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C. Bertrand Schultz
University of Nebraska-Lincoln

Thompson Mylan Stout
University of Nebraska-Lincoln

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ANCIENT SOILS AND CLIMATIC CHANGES IN THE CENTRAL GREAT PLAINS*

C. Bertrand Schultz and Thompson Mylan Stout

Department of Geology and State Museum
University of Nebraska-Lincoln
and Nebraska Academy of Sciences
Lincoln, Nebraska 68588

An exceptionally clear record of climatic changes has been preserved in the Quaternary and Tertiary soils and loess deposits of the central part of the United States. Major extinctions of mammals also coincide with regional breaks in sedimentation, perhaps at glacial maxima.

The Quaternary stratigraphy is now well known in this region, with initial Quaternary glaciation succeeding end-Tertiary (Ogallala) alluviation and soil development. The Quaternary ("Ice Age") succession of cutting-and-filling cycles that record episodes of glaciation and inter-glaciation begins just after the completion of the main caliche-complex of the end-Ogallala or end-Pliocene (*circa* 3.2 m.y. ago). The soils, such as the Sangamon soil-complex, unquestionably document times of equable temperature and abundant rainfall favorable for the growth of plains grasses and other vegetation, as well as for mammals. Unconformities cutting the soils record the onset of drought, followed by dominant colluviation, alluviation, and loess deposition. Since the outwash deposits rest on surfaces of major disconformity, the glacial-maximum is believed to be represented by this widespread erosion of the denuded plains. The retreating ice is represented by outwash and by widespread loess deposition transitional to the next period of inter-glaciation and significant soil development.

Thus, a terrace-cycle is easily recognizable, with the major soils and most-important erosional breaks being of greatest importance. Six couplet-episodes seem to represent progressively diminishing and weaker glaciations through the Quaternary to the present, and there are six valley-fills forming terraces (T-5 to T-1, plus the T-0 or modern floodplain). The earlier valley-fills, represented in cuts through the terraces, are more complex than the later ones.

Similar climatic changes (associated with major extinctions), also with soils, unconformities, and loess deposits, characterize the Medial and Late Tertiary (Oligocene–Pliocene) of the Great Plains. The major breaks probably represent the Tertiary glaciations of the deep-sea cores.

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INTRODUCTION

The fascinating study of ancient soils (*Paleopedology*) has only recently attained the status of a distinct field in geology (Yaalon, 1971; Buurman, 1972, 1975; Schiebout, 1979). However, investigations of buried soils and loesses in the Central Great Plains of the United States have been under way by us and by our associates for about fifty years, with some observations by others very much earlier (*e.g.*, Barbour, 1892, 1897; Darton, 1899).

An interest in Quaternary soils and loesses, especially with regard to their regional development in valley-fills and in climatic interpretations (Schultz and Stout, 1945), soon led to recognition of them in Tertiary and older sediments of the region. But the experience of the Great Drought in the mid-1930s made clear that there are (Matthai, 1979; Rosenberg, 1978; Roberts, 1973, 1979; McCormac and Seliga, 1979; Hansen *et al.*, 1978; Ahlbrandt *et al.*, 1980; Aandahl, 1972) and were definite regional-climatic controls, which we now believe are but part of larger, even global, climatic changes. These larger aspects and interpretations are the subject of this paper.

SOILS AND DROUGHT

Figure 1 summarizes what has been learned in a general way (Schultz and Stout, 1945, 1948, 1977) concerning the relation between soils and drought in the thick-loess region of the Central Great Plains, where the thickest loesses in North America occur. When moisture and temperature are favorable for luxuriant plant growth, the soil is built up on the parent loess (A), but with the onset of drought (B) the plant community is greatly reduced in numbers and kinds. The growing plants are unable to hold the soil in place, so *dusting* and

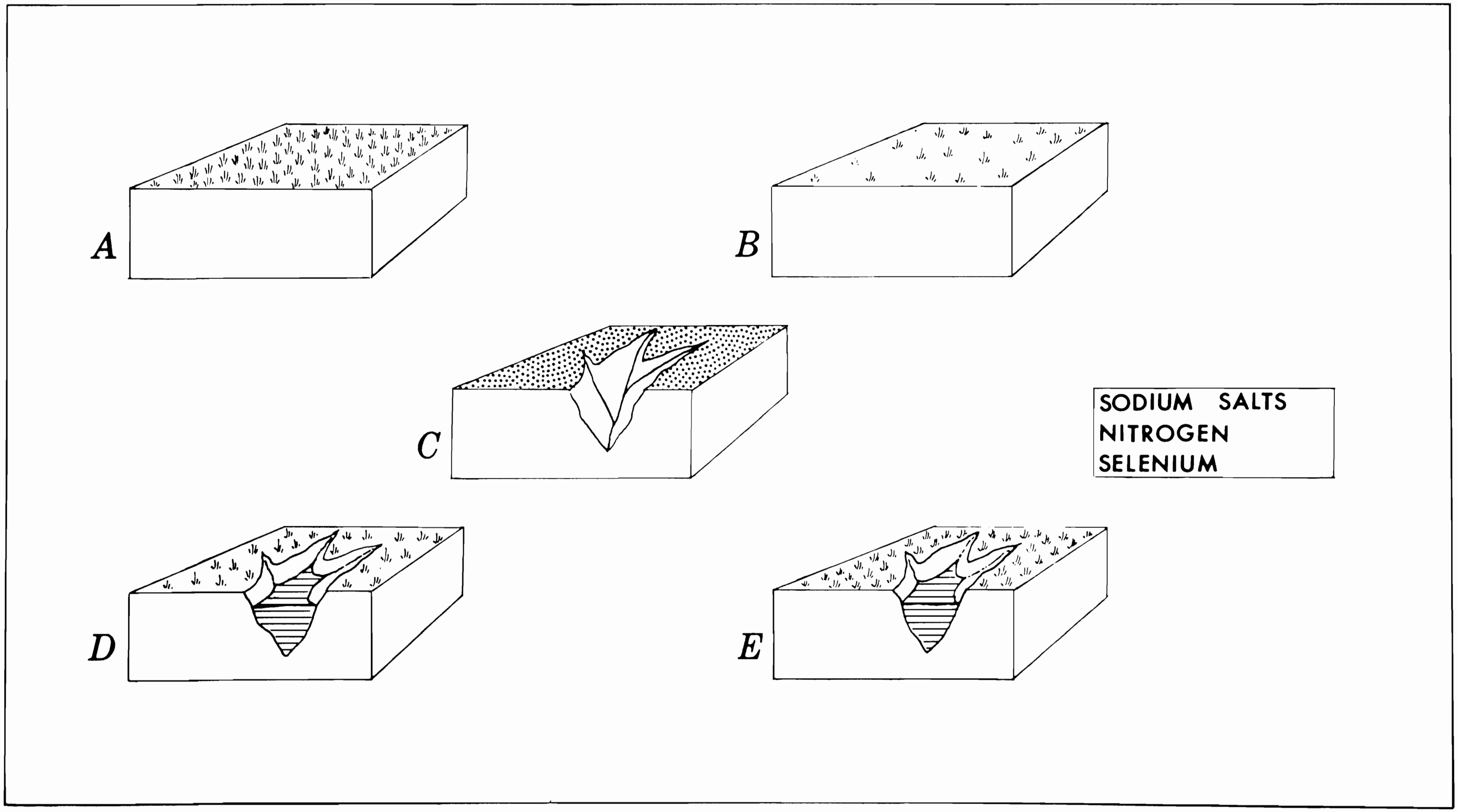

FIGURE 1. Drought and recovery in the Central Great Plains. **A.** before drought, **B.** inception of drought, **C.** "gullying" and "dusting," **D.** alluviation and colluviation, and **E.** recovery. For discussion of fixation of sodium salts and nitrogen- and selenium-poisoning, *see* text. From Schultz and Stout (1977).

gullying (C) are normal processes that proceed rapidly once the prairie sod is broken. Colluviation and alluviation (D) follow throughout the drought, until its cessation brings about recovery (E). The drought is accompanied by fixation of sodium salts, and by nitrogen- and selenium-poisoning (Schultz and Stout, 1977; Schultz and Hillerud, 1978; Wiese and Axthelm, 1973), which has a disastrous effect on animal life (*see* discussion on Extinctions later in this paper).

A distinction must be made between major and minor droughts for there are widespread episodes of cut-and-fill in the Central Great Plains (especially in the time of Man) that can be identified and correlated from Canada to Mexico. Many of these must surely record droughts of greater intensity and duration than the Great Droughts of the 1930s and 1976-77 (Matthai, 1979).

SOILS AND THE GLACIAL CYCLES

Such intense and prolonged droughts are closely associated with regional dissections, believed to represent glacial maxima, for in the periglacial region and marginal to the ice front outwash sediments (or clear-equivalents) rest on the surface of unconformity. The outwash grades upwardly to finer sediment, including loess, with a capping soil (or soils), which must be interpreted as representing conditions like those at present (interglacial or interstadial). The entire history of the Quaternary, which began perhaps 3.2 m.y. ago (Shackleton and Opdyke, 1977; Stout, 1978; Schultz and Hillerud, 1978), is thus recorded in the succession of six valley-fills, each of which is actually double or even more complex (Figs. 2-3), weakening toward the present.

QUATERNARY SOILS AND VALLEY-FILLS

This sequence (Figs. 2-3) has been much studied for a very long period. The second valley-fill above the floodplain (Terrace-2, T^2, or Kersey) is evidently at least of two parts, an older *substratum* (Terrace-2B) and an overlying *topstratum* (Terrace-2A). Basically, the others are also double, but there are complexities due to minor soils and channeling that allow some differences in interpretation. (*See also* Schultz and Hillerud, 1977a and b, 1978; Schultz *et al.,* 1951; Stout and Schultz, 1971; Stout, 1971, 1973.)

Three of the Quaternary soil-complexes require special discussion here.

