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Lithostratigraphic revision and correlation of the lower part of the White River Group: South Dakota to Nebraska

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ABSTRACT

Lithologic correlations between type areas of the White River Group in Nebraska and South Dakota have resulted in a revised lithostratigraphy for the lower part of the White River Group. The following pedostratigraphic and lithostratigraphic units, from oldest to youngest, are newly recognized in northwestern Nebraska and can be correlated with units in the Big Badlands of South Dakota: the Yellow Mounds Paleosol Equivalent, Interior and Weta Paleosol Equivalents, Chamberlain Pass Formation, and Peanut Peak Member of the Chadron Formation. The term "Interior Paleosol Complex," used for the brightly colored zone at the base of the White River Group in northwestern Nebraska, is abandoned in favor of a two-part division. The lower part is related to the Yellow Mounds Paleosol Series of South Dakota and represents the pedogenically modified Cretaceous Pierre Shale. The upper part is composed of the unconformably overlying, pedogenically modified overbank mudstone facies of the Chamberlain Pass Formation (which contains the Interior and Weta Paleosol Series in South Dakota). Greenish-white channel sandstones at the base of the Chadron Formation in Nebraska (previously correlated to the Ahearn Member of the Chadron Formation in South Dakota) herein are correlated to the channel sandstone facies of the Chamberlain Pass Formation in South Dakota. The Chamberlain Pass Formation is unconformably overlain by the Chadron Formation in South Dakota and Nebraska. The Chadron Formation in South Dakota is divided into the Ahearn, Crazy Johnson, and Peanut Peak Members in South Dakota. Of these three, only the bluish-green, hummocky weathering mudstones of the Peanut Peak Member are present in northwestern Nebraska. These mudstones were previously classified as the lower part of the "Chadron B" in Nebraska and correlated with the Crazy Johnson Member in South Dakota. The term Chadron B is abandoned and the correlation to the Crazy Johnson Member rejected. The remainder of the Chadron Formation in northwestern Nebraska (the Chadron B and "Chadron C"), along with the basal beds of the Brule Formation ("Orella A"), are included within the newly defined Big Cottonwood Creek Member. The Chadron C was initially used to define strata between the "upper" and "lower purplish-white layers" and was correlated to the Peanut Peak Member in South Dakota. The term Chadron C is abandoned and the correlation with the Peanut Peak Member of South Dakota is rejected. The contact between the Peanut Peak Member and Big Cottonwood Creek Member of the Chadron Formation in northwestern Nebraska is intertonguing, except where strata of the Big Cottonwood Creek Member fill depressions and minor valleys in the Peanut Peak Member. The Peanut Peak Member of northwestern Nebraska differs from the Big

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Cottonwood Creek Member in that the Peanut Peak Member is composed of smectite-rich mudstone and claystone, weathers into hummocky hills and slopes, is less variegated in color, and has less silt. The Big Cottonwood Creek Member is siltier, cliff forming, and contains the various purplish-white layers of Schultz and Stout (1955). These proposed revisions and correlations are applicable to other exposures of the White River Group across the Great Plains.

INTRODUCTION

The Eocene/Oligocene White River Group of the northern Great Plains is composed of a thick sequence of volcaniclastic fluvial, eolian, and lacustrine strata that extend from southwestern North Dakota to northeastern Colorado (Fig. 1). The White River Group has been the subject of numerous studies over the past 150 yr. Starting with the expeditions of Meek and Hayden (1857) and Darton (1899), research on vertebrate and invertebrate paleontology, sedimentology, stratigraphy, and paleopedology of the White River Group has provided crucial information on mammalian evolution and the nature of late Paleogene paleoclimates (Hatcher, 1893; Wanless, 1922, 1923; Ward, 1922; Clark et al., 1967; Prothero and Berggren, 1992). Recent research has refined the chronology, biostratigraphy, and lithostratigraphy of the White River Group. The Chadronian-Orellan boundary, now placed at 33.59 ± 0.02 Ma (Obradovich et al., 1995), restricts the Chadronian Land-Mammal Age to the Late Eocene (Prothero and Swisher, 1992); a revision of the defining characters of the Chadronian/Orellan North American Land Mammal Age has just been proposed (Prothero and Whitlesey, this volume); a new lithostratigraphic unit, the Chamberlain Pass Formation, has been recognized as the oldest unit of the White River Group in the Big Badlands of South Dakota (Evans and Terry, 1994; Terry and Evans, 1994), and the lithostratigraphy of the White River Group of southwestern North Dakota has been recently revised (Murphy et al., 1993).

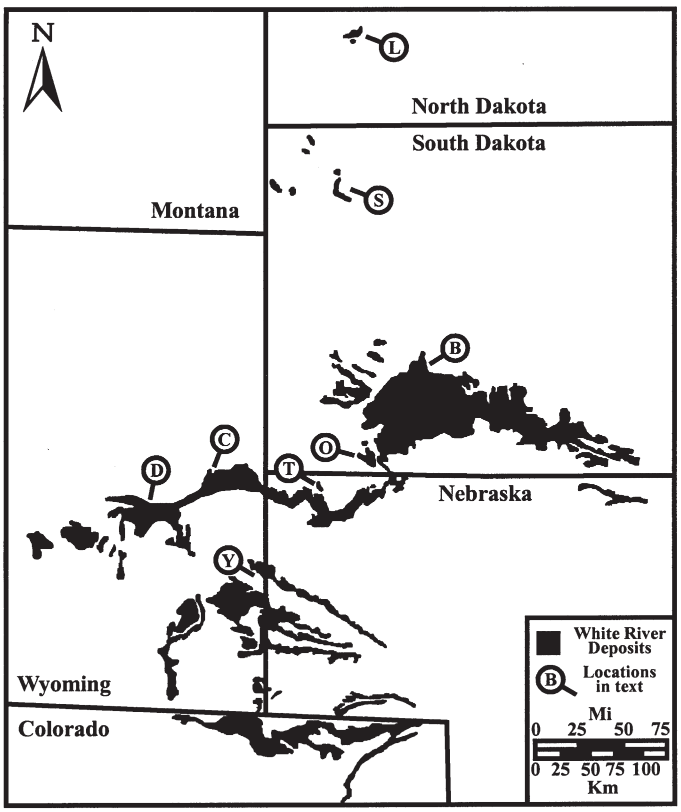


Figure 1. Generalized outcrop map of the White River Group/Formation across the northern Great Plains. Letters indicate particular research localities: B = Big Badlands/Badlands National Park, South Dakota; C = Lance Creek, Wyoming; D = Douglas, Wyoming; L = Little Badlands, North Dakota; O = Oelrichs, South Dakota; S = Slim Buttes, South Dakota; T = Toadstool Park, Nebraska; Y = Yoder, Wyoming. Modified from the American Association of Petroleum Geologists Geological Highway Map Series; Northern Great Plains (Map 12) (AAPG, 1972) and Northern Rocky Mountain Region (Map 5) (AAPG, 1984).

Based on my recent observations of the White River Group between the Big Badlands of South Dakota and the Toadstool Park area of northwestern Nebraska (Fig. 1), I propose a new lithostratigraphy for the lower part of the White River Group of northwestern Nebraska, namely, the Interior Paleosol Complex of Schultz and Stout (1955) and Chadron Formation, and provide herein a new lithostratigraphic correlation model to the Big Badlands of South Dakota. These lithostratigraphic revisions are based on criteria within the North American Stratigraphic Code (NACSN, 1983) for the recognition and definition of lithostratigraphic units, detailed measured sections, visual tracing of rock units, paleopedology, and use of the Big Badlands of South Dakota as a "standard section."

GEOGRAPHIC AND GEOLOGIC SETTING

The study area is located south of the Black Hills in the vicinity of Toadstool Park, Nebraska, a recreational area administered by the U.S. Forest Service (Fig. 1). Outcrops of the late Eocene–Oligocene White River Group in this area form the base of the Pine Ridge escarpment across Sioux and Dawes Counties. Isolated outliers occur north of the Pine Ridge escarpment and are either capped and protected by more resistant layers, such as limestone or sandstone, to form buttes and tables, or are eroded into steeply sloping and spired outcrops. Regional uplift during the Laramide Orogeny forced the retreat of the Cretaceous Interior Seaway, resulting in subaerial exposure and weathering of Cretaceous sediments in the study area. The Hartville, Laramie, and Black Hills uplifts provided sediment for late Eocene rivers that flowed east-southeast across the study area (Clark, 1975; Stanley and Benson, 1979). Uplift of the Black Hills is believed to have ended in the Eocene prior to deposition of the White River Group (Lisenbee and DeWitt, 1993). The majority of the White River Group is composed of air-fall and fluvially reworked volcaniclastics that rest unconformably on the pedogenically modified Cretaceous Pierre Shale. The volcaniclastics that constitute a large part of the White River Group were probably derived from volcanic sources in Nevada and Utah (Larson and Evanoff, 1995; this volume). The White River Group in northwestern Nebraska is overlain by the Arikaree Group.

SOUTH DAKOTA

I use the Big Badlands of South Dakota as a lithostratigraphic standard with which to compare the lithostratigraphy of northwestern Nebraska. The majority of recent stratigraphic revision and interpretation related to the Chadron Formation and older units is based on measured sections and descriptions in the Big Badlands of South Dakota (Retallack, 1983, Evans and Terry, 1994; Terry and Evans, 1994). These recent changes, along with older concepts, are briefly reviewed so that comparisons with Nebraska sections can be made.

The 'Interior Weathered Zone' of South Dakota

Across the northern Great Plains, the White River Group rests on a zone of ancient pedogenic modification. Several names have been applied to this zone of pedogenic alteration, including the Interior Phase (Toepelman, 1922; Ward, 1922), Interior Formation (Wanless, 1922), Interior Paleosol Complex (Schultz and Stout, 1955), Eocene Paleosol (Pettyjohn, 1966), Interior Zone (Clark et al., 1967), and Interior Paleosol (Harksen and Macdonald, 1969a; Martin, 1987). Subsequently, Retallack (1983) determined that this "zone" in the Big Badlands of South Dakota was composed of two separate paleosols, the lower Yellow Mounds Paleosol Series that developed on the Pierre Shale following the retreat of the Cretaceous Seaway, and the upper Interior Paleosol Series that developed on distinct overlying fluvial deposits (Fig. 2A). The Yellow Mounds Paleosol Series in the Big Badlands is easily recognized as a bright yellow- and orange-colored zone, up to 26 m (85 ft) in some locations, which gradually gives way to unaltered Pierre Shale with increasing depth. The Interior Paleosol Series in the Big Badlands of South Dakota is easily recognized as the reddish band seen above the Yellow Mounds Paleosol Series at the top of the Interior Zone (Fig. 2A).

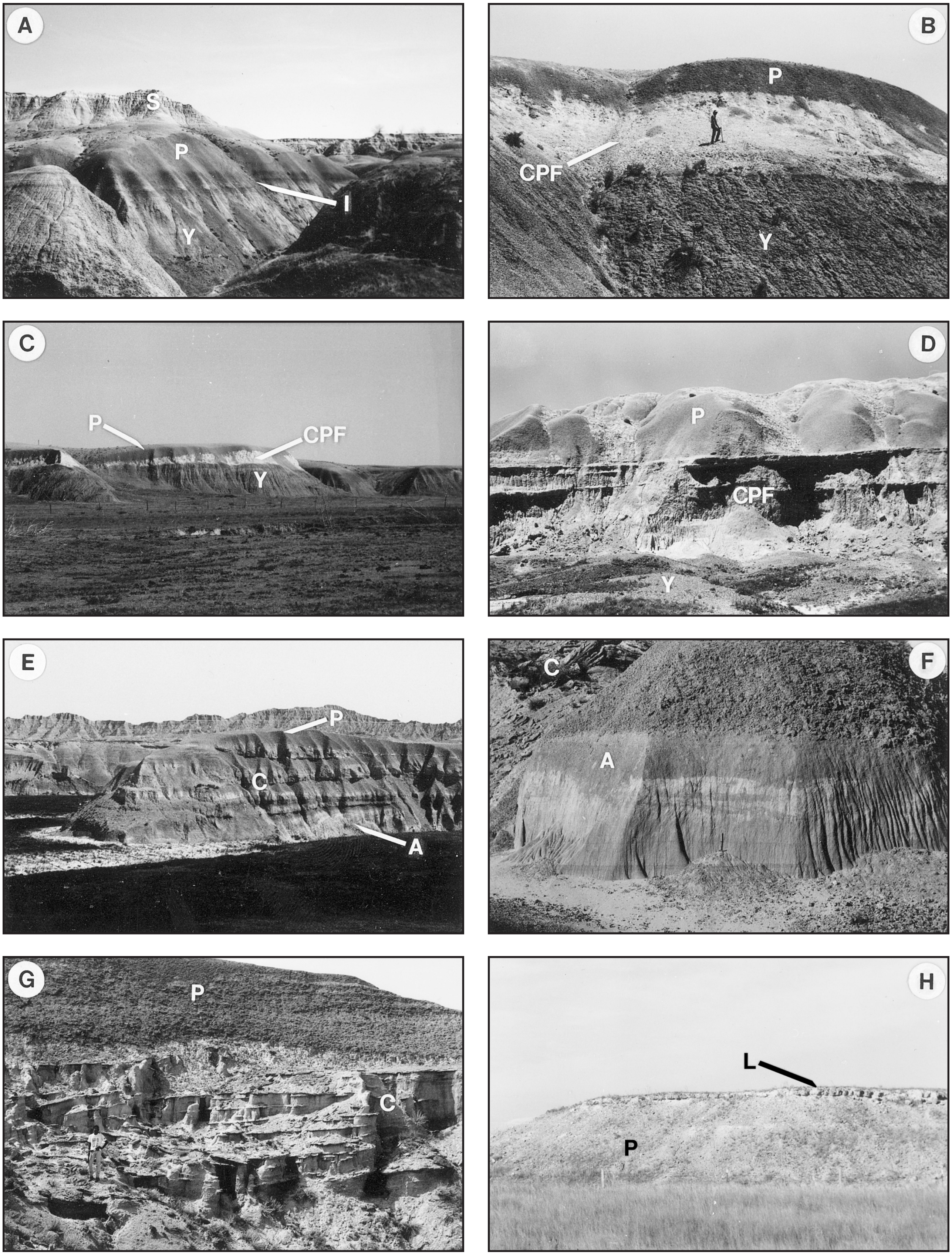
Terry (1991), Evans and Terry (1994), and Terry and Evans (1994) determined that the Interior Paleosol Series of Retallack (1983) represents the pedogenically modified distal overbank deposits of a distinct fluvial system predating the overlying Chadron Formation (Fig. 3A). Evans and Terry (1994) combined the Interior Paleosol Series, along with isolated, "blazing white" channel sandstone deposits considered by Clark et al. (1967) to be equivalent to the Slim Buttes Formation of northwestern South Dakota, into the Chamberlain Pass Formation in the Big Badlands of South Dakota (Fig. 2A–D). The Chamberlain Pass Formation represents the oldest preserved phase of Paleogene fluvial activity in the Big Badlands region following the final retreat of the Cretaceous Seaway. The Chamberlain Pass Formation of South Dakota is in all cases overlain by massive bluish-green and gray hummocky mudstones lithologically equivalent to the "undifferentiated Chadron Formation" (Fig. 2A–D) found outside of the Red River Valley of Clark (1937).

