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PROVINCIAL LAND MAMMAL AGES CORRELATED WITH VALLEY-FILL SEQUENCES IN THE GREAT PLAINS OF NORTH AMERICA*

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The Quaternary Provincial Land Mammal Ages (Blancan, Irvingtonian, Rancholabrean, and Recent) are here correlated with the fossiliferous valley-fill sequences in the Great Plains of North America, based on faunal, stratigraphic, and geomorphologic evidence.

The fossil mammals from the valley-fills (Broadwater) of the highest terrace (Terrace-5, T-5) are of Blancan age, long known to be equivalent to the Villafranchian of Europe and Asia. The earliest Blancan faunas, chiefly from the middle part of the Broadwater, are equal to the Late Rexroadian of Kansas, whereas the later ones, from the upper or Red Cloud portion of the Broadwater, equate with the Senecan of central Nebraska.

The mammals from the next-younger terrace (T-4), which come from the lower and middle parts (provisionally Sappan) as well as from the upper part (designated Sheridanian, although this term could be applied to the whole), correlate with the Irvingtonian.

The uppermost parts of both the T-5 and T-4, equal to Sangamon ("Last Interglacial") and Wisconsin ("Last Glacial"), together with the T-3 and T-2B sediments, yield fossil mammals that correlate with the Rancholabrean. The Rancholabrean seems to have required not more than 120,000 yr contrasted with perhaps 2 m.y. necessary for the Irvingtonian. The very youngest valley-fills (of T-2A, T-1, and T-0) are Recent or Holocene, representing only the last 10,500 to 12,500 yr ago.

A major unconformity and faunal break separate these Quaternary valley-fills from the Latest Tertiary Kimball Formation of the Ogallala Group, dividing the Blancan from the Kimballian. It seems clear that the "Great Ice Age" may be considered to have begun perhaps 3.2 m.y. ago, and that the Pliocene/Quaternary boundary probably should be drawn between the Kimball and Broadwater. This boundary corresponds very closely to the Pliocene/Quaternary break identified in deep sea cores and elsewhere in the world by many workers.

† † †

INTRODUCTION

During the last half-century much has been learned concerning the Cenozoic stratigraphy, geomorphology, and paleontology of the Central Great Plains of the United States, especially the importance of such unconformities and faunal breaks as that at the Pliocene/Quaternary boundary. However, all available evidence is often not considered when vertebrate faunas near such boundaries are "dated." Frequently, there is dependence on one line of evidence, such as the radiometric dating of volcanic ash (tephra), even though a particular ash bed may not be directly associated with the fossil assemblage under consideration. Attempts have been made also to correlate the valley-fills containing these fossils with glacial tills (continental and mountain), but the till stratigraphy still is not fully understood and some false assumptions have been made concerning the geological ages and relations of such tills. As a result, the true geologic sequence of the fossil vertebrates (chiefly mammals) may be distorted, and even the faunal breaks may not be always recognized as related to unconformities.

