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CLIMATIC CHANGE AND THE EXTINCTION OF LARGE MAMMALS DURING THE QUATERNARY

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There is an abundance of soils and paleosols as well as terraces and terrace fills and erosional forms of pediments to aid in working out a precise stratigraphic sequence for the Quaternary animals. The dating and correlation of Quaternary deposits are complex, and we must realize that there were numerous glacial advances and retreats. A continuing reexamination of the relationship of the mammalian faunas to the paleosols, terrace fills, volcanic ashes, and other geologic features must be done in order to provide a proper framework for the interpretation of the mammalian stratigraphic sequences.

The horses and camels, which had so successfully lived in the Great Plains Region for some 40,000,000 years, had some very aggressive competitors during the latter part of the Quaternary when the giant bison, mammoths, and other large mammals arrived from Asia prior to the Illinoian Glaciation. These migrant forms consumed great quantities of grass and herbs, which hitherto had supported the native horses and camels. Fossil evidence indicates that the vast herds of camels and horses began to diminish as the intruders increased in numbers.

The inhospitable climates of the Illinoian and Wisconsinan glaciations contributed greatly to the reduçtion in numbers of the grazing animals. As much as 56 meters of loess was deposited on the Yarmouth Interglacial sediments and elsewhere in some localities in the Central Great Plains. The diminution in size and their ability to adjust to environmental changes undoubtedly contributed to the success of the bison to survive the rigorous climates.

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INTRODUCTION

There have been many suggestions and theories regarding the migrations and the causes of extinction of many of the large Late Quaternary mammals. The approximate times of migration of certain Quaternary mammals to North America from Asia, via the Bering "land bridge," have not been agreed upon by various workers. As the result of this, many conflicting statements exist in the literature. Often the stratigraphic evidence used to solve these problems has been based on postulation and much of the available geological evidence has not been considered. (See Schultz and Hillerud, 1976, 1977a, 1977b, for some of the evidence.)

We are fortunate to have so much geological data relating to Quaternary deposits for us to use in developing faunal sequences. The correct identification of the numerous till and intertill deposits is of utmost importance. However, John Frye (1969) has reminded us that workers studying Quaternary stratigraphy "also have available for our use a group of criteria generally not available or usable for older strata. Three of these criteria are—soils, both as they occur at the surface and buried in a sequence of sediments; the constructional forms of alluvial terraces; and the erosional forms of pediments." The dating and correlation of the Quaternary deposits are complex, and we must realize that there were many glacial advances and retreats. Even some of the re-advances and retreats of the glaciers and the resulting interstadials were major events, and some local faunas are actually related to them and not to some interglacial period. A continuing reexamination of the relationship of the mammalian faunas to the paleosols, the terrace fills, the volcanic ashes, and other geologic features must be done in order to provide a proper framework for the interpretation of a mammalian sequence. The absence of a species at one fossil locality also does not mean that it did not exist contemporaneously elsewhere.

The end of the Kimballian Provincial Land Mammal Age represented "the final, and nearly complete coalescence of the 'plain of aluviation' 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" (Frye, 1970). James L. Lamb (personal communication, Feb. 1978) suggested that a dry tropical climate prevailed as far north as Nebraska during the Middle and Late Kimballian (Uppermost Ogallala) time. These widespread climatic conditions undoubtedly resulted in the extinction of many of the large mammals, including the longirostrine mastodont, *Amebelodon*; the horses, *Calippus, Hipparion, Neohipparion, Protohippus,* and *Pliohippus*; the rhinoceroses, *Aphelops* and *Teleoceras*; the horned ruminants, *Cranioceras, Texoceros,* and *Sphenophalos*; and the giant closed-orbit sabre-toothed cat, *Barbourofelis.* The catastrophic climate at the end of Tertiary or Late Kimballian times undoubtedly accounts for the almost total absence of vertebrate remains in the Great Plains in the Upper Ogallala (Kimball Formation) deposits. There appears to be some three to four million years unaccounted for, as far as the stratigraphic record of the vertebrates are concerned. Most of the known Kimballian fossils are from the lower part of the Kimball Formation, but are definitely higher than Ash Hollow Formation (which is of post-Hemphillian age). Since there has been much controversy concerning the relationship of the Hemphillian and the Kimballian, perhaps "Kimballian" (the period of extinction) should be considered a subset of the Hemphillian. Climatic conditions for the preservation of fossils certainly were not favorable, and perhaps some of the gaps in this time period will be filled when fossils are found in other regions.