Sangamon Soil-Complex

This is developed on "red" (Loveland) loess and overlain by yellowish-buff (Peoria, or Peorian) loess, at the top of the fourth valley-fill above the floodplain (Terrace 4, T^4, or Sheridan), or in the mantle of the oldest fill. Two humic horizons, one very thick, can be identified in the thick-loess area of west-central Nebraska, but these fuse into a composite profile (brunozem/udoll to chernozem/ustoll) when traced into eastern Nebraska and western Iowa. To the west, in western Nebraska and in the Southern High Plains, there is partial calichification. These relations lead us to suggest that in Sangamon time (Follmer *et al.,* 1979) the thirty-inch (76 cm) rainfall line probably was situated in west-central Nebraska, perhaps two hundred miles (322 km) west of its present position.

An imaginary line, approximately along the Missouri River, just east of this thirty-inch line is generally taken to separate the dry pedocal soils from the moist pedalfer soils. It therefore defines roughly the soils of the arid-semiarid-subhumid regions from those of the humid regions. The movement of this rainfall boundary west across Nebraska is to some extent the expectable shift in a moist interglacial such as the Sangamon. In times of extreme drought, such as that following the Sangamon, this boundary surely shifted outside Nebraska, at least into Iowa. The post-Sangamon erosion was spectacular, for tabular remnants of Sangamon soil margined by the next-younger Todd colluvium and sandy alluvium and overlain by yellowish-buff loess (Peoria, or Peorian), are to be seen throughout central Nebraska.

End-Broadwater Soil-Complex

This occurs at the top of the oldest valley-fill (Terrace-5, T^5, or Broadwater), developed just above the upper gravels (Red Cloud) of the Broadwater Formation, Early Pleistocene, that seem to represent in western Nebraska the outwash or outwash-equivalent of Kansan mountain-glaciation. The older of the two caliches is considered by one of us (T.M.S.) to represent the "True Yarmouth" and the younger to equate with the "Sappa Soil" elsewhere in Nebraska. They are separated by an unconformity, and there is another unconformity on top of the younger caliche. Both caliches may contain *Yucca* roots, another indication of the semiarid climate.

Lisco Soil-Complex

This likewise occurs in western Nebraska, but in the middle of the Broadwater Formation, at the horizon of the diatomaceous marl-peat bed that yields the "Aftonian" (Early Pleistocene, Fullerton-equivalent) fossil mammals at the Broadwater Quarries (Schultz and Stout, 1945, 1948). It is usually a caliche, also with *Yucca* roots, and like other Quaternary and some Tertiary soils can be readily correlated with southwestern Kansas (Stout *et al.,* 1965; Fig. 9-41).

TERTIARY SOILS AND VALLEY-FILLS

Figure 3 shows additionally the principal offset valley-fills of the Pliocene (Ogallala), Late Miocene (Hemingford),

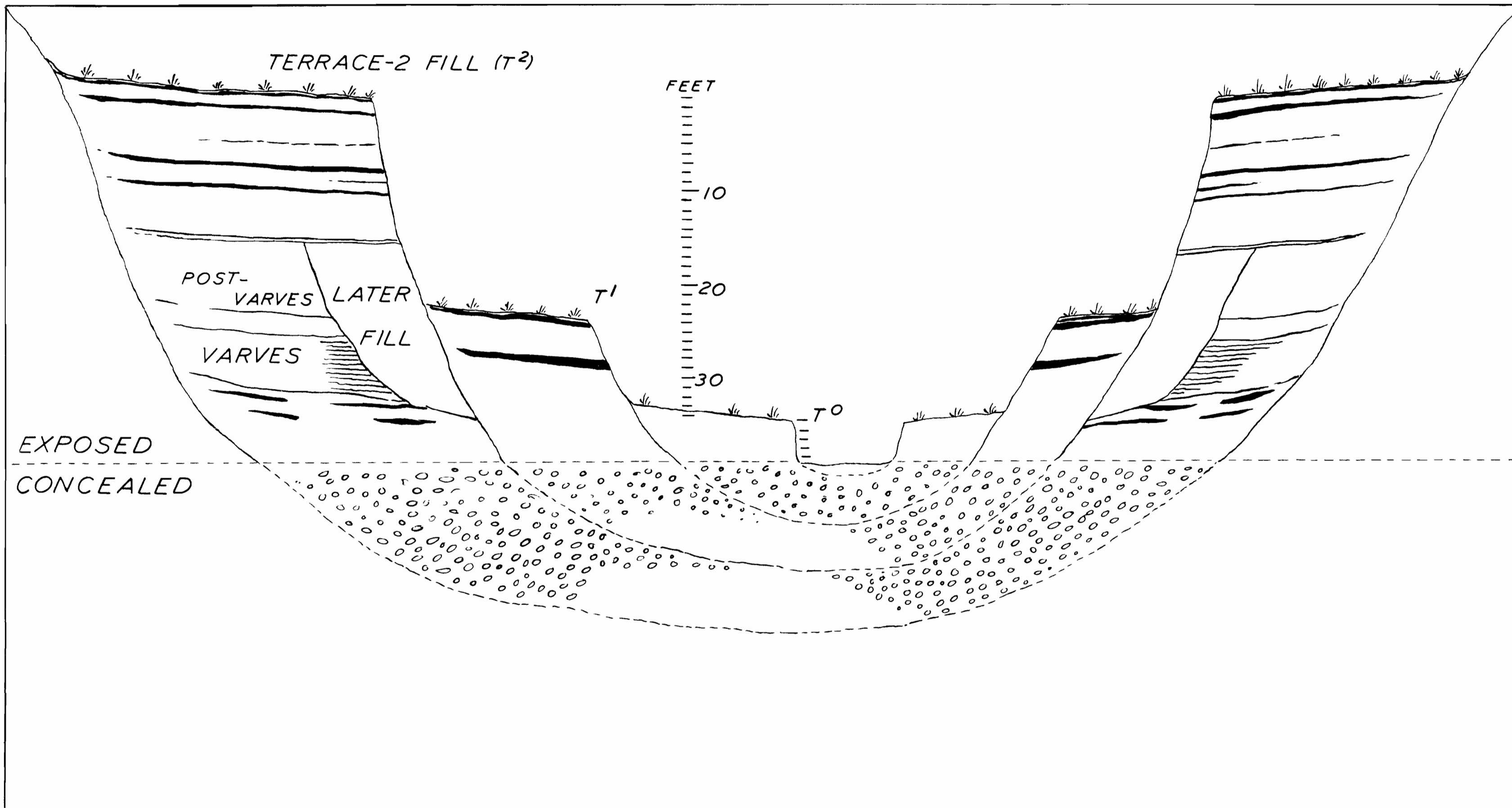

FIGURE 2. Late Quaternary valley-fills and terraces near Horn, at the Sand Creek Bridge, northwest of Crawford, Sioux County, Nebraska. From observations of the authors (*in* Stout *et al.*, 1965). The terrace-fill concept to a large extent was developed in this area, but it now appears that only the 2-A valley-fill is shown here, and that the entire later sequence is somewhat more complex than originally thought. Artifacts and fireplaces of Early Man are found commonly in the Terrace-2 fills (T^2) in this area.

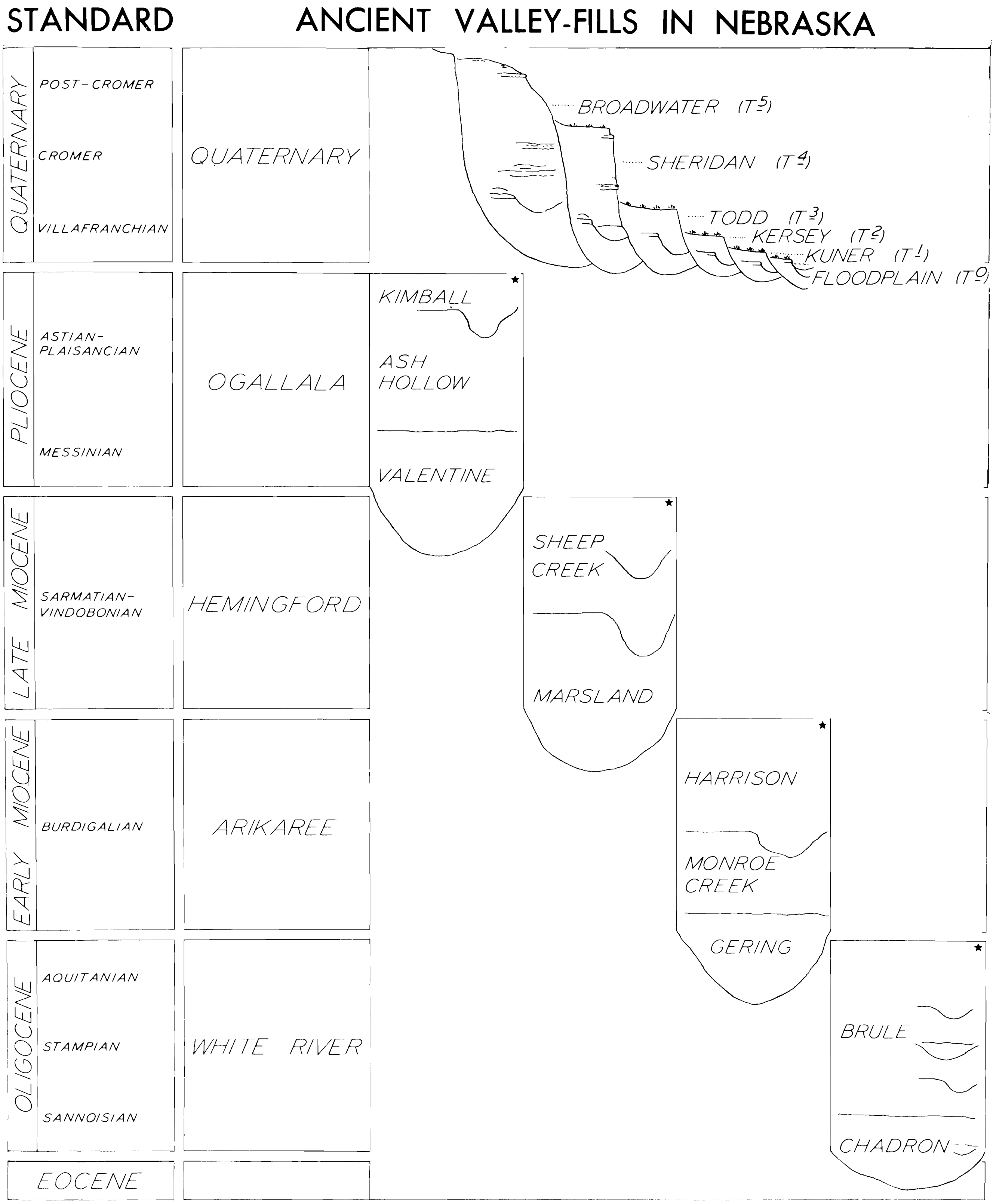

FIGURE 3. Ancient valley-fills in Nebraska, Oligocene-Quaternary. Stars indicate positions of the very important terminal soils, after which there was regional dissection coincident with major mammalian extinctions. The Quaternary valley-fills (terraces, T^5-T^0) are successional, oldest to youngest. The Tertiary valley-fills mostly occupy offset positions. From Stout *et al.* (1971).

