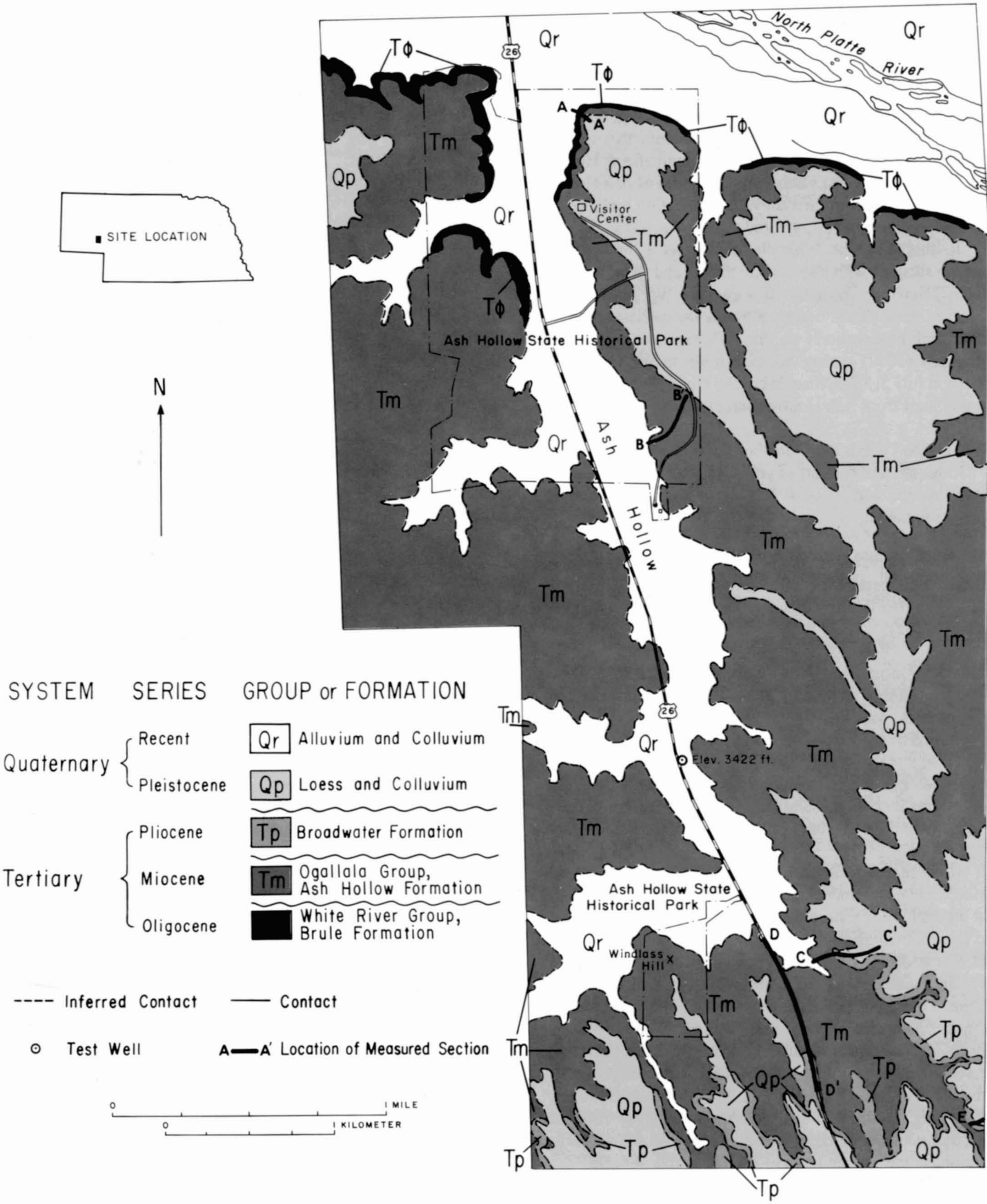

Fig. 6. Geologic map of Ash Hollow Park and vicinity showing location of measured stratigraphic sections.

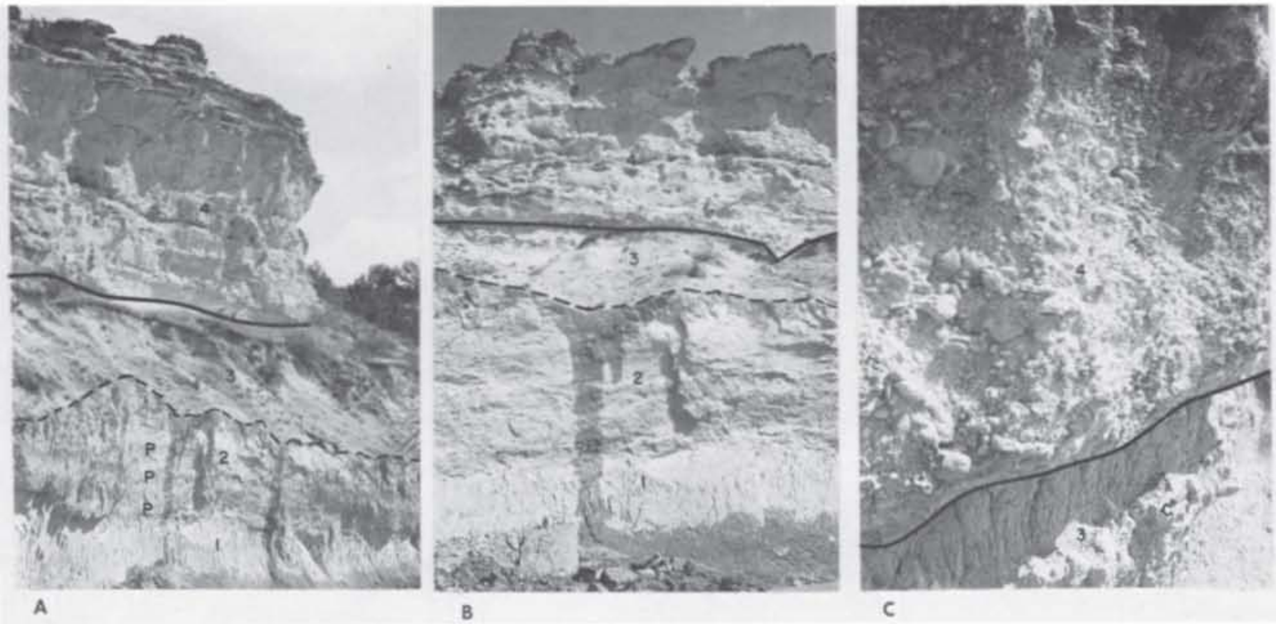

*Fig. 7. Exposures in Ash Hollow: **a)** Brule-Ash Hollow contact (solid line) on the east side of Ash Hollow Creek north of Ash Hollow Cave. Beds are numbered as in appendix II and figure 8* (see pocket on inside back cover). *"P" is a paleosol. Dashed line is edge of erosion surface, probably within the Whitney Member of the Brule Formation; **b)** Intermittent springs emerging along an erosional surface, probably within the Whitney Member of the Brule Formation; **c)** Ash Hollow Formation basal conglomerate, bed 4, composed of concretions eroded from bed 3.*

Whitney by local stream erosion. The sequence above the conglomerate consists of generally unstratified, calcite-cemented sandstone with conglomeratic lenses like those in the basal conglomerate. These two units form a single massive ledge (fig. 7).

Directly above this massive ledge, which contains the Ash Hollow Cave, is a sequence of rocks composed predominantly of sandstone ledges (called *mortar ledges* in some publications because they have the general appearance of concrete) with interbedded sandstones and siltstones (figs. 8 and 9). Some of these beds grade laterally into a granitic sand and gravel (stratigraphic section B-B', fig. 8). Above this sand and gravel, the strata consist of alternating mortar ledges and weakly cemented interbeds.

Mortar ledges do not appear to be truly geological beds. Engelmann (1876, p. 261) recognized this and stated:

> What appear to be bedrock strata are frequently no separate layers, but merely concretionary seams. Wherever large masses of the bluffs have become detached and fallen down, and thus new faces have been formed, they appear quite uniform, without a distinct stratification. After some time, however, the softer portions wear out under atmospheric influences, while the harder ones, distributed in more or less horizontal lines, are left protruding...

In most cases, these seams, as Engelmann calls them, are richer in calcium carbonate and are rapidly cemented into ledges during surface weathering.

Among the important unconsolidated and consolidated sediments included in the Ash Hollow sequence are massive sand bodies containing interspersed grains of granule size or larger. We call such sand bodies *pebbly sands* or, if the grains are cemented, *pebbly sandstones*. The possible origin of this material has been discussed by several workers. Lueninghoener (1934), following the usage of Lugn (1927), called these beds *pudding sands*. Lugn (1927, p. 98-99) reported modern pudding sand accumulating in a part of the Mississippi River as a homogeneous mass of sand several feet thick "containing relatively large pebbles evenly distributed through it, much like raisins or plums distributed through the matrix of a pudding." He suggested that such sediment builds up when larger rolling grains are uniformly incorporated with finer grained materials carried in suspension or by saltation (bouncing). Lugn stated that pudding sands in the Mississippi River grade laterally into better-sorted sand and gravel masses. This phenomenon can also be observed in the Ash Hollow Formation at Ash Hollow and other sites. Frye, Leonard, and Swineford (1956, p. 58-59) felt that the poor sorting and massive nature of such sands were the result of "rapid but intermittent sedimentation, with little opportunity for reworking, each deposit remaining for relatively long periods in a near-surface position thus allowing some mixing

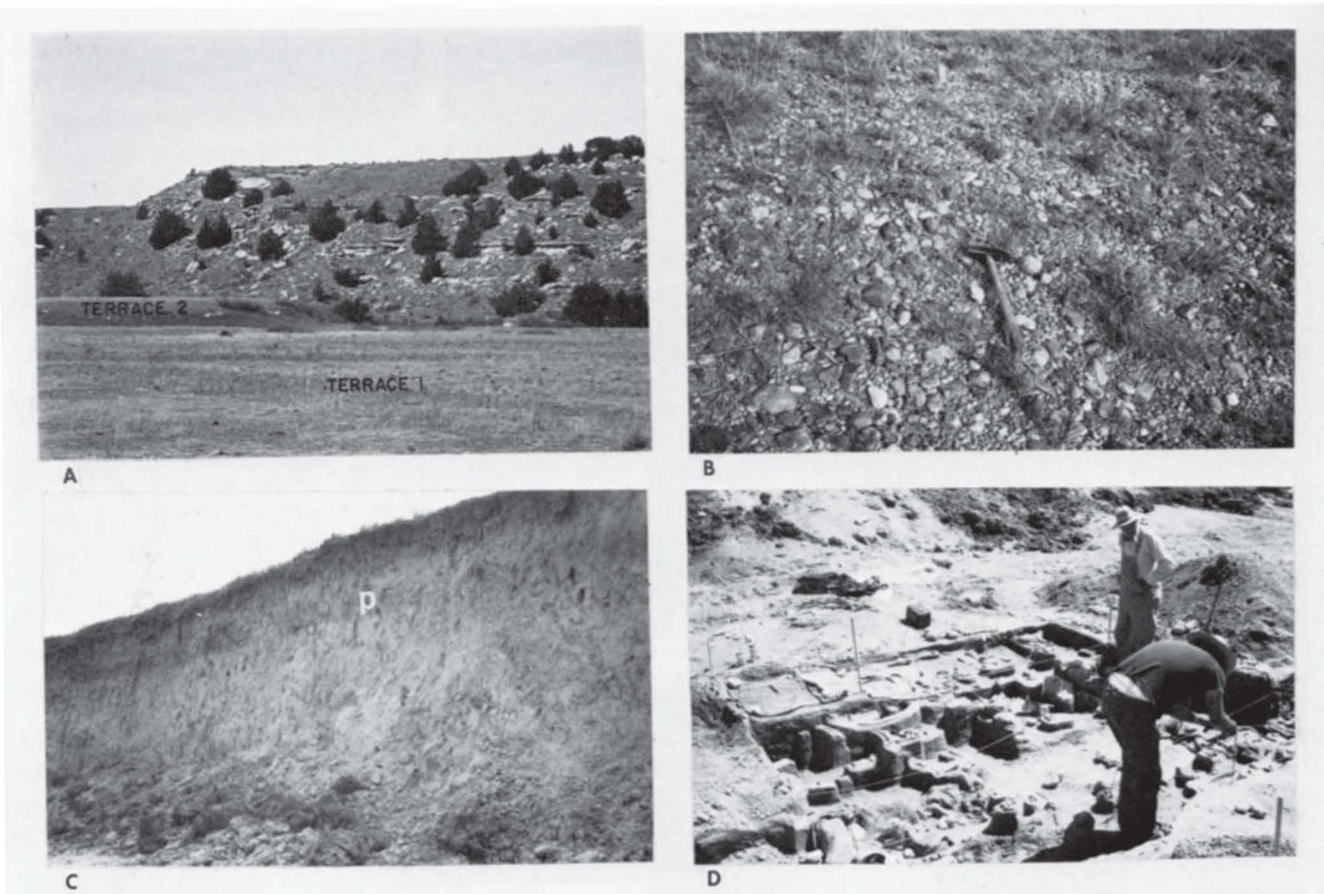

Fig. 9. Exposures in Ash Hollow: ***a)*** *Ash Hollow Formation outcrops and Quaternary terrace deposits (1) and (2), east of Windlass Hill turnoff;* ***b)*** *Broadwater Formation (Pliocene) gravel (hammer is 14 inches long);* ***c)*** *Quaternary Loess with buried soil (P).; d) University of Nebraska State Museum field party excavating a bison kill site in Ash Hollow.*

by surface processes." Thomasson (personal communication, 1980), after examining the sands at a North Platte River bathing beach, suggested that a rather uniform mixing of sands with coarser fragments could be accomplished by herds of large mammals crossing the exposed sands. Other workers have hypothesized that these sands are slope deposits or remains of debris flows, but lack of slope in the first case and different shape for the deposits in the second seems to rule out these hypotheses. Unfortunately, no current explanation is accepted universally as the cause of these peculiar deposits.