The first cooling of the oceans as well as the land apparently took place some 3.2 to 3.4 million years ago (Bout, 1970; Mercer 1976; Shackleton and Opdyke, 1977; Stainforth, et al., 1975; Van Hinte, 1975; Zagwijn, 1974). Thus the Blancan and Villafranchian are part of the "Ice Age," even though the fossils of this age are frequently considered to be Pliocene (pre-Quaternary or pre-Pleistocene). Frequently the Neogene-Quaternary boundary is placed at 1.9 to 2.2 m.y. B.P. (Berggren, 1972; INQUA Subcommission on Pliocene-Pleistocene Boundary Symposium, Tbilisi, Georgian S.S.R., 1972 Berggren and Van Couvering, 1974; Van Couvering, 1978; also see Fig. 1, this chapter, for tentative positions of both the 3.4 ± m.y. and the 2.2 ± m.y. B.P. boundaries). The radiometric datings of the volcanic ashes in the Great Plains by Izett, et al. (1970, 1971, 1972) and by Boellstorff (1973, 1976) have been very helpful in the comparison of major geologic events in other parts of the world. The great period of erosion, following the final deposition of the Kimball Formation apparently took place some 3.2 to 3.4 million years ago. The major period of erosion of the deposits containing Blancan fossils seems to date about 2.2 million years ago. The erosion at the end of the Pleistocene, prior to the deposition of the Holocene deposits, appears to date back to some 10,500 to 12,500 years ago. All three erosional breaks correspond closely to the major times of extinction (Fig. 1). However the main times of extinctions apparently took place prior to the erosional periods, but in each case a few forms may have lingered on in isolated localities for a short time before final extinction took place.

TERRACE FILLS

A chart (Fig. 1) shows graphically the general relationship of the various prominent paleosols which are found in (or capping) the terrace fills. The actual geologic history of the terrace fills is much more complex than is shown in the chart. The distribution of major loess deposits and volcanic ashes is indicated. Terrace-5 is of Blancan age and appears to be equivalent to the Early and Middle Villafranchian of Europe. The relationship between this fill and the older Ogallala rocks is shown. This chart is the most recent in a continuing series of approximations of the Quaternary terrace stratigraphy relating to the faunal sequence of the Late Cenozoic (Schultz and Stout, 1945, 1948, 1961, 1977; Schultz, Lueninghoener, and Frankforter, 1951; Schultz and Tanner, 1957; Schultz, 1968, 1972, 1976a, 1976b; Schultz and Martin, 1970, 1977; Schultz, Tanner, and Martin, 1969, 1972; see also Schultz and Falkenbach, 1968, for faunal evidence in Ogallala). The work of Kukla (1970, 1977) has been helpful in the interpretation and correlation of loesses and paleosols. The Ogallala (Kimball, Ash Hollow, and Valentine) is pre-Terrace-5. Kimballian Provincial Age (Schultz and Stout, 1961; Schultz, Schultz, and Martin, 1970) faunas are derived from the Kimball Formation in the Great Plains. The Hemphillian faunas are from the upper part of the Ash Hollow Formation, the Clarendonian from the lower portion of the Ash Hollow, and the Valentinian from the Valentine Formation. It is apparent that the Terrace-4 fill is very complex and is especially important because fossil mammalian remains dating from approximately 2.2+ million years B.P. to 10,000 years B.P. are found associated with this fill although the terrace fills -3, -2B, 2A, 1, and -0 overlap in time (120,000 years) with the aeolian deposits in the upper portion of the Terrace -4 fill.