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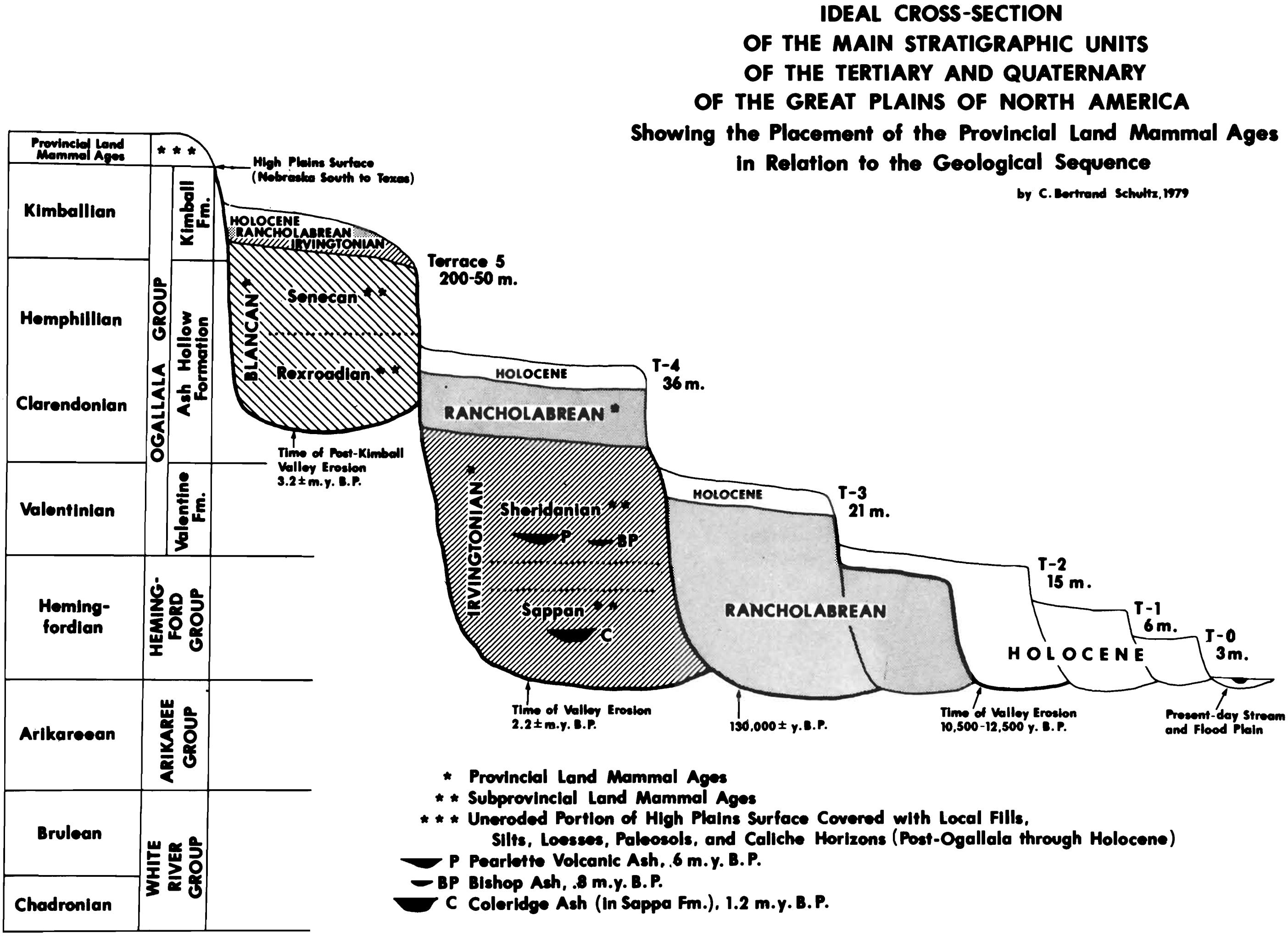

FIGURE 1. Diagrammatic or ideal cross-section of the main stratigraphic units of the Tertiary and Quaternary of the Great Plains of North America, showing the placement of the Provincial Land Mammal Ages in relation to the geological sequence. [Subdivisions of Quaternary Provincial Land Mammal Ages *from* Schultz, Martin, Tanner, and Corner (1977 and 1978); Figure *from* Schultz (1979 and 1981).]

The placement of the Pliocene/Quaternary boundary (or the Pliocene/Pleistocene boundary) has long been a major problem (Schultz and Stout, 1948 and 1980; Stout 1978), not only in North America but in other parts of the world, including the type localities in Italy. Although it is evident that additional field work is necessary to resolve some of the problems, regional working groups representing different disciplines should join in re-examining and perhaps re-interpreting the field and faunal relations in order to reach provisional consensus. This paper is concerned with the correlation of the remarkable fossil mammal assemblages found chiefly in valley-fills in the Central Great Plains, in order to emphasize certain significant faunal and stratigraphic breaks in the sequence.

THE LATE TERTIARY KIMBALL FORMATION

A nearly complete succession of fossil mammals from Early Oligocene (Chadronian) through Pliocene (Kimballian), as well as from the Quaternary, allows unusual stratigraphic documentation for the Provincial Land Mammal Ages in the Central Great Plains (Figs. 1 and 2), probably the best record in North America. By the end of the Tertiary, the dominantly fluviatile sediments yielding these mammals had attained a

