1987

Paleogeomorphic Significance of Two Paleosols in the Dakota Formation (Cretaceous), Southeastern Nebraska

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ABSTRACT

Much of the Dakota Formation in southeastern Nebraska consists of channel sediments from high-sinuosity streams and associated paleosol-containing floodplain siltstones. Two paleosols, one in Lancaster County, Nebraska and another in Jefferson County, are overlain by extensive channel sandstones; the contact of the paleosol-bearing units and the sandstones represents an abrupt facies change and a significant intraformational diastem. The paleosols have discernible B horizons; one paleosol is particularly thick and has well-differentiated A, E, and C horizons. These paleosols are probably the products of long periods (perhaps 10,000 years in the case of the thick paleosol) of local non-deposition controlled by eustatic changes in sea level.

INTRODUCTION

Paleosols are important as paleoenvironmental indicators and as evidence for diastems in the rock record. Retallack (1981, 1983) has outlined the paleoecologic and stratigraphic value of paleosols from a number of Phanerozoic rock units, and has recognized their value in quantifying rates of sedimentation and the duration of periods of paleogeomorphic stability (Retallack, 1984). Sedimentologists and pedologists alike have noted the presence of variably-developed paleosols in sequences of fluvial sedimentary rocks, and have appreciated their implications to the stability or instability of floodplains in response to auto- or allocyclic controls.

The Dakota Formation (middle Cretaceous) in southeastern Nebraska consists mostly of fluvial sediments grading upward into deltaic and transitional nearshore marine deposits. The formation tentatively can be divided into three stratigraphic zones: (1) a basal zone of coarse fluvial deposits; (2) a middle zone of finer-grained fluvial deposits; and (3) an upper zone of nearshore marine and deltaic sediments. The basal zone consists of coarse sands and gravels filling alluvial channels cut into Paleozoic bedrock, and has been interpreted as deposits of a series of braided streams draining areas of low relief to the northeast. In Jefferson County, Nebraska, the only part of the study area where the upper contact of the Dakota is exposed, the contact between the upper, marine-influenced Dakota and the deltaic Graneros Shale is gradational through a series of dark silty clay shales. The thick middle part of the formation, interpreted as deposits of higher-sinuosity streams, contains 0.5 to 3.5 m thick beds of siltstones and clayey siltstones which commonly show varying degrees of paleosol development. Two paleosols from this part of the formation represent important aspects of regional soil development during the early Late Cretaceous. Although their outcrops are about 50 km apart, the paleosols appear to have had similar developmental histories.

LOCATION OF STUDY

The Dakota Formation crops out in a broad belt trending north-northeast across the eastern third of