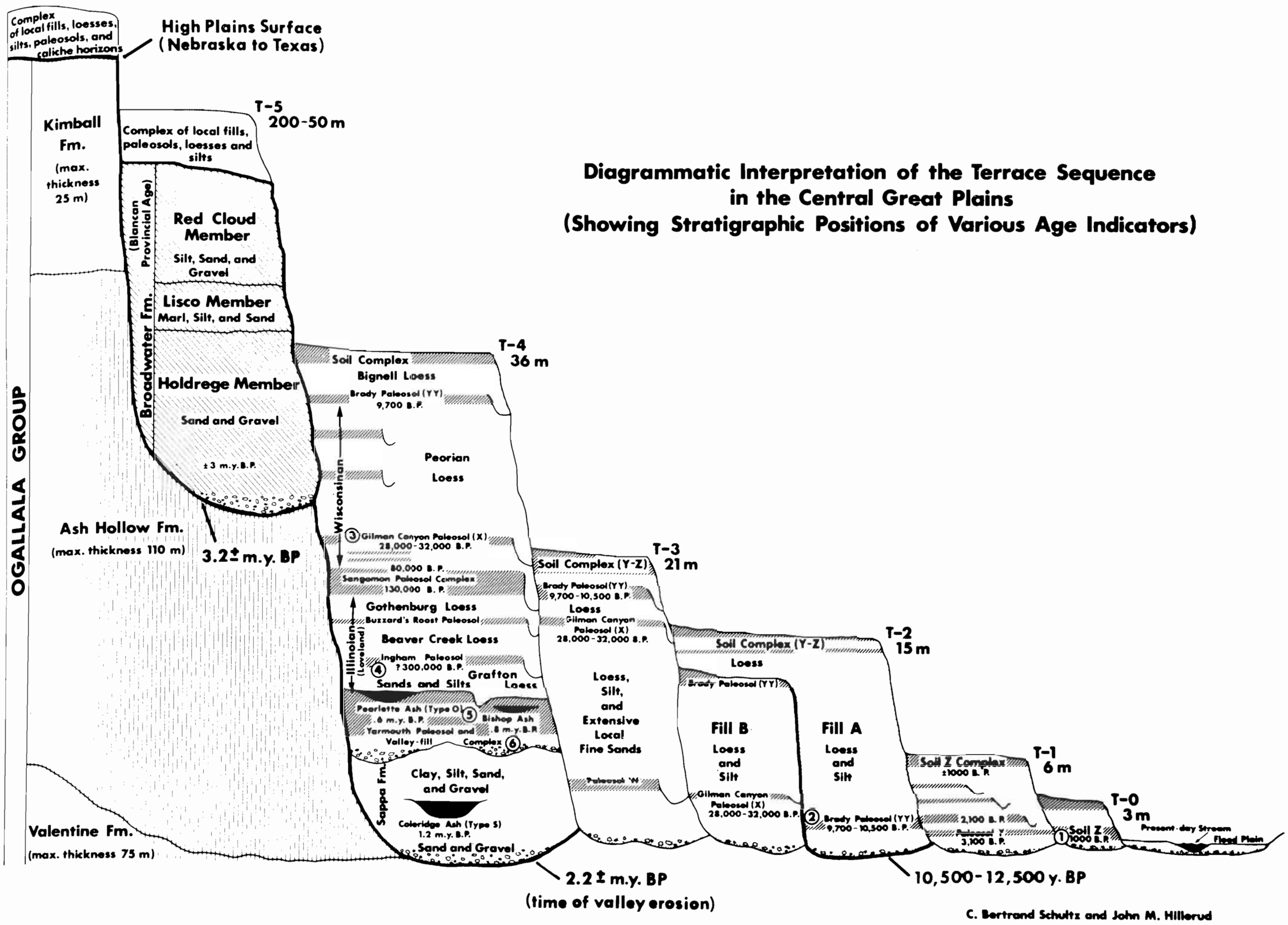


Figure 1. Diagrammatic interpretation of the sequence of post-Kimballian terrace fills as developed in the Central Great Plains of North America. The stratigraphic distribution of the chief loesses, soils, paleosols, and other sediments are shown in relation to the sequence of chief mammalian faunal zones. This chart is the most recent in a continuing series of approximations of the Quaternary terrace stratigraphy relating to the faunal sequence of the Late Cenozoic (Schultz and Stout, 1945, 1948, 1961; Schultz, Lueninghoener and Frankforter, 1951; Schultz and Tanner, 1957; Schultz, 1968; Schultz and Martin, 1970; Schultz, Tanner and Martin, 1969, 1972; Schultz, 1975; Schultz and Hillerud 1976, 1977a, 1977b). The Ogallala (Kimball, Ash Hollow, and Valentine) is pre-Terrace-5. Kimballian Provincial Age faunas are derived from the Kimball Formation in the Great Plains. The Hemphillian faunas are from the upper part of the Ash Hollow Formation, the Clarendonian from the lower Ash Hollow, and the Valentinian from the Valentine Formation. The Terrace-5 fill complex contains vertebrate fossils of Blancan age. The paleosols X and W in Terrace-3 and -2A fills have been correlated with two minor paleosols