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THE DAKOTA GROUP OF NORTHEASTERN NEW MEXICO AND SOUTHERN COLORADO

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Abstract—The history of Dakota Group terminology is briefly reviewed in northeastern New Mexico and southeastern Colorado and traced from the type area in northeastern Nebraska. Component formations of the Dakota Group in this region are reviewed with the purpose of providing correlations between northeastern New Mexico and Colorado and placing northeastern New Mexico stratigraphic terminology within the larger framework of the Western Interior. The twofold division of the Dakota Group (Purgatoire and Dakota formations) is rejected in favor of a fourfold division comprising the Lytle, Plainview (not present in northeastern New Mexico), Glencairn (and Tucumcari) and Muddy formations. The Muddy Formation of Wyoming is extended along the Colorado Front Range into northeastern New Mexico, and component members are also correlated: the Mesa Rica Sandstone is correlated with the lower sandstone unit and Kassler Sandstone of Colorado; the Pajarito Shale with the Dry Creek Canyon Member and Van Bibber Shale; and the "Dakota" Sandstone (a term rejected here) with the upper "J" Sandstone and Horsetooth Member. Primary effects on deposition of the Dakota Group appear to be related to sea-level and sediment-influx fluctuations, although contemporaneous basement movements had strong local effects.

INTRODUCTION

Strata of the Dakota Group in northeastern New Mexico have, until recently, been poorly investigated, and their exact relationships have been the object of some uncertainty. The Dakota Group of Colorado, particularly southeastern Colorado and the Front Range foothills, has been more intensely studied, particulary its inter- and intra-formational relationships in the Denver Basin. The only recent study covering this trans-state region is Scott (1970), who concentrated on the marine strata of the southern plains; his conclusions are at some variance with those presented here. This paper attempts to review the relationships of the Dakota Group of southeastern Colorado and northeastern New Mexico (Fig. 1) and extend the correlation northward to provide a regional framework for the Dakota Group.

Historically, the status of the Dakota Group has been fraught with difficulties because its type section lies in northeastern Nebraska, and correlations westward and southward across the Western Interior seaway to the Rocky Mountain region have been approximate at best. The extremely variable nature of the Dakota strata further complicates the picture. A fundamental problem with the Dakota is the differing tectonic regimes existing on either side of the Western Interior foreland basin. During the late Early Cretaceous and early Late Cretaceous, Sevier orogenic episodes provided an abundant source of sediment, while the eastern source area providing sediment for the type Dakota area was a cratonic lowland. Tectonic and eustatic episodes govern the patterns of pre-Benton deposition and have to be considered in understanding the correlation of the Dakota units. Nomenclature of Lower Cretaceous clastic deposition in Idaho, western Wyoming and Montana more closely reflects the differing tectonic regimes, while the southern Rocky Mountain nomenclature still maintains the nomenclature of the eastern Great Plains.

STRATIGRAPHIC NOMENCLATURE OF THE DAKOTA GROUP

The term Dakota Group was first coined by Meek and Hayden (1861) for a sequence of sandstone, shale and lignite in Dakota County, northeastern Nebraska, west of Sioux City along the bluffs of the Missouri River. The term "Dakota" has been used at several nomenclatorial levels (Tester, 1929), the first formal usages being as follows: Group (Meek and Hayden, 1861), Series (Grabau, 1924), Stage (Bain, 1896), Formation (White, 1894) and Sandstone (Berry, 1922). Hague and Emmons (1877) used several of these levels informally. The Dakota Group received considerable attention in the ensuing decades, but it was not until 1943 that a type section was formally designated (Condra and Reed, 1959). White (1870) introduced a twofold division of the Dakota (a lower "Nishnabotny" [Nishnabotna] Sandstone and an upper

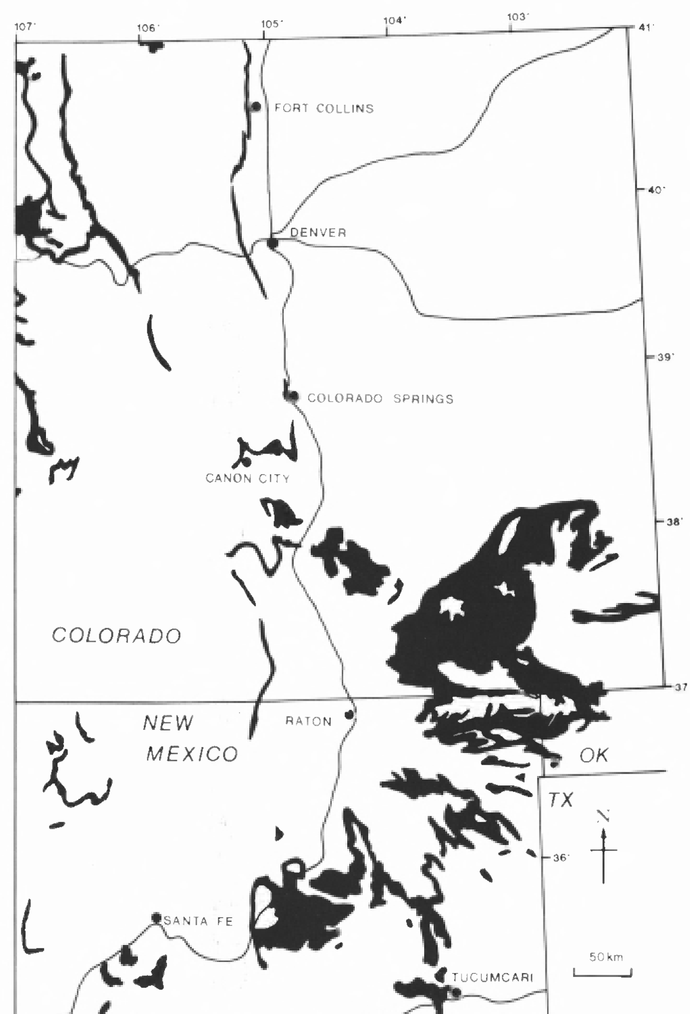

FIGURE 1. Outcrop of Dakota Group rocks in northeastern New Mexico, northwestern Oklahoma and Colorado west of longitude 107° (after American Association of Petroleum Geologists, Geological Highway Map 2, Southern Rocky Mountain Region, 1967).

Woodbury Sandstone), but Condra and Reed recognized three formations which they correlated with the Lakota, Fuson and, uppermost, the Omadi Sandstone, thus recognizing the Dakota as a Group. Witze et al. (1983), following the conclusions of White (1870) and recent workers in northeastern Iowa (Munter et al., 1983; Schoon, 1971), reject Condra and Reed's formations in favor of formational status for the Dakota. In Kansas, the Nishnabotna has been correlated with the Terra Cotta Member and the Woodbury has been correlated with the Janssen Member of the Dakota. These correlations are in some dispute owing to the significant facies changes between central Kansas and northern Nebraska. By the mid-1920's, the term Dakota Sandstone, derived from "Dakota Group Sandstone," was widely used throughout the western states.

A threefold division of the Dakota Group (upper and lower sandstone, and intervening middle shale) was first recognized in southeastern Colorado by Gilbert (1897) (Fig. 2) and he assigned it a Late Cretaceous age. On the basis of Darton's (1905) and Stanton's (1905) report of Early Cretaceous fossils in the middle shale, subsequent quadrangle mapping by Stose (1912) and Finlay (1916) (Fig. 2) divided the group into two formations: the Lower Cretaceous Purgatoire Formation and the Upper Cretaceous Dakota Sandstone, a scheme which was extended into northeastern New Mexico by Darton (1928). Finlay divided the Purgatoire Formation into the lower Lytle Sandstone Member and the overlying Glencairn Shale Member. McLaughlin (1954, 1966), working in southern Colorado, used the Kansas terms Cheyenne Sandstone and Kiowa Shale, as did Mankin (1958) in northeastern New Mexico. The basal sandstone of the Glencairn was named the Plainview Formation (Altschuld, 1980; Gustason and Kauffman, 1985) (Fig. 2), a term extended southward from the north-central Colorado Plainview Sandstone Member of the South Platte Formation (Waagé, 1955), and raised to formational status by MacKenzie (1963). The Dakota Sandstone remained undivided until Waagé (1953) identified a lower sandstone unit, the Dry Creek Canyon Member, and the upper sandstone unit (Fig. 2), which he later correlated with the upper part of his South Platte Formation (Waagé, 1955).

Lee (1927) extended usage of the term Muddy Sandstone (an informal driller's term used since the 1920's in central Wyoming until a type section was defined by Paull [1962]) into northern Colorado, a view upheld by MacKenzie (1963, 1965, 1971) and Young (1970). Gustason and Kauffman (1985), apparently unaware of Paull's (1962) paper, suggested formalizing the Muddy Sandstone in the Canon City region in preference to the term Dakota Sandstone. This recommendation does much to alleviate the improper use of Dakota Sandstone and does aid interstate correlation. The Newcastle (Sandstone) Formation of northeastern Wyoming might be used instead of the Muddy since this also correlates with the "J" or Dakota Sandstone (Baker, 1962; Grace, 1952; Waagé, 1959). The terminology used in this paper largely follows that

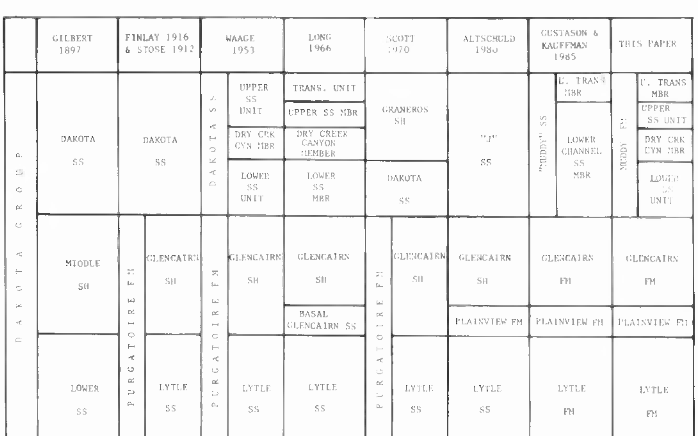

FIGURE 2. The development of stratigraphic nomenclature in southeastern Colorado.

of Gustason and Kauffman (1985), recognizing the Lytle, Plainview, Glencairn and Muddy formations within the Dakota Group in Colorado.