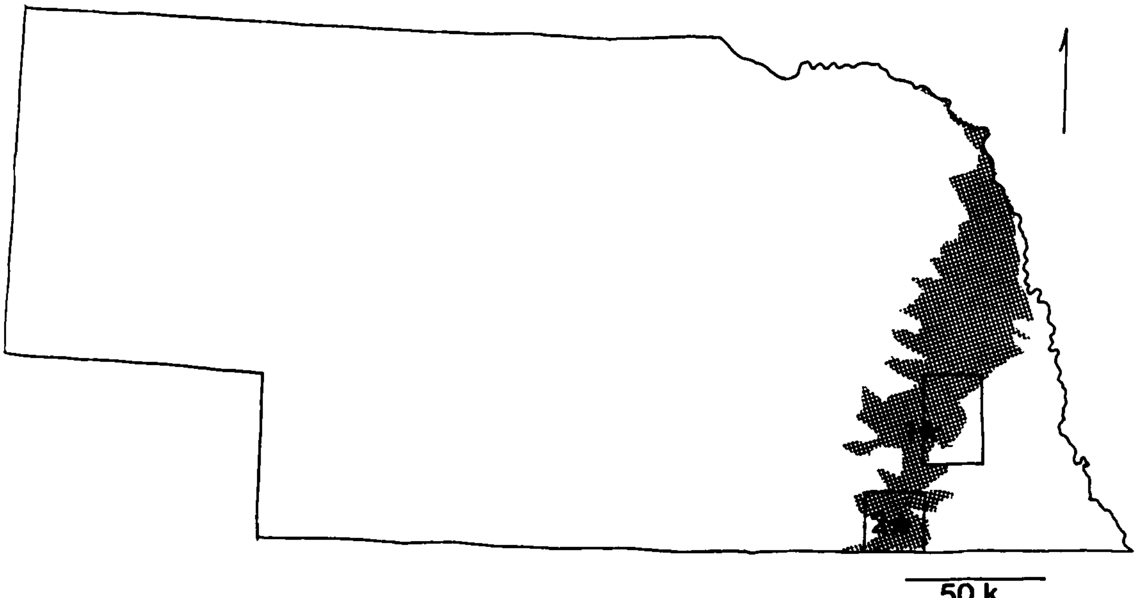

Figure 1. Main area of outcrop and subcrop of Dakota Formation in Nebraska; small outliers omitted.

Nebraska; both study localities are in the southern part of this area (Fig. 1). Locality 1 is an abandoned brick clay pit in the NE 1/4, SE 1/4, SE 1/4, of section 30, T. 10 N., R. 5 E., near Pleasant Dale, Lancaster County. Locality 2 is a near-vertical bank exposure on the south side of the Little Blue River in the N 1/2, NW 1/4 of section 6, T. 1 N., R. 3 E., southeast of Fairbury, Jefferson County. These localities are important because they offer relatively fresh exposures of complete paleosols.

SEDIMENTOLOGIC FRAMEWORK

The middle part of the Dakota Formation in the area of study is characterized by five associations of lithofacies: (1) 0.5 to 3.5 m thick, laterally continous units of structureless siltstones with variably-developed paleosols; (2) epsilon cross-stratified channel fills up to 50 m wide containing trough cross-stratified, very fine to medium-grained sandstones and interbedded gray siltstones with rare and poorly-differentiated soil development; (3) small, single facies channel fills of planar cross-stratified, fine to coarse-grained, poorly-sorted sandstone or paleosol-pebble conglomerate in a matrix of another, laterally continuous facies; (4) small, multiple facies channel fills otherwise similar to the above; and (5) large, laterally-continuous bodies of very fine to medium sandstone containing cosets of planar and trough cross-stratification. Together, these facies associations represent deposits of laterally continuous floodplains, high-sinuosity streams, accessory channels of high-sinuosity streams (chutes), and large, moderate-sinuosity streams (Joeckel, 1984).

DAKOTA FORMATION PALEOSOLS—GENERAL

Reddish-mottled siltstones (0.5 to 2.5 m thick) are common in the Dakota Formation; large exposures show these siltstones extending laterally from the various types of channel fills. Many larger exposures reveal paleosols which delineate the tops of multiple, cross-cutting channel fills. Horizonation in these paleosols often is difficult to discern because of poor exposure. At many localities, however, it appears that only homogenous mottled zones are present, probably representing the B and/or C horizons of gleyed alluvial soils. Lower limits to soil development (*i. e.,* a C horizon contact with underlying silt) are sometimes visible where mottling ends within an in dividual depositional unit. Some exposures show clear horizons, paleosols, often with a yellowish-brown upper horizon and a reddish-mottled horizon underneath. These probably represent more mature soils, possibly developed from gleyed alluvial soils, that developed on temporarily stabilized land surfaces with better drainage. Paleosols at localities 1 and 2 are examples of these well-horizonated types.

DESCRIPTION OF LOCALITY 1

The stratigraphic section at locality 1 (Fig. 2) is dominated by a 6 m thick, trough and planar cross-tratified sandstone body, the lateral limits of which are not visible in outcrop. Many small (1 to 2 m wide) channels filled with sand and sand-supported mudstone clasts are present within this body. Below the sandstone body is an exposure of variably-colored and textured mudstones capped by a laterally-continuous, well-horizonated paleosol. A well-cemented zone 2 to 5 cm thick occurs at the base of the sandstone immediately above the paleosol.