Volcanic ash lentils occur in the Ash Hollow Formation. Diffendal (1980b) reported at least seven volcanic ash deposits in exposures at Greenwood Canyon, about 50 miles west-northwest of Ash Hollow. Field data show that at least six ash horizons occur near Ash Hollow. At both localities the beds vary greatly in purity, thickness, texture, and geometry. Ash beds contain nearly 100 percent volcanically derived debris such as glass shards, biotite, plagioclase, zircon, and other minerals. Ash deposits range from less than 1 inch thick to more than 20 feet thick, but the majority discovered so far in the Ash Hollow Formation of western Nebraska are less than 5 feet thick. Volcanic ash particles can be any diameter less than 4 millimeters and may be loose to firmly cemented. The shape of ash deposits ranges from widespread blankets to lenses and narrow stream-channel fills. Contacts with laterally adjacent units may be sharp or gradational (changing gradually to sands, diatomites, or limestones). The most probable ash sources are in northern Nevada and southern Idaho.

Two of the ash lentils at Ash Hollow have been dated by the fission-track method. Boellstorff (1978, p. 46) reported a date of 8 +/- 0.3 million years BP (Before Present) for the ash exposed in the road cut along U.S. Highway 26 east of Windlass Hill and a date of 6.8 +/-0.3 million years BP for an ash exposed west of Windlass Hill about 120 feet higher in the Ash Hollow Formation than the first lentil.

The eruptions producing the Ash Hollow Formation ash beds, while they were probably small by earlier Miocene and Oligocene period standards, in all likelihood dwarfed the May 1980 eruption of Mount St. Helens in Washington state. This eruption dropped ash blankets less than half an inch thick over the terrain several hundred miles from the volcano.

Diatomites are another kind of sedimentary rock found in the Ash Hollow Formation in many areas, including Ash

Hollow (Thomasson, 1980b). These lens-shaped, calcareous freshwater pond deposits are usually chalky in appearance but frequently contain relatively little calcium carbonate (the principal component of chalk). Diatomites actually are formed primarily from microscopic coverings of silicon dioxide secreted by an alga called a *diatom*.

Many of the hard, white-colored beds in the Ash Hollow Formation resemble limestone. Closer examination of most of these beds demonstrates, however, that they are usually diatomites cemented with calcium carbonate, fine-grained volcanic ash, or a calcium-carbonate precipitate called *caliche* or *calcrete*, which forms in soils developed under variable climatic conditions (Reeves, 1976). All these rocks, as well as the so-called mortar ledges described earlier, probably have been called *limestone* or *magnesia rock* by well drillers and many other people, but only caliches can be true limestones (a sedimentary rock containing more than 50 percent calcium carbonate). Other limestones are rare in the Tertiary sequence in western Nebraska, occurring primarily as lens-shaped bodies deposited in short-lived ponds.

On top of the Ash Hollow Formation is a very coarse, stream-deposited sand and gravel placed within the Sidney Member of the Kimball Formation by Lugn (1939, p. 1261). Stout (1971, p. 38) followed this suggestion too. Diffendal, Pabian, and Thomasson (1982) placed these sands and gravels in the Ogallala Group. But subsequent recovery of much younger Pliocene fossils from them has proven all three of these ideas to be untenable. These stream deposits are equivalent in age to the Broadwater Formation discussed by Swinehart and others (1985).

If the shape of the bottom and the top of the Ash Hollow Formation sediments is not carefully worked out, an observer might believe that the formation is a uniformly thick, blanket-like deposit of poorly sorted, heterogeneous sediment. Although the formation, both at Ash Hollow and elsewhere in the Nebraska Panhandle, is poorly sorted and heterogeneous, it is anything but a uniformly thick blanket. In 1972, the Conservation and Survey Division of the University of Nebraska-Lincoln drilled a test hole about 2 miles south-southeast of the Ash Hollow Park visitor center that ended in the Ash Hollow Formation at an altitude of 3,242 feet or about 150 feet lower than the Brule-Ash Hollow Formation contact at the mouth of Ash Hollow (test hole 2-B-72, fig. 8, and appendix III). As stratigraphic sections C-C' and E-E' (fig. 8) illustrate, the top surface of the Ash Hollow Formation is not flat either. Instead it was carved by later stream erosion into a series of hills and valleys similar to those seen today, but perhaps on a smaller scale.

Pliocene Series-Broadwater Formation

Fragmentary remains of molars from *Stegomastodon mirificus* have been recovered from the sands and gravels overlying the Ash Hollow Formation of the Ogallala Group in the vicinity of Ash Hollow Park and in these sediments farther to the east in Keith County. Furthermore, regional geologic mapping done by Swinehart and others (1985) has demonstrated the connection of these sediments with the continuation of the type Broadwater sediments to the northeast of Ash Hollow beneath the Nebraska Sand Hills. For these reasons we have revised our earlier opinion about the age of these sands and gravels and have placed them in the Broadwater Formation (fig. 6; stratigraphic sections C-C', D-D', and E-E', fig. 8; and fig. 9).

Quaternary deposits

Older colluvium and loess

Quaternary stream erosion dissected parts of the Broadwater and Ash Hollow formations. A blanket of slope deposits, called colluvium, overlies the old, eroded Broadwater Formation surface in many places. This colluvium consists of extensively burrowed, wind- and water-deposited sand and silt combined with coarse sand and gravel derived from erosion of the Broadwater. Concretions cemented by calcium carbonate occur scattered throughout this unit.

A wind-transported deposit called loess (pronounced *lus)*, ranging from clay and silt to fine sand, drapes over the colluvium and older formations exposed in the park. Color and texture changes, as well as dark horizons (paleosols, fig. 9), indicate that loess deposition was not continuous. It is likely that the loess was deposited during extended drought in duststorms similar to those of the mid-1930s when wind transport was more important than it is generally in the Panhandle today.

Stout (1971) has divided the loess and colluvium into several additional units. We have chosen to leave the loess and colluvium undivided for a simpler presentation.

Younger colluvium and alluvium

The next youngest sequence of deposits constitutes terrace fills preserved on the present valley floor of Ash Hollow (fig. 9). These extremely complex materials include alluvium (sands and gravels deposited by local streams) along the course of an earlier pre-Ash Hollow Creek and its tributaries, interbedded with adjacent floodplain and slope deposits and ancient lake bed remnants. The youngest deposits in the park are the sands and gravels found beneath the present creek channel and the modern slope deposits.

General Paleontology

Evidence of past life: fossils and subfossils

Although the term *fossil* was originally used to describe any object dug from the earth, it is now used in a restricted sense to indicate any evidence of past life. Paleontologists do not agree on the minimum age necessary to classify organic remains as fossils, so the term *subfossil* has come into the literature to include those remains that are of an age intermediate between modern remains and those judged to be fossils. Entombed in the strata and sediments exposed in Ash Hollow Park are a variety of organic remains ranging from older fossils and subfossils to remains of modern organisms Fossils and their more recent counterparts may be of any size. Skeletons of fossil vertebrates, such as mastodons, camels, and rhinoceroses from the Ash Hollow Formation, rival the sizes of similar living forms, while some Quaternary horses, camels, mammoths, and beavers exceed the size of their living counterparts. At the opposite end of the size scale, plant phytoliths and diatom coverings called *frustules* are so small that they can be seen only by using high-powered microscopes.

In addition, fossils may vary greatly from their original composition. Some specimens of fossils, subfossils, and modern forms of bones, frustules, and shells are chemically unchanged, whereas others are preserved only as impressions in rocks and sediments, the original materials having entirely decomposed. Many bones and porous structures such as wood remain chemically unaltered but have had all their spaces filled with calcium carbonate, silica, or other crystalline cements, whereas other structures have been replaced entirely by other minerals but retain their original form. These various kinds of preservation produce such color and density differences in the fossils that bones of the same species of animal dug from different sites may be either white or very dark gray and may be very heavy or quite light.

Collecting fossils

Collecting any materials within the park is a crime punishable by a heavy fine. It is also unfair to deprive future visitors of seeing those materials in place. If you find fossils or artifacts in the park, tell the superintendent of the park and he will have qualified people collect them.

Even if you should find vertebrate fossils on your property or discover them on someone else's property where you have been allowed to collect them, it is best to contact someone trained in collecting techniques, such as paleontologists from the University of Nebraska State Museum (W436 Nebraska Hall, Lincoln, NE 68588-0514; 402-472-2657), to help you excavate the fossils properly. Destroying the fossils while trying to collect them will benefit no one and may cause hard feelings. So when in doubt, don't dig them out. Please ask a professional for advice.

When you are collecting, you will want to locate the site as precisely as possible on a topographic map or aerial photograph of the area and to describe as clearly as possible the geologic horizon and conditions at the site both verbally and by close-up and long-range photographs. All too often fossils in private collections lack even the most basic documentation and so are valueless as scientific tools, either to collectors or to other researchers. The size, preservation, and nature of the enclosing sediment dictate the proper collecting techniques. Very small fossils, such as microscopic diatoms, seeds, invertebrate skeletons, and small vertebrates, can be collected directly from the outcrop if the rock or sediment is soft. They can be stored in pill bottles or small sacks, but they should be cushioned with tissue or other materials to avoid crushing or breaking them. Isolated teeth, bones, or wood lying on the surface can be picked up without much danger of destruction, but they also should be carefully wrapped for transportation. Appendix IV is a list of equipment that should prove useful to collectors.

Collecting poorly preserved or highly fractured large fossil bones and large skeletal materials from well-consolidated sedimentary rocks may require much time and money. In a hard matrix, it may take hours or days to expose a fossil such as a large land-turtle shell without damaging it. With a turtle shell or large mammoth limb bone, it may take many people to lift it once freed from the matrix. You should avoid three things in your work: 1) underestimating the job; 2) losing patience; and 3) starting a job you cannot complete without destroying the fossil. Better not to start a project than not complete it. Halting a partially completed project will expose it to the weather. This exposure soon will destroy it.

If you find large fossils and want to collect them, keep the cautions above in mind. Figure 10 illustrates the steps in plaster casting and collecting a large or poorly preserved vertebrate fossil. Try out the following procedures by using a bone from a cow or other large vertebrate so that you can develop the skills needed before you start to work on an important fossil:

1) Carefully dig away the matrix (or surrounding material) from the top and sides of the fossil without digging underneath it (fig. 10a). Leave it supported on a matrix pedestal.

2) Once the specimen is exposed, apply a thick, liberal coat of a mixture of six parts of denatured alcohol to one part of white shellac to the surface of the bone and allow the mixture to dry. Additional coatings may be required. Should any small pieces of bone break off, collect and wrap them in tissue so that they can be glued in place during future preparation.

3) Using a linoleum knife or sharp pocket knife, cut strips of burlap to a length and a width appropriate for the size of specimen. The strips should be shorter and narrower than the whole specimen so that they can be overlapped. This adds strength to the cast that you will make later.

4) Start covering the exposed bone with folded layers of toilet paper, moistening the paper with water (fig. 10b).