In northeastern New Mexico, the Tucumcari Shale was first studied by Marcou (1858) at a section on Pyramid Mountain southwest of Tucumcari and later named the "Tucumcari Beds" (Marcou, 1889; Cummins, 1892; see Kues, 1985, for historical background). Dobrovolny et al. (1946) recognized the Tucumcari Shale as a member of the Purgatoire Formation into which they also included their newly named Mesa Rica Sandstone and Pajarito Shale, formerly part of the Dakota Sandstone. No type sections for the Mesa Rica and Pajarito were designated (see Payne et al., 1986). Griggs and Read (1959) preferred formational status for Dobrovolny et al.'s members, urging the abandonment of the term Purgatoire in New Mexico. Griggs and Read were unclear about how these formations should be grouped, and Gage and Asquith (1977) have interpreted this to mean the erection of a Purgatoire Group rather than a Dakota Group. McLaughlin (1954, 1966), Scott (1970) and Waagé (1953) maintain usage of the Purgatoire Formation throughout the southern plains, including northeastern New Mexico, and recognize the Tucumcari Shale (Glencairn of Colorado) and the Lytle Sandstone as members of the Purgatoire. Scott (1970) incorrectly regarded the Mesa Rica and overlying Pajarito as being equivalent to the Dakota Sandstone (which he regarded of formational status), and thus not members of the Purgatoire (Fig. 2).

The relationship between the Mesa Rica Sandstone and Dakota Sandstone was subsequently investigated by Asquith and Gilbert (1976), Gilbert and Asquith (1976), Jacka and Brand (1972), Lucas et al. (1986), Mateer (1985) and Wanek (1962), where the Mesa Rica Sandstone and Pajarito Shale are identified as subjacent units to the Dakota Sandstone. Lucas et al. (unpublished) have provided an argument for making the Mesa Rica, Pajarito and Dakota (to be renamed), formational units within the Dakota Group. However, as these formations are correlated (see later) north in Colorado they become members of the Dakota, "J" or Muddy Sandstone which has formational status. Despite strong local arguments for the Lucas et al. proposition, it would create a hierarchical change across the New Mexico-Colorado state line which is, in this author's opinion, undesirable. A similar nomenclatorial change would also occur across into Kansas where the Dakota Sandstone has formational status (Witze et al., 1983). It would be more consistent, at a regional level, if the Mesa Rica, Pajarito and upper sandstone (Dakota Sandstone of previous usage) become members of an upper Dakota Group formation, as originally suggested by Finlay (1916), but using a different, and more appropriate name, such as Muddy (Sandstone) Formation (see later). This would involve a tripartite Dakota Group in New Mexico: Lytle Formation (where present), Tucumcari Formation and Muddy Formation, the latter consisting of the Mesa Rica Sandstone, Pajarito Shale and "Dakota" Sandstone (to be renamed) members (Fig. 2).

LYTLE FORMATION

The Lytle Formation is the basal formation of the Dakota Group throughout eastern Colorado and the northern plains (known there as the lower Cloverly and Lakota Formations), and extends southward into the Dry Cimarron Valley of northeastern New Mexico and northwestern Oklahoma (Figs. 3–4). Scott (1970, p. 1233) identified the basal sandstone of the Tucumcari Formation at Tucumcari Mountain as possibly being "in part equivalent to the Lytle Sandstone Member [of the Purgatoire Formation]," although he included it within the Tucumcari. The southward extent of the Lytle Formation has not been demonstrated south of the Dry Cimarron Valley, although Baldwin and Muehlberger (1959) indicated sandstones in southern Union County, New Mexico, but they are unclear about whether these are uppermost Morrison or lowermost Purgatoire (i.e., Lytle). The Lytle is missing in the western part of northeastern New Mexico (Fig. 4, sections K–N).

The Lytle Formation unconformably overlies the Jurassic Morrison Formation and is characterized by thickness variations from zero to several tens of m (36 m at the type section just south of Colorado Springs [Finley, 1916; see also Waagé, 1955]). The Lytle reflects a fluvial system that, during the ?Aptian-early Albian, infilled the con-

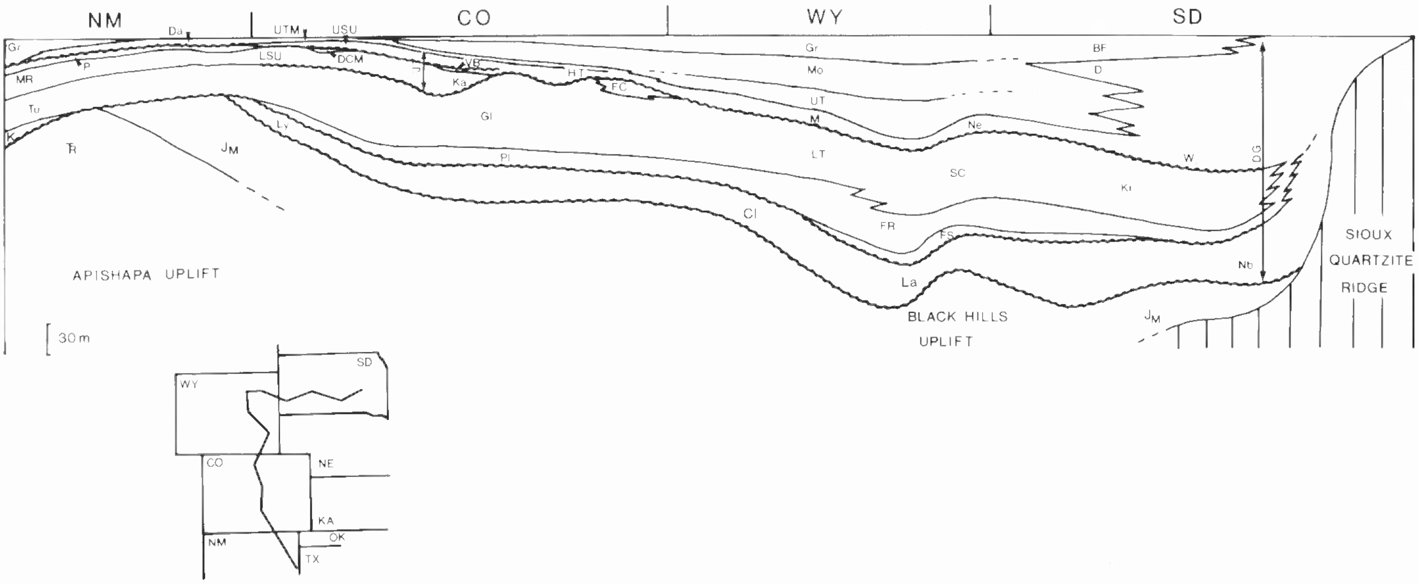

FIGURE 3. Generalized cross section of the Lower Cretaceous rocks from northeastern New Mexico to southern South Dakota (modified after Haun and Barlow, 1962, figs. 3, 5). Abbreviations are: BF = Belle Fourche Shale; Cl = Cloverly Formation; "D" = "D" sandstone; "Da" = Dakota Sandstone; DCM = Dry Creek Canyon Member; DG = Dakota Group; FC = Fort Collins Member; FR = Fall River Sandstone; Gl = Glencairn Formation; Gr = Graneros Shale; HT = Horsetooth Member; "J" = "J" sandstone; JM = Morrison Formation; K = Kiamichi Shale; Ka = Kassler Sandstone; Ki = Kiowa Shale; La = Lakota Sandstone; LSU = lower sandstone unit; LT = lower Thermopolis Shale; Ly = Lytle Formation; M = Muddy Formation; Mo = Mowry Shale; MR = Mesa Rica Sandstone; N = Nishnabotna Member; P = Pajarito Shale; Pl = Plainview Formation; SC = Skull Creek Shale; Tu = Tucumcari Formation; USU = upper sandstone unit; UT = upper Thermopolis Shale; UTM = upper transitional member; VB = Van Bibber Shale; W = Woodbury Member.