Sediments underlying the sandstone body at locality 1 consist of: (1) a 4 m thick poorly-laminated gray siltshale with abundant well-preserved angiosperm and gymnosperm organs, grading laterally into; (2) white (10YR 8/1) and brownish-yellow (10YR 6/6) structureless siltstones overlain by; (3) a yellowish-brown (10YR 5/4) friable fine sand. Considering the crude lamination of the unit 1 siltshales and the abundance of well-preserved plant remains (*e. g., Salix*-like leaves and conifer shoots), I interpret these siltshales as the deposits of a small floodplain lake or floodbasin. Retallack and Dilcher (1981) noted similar plant-bearing lacustrine deposits in the Dakota Formation of central Kansas.

The upper 80 cm of unit 1 are lighter in color than the underlying part. Organic material in the upper 80 cm interval appears to have been oxidized downward from the top of the interval; organics have been eliminated in the uppermost 30 cm.

The uppermost 20 cm of unit 1 contains differentiated A and B horizons. The A horizon is approximately 5 to 14 cm thick, blocky, and light yellowish-brown (2.5Y 6/4) or brownish-yellow (10YR 6/6) in color. The A horizon is plastic when wet. Individual blocks from the A horizon are angular in form and about 5 mm across; they may be preserved peds. The B horizon is brittle and lacks visible peds. At first glance, the B horizon appears to consist of coalesced, diffuse, red (10R 4/6) patches grading between the A horizon and the underlying, relatively thick C horizon. However, closer inspection reveals that the B horizon is mostly red, but contains a few thin (about 5 mm wide), discontinuous, reddish-gray (10R 6/1) and brownish-yellow (10R 6/6) bands. Both types of bands are diffuse and contain sparse, irregular, red (10R 4/6) mottles. Reddish-gray (10R 6/1) patches 2 to 4 mm across are present in the massive, red part of the B horizon and probably are drab halos which formed around roots. Under the B horizon is a massive, diffuse, olive (5Y 5/3) zone which grades in color between the B horizon above and the C horizon (10YR 6/1 gray) below. This olive-colored zone is best described as a BC horizon. The locality 1 paleosol can be traced laterally for about 30 m to the end of the quarry wall.

Other evidence for temporary stability (*i. e.,* surficial oxidation and plant colonization) is present in the lowermost part of unit 1 in the form of ferruginized bedding planes and fractures, and a 6 cm zone containing numerous large, vermicular, red (10R 4/6) mottles which appear to have been associated with rhizospheres. The entire section indicates a gradual trend toward increased stability beginning with ferruginized bedding planes and reaching its peak in development of the paleosol.