in the Peorian Loess of the Terrace-4 fill (Schultz, 1968; Schultz and Martin, 1970; Schultz, Tanner and Martin, 1972; Schultz, 1975); but here Paleosol X is considered to be the Gilman Canyon Paleosol at the top of the Gilman Canyon Formation (Reed and Dreeszen, 1965). Paleosol W appears to be equal, at least in part, to the Sangamon Paleosol. The greater portion of the Peorian Loess is restricted to the loess, which is post-Gilman Canyon and pre-Brady Paleosol. The Brady Paleosol originally (Schultz and Stout, 1945, 1948) was considered to be Soil X, but later Schultz, Lueninghoener, and Frankforter (1951) designated it Soil YY, after they discovered a second major fill (B) and paleosol in the Terrace-2 fill complex. Schultz and Hillerud (1976, 1977a, and 1977b) have related Soil X to the Gilman Canyon Paleosol (Schultz and Martin, 1970) near the base of the Peorian Loess. (See also Stout, et al., 1971:43-50, 66.)

The Holocene deposits are represented by the Terrace-2A, -1 and -0 fills, and also the superficial sediments on the older terrace fills (T-2B, -3, -4 and -5) and on upland surfaces. The Holocene portion of the Terrace sequence is shaded in the drawing (with small dots) in order to distinguish it from the Pleistocene.