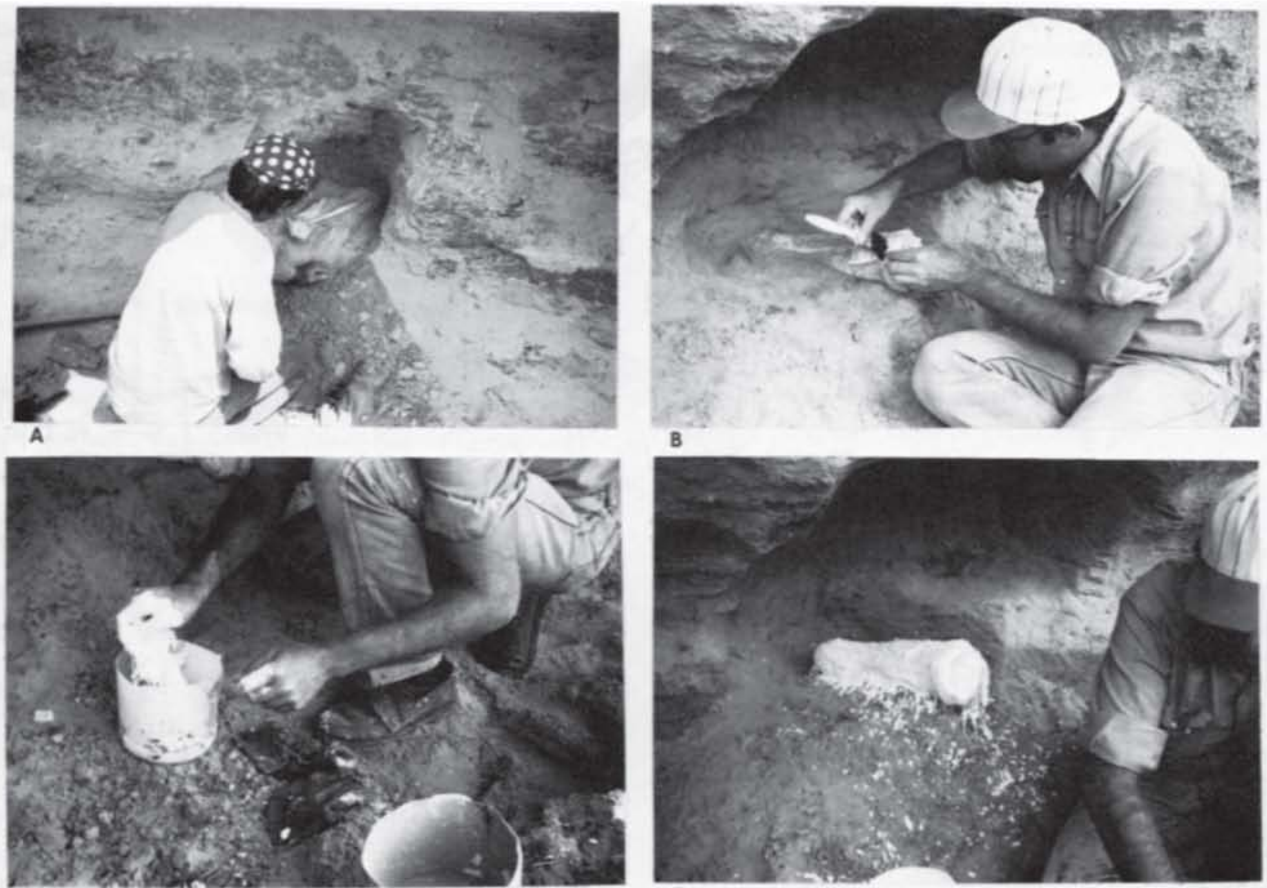
A
B
C
D

Fig. 10. *Collecting vertebrate fossils:* ***a)*** *exposing fossil.* ***b)*** *covering fossil with toilet paper.* ***c)*** *preparing plaster and burlap.* ***d)*** *covering fossil with plaster cast.*

While you are working on this step, have a helper mix plaster into water to make a moderately thick plaster. (A mixture too thick will set up too quickly; one that is too thin won't solidify.)

5) Moisten the burlap strips with water, wring them out, cover them completely with the plaster mixture (fig. 10c), strip off excess plaster with your hand, and apply the plaster-covered burlap over the toilet-paper-covered bone. Usually the long dimension of the burlap is applied parallel to the length of the bone. Overlap the burlap strips to add strength and smooth the strips so they fit snugly and leave no gaps between the bone and the burlap (fig. 10d). If the bone is very large, you may want to add a strip of wood lengthwise over the burlap after the last step is completed and cover part or all of the wood with more burlap to strengthen the cast.

6) After the plaster has completely hardened, carefully use a chisel or pick to make a horizontal fracture in the matrix beneath the cast and bone. Turn the cast over quickly, but with great caution, supporting the matrix as much as possible so that the specimen will not collapse and fall out of the cast.

7) Trim parts of the cast sticking above the matrix.

8) Cover any exposed bone with toilet paper, moisten the paper, and cover the matrix surface with the plaster-covered burlap, overlapping the edge of the first cast and following the steps outlined above.

9) Allow the plaster to set.

10) Mark the cast with an identifying number and record it in your notes and on a map or photo showing the site location. When you get the specimen back to your work space, open the side of the specimen you cast last by moistening the plaster surface with water and stripping off the burlap. Using dental tools, carefully remove the matrix covering the specimen and pour coat after coat of the alcohol and shellac mixture on the specimen until it will absorb no more. Glue any broken parts in place, using a good grade of household cement.

11) Note well that denatured alcohol is very flammable.It should be used only in well-ventilated areas away from any flame. It is also poisonous and should not be ingested either directly or indirectly.

If the specimen is still so weak that it would break if

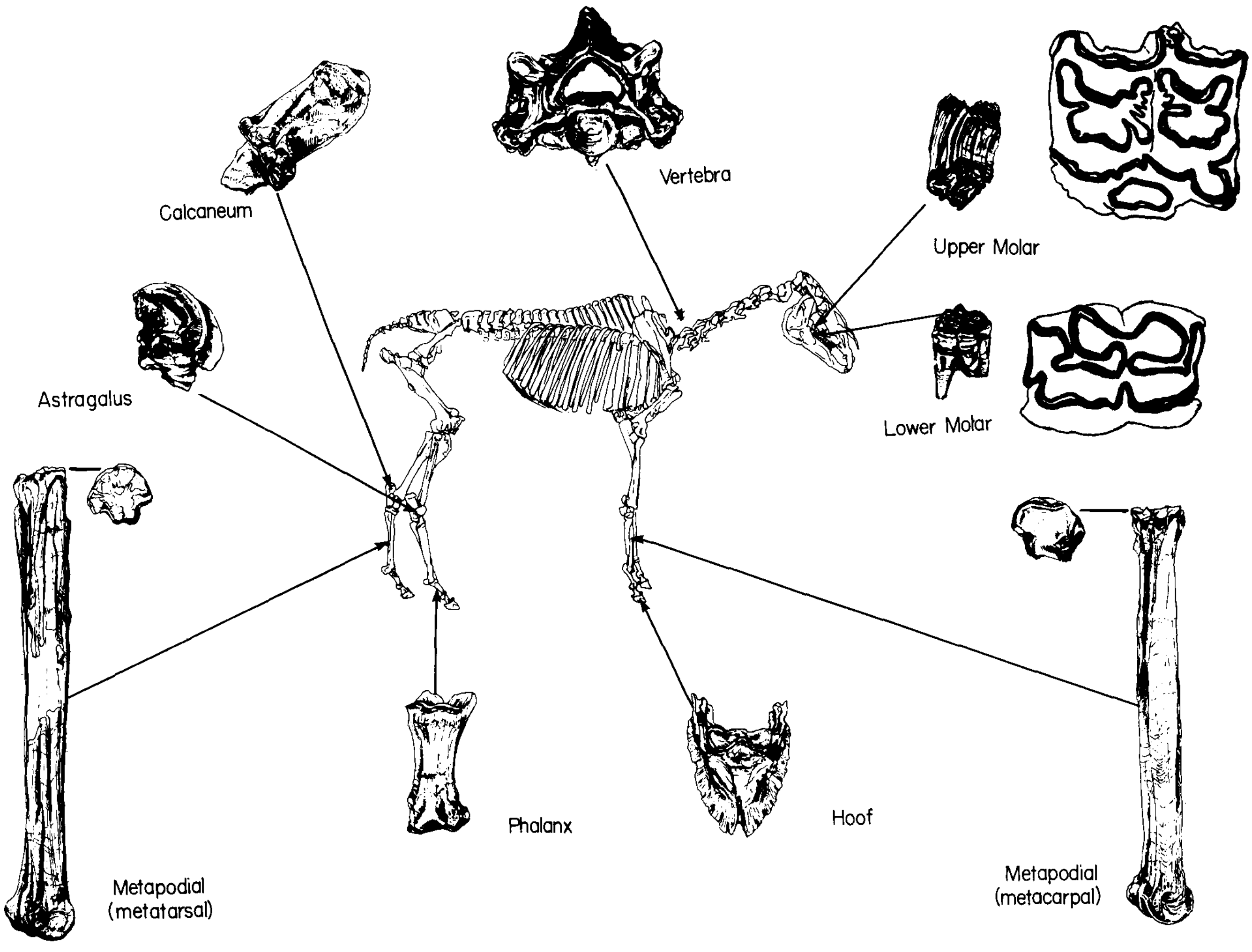

Fig. 11. Horse bones and teeth commonly preserved as fossils; illustrated by Frankie Gould, formerly CSD.

lifted, make a new cast over the exposed top half of the specimen by following the steps outlined above, then turn the specimen over, cover the rest of the bone in toilet tissue, this time extending the tissue over the previously prepared cast, and make a cast covering the overturned lower half of the bone. Once the cast is hard, trim the edges of the upper and lower casts with shears and either side of the bone can be displayed with relatively little danger of breaking.

If the collecting process just mentioned seems like too much work, don't start to remove the fossil. Anything less than following all the procedures just described probably will result in the destruction of the specimen and its loss to the scientific community.

Vertebrate fossils

One of the early discoveries of anatomists was that vertebrate skeletons, even of very different animals, were similar to one another. This is particularly true with mammals. Figure 11 shows a horse skeleton. While the horse is far removed from man biologically , the same general arrangement of major bones and groups of bones occurs in both. One of the remarkable things about evolutionary changes is their capacity to produce great variations in skeletal form and function through the variation of bone size and shape and through the reduction in the number of bones. Some of the bones commonly found intact as fossils have been illustrated in figure 11 to provide a better idea of where they belong in the skeleton. The shape, size, and structure of teeth also indicate to the paleontologist something about the diet and life habits of an animal. Molar shape, root development, and structural patterns can be used to identify fossil vertebrates to the genus or even the species level. Look at the horse teeth in figure 12 and see how easy it is to separate one horse from another by comparing enamel patterns.

Fossils from the Whitney Member of the Brule Formation

Plants

Rare endocarps of hackberries have been found in the Whitney Member.

Invertebrates

Invertebrates from the Whitney Member of the Brule Formation in or near Ash Hollow Park are not common. Most of them are limited to local, lens-shaped beds of limestone or diatomite. Forms so far identified include shells and molds of tiny, bean-shaped ostracods, small freshwater clams and snails, and low-spired land snails (fig. 12).

Vertebrates

Vertebrate fossils also occur in the Whitney Member, but they are generally rare in the Ash Hollow Park area. Perhaps the three most common forms are turtles, oreodonts, and rodents (figs. 12 and 13). The shells of fossil land turtles are often preserved and sometimes the skeleton is preserved within the shell. Oreodonts are related to sheep, deer, cattle, and other even-toed herbivorous (plant-eating) mammals, all of which are called *artiodactyls*, although they are not directly ancestral to any living forms. Some later forms of oreodonts developed a short proboscis or trunk. The shape of oreodont teeth tends to support the idea that oreodonts were ruminants (cud-chewing animals). Rodent fossils include early forms of beavers.

The siltstones of the Whitney Member are very compact and hard. Any attempt at collecting fossils found in them will be very difficult and time consuming. Because most of the vertebrate fossils and the enclosing rocks are often fractured, anybody collecting from this unit should use the cast method described earlier.

Fossils from the Ash Hollow Formation

Plants

Stansbury (1852) reported the first fossil plants from the Ogallala Group during a brief visit to Ash Hollow Canyon in 1849. He said: "Toward the lower part of the gorge was a bed or layer of marl, in which were the remains of what very much resembled the seeds of a plant." Since then, the exquisitely preserved remains of large numbers of plants have been described from several stratigraphic levels in Ogallala deposits throughout the High Plains (Elias, 1942; Frye, Leonard, and Swineford, 1956; Thomasson, 1979). Occurring in a stratified and nearly complete sequence of deposits over a widespread area and extended length of time stretching from North Dakota to southern Texas and New Mexico, these fossils offer a unique opportunity to study the evolution of the represented species.

More than 30 species of fossil plants have been collected from the Ogallala Group. The flora includes algae such as diatoms and stoneworts, primitive vascular plants such as horsetails (also called *scouring rushes*), and more advanced flowering plant groups such as herbaceous grasses, sedges, pondweeds, woody hackberries, and borages that include living plants such as forget-me-nots, bluebells, and puccoons (figs. 14-16). Although most of the fossils represent the remains of reproductive structures such as seeds and fruits (collectively called *seeds* in scientific literature), a significant number of leaf, stem, rhizome, wood, and root fragments have also been recovered (figs. 16a-e). The fossils, which are preserved in three dimensions, are almost exclusively composed of silica, with only a few being formed of calcite.

The grasses, one of the most abundant fossil plant groups in the Ogallala (fig. 14), are found as the preserved bracts or husks (called the *anthoecium*) that surround the grain in living grasses. The fossilized anthoecia are quite remarkable, usually retaining as fossils all the features of the living grass, including such delicate structures as hairs (fig. 14a). The detailed microfeatures (for example, epidermal cell patterns), seen when the fossils are examined at high magnification, are equally well preserved (fig. 14i). When compared with living forms, such microfeatures tell a great deal about the evolutionary changes that occurred between the fossils and their living forms.

At Ash Hollow, the most common fossil plants are grasses, represented by more than 15 species in five genera. Most of these are related to living forms that occur mostly in grasslands of Central and South America, such as *Piptochaetium, Stipa*, and *Nassella* (Thomasson, 1980b). Nevertheless, certain fossil forms collected in Ash Hollow Canyon strata have relationships and similarities to grasses now found on the slopes of Ash Hollow Canyon. Among these are the needle-and-thread and millet grasses so common in Ash Hollow Park. Other fossil grasses collected from the Ash Hollow Formation at Ash Hollow are related to modern rice grasses. The fossil grasses found in the Ogallala Group represent the most complete and best preserved geologic record of this group of plants in the world.