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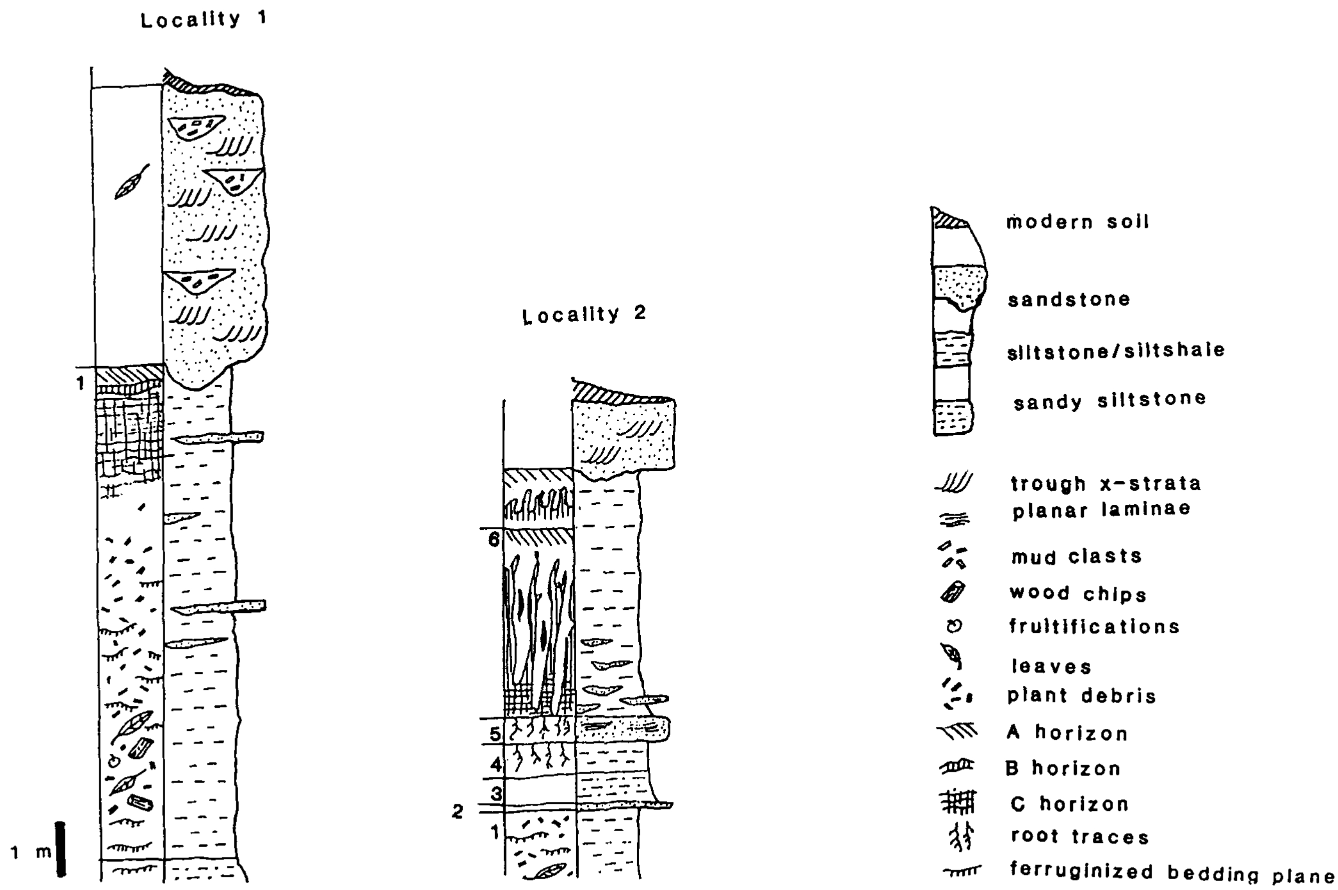

Figure 2. Stratigraphic sections at localities 1 and 2.

DESCRIPTION OF LOCALITY 2

The stratigraphic section at locality 2 (Fig. 2) consists of approximately 6.5 m of siltstone, fine sand, and sandy siltstone (containing two discrete paleosols) overlain sharply by approximately 1.5 m of medium-grained friable quartz sandstone. This overlying sandstone is laterally continuous with a planar and trough cross-stratified channel sandstone incised into the underlying units at the north end of the exposure. Cross-stratification cosets in the sandstone are approximately 1 m thick. The sandstone is moderately- to well-sorted and contains scattered quartz or chert granules. A hard, brittle, limonite-cemented zone about 2 cm thick is present in the sandstone at its contact with the underlying, eroded paleosol. The lower, paleosol-bearing units can be traced laterally in exposure for about 300 m and crop out on either side of the channel sandstone (Fig. 3).

In succession, the depositional units comprising the lower part of the section are: (1) a crudely-laminated gray sandy siltstone with ferruginized bedding planes and fracture planes and scattered plant fragments; (2) a dark yellowish-brown silty fine sand of variable thickness containing abundant finely-disseminated plant debris and pyrite blebs; (3) a grayish-brown, structureless sandy siltstone with numerous light gray mottles; (4) a structureless gray siltstone with many subvertical to vertical concentric root traces and vermicular mottles; (5) a reddish-brown, thinly-laminated fine sand containing abundant concentric root traces; and (6) a thick sandy to clayey siltstone containing relict lenses of medium sand and two well-horizonated paleosols.