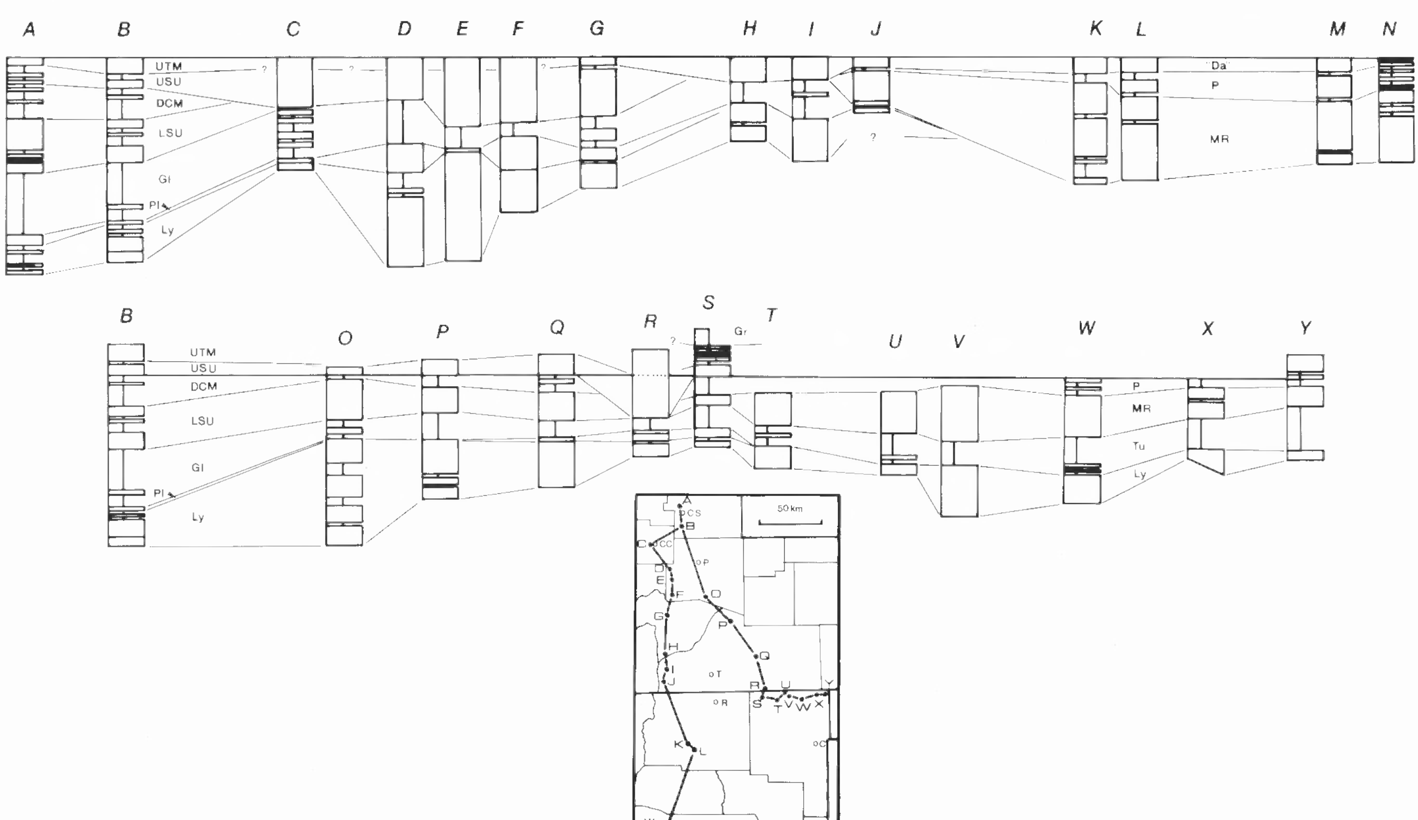

FIGURE 4. Two cross sections of the Dakota Group in southern Colorado and northeastern New Mexico. A–N is from Colorado Springs to Las Vegas (datum = top of Muddy Formation), and B–Y (datum = top of Dry Creek Canyon Member) is from Colorado Springs to the eastern Dry Cimarron Valley, Union County, New Mexico (note: sections S–Y are at a different horizontal scale than sections B–S). The individual sections are not detailed and reflect predominantly sandstone (and conglomerate) or shale (mudstone and siltstone) lithologies. See Appendix 1 for location of sections and Figure 3 for explanation of abbreviations.

siderable topographic relief left by the Tithonian-Aptian erosional hiatus scoured into the Morrison. Thickest development of the Lytle appears to be in Morrison valley infills, and it becomes progressively less thick to the east and south, pinching out entirely over northeastern New Mexico (Long, 1966).

The nature of the basal contact of the Lytle with the Morrison is often difficult to identify since both formations are fluviatile in nature. While it has been suggested that on palynomorph evidence the Lytle may reflect continued Morrison sedimentation, throughout the Neocomian (Taylor, 1974; Scott and Taylor, 1977), the drainage channel directions of both formations are significantly different, to the northeast for the Lytle, and to the north for the Morrison (MacKenzie and Poole, 1962; MacKenzie and Ryan, 1962). At most outcrops, the lithological change is quite noticeable, going from the characteristic maroon shales of the Morrison into the white to light gray sandstones and gravel conglomerates of the Lytle (Fig. 5B). However, where sandstones represent the uppermost Morrison, the boundary with the Lytle is locally difficult to identify (Fig. 5A). The Lytle is generally more quartzitic than upper Morrison sands (where present); it is 97% quartz, 2% chert and 0.12% feldspar in the Canon City embayment area (Morris, 1961). Carter (1957) found a close petrographic similarity of the Lytle to the Burro Canyon Formation (?Aptian) of the western slope of the Rocky Mountains.

Recent consensus now recognizes the regional unconformity between the Lytle and Morrison evident in most localities along the Front Range (Gustason and Kauffman, 1985) (Fig. 3). In north-central Colorado, Wescott (1979) recognized no unconformity between the Lytle and Morrison formations, but the lithological change from maroon siltstone to a conglomeratic sandstone is marked. Lytle facies are characteristically braided fluvial to high-energy meandering stream, with fine- to medium-grained light yellow to light gray sandstones with frequent conglomeratic horizons (Fig. 5A). Planar and trough crossbedding are common throughout the unit. Green to gray mudstones and siltstones are occasionally present in the lower part, but generally less than 10% of the unit, and all such occurrences can be identified as overbank floodplain deposits. Mudstones become progressively more common to the east. The upper boundary with the Plainview Formation is sharp and disconformable with a noticeable change from light gray sandstone to darker shale and light brown sandstone above.

No formal attempt has been made to subdivide the Lytle although Waagé (1953), working in the Canon City area, did differentiate between the lower, massive, poorly-sorted, fine- to medium-grained light sandstone and conglomeratic unit and an upper, medium-grained, brown-weathered sandstone with occasional conglomerates. The lateral continuity of this division is restricted to the Canon City embayment, and even here it is highly variable. In the northern Front Range, Waagé (1955) found no useful division of the Lytle, although Wescott (1979) differentiated a lower coarse-grained and conglomeratic part and an overlying coarse- to medium-grained part. These he referred to Donjek and Saskatchewan braided stream models (after Miall, 1978), reflecting the gradational change from proximal to distal facies caused by rising base level during sea-level rise. A characteristic of Saskatchewan-type braided streams is the increase in overbank and floodplain mudstones. Long (1966) suggested that Waagé's lower unit is fluvial and his upper unit is transitional, causing him to include the latter within the Glencairn Formation. However, Kauffman (quoted in Scott, 1970, p. 1232) mentioned that the upper unit is laterally traceable to more typical massive Lytle sandstones. Kauffman (1961) attempted a fourfold division of the Lytle Formation in Huerfuano Park based on four, locally-persistent conglomeratic horizons. Recently, Wyatt (1985) examined the Lytle between Walden and Beulah, central Colorado, and identified a basal trough-bedded conglomeratic channel horizon overlain by a meander-belt horizon of finer-grained sandstone and siltstone. He further identified an upper transgressive sandstone characterized by massive sandstone and heavily burrowed siltstone. Documentation of this sequence has not been forthcoming.

Body fossils are extremely scarce in the Lytle, but the rare ostracods and bivalves do indicate an Aptian-Albian age. Logs, and log impressions have been noted, especially in southeastern Colorado (Long, 1966). Fossils from homotaxial units in the Black Hills (Lakota) and the Western Slope (Burro Canyon and Cedar Mountain Formations) support an Aptian-middle Albian age for the Lytle (Peck and Craig, 1962; Tschudy et al., 1984; Ryer and Gustason, 1986). Clearly, more fossil data from the Lytle itself are required to firmly establish its age. Basan and Scott (1979) identified common, but poorly preserved, trace fossils (*Skolithos* and *Arenicolites*) in the upper part of the Lytle which

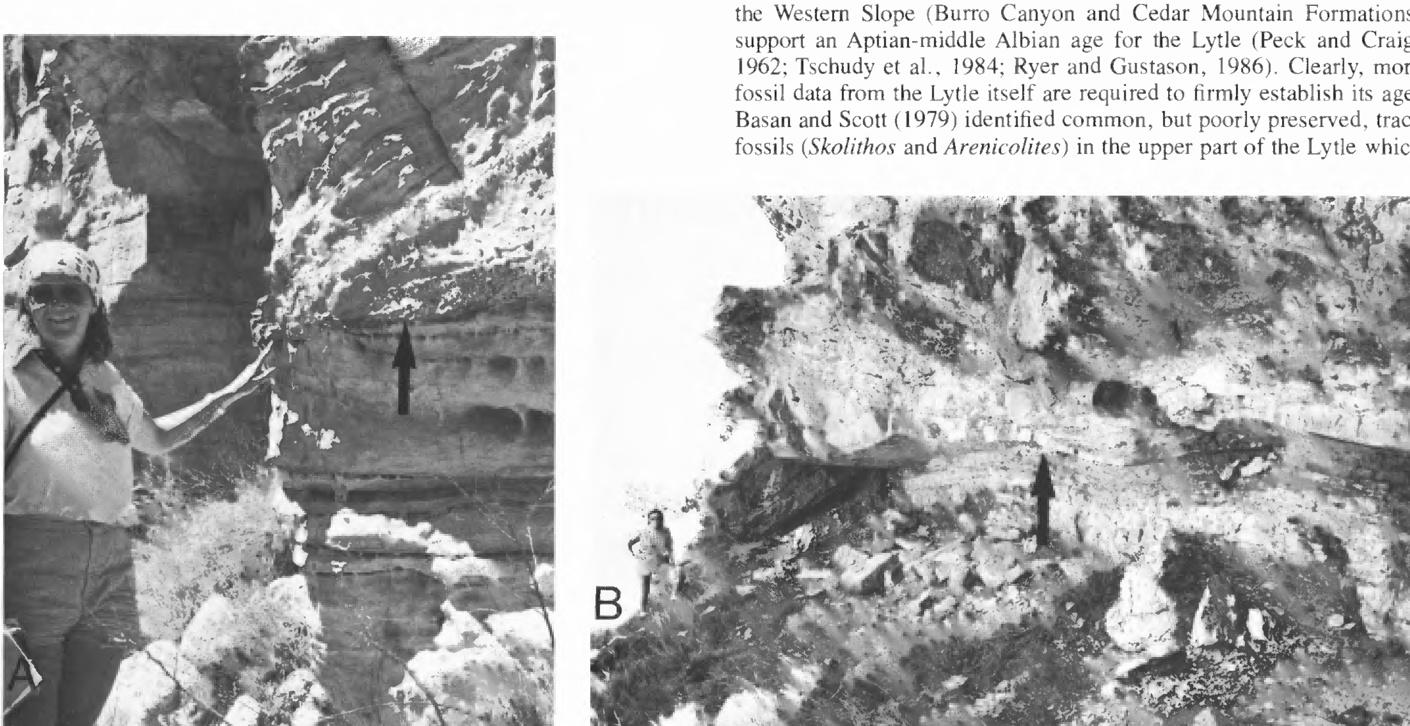

FIGURE 5. The lowermost Lytle Formation, northeastern New Mexico. A, Light orange sandstones of the lower Lytle Formation overlying the light gray sandstones of the Morrison Formation; the disconformity (indicated by arrow) is marked by an undulating, laterally-persistent gravel-conglomerate horizon. The pronounced change from low angle planar crossbedding of the Morrison to the high-angle trough crossbeds of the Lytle indicates a change from low energy meander-plains to high energy braided-stream environments; Travesser Park, Dry Cimarron Valley (SW¼, sec. 12, T31N, R32E). B, Undulating Lytle-Morrison Formation contact (arrow) near Wedding Cake Butte, Dry Cimarron Valley (NE¼, sec. 33, T32N, R35E); here, the Morrison is represented by purple to maroon mudstones disconformably overlain by medium- to coarse-grained high-angle crossbedded sandstones of the Lytle Formation.

they interpret as inner to middle estuarine facies in the Canon City area. However, fluvial trace fossils are known (e.g., Stanley and Fagerstrom, 1974; Fitzgerald and Barrett, 1986) and thus do not rule out a mature fluvial origin for the upper Lytle facies. However, it appears that Basan and Scott (1979) place the Lytle-Glencairn boundary at what is here considered the Plainview-Glencairn boundary. Thus, their ichnofauna is probably from the Plainview Formation.