Early Miocene (Arikaree), and Oligocene (White River), expanded in the following illustrations. At the top of each there is a prominent soil-complex (indicated by a star), following which there is a major unconformity. Less-important soils (noted by black dots on Figs. 4-7) and minor unconformities also occur, but only selected soils are discussed.

End-Ogallala Soil-Complex (Fig. 4)

This caps the High Plains (Kimball Formation, Ogallala Group/Stage, Late Pliocene) from Nebraska to Texas, forming the High Plains Surface. Recent reviews of the geomorphic evolution and stratigraphy of the Southern High Plains are by Walker (1978) and G. E. Schultz (1977). Usually only minor younger soils and thin loesses cover the High Plains Surface in western Nebraska, but there may be small-to-large deflation pockets, some very large indeed in the Southern High Plains, where John C. Frye and A. Byron Leonard have long studied the relations and detailed stratigraphy.

Algal limestones occur only rarely at this horizon in Nebraska, where usually just the caliche-complex with slabby claystones and siltstones occurs, and there is now little to support the hypothesis of a single large lake extending from Nebraska to Texas. The limestones seem to have formed in meander ponds or small lakes, although reeflike limestone does occur at one locality in western Kansas.

The High Plains Surface can be traced or projected from western to eastern Nebraska, and it is especially clear near Creighton, in Knox County (northeastern Nebraska), where an unusual deposit of fossil-rhinoceros remains occurs within the village. At the nearby Airstrip Locality, University of Nebraska parties have found other abundant fossil mammals in gravels, including specimens of a large mylagaulid rodent that can be matched with one from near Creighton, with another from near Sidney and Dalton in western Nebraska, and with many from near Guymon, Oklahoma. All of these compared specimens are found in the Kimball or Kimball-equivalents, from just below the High Plains Surface, so there is no real basis for a post-Kimball age determination for the Airstrip Locality.

End-Ash Hollow Soil (Fig. 4)

This is a caliche that has spectacular development at Cedar Point, northeast of Ogallala, in western Nebraska, where it contains very large root-casts of the yucca plant and a mass of other plant materials embedded at the base and in a caliche-ledge. The yucca still lives on these slopes, and its roots are found abundantly in other soils (caliches) lower in the Ash Hollow Formation. Excellent exposures with them occur along the road northeast of Ogallala leading to the Kingsley Dam for Lake McConaughy, and at the south end of the dam.

Caprock Bed Soil-Complex (Fig. 4)

This occurs near the base of the Ash Hollow Formation (Ogallala Group/Stage, Medial Pliocene) in western and northern Nebraska, often at the top of a prominent escarpment. There are several channels associated with it, as investigated by Morris F. Skinner and associates, but we view it as probably a "double caliche," similar to that noted previously at the top and just above the Broadwater Formation.

End-Hemingford Soil-Complex (Fig. 5)

We recognize this caliche principally at two localities in western Nebraska above fossil sites which have yielded the so-called "Lower Snake Creek" mammals (*see* Skinner *et al.*, 1977; Galusha, 1975, for background terminology), which we prefer to place in an expanded Sheep Creek Formation (Hemingford Group/Stage, Latest Miocene).

End-Marsland Soil-Complex (Fig. 5)

This is another double-ledged caliche ("double caliche"), similar to that comprising the Caprock Bed and the summit-beds of the Broadwater, discussed above. It occurs at the top of the Marsland Formation (Hemingford Group/Stage, Late Miocene), and it is overlain unconformably by the "Box Butte" (Galusha, 1975), which we regard as Sheep Creek. This soil-complex is well developed in western Nebraska and northeastern Colorado.

End-Arikaree Soil Complex (Fig. 6)

An impressive soil-complex occurs just south of the now-abandoned town site of Andrews, in western Nebraska (Sioux County), and it is equally well shown north-northwest of Harrison (also in Sioux County). The "Eagle Crag" Locality of the early expeditions of the University of Nebraska (Barbour, 1892, 1897, and unpublished field notes) is situated just north of Harrison. It was there that the principal examples of the peculiar "Devil's Corkscrews" or "Daimonelix" screws that are and were formerly on display at the University of Nebraska State Museum were collected (Schultz, 1942). These were given a different mode of origin by Barbour, but since O. A. Peterson's announcement in 1904-1905 of finding the remains of fossil beavers in them, they have been generally regarded as the burrows of fossil beavers (Schultz, 1942; Martin and Bennett, 1977). Stout's work on the fossil beavers has resulted in the recognition of three different beavers as responsible.

The fossil burrows, Daimonelix, occur at numerous horizons in the upper part of the Harrison Formation (Arikaree Group/Stage, Early Miocene), with each burrow system directed downward from a soil, especially the capping one.

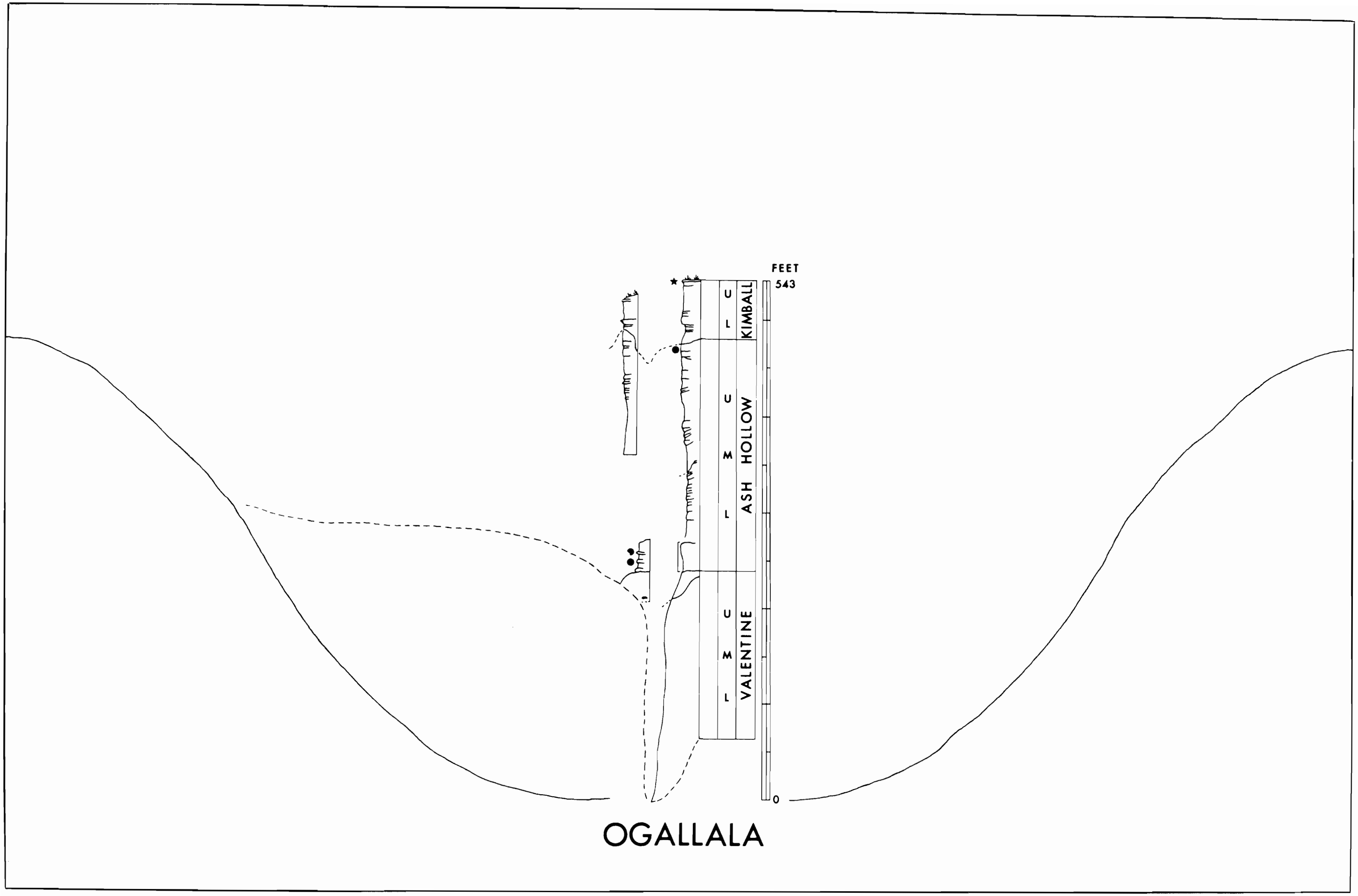

FIGURE 4. Schematic diagram of Pliocene (Ogallala) valley-fill in western Nebraska. Star indicates position of the end-Ogallala caliche (High Plains Surface). Black dots show positions of other soils (caliches), some with fossil roots of *Yucca*.