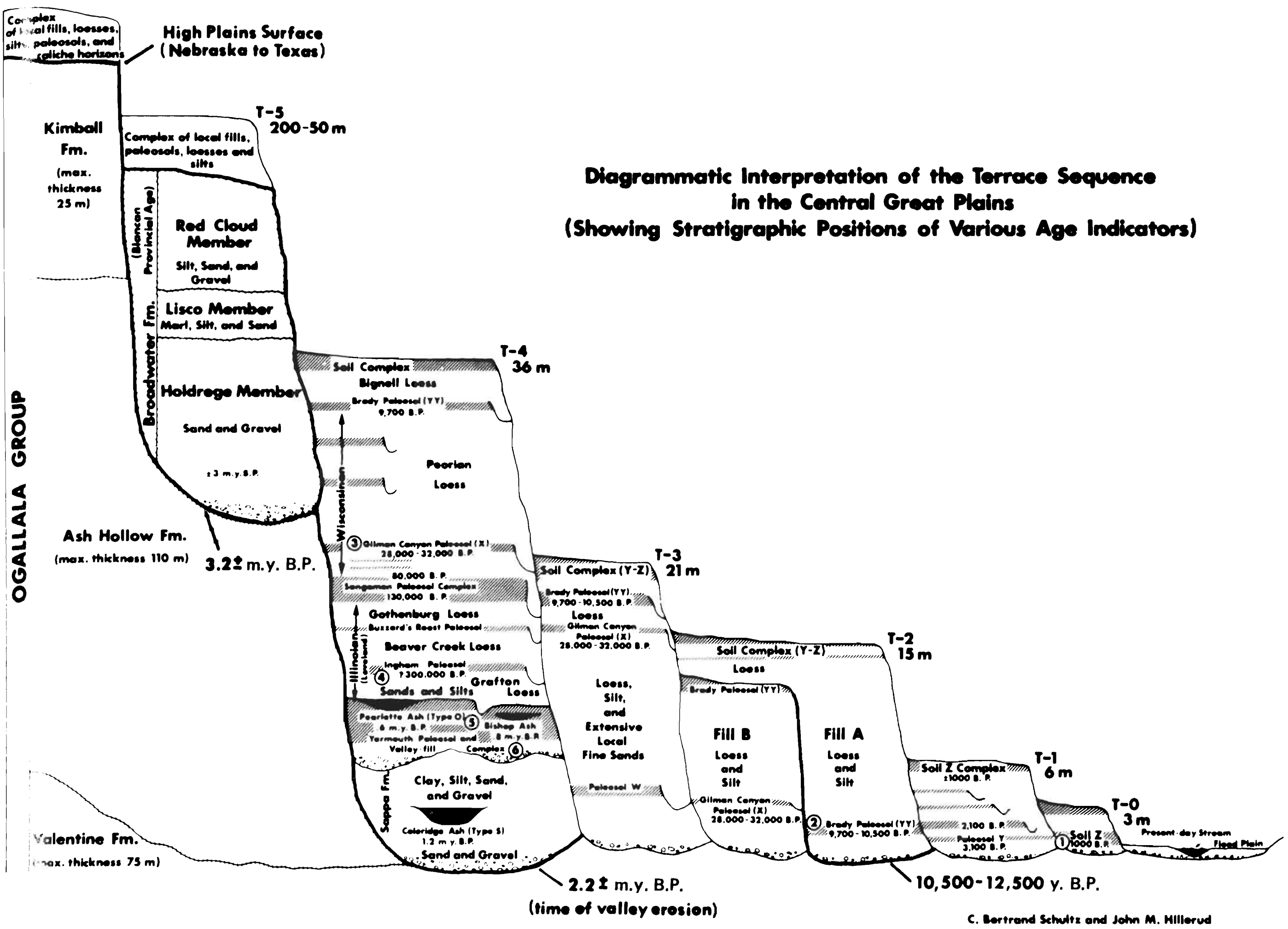

FIGURE 2. Diagrammatic interpretation of the terrace sequence in the Central Great Plains (showing stratigraphic positions of various age indicators). (*From* Schultz and Hillerud, 1978.)

maximum thickness of about 758 m (2,500 ft) and filled basinal areas developed on the eroded Cretaceous to a nearly level aggradational plain. This High Plains Surface, into which the Quaternary cut-and-fill deposits are incised, has remained largely intact from Nebraska to Texas, and the Late Tertiary Kimball Formation (Lugn, 1939; Schultz and Stout, 1948 and 1980) immediately underlies it over much of the Central Great Plains.