According to Scott (1970) and Scott and Taylor (1977), the Lytle is slightly younger than the Cheyenne Sandstone of the eastern margin of the Kiowa-Skull Creek seaway since it apparently grades laterally into the lower part of the *Adkinites bravoensis* zone in the Kiamichi Shale to the east. However, since Gustason and Kauffman (1985) report *A. bravoensis* in the overlying Glencairn near Canon City, the Lytle can only be equivalent to the very lowest part of the *A. brazoensis* zone, indicating that it is probable that the Lytle and the Cheyenne are very similar in age. The Cheyenne Sandstone contains a diverse flora (Berry, 1922; Ward, 1986) showing a close similarity to the early Late Albian Fredericksburg Group of northern Texas and underlies the Upper Albian *Venezoliceras kiowanum* zone (Franks, 1975). The Lytle and Cheyenne consist of similar facies despite the source areas being quite distinct and, given their close contemporaneity, it is suggested that sea-level rise was the primary catalyst for their deposition.

PLAINVIEW FORMATION

Waagé (1955), in describing the Dakota Group of north-central Colorado, erected the South Platte Formation (the type section is near Eldorado Springs, Colorado) overlying the Lytle Formation. The basal sandstone of this South Platte Formation was named the Plainview Sandstone Member, a unit that MacKenzie (1963) raised to formational status, a decision subsequently extended by Altschuld (1980) into the Canon City area (Fig. 2). This is the same unit that Long (1966) and Taylor (1974) identified as a basal Glencairn sandstone in southeastern Colorado, but which is now regarded a separate formation lying between the Lytle and the Glencairn formations (Fig. 6B).

The Plainview Formation is generally thin (3–8 m) and extends along the entire Front Range Dakota outcrops (Long, 1966; Wescott, 1979), but to the south it apparently pinches out before crossing the border into New Mexico where it has not been identified (Figs. 3; 4, sections H–N, T–Y). In the type area, west of Denver, Waagé (1955) indicated a marginal marine environment of deposition, although further south this unit takes on increasingly paludal characteristics (Waagé, 1955; Altschuld, 1980). The Plainview facies consist of a fining upward, fine-grained sandstone (occasionally conglomeratic) to mudstone and shale sequence with abundant parallel to trough crossbedding and ripple marks.

Body fossils have not been reported, but occasional trace fossils—*Skolithos, Thalassinoides*—were identified by Basan and Scott (1979), and Gustason and Kauffman (1985) report *Planolites, Ophiomorpha* and *Rhizocorallium* from the Canon City area. Wescott (1979) and Chamberlin (1976) recognized *Cruziana, Planolites, Trichichnus* and plant roots from the Plainview near Fort Collins. Long (1966) reported dinosaur tracks south of Canon City; log impressions and other carbonaceous material are common throughout.

This formation is almost certainly a mature alluvial floodplain to paralic environment in the southern part of Colorado, although further north it has been interpreted as being intertidal (Altschuld, 1980; Gustason and Kauffman, 1985). The marked basal, regional, erosional disconformity with the Lytle Formation indicates rejuvenation of the river system responsible for depositing the Lytle alluvial complex, possibly as a result of a minor eustatic fluctuation. The Lytle-Plainview contact is reflected by a general lithology change which Waagé (1955) termed a transgressive disconformity. By the end of Plainview time, continued eustatic rise of the Western Interior seaway is manifested by the appearance of an intensely bioturbated sheet sandstone (*Thalassinoides*) which is regarded by Gustason and Kauffman (1985) as the boundary between the Plainview and Glencairn formations. East of the Front Range, the Plainview is thinner, and the alluvial-deltaic plain facies are frequently absent, instead consisting mainly of marginal marine sandstones.

In Wyoming and South Dakota the Plainview equivalent is called the Fall River Sandstone, the upper formation of the Inyan Kara Group (Waagé, 1959) of northeastern Wyoming, a correlative of the upper Cloverly Formation of central Wyoming (Figs. 3, 7).

GLENCAIRN–TUCUMCARI FORMATION

The Glencairn Formation is the southeastern Colorado equivalent of the Kiowa-Skull Creek marine episode recorded throughout the Western Interior (see Fig. 3; Kauffman [1984] reviews this cyclothem). Although Finlay (1916) first named this as the middle member of the Purgatoire Formation, he never published a type section; Long (1966) and Gustason and Kauffman (1985) give thorough descriptions of this formation for southeastern Colorado in the Canon City-Pueblo area. The southern Front Range marks the approximate western extent of this marine incursion (Haun, 1959), and the Glencairn facies reflect the lateral discontinuity of nearshore depositional environments in this region. Unlike the equivalent Kiowa Shale near the center of the seaway, which is predominantly dark gray shale (16–30% sandstone interbeds: Scott, 1970), the western Glencairn consists of as much as 75% sandstone interbeds (e.g., Fig. 4, section C). Additionally, these sandstones are

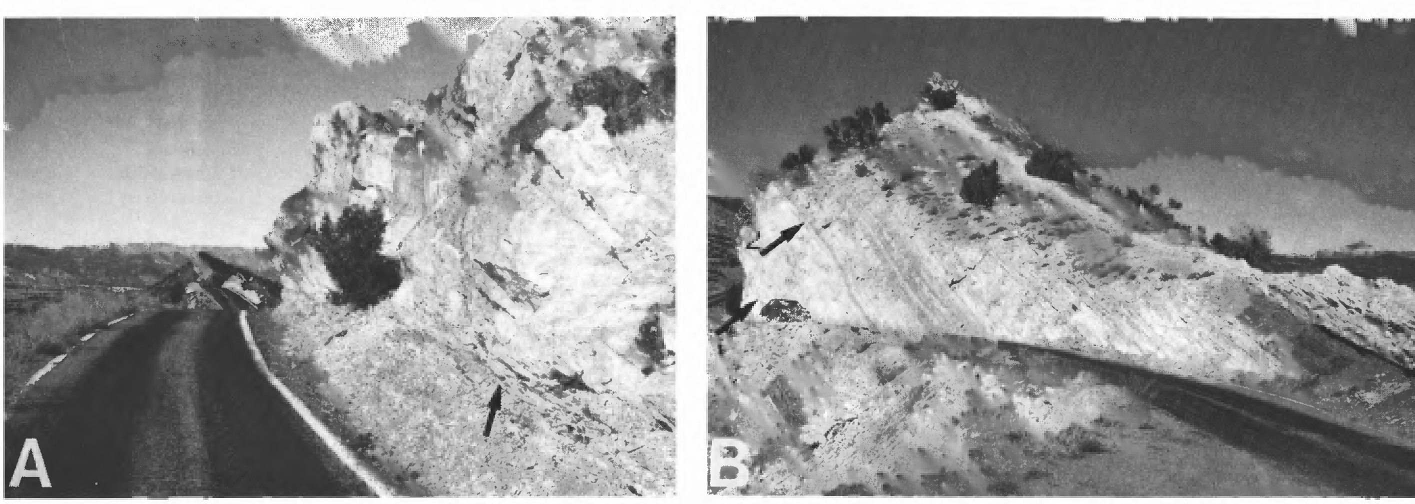

FIGURE 6. Upper and lower contacts of the Glencairn Formation at the Skyline Hogback, Canon City (sec. 32, T18N, R70W). A, The Glencairn-Muddy Sandstone contact (arrow); note the massive sandstone (lower sandstone unit, or channel sandstone member of Gustason and Kauffman, 1985) which is interpreted as a response to sea-level rise when aggrading channels eroded into Glencairn rocks following a rapid marine regression during latest Glencairn time. B, The Plainview-Glencairn Formation contact; the sandstone immediately overlying the Plainview Formation (1) is the first progradational sequence of Gustason and Kauffman (1985); a gravel lag on top of this lower sandstone (2) can be correlated northward into the Denver Basin.

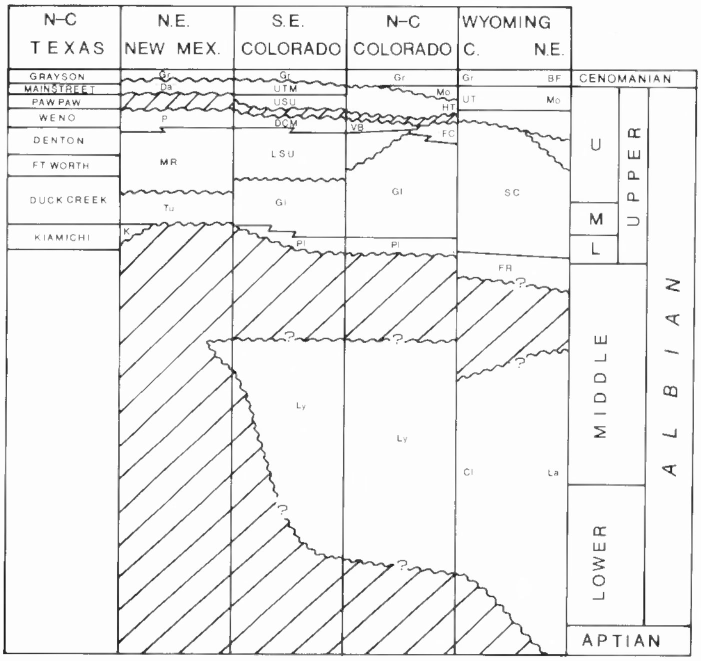

FIGURE 7. Stratigraphic correlation of Albian rocks along the western margin of the Western Interior seaway. See Figure 3 for explanation of abbreviations.

more common toward the upper part of the formation where occasional carbonaceous sandy shales and coals are present. Basan and Scott (1979), noting the intense bioturbation in addition to the lenticular or wavy stratification in the shales, suggest a tidal estuarine environment (also see Scott, 1974 and Scott and Taylor, 1977).