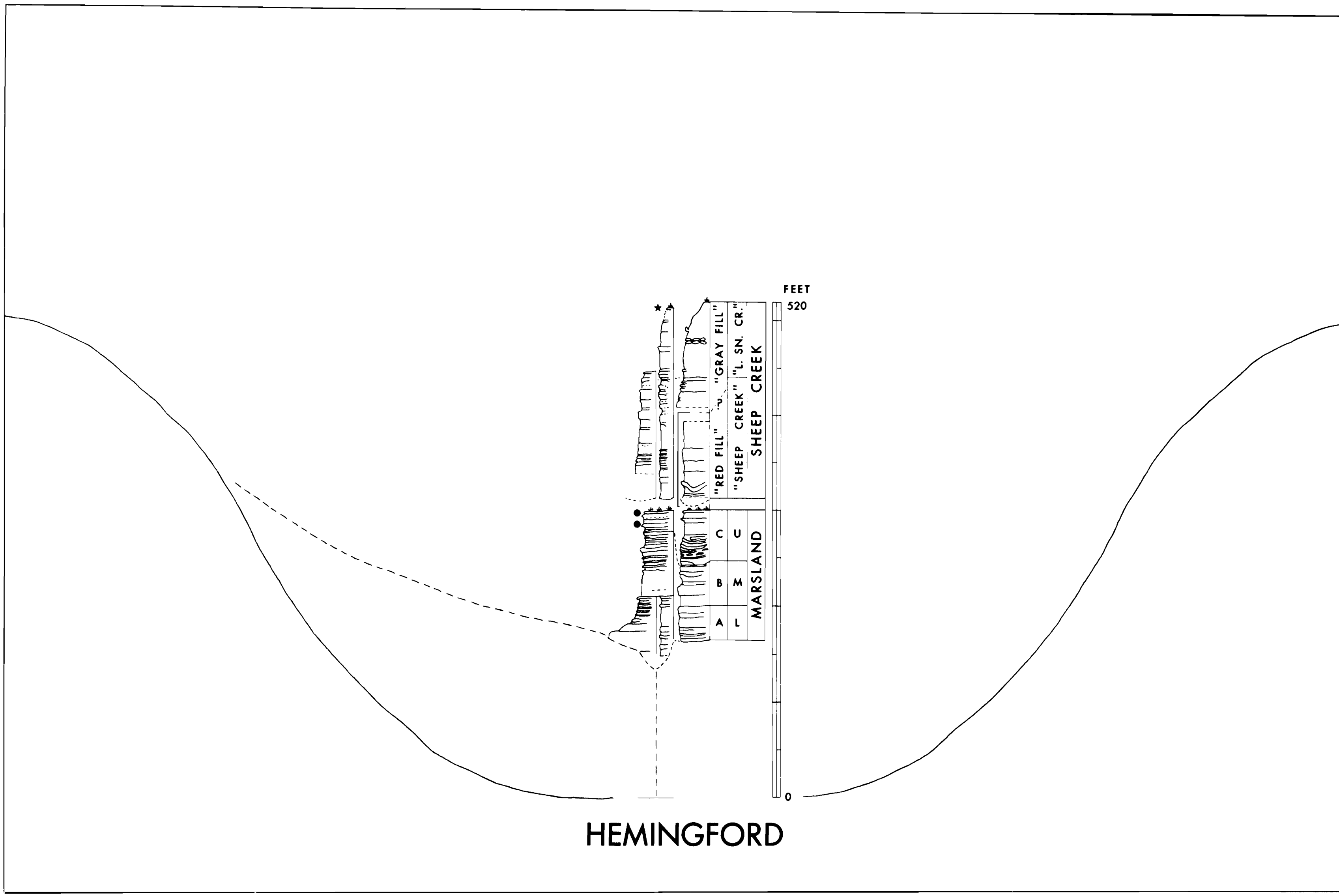

FIGURE 5. Schematic diagram of Late Miocene (Hemingford) valley-fill in western Nebraska. Star indicates position of the end-Hemingford caliche. Black dots show positions of other caliches.

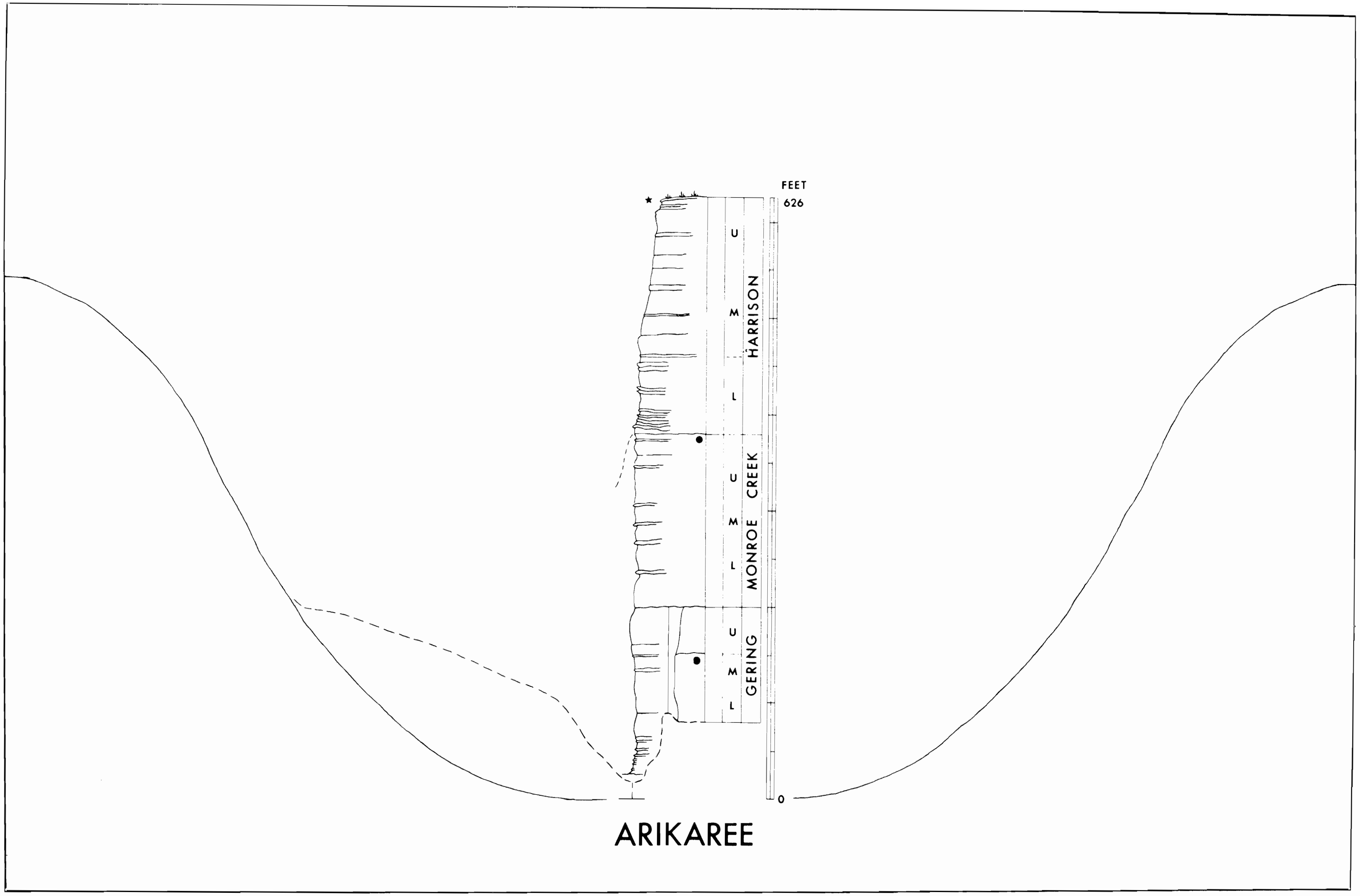

FIGURE 6. Schematic diagram of Early Miocene (Arikaree) valley-fill in western Nebraska. Star indicates position of the end-Arikaree caliche-complex, associated with fossil-beaver burrows ("Daimonelix"). Black dots show positions of other soils.

A good example has been found by Lloyd G. Tanner in the Gering Formation (personal communication).

End-Monroe Creek Soil (Fig. 6)

This is the interval at the top of the Monroe Creek Formation that has small, potato-sized concretions along the Pine Ridge, especially in Smiley Canyon, in northwestern Nebraska. Other minor soils occur in either the Gering or Monroe Creek south of Oshkosh, in Garden County, Nebraska.

Minor Soils in the Gering (Fig. 6)

At Castle Rock, Scotts Bluff County, Nebraska, there is a condensed section of the Gering Formation (Early Miocene) displaying the *Bayard Paleosol Complex* (Schultz and Stout, 1955; Vondra *et al.,* 1969; Darton, 1899). It evidently represents the capping of a drainage divide, marginal to a major valley of Gering time, but in the valley-fill itself (which has both a fluviatile and loessic facies) a minor soil occurs at nearby Chimney Rock (Darton, 1899) and another probably occurs elsewhere at the disconformity in about the middle of the formation.

End-White River Soil-Complex (Fig. 7)

This has been identified at several localities along the Pine Ridge in northwestern Nebraska and along the Wildcat Ridge and related outliers in western Nebraska, wherever the White River (Oligocene) summit-sediments can be observed (Schultz and Stout, 1955; Schultz *et al.,* 1955; Schultz *et al.,* 1967; Vondra *et al.,* 1969). These highest White River sediments, known as the Whitney Member of the Brule Formation, are of considerable interest because they seem to be mostly an ancient loess that is in every respect similar to the Peoria (or Peorian) loess of the Late Quaternary (Schultz and Stout, 1955; Tychsen, 1954). There is obvious thinning between the two principal beds of volcanic ash (tephra) of the Whitney along the North Platte Valley east of the Wildcat Ridge and into southwestern South Dakota north of the Pine Ridge, as near Oelrichs, South Dakota. Minor soils may be detected in the Whitney at many localities in western Nebraska and northeastern Colorado, and thin beds of volcanic ash (tephra) occur above the Upper Ash bed. There is some unconcentrated ash throughout the Whitney, but the base of each ash bed is a sharp contact whereas the upper surface is gradational to the overlying loess (except in places at the top of the Lower Ash bed). Snails of the genus *Helix* occur abundantly.