Chadron Formation of South Dakota

The intentions behind, and locations of, type section(s) for the Chadron Formation are not universally agreed on. The history of stratigraphic nomenclature for the Chadron Formation was reviewed by Harksen and Macdonald (1969a) and Singler and Picard (1980). I mention only those studies relevant to my stratigraphic revisions and correlations. Clark (1937) determined that the Chadron Formation was divisible into an eastern and western facies. According to Clark (1937), the eastern facies is composed of three members: (1) restricted basal white channel fills (Fig. 2C,D); (2) massive clays that contain intermittent limestone bands (Fig. 2C,D); and (3) laminated lenses of fine sand, silt, and limestone. The western facies is also composed of three members (Fig. 2E). The lowermost member consists of red and green sands and clays that fill the bottom of, and are confined to, a paleovalley (the Red River Valley) cut into and through the underlying Interior Zone (Fig. 2F). The base of the lower member is marked by a coarse gravel of quartz, quartzite, and granitic debris. The middle member is a succession of greenish clays and sands 12 to 15 m thick (40–50 ft) that contains fossils of brontotheres, rhinoceroses, *Mesohippus*, and *Archaeotherium* (Fig. 2G). The middle member is overlain by 6 to 9m (20–30 ft) of massive buff and green clay that contains numerous discontinuous limestone lenses and occasional, sharply restricted greenish-colored sandstone lenses (Fig. 2E,G). Clark recognized the upper member based on the decrease of sandstone and the disappearance of brontothere bones.

Based on an interfingering relationship of the eastern and western facies, Clark (1937) determined that: (1) the lower member of the western facies was restricted to the Red River Valley cut into the Interior Zone, but was somehow related to the basal white channel fills of the eastern facies; (2) the middle member of the western facies graded into the massive clays of the eastern facies; and (3) the upper member of the western facies correlates to the laminated lenses of the eastern facies. Clark (1954) eventually designated the lower, middle, and upper members of the western facies as the Ahearn, Crazy Johnson, and Peanut Peak Members, respectively (Fig. 2E).

Clark (1937) was uncertain of the exact age relationships of the eastern facies basal white channel fills and the lowermost member of the western facies (Ahearn Member; Fig. 2B,C,F). He recognized a difference in mineralogy and paleotopographic position, and suggested that the basal white channel fills of the eastern facies were tributaries that were left hanging by the downcutting of the ancient Red River (Clark, 1937). Clark et al.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(1967) later suggested a correlation of the basal white channel fills of the eastern facies to the Eocene Slim Buttes Formation in Harding County, northwestern South Dakota. According to Clark et al. (1967), the Crazy Johnson and Peanut Peak Members are identifiable only where they overlie the Red River Valley (Figs. 2E–G, 3A). These two units blend indistinguishably into a uniform blanket of undifferentiated, bluish-green, hummocky mudstones outside the Red River paleovalley (Figs. 2A–D, 3A).

The stratigraphic succession of pedogenically altered Pierre Shale (Yellow Mounds Paleosol Series), Chamberlain Pass Formation (Interior and Weta Paleosol Series, and blazing white channel sandstone), and deposits of the Chadron Formation outside the Red River Valley produces a characteristic pattern of colors and lithologies that can be recognized in outcrops of the White River Group throughout the Big Badlands region (Figs. 2A–D, 3A). The entire Big Badlands region is underlain by pedogenically altered Pierre Shale, which displays mainly bright yellow colors, but also contains purple, lavender, and orange (Fig. 2A). The altered Pierre Shale is unconformably overlain by the Chamberlain Pass Formation. The Chamberlain Pass Formation is easily recognized as the reddish stripe at the top of the Interior Zone and white channel sandstone bodies (Fig. 2A–D). The Chamberlain Pass Formation is overlain by the bluish-green, hummocky, undifferentiated mudstone of the Chadron Formation deposited outside of the Red River Valley (Fig. 2A–D). The undifferentiated Chadron mudstone in the Big Badlands is overlain by the Brule Formation. The contact between the Chadron and Brule Formations is easily recognized by the change from the bluish-green, hummocky, popcorn-textured weathered surface of the Chadron Formation to the tread-and-riser topography of the silty, brown, beige, and red-striped Brule Formation (Fig. 2A). The upper part of the Peanut Peak Member occasionally contains several lacustrine limestone beds (Evans and Welzenbach, this volume). These limestone beds sometimes mark the contact of the Chadron and Brule Formations (D. O. Terry, 1995, unpublished data), and also occur as resistant caprocks on isolated buttes protecting the underlying Peanut Peak Member (Fig. 2H).

Figure 2. Photographs of the pedogenically modified Pierre Shale (Yellow Mounds Paleosol Series = Y), Interior Paleosol Series (I) within the Chamberlain Pass Formation (CPF), Peanut Peak Member (P) of the Chadron Formation, and Scenic Member (S) of the Brule Formation outside of the Red River Valley in the Big Badlands of South Dakota. A; Location D in Figure 3A; B; location A in Figure 3A; C; location E in Figure 3A; D; location G in Figure 3A; E–G; Ahearn (A), Crazy Johnson (C), and Peanut Peak Members of the Chadron Formation within the Red River Valley of Clark et al. (1967) in Figure 3A. Red River Valley outcrops located in the NW1/4 sec. 33, T. 43 N., R. 12 E., Heutmacher Table. Pick in bottom center of 2F, 90 cm long. Note person in center left of Figure 2G for scale. H: Lacustrine limestone (L), similar to the Bloom Basin limestone beds of Evans and Welzenbach (this volume), overlying the Peanut Peak Member of the Chadron Formation. Outcrop located in the S1/2NE1/4 sec. 12, T. 4 S., R. 18 E., Conata 7.5′ Quadrangle.

OBSERVATIONS IN NORTHWESTERN NEBRASKA

The same stratigraphic succession of lithology and colors of the pedogenically altered Pierre Shale, Chamberlain Pass Formation, and undifferentiated Chadron Formation in the Big Badlands of South Dakota is also present in the Toadstool Park region of northwestern Nebraska. Based on measured sections, paleopedology, and visual tracing of these units between the Big Badlands and Toadstool Park, the following pedostratigraphic and lithostratigraphic terms are extended from the Big Badlands of South Dakota and applied to exposures in the Toadstool Park area: *Yellow Mounds Paleosol Equivalent, Interior Paleosol Equivalent, Weta Paleosol Equivalent, Chamberlain Pass Formation,* and *Peanut Peak Member* of the Chadron Formation. This terminology is used throughout the following descriptions of paleosol profiles and measured sections in the Toadstool Park area. Comparisons with previous stratigraphic paradigms in the Toadstool Park area and concepts of regional correlation are discussed following descriptions of measured sections.

'Interior Paleosol Complex' of northwestern Nebraska

The same episodes of pedogenesis that formed the Yellow Mounds and Interior Paleosol Series of Retallack (1983) in South Dakota are herein recognized in Nebraska (Fig. 4) and serve to divide the Interior Paleosol Complex of Schultz and Stout (1955) into two distinct paleosol profiles. These episodes of pedogenesis qualify as *geosols*, ancient land surfaces of regional extent and stratigraphic utility that represent significant periods of pedogenesis (NACSN, 1983). Application of the terms Yellow Mounds, Interior, and Weta within the following paleosol descriptions does not imply that the same types of paleosols are preserved within the Toadstool Park region, only that they are similar in their general environment and parent materials on which they formed.

Within modern landscapes, the type of soil, and hence the classification of that soil, can change within distances of only a meter. This concept is valid for paleosols as well. Retallack (1994) has proposed the term *pedotype* for recognizing individual types of paleosol profiles. Each pedotype serves as a "type profile" to which other paleosols can be compared. Pedotypes are named for the area in which they occur, or for distinct characteristics of the paleosol. At this time, the terms Yellow Mounds, Interior, and Weta are valid only for the original sections in which they were described. The paleosols within the Interior Paleosol Complex of northwestern Nebraska, specifically within the Chamberlain Pass Formation, appear to differ sufficiently from the original descriptions of Retallack (1983) and Terry and Evans (1994) to warrant classification as new pedotypes. This is beyond the scope of this chapter. I therefore use the term "paleosol equivalent" to recognize a correlative *episode of pedogenesis* that created similar altered zones on top of the Pierre Shale (Yellow Mounds *Paleosol Equivalent*), and altered the Chamberlain Pass Formation (Interior *Paleosol*

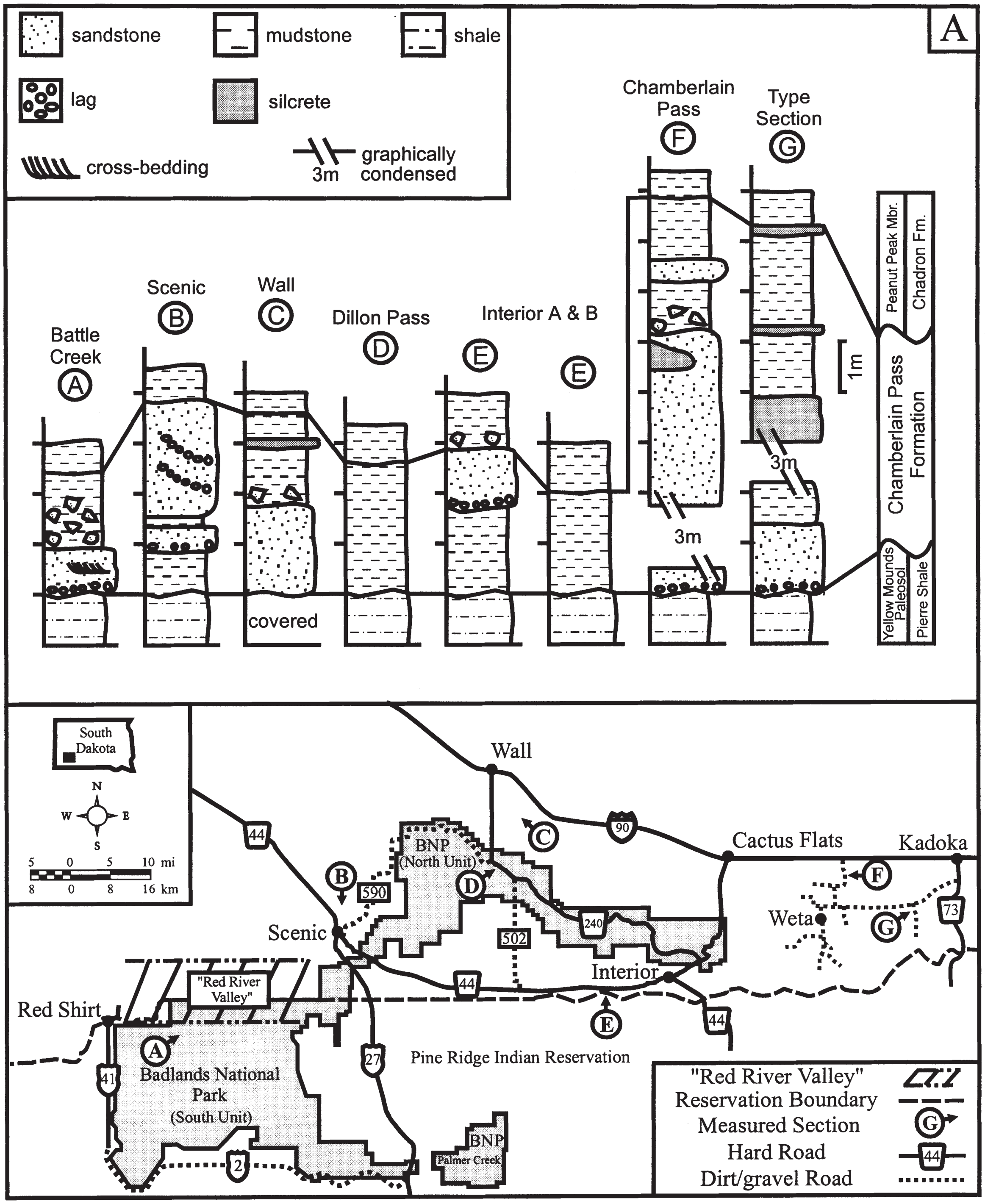


Figure 3A: Location map and measured sections of the Yellow Mounds Paleosol Equivalent, Chamberlain Pass Formation, and Peanut Peak Member of the Chadron Formation in the Badlands National Park area in relation to the "Red River Valley" of Clark et al. (1967) (modified from Evans and Terry, 1994). The section at Dillon Pass is based on data from Retallack (1983). Locations of measured sections as follows: A: SW1/4 sec. 12, T. 42 N., R. 46 W., Heutmacher Table 7.5′ Quadrangle. B: Center of sec. 11, T. 3 S., R. 13 E., Scenic 7.5′ Quadrangle. C: SW1/4SE1/4 sec. 26, T. 1 S., R. 16 E., Wall 7.5′ Quadrangle. D: NW1/4SW1/4 sec. 21, T. 2 S., R. 16 E., Wall SW 7.5′ Quadrangle. E: SE1/4SW1/4NW1/4 sec. 12, T. 4 S., R. 17 E., Conata 7.5′ Quadrangle. F: NE1/4NE1/4SE1/4NW1/4, sec. 2, T. 3 S., R. 20 E. G: E 1/2NE1/4, sec. 21, T. 3 S., R. 21 E., Kadoka Quadrangle.