The vertebrates found in the Kimball Formation (uppermost portion of the Ogallala Group) are chiefly from the lower-to-middle portions of the formation (Schultz and Stout, 1948). Their rarity in the upper part of the Kimball may be due in part to conditions unfavorable for preservation of bones and teeth associated with the development of the "End-Ogallala Soil-Complex" (Schultz and Stout, 1977 and 1980).[1]

[1]A similar situation occurs with respect to an Oligocene paleosol known as the "Green Ledge" or "Bench Paleosol" in northwestern Nebraska (Schultz, Tanner, and Harvey, 1953 and 1955; Schultz and Stout, 1955 and 1980; Harvey, 1960). This is a persistent, unfossiliferous marker-bed that is about 7.6 m (25 ft) thick in the Toadstool Park area of northwestern Nebraska, but extends into adjacent states. A non-depositional hiatus at this horizon was suspected in the 1940s, rather early in the research on several lineages (subfamilies) of sheeplike fossil mammals known as oreodonts (Schultz and Falkenbach, 1968), and field exploration by University of Nebraska State Museum interdisciplinary groups resulted in the discovery of the paleosol-complex.

An excellent summary of the calichification associated with the development of the High Plains Surface, especially in the Southern High Plains (G. E. Schultz, 1977; Frye, Leonard, and Glass, 1978; Walker, 1978), occurs in a review of Ogallala stratigraphy by John C. Frye:

> The Kimball zone is characterized by silts and sands, strongly developed caliche at the top, and sparse and highly localized channel gravels. Throughout the region it contains more calcium carbonate cementation than the other zones and is less permeable and less fossiliferous. The Kimball represents the final, and nearly complete coalescence of the "plain of alluviation" that concluded the deposition of the Ogallala Formation. As the climate had become hotter and drier and the rate of deposition was greatly reduced, processes of soil formation gained ascendency over processes of deposition. There is less north-to-south contrast in the Kimball than in the other zones. It is well indurated, gray where predominantly caliche, and tan to purple where the color is not masked by the accumulation of carbonates.
>
> The Ogallala-climax Soil caps the Ogallala Formation. The strongly developed caliche of this soil has been called "cap rock," "algal limestone," "pisolitic limestone," and "caliche." Regardless of its name, it is a most unusual rock. The fact that this carbonate layer originated as a soil caliche seems to be established beyond debate but its present form and character are attributable to a long and complex series of desiccations, brecciations, recementations, and additions during the Pleistocene, following the early removal of the A-horizon and Upper B-horizon of the original soil. Furthermore, at some places veneers of sheet-wash and of eolian sediment covered this soil during the Pleistocene, and these relatively thin veneers locally contain one or more of the caliches of the Afton, Yarmouth, Sangamon, and other Pleistocene soils. As a result, what is now loosely called Cap Rock may be a composite of "Ogallala-Climax" soil and the effects of much of Pleistocene time. However, it is not our purpose here to discuss the modifying effects of a complex and violently fluctuating Pleistocene history (Frye, J. C. 1970. Unpublished manuscript for Ogallala Aquifer Symposium, Lubbock, Texas, Texas Technological College, Geosciences Department: 12–13).

The unconformity between the Kimball (highest Ogallala) and oldest Quaternary (Broadwater Formation, valley-fill of Terrace-5, T-5) in the Central Great Plains coincides with major extinction of the fossil mammals (Schultz and Stout, 1945, 1948 and 1980; Stout, 1978). It likewise marks the introduction of new migrant mammals from Eurasia and thus differentiates the Kimballian and Blancan (Villafranchian) Land Mammal Ages. That it coincides also with the beginning of the "Great Ice Age" was suggested many years ago by Schultz and Stout (1948) and more recently by Stout (1978) and Schultz and Stout (1980). It has been suggested further that this "first cooling" of the Quaternary may have begun much earlier than usually thought:

> But attention needs to be given also to the climatic data on the lands. In Iceland, for example (Gladenkov, 1978; Epshteyn, 1978; McDougall and Wensink, 1966), the warm water, Coralline-Crag equivalent is overlain by the colder Red-Crag equivalent that is associated with what may be considered as the first glaciation of the Quaternary. This correlates, in my opinion, with the Reuver-Pretiglian break in the Netherlands (see Zagwijn, 1974, for background) and with the unconformity below the Early Villafranchian site of Perrier-Étouaires (Bout, 1970, 1960; Brun, 1974; Goër de Hervé, 1974) in central France that has been dated as before 3.3 million years. This is approximately the time of the First Patagonian Glaciation (Mercer, 1976) and about the time of initiation (3.2 million years) of early Northern Hemisphere glaciation according to Shackleton and Opdyke (1977), from oxygen isotope and paleomagnetic evidence (Stout, 1978: 6–10).