Fossil mammals collected from the Whitney seem to reflect the dominant loess lithology, with adaptations to a plains or even "desert" habitat noticeable especially in the sheeplike oreodonts (Schultz and Falkenbach, 1968:402-407) and rhinoceroslike hyracodonts (personal communication from Lloyd G. Tanner).

Lower Ash Soil (Fig. 7)

This is the most prominent volcanic-ash (tephra) bed in the Whitney Member of Nebraska and adjacent states, and it seems to have been altered to a soil at its top surface, with a channel-sandstone system incised into lower beds from this horizon just east of Douglas, in eastern Wyoming. The ash contains small concretions almost everywhere (as does much of the Lower Whitney, and even the Middle and Upper Whitney in places) and these in the ash bed occur irregularly, not in rows. The concretions sometimes enclose fossil-mammal skulls or skeletons, commonly turtles, and even one snake has been collected. Snails of the genus *Helix* are abundant in the ash bed, as elsewhere in the Whitney.

"The Bench" Soil-Complex (Fig. 7)

This occurs with a prominent topographic expression below the top of the Orella Member, Brule Formation (White River, Oligocene) in northwestern Nebraska, eastern Wyoming, and northeastern Colorado. The Orella is next older than the Whitney, discussed above, and it generally contains less loess. However, some parts of the upper portion of the Orella (Orella C) may be chiefly loess that resembles the loess of the Whitney, but is older.

It is possible to walk easily at "The Bench," and fossil mammals occur abundantly at this horizon. From color-photographs or after a rain, this is seen to be a Purplish-White Layer (*see* following discussion). The presence of a considerable time-break at this horizon was not considered until it was found that certain of the lineages of leptauchenin oreodonts (sheeplike mammals) displayed marked changes in their organs of hearing (*bullae*) here (Schultz and Falkenbach, 1968). However, a soil-complex was evidently present through a thickness of about 25 ft (7.6 m) above a persistent marker-bed. This is the "Green Ledge" (Schultz and Stout, 1955; Schultz *et al.,* 1955), which has been traced from northwestern Nebraska and eastern Wyoming into northeastern Colorado.

Soil Marginal to the "Toadstool Park Channel" (Fig. 7)

At the famous Toadstool Park, now a tourist attraction in northwestern Nebraska, the sandstone masses weather out into unusual "toadstool" forms. It is marginal to this channel-sandstone that an interesting soil has been identified (Schultz *et al.,* 1955; Schultz and Stout, 1955; Harvey, 1960). There is noticeable leaching, with lime-accumulation at depth, but little or no preservation of an "A" horizon. However, soils with humus-preservation do occur near Douglas, in eastern

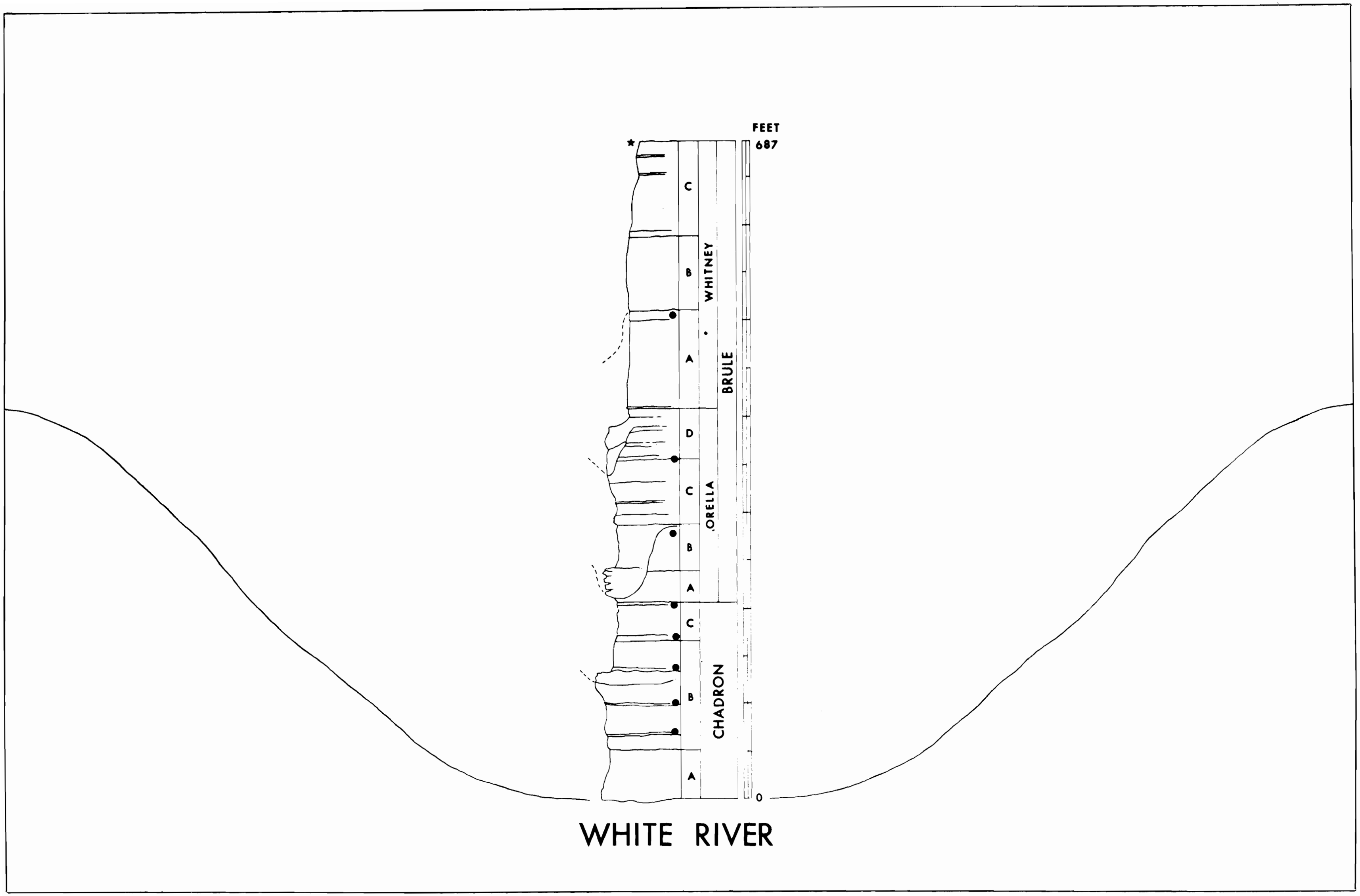

FIGURE 7. Schematic diagram of Oligocene (White River) valley-fill in western Nebraska. Star indicates position of the end-White River soil-complex. Black dots show positions of other soils.

Wyoming, at about this stratigraphic position, and soils much lower in the section (Orella A and Chadron C) near the Toadstool Park and northeast of Chadron (Dawes County, Nebraska) also have humus in places. Some of the latter horizons contain weathered fossil-mammal specimens even if no humus is present, and there is prominent color-banding of the "B" and "C" horizons of the profiles. Weathered specimens in the Chadron are usually associated with pink clay, whereas unweathered ones are usually intact in green clays, interpreted as ancient marshes (Schultz and Stout, 1955) separated by low pink-clay divides. "Cemeteries" or "boneyards" of remains of titanotheres (rhinoceroslike mammals) are occasionally encountered in the Chadron (basal White River) of western Nebraska and adjacent "badlands" regions, often in such marshes.

Purplish-White Layers (Fig. 7)

These occur chiefly in the Chadron Formation of northwestern Nebraska, but they can be recognized in different drainage systems of White River (Oligocene) age also in southwestern South Dakota, eastern Wyoming, western Nebraska, and northeastern Colorado. Since they occur usually in axial positions with respect to these ancient valley-fills, the frequent occurrence of charophyte (algal) limestones, interpreted as deposits in meander pools or small lakes, is expectable. At the margins of the valleys the Purplish-White Layers have been observed in northwestern Nebraska to grade laterally into gypsum evidently derived from the Cretaceous (Schultz and Stout, 1955). They are believed by us to be concentrations of gypsum and lime, very near the surface of the ground, such as occur today in places in eastern Wyoming under a semiarid climate. Extinctions of some of the common Chadron mammals seem to have been in relation to these Purplish-White Layers, so climatic changes toward aridity may be inferred. However, at a few places in the collecting areas in northwestern Nebraska, fossil-mammal specimens are abundant in the Purplish-White Layers.

PRE-WHITE RIVER (PRE-OLIGOCENE) SOILS

In Nebraska the White River (Oligocene) sediments rest unconformably upon very much older rocks, chiefly Cretaceous, but in Wyoming, Colorado, and Utah the hiatus may be filled by Eocene-Paleocene. A lateritic soil, the *Interior Paleosol Complex* (Schultz and Stout, 1955), is developed below the White River on truncated Cretaceous in Nebraska outcrops; this is the pre-White River Surface. The soil may be dated as having terminated in the Late Eocene because large masses of the soil and brilliant color-bands derived from the profile of weathering are reworked in the basal White River (Chadron). A reasonable explanation for such a succession of brilliant color-bands in the weathered profile is to be found in the classical report on Arkansas bauxite (Gordon *et al.,* 1958: 32-33, Fig. 6).

Farther west, particularly in Wyoming, the Eocene and Paleocene soils require study, not only for commercial purposes (uranium ores), but also to investigate the possibility of correlation with the Gulf Coastal Plain (Schiebout, 1979), with northwestern Europe, and with other parts of the world (Stout, 1977).