Equally abundant with the grasses in Ogallala Group deposits are fossils that belong to a group known as the *borages*. The most commonly preserved part of the borages is the small, spherical, trigonous or ellipsoid, stony fruit called a *nutlet.* The overall shape and surface features of the nutlets identify specific groups within the borages. Many fossil borages are related to forms living on the plains; but at least one group of Ogallala borages, typified by the genus *Anchusa*, exhibits an alliance with forms now restricted to Europe. Several distinctive borages are found in strata at Ash Hollow Park. Two of the most common of these, *Cryptantha and Biorbia* (figs. 15a and 15b), can be observed in the bluffs

Fig. 12. (See opposite page.)** Typical fossils and rocks from Ash Hollow vicinity: **a)** oreodont, Brule Formation, left upper jaw with three molars, x 1 (note: in this and all subsequent figures, "x" indicates the approximate number of diameters the image is reduced or enlarged from its actual size); **b) Leptauchenia, *oreodont, Brule Formation, bottom of skull showing teeth, x 0.6; **c)**?*Helix, *snail, Brule Formation, x 1; **d)*** Pliohippus, *horse, Ash Hollow Formation, portion of lower jaw, x 0.28; **e)*** Neohipparion, *horse, Ash Hollow Formation, portion of lower jaw, x 0.38; **f)*** Calippus, *horse, Ash Hollow Formation, portion of lower jaw, x 0.39; **g)*** Equus, *horse, Quaternary, upper molar, x 1; **h)*** Neohipparion, *horse, Ash Hollow Formation, upper molar, x 1; **I)*** Dinohippus, *horse, Ash Hollow Formation, upper molar, x 0.7; **j)*** Merychippus, *horse, Ash Hollow Formation, portion of lower jaw, x 0.7; **k)*** Neohipparion, *horse, Ash Hollow Formation, lower molar, x 0.6; **l)*** Neohipparion, *horse, Ash Hollow Formation, lower premolar, x 1; **m)** horse incisor, Ash Hollow Formation, x 1; **n)** camel, Ash Hollow Formation, upper molar, x 1; **o)** dog-like carnivore, Ash Hollow Formation, lower molar, x 1; **p)*** Dipoides, *beaver, Ash Hollow Formation, portion of lower jaw x 1.0; **q)** photomicrograph of fossil conifer wood, x 90; **r)** photomicrograph of altered conifer wood. Note the crushed and partially or completely replaced vessels in the lower half of the picture, x 90; **s)** photomicrograph of diatomite (d is a diatom, x 750); **t)** photomicrograph of impure volcanic ash with individual ash shard (s) and rock fragment (r), x 90.*

near the visitor center.

Other flowering plant groups found as fruit or seed fossils in the Ogallala include sedges, pondweeds, buckwheats, and hackberries (figs. 15c-f). Less abundant than grasses and borages, sedges and pondweeds are very significant as they usually grow in aquatic or marshy environments.

Fossil wood, which has been reported only rarely from the Ogallala in general, has been collected from at least one level in the Ash Hollow Formation near the park. Fossil wood preserving cellular details (fig. 16c) occurs low in the section at Ash Hollow. Such wood doubtless represents the remains of plants living in or near Ash Hollow during the Miocene.

Leaf and stem fragments of several groups have been collected from the Ogallala in Kansas (Thomasson, 1979) and at Ash Hollow (figs. 16a, 16b, 16d, and 16e). Among the plants represented by these fossils are primitive species such as horsetails (Thomasson 1980a) and more advanced species such as grasses (figs. 16a and 16b).

Finally, two kinds of algae, diatoms and charophytes (stoneworts), occur as fossils in the Ogallala. The fossils of both groups are generally found in freshwater pond deposits, although the charophytes may occasionally be found in channel sands. The diatoms are preserved as microscopic, siliceous frustules which, when living, encased the algae (figs. 12s, 16h, and 16i). These frustules, intricately sculptured, represent a wide variety of genera and species. Fossil charophyte remains include characteristic spiral stem fragments and egg cases called *limeshells* (figs. 16f and 16g).

Some sedimentary structures in rocks of the Ogallala Group have been called plant fossils but probably do not owe their origin to plants at all. The largest of these structures are distinctive, occasionally branching, vertically elongated siliceous concretions up to several feet long and up to one foot in diameter. Lueninghoener (1934, p. 19), following ideas he attributed to Elias, suggested probably for the first time that these structures were casts of yucca roots. Since then this suggestion has continued to be used by some authors (Stout, 1971). Thomasson compared these structures with modern yucca roots and found that the concretions probably were not yucca casts because they lacked root structures and the side roots common to yucca. These concretions may have been produced by either organic or inorganic processes. They are good features for local correlation since they occupy beds that often crop out or underlie areas of several square miles and that probably formed simultaneously.

Invertebrates

Ostracod carapaces, snail and clam shells, and spicules of freshwater sponges occur in freshwater pond deposits in the Ash Hollow Formation just as they do in the Whitney Member (fig. 12). Frequently, the shells have been dissolved, leaving only an impression of the outside of the shell preserved in the rock. Occasionally, the whole shell remains.

Vertebrates

The Ash Hollow Formation has yielded a tremendous number and variety of fossil vertebrates in Nebraska and adjacent areas, some of which are virtually complete skeletons (*see* Voorhies and Thomasson, 1979). The most common forms of skeletal material come from horses, mastodons, antilocaprids, rhinoceroses, and camels (figs. 12 and 13).

Fossils of oreodonts, rodents, peccaries, sloths, carnivores resembling dogs, saber-toothed cats, and other forms either occur less commonly or are more difficult to find. Very large land turtle shells up to 39 inches in diameter are relatively common and are sometimes found as complete specimens in the Ash Hollow Formation. Reptile, bird, amphibian, and fish fossils have been found occasionally.

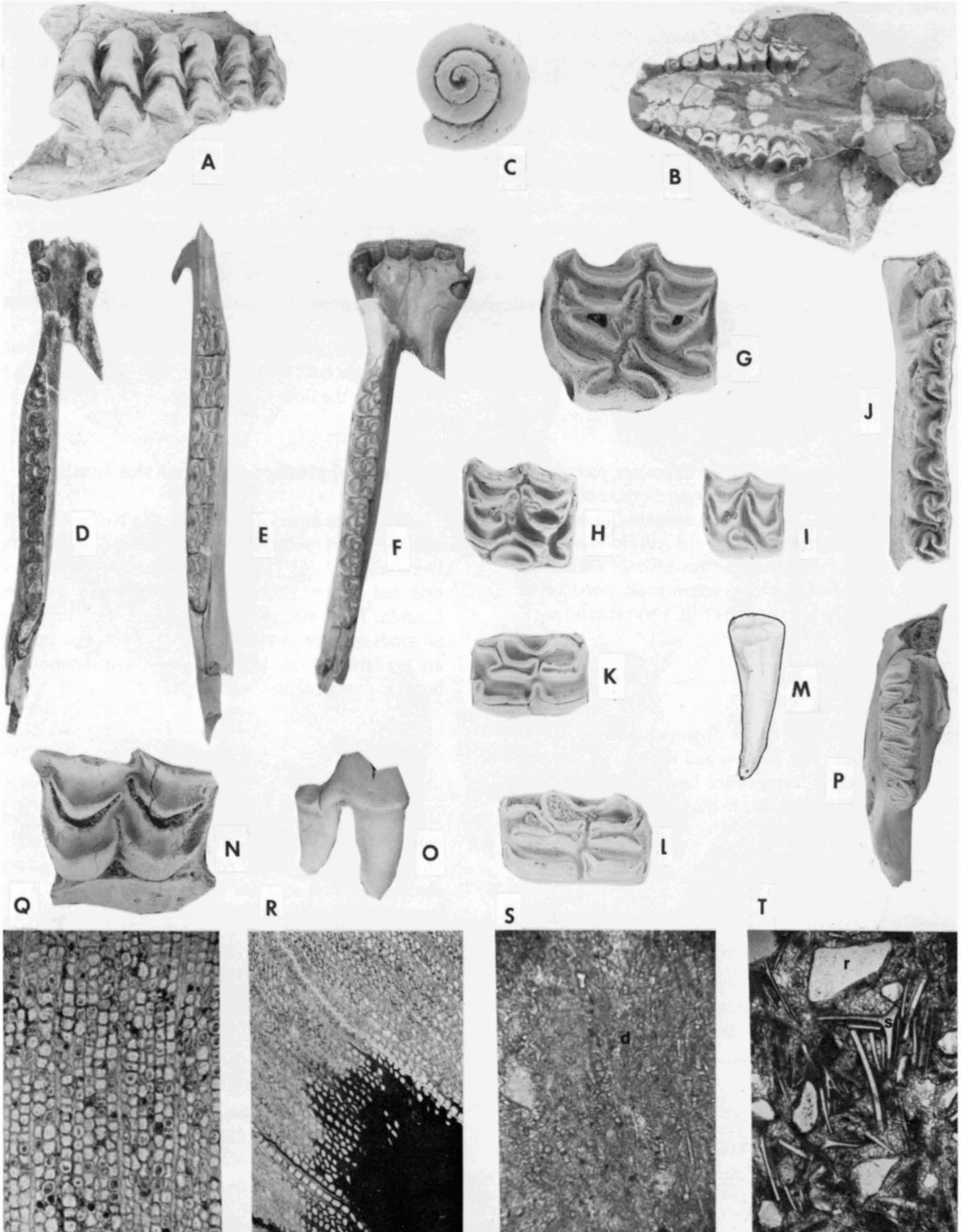
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Fig. 13. (See opposite page.) *Typical fossils from Ash Hollow vicinity:* ***a)*** Camelops, *camel, Quaternary, bottom view of skull x 0.2;* ***b)*** Camelops, *camel, Quaternary, side view of skull, x 0.2;* ***c)*** Camelops, *camel, Quaternary, jaw, x 0.25;* ***d)*** Teleoceras, *rhinoceros, Ash Hollow Formation, bottom view of skull, x 0.2;* ***e)*** Mammuthus, *mammoth, Quaternary, top of molar tooth, x 0.26;* ***f)*** Mammuthus, *mammoth, Quaternary, side of molar tooth, x 0. 18;* ***g)*** Neohipparion, *(two on left), Ash Hollow Formation, and* Equus *(two on right) Quaternary, posterior metapodials, x 0.21;* ***h)*** ?Serridentinus, *mastodon, Ash Hollow Formation, side view of molar tooth, x 0.3;* ***I)*** ?Serridentinus, *mastodon, Ash Hollow Formation, top view of molar tooth, x 0.4;* ***j)*** *Front metapodials (metacarpals) of camels.* Poebrotherium *(top), Brule Formation;* Oxydactylus *(middle) and* Megatylopus *(bottom), Ash Hollow Formation, x 0.21;* ***k)*** Bison, *Quaternary, side view of portion of right upper jaw with premolars and molars, x 0.27;* ***l)*** Bison, *Quaternary, top view of portion of right upper jaw, third molar to first premolar left to right, x 0.4;* ***m)*** *turtle, Brule Formation, x 0.4 (specimens courtesy of the University of Nebraska State Museum).*

Fossils from the Broadwater Formation

Plants

Light and dark brown fossil wood fragments, probably of Cretaceous age, occur in the Broadwater Formation. These were eroded from Cretaceous rocks in northern Colorado and southern Wyoming and transported to the Ash Hollow area by the river system that deposited the Broadwater Formation. The light brown clasts (fig. 12q) retain good wood vessel structure, but the dark brown clasts (fig. 12r) often do not.

Vertebrates

Fragmentary molar teeth of *Stegomastodon mirificus* have been found near Ash Hollow and farther east in Keith County. Teeth of early forms of the horse *Equus* have also been found from the Broadwater to the east in Keith County.

Quaternary fossils

Plants

No fossil plants have been found in the loess but gyrogonites or limeshells of charophyte algae (fig. 17), seeds, and fossil wood occur in the more recent terrace fills.

Invertebrates

Ostracod carapaces (fig. 17) occur in pond and terrace deposits. Shells of clams and of aquatic and terrestrial snails also may be found (fig. 17).

Vertebrates

The loess deposits on the upland that is south of the park potentially could yield fossil horses, camels, and mammoths, but none has been reported to date. Skeletons of bison and other animals have been found in the younger stream terrace deposits on the floor of the valley.