The well-defined, concentric root traces in units 4 and 5 vary in size from 1 to 7 mm in diameter and have clearly disrupted original stratification; the root traces are direct evidence for plant colonization at many surfaces. Colonization was temporary and differentiation of soil horizons did not occur, but rudiments of pedogenesis were nonetheless present. Given the context of other exposures in the area, units 1 through 5 are probably the result of frequent depositional episodes on the proximal part of the floodplain of a mixed-load stream. Unit 6 was probably the result of comparable depositional episodes, but also records periods of relative long-term stability (nondeposition). As at locality 1, a long-term trend toward floodplain stability reaches its climax in development of a well-horizonated paleosol.

Unit 6 is the focus of interest because it contains two well-horizonated paleosols comprising most of its 4 m thickness; the lower profile is about 2.5 m thick and begins near the base of the unit, whereas the upper

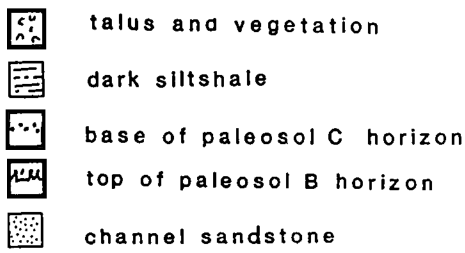

Figure 3. Field relationships of units at locality 2, looking south from bridge over Little Blue River in NE 1/4, NW 1/4, NW 1/4 sec. 6, T. 1N., R. 3 E., Jefferson County, Nebraska (schematic diagram from a field sketch).

Figure 4. Lower, well-horizonated paleosols at locality 2; B horizon (dark) is prismatic or columnar in geometry, and E horizon (light) tongues deeply into B horizon. The A horizon of lower profile is visible as a medium-dark band, as are much thinner horizons of upper profile. Man is about 1.8 m tall.

directly overlies the lower and is about 0.3 m thick. Each paleosol is separable into three major horizons: (1) a silt-rich, reddish-colored and mottled B horizon which consists of large (1 to 2.5 m high and averaging 30 cm in diameter) prismatic structures and contains peds; (2) a white (10YR 8/1) structureless E horizon overlies and tongues deeply into the B horizon; and (3) a yellow (10YR 3/1) and very pale brown (10YR 8/3) structureless A horizon (Fig. 4). The lower profile also contains a separable C horizon.

Prismatic structures in the B horizons of both paleosols and the C horizon of the lower paleosol are the most striking aspect of the paleosols, and were the features which led to their discovery. Individual prisms in the B horizon of the lower profile are up to 30 cm in diameter and have a complex internal zonation of color and structure (Fig. 5). Within a prism, the outermost zone is usually dark red (10R 3/6) and red (10R 4/8), brittle, and impregnated with hematite. Some parts of the B horizon are entirely red, except for scattered dark red fracture planes. Small white (10R 8/1) patches less than 2 cm across are visible on the exposed outer surfaces of many prisms. A diffuse boundary commonly exists between this outer zone and the inner zone, which consists of a reddish-gray (10R 5/1) and weak red (10R 5/2) groundmass and many distinct dark red (10R 3/6) mottles. When viewed closely in hand specimen and petrographic thin-section, some of these mottles appear to be opaque iron sesquioxide (and possibly clay) cutans deposited along planar voids roughly defining angular blocky peds of variable size (generally less than 2 cm square). The color of these peds is reddish-gray (10R 5/1), diffusing to weak red (10R 5/2) at their margins. Prismatic structures in the C horizon of the lower profile are yellowish-brown (10YR 5/6), lack peds, and grade upward into those of the B horizon. The lower part of the C horizon contains relict planar laminae 1 to 2 mm thick.

The contact of the B and E horizons is sharp, even in thin section. Small glaebules (0.1-0.25 mm in diameter) consisting of a core of radial, anisotropic crystals (probably siderite) surrounded by a rind of isotropic iron sesquioxide appear in the E horizon near its contact with the B. These glaebules probably represent a pedochemical gradient of iron oxidation-reduction apparent in the original soil. Subvertically-oriented illuviation argillans also are visible in thin section and indicate either that the horizon was not completely structureless in its original state, or that it was influenced by illuviation from the overlying paleosol.