For example, the famous bauxite-laterite deposits of Arkansas and other parts of south-central and southeastern United States occur at the Midway-Wilcox boundary. The Arkansas bauxite-laterite is interpreted to be the result of a single period of weathering associated with the withdrawal of the Midway (Paleocene) sea: "The climatic conditions that favored bauxitization probably also affected a large part of the North American continent" (Gordon *et al.,* 1958:152).

The Early Tertiary cycles of transgression and regression are similar between the Gulf Coast region of North America (Mellen, 1950; Murray, 1961; Rainwater, 1964), the Anglo-Franco-Belgian Basin (*compare* Stamp, 1921), India-Pakistan-Burma (Nagappa, 1959), and New Zealand (Vella, 1965, 1967). Since it seems likely that these are eustatic cycles and world-wide (Vella, 1965, 1967:141-144, Table 7; Vail *et al.,* 1977; Payton, 1977; Stout, 1978), confirmed between the Gulf-Atlantic Coastal Plain and northwestern Europe (Loeblich and Tappan, 1957a and b), correlation of soils should logically follow. The Tertiary soils of the Anglo-Franco-Belgian Basin are now becoming well known (Pomerol, 1969; Blondeau, 1965; Buurman, 1972, 1975; Stamp, 1921), but some were observed on field trips there by one of us (T.M.S.) that seem not to have been described.

Such cycles of transgression and regression likewise characterize the Cretaceous (Hancock, 1975; DeGraw, 1975; Cooper, 1977; Kauffman, 1970 a and b, 1972, 1973 a and b, 1977, 1979; Nagappa, 1959; Asquith, 1970, 1974; Brenner, 1978; Stout, 1978), and there are soils as well. Variegated horizons have been noted by Moxon *et al.* (1939) in the Late Cretaceous of South Dakota, but they occur in the Niobrara of northwestern Nebraska also.

Similar soils, long interpreted by us as laterites (Thorp and Reed, 1949; Reed, 1954; Franks, 1980) or possibly *terra rossas*, have been studied in the Early Cretaceous (Dakota) of eastern Nebraska and north-central Kansas. They have some economic importance (brick-clay, ceramics), much as in the Black Hills and Front Range, as reported by Karl Waagé. At the Yankee Hill Brick Pits, near Lincoln, Nebraska, fossil logs occur on the surface of such a soil profile that is being worked at shallow depths for brick-clay, and well-preserved leaves are found abundantly. Near Sidney, in western Nebraska, R. L.

Cramer (personal communications) has taken several cores from holes drilled into the Dakota that showed trees and roots in place in a soil representing divides marginal to shallow valleys filled with channel-sandstones.

These variegated soil profiles of the Cretaceous of the Central Great Plains are very much like the "Violet Horizons" reported for the Permian and Triassic of Germany (Ortlam, 1966, 1971; Gwinner, 1955). They are also similar to the "red beds" of the Late Carboniferous and "Permian" of the Northern Midcontinent, studied for several decades at the University of Nebraska (Stout, 1978). Most of the "red beds" can be traced from Nebraska to Oklahoma, and they are related to a cyclicity of transgressions and regressions that is very like that of the Quaternary, probably due to glacio-eustasy.

The oldest known soil reported from Nebraska is one encountered in drilling to the Precambrian basement in central Nebraska, and it was found where the Late Cambrian rests on this basement (Reed, 1954).

MAMMALIAN EXTINCTIONS

It has been noted above in the preceding discussion that there are major soil-complexes (starred on Figs. 3-7) at the top of each of the main Tertiary divisions (groups/stages), succeeded by regional unconformities. Major mammalian extinctions occur at these times, with less-important ones associated with lesser soils and unconformities. The explanation that we suggest for both is climatic change, prolonged drought (Fig. 1) possibly accompanied by intense cold.

We have previously summarized some related aspects:

> Now, let us consider some other factors, such as the fixation of sodium salts, and also the concentration of nitrogen or selenium in some of the plants that, at the height of the drought, would have been almost the only plants left available to the grazers. For example, in the mid-1930's we were collecting fossils in the Big Badlands, near Scenic, South Dakota, when thousands of cattle were driven into Scenic to be slaughtered because of the extreme selenium poisoning. The problem of selenium concentration ('Alkali Disease') has been discussed adequately for the Cretaceous (Pierre and Niobrara formations) of South Dakota by Moxon, Olson, and Searight (1939), and we have been told of the same problem having been encountered with respect to Cretaceous shales in Ireland. As regards concentration of sodium salts and nitrogen fixation, we can only refer to the literature. . . . (Schultz and Stout, 1977:196).

To this statement we would add now the notion that climatic changes can be widespread, even world-wide in their effects. Examples would be the Cretaceous-Tertiary boundary (Bramlette, 1965; Russell, 1979a and b; Worsley, 1974) and the Permo-Triassic boundary (Pitrat, 1970), both with effects on the ocean as well as the land.

Even the tropics would be affected during an ice age (Manabe and Hahn, 1977; Petters, 1980). For example, Mabesoone *et al.* (1977:136-137) point out that during the glacial periods the climate of parts of Brazil was drier and cooler: "This extreme dryness must have been the cause of the disappearance of the giant-mammal fauna of the area studied." There were also prominent soils documenting the more humid events, when animals and plants were at times abundant, so climatic correlations are possible.

It also seems likely to us that the major breaks in the Tertiary history of the Central Great Plains, which coincide with important mammalian extinctions, probably represent the Tertiary glaciations recorded in deep-sea cores. Two of these seem very clear indeed.

(1) Eocene-Oligocene Boundary

This was postulated by Cavelier (1976), upon the data of Devereux (1967), as a time of glaciation that coincided with major extinctions in western Europe and elsewhere. This glaciation is now generally admitted by other investigators of deep-sea cores (Geitzenauer *et al.*, 1968; Kennett, 1977; Margolis *et al.*, 1977; Haq *et al.*, 1977). Sea-level changes in New Zealand (Vella, 1965, 1967) and elsewhere (Stamp, 1921; Rainwater, 1964) may be related, as becomes evident for other Tertiary glaciations (W. F. Tanner, 1968; Rutford *et al.*, 1968; Rutford, 1978; Birkenmajer, 1980; Epshteyn, 1978; Gladenkov, 1978). There is a rich literature on Tertiary transgressions and regressions, and several other glaciations have been postulated in the Tertiary by students of deep-sea cores.

(2) Pliocene-Quaternary Boundary

The post-Ogallala pre-Broadwater interval was discussed by us more than three decades ago (Schultz and Stout, 1948), and re-emphasized on many occasions since, as a time of major mammalian extinction as well as of erosion and glaciation in the Central Great Plains. Correlation of this boundary in the Midcontinent with the Gulf Coast (and with Italy) has been the subject of much additional discussion (Akers and Holck, 1957; Murray, 1961; Poag, 1969, 1971, 1972; Poag and Valentine, 1976; Lamb and Beard, 1972; Beard *et al.*, 1976; Boellstorff, 1976, 1978a and b; Lineback and Wickham, 1977). By use of the fossil mammals and the tracing of valley-fills (Stout, 1978), a more-refined correlation is possible, but this also requires a global approach.

Better intercontinental correlations for the Tertiary and Quaternary obviously require the utilization of all available data, especially with regard to transgressions and regressions and associated reflections of climatic change, and with respect to fossil mammals and plants.

SUMMARY

Climatic changes and soil development evidently have been part of the geologic history of the Central Great Plains for much or all of the time from the Cambrian. A global approach to such studies is necessary.

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REFERENCES

Aandahl, A. R. 1972. *Soils of the Great Plains.* Map, with associated Soil Teaching Aid and carousel of slides (1980), published privately at Lincoln, Nebraska 68508, Post Office Box 81242.

Ahlbrandt, T. S., S. G. Fryberger, J. H. Hanley, and J. P. Bradbury. 1980. Geologic and paleoecologic studies of the Nebraska Sand Hills. *Professional Papers of the United States Geological Survey,* 1120A-C:vi, 38p.

Akers, W. H., and A. J. J. Holck. 1957. Pleistocene beds near the edge of the continental shelf, southeastern Louisiana. *Bulletin of the Geological Society of America,* 68(8): 983-992.

Asquith, D. O. 1970. Depositional topography and major marine environments, Late Cretaceous, Wyoming. *Bulletin of the American Association of Petroleum Geologists,* 54:1184-1224.

_____. 1974. Sedimentary models, cycles, and deltas. *Bulletin of the American Association of Petroleum Geologists,* 58:2274-2283.

Barbour, E. H. 1892. Notes on a new order of gigantic fossils. *University Studies, University of Nebraska,* 1(4, article 1): 301-335.

_____. 1897. Nature, structure and phylogeny of Daemonelix. *Bulletin of the Geological Society of America,* 8:305-314.

Beard, J. H., J. Boellstorff, L. C. Menconi, and G. R. Stude. 1976. Fission-track age of Pliocene volcanic glass from the Gulf of Mexico. *Transactions of the Gulf Coast Association of Geological Societies,* 26:156-169.

Birkenmajer, K. 1980. Discovery of Pliocene glaciation on King George Island, South Shetland Islands (West Antarctica). *Bulletin de l'Académie polonaise des Sciences* (Series: Sciences de la Terre), 27(1-2):59-67.

Blondeau, A. 1965. Le Lutétien des Bassins de Paris, de Belgique et du Hampshire. Étude sédimentologique et paléontologique. *Thèse, Docteur ès-sciences naturelles, Faculté des Sciences, l'Université de Paris* (series A, 4512-5359, 15 Octobre, 1965):467p.

Boellstorff, J. 1976. The succession of Late Cenozoic volcanic ashes in the Great Plains: a progress report. *Guidebook of the Midwestern Friends of the Pleistocene,* 24th Annual Meeting (May, 1976), Kansas Geological Survey: 37-71.