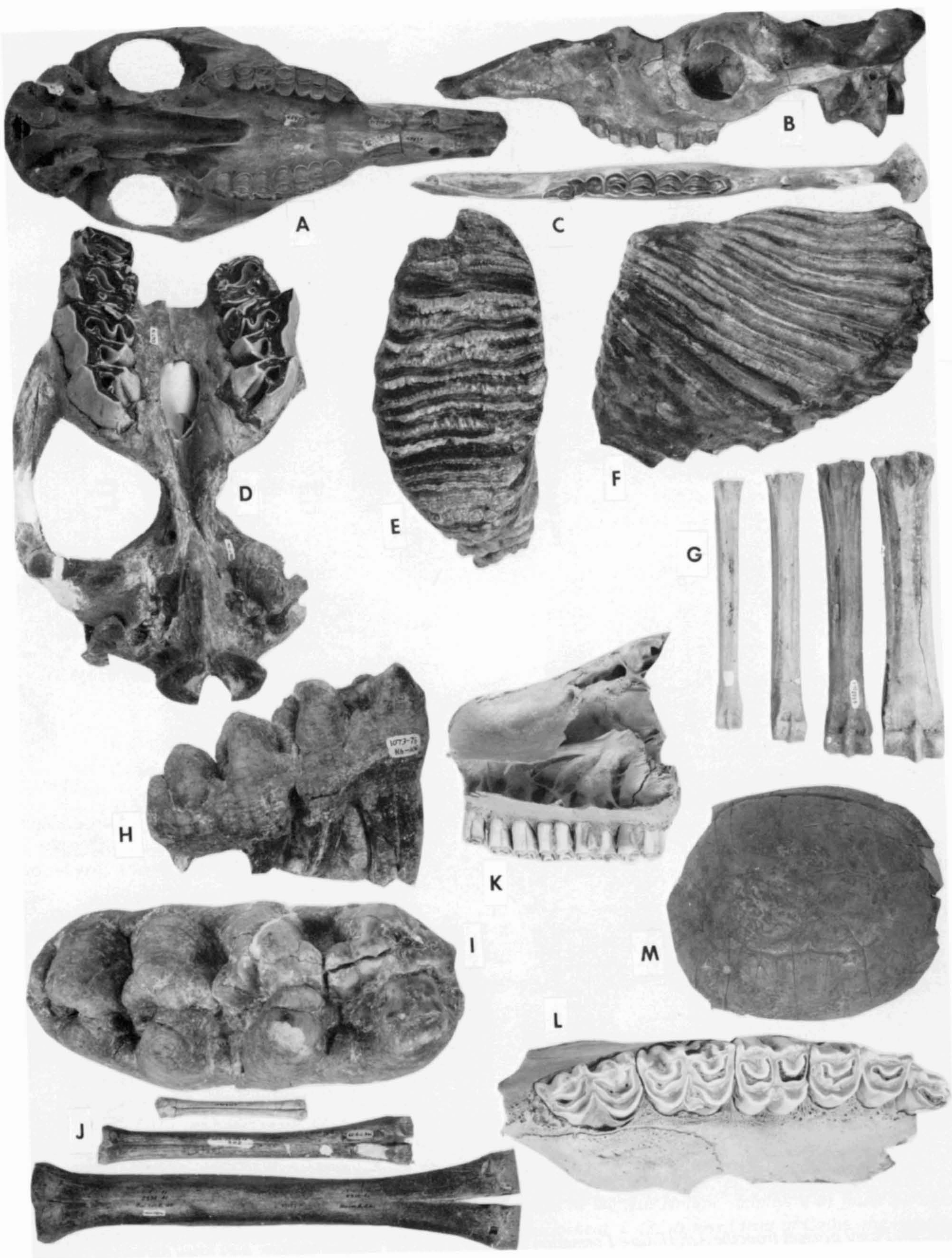
Additional studies of Nebraska fossils

If you are especially interested in Nebraska fossils, the authors direct your attention to the publications of the University of Nebraska State Museum and of the Conservation and Survey Division of the University of Nebraska-Lincoln. These two organizations have done much work on all kinds of Nebraska fossils, and most of their publications are available for sale by the organizations themselves or for borrowing in libraries.

Geologic History

The geological events leading up to the development of the present Ash Hollow area began in Precambrian time several billion years ago. All data for this early history must come from well samples or cores of rock that once were buried about 5,000 feet beneath the park today. Lidiak (1972) indicated the Precambrian rocks under an area about 10 miles northwest of Ash Hollow consisted of quartz-feldspar gneiss (a metamorphic rock) and metagabbro (a metamorphosed igneous rock). Sedimentary rocks of late Pennsylvanian age containing marine invertebrate and fish fossils rest unconformably on the Precambrian rocks and are similar to the strata exposed along the lower Platte River valley in eastern Nebraska and along the Front Range of Wyoming and Colorado. Permian-age evaporites (gypsum, halite) overlie the Pennsylvanian sequence. Triassic rocks are absent in this area, but many deep-well samples and logs show that the Morrison Formation of Jurassic age and an extensive sequence of Late Cretaceous strata occur in the subsurface of Garden County.

In the Late Cretaceous, about 67 million years ago, the Laramide Orogeny (mountain-building episode) began.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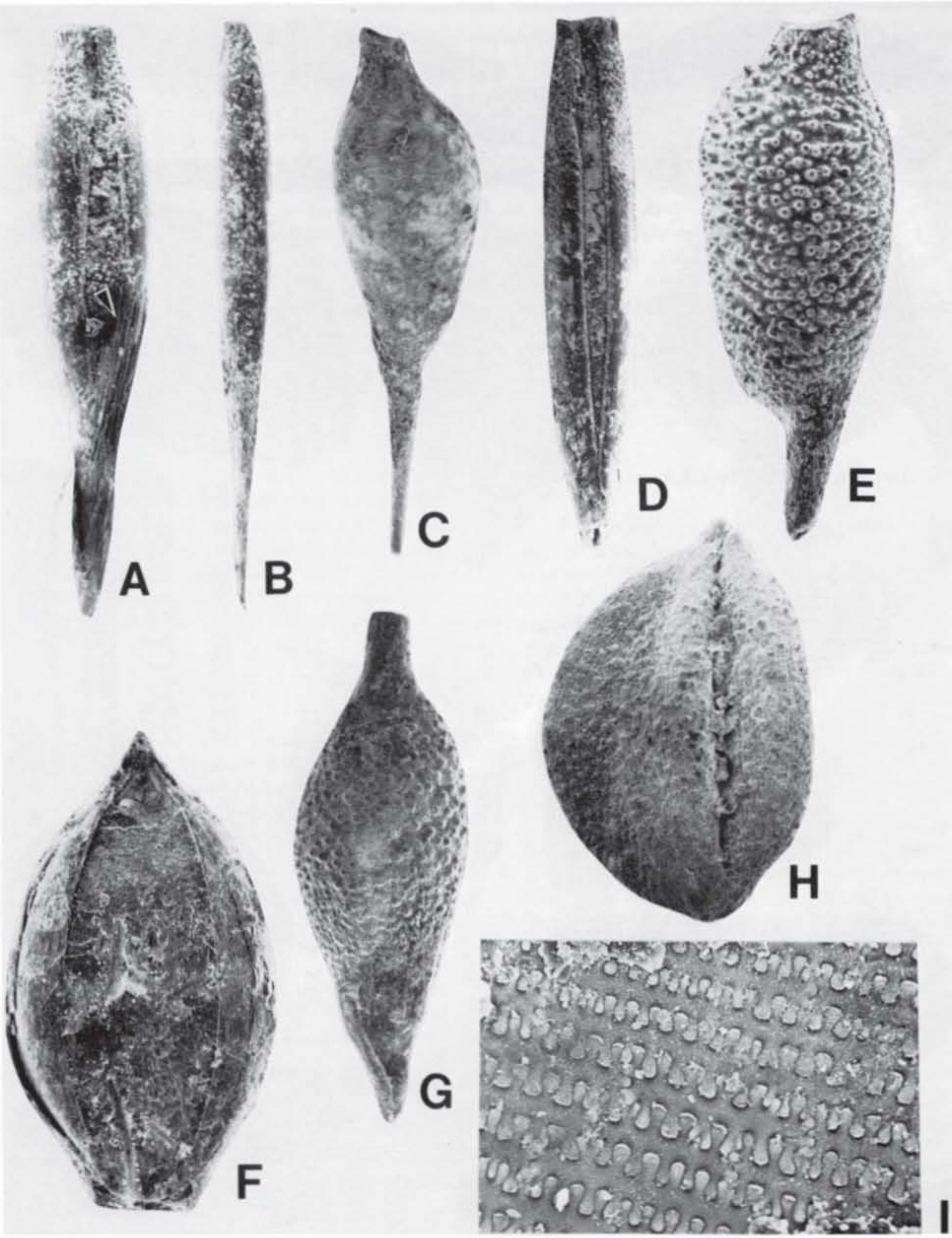

Fig. 14.** Fossil grasses from the Ash Hollow Formation deposits in the Ash Hollow vicinity: **a-e)** fossil anthoecia (husks) of various members of the genus* Berriochloa *(a, x 20; b, x 10; c, x 13; d, x 13; e, x 36). These grasses are related to living needle-and-thread or spear grasses; **f)** fossil millet,* Panicum, *x 30; **g) Nassella, *fossil grass with principal living relatives in Central and South America, x 36; **h)** fossil rice cutgrass,* Archaeoleersia, *x 20; **i)** microstructure of the epidermis of fossil* Berriochloa *showing interlocking cells, x 470.*

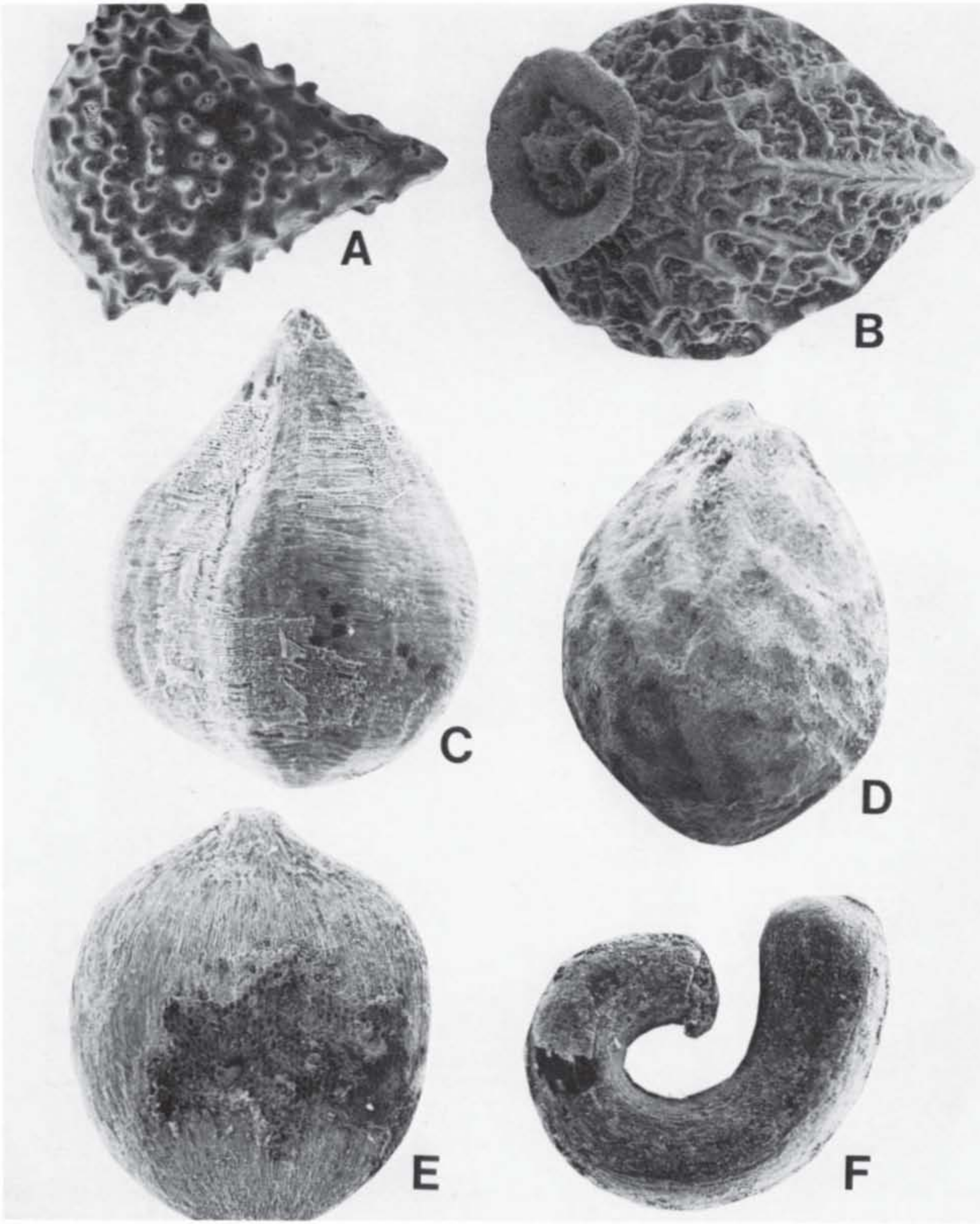

Fig. 15. *Fossil plants from the Ash Hollow Formation deposits in the Ash Hollow vicinity:* ***a-b)*** *fossil borages,* Cryptantha *(x 30) and* Biorbia *(x 27);* ***c)*** *undescribed fossil buckwheat, x 43;* ***d)*** *fossil fruit of* Celtis, *the common hackberry tree, x 15;* ***e)*** *fossil sedge,* Carex, *x 36;* ***f)*** *seed of the aquatic pondweed,* Potamogeton, *x 36.*