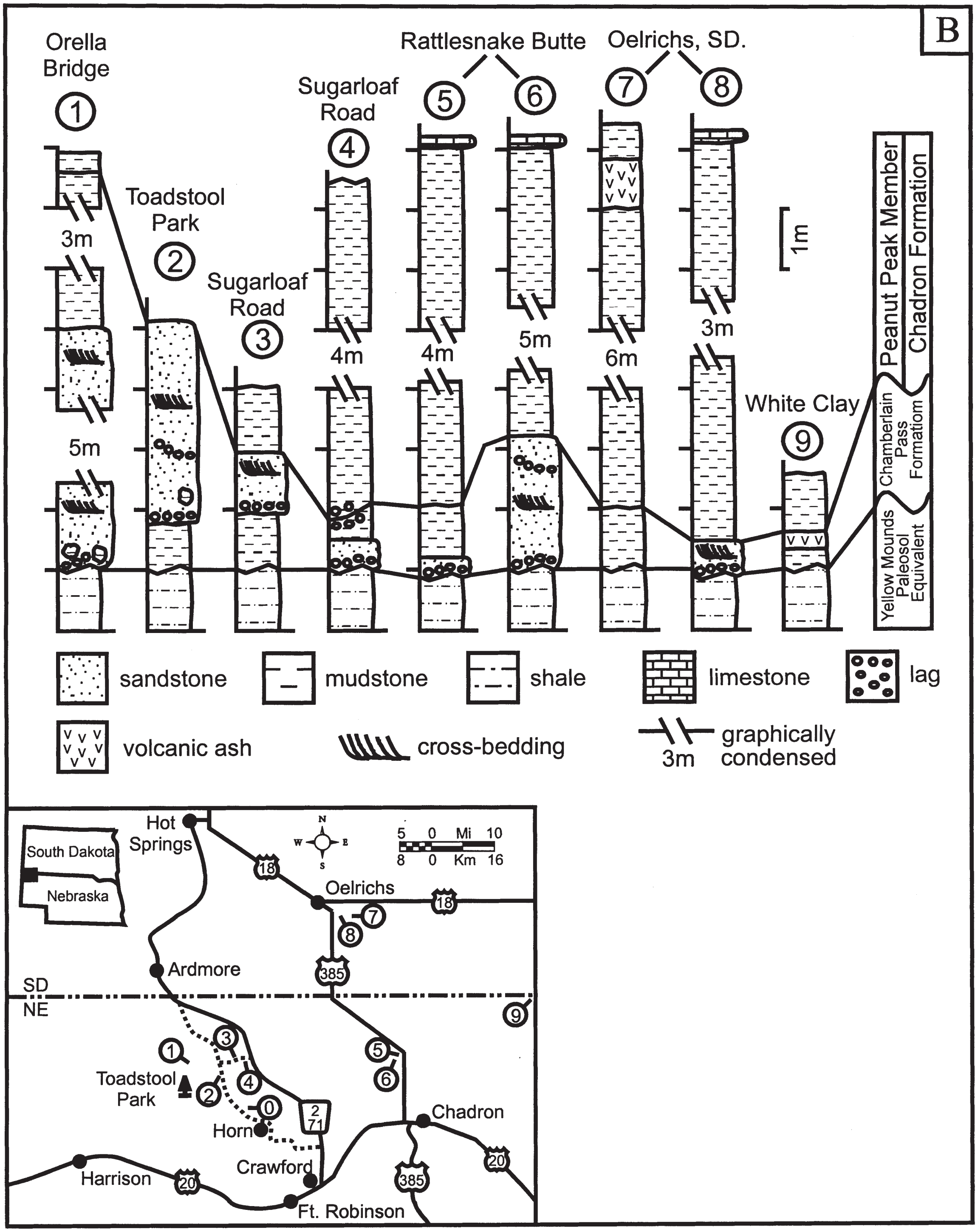


Figure 3B: Location map and measured sections of the Yellow Mounds Paleosol Equivalent, Chamberlain Pass Formation, and Peanut Peak Member of the Chadron Formation in northwestern Nebraska and southwestern South Dakota. Modified from Terry et al. (1995). Locations of measured sections are as follows: 1: NE1/4NE1/4SW1/4SW1/4SEC 36, T. 34 N., R. 54 W., Five Points 7.57, T. 34 N., R. 52 W., Wolf Butte 7.5′ Quadrangle. 4: NE1/4SE1/4SW1/4 sec. 18, T. 34 N., R. 52 W., Wolf Butte 7.5′ Quadrangle. 5, 6: NE1/2 sec. 9, T. 34 N., R. 49 W., Bohemian Creek 7.5′ Quadrangle. 7: SE1/4SE1/4SW1/4 sec. 16, T. 10 S., R. 8 E., Oelrichs 7.5′ Quadrangle. 8. SE1/4SE1/4 sec 17, T. 10 S., R. 8 E., Oelrichs 7.5′ Quadrangle. 9. NW1/4 sec. 24, T. 35 N., R. 45 W., Whiteclay 7.5′ Quadrangle.

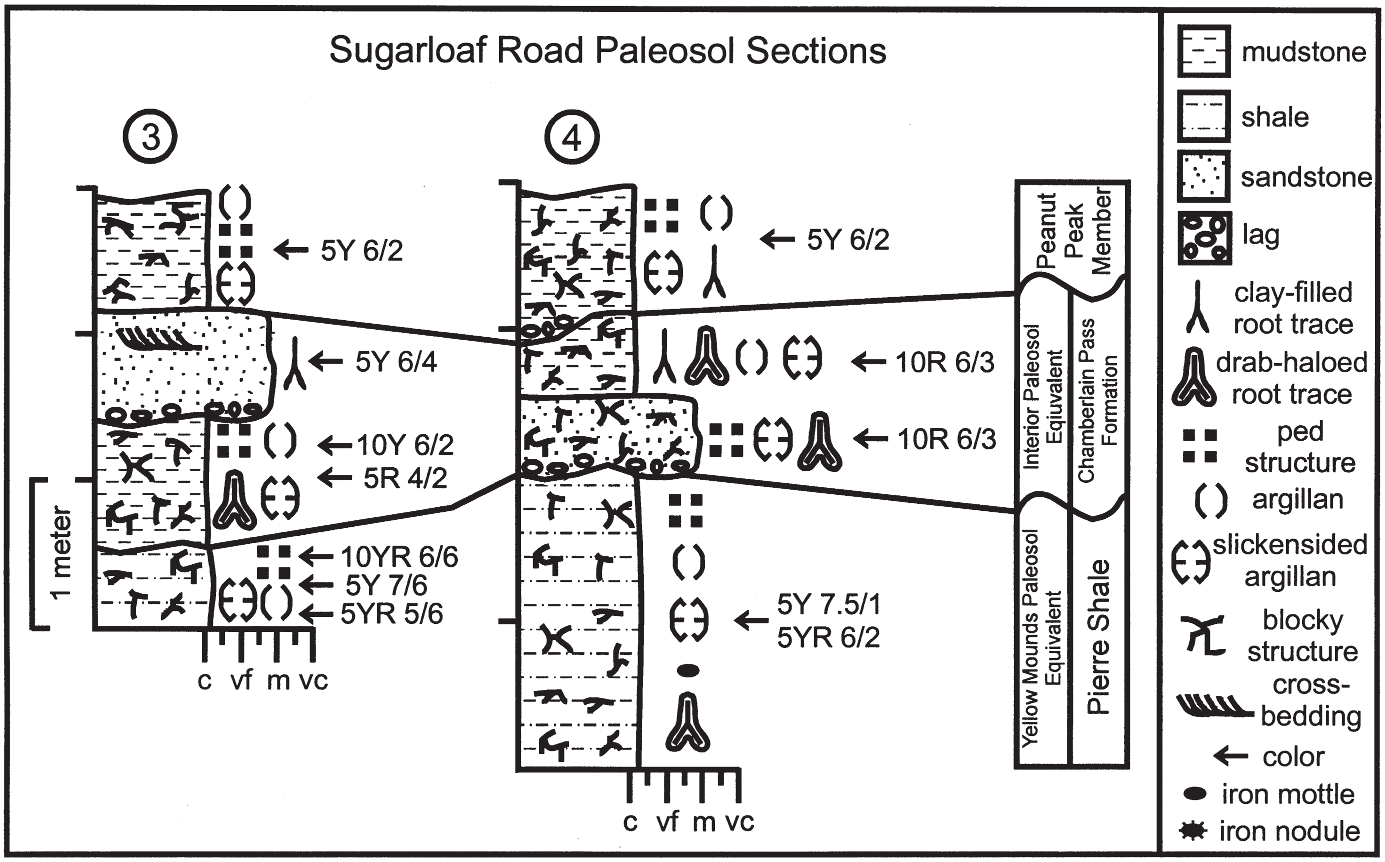


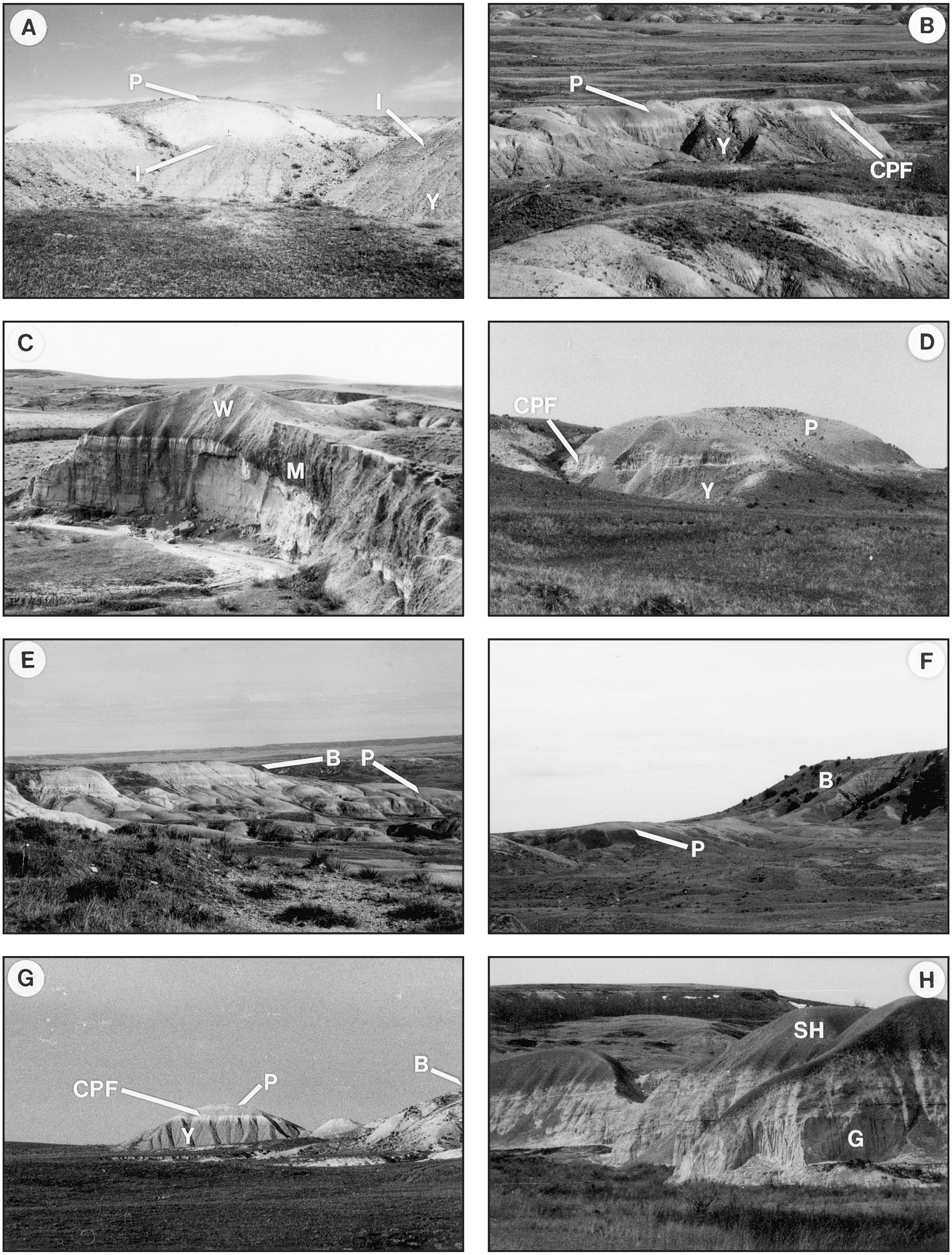
Figure 4. Measured sections of the Pierre Shale and Chamberlain Pass Formation (Interior Paleosol Complex of Schultz and Stout, 1955) in northwest Nebraska showing the pedogenic characteristics of the Yellow Mounds Paleosol Equivalent and Interior Paleosol Equivalent. Measured sections correspond to locations in Figures 3B and 5A,B. Color designations based on Munsell Soil Color Charts (1975).