_____. 1978a. A need for redefinition of North American Pleistocene stages. *Transactions of the Gulf Coast Association of Geological Societies,* 28:65-74.

_____. 1978b. Chronology of some Late Cenozoic deposits from the Central United States and the Ice Ages. *Transactions of the Nebraska Academy of Sciences,* 6:35-49.

Bramlette, M. N. 1965. Massive extinctions in the biota at the end of Mesozoic time. *Science,* 148(3678):1696-1699.

Brenner, R. L. 1978. Sussex Sandstone of Wyoming—example of Cretaceous offshore sedimentation. *Bulletin of the American Association of Petroleum Geologists,* 62: 181-200.

Buurman, P. 1972. Paleopedology and stratigraphy on the Condrusian Peneplain (Belgium) with a reconstruction of a paleosol. *Centre for Agricultural Publishing and Documentation, Wageningen* (Agricultural Research Reports, 766): 67p.

____. 1975. Possibilities of palaeopedology. *Sedimentology,* 22:289-298.

Cavelier, C. 1976. La limite Éocène-Oligocène en Europe occidentale. *Thèse, Docteur ès-sciences naturelles, l'Université Pierre et Marie Curie* (23 Janvier, 1976, 2 vols.): 353p. (Published in 1979 as *Mémoires, Sciences géologiques, Bureau de Recherches géologiques et minières, France,* 54:280p.)

Cooper, M. R. 1977. Eustacy during the Cretaceous: its implications and importance. *Palaeogeography, Palaeoclimatology, Palaeocology,* 22:1-60.

Darton, N. H. 1899. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian. *Reports of the United States Geological Survey,* 19 (1897-1898, part 4):719-814.

DeGraw, H. 1975. The Pierre-Niobrara unconformity in western Nebraska. *In* W. G. E. Caldwell (ed.), *The Cretaceous system in the western interior of North America, Special Papers of the Geological Association of Canada,* 13: 589-606.

Devereux, I. 1967. Oxygen isotope paleotemperature measurements on New Zealand Tertiary fossils. *New Zealand Journal of Science,* 10 (December):988-1011.

Epshteyn, O. G. 1978. Mesozoic-Cenozoic climates of northern Asia and glacial marine deposits. *International Geology Review,* 20(1):49-58.

Follmer, L. R., E. D. McKay, J. A. Lineback, and D. L. Gross. 1979. Wisconsinan, Sangamonian, and Illinoian stratigraphy in central Illinois. (Midwest Friends of the Pleistocene, 26th Field Conference, May 4-6, 1979). *Guidebook of the Illinois State Geological Survey,* 13:v, 139p.

Franks, P. C. 1980. Record of an Early Cretaceous marine transgression – Longford Member, Kiowa Formation. *Bulletin of the Kansas Geological Survey,* University of Kansas, 219:v, 55p. (*See also Geology,* 8[1]:56-61).

Galusha, T. 1975. Stratigraphy of the Box Butte Formation, Nebraska. *Bulletin of the American Museum of Natural History,* 156:68p.

Geitzenauer, K. R., S. V. Margolis, and D. S. Edwards. 1968. Evidence consistent with Eocene glaciation in a South Pacific deep sea sedimentary core. *Earth and Planetary Science Letters,* 4(2):173-177.

Gladenkov, Y. B. 1978. Correlation of upper Cenozoic marine deposits in Boreal regions (based on mollusks). *International Geology Review,* 20(1):59-72.

Gordon, M. Jr., J. I. Tracey, Jr., and M. W. Ellis. 1958. Geology of the Arkansas Bauxite region. *Professional Papers of the United States Geological Survey,* 299:viii, 268p.

Gwinner, M. P. 1955. Beitrag zur Enstehung und Paläogeographie des südwestdeutschen Bundsandsteins. *Jahresberichte und Mitteilungen des Oberrheinischen geologischen Vereines,* Neue Folge, 37-NF:12-28.

Hancock, J. M. 1975. The sequence of facies in the Upper Cretaceous of northern Europe compared with that in the western interior. *In* W. G. E. Caldwell (ed.), *The Cretaceous system in the interior of North America, Special Papers of the Geological Association of Canada,* 13: 83-93.

Hansen, W. R., J. Chronic, and J. Matelock. 1978. Climatography of the Front Range Urban Corridor and vicinity. *Professional Papers of the United States Geological Survey,* 1019:59p.

Haq, B. U., I. Premoli-Silva, and G. P. Lohmann. 1977. Calcareous plankton paleobiogeographic evidence for major climatic fluctuations in the Early Cenozoic Atlantic Ocean. *Journal of Geophysical Research,* 82(27):3861-3876.

Harvey, C. 1960. Stratigraphy, sedimentation, and environment of the White River Group of the Oligocene of northern Sioux County, Nebraska. Unpublished doctoral dissertation. Lincoln, Nebraska, University of Nebraska: 151p.

Kauffman, E. G. 1970a. Cretaceous marine cycles of the western interior. *Mountain Geologist,* 6:227-245.

____. 1970b. Population systematics, radiometrics and zonation – a new biostratigraphy. *Proceedings of the North American Paleontological Convention,* Session 1 (1969, Lawrence, Kansas), part F:612-666.

_____. 1972. Evolutionary rates and patterns of North American Cretaceous Mollusca. *International Geological Congress,* Session 24 (Montréal, 1972), Report of Section 7: 174–189.

_____. 1973a. Stratigraphic evidence for Cretaceous eustatic changes. *Abstracts with programs, Geological Society of America,* 5:686–687. (Abstract.)

_____. 1973b. Extinction patterns in the Cretaceous. *Abstracts with programs, Geological Society of America,* 5:687. (Abstract.)

_____. 1977. Evolutionary rates and biostratigraphy. *In* E. G. Kauffman and J. E. Hazel (eds.), *Concepts and methods of biostratigraphy.* Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, Incorporated: 109–141.

_____. 1979. Cretaceous. *In* R. C. Moore, R. A. Robison, and C. Teichert (eds.), *Treatise on invertebrate paleontology* (Geological Society of America and the University of Kansas), Part A (Introduction). Boulder, Colorado, Geological Society of America, Incorporated: A418–A487.

Kennett, J. P. 1977. Cenozoic evolution of Antarctic glaciation, the Circum-Antarctic ocean, and their impact on global paleoceanography. *Journal of Geophysical Research,* 82(27):3843–3860.

Lamb, J. L., and J. H. Beard. 1972. Late Neogene planktonic foraminifers in the Caribbean, Gulf of Mexico, and Italian stratotypes. *Paleontological Contributions of the University of Kansas,* 57 (Protozoa 8): 67p.

Lineback, J. A., and J. T. Wickham. 1977. Correlation of the Quaternary stratigraphic record of Illinois with marine paleoclimatic programs. *Abstracts with programs, Geological Society of America,* 9:1071. (Abstract.)

Loeblich, A. R., Jr., and H. Tappan. 1957a. Planktonic foraminifera of Paleocene and Early Eocene age from the Gulf and Atlantic coastal plains. *Bulletin of the United States National Museum,* 215:173–198.

_____, and _____. 1975b. Correlation of the Gulf and Atlantic coastal plain Paleocene and Lower Eocene formations by means of planktonic foraminifera. *Journal of Paleontology,* 31(6):1109–1137.

Mabesoone, J. M., J. L. Rolim, and C. de Castro. 1977. Late Cretaceous and Cenozoic history of northeastern Brazil. *Geologie en Mijnbouw,* 56(2):129–139.

Manabe, S., and D. G. Hahn. 1977. Simulation of the tropical climate of an Ice Age. *Journal of Geophysical Research,* 82(27):3889-3911.

Margolis, S. V., P. M. Kroopnick, and D. E. Goodney. 1977. Cenozoic and Late Mesozoic paloceanographic and paleoglacial history recorded in Circum-Antarctic deep-sea sediments. *Marine Geology,* 25(1-3):131-147.

Martin, L. D., and D. K. Bennett. 1977. The burrows of the Miocene beaver *Palaeocastor,* western Nebraska, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 22: 173–193.

Matthai, H. F. 1979. Hydrologic and human aspects of the 1976-77 drought. *Professional Papers of the United States Geological Survey,* 1130:v, 84p.

McCormac, B. M., and T. A. Seliga. 1979. Solar-terrestrial influences on weather and climate. Dordrecht, Holland, D. Reidel Publishing Company: xiii, 346p.

Mellen, F. F. 1950. Status of Fearn Springs Formation. *Bulletin of the Mississippi State Geological Survey,* 69:20p.

Moxon, A. L., O. E. Olson, and W. V. Searight. 1939. Selenium in rocks, soils and plants. *Technical Bulletin of the South Dakota State College of Agriculture and Mechanic Arts,* 2:94p.

Murray, G. E., 1961. *Geology of the Atlantic and Gulf Coastal Plain of North America.* New York, Harper and Brothers: xviii, 692p.

Nagappa, Y. 1959. Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region. *Micropaleontology,* 5(2):145-192.

Ortlam, D. 1966. Fossile Böden und ihre Verwendung zur Gliederung des höheren Bundsandsteins im nördlichen Schwarzwald und südlichen Odenwald. *Jahresberichte und Mitteilungen des Oberrheinischen geologischen Vereines,* Neue Folge, 48-NF:69-78.

_____. 1971. Paleosols and their significance in stratigraphy and applied geology in the Permian and Triassic of southern Germany. *In* D. H. Yaalon (ed.), *Paleopedology: origin, nature and dating of paleosols.* Jerusalem, International Society of Soil Science and Israel Universities Press: 321-327.

Payton, C. E. (ed.). 1977. Seismic stratigraphy – applications to hydrocarbon exploration. *Memoirs of the American Association of Petroleum Geologists,* 26:v, 516p.

Petters, S. W. 1980. Maastrichtian-Paleocene cyclothems and paleoclimate in SE Iullemmeden Basin, west Africa. *Newsletters in stratigraphy*, 8(3):180-190.