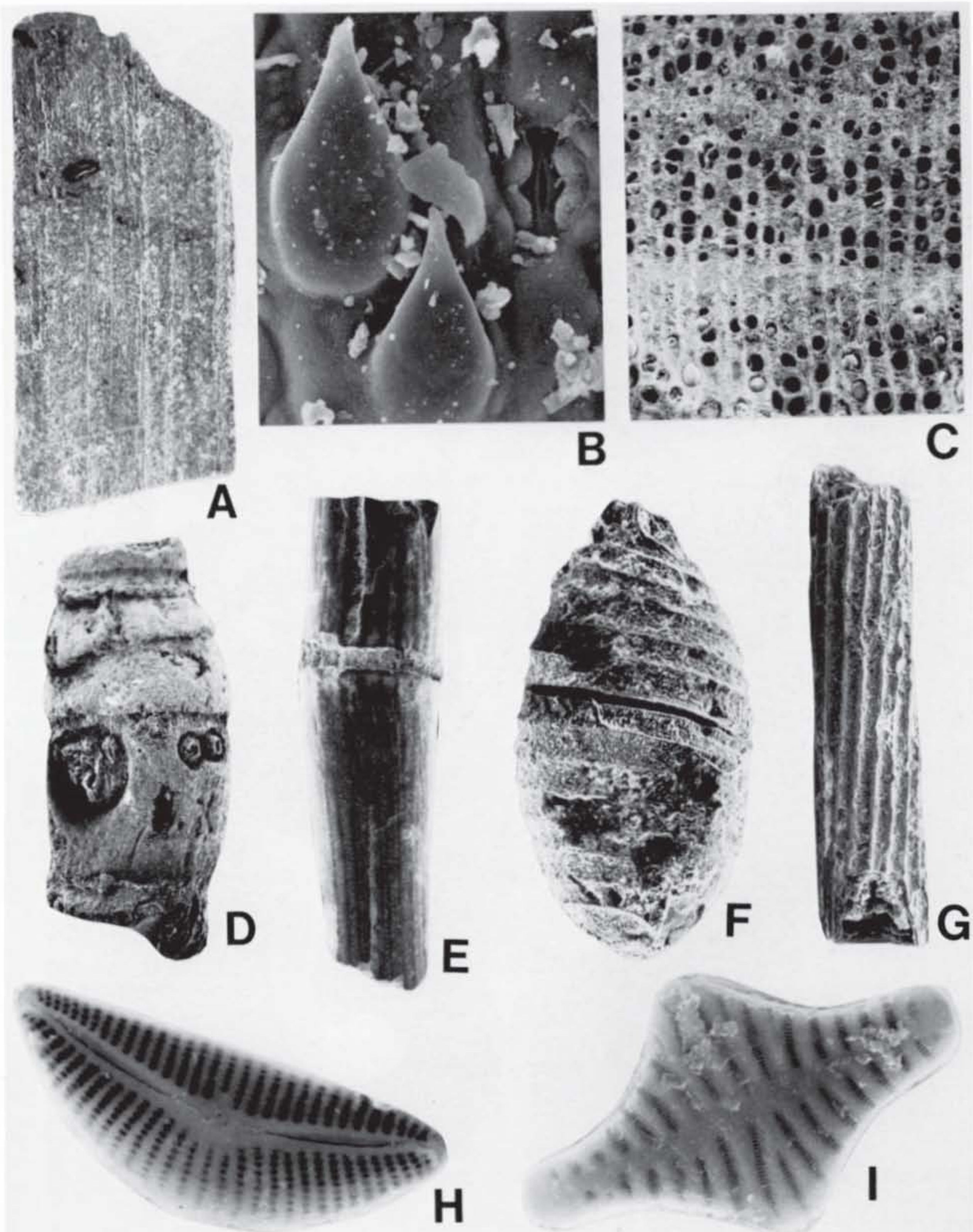

Fig. 16. *Fossil plants from Ash Hollow deposits in the Ash Hollow vicinity:* ***a)*** *leaf fragments of an unknown fossil grass, x 19;* ***b)*** *Enlargement of the fragment in "a," showing microstructure, x 1200;* ***c)*** *cross section of an unidentified fossil wood showing the pore structure, x 17;* ***d)*** *fossil rhizome (underground stem), x 13;* ***e)*** *unidentified fossil stem, x 13;* ***f)*** *limeshell of a fossil stonewort, x 109;* ***g)*** *stem fragment of a fossil stonewort, x 109;* ***h-i)*** *frustules of diatoms,* Cymbella *(x1800) and* Fragilaria *(x 2150).*

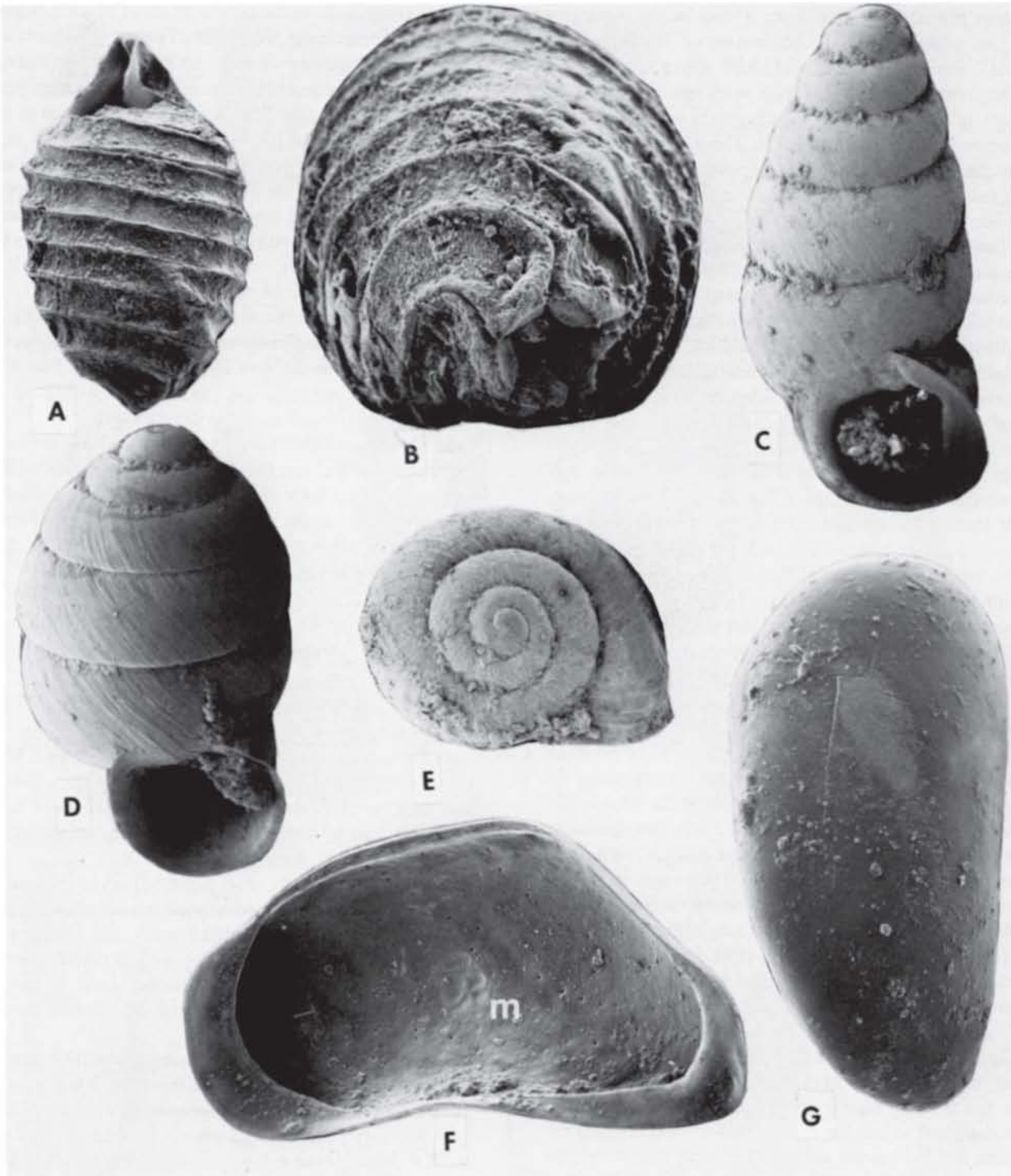

Fig.17. *Quaternary fossils from Ash Hollow vicinity:* ***a)*** Chara, *algal gyrogonite, side view, x 60;* ***b)*** Chara, *algal gyrogonite, top view showing five individual spirally coiled calcite ribbons combined to form the structure, x 120;* ***c)*** ?Pupoides, *gastropod, x 26;* ***d)*** ?Pupoides, *gastropod, x 26;* ***e)*** ?Hawaiia, *gastropod, x 26;* ***f)*** *ostracod, internal view showing muscle scars(m), x 120;* ***g)*** *ostracod, external view, x 120.*

Mountain chains extending from Alaska to the Andes of Chile, including the Rocky Mountains of Wyoming and Colorado, were formed and raised high above sea level. By late Eocene time, about 37 million years ago, the first thick sequence of continental deposits began to accumulate over what is now the Nebraska Panhandle. These deposits included stream-channel and eolian (wind-deposited) sediments. The eolian sediments were produced during major episodes of vulcanism that occurred in Wyoming, Colorado, and the Great Basin of Nevada, having been deposited in Nebraska as the thick sequence of volcanic ash in the White River Group. This period of volcanic activity appears to have lasted several million years, during which there was sufficient time between ash falls to allow for soil development and for small flood-plain lakes and ponds to form and then fill with sediment.

Between the end of Whitney deposition and the beginning of Ash Hollow Formation deposition, a major valley system was carved into the Whitney Member. Then, beginning in Miocene time about 9 to 11 million years ago, stream-transported sediments of the Ash Hollow Formation, at first locally derived and then later derived from distant sources in the Rocky Mountains, were deposited in this valley system. Stream deposition in these paleovalleys went on discontinuously for the next 4 to 6 million years. Volcanic ash falls occurred occasionally during this time. These ash falls were large in comparison to ash falls from modern eruptions but were small in comparison to the ash falls in Whitney times described above. Beginning about 4 million years ago, the Broadwater Formation was deposited by a river ancestral to the South Platte River, which drained parts of the Southern Rocky Mountains of north-central Colorado and parts of the adjacent Great Plains. The river deposits of the Broadwater Formation were later eroded in part by rivers and streams to form a complex land surface of hills and valleys. From about 1.2 million years ago until about 10,000 years ago, wind- and water-deposited colluvium and wind-blown silts (loess) were periodically deposited over this surface, largely masking its relief (Schultz and Hillerud, 1978, offer dates). Subsequent downcutting by streams produced the Ash Hollow drainage. Alternating periods of deposition and erosion during the last 10,000 years have produced the contemporary landscape.

The Cenozoic history of the park shows many periods of erosion, and these may have destroyed evidence of some faunas and floras. The repeated cycles of wind deposition, then erosion, and stream deposition, then erosion affected the organisms that lived in the area in many ways. Aquatic plants and animals had either to adapt or perish in such changing climates, but plants and animals could either evolve or migrate in the face of changing conditions. The Cenozoic history of the Great Plains provides both well-documented examples of evolution and of migration of animals as environmental conditions changed. The environment was often very unpleasant during active deposition of the Whitney silts and the Quaternary loess sequences. The huge quantities of dust in the air during those times may help to explain the relative rarity of fossils in these strata. Threatened creatures had to emigrate from the area at the onset of such conditions.

The fossils in the Ash Hollow Formation suggest periods of somewhat greater warmth and moisture than today. The temperature extremes of the Great Plains today were probably not present during the Miocene, but the presence of growth rings in fossil wood (fig. 16) from the formation suggests seasonability, probably with alternating wet and dry seasons. Thomasson (1979) has reviewed the evidence supporting these assertions and has argued for broad grassland and stream environments with a climate "characterized as subhumid and subtropical, with temperatures rarely, if ever, reaching 0 degrees C or exceeding 38 C."

Over the last several million years, alternating major cycles of drought and moisture and of erosion and deposition have occurred in the Ash Hollow and Great Plains areas. These cycles seem to be linked to well-defined global declines and rises of sea level described by Vail, Mitchum, and Thompson (1977) and by Vail and Hardenbol (1979), attributed by them to a complex interplay between worldwide tectonic and climatic changes. Careful geologic study may provide some insight about future conditions and trends of these cycles, allowing us to better prepare for and cope with such possible environmental changes.

Prehistory and History

Ash Hollow has been the site of archeological and anthropological interest for many years. The first major work was the excavation of Ash Hollow Cave by Metcalf, Fletcher, MacKenzie, Smith, and others in 1939. Champe (1946) used the data collected during the excavations in 1939 and provided to him by the Nebraska State Historical Society to produce his book, *Ash Hollow Cave*.

Champe reported (1946, p. 54-57) seven cultural levels (A-G) that are stratified and often separated from one another by barren sands. He attributed Lens A, the youngest of the seven, to the Dismal River culture. Lenses B and C contained Upper Republican artifacts, whereas Lens D contained Woodland artifacts. Some of the artifacts obtained from these levels are illustrated in figure 18.

Champe (1946, p. 85) also reported tentative dates from these layers. G, the oldest, ranges from 1 to 300 Common Era (CE; *Common Era* is a non-discriminatory reference to what was formerly called *Anno Domini,* for *year of our Lord*, or *AD)*, F from 300 to 600 CE, E from 600 to 1000, D from 1000 to 1300, C and B from 1300 to 1500, and A from 1500 to 1700, all CE. Since these dates were published, much older material has been found in the area.