Equivalent and Weta *Paleosol Equivalent*), to establish correlations to South Dakota.

In northwestern Nebraska, the Interior Paleosol Complex (Schultz and Stout, 1955) is composed of two separate paleosols that developed on different parent materials (Fig. 4). The lower paleosol (Yellow Mounds Paleosol Equivalent) developed on the Cretaceous Pierre Shale and altered the normally black shale to bright yellow, purple, lavender, and orange (Fig. 5A). Pedogenic alteration gradually decreases downward and gives way to unaltered black shale. Pedogenic features are common, including soil horizons, root traces, argillans, concretions, and nodules. In places (Fig. 5C), the Yellow Mounds Paleosol Equivalent has been completely removed by rivers of a younger, overlying fluvial system, sometimes resulting in blocks of altered Pierre Shale being incorporated into the channel sandstone facies of this younger fluvial system.

The upper paleosol (Interior Paleosol Equivalent) developed on the channel sandstone and overbank mudstone facies of a distinct, post-Pierre/pre-Chadron fluvial unit, the Chamberlain Pass Formation (Figs. 5A–D, 6A). The lower contact of the Chamberlain Pass Formation with the Yellow Mounds Paleosol Equivalent is unconformable, and easily recognized by a change in color and lithology from the underlying black or bright yellow Pierre Shale

Figure 5. Photographs of the Yellow Mounds Paleosol Equivalent (Y), Interior Paleosol Equivalent (I), Weta Paleosol Equivalent (W), Chamberlain Pass Formation (CPF), and the Peanut Peak (P) and Big Cottonwood Creek Members (B) of the Chadron Formation in eastern Wyoming, northwestern Nebraska, southwestern South Dakota and southwestern North Dakota. Yellow Mounds Paleosol Equivalent and Interior Paleosol Equivalent = the Interior Paleosol Complex of Schultz and Stout (1955). Peanut Peak Member = the lower part of the Chadron B of Schultz and Stout (1955). Big Cottonwood Creek Member = the upper potion of the Chadron B, Chadron C, and Orella A of Schultz and Stout (1955). A; Location 3 in Figure 3B. Rock pick in center of photograph is 90 cm long. B: Location 4 in Fig. 3B. C: Loc. 1 of Figs. 3B and 6A. The channel sandstone facies of the Chamberlain Pass Formation (Chadron A of Schultz and Stout, 1955) rests on the Pierre Shale (covered). The channel sandstone is overlain by 5YR 6/4 (light reddish-brown) mudstone (M) that formed a clay plug within an abandoned meander loop. D; Location 6 of Figures 3B and 6C. E; Location 4 of Figure 3B. F; Locations 7 and 8 of Figure 3B. G; Exposures at Location C in Figure 1 near Lance Creek, Wyoming. Outcrop is located at the intersection of Highways 270 and 272, ~4.8 km (3 mi) northeast of Lance Creek. H; Exposures at Location L in Figure 1 near Dickinson, North Dakota. Outcrop located in the E1/2 sec. 7, T. 137 N., R. 97 W., New England NW Quadrangle. G = Golden Valley Formation, SH = South Heart Member of the Chadron Formation (Murphy et al., 1993).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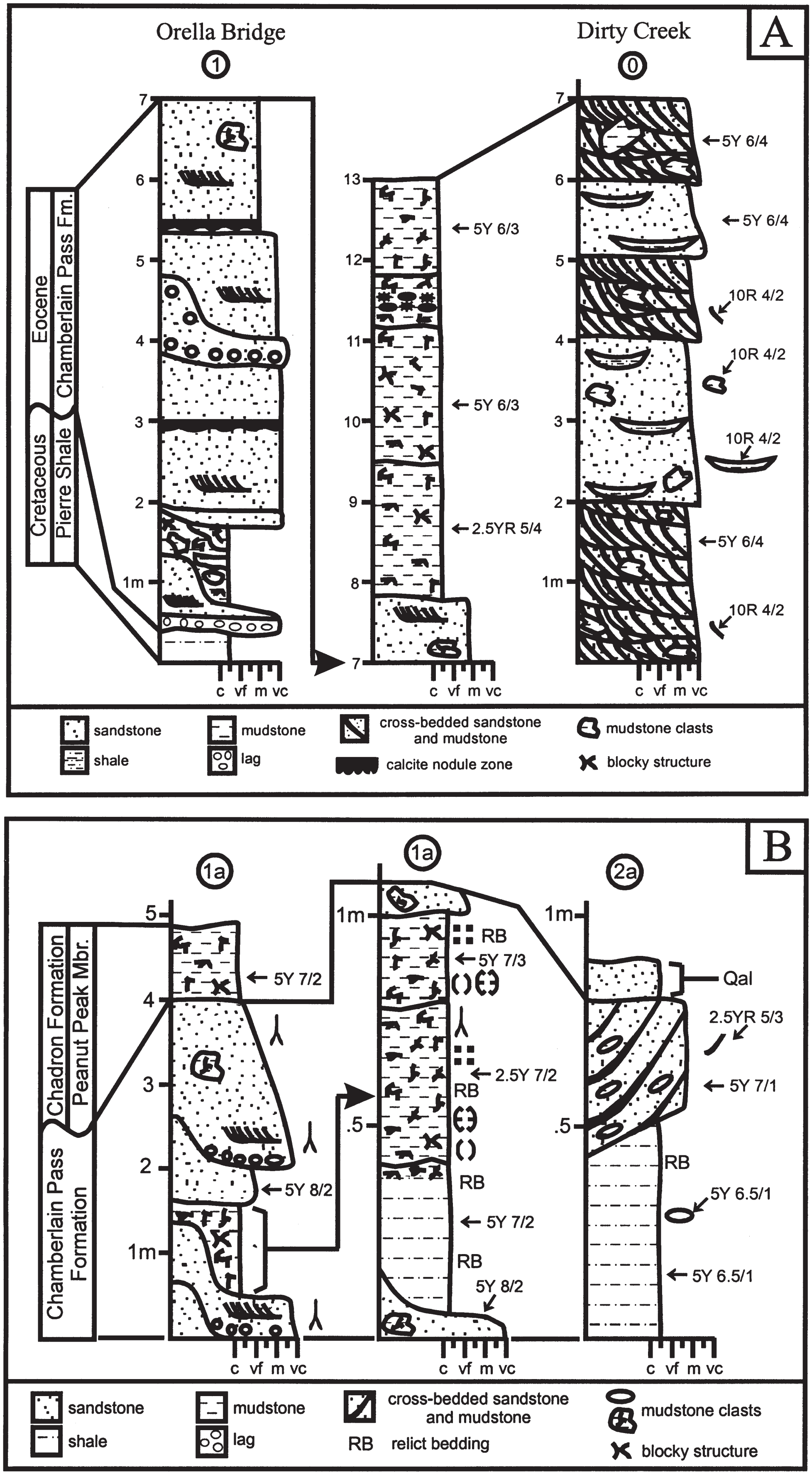
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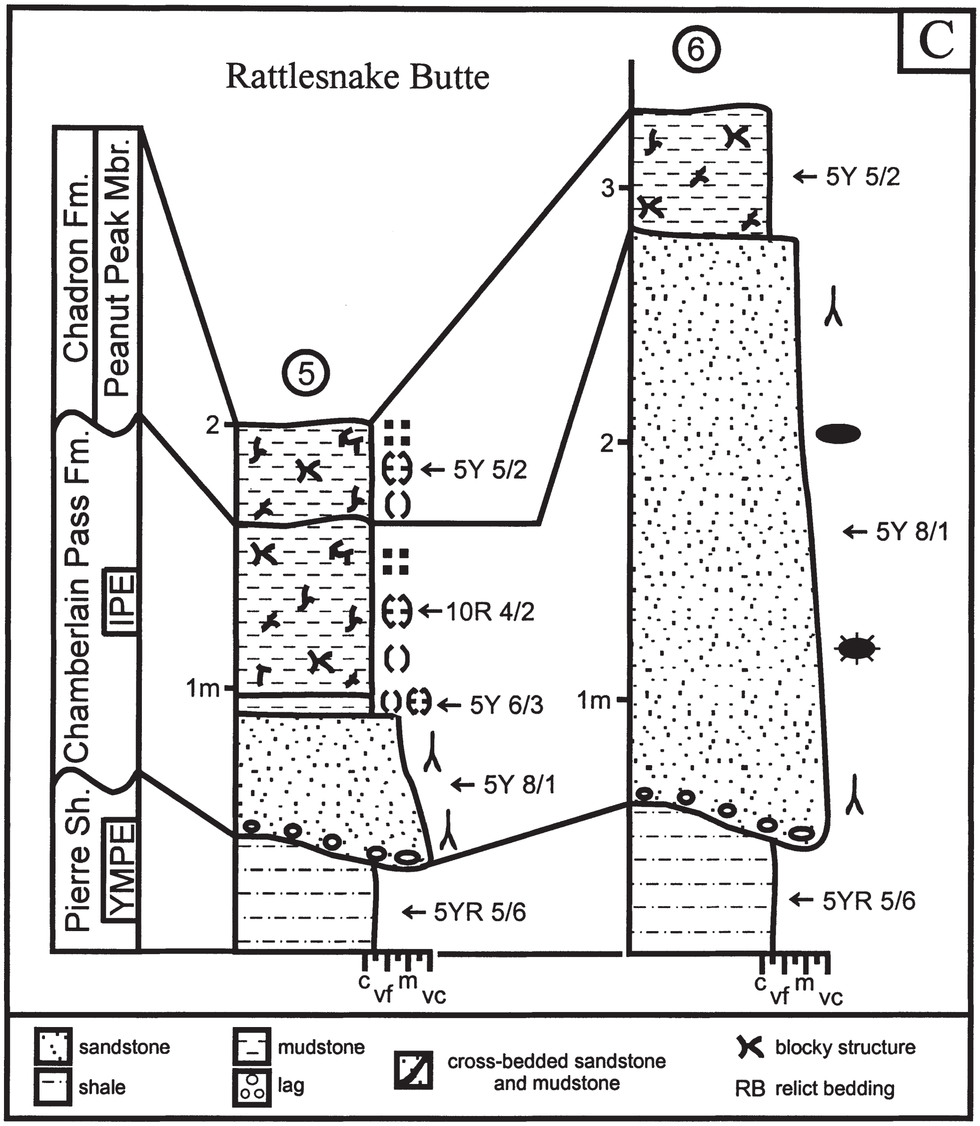

Figure 6 (on this and facing page). Detailed measured sections of various outcrops in the Toadstool Park area showing pedogenic structures and lithologic characteristics of stratigraphic units. A; Measured sections of the Orella Bridge exposure of Figures 3B and 5C and the Dirty Creek exposure. The Dirty Creek measured section is located in the NW1/4SW1/4NW1/4 sec. 13, T. 33 N., R. 53 W., Roundtop 7.5′ Quadrangle. The Dirty Creek Section is notable for its large amount of 10R 4/2 mudstone clasts, presumably derived from bank failure, and cross-bedded sands and 10R 4/2 muds. B; Section 1A is associated with the Orella Bridge exposures of Figures 3B and 5C and is located ~1.6 km to the west in the SW1/4SW1/4 sec. 35, T. 34 N., R. 54 W., Five Points 7.5′ Quadrangle. Section 2a is within the Big Cottonwood Creek Drainage, ~0.8 km to the northwest of Section 2 in Figure 3B, within the SW1/4NE1/4 sec. 4, T. 33 N., R. 52 W., Roundtop 7.5′ Quadrangle. C; Sections 5 and 6 of Figures 3B and 5D at Rattlesnake Butte. See Figure 4 for additional explanations of lithologic and pedogenic symbols.

to white channel sandstone and red overbank mudstone of the Chamberlain Pass Formation (Fig. 5A–D). The channel sandstone lithofacies of the Chamberlain Pass Formation is composed of as much as 8 m (26 ft) of yellowish, pale olive, and white, medium- to coarse-grained, trough and tabular cross-bedded sandstones commonly marked by a basal lag (Figs. 5B–D, 6A). Sandstone bodies are multistoried, showing rough fining-upward sequences. Although lateral accretion surfaces have not been identified, the ancient rivers could be considered "meandering" in the sense that they show evidence of lateral migration, including bank failure due to undercutting, general fining upward with eventual pedogenic modification of cohesive overbank deposits, and oxbow lakes that were filled to form clay plugs. Vertical accretion is suggested by the superposition of channel sandstone over mudstone and mudstone over sandstone (Fig. 3B). The channel sandstone facies occasionally contains thin, lenticular mudstone bodies that have been modified by pedogenesis (Fig. 6B).