Pitrat, C. W. 1970. Phytoplankton and the Late Paleozoic wave of extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 8(1):49-66.

Poag, C. W. 1969. The Pliocene-Pleistocene boundary in the Gulf Coast region. *Tulane Studies in Geology and Paleontology*, 7(1-2):72-74, 90.

______. 1971. A reevaluation of the Gulf Coast Pliocene-Pleistocene boundary. *Transactions of the Gulf Coast Association of Geological Societies*, 21:291-308.

______. 1972. Correlation of Early Quaternary events in the U.S. Gulf Coast. *Quaternary Research*, 2:447-469.

______, and P. C. Valentine. 1976. Biostratigraphy and ecostratigraphy of the Pleistocene Basin Texas-Louisiana continental shelf. *Transactions of the Gulf Coast Association of Geological Societies*, 26:185-256.

Pomerol, C. 1969. Progrès récents dans la connaissance des formations tertiaires du Bassin de Paris. *Bulletin de la Société géologique de France*, series 7, 10:5-12.

Rainwater, E. H. 1964. Transgressions and regressions in the Gulf Coast Tertiary. *Transactions of the Gulf Coast Association of Geological Societies*, 14:217-230.

Reed, E. C. 1954. Evidence of ancient soils in Cretaceous and Pre-Cambrian rocks. *Proceedings of the Nebraska Academy of Sciences*, Annual Meeting, 64:15. (Abstract.)

Roberts, W. O. 1973. Relationships between solar activity and climate change. *In* W. R. Bandeen and S. P. Maran (eds.), Possible relationships between solar activity and meteorological phenomena. *Special Publications, National Aeronautics and Space Administration (NASA)*, NASA SP-366:13-24.

______. 1979. Variations in the sun and their effects on weather and climate. *Proceedings of the American Philosophical Society*, 123(3):151-159.

Rosenberg, N. J. (ed.). 1978. North American droughts. (American Association for the Advancement of Science, Selected Symposia Series, vol. 15.) Boulder, Colorado, Westview Press: xx, 177p.

Russell, D. A. 1979a. The enigma of the extinction of the dinosaurs. *Annual Review of Earth and Planetary Sciences*, 7:163-182.

______. 1979b. The Cretaceous-Tertiary boundary problem. *Episodes, Geological Newsletter, International Union of Geological Sciences (IUGS)*, 1979(4):21-24.

Rutford, R. H. 1978. The evidence for climatic change from Antarctica? *Transactions of the Nebraska Academy of Sciences*, 6:55-56.

______, C. Craddock, and T. W. Bastien. 1968. Late Tertiary glaciation and sea-level changes in Antarctica. *In* W. F. Tanner (ed.), Tertiary sea-level fluctuations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 5(1):15-39.

Schiebout, J. A. 1979. An overview of the terrestrial Early Tertiary of southern North America—fossil sites and paleopedology. *Tulane Studies in Geology and Paleontology*, 15(1-4):75-93.

Schultz, C. B. 1942. A review of the Daimonelix problem. *University of Nebraska, Studies in Science and Technology*, 2.

______, and C. H. Falkenbach. 1968. The phylogeny of the oreodonts. Parts 1-2. *Bulletin of the American Museum of Natural History*, 139:498p.

______, ______, and C. F. Vondra. 1967. The Brule-Gering (Oligocene-Miocene) contact in the Wildcat Ridge Area of western Nebraska. *Bulletin of the University of Nebraska State Museum*, 6(4):iv, 43-58.

______, and J. M. Hillerud. 1977a. Climatic changes and large mammal populations in the Great Plains of North America during Late Quaternary times. *In Quaternary Glaciations in the Northern Hemisphere*, International Geological Correlation Programme (IGCP), Report 4 (Stuttgart-Prague), Project 73/1/24:218-233.

______, and ______. 1977b. The antiquity of *Bison latifrons* in the Great Plains of North America. *Transactions of the Nebraska Academy of Sciences*, 4:103-116.

______, and ______. 1978. Climatic change and the extinction of large mammals during the Quaternary. *Transactions of the Nebraska Academy of Sciences*, 6:95-105.

______, G. C. Lueninghoener, and W. D. Frankforter. 1951. A graphic résumé of the Pleistocene of Nebraska (with notes on the fossil mammalian remains). *Bulletin of the University of Nebraska State Museum*, 3:1-41.

_____, and T. M. Stout. 1945. The Pleistocene loess deposits of Nebraska. *American Journal of Science*, 243:231-244, 270.

_____, and _____. 1948. Pleistocene mammals and terraces in the Great Plains. *Bulletin of the Geological Society of America*, 59:553-588, 623-625.

_____, and _____. 1955. Classification of Oligocene sediments of Nebraska. *Bulletin of the University of Nebraska State Museum*, 4:17-52.

_____, and _____. 1977. Drought and the model of a Quaternary terrace-cycle. *Transactions of the Nebraska Academy of Sciences*, 4:191-201.

_____, L. G. Tanner, and C. Harvey. 1955. Paleosols of the Oligocene of Nebraska. *Bulletin of the University of Nebraska State Museum*, 4:1-16.

Schultz, G. E. (ed.). 1977. Guidebook, Field Conference on Late Cenozoic biostratigraphy of the Texas Panhandle and adjacent Oklahoma, August 4-6, 1977. *West Texas State University (Kilgore Research Center), Special Publication*, 1:160p.

Shackleton, N. J., and N. D. Opdyke. 1977. Oxygen isotope and palaeomagnetic evidence for early Northern Hemisphere glaciation. *Nature*, 270(5634):216-219.

Skinner, M. F., S. M. Skinner, and R. J. Gooris. 1977. Stratigraphy and biostratigraphy of Late Cenozoic deposits in central Sioux County, western Nebraska. *Bulletin of the American Museum of Natural History*, 158:263-370.

Stamp, L. D., 1921. On cycles of sedimentation in the Eocene strata of the Anglo-Franco-Belgian Basin. *Geological Magazine*, 58:108-114, 146-157, 194-200.

Stout, T. M. 1971. Quaternary classification and sedimentary model. *In* M. Ters (ed.), *Études sur le Quaternaire dans le Monde, Conference of the International Association (Union) for Quaternary Research (INQUA)*, Session 8 (Paris, 1969, vol. 2):790. (Abstract.)

_____. 1973. Revised classification of the Quaternary and Medial to Late Tertiary, based upon the standard for the Great Plains (U.S.A.) and intercontinental correlations. *Conference of the International Association (Union) for Quaternary Research (INQUA)*, Session 9 (Christchurch, 1973): 347-348. (Abstract.)

_____. 1977. Frontiers of Nebraska geology. *Transactions of the Nebraska Academy of Sciences*, 4:117-120.

_____. 1978. The comparative method in stratigraphy: the beginning and end of an Ice Age. *Transactions of the Nebraska Academy of Sciences*, 6:1-18.

_____, H. M. DeGraw, L. G. Tanner, K. O. Stanley, W. J. Wayne, and J. B. Swinehart, II. 1971. Guidebook to the Late Pliocene and Early Pleistocene of Nebraska. *Guidebook of the University of Nebraska Conservation and Survey Division (Nebraska Geological Survey)*: 109p.

_____, V. H. Dreeszen, and W. W. Caldwell. 1965. Central Great Plains, Field Conference "D" (August 14-28, September 8-18). *In* C. B. Schultz and H. T. U. Smith (eds.), *Guidebooks for Field Conferences, International Association (Union) for Quaternary Research (INQUA)*, Session 7 (Boulder): 124p. (Published by the Nebraska Academy of Sciences.)

_____, and C. B. Schultz. 1971. Mapping ancient valley-fills in Nebraska, in relation to Tertiary and Quaternary classification. *Abstracts with programs, Geological Society of America*, 3(4):282. (Abstract.)

Tanner, W. F. (ed.). 1968. Tertiary sea-level fluctuations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 5(1): 171p.

Thorp, J., and E. C. Reed. 1949. Is there laterite in rocks of the Dakota Group? *Science*, 109(2821):69.

Tychsen, P. C. 1954. A sedimentation study of the Brule Formation in northwestern Nebraska. Unpublished doctoral dissertation. Lincoln, Nebraska, University of Nebraska: 189p.

Vail, P. R., R. M. Mitchum, Jr., R. G. Todd, J. M. Widmier, S. Thompson, III, J. B. Sangree, J. N. Bubb, and W. G. Hatlelid. 1977. Seismic stratigraphy and global changes of sea level. *In* C. E. Payton (ed.), *Seismic stratigraphy—applications to hydrocarbon exploration. Memoirs of the American Association of Petroleum Geologists*, 26:49-212.

Vella, Paul. 1965. Sedimentary cycles, correlation and stratigraphic classification. *Transactions of the Royal Society of New Zealand*, 3:1-9.

_____. 1967. Eocene and Oligocene sedimentary cycles in New Zealand. *New Zealand Journal of Geology and Geophysics*, 10:119-145.

Vondra, C. F., C. B. Schultz, and T. M. Stout. 1969. New members of the Gering Formation in western Nebraska, including a geological map of Wildcat Ridge and related outliers. *Papers of the Nebraska Geological Survey,* 18: 1-18.

Walker, J. R. 1978. Geomorphic evolution of the Southern High Plains. *Bulletin of the Baylor Geological Society,* 35:ii, 32p.

Wiese, R. A., and D. D. Axthelm (eds.). 1973. *Nitrogen in Nebraska's environment: conference proceedings.* Lincoln, Nebraska, University of Nebraska, Institute of Agriculture and Natural Resources: 197p.

Worsley, T. 1974. The Cretaceous-Tertiary boundary event in the ocean. *In* W. W. Hay (ed.), *Studies in paleo-oceanography. Special Publication of the Society of Economic Paleontologists and Mineralogists,* 20:94-125.

Yaalon, D. H. (ed.). 1971. *Paleopedology: origin, nature and dating of paleosols.* Jerusalem, International Society of Soil Science and Israel Universities Press: 350p.