Archaeological studies have continued in the Ash Hollow basin since Champe's work. In the summers of 1979, 1980, and 1981, a crew led by Thomas Myers and Lloyd Tanner of the University of Nebraska State Museum excavated a bison-kill site preserved in the terrace deposits in Ash Hollow Creek valley (fig. 9). The site contained bones of bison about one-and-a-half times larger than modern bison, as well as

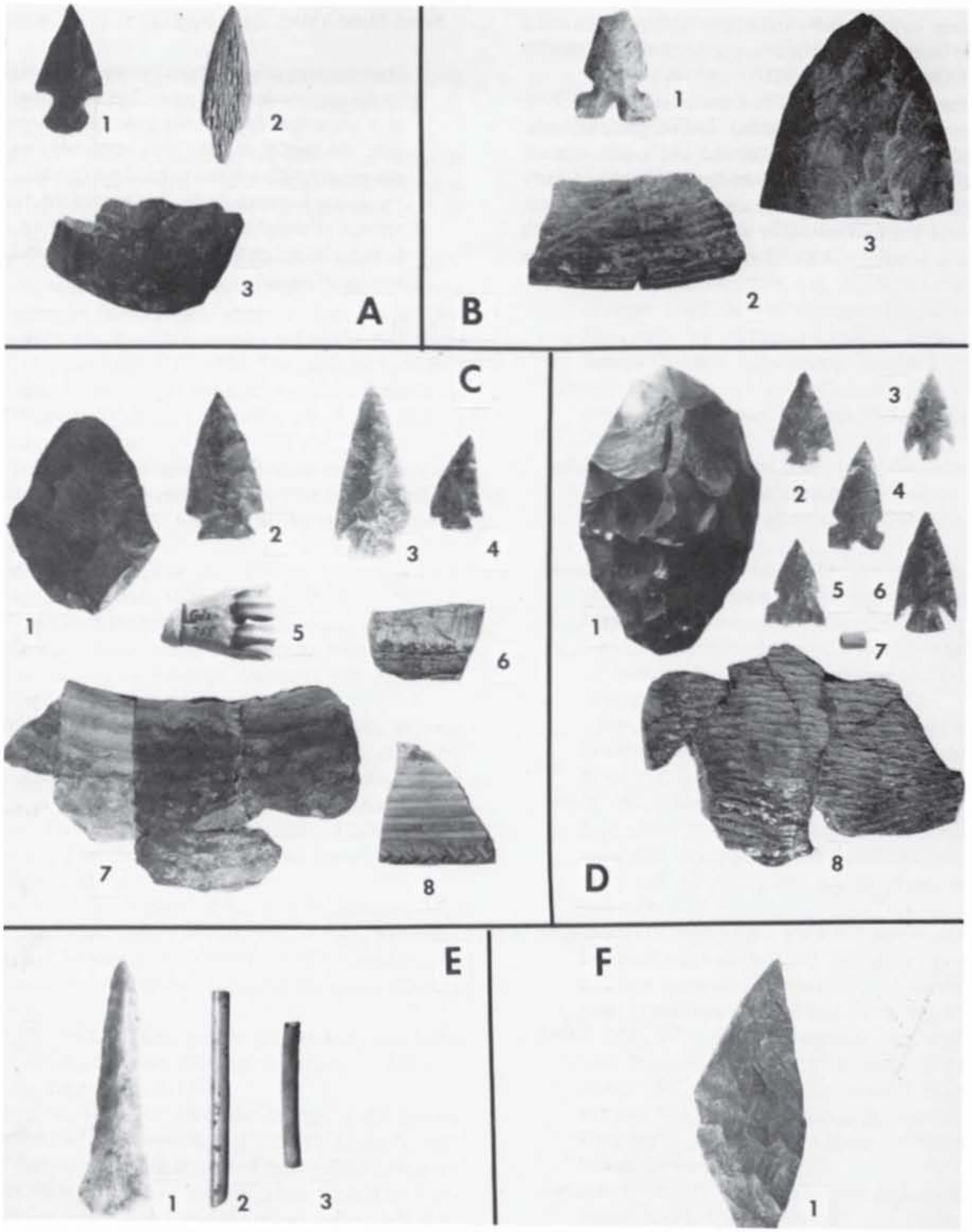

Fig. 18. Artifacts from Ash Hollow Cave (all x 0.7, except A2, C5, D7, E2, E3: x 0.8): ***Lens A:*** *1) stone point; 2) bone point; 3) ceramic sherd--Dismal River Type.* ***Lens B:*** *1) stone point; 2) ceramic sherd--Type Z; 3) knife --broken.* ***Lens C:*** *1) retouched flake; 2) stone point; 3) stone point; 4) stone point; 5) deer metapodial used to make awls; 6) ceramic sherd--Upper Republican Type; 7) ceramic sherd--Type T; 8) ceramic sherd--Type S.* ***Lens D:*** *1) preform biface; 2) stone point; 3) stone point; 4) stone point; 5) stone point; 6) stone point; 7) small bead; 8) ceramic sherd--Woodland Type.* ***Lens E:*** *1) expanding base drill; 2) long bead; 3) long bead.* ***Lens F:*** *1) knife (photographs courtesy of the Nebraska State Historical Society).*

bones of deer, coyotes, mice, and frogs. Hide scrapers and a spear point found with the bones suggest that the site may be as old as 6,000 to 9,000 years BP.

The features that drew Native Americans to Ash Hollow are unknown but probably included shelter, game animals, other food supplies, wood, shade, and ample water. In all likelihood, these factors contributed to the visits of early trappers and explorers also. Later settlers found Ash Hollow a convenient place to stay after a journey from the South Platte and a relatively difficult descent to the floor of the North Platte Valley. Stansbury (1852, p. 41) remarked:

> Here we were obliged, from the steepness of the road, to let the wagons down by ropes, but the labour of a dozen men for a few days would make the descent easy and safe. The bottom of Ash Creek is tolerably well wooded, principally with ash and some dwarf cedars. The bed of the stream was entirely dry, but toward the mouth several springs of delightfully cold and refreshing water were found, altogether the best that has been met with since leaving Missouri.

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Appendix I

Glossary

clast: a grain, fragment, or individual component of a sediment produced by the mechanical breakdown of a larger rock mass.

concretion: a hard rock, usually imperfectly round, formed by precipitation from water in the pores of another rock and usually varying greatly in composition from that of the rock in which it occurs.

conglomerate: a coarse-grained sedimentary rock composed of rounded clasts larger than 2 millimeters in the narrower diameter, usually included in a matrix of sand, silt, or any of the natural cementing materials.

endocarp: a fossilized fruit pit or stone.

fission track: a tube of radiation damage in a mineral or glass, caused by nuclear particles formed during spontaneous fission of trace quantitites of uranium 238.

honeycomb structure: caliche resembling a honeycomb.

lentil: a lens-shaped mass of rock occurring within the strata of some different material.

lithology: the physical character of a rock formation described in terms of its structure, texture, color, and mineral composition.

marl: impure calcium carbonate, usually white to light gray, typically precipitated in freshwater lakes and ponds, largely through the chemical action of aquatic plants; also called bog lime.

matrix: the natural material in which a fossil is embedded; also, the finer grained material filling the spaces between larger grains of a sediment or sedimentary rock.

Miocene: an epoch or subdivision of the late Tertiary Period.

Oligocene: an epoch or subdivision of the early Tertiary Period.

pedotubule: a cemented tubular structure in soil or sediment formed around roots and other organic or inorganic materials.

phytolith: a siliceous part of a living plant that secretes mineral matter.

Pleistocene: an epoch or subdivision of the Quaternary Period.

Pliocene: an epoch or subdivision of the late Tertiary Period.

rhizome: a horizontal underground stem of a plant, often enlarged or thickened by the storage of reserve food.

sandstone: a medium-grained, clastic sedimentary rock composed of sand-sized fragments 1/16 to 2 millimeters in diameter that are more or less firmly united by a natural cement.

siltstone: a sedimentary rock in which silt (1/256 to 1/16 millimeter in diameter) predominates over clay (< 1/256 millimeter in diameter).

spicule: a microscopic skeletal element of a sponge, typically in the form of a needle or fused cluster of needles.

stratify: to deposit in layers or strata.

terrace: a former floodplain underlain by sediment deposited by a stream when the stream was flowing at a higher level; typically forming a relatively level bench along a valley side adjacent to a recent floodplain.

tectonic: of or relating to geological structural features as a whole, particularly as such structures are affected by folding or faulting.

well log: a detailed record obtained during well drilling, correlating with depth information such as changes in electrical resistivity, spontaneous potential, radioactivity, and rock type.

Appendix II

Measured sections of exposed rocks in the vicinity of Ash Hollow (fig. 8)

Section A-A', east valley side at the mouth of Ash Hollow Creek;
NW 1/4, NE 1/4, sec. 3, T. 15 N., R. 42 W. (fig. 8).

Tertiary System: Miocene Series
Ogallala Group-Ash Hollow Formation

Thickness		in feet
Unit 5.	Sandstone and sand, yellowish gray with pedotubules, fossil seeds, floating pebbles	10
Unit 4.	Lithic conglomerate, cross-bedded and sandstone, massive, with calcrete at top; gravel clasts reworked from concretions; base and top irregular; seed fossils	45-46

Tertiary System: Oligocene Series
White River Group-Brule Formation-Whitney Member

Unit 3.	Siltstone, massive, fractured, grayish orange-pink, with lime -cemented, vertically elongated concretions in the upper 4 to 5 feet, base and top irregular	24
Unit 2.	Siltstone, massive, grayish orange-pink, with up to three dark, weathered horizons (paleosols); top irregular base nearly horizontal	11.7
Unit 1.	Siltstone, massive, fractured, grayish orange-pink	17.5

Section B-B', in Ash Hollow State Park, on the east side of the valley, about 350 yards north of parking lot at the schoolhouse;
SE 1/4, NE 1/4 and NE 1/4, NE 1/4, sec. 10, T. 15 N., R. 42 W. (fig. 8).

Tertiary System: Miocene Series
Ogallala Group-Ash Hollow Formation

		Thickness in feet
Unit 15.	Covered interval	7.2
Unit 14.	Sand and sandstone, light brown, pebbly	17.5
Unit 13.	Lithic pebble conglomerate, light brown	0.7
Unit 12.	Silt, light brownish gray, sandy	9
Unit 11.	Silt, light brown, sandy to pebbly	6
Unit 10.	Sand and gravel, pink granitic, with some bone fragments	12
Unit 9.	Sandstone, light brown	1
Unit 8.	Sand and gravel, pink granitic, partially cemented, with bone fragments	10.2
Unit 7.	Sand and sandstone, pale yellowish gray, with pedotubules and seed fossils	11.7
Unit 6.	Sandstone, pale yellowish gray, with pedotubules and seed fossils	4
Unit 5.	Sand, very fine, pale yellowish gray, with pedotubules	11
Unit 4.	Sandstone, massive, light gray, pebbly	1.5
Unit 3.	Sand, very fine, light yellowish gray	16.7
Unit 2.	Sandstone, light brown, pebbly	3
Unit 1.	Sand and sandstone, pale yellowish gray, with pedotubules, seed fossils, and honeycomb caliche in some ledges	42

Section C-C', east side of valley, about 500 yards southeast of Windlass Hill parking area;
S 1/2, S 1/2, NE 1/4, NW 1/4 and S 1/2, S 1/2, NW 1/4, NE 1/4, sec. 23, T. 15 N., R. 42 W. (fig. 8).
Because this outcrop is on private property, permission must be obtained to enter.

Quaternary System: Pleistocene Series

Unit 33.	Loess, massive, light brown, silty to very fine sandy; easily eroded into steep-sided valleys; draped over older beds	0-10
Unit 32.	Sand, massive to poorly stratified, white to moderate brown, silty to pebbly, burrowed, with concretions draped over older beds	0-10

Tertiary System: Pliocene Series
Broadwater Formation

Unit 31.	Sand and gravel, pink, granitic, with fossil wood, base and top irregular	0-15

Tertiary System: Miocene Series
Ogallala Group-Ash Hollow Formation

Unit 30.	Sand and sandstone, yellowish gray to very light brown, with seed fossils; upper 3 to 5 feet, caliche with honeycomb structures	23.3
Unit 29.	Sandstone, light yellowish gray with pedotubules	3.7
Unit 28.	Sandstone, light brown, with pedotubules, honeycomb structure	4.8
Unit 27.	Sand, brown, mottled	4
Unit 26.	Sandstone, light brown, pebbly	1.5
Unit 25.	Sand, brown	1.5
Unit 24.	Sandstone, brown to white, caliche with honeycomb structure	1
Unit 23.	Sand, brown	9
Unit 22.	Sandstone, light brown, pebbly, with numerous vertically elongated concretions (yucca bed)	3
Unit 21.	Sand and silt, brown	6
Unit 20.	Sandstone, very light gray to brown, with pedotubules, and some large, vertically oriented concretions (yucca bed)	5.8
Unit 19.	Sand, yellowish gray, silty	6
Unit 18.	Sandstone and sand, brown	12.8
Unit 17.	Sandstone, brown, with burrows and pedotubules	1.8
Unit 16.	Sand, brown, with pedotubules	10
Unit 15.	Sandstone, light brown with pedotubules	2
Unit 14.	Sand, brown	10
Unit 13.	Sandstone, brown, with pedotubules	5.2
Unit 12.	Sandstone, brown and white, mottled, honeycomb structure, calcite, burrows	3.3
Unit 11.	Sand, brown, pebbly, with claystone clasts at base, filled burrows at top	3.6
Unit 10.	Claystone, massive, light tan	1
Unit 9.	Sand, brown, pebbly, with pedotubules	7
Unit 8.	Sand, pebbly, and sand and gravel, pink, granitic, with bone fragments	3
Unit 7.	Sand and pebbly sand, brown	10

Unit 6.	Sandstone, brown, with pedotubules	6.3
Unit 5.	Sandstone, brown	5.6
Unit 4.	Sand, brown, with pedotubules	11.5
Unit 3.	Silt, white, limy, with fine ash	1
Unit 2.	Volcanic ash, very light gray	1-3.5
Unit 1.	Silt, light tan, may be covered by Quaternary terrace deposits	8.5

Section D-D', roadcut on U.S. Highway 26, about 1,000 feet south of the entrance to the Windlass Hill parking area; C N 1/2, NW 1/4, trending southeasterly to about C SL NE 1/4, SW 1/4, sec., 23, T. 15 N., R. 42 W., Garden County (fig. 8).