The Glencairn varies along the southern Front Range from 13–19 m (Gustason and Kauffman, 1985) and is more than 30 m thick in southeastern Colorado (Long, 1966, section #23). Long's (1966) isopach maps of the Lytle and Glencairn (including the Plainview) show an inverse relationship where topographic lows in the Lytle are filled by Glencairn (and Plainview) sediments. The Glencairn thins considerably south toward the New Mexico border, particularly in the west where it disappears completely (Fig. 4, section K–N). However, since the Apishapa uplift marked a partial barrier between the northern and southern arms of the Western Interior sea during the early to middle Late Albian (Fig. 3), it is probable that prior to breaching this boundary (during late Late Albian time), the shoreline in southeastern Colorado ran west-southwest to east-northeast along the edge of the Apishapa uplift.

The Glencairn lies on the Plainview Formation, a boundary traceable by a thin regional conglomerate (Waagé, 1953; Long, 1966; Gustason and Kauffman, 1985) (Fig. 6B). A basal Glencairn sandstone is generally present along the Front Range, but elsewhere to the south and east, this sandstone is missing, indicating the proximal coastal restriction of the basal Glencairn sandstone.

Sandwiched between the largely unfossiliferous fluvial beds of the upper and lower Dakota Group, the Glencairn shales provide a useful biostratigraphic age control with their rich invertebrate fauna. The molluscan fauna typically found includes the middle late Albian forms *Inoceramus comancheanus*, *Texigryphaea pitcheri*, *Lopha quadruplicata*, and the late late Albian forms *Inoceramus bellvuensis*, *Texigryphaea tucumcarii*, *Scabrotrigonia emoryii*, *Protocardia texana*, *Eopachydiscus brazoensis*, *Ostrea noctuensis*, *O. larimerensis* and *Anchura kiowana* (see Scott, 1970, Gustason and Kauffman, 1985, and Kauffman, 1984 for more complete faunal lists). These forms support correlation with the lower Washita Group of northern Texas (Duck Creek, Fort Worth and Denton formations) (Scott, 1970), although the reported presence of *Adkinsites brazoensis* from the Glencairn (Gustason and Kauffman, 1985) suggests that this formation extends down into the early late Albian (Kiamichi equivalent) or that this biozone extends into the Duck Creek zone (middle middle Albian) (Fig. 7). The power of correlation of this fauna is enhanced by the late Albian convergence of the northern and southern arms of the Western Interior seaway, with southeastern Colorado marking the approximate zone of mixing of these faunas (see Kauffman, 1984 and Gustason and Kauffman, 1985 for detailed analyses). Basan and Scott (1979) reported a relative abundance of the trace fossils *Ophiomorpha*, *Thalassinoides* and *Rhizocorallium* in the Glencairn shales, and Chamberlin (1976) identified the following from the Skull Creek, mostly in the upper part, in the Denver Basin: *Arenicolites*, *Skolithos*, *Asterosoma*, *Teichichnus*, *Scoyenia*, *Crossopodia* and *Terebellina*.

Gustason and Kauffman (1985) identified five upward-coarsening cycles within the Glencairn which they suggested might represent small scale fifth-order depositional events possibly related to Milankovitch type climatic periodicity, such as has been postulated for the Greenhorn cycle sequence (Barron et al., 1985), or to eustatic fluctuations. More widespread studies are required to document the lateral continuity of these cycles before this postulate can be confirmed in the Glencairn. As Gustason and Kauffman point out, the five progradational cycles in the Glencairn at Canon City possibly have a total duration of about 0.5 m.y., thus averaging about 0.1 m.y. per cycle, similar to that predicted by Milankovitch cyclicity. The observed sharp upper surfaces of each upward coarsening sandstone suggest minor erosion at the termination of each cycle. Such characteristics would reflect sea-level-caused allocyclicity rather than simple increased terrestrial sediment influx as would be inferred by Milankovitch climatic events. However, it should be noted that these sandstones-shale cycles are very poorly developed, even totally absent, in the Tucumcari Shale south of the Apishapa uplift, suggesting these fifth-order events are localized. Further work is required before further comment can be made about this suggestion.

The upper part of the Glencairn Formation is dominated by sandy lithologies which reflect the general high stand to regression of the Kiowa-Skull Creek seaway; Gustason and Kauffman (1985) placed the maximum point of regression at the top of the Glencairn (their fifth cycle) in the Canon City-Pueblo area.

The Tucumcari Formation is known principally from the Tucumcari region and consists of 0 to 22 m of gray fissile shale containing a rich molluscan, foraminiferan and ostracode fauna with occasional buff sandstone interbeds (see Kietzke, 1985; Kues, 1985; and Kues et al., 1985 for a review of the Tucumcari). This marine offshore formation is thought to be a bay-shoreface environment (Scott, 1974), probably in a prodelta situation (Kisucky and Wright, 1985, 1986; Kisucky, 1986).

Immediately overlying the shale lithology is a 2 to 3 m massive sandstone which contains a typical Tucumcari molluscan fauna despite the differing lithology. Griggs and Read (1959) and Payne et al. (1986) included this sandstone within the Mesa Rica Sandstone, but Scott (1970, 1974), following Dobrovolny et al. (1946), preferred retaining it within the Tucumcari Formation. Since the Tucumcari and Mesa Rica are currently defined lithologically, the temptation has been for the base of the Mesa Rica to be placed on top of the shaley facies of the Tucumcari and not above the fossiliferous sandstone unit containing a Tucumcari fauna. However, it is argued here that the upper sandstone is a high stand facies of the Tucumcari and thus is genetically related. Furthermore, the boundary between the upper sandstone and the Mesa Rica proper is marked by a pebble-conglomerate disconformity reflecting a regressive disconformity separating the Tucumcari high stand from the sea-level rise causing Mesa Rica deposition. This author has not examined the Tucumcari-Mesa Rica boundary in detail at localities other than the San Jon roadcut (13 km south of San Jon) and Bull Canyon (secs. 27 and 28, T9N, R26E). Kues (1986a) and Lucas et al. (1985) reported a sandy fossiliferous horizon in the upper Tucumcari/lower Mesa Rica Sandstone from northeast and southeast of Santa Rosa, respectively, but Lucas et al. (1986) showed no fossiliferous sandstone overlying the Tucumcari shale facies at Clayton Lake, Union County. It is urged here that the top of the Tucumcari Formation should include beds containing a typical molluscan fauna regardless of the lithology.

The base of the Mesa Rica is marked by a disconformity (often a pebble lag deposit) at most localities, although Kisucky and Wright (1986) report interfingering between the Pajarito and Mesa Rica.

The base of the Tucumcari lies disconformably upon the Morrison Formation in east-central New Mexico (Fig. 3), although at Tucumcari Mountain there is a thin sandstone and conglomerate bed which has been interpreted as being Cretaceous (e.g., Bullard, 1928; Mankin, 1958; and Scott, 1970) and Jurassic (e.g., Dobrovolny et al., 1946; Payne et al., 1986) in age. The sandstone is not observed at other localities in east-central New Mexico (see Lucas et al., 1985) except to the north, in the Dry Cimarron Valley, where the Lytle Formation is documented.

Kues (1986b) reported a Kiamichi Shale fauna from the Portales area of extreme east-central New Mexico which underlies the Tucumcari Formation. A thin basal conglomerate containing *Ceratostrean texana* lies disconformably on Triassic mudstones indicating an absence of a lower (Lytle equivalent) fluvial sandstone (Fig. 3).

MUDDY FORMATION

Introduction

The Muddy ("J" or "Dakota" Sandstone) Formation is a highly variable unit of paludal and paralic environments extending from southern New Mexico to the Canadian border, and a burdensome terminology has evolved during the past 60 years, especially in the western Denver basin. Outside this basin, the Muddy generally comprises 20–50 m of brown, medium- to coarse-grained crossbedded sandstone with frequent shaley interbeds. Three units can be identified in the south-central and southeastern part of Colorado: lower sandstone unit, Dry Creek Canyon Member and upper sandstone unit (Waagé, 1953) (Fig. 2). The upper and lower sandstone units were not designated as formal members of the "Dakota" Formation of Waagé, rather as convenient descriptors for sandstones separated by the Dry Creek Canyon Member.

Lower sandstone unit–Mesa Rica Sandstone

The lower sandstone unit forms a characteristic cliff-forming, medium-grained, brown-buff sandstone 10–15 m thick on average. Bedding is variable, from massive to platey with parallel and trough crossbedding and well-developed and temporally persistent channels preserved. Sediment transport direction in southeastern Colorado is consistently from south-southwest to east-northeast. The base of this member is generally erosional (scouring) with intermittent conglomeratic horizons, although gradational contacts have been noted with the underlying Glencairn Formation (Long, 1966). Where the Dry Creek Canyon Member is present, the upper boundary of the lower sandstone unit was reported by Long (1966) as generally disconformable, although this boundary appears to be local and of limited significance. The lower sandstone in southeastern Colorado is here interpreted as an alluvial plain and delta front aggrading in response to sea-level rise (Fig. 6A), although Taylor (1974) viewed the lower sandstone unit as a marginal marine beach-bar to tidal estuarine complex developing into a lagoonal sequence in the Dry Creek Canyon Member. It is difficult to reconcile the consistent east-northeast drainage patterns with this interpretation, since this direction runs almost adjacent to the late Kiowa-Skull Creek cycle shoreline (e.g., McGookey et al., 1972).

The extension of the lower sandstone unit northward into the Denver-Julesberg basin was first documented by Waagé (1955) where he correlates this with the Kassler Sandstone Member of his South Platte Formation (Figs. 3, 7). In the northwestern Denver basin, the Kassler Sandstone pinches out northward over the Wattenberg paleotectonic high (MacKenzie, 1971; Weimer, 1983, 1984). The Muddy Formation north of this uplift, in the Fort Collins area, consists of two members (Horsetooth and Fort Collins members) which are separated by a substantial erosional disconformity, probably the same as that at the base of the Kassler Sandstone (Weimer, 1983, 1984) (Figs. 3, 7). The exact correlation of the Kassler Sandstone to the north is currently unclear.