The overbank mudstone lithofacies of the Chamberlain Pass Formation is composed predominantly of massive mudstone that has been overprinted by pedogenesis. Occasional silty yellowish-olive mudstone and siltstone units constitute a proximal overbank facies ranging as much as 3 m (9.8 ft) in thickness. The distal overbank mudstone lithofacies ranges in thickness from 0.8 to 1.8 m (2.6–6), and is easily recognized as a reddish stripe that overlies the yellow and orange Yellow Mounds Paleosol Equivalent (Figs. 4, 5A). Proximal overbank mudstones were subjected to different pedogenic processes than distal overbank areas, and sometimes contain Fe-oxide concretions and nodules resulting from alternating wet and dry soil conditions (Weta Paleosol Equivalent).

The upper contact of the Chamberlain Pass Formation/Interior Paleosol Equivalent with the overlying Chadron Formation is unconformable and easily recognized by a change in color and lithology. The Chamberlain Pass Formation is composed of yellowish, pale olive, and white channel sandstone and the red and yellowish-olive mudstone. This sharply contrasts with the bluish-green and gray hummocky mudstone of the overlying Chadron Formation (Figs. 5B,D, 6B,C). Depending on the proximity to Chamberlain Pass Formation channels, the upper contact is sometimes very sandy, possibly as the result of incorporation of channel sands of the Chamberlain Pass Formation into the overlying Chadron Formation.

Measured sections of the "Interior Paleosol Complex" in northwestern Nebraska. Recognition and differentiation of both periods of pedogenic modification and their associated lithostratigraphic units are straightforward. Two measured sections (sections 3 and 4 of Fig. 3B) are described here (Fig. 4) to establish the validity of paleosol differentiation, lithostratigraphic divisions, and correlations to South Dakota. Colors are based on Munsell Soil Color Charts (1975). All colors are from fresh, excavated samples unless denoted otherwise.

Section 3 (Figs. 3B, 4, 5A) is marked at its base by modified Pierre Shale (Yellow Mounds Paleosol Equivalent). The Yellow Mounds Paleosol Equivalent is colored 10YR 6/6 (dark yellowish-orange), 5YR 5/6 (light brown), and 5Y 7/6 (moderate yellow). Pedogenic features include argillans coating peds and lining fractures within the soil, and slickensided argillans possibly formed by lithostatic compaction, or the expansion and contraction of the soil profile by wetting and drying. This zone of pedogenic alteration shows relict bedding from the original depositional fabric of the Pierre Shale. Progressing upward, the Yellow Mounds Paleosol Equivalent is replaced by the pedogenically altered overbank mudstone facies of the Chamberlain Pass Formation. The change is gradual over several centimeters and is recognized as reddish argillans (5R 4/2, grayish-red) from the overlying paleosol that coat, and eventually surround, fragments of the underlying Yellow Mounds Paleosol Equivalent.

The overlying paleosol (Interior Paleosol Equivalent) of the Chamberlain Pass Formation contains red (5R 4/2, grayish-red) platy peds with argillans and slickensided argillans of the same color, 0.5 to 2 mm in diameter mottles (5GY 7/4; moderate yellow green) mottles that are sometimes surrounded by 10YR 6/6 (dark yellowish-orange) haloes. These mottles likely represent drab-haloed root traces as defined by Retallack (1983). Some mottles are large, as much as 10 cm long by 1 to 3 cm wide. Some mottles are reversed in color, with the 10YR 6/6 (dark yellowish-orange) color surrounded by the 5GY 7/4 (moderate yellow-green). Progressing upward, peds become subangular blocky with the same argillans, slickensided argillans, and mottles seen lower in the Interior Paleosol Equivalent. The top of the 5R 4/2 (grayish-red) part of the Interior Paleosol Equivalent is marked by a transitional, but wavy, contact over 2 cm to a 13-cm-thick 10Y 6/2 (pale olive) claystone.

This overlying pale olive claystone also contains pedogenic features, including 1-to-3 mm 10YR 6/6 (dark yellowish-orange) mottles, platy peds, and slickensided argillans. Inclusions of the underlying 5R 4/2 (grayish-red) mudstone are common within this zone. The top of this paleosol is sharply truncated by a channel sandstone of the Chamberlain Pass Formation. The contact is marked by a lag dominated by quartz and quartzite pebbles and cobbles, and numerous claystone and mudstone clasts that give this basal lag a rusty iron color. The clay and mud chip lag is a combination of 5R 3/4 (dusky red), 10YR 6/6 (dark orangish-yellow), and 5YR 5/6 (light brown) fragments that represent erosion of the underlying Yellow Mounds Paleosol Equivalent and pedogenically modified mudstone of the Chamberlain Pass Formation. This basal lag is 7 cm thick and changes upward into a 5Y 7/2 (yellowish-gray) clay chip dominated zone before giving way to a 77-cm-thick, coarse- to fine-grained 5Y 6/4 (dusky yellow) channel sandstone. The sandstone is capped by 5Y 6/2 (light olive-gray) mudstone of the Chadron Formation. The contact is gradational, likely reflecting the incorporation of Chamberlain Pass Formation sediments into the base of the overlying Chadron Formation.

Section 4 is located ~1 km east of section 3 (Figs. 3B, 4, 5B). The base of section 4 is also marked by the Yellow Mounds Paleosol Equivalent (Figs. 4, 5B). Progressing upward, the color of the Yellow Mounds Paleosol Equivalent remains constant as a mixture of 5Y 7.5/1 (light gray) and 5YR 6/2 (pinkish-gray) shale. Pedogenic features are numerous, including angular blocky, and platy peds, 5-by-1-cm iron mottles (7.5YR 5/6, strong brown) that parallel relict bedding, argillans and slightly slickensided argillans, and 10YR 6/6 (dark orangish-yellow) root traces as much as 5 cm wide that branch downward and are sometimes filled with gypsum. Closer to the contact, 10R 4/3 (weak red) slickensided argillans from the overlying paleosol (Interior Paleosol Equivalent) have formed within the Yellow Mounds Paleosol Equivalent. The contact with the overlying Chamberlain Pass Formation is sharp and erosive.

The base of the Chamberlain Pass Formation at this locality is marked by a band of large, cherty cobbles as much as 8 cm in diameter. Root traces from the underlying Yellow Mounds Paleosol Equivalent are truncated by this contact. Root traces from the overlying Interior Paleosol Equivalent extend downward into this band of cobbles, are deflected around the cobbles, and eventually penetrate into the underlying Yellow Mounds Paleosol Equivalent. The Chamberlain Pass Formation changes upward from a 47-cm-thick, 10R 6/3 (pale red) clay-rich sandstone to a 54-cm-thick, 10R 6/3 (pale red) silty claystone. The upper 7 cm of the sandstone is brecciated, likely due to pedo-brecciation. Pedogenic features are numerous, including platy and subangular peds, argillans and slickensided argillans, root traces identical in size and color to those from the Yellow Mounds Paleosol Equivalent, and 10R 4/2 (weak red) clay-filled root traces. A large amount of claystone breccia is also present in this interval, but decreases upward. The breccia ranges in size from 1 to 15 mm and is 2.5YR 6/2 (pale red) and 10R 4/3 (weak red) in color. The breccia is likely derived from the lateral migration and cutbank erosion of cohesive overbank sediments by rivers of the Chamberlain Pass Formation. The top contact of the Chamberlain Pass Formation is sharply truncated by an erosion surface and is marked by a thin band of fluvially transported quartz and quartzite cobbles. Root traces within Chamberlain Pass Formation are truncated at the upper contact. The Chamberlain Pass Formation is overlain by 5Y 6/2 (light olive-gray) mudstone of the Chadron Formation. Chadron Formation mudstone was also altered by pedogenesis, as indicated by the presence of argillans, slickensided argillans, platy and angular blocky peds, and clay-filled (10YR 5.5/1, gray) root traces.

Age. The age of the Yellow Mounds Paleosol Equivalent is constrained by the age of overlying units across the northern Great Plains. Pettyjohn (1966) described a regionally extensive zone of alteration (the "Eocene Paleosol") across the northern Great Plains that had formed on units as old as the Early Cretaceous Skull Creek Shale, and as young as the Slim Buttes Formation in northwestern South Dakota. The Eocene Paleosol is overlain by the White River Group across the study area. Although Pettyjohn (1966) acknowledged the likely time-transgressive nature of the Eocene Paleosol, he considered the period of soil formation to be predominantly of Eocene age. Retallack (1983) classified the Yellow Mounds Paleosol Series as an Ultisol. Modern soils of a similar nature are estimated to require at least 10,000 yr, to possibly several million years, to form (Cady and Daniels, 1968; Buol et al., 1973; Birkeland, 1974; Soil Survey Staff, 1975). No direct age determination for the duration of pedogenesis that formed the Yellow Mounds Paleosol Equivalent in the Toadstool Park area can be made, other than it is post–late Cretaceous to late Eocene in age.

No radiometric dates have been obtained from the Chamberlain Pass Formation in South Dakota or Nebraska, although exposures of the Chamberlain Pass Formation immediately west of White Clay, Nebraska are overlain by a white bentonite (location 9 of Fig. 3B). Careful searching may yield a pocket of datable material. The best estimates come from comparisons to fossils recovered from lithologic units of the same stratigraphic position and general lithology as the Chamberlain Pass Formation, and age constraints from overlying deposits. Vertebrate fossils from the Chamberlain Pass Formation are rare, but those that have been identified indicate a Chadronian "age" (Wood et al., 1941; Emry et al, 1987). Vertebrate fossils from the Chamberlain Pass Formation include a fragment of *Trigonias* (Clark et al., 1967) from the channel sandstone facies near Kadoka, South Dakota (loc. G of Fig. 3A), Chadronian vertebrates from beds of similar lithology and stratigraphic position in the East Short Pine Hills in southwestern Harding County, South Dakota (Lillegraven, 1970), and a brontothere jaw from the channel sandstone facies of the Chamberlain Pass Formation (loc. 1 of Figs. 3B, 5C) in northwestern Nebraska (Vondra, 1958b). This brontothere (UNSM field nos. 205-55/206-55) was recently located in the University of Nebraska State Museum collections and prepared (see LaGarry et al., 1996), and includes well-preserved right and left mandibles of a small individual and several isolated teeth. The jaws are unique in that the p2–m3 length of 29 cm is larger than that reported for *Duchesneodus* (see Lucas and Schoch, 1989), but smaller than that reported for typical medial Chadronian brontotheres, such as *Brontops* (see Mader, 1989). Although measurements and comparisons are preliminary, this brontothere may represent an early or medial Chadronian species.

This evidence, combined with the recently published age revision of the Chadronian North American Land-Mammal "age" (Swisher and Prothero, 1990), restricts the Chamberlain Pass Formation to the late Eocene. In addition to Vondra's (1958b) brontothere mandibles, LaGarry et al. (1996) have recovered a suite of vertebrate remains from the overbank and channel sandstone facies of the Chamberlain Pass Formation in northwestern Nebraska. The remains are fragmentary, but once identified may help to refine the age of the Chamberlain Pass Formation in northwestern Nebraska.

Chadron Formation of northwestern Nebraska

Lower member. The Chadron Formation of northwestern Nebraska is composed of two distinct members that are recognized on the basis of lithology, color, and erosional relief (Fig. 5E). The lower member, to which the name *Peanut Peak Member* is applied, is composed of as much as 8.65 m (28 ft) of predominantly bluish-green and gray hummocky mudstone with occasional pockets of red, green, and yellow mudstone in upper parts (Figs. 3B, 4, 5A). This unit is smectite-rich, weathers into haystack-shaped hills and slopes with a popcorn-like surface, and overlies the Chamberlain Pass Formation.

The upper contact of the Peanut Peak Member with the overlying remainder of the Chadron Formation is variable. In places it is unconformable, such as along the east end of Sugarloaf Road (location 4 of Figs. 3B, 5E), where the remainder of the overlying Chadron Formation fills depressions/paleovalleys within the Peanut Peak Member (Terry and LaGarry, this volume). In contrast, at Toadstool Park, the contact of the Peanut Peak Member with the overlying remainder of the Chadron Formation is intertonguing, with lenses of the Peanut Peak Member visible in the overlying upper member and lenses of the overlying upper member visible within the Peanut Peak Member (Terry and LaGarry, this volume). The Peanut Peak Member differs from the overlying remainder of the Chadron Formation in that it is composed of smectite-rich mudstone and claystone, weathers into bluish-green and gray hummocky hills and slopes, is less variegated in color, has less silt, and contains none of the "purplish-white layers" of Schultz and Stout (1955) (Fig. 5E).