Quaternary System: Pleistocene Series

Unit 14.	Loess, silty to very fine sandy; light gray to pale brown; up to	50

Tertiary System; Pliocene Series
Broadwater Formation

Unit 13.	Gravel, pink, granitic; with caliche at top, locally lime-cemented; white, siliceous coatings on some grains; contains some petrified wood	10-25

Tertiary System: Miocene Series
Ogallala Group-Ash Hollow Formation

Unit 12.	Sand, fine to very fine, grayish yellow with some limonite stains; pedotubules common; slightly calcareous	8-10
Unit 11.	Sandstone, fine to very fine grayish yellow sand with calcareous cement, pedotubules, about	2
Unit 10.	Sand, fine to very fine, orange pink to light brown, with thin continuous, very light gray, calcite-cemented ledges, about	11
Unit 9.	Sand and sandstone, very fine to fine with occasional pebbles, light gray to light yellow brown, about	7
Unit 8.	Sandstone, very fine to fine, light gray, forming ledges with abundant pedotubules, about	2
Unit 7.	Sand and sandstone, very fine to fine, orange pink and light brown, with thin, continuous, very light gray, calcite-cemented ledges, about	11
Unit 6.	Sandstone, massive, fine to very fine, light gray to light gray brown, calcite-cemented	2-3
Unit 5.	Sand and sandstone, very fine to fine, orange pink to light brown, with thin, discontinuous, very light gray, calcite-cemented ledges, about	75
Unit 4.	Conglomerate, with lithic fragments and a few granitic pebbles, ledge-forming, in a discontinuous lens, about	1
Unit 3.	Sand and sandstone, very fine to fine, orange pink to light brown, with thin, discontinuous, very light gray, calcite-cemented ledges, about	50
Unit 2.	Volcanic ash, white, calcite-cemented	0-3
Unit 1.	Sand and sandstone, very fine to fine, orange pink to light brown, with thin, discontinuous, very light gray cemented ledges	15

Section E-E', about 1 mile southeast of the Windlass Hill parking area;
NE 1/4, SE 1/4, SE 1/4, sec. 23, T. 15 N., R. 42 W., Garden County (fig. 8).
Because this section is on private property, permission must be obtained to enter.

Quaternary System: Pleistocene Series

Unit 9.	Loess, silty to very fine sandy, light brown, draped over older beds	0-10
Unit 8.	Colluvium, sandy silt and silty sand, white to brown, burrowed, with concretions; draped over older beds	10-15

Tertiary System: Pliocene Series
Broadwater Formation

Unit 7.	Sand and gravel, pink, granitic	7-8
Unit 6.	Sand, very fine, brown	5
Unit 5.	Silt, white,	1
Unit 4.	Sand, fine, light brown	0.8
Unit 3.	Sand, fine, light brown	1.8
Unit 2.	Sand, very fine, light brown	1.1
Unit 1.	Sand and gravel, pink, granitic, with irregular base; yielded partial molar of *Stegomastodon mirificus*(?)	23.3

Appendix III

Description of test hole 2-B-72

Conservation and Survey Division, University of Nebraska-Lincoln, test hole 2-B-72, NW 1/4, NE 1/4, NE 1/4, SE 1/4, sec. 15, T. 15 N., R. 42 W., altitude: 3,422 feet, Garden County, Nebraska.

		Depth, in feet From	To
Quaternary System			
Unit 22.	Silt, yellowish brown, with very fine sand	0	6
Unit 21.	Sandstone, pebbles, moderate yellowish brown, with granitic gravel	6	
Unit 20.	Very fine sand, dark yellowish brown	11	13.5
Unit 19.	Gravel, sandstone pebbles, dark yellowish brown with granitic gravel	13.5	16
Unit 18.	Silt, dusky yellowish brown (soil?)	16	18
Unit 17.	Silt and very fine sand, dark yellowish brown, some granitic and lithic gravel, finer grained at 27 feet	18	34.5
Unit 16.	Gravel, pale to dark yellowish brown, siltstone clasts with granite	34.5	37
Unit 15.	Sandstone, fine to very fine, yellowish gray, lime- cemented, very ashy in some fragments	37	43
Tertiary System: Miocene Series Ogallala Group-Ash Hollow Formation			
Unit 14.	Sandstone, very fine to siltstone, yellowish gray to light olive gray, calcite-cemented, some ash shards throughout, finer grained toward base	43	51
Unit 13.	Sandstone, very fine, yellowish brown, much calcite cement decreasing downward, probably caliche	51	57
Unit 12.	Sandstone, very fine, light olive gray, hackberry (Celtis) seeds at top, thin caliche occasion ally present (limier layers), pedotubuies at 64 to 65 feet	57	67
Unit 11.	Sandstone, very fine to siltstone, yellowish brown, much calcite cement (caliche)	67	69.5
Unit 10.	Siltstone with some very fine sand, dark yellowish brown with some pedotubules	69.5	76.5
Unit 9.	Sand and sandstone, very fine to medium, moderate yellowish brown, variable amounts of cement, finer grained downward	76.5	80
Unit 8.	Siltstone to very fine sandstone, dark yellowish brown, poorly cemented, with pedotubules, calcite cement increasing toward base	80	96.5
Unit 7.	Diatomaceous silt, light olive gray	96.5	98.5
Unit 6.	Siltstone to very fine sandstone, dark yellowish brown with pedotubules, calcite cement increasing downward	98.5	115
Unit 5.	Siltstone to very fine sandstone, yellowish gray, much calcite cement (caliche), rodent incisor at 1 25 feet, coarser downward with fine sand at 125 feet, many ash shards at 125 feet and below	115	132
Unit 4.	Siltstone, very pale orange to pale yellowish brown, much calcite cement	132	145
Unit 3.	Silt, light olive brown	145	148
Unit 2.	Ashy silt, dark yellowish brown, with biotite and muscovite flakes	148	159.5
Unit 1.	Sand and sandstone, fine to medium grained, granitic, loose, increasing calcite and silica cement below 165 feet, grains increasingly greenish below 165 feet, some finer grained beds at 172 to 173 feet, very well cemented at 173 feet and at 179 feet	159.5	179.2

Appendix IV

Collecting equipment

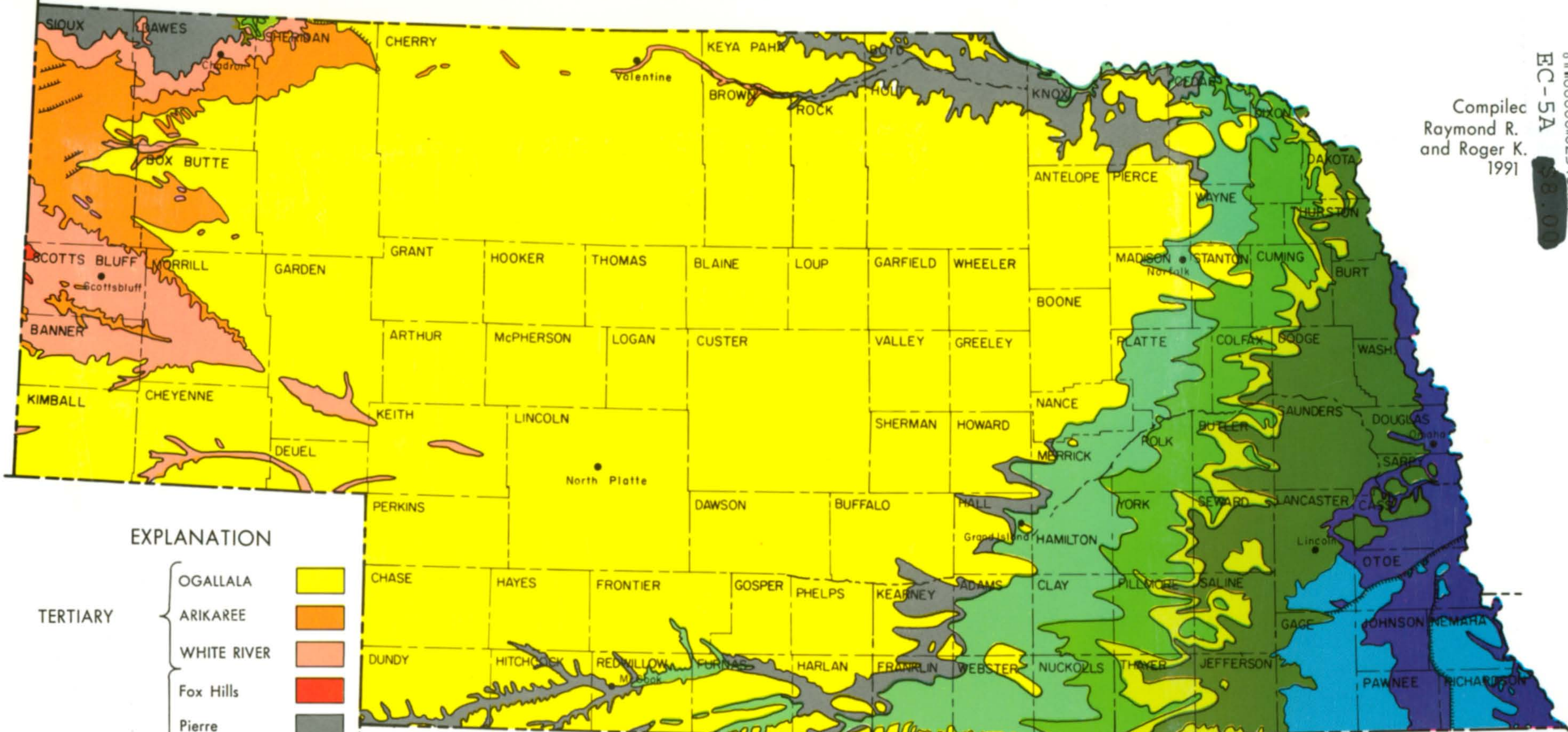
(Equipment useful for field work)

Shovel
Small pick
Rock hammer with chisel head
Small whisk broom or small paint brush
Dental probes
Small flat trowel
Ice pick
Linoleum knife
Hand lens
Marking pen
Burlap bags
Plaster of paris
Water container
Water
Empty buckets for mixing plaster
Toilet paper
Maps
Notebook
Camera and film
Small pill bottles
Paper sacks
Household cement
Preservative (shellac and denatured alcohol)

Fig. 8. Measured stratigraphic sections. Locations shown on figure 6 and described in appendixes II and III. Figure from pocket on inside back cover of Diffendal, Pabian, and Thomasson, 1996 (*Geologic History of Ash Hollow State Historical Park, Nebraska* Conservation and Survey Division, University of Nebraska-Lincoln).

GEOLOGIC BEDROCK MAP OF NEBRASKA

Compilec
Raymond R.
and Roger K.
1991



Drafted by Jerry P. Leach

EXPLANATION

TERTIARY
- OGALLALA
- ARIKAREE
- WHITE RIVER

CRETACEOUS
- Fox Hills
- Pierre
- Niobrara
- Carlile
- Greenhorn–Graneros
- DAKOTA

JURASSIC

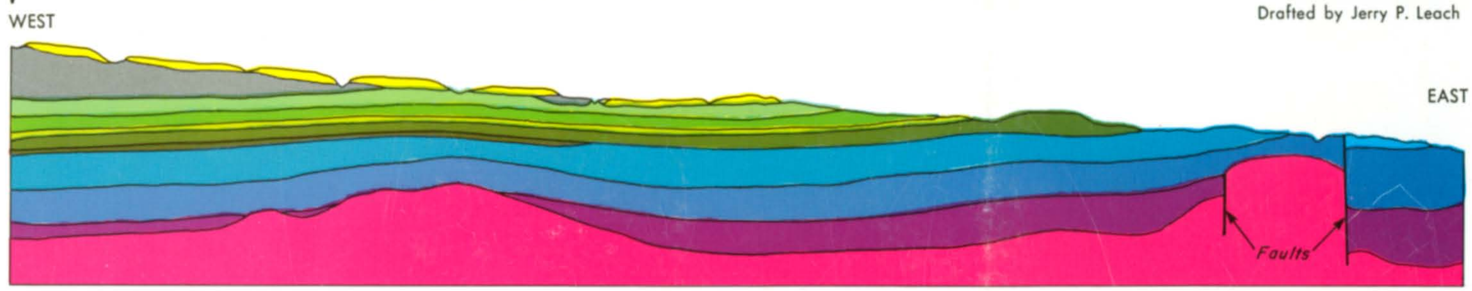
PERMIAN

PENNSYLVANIAN

MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN

PRECAMBRIAN

Fault



GEOLOGIC CROSS SECTION ALONG SOUTHERN NEBRASKA BORDER

20 0 20 40 60
Scale in Miles

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.