To the south, in northeastern New Mexico, strata homotaxial with the lower sandstone unit represent an aggrading alluvial plain and deltaic complex depositing the Mesa Rica Sandstone over the Tucumcari Formation (Fig. 3, 7). The western part of this system, in the vicinity of Las Vegas, is clearly fluvial in origin (the lower braided fluvial interval of Gilbert and Asquith, 1976) (Fig. 8A, 8B), whereas the eastern part, the Tucumcari basin and immediately to the north, consists of up to 30 m of delta-front and delta-channel facies which flowed in an east-southeast direction (Gage and Asquith, 1977; Kisucky and Wright, 1985, 1986; Mateer, 1985; Kisucky, 1986; Payne et al., 1986). The transition between the deltaic eastern facies, and the fluvial western facies has not yet been clearly mapped, and has been the cause of misunderstanding with regard to the correlation of the Mesa Rica and the "Dakota" sandstones. In the west, the "Dakota" Sandstone was regarded as the entire sand unit beneath the Graneros Shale, while in the east the "Dakota" and Mesa Rica were identified as separate units (Wanek, 1962; but see Scott, 1970; Fig. 2). Trace fossils are exceedingly common in the delta front facies and include *Ophiomorpha, Skolithos, Arenicolites, Rhizocorallium, Planolites, Thalassinoides* and *Corophioides* (Bejnar and Lessard, 1976; Gage and Asquith, 1977), but are rare further west in the fluvial facies (*Planolites* only; Bejnar and Lessard, 1976).

Dry Creek Canyon Member–Pajarito Shale

The Dry Creek Canyon Member (Waagé, 1953) is a highly variable unit, 0–20 m thick, of gray shale and fine-grained upward-fining sandstone interbeds interpreted by Long (1966) and Taylor (1974) as a freshwater swamp to delta-plain facies, which in some places experienced marine influence as evidenced by reports of Foraminifera from eastern Las Animas County (Long, 1966, section 21). The sandstone units can generally be recognized as stream channels by their lenticularity and basal scours. Waagé (1953) attributed the discontinuous nature of this member to a two-stage channel erosion by the overlying upper sandstone unit, suggesting that this was once a continuous unit across southern Colorado. This channeling has, in places, cut through into the Glencairn Formation (Waagé, 1953; Long, 1966) (Fig. 4, sections C–G, R).

The lower boundary with the lower sandstone unit here is regarded as regionally conformable, and in some places is demonstrably intercalating (Beaver Creek Canyon, northeast of Canon City). The upper boundary, however, is marked by an erosional disconformity with either the upper sandstone unit or the upper transitional member. The Dry Creek Canyon Member is occasionally absent, but when present does reveal continuity of facies at a consistent stratigraphic level. Although the upper and lower sandstone units are not always separable, Waagé's (1953) tripartite division reflects the depositional history of the Muddy and is traceable throughout the Front Range, although with some difficulty along the western edge of the Denver basin where pronounced delta development has complicated the overall correlation (Fig. 3).

Waagé (1955) correlated the Dry Creek Canyon Member with the Van Bibber Shale Member of his South Platte Formation in the Denver Basin to the north, but, as with the Kassler Sandstone, the northward extension of this unit into Wyoming is not entirely clear (Fig. 3). It is doubtful whether the delta-plain facies extended into Wyoming, but if they did, it appears that they were eroded during the hiatus between Fort Collins and Horsetooth deposition.

In northeastern New Mexico, the Pajarito Formation overlies the Mesa Rica Sandstone conformably (although there is some local channeling in northeastern New Mexico [Fig. 9]) and is lithologically similar to the Dry Creek Canyon Member. The Pajarito has been interpreted as a delta-plain facies composed of light gray shale and sandy shale with frequent fine-grained sandstone-channel interbeds containing abundant plant fragments (Asquith and Gilbert, 1976; Gilbert and Asquith, 1976; Mateer, 1985; Kisucky and Wright, 1986; Payne et al., 1986), and dinosaur footprints (Gillette and Thomas, 1985; Lucas et al., 1986; Lucas et al., in press). The Pajarito is not clearly defined in the western area, along the foothills of the Sangre de Cristo front range, although a shaley horizon (meander belt interval of Gilbert and Asquith [1976]) is present just below the uppermost transgressive sandstone at the Romeroville roadcut (6 km south of Las Vegas), and in well-logs (Fig. 4,

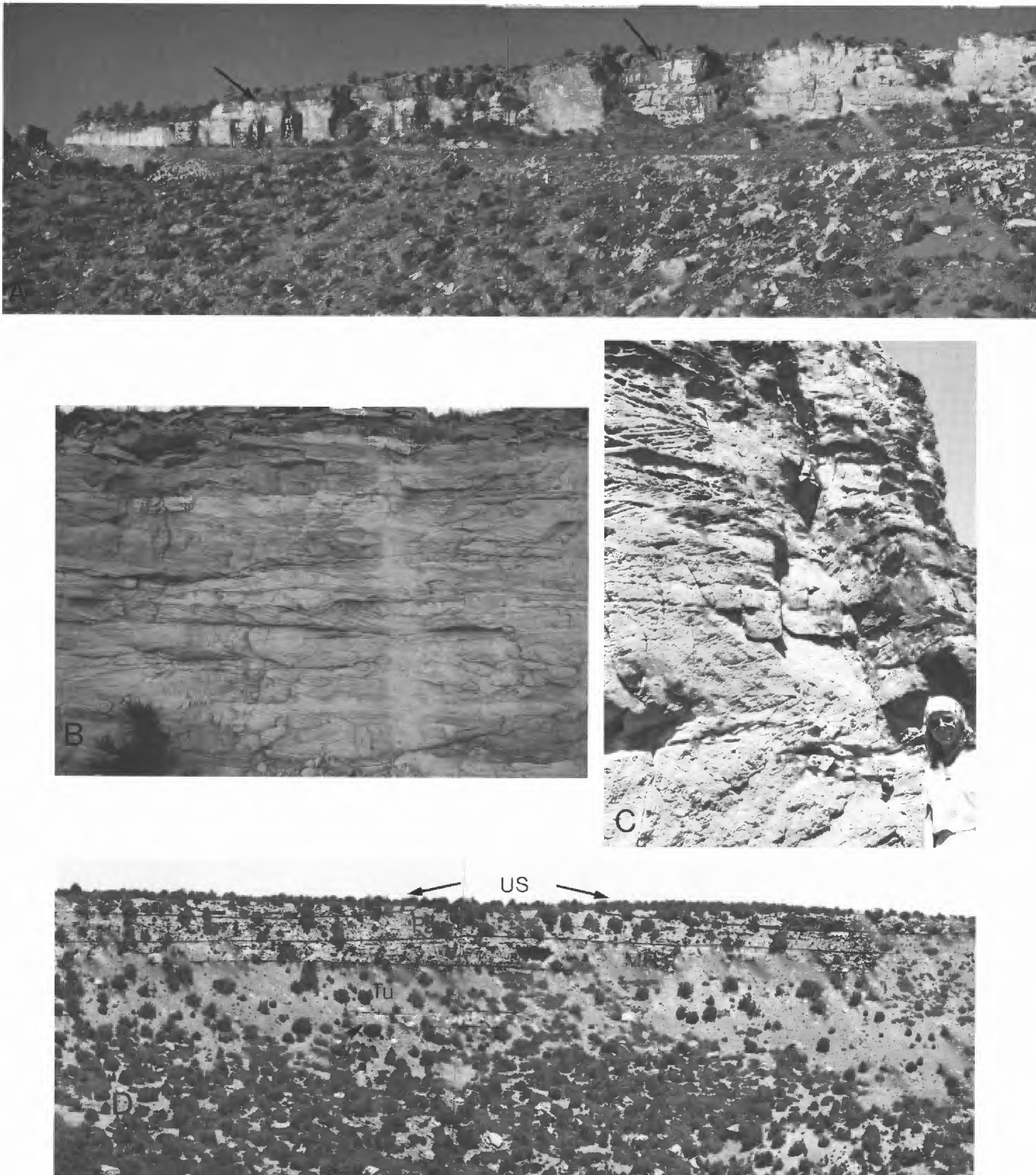

FIGURE 8. Upper Dakota sandstones in northeastern New Mexico. A, The light gray Mesa Rica Sandstone underlying the darker (orange) "Dakota" Sandstone on the west side of the Canadian River Valley, west of Roy (SE¼, sec. 29, T20N, R24E) (arrows mark boundary); scouring by the "Dakota" Sandstone into the Mesa Rica Sandstone is clearly evident. B, Detail of the Mesa Rica Sandstone taken at the west end of the outcrop seen in A; note the shallow trough crossbedding typical of a lower point bar-channel sequence of a braided fluvial system; sorting is relatively poor. C, The Mesa Rica Sandstone in the eastern Dry Cimarron Valley (NE¼, sec. 33, T32N, R35E), southwest of Wedding Cake Butte; the stacked planar crossbedded sequences (~30 cm thick) are characteristic of the eastern Mesa Rica and reflect inter-channel bar facies in a broad fluvial system. D, Panoramic view of the west side of Travesser Park, Dry Cimarron Valley (SW¼, sec. 12, T31N, R32E) showing the Dakota Group strata; Ly = Lytle Formation, Tu = Tucumcari Formation, MR = Mesa Rica Sandstone, Pa = Pajarito Shale, US = upper sandstone ("Dakota Sandstone" of older usage).