I extend the usage of the term Peanut Peak Member to include the undifferentiated, bluish-green and gray hummocky mudstone of the Chadron Formation outside of the Red River Valley, South Dakota, of Clark et al. (1967), and its lithologic equivalents in northwestern Nebraska, for several reasons: (1) It serves no purpose to introduce a new lithostratigraphic name for these strata. The term Peanut Peak Member has already been employed by Clark (1954) and Clark et al. (1967) for greenish, gray, tan, and orange hummocky mudstone within the upper part of the Red River Valley in the Big Badlands (Fig. 2E,G). (2) By visually tracing this unit from the Big Badlands of South Dakota into northwestern Nebraska, the Peanut Peak Member (as used herein) is no longer a geographically isolated unit within the Red River Valley. This sense of geographic restriction and dissimilarity with the majority of the Chadron Formation outside the Red River Valley (undifferentiated Chadron Formation) led Harksen and Macdonald (1969a,b) to reject the divisions of the Chadron Formation established by Clark (1937, 1954) and to suggest a reference section for the Chadron Formation located 4.83 km (3 mi) southeast of the type geologic locality for the "*Titanotherium* Zone" as established by Osborn (1929). Harksen and Macdonald (1969a) believed that this section better represented the general lithology of the Chadron Formation. (3) This package of undifferentiated bluish-green and gray hummocky mudstone is overlain in northwestern Nebraska by the remainder of the Chadron Formation (Terry and LaGarry, this volume), which is itself a distinct lithostratigraphic unit (Fig. 5E). Thus, this package of bluish-green and gray hummocky mudstone that overlies the Chamberlain Pass Formation in both the Big Badlands of South Dakota and northwestern Nebraska must have a formal lithostratigraphic designation (see NACSN, 1983) other than "undifferentiated Chadron Formation" (Figs. 2A–D, 5A–E).

Age. The Peanut Peak Member in northwestern Nebraska has not been directly dated by radiometric means. The best estimates are based on faunal content and magnetostratigraphic correlation. Based on its fossil content, the Peanut Peak Member is Chadronian, as are the underlying Chamberlain Pass Formation and overlying remainder of the Chadron Formation. Based on paleomagnetic data, the Peanut Peak Member of the Chadron Formation in northwestern Nebraska falls within Chron 15 (Prothero and Swisher, 1992). This evidence, combined with the recently published age revision of the Chadronian NALMA (Swisher and Prothero, 1990), restricts the Peanut Peak Member of the Chadron Formation in northwestern Nebraska to late Eocene.

Upper member. The overlying remainder (upper member) of the Chadron Formation in northwestern Nebraska is a siltier, cliff-forming, and variegated unit of pedogenically modified claystone, silty claystone, and siltstone with occasional isolated channel sandstone bodies (Terry and LaGarry, 1994, this volume; Terry, 1995; Terry et al., 1995) (Fig. 5E). Terry and LaGarry (this volume) redefine this remaining upper part of the Chadron Formation in northwestern Nebraska as the *Big Cottonwood Creek Member*. The Big Cottonwood Creek Member of the Chadron Formation contains the various purplish-white layers of Schultz and Stout (1955); lighter colored bands of rock composed of gypsum, volcanic ash, or limestone that stand out in contrast to the surrounding badlands. Some purplish-white layers represent paleosol profiles. Descriptions and usage of the various purplish-white layers in Nebraska are discussed by Terry and LaGarry elsewhere in this volume. The contact of the Big Cottonwood Creek Member of the Chadron Formation with the overlying Brule Formation in northwestern Nebraska is marked by a change from variegated silty mudstone and claystone of the Big Cottonwood Creek Member of the Chadron Formation to tan and brown clayey siltstone, siltstone, sheet sandstone, and channel sandstone of the Orella Member of the Brule Formation. This Chadron/Brule Formation boundary differs greatly from previous stratigraphic concepts for units in northwestern Nebraska, and is discussed by Terry and LaGarry (this volume) and LaGarry (this volume).

I have traced the Big Cottonwood Creek Member northeast into South Dakota to the town of Oelrichs with no change in stratigraphic relationships (Fig. 5F). At Oelrichs, the Big Cottonwood Creek Member interfingers with lacustrine limestone similar to those described by Welzenbach (1992), Welzenbach and Evans (1992), and Evans and Welzenbach (this volume). These limestones (Fig. 2H) are within the upper part of the Chadron Formation (= Peanut Peak Member as defined in this chapter) in the Big Badlands of South Dakota (Welzenbach, 1992; Welzenbach and Evans, 1992), and occasionally mark the boundary between the Chadron and Brule Formations (D. O. Terry, 1995, unpublished data). The siltier, variegated, and cliff-forming Big Cottonwood Creek Member of the Chadron Formation in northwestern Nebraska is absent in the Badlands National Park area

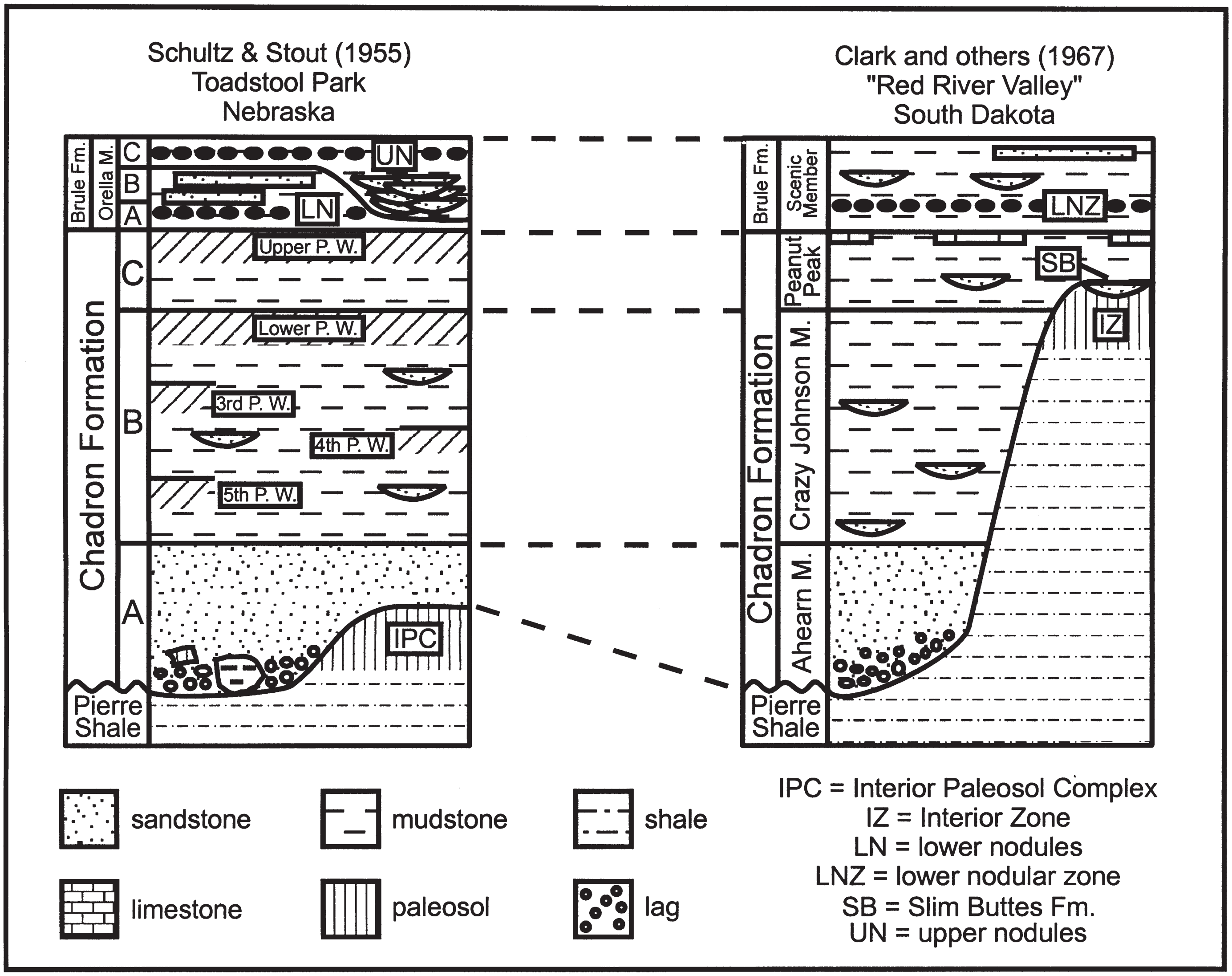

Figure 7. Stratigraphic terminology of Schultz and Stout (1955) for the Chadron Formation of northwestern Nebraska and their suggested correlations to members of the Chadron Formation within the Red River Valley of Clark et al. (1967) in the Big Badlands of South Dakota.

(Fig. 2A–E). Within Badlands National Park the Peanut Peak Member of the Chadron Formation is overlain by Bump's (1956) Scenic Member of the Brule Formation (Fig. 2A).

Comparisons with previous stratigraphic hierarchies and correlations

The stratigraphic terminology of Schultz and Stout (1955) for members of the Chadron Formation in northwestern Nebraska, although never formally defined in type sections or assigned names other than A, B, C, and/or "lower," "middle," "upper," has become entrenched in the literature (Fig. 7). This terminology and the suggested regional correlations associated with it have become commonly cited and accepted (Schultz et al., 1955; Leonard, 1957; Vondra, 1958a, 1960; Swenson, 1959; Harvey, 1960; Schultz and Falkenbach, 1968; Stone, 1972; Singler and Picard, 1979, 1980, 1981; Schultz and Stout, 1980; Retallack, 1983; Martin, 1985; Swinehart et al., 1985; Prothero and Swisher, 1992; Murphy et al., 1993).

Within the stratigraphic paradigm of Schultz and Stout (1955), the White River Group of northwestern Nebraska rests on the Interior Paleosol Complex (Fig. 7), a zone of pedogenic alteration that modified the Cretaceous Pierre Shale from its usual black color into a bright yellow zone capped by a reddish horizon. The first deposits of the White River Group are represented by the basal sands and conglomerates of the "Chadron A," which in turn are overlain by mudstones of the "Chadron B" and "Chadron C," respectively. The boundaries of the Chadron B and Chadron C are defined by purplish-white layers. The contact between the Chadron B and Chadron C is marked by the "lower" or "second purplish-white layer." The top of the Chadron Formation (top of the Chadron C) is marked by the "upper purplish-white layer," a regionally extensive volcanic ash. The Chadron Formation is overlain by the Orella Member of the Brule Formation. The lowest part of the Orella Member, which Schultz and Stout (1955) have defined as the "Orella A," directly overlies the upper purplish-white layer. These divisions were established, and the boundaries chosen, as a convenient guide for the stratigraphic documentation of collected fossils (Schultz and Stout, 1955).

Schultz and Stout (1955) proposed that their stratigraphic divisions of the Chadron Formation in northwestern Nebraska could be directly correlated to Clark's (1937, 1954) three-fold division of the Chadron Formation in the Big Badlands of South Dakota (Fig. 7). Namely, the Chadron A, B, and C of Nebraska correlated with the Ahearn, Crazy Johnson, and Peanut Peak Members of South Dakota, respectively. Schultz and Stout (1955) also considered the Chadron A to be equivalent to the "Yoder Beds" of Schlaikjer (1935) and Kihm (1987) near Torrington, Wyoming (Fig. 1), and the Interior Paleosol Complex of northwestern Nebraska to be equivalent to the Interior Zone of Ward (1922) near Interior, South Dakota.

Schultz and Stout's (1955) stratigraphic divisions of the Chadron Formation in northwestern Nebraska were based on event beds such as volcanic ashes and paleosols. Several new developments invalidate these divisions and the proposed correlations to units in South Dakota: (1) The use of event beds is in direct violation of the current North American Stratigraphic Code (NACSN, 1983) for recognition of lithostratigraphic units (e.g., groups, formations, and members). (2) Retallack (1983) recognized that the Interior Zone of South Dakota is composed of two separate paleosols, the Yellow Mounds and Interior Paleosol Series (Fig. 2A). (3) The Chamberlain Pass Formation of Evans and Terry (1994), Terry and Evans (1994), is now recognized in northwestern Nebraska and the Badlands of South Dakota (Figs. 2A–D, 3, 5A–D, 6). (4) The stratigraphic units of Schultz and Stout (1955) do not lithologically correlate to their suggested counterparts in the Big Badlands of South Dakota. (5) In addition, Schultz and Stout's (1955) units in Nebraska cannot be matched to rock units in South Dakota based on the principle of superposition, nor can the purplish-white layers be visually traced into the Big Badlands of South Dakota.