Other recent literature emphasizes the significance of this "first cooling" of the "Great Ice Age" as having occurred at perhaps 3.2–3.3 m.y. ago rather than arbitrarily at about 1.9 m.y. ago as preferred by other workers:

1. The Icelandic data indeed seem to be critical. Gladenkov (1981:20, Table 1) related the boundary there between equivalents of the Coralline and Red Crags at 3.0–3.5 m.y., whereas earlier McDougall and Wensink (1966:232) had dated a basalt underlying a tillite at 3.10 ± 0.10 m.y., "which suggests that regional glaciation commenced in Iceland at about this time," and that "the base of the Pleistocene may be as old as 3 m.y." It may be recalled in this connection that the well-known resolution of the 1948 International Geological Congress in London suggested that the Pliocene/Pleistocene boundary should be drawn in part between the Coralline and Red Crags in Britain.

2. The oxygen isotope and palaeomagnetic analysis of an Equatorial Pacific piston core by Shackleton and Opdyke (1977) also "shows that glacial–interglacial fluctuations have characterised Earth's climate for the past 3.3 Myr, before which there was a period of stable 'interglacial' or 'preglacial' climate." This is essentially in agreement with the conclusion of Mercer (1976:130) that "the first known glaciation in

southern South America occurred about 3.5 MY ago, towards the end of the Gilbert reversed magnetic-polarity epoch, . . ."

3. The "Pliocene/Nebraskan boundary" was placed by Beard (1969) at 2.8 m.y. in his time scale of geomagnetic reversals, but he showed the trend beginning at about 3.? m.y. Somewhat later, Stainforth, Lamb, Luterbacher, Beard and Jeffords (1975) noted that "the Nebraskan glacial interval, which began with the onset of climatic deterioration about 2.8 to 3.0 million years ago and continued for some 800,000 years, is preceded in the late Neogene by a long interval lacking recognizable cold periods. . . ." A similar result was obtained by Kerr (1980), also reporting on Exxon research in part in the Gulf of Mexico wells, with the Pliocene/Pleistocene boundary placed at 2.8 m.y., although his chart showed a pronounced drop in sea level starting at 3.8 m.y.

4. An Exxon offshore Louisiana well produced from a depth of about 1,524 m (5,000 ft) volcanic ash dated by the fission-track method at 3.10 ± 0.43 m.y. (Beard, Boellstorff, Menconi, and Stude, 1976). The ash occurs about 305 m (1,000 ft) below the base of a prominent marine shale, the Upper Marine Shale, and the Pliocene/Pleistocene boundary has been variously placed above the base, near the base, or below the base of this important, regionally transgressive, shale in the Gulf of Mexico subsurface.

5. An ash has been reported by Boellstorff (1978a) also to occur between tills in a boring in the classical "type Aftonian" area near Afton, Iowa, which he dated at 2.2 x 10^6 yr by the fission-track method. This seems to be very important evidence likewise as to the time of the onset of continental glaciation because this locality is very far south and toward the terminus of the great Early Quaternary ice masses of North America. Boellstorff (1978a) stated from this that "the Pliocene/Pleistocene boundary has tentatively been dated about 2.5 ± 0.1 x 10^6 years" and that "glacial deposits in the central United States older than about 2.2 x 10^6 years may span that boundary." (Also *see* Boellstorff, 1978b).

6. However, less-acceptable dates from volcanic ashes (glass) by the fission-track method are reported by Boellstorff (1978a:46, Fig. 6) from ash samples in the Kimball and Ash Hollow formations of western Nebraska where stratigraphic relations are clear (Schultz and Stout, 1948 and 1980; Stout, DeGraw, Tanner, Stanley, Wayne, and Swinehart, 1971). He obtained very much *older* dates from samples stratigraphically *higher*, so it is evident from this apparent reversal that either the method has been misapplied or the stratigraphic relations have been misinterpreted, and that restudy of both is necessary. Also it is possible that calichification may have had some effect upon fission-track dating.