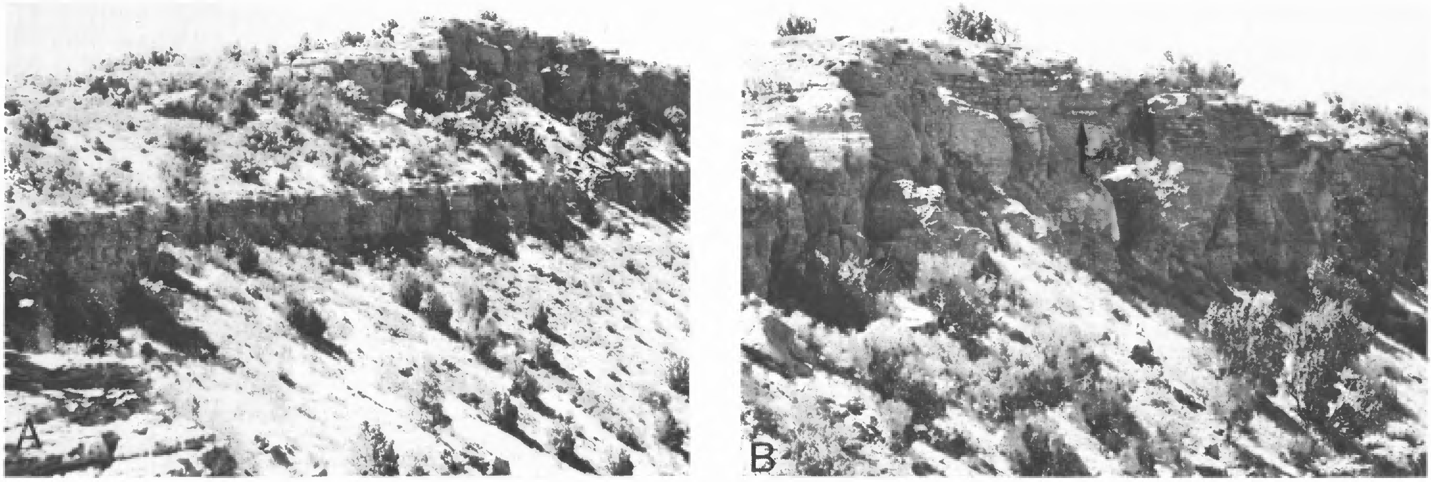

FIGURE 9. A, The Lytle Formation (lower sandstone), Glencairn Formation (covered slope) and Mesa Rica Sandstone (upper sandstone) southwest of Wedding Cake Butte, Dry Cimarron Valley (NE1/4, sec. 33, T32N, R35E). B, Detail from A showing the Pajarito Shale (arrow marks base) channeling into the Mesa Rica Sandstone.

sections N, and K–M, respectively; Fig. 10; see also Bejnar and Lessard, 1976).

Upper sandstone unit

The upper sandstone unit of the Muddy Formation is one that is in some confusion: in southern Colorado Long (1966) and Waagé (1953) recognized this unit between the Dry Creek Canyon Member and the uppermost transitional sandstones, while Taylor (1974) did not recognize an upper transitional bed (just an upward change in lithology from massive to flaggy sandstone). Gustason and Kauffman (1985) divided their Muddy Sandstone into a lower channel-sandstone member and an upper transitional member.

The informal upper sandstone unit at Waagé's (1953) "type" section is a massive sandstone with thin upper horizons of mudstones (10–30 m), and it overlies the shales of the Dry Creek Sandstone Member or the lower sandstone unit with an erosional disconformity which is locally angular (e.g., at the Teller Reservoir). The upper boundary is planar with the upper transitional sandstones, although there is an abrupt change in lithology. Unlike the regular, finely-bedded flaggy sandstones of the transitional sandstones, the upper sandstone unit is highly irregular with frequent channel sandstones and thin, shaley overbank deposits, similar to the lower sandstone unit. This upper unit is not always present as evidenced by the Dry Creek Canyon Member directly underlying the transitional sandstones (cf., Long, 1966, section 27; also northeastern New Mexico, see later).

FIGURE 10. The upper part of the Mesa Rica Sandstone, the Pajarito Shale and the transgressive "Dakota" Sandstone, north end of the Romeroville roadcut (I-25) about 5 km south of Las Vegas.

The absence of both the Dry Creek Canyon Member and the upper sandstone unit at Canon City and Pueblo (Gustason and Kauffman, 1985) (Fig. 4, section C) is difficult to interpret, but the regional disconformity between their lower channel sandstone member and their upper transitional member may represent these "missing" units. Alternately, given the extreme variability of these facies, the lower part of Gustason and Kauffman's upper transitional member may be partially homotaxial with the Dry Creek Canyon Member and the upper sandstone unit, but represents different facies.

Upper transitional member

The upper transitional member of Gustason and Kauffman consists of 7.5 m of laminated fine-grained sandstone, trough-bedded, fine-grained sandstone and ripple laminated sandstone with abundant trace fossils. It is correlative with the transitional sandstone of Long (1966) which is generally 10 m thick and consists of finely-bedded, flaggy dark orange to brown sandstone (darker than the upper sandstone unit), frequently with ripple marks and trace fossils. Long (1966, p. 233) reported a consistently gradational contact with the overlying Graneros Shale, but notes elsewhere (p. 401) a "clean basal contact" of the Graneros with the "Dakota" below. The Graneros-"Dakota" contact is difficult to identify in the southeastern plains owing to the nature of the outcrop since the shales and flaggy sandstones of the upper transitional member are prone to erosion, leaving only the massive sandstones of the upper sandstone unit. Hogback exposures along the Front Range reveal this contact more readily, and it is consistently disconformable. Given the indistinctness of the eastern contact exposures, this boundary is here regarded as a regional disconformity. In the Denver Basin, the transitional sandstones are 10–20 m thick (Poleschook, 1978) and constitute freshwater to brackish lagoons, tidal flats and thin channels.

Kauffman et al. (1977) identified an approximately 3 m upper transitional facies of the "Dakota" Sandstone in northwestern Oklahoma, overlying a silty, occasionally lignitic, facies of paralic origin believed to be the equivalent to the Pajarito Shale. Stovall (1943) also recorded increasingly platy bedding in the massive uppermost "Dakota" Formation of the same region. These transitional beds become thicker to the west as the rapid Graneros sea approached the land, marking the initial submergence of the Greenhorn transgressive cycle along the western margin of the Western Interior seaway.

In the western part of northeastern New Mexico, the upper sandstone unit is apparently missing, with only transitional beds present, lying directly on the Pajarito Shale (or meander belt interval of Gilbert and Asquith, 1976) (Fig. 4, sections J–N; Fig. 10). At the Romeroville roadcut, a thin (approximately 3 m) thick- to fine-bedded sandstone overlies the Pajarito Shale and represents a transgressive sheet-sand body with abundant trace fossils toward the top, including *Lockeia* sp.

(see Archer and Maples, 1984). According to Gilbert and Asquith (1976) this sandstone grades into the dark gray shales of the overlying Graneros, although S. Lucas (written commun., 1987) indicates that this is a sharp boundary; this contact has not been thoroughly investigated by the author.

The eastward extent of this sequence is not clear, although Wanek (1962) identified the Mesa Rica, Pajarito and "Dakota" Sandstone unconformably overlain by Ogallala debris in the Montoya region (north of Conchas Reservoir). Mankin's (1958) Gallegos River section may also reflect a similar sequence. At exposures in the Canadian River valley west of Roy, the "Dakota" Sandstone lies disconformably on the Mesa Rica Sandstone where scouring is clearly seen (Fig. 8A). In the extreme northeast, the "Dakota" Sandstone has been identified overlying the Pajarito Shale at Clayton Lake as "22.5 m of quartzose sandstone that is mostly yellowish orange and intensively bioturbated" (Lucas et al., 1986, p. 60) and conformably underlies the Graneros. This entire sand body thus appears to be marine and either constitutes an abnormally thick and massive transitional sandstone, or represents the upper sandstone unit. This "Dakota" Sandstone is found capping the valley sides in the eastern Dry Cimarron Valley (Fig. 4, section Y; Fig. 8D), although the problem of identifying the upper transitional member on the plains of northeastern New Mexico is the same as in southeastern Colorado: it is frequently eroded, leaving the more resistant upper sandstone unit. Southeast of Tucumcari (T32E, R8N), the Pajarito Shale is overlain directly by the Graneros Shale (Kues et al., 1985) although a persistent thin sandstone is generally present at the top of the Pajarito which may represent a transitional sandstone.

Foraminiferal assemblages reported by Long from the upper transitional member (NE¼, sec. 29, T26S, R68W, and NW¼, sec. 27, T13S, R67W) share elements with the overlying lower part of the Graneros Shale (e.g., *Miliammina ischnia* and *Verneuiluoides perplexus*). While the former species is known from Albian to Cenomanian (Eicher, 1960), the latter is restricted to the Mowry and lowermost Graneros Shale. That the upper transitional member is apparently coeval with the Mowry Shale further north is in accordance with the widely held belief that the Dakota Group formations become progressively younger to the south (e.g., Young, 1960, 1970; Long, 1966) (Fig. 3).

CORRELATION WITH TYPE MUDDY FORMATION

The type section of the Muddy (Sandstone) Formation lies 8 km northeast of Greybull, Bighorn County, Wyoming (N½, sec. 32, T53N, R93W) and consists of a massive sandstone with varying amounts of mudstone, siltstone and lignitic coal with occasional chert conglomerates. It is overlain by dark marine shale of the Shell Creek Shale (lower Mowry) and overlies the Thermopolis Shale (equivalent to the Skull Creek Shale) (Paull, 1962). This formation reflects a deltaic facies, although given the variable nature of this unit, Paull (1962) provided additional reference sections of neritic and back-bar facies (see also Dresser, 1974; Curry, 1978). This unit was informally named by Hintze (1951) and subsequently became a common oil-worker's term throughout central Wyoming until formalized by Paull.

The correlation of the Muddy Formation southward into Colorado has been generally recognized (e.g., Eicher, 1960; Haun and Barlow, 1962) since Lee's extensive work along the Front Range (Lee, 1923, 1927), but a more detailed lithologic and stratigraphic regional analysis was not forthcoming until more recently (Cardinal, 1970; Cronoble, 1978). In north-central Colorado and southeastern Wyoming, Cronoble identifies lower (fluvial and swamp facies) and upper (shallow marine and beach facies) units which he regards as initially regressive and then still-stand to transgressive. This correlates closely with the Fort Collins Member (regressive marine sandstone) and the overlying Horsetooth Member (shallow marine sandstone in delta-destruction phase) of the Muddy Formation according to MacKenzie (1965, 1971) in the northern Denver basin (Figs. 3, 7). The exact correlation of the Fort Collins Member to the south is unclear, but it appears to precede Kassler Sandstone deposition (Weimer, 1983, 1984), and, being a marine sandstone, it might represent sediment derived from hinterland entrenchment during the low-stand, or gradual lowering of sea-level, at the end of the Skull Creek cyclothem. The Horsetooth Member of the Muddy appears to reflect a similar depositional event as the upper sandstone unit and upper transitional member in southern Colorado. In the western Denver Basin, the unusually thick delta development of the Muddy ("J" Sandstone) associated with demonstrable syntectonic activity (Weimer, 1983, 1984) gave rise to a complex local facies pattern which, although difficult to trace north and south directly, does reflect depositional episodes that are correlateable insofar as they record valley-fills during rising base levels (see discussion).