In the A horizons of both paleosols, two color zones are visible. A structureless yellow (10YR 7/6) zone overlies a very pale brown (10YR 8/3) zone with a sharp boundary. A clear (*i. e.*, more diffuse) boundary is present between the very pale brown zone and the underlying E horizon; in some areas of the profile this boundary may be irregular. Slabbing and polishing of specimens from the pale brown zone reveals numerous small (less than 2 mm across) subvertically-oriented planar voids containing brownish-yellow (10YR 6/8) argillans. Similar subhorizontally-oriented argillans are visible in hand specimen; these argillans may occur at the boundaries of large subangular blocky peds. Small (2-5 mm in diameter) carbonate nodules present in the horizon and associated with modern roots are undoubtedly of very recent origin.

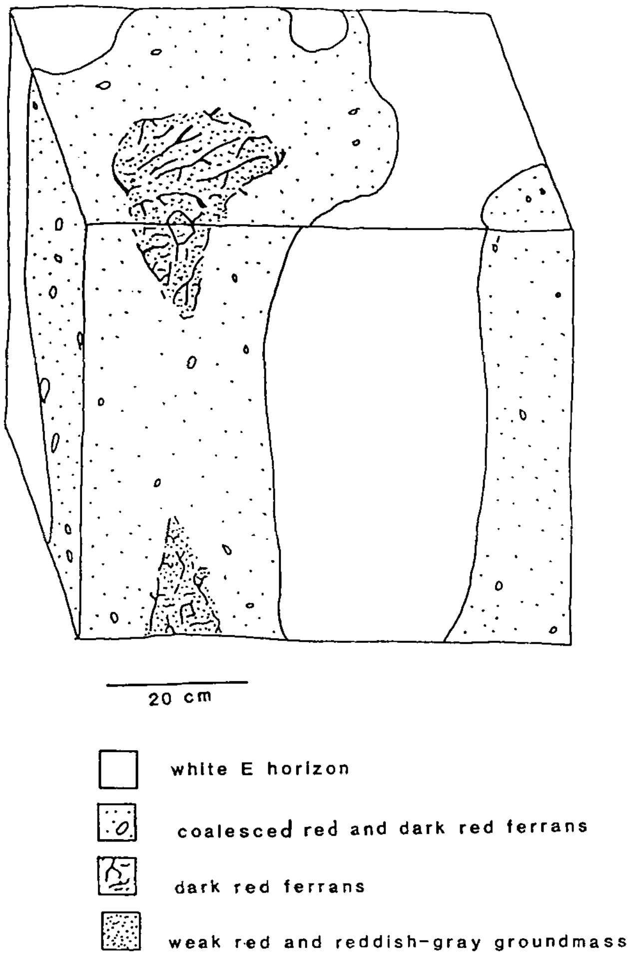

Figure 5. Schematic block diagram showing internal structure of E and B horizons of paleosols at locality 2.

MINERALOGY

The clay mineralogy of the lower paleosol at locality 2 provides insight into climatic conditions during the Cretaceous. X-ray diffraction analysis of the untreated < 2 micron fraction of both E and B horizons detected kaolinite with some illite; hematite is the iron mineral responsible for the coloration of the B horizon. Settling tube analysis indicates that the B horizon contains approximately 18.5 percent clay-grade particles and the E horizon contains approximately 15.5 percent clay-grade particles. The A horizon of the lower paleosol at locality 2 contains kaolinite and a trace of goethite, which produces the yellowish color of that horizon.

The B and E horizons contain significant amounts (approximately 42 %, and 43 %, respectively) of fine and very fine quartz sand, whereas the A horizon contains only 6 percent sand. Muscovite flakes are common in the fine and very fine size fraction, and feldspar is conspicuously absent in whole-sample x-ray diffraction analysis.

CLASSIFICATION OF THE PALEOSOLS

Interpretation of the paleosols begins with those from locality 2, because they are so well horizonated. Critical points for the classification are the strongly glossic E horizon and the resistant, prismatic B horizon.