TERRACE FILLS AND PALEOSOLS

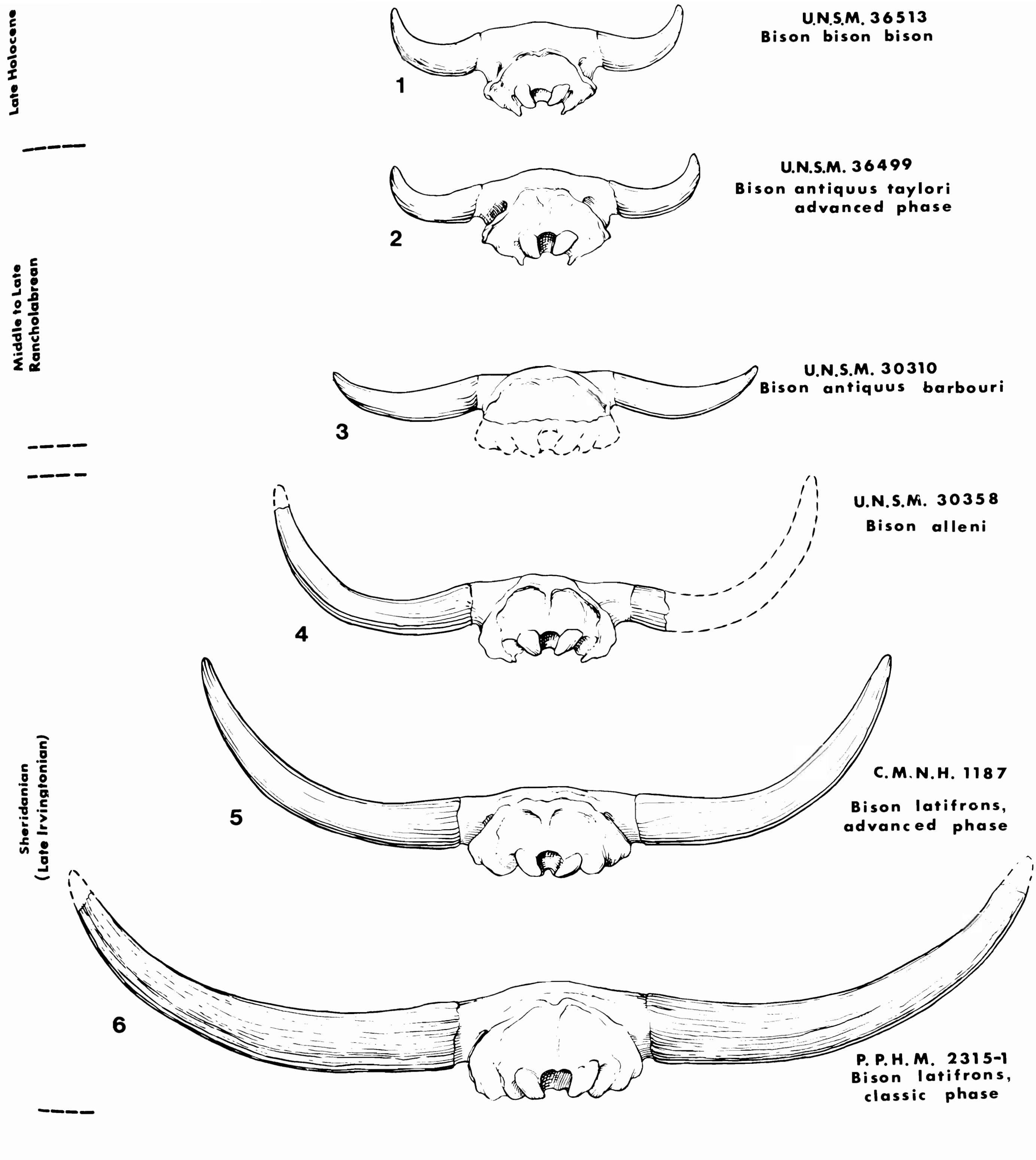
Paleosol W in the Terrace-3 fill has tentatively been correlated with the Sangamon Paleosol in the Terrace-4 fill, at least in part. The two paleosols, W and X, had previously been provisionally correlated with two minor or incipient paleosols which occur in the Peorian Loess (Schultz, 1976a), but additional geologic and paleontologic data provided evidence for the revision. Schultz and Stout (1948) had originally called the Brady Paleosol "Soil X." The "Citellus Faunal Zone" of Schultz (*In* Lugn and Schultz, 1934) appears to equate with all of the Gilman Canyon Formation, but most of the fossils are associated with the paleosol at the top of the formation. Thus the date of the fossils, including the holotypes of *Mammuthus (Archidiskodon) maibeni* (Barbour) and *Bison antiquus barbouri* (Schultz and Frankforter) would be some 28,000 to 32,000 years B.P. (Dreeszen, 1970) and would not be Sangamon in age, if the radiometric dates are correct. The stage of development of both the mammoth and the bison also would suggest these later dates for Paleosol X with which these specimens were associated. However, these dates should be considered as minimal ones until more C-14 soil samples have been processed and new techniques for dating paleosols have been more precisely developed.