Using my newly proposed lithostratigraphic hierarchy (Figs. 3B, 8, 9), the Interior Paleosol Complex of Schultz and Stout (1955) is composed of the pedogenically modified Pierre Shale and the pedogenically modified overbank mudstone of the Chamberlain Pass Formation, which corresponds to the Yellow Mounds Paleosol Equivalent and Interior Paleosol Equivalent,

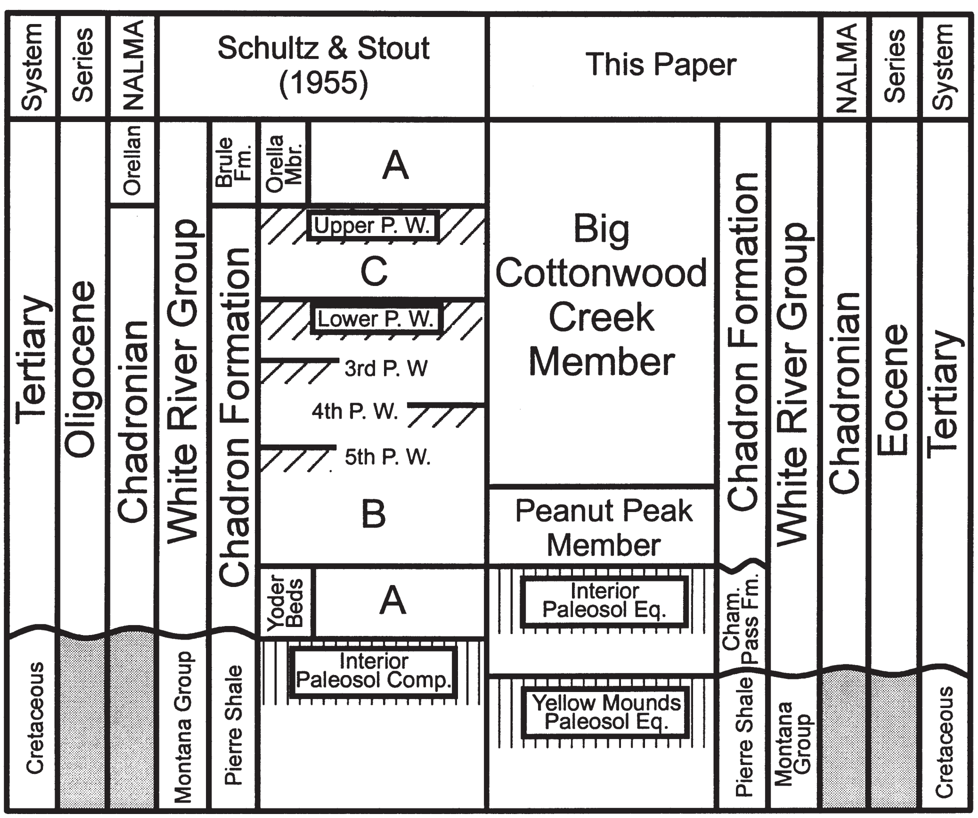

Figure 8. Proposed stratigraphic revisions for the lower part of the White River Group of northwestern Nebraska.

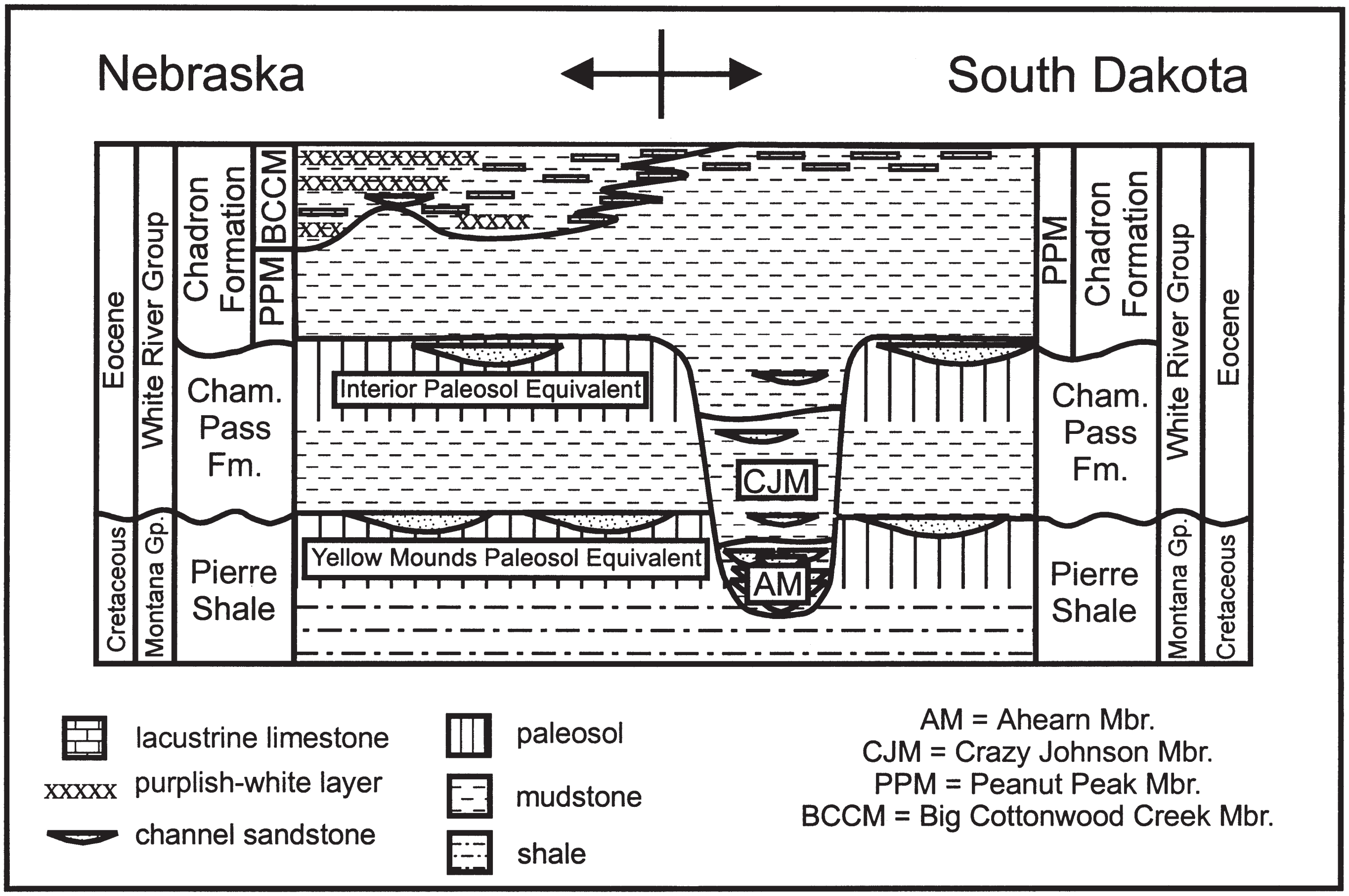

Figure 9. Diagram showing the proposed regional geographic relationships of the various members of the Chadron Formation between the Toadstool Park area of northwestern Nebraska and the Red River Valley of Clark et al. (1967) in the Big Badlands of South Dakota. Modified from Terry et al. (1995).

respectively (Figs. 2A, 5A,B). The Chadron A of Schultz and Stout (1955) corresponds to the channel sandstone facies of the Chamberlain Pass Formation (Figs. 2B–D, 5B–D). The lower part of the Chadron B, the bluish-green, smectite-rich hummocky mudstone, is equivalent to the Peanut Peak Member as defined in this chapter (Figs. 2A–G, 5A–E). The overlying siltier, variegated, and cliff-forming remainder of the Chadron B, Chadron C, and Orella A of the overlying Brule Formation is contained within a newly recognized, separate, and distinct lithostratigraphic unit that Terry and LaGarry (this volume) designate as the *Big Cottonwood Creek Member* of the Chadron Formation (Figs. 5E,F, 8, 9).

DISCUSSION

Regional correlations

Nebraska. The Yellow Mounds Paleosol Equivalent, Chamberlain Pass Formation, and Chadron Formation are not exposed south of the Pine Ridge Escarpment. Swinehart et al. (1985) were able to identify three subsurface depositional sequences within the White River Group based on a detailed analysis of ~11,600 electric logs of oil and gas wells and samples and logs from 500 others. The lowest of these three sequences encompassed the bottom of the Chadron Formation to the unconformity within the Orella Member of the Brule Formation. This "Chadron Sequence" rests upon an oxidized zone that is likely the same period of pedogenesis that produced the Interior Paleosol Complex (Yellow Mounds and Interior Paleosol Equivalents) in northwestern Nebraska and across the Great Plains. J. B. Swinehart (1994, personal communication) has observed cored sandstone in Sheridan County, Nebraska that is lithologically similar to the channel sandstone facies of the Chamberlain Pass Formation. This sandstone, along with the upper part of the subsurface oxidized zone, is likely equivalent to the Chamberlain Pass Formation.

Wyoming. Buttes near Lance Creek, Wyoming, display a yellowish zone, possibly the Yellow Mounds Paleosol Equivalent, overlain by a white sand body similar to the Chamberlain Pass Formation (Figs. 1, 5G, 10). This white sand body is in turn overlain by greenish-gray hummocky mudstones similar to the Peanut Peak Member. The remainder of the butte is composed of strata lithologically similar to the Big Cottonwood Creek Member of Terry and LaGarry (this volume) and Terry et al. (1995).

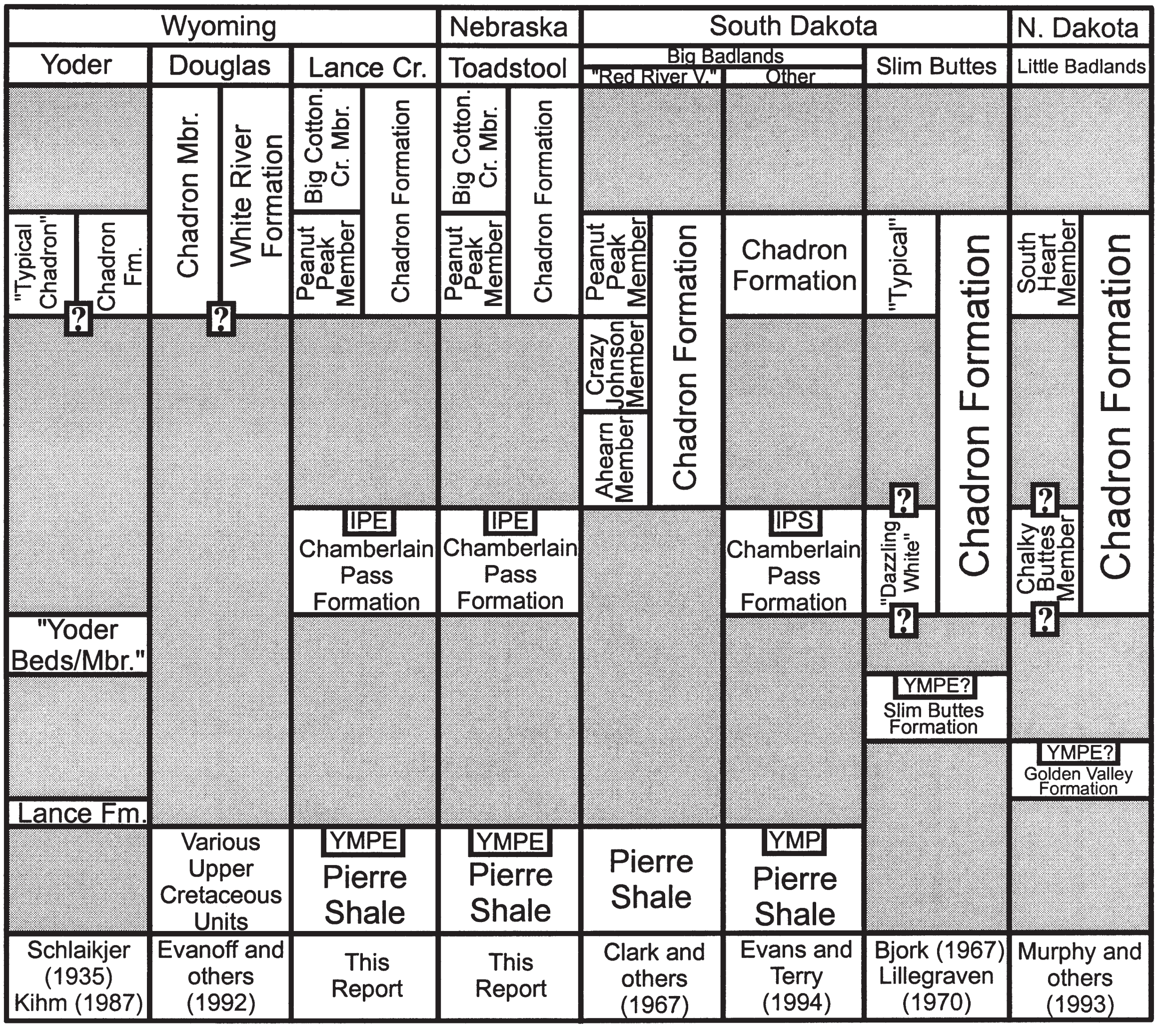

Figure 10. Proposed lithologic equivalency chart for the Chamberlain Pass Formation and the various members of the Chadron Formation in relation to underlying units and major periods of pedogenic modification. IPS and YMP = Interior and Yellow Mounds Paleosol Series of Retallack (1983), respectively; IPE = Interior Paleosol Equivalent; YMPE = Yellow Mounds Paleosol Equivalent.

These similarities were also noted by Schultz and Stout (1955) and Luebke (1964), but were classified and interpreted within the stratigraphic hierarchy developed for the Toadstool Park area by Schultz and Stout (1955).

At Yoder, Wyoming, I have observed beds lithologically similar to the Peanut Peak Member (Figs. 1, 10) overlying the Yoder Beds of Schlaikjer (1935) and Kihm (1987). I do not agree with the correlation of the Yoder Beds by Schultz and Stout (1955) to the Chadron A (channel sandstone facies of the Chamberlain Pass Formation) of northwestern Nebraska for several reasons. (1) First, the two deposits are composed of different lithologies. The Yoder beds are composed of finely bedded, coarse red sandstone, red and greenish sandy clays, and reddish-green clays with channels of intricately cross-bedded, wine-colored coarse gravels to fine sandstone (Schlaikjer, 1935). Channel sandstone of the Chamberlain Pass Formation is composed of blazing white to yellowish-white, coarse- to fine-grained, cross-bedded, and multistory sandstone bodies, commonly marked at the base by quartz-rich lag deposits. Reddish clay is present, but only as occasional streaks, or as a thick clay plug developed on top of the channel sandstone facies just north of Toadstool Park, Nebraska (Terry, 1991; Evans and Terry, 1994; Terry et al., 1995). (2) The Yoder Beds are areally restricted within a few miles of the Yoder and Veteran, Wyoming, area within a paleovalley formed in the underlying Cretaceous Lance Formation. Outside this area the Lance Formation is overlain by greenish-gray hummocky mudstone of the Chadron Formation (Kihm, 1987). The channel sandstone within the Chamberlain Pass Formation is part of an areally extensive and distinct fluvial lithostratigraphic unit. (3) The Yoder Beds are very fossiliferous, whereas the Chamberlain Pass Formation is almost devoid of fossils.