Duchaufour (1982, p. 334-352) used the term "modal pseudogley" to describe seasonally hydromorphic soils in which the blocking of pore spaces via long-term clay illuviation and sesquioxide precipitation creates a relatively impermeable prismatic B horizon. Drainage is gradually limited to dry season desiccation cracks, and a perched water table develops above the B horizon during the wet season. Extensive eluviation of iron compounds from the overlying E horizon occurs because leaching solutions are slowed in drainage; through time the E horizon becomes glossic in geometry as it follows the trends of cracks through the B horizon. FitzPatrick (1983, p. 256-259), in a comprehensive classification of his own, formulated the term "podzoluvisol" to describe such soils. According to FitzPatrick, the diagnostic feature is an argillic, prismatic B horizon in which individual prisms have "exteriors . . . enriched and weakly cemented or indurated with iron and having redder hues and stronger chromas than the interiors."

The B horizon phenomena described by Duchaufour are fragipans in the terminology commonly used by American pedologists. Fragipans are resistant subsurface horizons which commonly are prismatic in geometry (Soil Survey Staff, 1975, p. 42) and may occur entirely within B horizons (Grossman and Carlisle, 1969, p. 240), a situation probably represented in the paleosols at locality 2. Bown and others (1982, p. 608) described fragipans in alluvial paleosols of the Oligocene Jebel Qatrani Formation of Egypt.

According to FitzPatrick's (1983, p. 258) cross-correlation of world soil classifications, "podzoluvisols" (pseudogleys) are Alfisols in the U.S.D.A. classification. Using presence of a fragipan and the glossic E horizon as diagnostic characters, the paleosols from locality 2 probably are similar to the Ferrudalfs or Fraglossudalfs of the U.S.D.A. classification (Soil Survey Staff, 1975, p. 126, 128).

Because the B horizon of the paleosol at locality 1 is marked by appreciable accumulation of iron oxide, the paleosol probably was similar in developmental history to the paleosols at locality 2. The paleosol at locality 1 probably is an Alfisol as well.

CLIMATIC AND BIOTIC IMPLICATIONS

Fragipan-containing soils commonly develop on sediments of alluvial coastal plains or glacial tills in climates in which a marked seasonal difference in soil moisture occurs (FitzPatrick, 1983, p. 258; Duchaufour, 1982, p. 341-343; Murphy, 1984, p. 251; Bouma and Van Der Plas, 1971, p. 83; Daniels and others, 1966; and Grossman and Carlisle, 1969). Seasonal accumulations of water would have occurred above the fully-developed prismatic B horizons of paleosols at locality 2 because porosity in soil voids gradually was reduced by their filling with iron oxides, silt, and possibly clay (Grossman and Carlisle, 1969, p. 260-261). Conditions of low Eh and iron eluviation in the E horizon thus were produced by action of perched water driving out soil atmosphere, concentration of organic acids within soil solution, and activities of anaerobic bacteria. Subsequent desiccation of the solum during dry periods allowed movement of soil atmosphere into the B horizon, where accumulated iron compounds oxidized inward from the outer surfaces of prisms. Development of this paleosol type presumably would have involved a number of developmental stages over a geologically significant period.

Grossman and Carlisle (1969, p. 262) concluded that "Fragipans are not necessarily restricted to old soils, but neither do they form in a matter of hundreds of years." Fragipan-containing soils on the Atlantic coastal plain studied by Daniels and others (1966) are developed on a pre-Wisconsin erosional surface (Grossman and Carlisle, 1969, p. 246), and thus are more than 10,000 years old.

In cool, humid climates (*e. g.*, Great Britian—Murphy, 1984), modern analogs usually are at least 30 percent thinner than the almost 3 m deep lower profile at locality 2. The difference in thickness may be due to a warmer climatic regime governing the Cretaceous soil. Other types of Alfisols in warm (*i. e.*, non-glaciated) regions of North America often are deeper than northern Alfisols, and have developed on surfaces of Sangamon or late Wisconsinan age (Soil Survey Staff, 1975, p. 133-139). A similar difference in depth exists between modern temperate-zone Spodosols and tropical "giant podzols" (Bridges, 1978, p. 86).