THE LATE TERTIARY KIMBALLIAN FAUNA AND FLORA

Kimballian mammals are generally similar to those found in the Ash Hollow and Valentine formations, but most are larger or show other anatomical modifications as the various mammalian lineages are traced by documented samples through the Ogallala Group (Pliocene). It is unfortunate that radiometric dating rather than stratigraphy has been the basis for a recent discussion (Marshall, Butler, Drake, Curtis, and Tedford, 1979) of the time or times of the "Great American Interchange" of terrestrial mammals between the Americas during the Late Tertiary and Quaternary. Several well-known Kimballian assemblages (Oshkosh, Dalton) from the Great Plains were wrongly placed in a chart because of uncritical acceptance of certain fission-track dates (Boellstorff, 1978a, Fig. 6).

The first appearance of South American mammals (ground sloth) in Nebraska is in about the middle-to-upper portion of the Ash Hollow Formation (Medial Pliocene), by contrast with the first appearance of long-jawed mastodonts at the base of the Valentine Formation (Early Pliocene) that documents an Early Pliocene migration from Eurasia. When considered stratigraphically, rather than by radiometric dates, intercontinental correlations do have significance.

More than a half-century of investigation has supplied this documentation for the occurrence of the fossil mammals within the Ogallala Group in the Central Great Plains,[2] and now much is known also with respect to the flora[3] and invertebrates. Additionally, some important observations were made by even earlier geologists such as Hayden, Meek, Darton, and Barbour. It is hard to appreciate now how different were the outcrops during the drought years of the mid-1930s, when some of the most significant discoveries of the fossil mammals of the Kimball and Ash Hollow were made!

For example, the difficult excavations from 1934 through 1936 at Guymon (Optima), Oklahoma, by Charles H. Falkenbach and John C. Blick for the Frick Collection at the American Museum of Natural History, probably would not be undertaken again there on such a scale. Neither would the

[2]New evidence concerning the Kimball mammals has been reported recently by Stout (1978) and by Schultz and Stout (1980), but *see also* Kent (1963 and 1967); Stout, Dreeszen, and Caldwell (1965); Tanner (1967 and 1975); Schultz, Schultz, and Martin (1970); Martin and Schultz (1975); Schultz and Martin (1975a and b); and Schultz, Martin, and Corner (1975).

[3]The Kimballian flora was reported by Lugn (1939) and Elias (1942), then revised by Frye, Leonard, and Swineford (1956) and Thomasson (1979).

extensive excavations at most quarry sites in Nebraska, and foot-exploration over many years in Nebraska and adjacent states, now be repeated, for many of the outcrops have been covered or disturbed or are not now available.

One of the most productive fossil-bearing quarries in the Kimball Formation, and indeed one of the most remarkable sites in North America, is situated near Cambridge, in Frontier County, Nebraska. This site ("Ft-40" of the University of Nebraska State Museum) yielded the splendid type specimens of a long-jawed mastodont (*Amebelodon fricki*) and saber-toothed cat (*Barbourofelis fricki*), as well as abundant materials of beaver (especially the important guide-fossil *Dipoides*), rhinoceroses (*Teleoceras, Aphelops*), and other mammals, and it has been worked at intervals since 1927. Although it is in an area disturbed by reservoir construction and use as a borrow pit, the stratigraphic relations of the Kimball to the underlying and fossiliferous Ash Hollow Formation are well known. Also its equivalents in western Nebraska (such as at Oshkosh, Greenwood Canyon, Dalton, and Sidney) have been established, as well as correlation with northeastern Nebraska (the preglacial Airstrip Site), Oklahoma (Guymon), Oregon (Rome), and even western Europe (Montpellier, Teruel). Thus, to correlate only by radiometric dates is to deny that geologic and paleontologic documentation has any value in biostratigraphy.