Paleosol X is well developed in the lower portion of Terrace-2B fill and is often considered as the Sangamon Paleosol since it is developed on reddish brown silts, with a color similar to that of the Loveland loess below the Sangamon at some localities, but it appears to be the valley or floodplain phase of the Gilman Canyon Paleosol. The excavating of the long core-trench into the loess hills north of the Republican River during the construction of the Harlan County Dam (U.S. Corps of Engineers) did provide valuable information regarding the relationship of Paleosol X to the other paleosols. Also, many fossil bones were found associated with it (Schultz, Lueninghoener and Frankforter, 1951). The fossils proved to be similar to those associated with Paleosol X at the top of the Gilman Canyon Formation in the Terrace-4 fill. Terrace-0, -1 and -2A fills are Holocene, and Terrace-2B and -3, as well as the upper portion of -4, are of Wisconsinan (Late Pleistocene) age. The chart used by Schultz (1976a, 1976b) has been revised in order to provide the latest evidence for the correlation of the paleosols as well as for the establishment of a more refined faunal sequence. Paleosol X in the lower portion of the Terrace-2B fill has now been correlated with the paleosol in the Terrace-4 fill which is at the top of the Gilman Canyon Formation of Reed and Dreeszen (1965). Paleosol YY in the lower part of the Terrace-2A fill appears to correlate with the type section of the Brady Paleosol at the top of the Terrace-4 fill in Lincoln County, Nebraska. Both date approximately 9,700 to 10,500 B.P. (See Ruhe, 1968, for identification of paleosols in loess deposits.)

FAUNAL EVIDENCE

Figure 2 shows the outlines of six bison skulls and indicates that the earliest known form, *Bison latifrons,* is pre-Illinoian in age. All specimens of this species from Nebraska and Kansas that have geologic provenience associated with them appear to be pre-Illinoian or earliest Illinoian at the latest. This would agree with Péwé's (1975) conclusions about fossil mammal discoveries in Alaska, where he collected specimens of mammoths and bison, *"Bison (Superbison),"* from gravel deposits that underlie Illinoian and Yarmouth (?) beds. Mammoth remains are plentiful in pre-Illinoian deposits, which are of Early Sheridanian in age, in Nebraska. Bovids also are known from these same deposits. *Bison latifrons,* however, is rare. The occurrence of *B. latifrons* from pre-Illinoian deposits has recently been reported by Schultz and Hillerud (1977a, 1977b). We also are in the process of publishing a series of eight papers under one cover on the bison of the Great Plains. This publication has been in preparation for the past eight years and will include computer-generated statistics on measurement parameters which define a number of Late Pleistocene

Figure 2. Posterior views of bison skulls from the Great Plains arranged in stratigraphic sequence. Skulls were drawn to same scale in order to illustrate the progressive diminution in size during the period of time from Middle Pleistocene to Late Holocene. *Bison antiquus* and *B. a. barbouri* are Late Rancholabrean in age, while *Bison alleni, B. latifrons* (advanced phase) and *B. latifrons* (classic phase) are Sheridanian (Late Irvingtonian) in age [see Schultz and Hillerud, 1977a, 1977b for stratigraphic distribution of bison remains; also Schultz, Martin, Tanner and Corner, 1977, 1978 for the division of Irvingtonian Provincial Mammal Time term into Late Sheridanian (upper) and Sappan (lower)]. The example of *Bison latifrons* used in the figure is from Schultz and Lansdown (1972). The chart is not intended to illustrate a single phylogenetic lineage, and the specimens here used may represent at least two separate lines of development. This sequence is similar to one first presented by Schultz and Frankforter (1946), but the geologic distribution has been modified because more precise stratigraphic evidence (including radiometric dating) is now available for correlating and dating the deposits from which the bison remains have been derived. The circled numbers (1 to 6) in Figure 1 indicate the approximate stratigraphic positions of each of the bison skulls illustrated here. (U.N.S.M. = University of Nebraska State Museum, Lincoln; C.M.N.H. = Colorado Museum of Natural History, Denver; P.P.H.M. = Panhandle-Plains Historical Museum, Canyon, Texas.)