Clay mineralogy of the lower paleosol at locality 2 is probably indicative of most paleosols from the Dakota Formation. Bowe (1972, p. 69), in an extensive study of mudrocks and sandstones in the Dakota Formation of eastern Nebraska and adjacent areas, concluded that the clays were "essentially kaolinitic . . . material transported from a soil developed in Paleozoic and precambrian rocks." Although Bowe did not recognize paleosols in mudrocks of the Dakota Formation, it is clear from his descriptions, and from my observations at his localities, that many of his samples were from paleosols. The predominance of kaolinite indicates a relatively warm and humid climatic regime.

The E horizons present in the paleosol from locality 2 suggest long-term colonization by forest vegetation. Forest vegetation probably was associated with the paleosol at locality 1 as well. Retallack and Dilcher (1981, p. 42-43) concluded that the "clear differentiation" of certain paleosols in the Dakota Formation of Kansas "into a gray or yellowish A horizon and a reddish brown B horizon indicates that they were forested soils of floodplains." Retallack and Dilcher speculated that extensive floodplain forests of conifers grew on these dry (*i. e.,* relative to nearby floodbasin or swamp conditions) soils. Evidence for succession of a plant community is presented by development of the soil at locality 1 over presumed lacustrine deposits containing remains of a discrete community similar to those postulated by Retallack and Dilcher (1981, p. 41).

DISCUSSION

The major paleosols from both localities are well-horizonated and mark significant intraformational disconformities between floodplain and fluvial channel sediments. Both probably developed on ancient terraces constructed of floodplain sediments which were incised by streams during periods of degradation (direct evidence for this is presented by the channelization of fluvial sands into the paleosols at locality 2).

Considering the general conclusions offered earlier about paleosols in the Dakota Formation, it is clear that fluvial sediments were deposited episodically. Inherent in the mechanics of a fluvial terrain is creation of temporarily stable surfaces (*e. g.,* terraces) by a series of events such as lateral channel migration, avulsion, degradation, and local non-deposition. These events may be controlled either by autocyclic (in-system) or allocyclic (out-of-system) mechanisms. Although there has been a tendency to assume that fluvial terraces are created by such events as drops in ultimate base level, Womack and Schumm (1977) clearly demonstrated that the production of small, temporarily stable fluvial terraces could be initiated by autocyclic controls. Autocyclic controls would be expected to produce events on a smaller time scale (*e. g.,* tens to hundreds of years) than allocyclic controls (perhaps thousands to hundred thousands of years). The degree of paleosol horizon differentiation should correlate directly with the duration of terrace stability, and hence may provide a means for differentiating auto- or allocyclic controls. Following this hypothesis, it appears that well-horizonated paleosols of the general type seen at localities 1 and 2 may represent surfaces stabilized by an allocyclic control, probably sea level change. This conclusion is supported by the tendency of similar modern soils to form on erosional surfaces produced by glacioeustatic sea level fluctuations.

The paleosols at localities 1 and 2 appear to be related in process because they developed under analogous depositional and geomorphic conditions. Furthermore, both have similar A horizons and differentiated B horizons marked by an increase in iron sesquioxide content. However, paleosols at locality 2 are better developed (E horizons are present and the B horizons show complex internal structure). It appears as if the paleosols at localities 1 and 2 represented stages in genesis of a particular soil type, the main difference between the two being time available for development.

ACKNOWLEDGMENTS

My deepest thanks go to my wife Kathy for her invaluable assistance in the field and her long-term moral support. My thanks to David Loope, Mike Leite, and Tom Bown for reading drafts of this manuscript and providing helpful criticism and encouragment. Mary Ann Holmes gave freely of her time to carry out the analyses of clay mineralogy, for which I am indebted. Bob Goodwin provided technical advice.

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MANUSCRIPT RECEIVED JANUARY 27, 1987
REVISED MANUSCRIPT RECEIVED JUNE 11, 1987
MANUSCRIPT ACCEPTED JUNE 20, 1987