THE QUATERNARY VALLEY-FILLS AND MAMMALS

The Central Great Plains area of North America, bounded on the west by the Rocky Mountains and extending eastward some 800 km (500 mi) to the region which was formerly covered by continental glaciers, has a splendid record of terraces and terrace-fills (Schultz and Stout, 1948 and 1980; Schultz, Lueninghoener, and Frankforter, 1951; Stout, Dreeszen, and Caldwell, 1965). The terraces and associated fills appear to have been climatically controlled during their formation, and are regional in extent. Fortunately, the terrace-fills have produced an abundance of vertebrate fossils in many areas. Eventually the terraces and terrace-fills will be more precisely correlated with the glacial tills, both continental and mountain.

There are six well-developed terraces (T-5, T-4, T-3, T-2, T-1, and T-0), and most of them can be traced along the major streams and their tributaries in the Plains region. The faunas representing the various Provincial Land Mammal Ages can be recognized in the terrace-fills (Fig. 1). The first major erosion at the end of the Tertiary took place some 3.2 to 3.4 m.y. ago, at the time of the first major cooling, when the Kimball Formation (the top of the Ogallala Group) was incised by streams coming chiefly from the Rocky Mountains or from the Northern Plains. Lugn and Schultz (1934) made the first attempt in North America to work out a sequence of the Quaternary mammals based on stratigraphic evidence. However, sufficient geomorphologic data were not available at that time to provide precise documentation for all of the fossils involved.

The oldest Quaternary valley-fill in the Central Great Plains is the Broadwater Formation (T-5). Its stratigraphic position next younger than the Kimball Formation (highest Ogallala) is very clear (Figs. 1 and 2), from which it is separated by a major, regional unconformity. The fossil mammals of the Broadwater are of Blancan (=Villafranchian) age and very different from those of the Kimballian. For instance, the long-jawed mastodonts and rhinoceroses were among those mammals that became extinct in North America with the Kimballian, to be replaced among others by short-jawed mastodonts (*Stegomastodon*) and horses of more modern aspect, the *Equus* (*Plesippus*).

The next-younger valley-fill may be more complex than previously thought (Figs. 1 and 2): it is the T-4 fill, well known throughout the Great Plains, and equivalent to the Irvingtonian. Mammoths and giant-bison, together with the much larger horse (*Equus*), easily differentiate these sediments paleontologically from those of the Broadwater.

The Sangamon Soil-Complex (Figs. 1 and 2) occurs in the middle-to-upper parts of both the T-5 and T-4, overlain by the Peorian and younger loess-cappings that are equivalent to the youngest valley-fills. The Sangamon and post-Sangamon (T-3, T-2B, T-2A, T-1, and T-0) sediments also yield different mammals, those of the T-3 and T-2B being of Rancholabrean age, and those from the youngest fills being of Holocene or Recent age. The extinction of so many of the Quaternary (Pleistocene) mammals occurred between the fills of T-2B and T-2A, thus clearly differentiating the Rancholabrean from the Recent faunas. This extinction seems to have taken place about 10,500–12,500 yr Before Present, but small herds of some species may have persisted for the next 2,000–3,000 yr (Schultz and Hillerud, 1978).

The data now available suggest that the two oldest Quaternary valley-fills (T-5 and T-4) represent the most of Quaternary time, and that the unconformity at the base of the T-4 fill may be dated at approximately 2.2 m.y.B.P. (Figs. 1 and 2).

CONCLUSIONS

The stratigraphic record of the Medial to Late Tertiary and Quaternary in the Central Great Plains allows precise documentation for the succession of the mammalian faunas. This midcontinent record, however, must be correlated with continental and marine sections elsewhere in the world, including the type localities in Italy, when Pliocene and Pleistocene dates are concerned.

Traditionally the Pleistocene (or Quaternary) has been considered synonymous with the "Great Ice Age" or "Glacial Age." If the 2± m.y. date were to be used as the approximate break between the Pliocene and Pleistocene (or between the Neogene and Quaternary), then perhaps we should introduce a new name for the "Great Ice Age" and call it the "Late Cenozoic Ice Age" or the "Glaciocene," which would encompass both the Pliocene and Pleistocene; however, this does not appear to be plausible. Certainly the first cooling and beginning of the "Great Ice Age" commenced some 3.2± m.y. ago and not 2± m.y.

The complexity of the geomorphology and stratigraphy of the Late Tertiary and Quaternary sediments certainly encourages the use of Provincial Land Mammal Age terms when the precise stratigraphic proveniences of the fossil mammal remains are uncertain.

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