Correlations of the revised strata discussed herein to exposures in the Douglas and Flagstaff Rim areas of central and east-central Wyoming have not yet been made (Fig. 1). The White River Group is labeled as a formation in Wyoming (Fig. 10) and contains the Chadron and Brule Members (Evanoff, 1990; Evanoff et al., 1992). The two members are separated by the widespread # 5 tuff (Evanoff et al., 1992). The Chadron Member is composed of green to brown clayey mudstone, typically nodular brown to tan sandy mudstone, thin sheet sandstone, and several thick ribbon sandstones (Evanoff et al., 1992). The overlying Brule Member is composed of nodular brown to tan sandy mudstone, massive tan sandy siltstone, rare ribbon sandstone, and rare conglomeratic sheet sandstone (Evanoff et al., 1992). The use of the names "Chadron" and "Brule" for these units is based on the slight lithologic difference between the two members and the similarities of these two units to the Chadron and Brule Formations in northwestern Nebraska (Evanoff et al., 1992). The ranking of these units as members is based on an occasional difficulty in distinguishing the two units in outcrop, and for their less distinct appearance as compared to Nebraska equivalents (Evanoff et al., 1992). Leonard (1957) measured numerous sections through the White River Group in the Douglas area and suggested correlations to Toadstool Park using the stratigraphic hierarchy of Schultz and Stout (1955). The validity of these correlations is unknown.

Northwestern South Dakota. Lithologically identical counterparts of the channel sandstone facies of the Chamberlain Pass Formation and the Peanut Peak Member of the Chadron Formation are visible in Harding County, South Dakota at Slim Buttes, 32 km (20 mi) east of Buffalo. Channel sandstone deposits are "dazzling white" in color, and rest on the golden brown, interbedded, and variegated sands, silt, and clays of the Eocene Slim Buttes Formation (Bjork, 1967). In contrast to Pettyjohn (1966), I am undecided as to the presence of the Yellow Mounds Paleosol Equivalent. I have observed iron oxide concretions in the same pedostratigraphic position as other Yellow Mounds Paleosol Equivalent outcrops, but I have not examined the Slim Buttes Formation for other evidence of pedogenic modification. The dazzling white sandstone is overlain by gray hummocky claystone, identical to the Peanut Peak Member, that Bjork (1967) lumped together with the white sandstone as the Chadron Formation (Fig. 10). Lillegraven (1970) used a different stratigraphic approach, dividing the Chadron Formation into the "golden brown," "dazzling white," and "typical Chadron" units (Fig. 10). I have not observed a reddish-colored overbank mudstone, similar to that within the Chamberlain Pass Formation, associated with the dazzling white sandstone at Slim Buttes. The contact between the dazzling white and typical Chadron is sometimes fractured, with gray clay filling the fractures (D. O. Terry, 1993, unpublished data). This is identical to the pedo-brecciation preserved at the contact of the Chamberlain Pass Formation and Peanut Peak Member of the Chadron Formation near Interior, South Dakota (Terry, 1991; Terry and Evans, 1994). Paleosols are preserved within the gray hummocky mudstone of the Chadron Formation at Slim Buttes (D. O. Terry, 1993, unpublished data). The Chadron Formation at Slim Buttes is overlain by the Brule Formation.

Southwestern North Dakota. The same stratigraphic succession at Slim Buttes, South Dakota is visible in the Little Badlands of southwestern North Dakota (Figs. 1, 5H). The Little Badlands near Dickinson, North Dakota display the general Eocene/Oligocene stratigraphy of this area (Fig. 10). The White River Group in the Little Badlands rests unconformably on the light brown to golden micaceous sandstone, siltstone, mudstone, and thin lignites of the Eocene Camels Butte Member of the Golden Valley Formation (Murphy et al., 1993). The Camels Butte Member was apparently subjected to the same period of pre–White River Group leaching that formed the Interior Paleosol Complex (Yellow Mounds Paleosol Equivalent) in the Big Badlands of South Dakota (Hickey, 1977) (Fig. 5H). This weathering changed the normally buff and yellow colors of the Camels Butte Member to bright orange, yellow, and white (Hickey, 1977).

The Camels Butte Member in this area is overlain by a chalky white, cross-bedded conglomeratic sandstone and sandy mudstone that Murphy et al. (1993) designate as the Chalky Buttes Member of the Chadron Formation. This unit, which ranges from 3 to 6 m (10–20 ft) in thickness in the Little Badlands, is similar stratigraphically and lithologically to the dazzling white sandstones at Slim Buttes and the channel sandstone facies of the Chamberlain Pass Formation in the Big Badlands of South Dakota. The Chalky Buttes Member is overlain by smectitic, gray to brown, hummocky mudstone and occasional limestone lenses that Murphy et al. (1993) designated as the "South Heart Member" of the Chadron Formation (Fig. 5H). The South Heart Member, which is 3 to 9 m (10–30 ft) thick in the Little Badlands, is identical in lithology and stratigraphic position to the "typical Chadron" at Slim Buttes and the Peanut Peak Member (as per this chapter) of the Chadron Formation in the Big Badlands of South Dakota (Fig. 10).

Great Plains geologic history

As initially envisioned by Evans and Terry (1994), the Chamberlain Pass Formation was contained within an asymmetric basin marked on its southern edge by the Pine Ridge fault zone and by the Sage Ridge fault on the northern edge. The Chamberlain Pass Formation was thought to represent the fluvial deposits of a drainage system headed in the Black Hills. As I have demonstrated herein, the Chamberlain Pass Formation extends beyond this basin. Its overall extent is unknown at this time, but I have seen similar deposits as far west as Lance Creek, Wyoming, east to White Clay, Nebraska, and north to Dickinson, North Dakota (Figs. 1, 3B, 5G,H). The Chamberlain Pass Formation may represent the deposits of a widespread Late Eocene fluvial system on the northern Great Plains.

The revision of the Chadron Formation is significant (see also Terry and LaGarry, this volume). Strata of the Peanut Peak Member are not geographically restricted within the Red River Valley of Clark et al. (1967), but occur instead as a distinctive lithologic unit that can be traced from Wyoming to North Dakota (Figs. 2, 5). As such, the Peanut Peak Member is a valuable lithostratigraphic marker for determining the superposition of various members and formations within the White River Group across the northern Great Plains (Fig. 10).

Along with the superposition of various lithologic units, the nature of the contacts between units may help to determine the geologic history of the region. The contact relationships of the Peanut Peak and Big Cottonwood Creek Members suggest that a period of low siliciclastic sedimentation developed across the southwestern South Dakota and northwestern Nebraska area following the deposition of the Peanut Peak Member. In the Big Badlands, the upper part of the Peanut Peak Member commonly contains one or more lacustrine limestones (Evans and Welzenbach, this volume). These limestone beds are widespread, and have been cited as the contact between the Chadron and Brule Formations in the Big Badlands of South Dakota (Wanless, 1923; Clark, 1937; Clark et al., 1967; Harksen and Macdonald, 1969a). Welzenbach (1992) has referred to these limestones near Wall, South Dakota, as the Bloom Basin limestone beds.

According to Welzenbach (1992) and Evans and Welzenbach (this volume), these limestones were deposited within perennial, stratified lakes. Based on the low amount of siliciclastics and the presence of tufa pillars, the lakes are believed to have been spring-fed. Evans and Welzenbach (this volume) suggest that the formation of these lacustrine limestones is due to the interaction of paleoclimate, equal rates of sediment supply and basin subsidence, and the development of a regional groundwater recharge system formed by the uplift of the Black Hills. These deposits may represent lacustrine environments on the terraces of an incised drainage system, and possibly indicate drainage disruption prior to the deposition of the overlying Brule Formation (Evans and Welzenbach, this volume). Similar limestone beds occur at the top of the Peanut Peak Member at Oelrichs, South Dakota and at Rattlesnake Butte, Nebraska (Fig. 3B).

In northwestern Nebraska, the contact of the Peanut Peak Member and overlying Big Cottonwood Creek Member is unconformable where the Big Cottonwood Creek Member fills shallow paleovalleys within the Peanut Peak Member (Terry and LaGarry, this volume). Paleovalley formation within the Peanut Peak Member may likely correspond to this regional period of reduced siliciclastic sedimentation. With renewed sedimentation, deposition of siliclastic sediments appears to have shifted to the northwestern Nebraska area. As deposition proceeded in Nebraska these paleovalleys were eventually filled and overtopped by 42 to 52 m (138–170 ft) of sediment to form the Big Cottonwood Creek Member. During this time, lacustrine deposition dominated in the Big Badlands area of South Dakota, but toward the southwest deposition was predominantly fluvial. Lacustrine deposition within the Big Cottonwood Creek Member progressively increases toward the northeast (Terry and LaGarry, this volume, Fig. 4), and is visible in measured sections between Toadstool Park in Nebraska and Limestone Butte near Oelrichs, South Dakota (Figs. 5F, 9).

The mechanism responsible for this shift in fluvial depocenters and formation of the Big Cottonwood Creek Member during the late Eocene is uncertain at this time, but may be at least partially influenced by renewed uplift of the Black Hills or Chadron Dome. According to Lisenbee and DeWitt (1993), the Black Hills was tectonically inactive during the deposition of the White River Group, although data collected by Evans (1996) challenges this hypothesis. The amount of time represented by deposition of the Big Cottonwood Creek Member in northwestern Nebraska may be equivalent to that of the "Bloom Basin limestone beds" of Welzenbach (1992) and other lacustrine limestones described by Evans and Welzenbach (this volume) near the top of the Peanut Peak Member in the Big Badlands (Figs. 2H, 9). Thus, these lacustrine limestones would represent a condensed section in the Big Badlands area that formed over a significant period of time. New data from Prothero and Whittlesey (this volume) indicate an unconformity spanning at least 400,000 yr between the Chadron and Brule Formations in the Sage Creek and Pinnacles area of the Big Badlands. The condensed section of the limestone beds near the Chadron/Brule contact in the Big Badlands and deposition of the Big Cottonwood Creek Member in northwestern Nebraska likely represents this interval of time.

CONCLUSIONS

Based on measured sections, the visual tracing of rock units between the Big Badlands of South Dakota and the Toadstool Park area of northwestern Nebraska, paleopedology, and the use of the Big Badlands of South Dakota as a stratigraphic standard, I propose the following lithostratigraphic changes within the lower part of the White River Group in northwestern Nebraska (Figs. 3B, 8, 9). These changes conform to guidelines of the North American Stratigraphic Code (NACSN, 1983) for recognizing lithostratigraphic units, and replace the informal, event boundary-based classification of Schultz and Stout (1955) (Fig. 7).

1. The term Interior Paleosol Complex of Schultz and Stout (1955) is abandoned. This zone is composed of two separate, pedogenically modified units; the Yellow Mounds Paleosol Equivalent that developed on the Cretaceous Pierre Shale, and the Interior Paleosol Series Equivalent that developed on the overbank deposits of the Chamberlain Pass Formation (Figs. 2A, 5A).

2. The Chamberlain Pass Formation of Evans and Terry (1994) is recognized in northwestern Nebraska. It is composed of the channel sandstone that Schultz and Stout (1955) called the "Chadron A" and red overbank mudstone originally included in the Interior Paleosol Complex (Figs. 2A–D, 5A–D). The term Chadron A is abandoned, and the correlation by Schultz and Stout (1955) of these channel sands (Fig. 2F) to the Ahearn Member of Clark (1954) and the Yoder Beds of Schlaikjer (1935) and Kihm (1987) is rejected.

3. The term "Chadron B" for strata above the Chadron A to the "second" or "lower purplish-white" is abandoned (Figs. 5B,D,E). The correlation of the Chadron B to the Crazy Johnson Member of Clark (1954) in South Dakota is rejected (Fig. 2G). The lower bluish-green and gray hummocky part of the Chadron B is instead lithologically correlated to the "undifferentiated

Chadron" deposited outside of the Red River Valley of Clark (1937) (Figs. 2A–D, 5B,D,E). The term "Peanut Peak Member" is expanded to include these undifferentiated strata outside of the Red River Valley in South Dakota and northwestern Nebraska.

4. The overlying siltier, variegated, and cliff-forming remainder of the Chadron B and overlying "Chadron C" is incorporated, along with the "Orella A" of the overlying Brule Formation, into a new lithostratigraphic unit (Fig. 5E,F), the *Big Cottonwood Creek Member* of the Chadron Formation (Terry and LaGarry, this volume). The term Chadron C is abandoned, and the correlation to the Peanut Peak Member of Clark (1954) within the Red River Valley in South Dakota is rejected (Fig. 2E,G).

This new lithostratigraphic interpretation provides a basis for the recognition of the regional superposition of members and formations within the White River Group across the northern Great Plains, and may help to refine the geologic history of this region, specifically, the interaction of tectonics and sedimentation, during a brief and discrete interval of the Paleogene.

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