Late Holocene
Middle to Late
Rancholabrean
Sheridanian
(Late Irvingtonian)
1
U.N.S.M. 36513
Bison bison bison
2
U.N.S.M. 36499
Bison antiquus taylori
advanced phase
3
U.N.S.M. 30310
Bison antiquus barbouri
4
U.N.S.M. 30358
Bison alleni
5
C.M.N.H. 1187
Bison latifrons,
advanced phase
6
P.P.H.M. 2315-1
Bison latifrons,
classic phase

and Holocene fossil bison samples; the data support the conclusions presented in this chapter.

There is a definite need for a revision of the classification of the bison based on stratigraphic as well as morphologic evidence. Flerov and Zablotski (1961) pointed out that the classification of the bison by Skinner and Kaisen (1947) "does not, in our opinion, correspond to reality." Flerov (1964, 1971) reported that he too believed that the bisons dispersed from Asia into America "before the maximum glaciation (Illinoian)." Sher (1971), however, considered a later migration of the bison to North America. Robertson (1974) also reported that "it is generally agreed that *Bison* probably reached North America in Early Rancholabrean times," i.e. Sangamon Interglacial or Early Wisconsinan. He quoted Hibbard, et al. (1965), Hibbard (1955), and Guthrie (1970) as authorities, but he did not support this with geologic evidence and also overlooked published data from the Central Great Plains (Schultz and Frankforter, 1946; Schultz, Tanner and Martin, 1972).

In the course of an extensive literature search, we have found that many scientists who work on local faunas rely on prior authority rather than on the interpretation of discrete field evidence available at the fossil sites. When a conclusion is quoted sufficiently it assumes a spurious validity very difficult to discredit. In the early part of this century, O. P. Hay (1913, 1914, 1930) considered many of the Middle and Late Pleistocene faunas to be Aftonian in age, basing his belief on the research of Samuel Calvin (1909, 1911) and Bohumil Shimek (1908, 1909) in Iowa. A host of contemporaries (including W. D. Matthew, 1918) also accepted this age determination for faunas of various Quaternary ages, and this was not challenged for many years. As a result, many workers thought that the Pleistocene represented too short a time to allow for much, if any, evolution to take place. This was largely due to the fact that most of Calvin's and Shimek's "Aftonian" vertebrates from Iowa actually were Late Pleistocene in age. This was pointed out by Lugn and Schultz (1934) and by Barbour and Schultz (1937), when a preliminary stratigraphic sequence of fossil vertebrates, based on geologic evidence, was presented for the first time in North America. Schultz and Stout (1945, 1948) proposed a terrace-fill sequence, which is still being used today. Since that time there has been an ever-increasing effort to establish a more refined stratigraphic sequence of the fossil vertebrates as new geologic evidence becomes available. Many workers, including A. L. Lugn (1935, 1962, 1968), G. C. Lueninghoener (1947), W. D. Frankforter (1950, 1971), Larry Frankel (1956, 1957, 1958), Frye, Willman and Glass (1968), Frye and Leonard (1965), Frye and Willman (1973), Reed, et al. (1965), Stout, Dreeszen and Caldwell (1965), Stout, et al. (1971), Skinner and Hibbard (1972), and Schultz and Martin (1970, 1977) [as well as Bayne, et al. (1971), in eastern Kansas and western Missouri] have contributed greatly to this continuing stratigraphic and geomorphic approach in the Great Plains during the past 35 years. The terrace-fill approach of relating the faunal evidence to the stratigraphy has proven to be most valuable in working out a more precise faunal sequence for the Quaternary of the Great Plains, from Texas to the Dakotas.

The study of the terraces and the complexity of the associated terrace fills is still in its infancy in North America, but there is an increasing number of geologists and paleontologists examining the evidence. The terrace fills have been correlated from one river valley to another, and we feel, as did such eminent geomorphologists as the late Kirk Bryan and Paul MacClintock, that the terraces of the Central Great Plains are regional in extent and the various associated cutting and filling cycles were controlled primarily by climatic changes. However, some epeirogenetic control must be considered, especially in the interpretation of the Terrace-5 and lower portions of the Terrace-4 fills. Both Bryan and MacClintock, by extended visits with vertebrate paleontologists and anthropologists in Nebraska and adjacent areas, encouraged research on the terraces and terrace fills; this has made it possible to provide a faunal sequence based on critical geologic evidence.

MIGRATION AND EXTINCTION

The extinction of so many of the large mammals of the Late Quaternary in the Great Plains took place gradually, as it did in Europe (C. A. Reed, 1970). Climatic changes and migrations both contributed significantly to the extinction of some 25 genera of mammals in North America, but paleohunters eventually killed off the greatly diminished herds with little effort because of the scarcity of food during the Late Pleistocene and Early Holocene.

The horses and camels, which had so successfully lived in the Great Plains Region for some 40,000,000 years, had some very aggressive competitors when the giant bison and mammoths arrived from Asia prior to the Illinoian Glaciation. These immigrant forms consumed great quantities of grass and herbs, which hitherto had been utilized by native horses, camels and other herbivorous forms. Fossil evidence indicates that the herds of the native mammals began to diminish as those of the intruders increased.

The inhospitable climates of the Illinoian and Wisconsinan glaciations contributed to the reduction in numbers of the grazing animals. As much as 56 meters of loess were deposited on the Yarmouth Interglacial sediments and elsewhere in some localities in the Central Great Plains. During a 16,000 year period, from approximately 28,000 to 12,000 B.P., 20 meters of loess accumulated in some areas in Nebraska. A virtual graveyard of mammals is to be found in the base of this loess ("Citellus Faunal Zone," Lugn and Schultz, 1934; Lugn, 1935, 1968; or Gilman Canyon Formation, Reed and Dreeszen, 1965). There were prolonged periods of droughts during the loess deposition, and the animals which survived were chiefly snails. At the same time as the loess deposition, some 55,000 square kilometers of major sand dunes were developing in Nebraska, and at times conditions similar to those found in the Sahara Desert today existed (Smith, 1965, 1968). It was a struggle for survival even for the large mammals, which had emigrated to other parts of North America to compete with other species in already overcrowded areas. Of the large grazers, the bison was the most successful, surviving into recent times. Their herds increased in numbers and they took over the grazing land of the Great Plains when favorable climatic conditions again prevailed. The diminution in size and the ability to adjust to varying environmental conditions undoubtedly contributed to the success of the bison (see Fig. 2).

People are always interested in the weather and wonder if the climates of the world do actually change, at least during their lifetimes. James Michener (1976) asked "where did the animals go?", writing about the extinction of our North American animals at the end of the "Ice Age." Bryson and Murray (1977) wrote about "mankind and the world's changing weather" and the "climates of hunger." Kukla and associates (1977) presented "new data on climatic trends" and showed that during the past 30 years in the Northern Hemisphere, the oscillatory cooling has not yet reversed. Schultz (1972) reported on the northern migration of the armadillos and other southern vertebrates into the Kansas, Colorado and Nebraska region of the Great Plains during the 1930's to 1950's. Then there was a sudden reversal of the migration to the south during the 1960's and 1970's as cooling began to take place. These recent migrations, of course, were the result of minor climatic changes which often go unnoticed. Observations of the present climatic trends as well as those of the past are necessary if we are to interpret our environments of the future. We now know that climatic changes may happen at a more rapid rate than we had thought, but much more research must be done before accurate long-range climatic forecasting can be accomplished. Certainly man must be prepared to face climatic disasters and adjust to them.

We feel that Paul Martin's (1973, 1975) paleohunters from Asia were not confronted with teeming herds of grazers when they came into the Great Plains, the Southwest, or other parts of North America; there was no reason for an "overkill." By 12,000 years B.P., except for the bison and very limited herds of horses, camels, and mammoths, there were not too many large animals to hunt, so "overkill" was not the chief cause of the extinction of a large number of Late Pleistocene Genera and species. The disastrous climate of the times had already taken its toll before man was well-established in North America. Even minor prolonged droughts, such as those of the 1930's, had disastrous effects on the grazing animals in the Great Plains (Schultz and Stout, 1977).

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