Recent work in the Powder River Basin of Wyoming indicates a basal Muddy Formation unconformity with the subjacent Skull Creek Shale and an infraformational erosional disconformity (Ryer et al., 1986; Gustason et al., 1986). These would appear to correlate with the Glencairn-Muddy disconformity and Dry Creek Canyon Member-upper sandstone unit disconformity found in northern and southern Colorado.

The Newcastle Formation is an eastern-source equivalent of the Muddy Formation found around the western margin of the Black Hills (Fig. 7). Weimer et al. (1982) detailed the facies relationships of this formation and demonstrated its largely fluvial nature, and it is topped by a thin transitional sandstone. Their analysis documented an upward transition from coarse braided-stream facies to high-sinuosity meandering streams with associated overbank-flood deposits, and finally to tidal flats and lagoonal facies prior to the incursion of the Mowry neritic shales. These three disconformity bounded units of the Newcastle Sandstone reflect similar depositional packages found in the Muddy Formation to the south in northern Colorado.

DISCUSSION

The purpose of this paper is to place the Dakota Group of northeastern New Mexico into a regional framework in order to clarify the stratigraphy. Usage of the term Dakota Sandstone or Dakota Formation for the upper Dakota Group in northeastern New Mexico is inappropriate and, rather than creating new names, extension of an already well documented formation name is preferred here. The only formal formational name available is the Muddy Formation which has already been progressively extended from north-central Wyoming into southern Colorado (e.g., Lee, 1927; MacKenzie, 1963; Gustason and Kauffman, 1985). The equivalency of strata of the upper Dakota Group in southern Colorado with those of northeastern New Mexico are sufficiently clear to warrant the extension of the term Muddy Formation into this region (Fig. 7). Biostratigraphical documentation of all nonmarine Dakota Group components has not yet reached the stage to permit such correlation, but a sequence stratigraphic approach does provide the necessary framework for such a proposal.

From the outline presented of the Dakota Group of southeastern Colorado and northeastern New Mexico, it is clear that eustatic events have played an important role in controlling sedimentation. Regional disconformities are found between the Jurassic Morrison Formation and the Lytle Formation, between the Lytle and Plainview Formation, between the Glencairn (and Tucumcari) Formation and the lower Muddy Formation (Mesa Rica and lower sandstone unit), between the lower and upper Muddy Formation (Dry Creek Canyon Member and upper sandstone unit) and between the Muddy Formation and the Graneros (and Mowry) shales. These disconformities can be recognized from northeastern New Mexico to Wyoming and bind depositional packages responding to sea-level changes which provide a useful tool for correlation across this sedimentologically complex region (Fig. 7). It is suggested here that most of the sandstones reflect sea-level rise causing aggradation of paludal and paralic sequences in addition to high sediment influx from the west. Only the uppermost Glencairn (and possibly Tucumcari) Formation and Fort Collins Member sandstones indicate rapid regressive deposition during the withdrawal of the Kiowa-Skull Creek seaway. Most major regression events are marked by the disconformities, some of which represent lengthy periods of substantial erosion (notably, the middle to upper Muddy Formation).

The deposition of the Dakota Group units largely by aggradation during eustatic rise was first suggested by Gustason and Kauffman (1985) in order to explain the stratigraphic section in the Pueblo-Canon

City area, and the extension of this interpretation appears valid throughout the region under consideration. The principal departure from previous interpretations is that of the lower sandstone unit of the Muddy Formation (and Mesa Rica), which has been regarded as a prograding delta complex building out over a regressing sea (Gage and Asquith, 1977; Berman et al., 1980; Kisucky and Wright, 1985; Mateer, 1985; Kisucky, 1986). However, the presence of a widespread disconformity at the top of the Glencairn-Tucumcari Formation (generally marked by sandstones) strongly suggests that maximum regression occurred prior to ensuing deposition of the lower Muddy Formation. If the lower Muddy Formation reflected continued regressive events, a disconformity would not be present. Furthermore, the nature of regressive events generally precludes a preserved stratigraphic record, especially on alluvial plain environments where entrenchment, not aggradation, would be occurring. Normally, the only preserved sediments would occur offshore and would be the product of onshore entrenchment. The Muddy Formation is not this type of offshore facies.

Sedimentation is an interplay between sea-level fluctuations, sediment influx and tectonic events. Clearly, sea-level fluctuations play an important role in determining the base level which controlled the sedimentation in this area. The significance of tectonic effects has not yet been thoroughly explored, although Weimer and colleagues have identified syntectonic events during Dakota Group deposition in the Denver Basin (Weimer, 1983, 1984) and on the western side of the Black Hills (Weimer et al., 1982). The contemporaneous movement of minor basement blocks significantly affected the local base levels and subsequent sedimentation, notably in directing major drainage systems and the development of deltas during Muddy time. The differing interpretations of the lower sandstone unit of the Muddy in southeastern Colorado by Long (1966) and Taylor (1974) may reflect basement activity prior to deposition deflecting fluvial systems off a topographic high, thus accounting for a lack of fluvial deposits in certain areas. Such tectonism would also control the rate of sediment supply in particular areas. However, it should be noted that tectonic effects noted in this northern region tend to be somewhat localized and, while explaining the geological history of these areas, the effects play a subordinate role in regional correlation with eustatic events.

Prior to Dakota Group deposition, a topographic positive extended northeast-southwest across southern Colorado and extreme northeastern New Mexico. This feature provided an important control upon subsequent sedimentation, and its presence helps interpret regional stratigraphic correlation. This basement high has been called various names including the transcontinental arch (e.g., Kauffman, 1984; Gustason and Kauffman, 1985), although Weimer (1983, 1984) views the transcontinental arch lying further north in northern Colorado and southeastern Wyoming. To avoid confusion, this feature is here termed the Apishapa uplift (Fig. 3; McGookey et al., 1972, fig. 1; King, 1977, fig. 65). The basement structure beneath the southeastern part of Colorado and northeastern New Mexico is complex and results from events surrounding the Late Paleozoic plate collision to the east (Ouachita foldbelt) (Kluth and Coney, 1981). While early Mesozoic peneplanation reduced the topography of this feature, it remained into the Cretaceous and provided a hindrance to the basin subsidence which dominated sedimentation in the Denver Basin and in Wyoming.

The manifestation of the Apishapa uplift on Dakota sedimentation can be seen in the eastward extension of the shoreline in northeastern New Mexico during Kiowa-Skull Creek time, and in the separation of boreal and Gulfian arms of the Western Interior seaway during the Albian (McGookey et al., 1972). Sedimentation on the southern and northern flanks of this uplift is noticeably different. The southern flank has no equivalent of the Lytle and Plainview formations, instead having the Kiamichi and Tucumcari formations overlying Triassic and Jurassic strata directly with no basal sandstone (Kues, 1986b; Fig. 3). Lytle and Plainview sediment-flow directions are directed (or deflected) northeast by this uplift. Faunal assemblage studies on the Tucumcari versus Glencairn by Scott (1970) and Kauffman (1984) clearly document the progressive admixing of salinities as the Apishapa uplift was submerged during the Late Albian for the first time. Sediment flow directions of the Muddy Formation in Colorado closely follow those of the Lytle, while those of the Mesa Rica in northeastern New Mexico flow to the southeast (Gage and Asquith, 1977; Kisucky and Wright, 1985; Mateer, 1985). The apparent absence (due to erosion or non-deposition) of upper sandstone unit equivalents over the Apishapa uplift further differentiates this area from regions to the north.

The absence of the Lytle and Plainview formations on the south flank of the Apishapa uplift indicates that coastal aggradation did not occur, although the reason for this is speculative. According to current sedimentary modeling, it might be assumed that sediment influx and subsidence was insufficient, and/or that the sea-level rise was too rapid to allow aggradation to occur. The possibility of different rates of sea-level rise on either side of the Apishapa uplift is worthy of further investigation.

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APPENDIX 1

Locality data for stratigraphic sections in Figure 4 are listed below.

A —Long (1966, section 32): sec. 27, T13S, R67W, El Paso County, Colorado.
B —Long (1966, section 16): secs. 2, 11, T16S, R67W, El Paso County, Colorado.
C —Skyline Hogback, Canon City; sec. 32, T18N, R70W, El Paso County, Colorado.
D —Long (1966, section 2): sec. 28, T21S, R68W, Pueblo County, Colorado.
E —Long (1966, section 1): sec. 1, T23S, R68W, Pueblo County, Colorado.
F —Long (1966, section 3): sec. 19, T24S, R67W, Pueblo County, Colorado.
G —Long (1966, section 7): sec. 29, T26S, R68W, Huerfano County, Colorado.
H —Long (1966, section 28): sec. 35, T30S, R69W, Huerfano County, Colorado.
I —Long (1966, section 29): sec. 30, T32S, R68W, Las Animas County, Colorado.
J —Long (1966, section 30): sec. 22, T34S, R69W, Las Animas County, Colorado.
K —American MPG Co., W. S. Ranch #1: sec. 1, T26N, R20E, Colfax County, New Mexico.

L —Keely Bell, C. S. Cattle Co. #1: sec. 21, T25N, R21E, Colfax County, New Mexico.

M—Continental Oil, Shoemaker-Reed #1: sec. 28, T17N, R18E, San Miguel County, New Mexico.

N —Romeroville roadcut (I-25), 5 km south of Las Vegas, San Miguel County, New Mexico.

O —Long (1966, section 8): sec. 32, T24S, R64W, Pueblo County, Colorado.

P —Long (1966, section 31): sec. 28, T27S, R61W, Las Animas County, Colorado.

Q —Long (1966, section 22): sec. 10, T31S, R58W, Las Animas County, Colorado.

R —Long (1966, section 26): sec. 18, T35S, R56W, Las Animas County, Colorado.

S —Baldwin and Muehlberger (1959, pl. 2, section 3): sec. 21, T31N, R29E, Union County, New Mexico.

T —Baldwin and Muehlberger (1959, pl. 2, section 7): sec. 30, T31N, R30E, Union County, New Mexico.

U —Baldwin and Muehlberger (1959, pl. 2, section 8a): sec. 3, T31N, R31E, Union County, New Mexico.

V —Baldwin and Muehlberger (1959, pl. 2, section 9): sec. 20, T31N, R32E, Union County, New Mexico.

W—Dry Cimarron Valley (Travesser Park): SW¼, sec. 12, T31N, R32E, Union County, New Mexico.

X —Dry Cimarron Valley (opposite Wedding Cake Butte): NE¼, sec. 33, T32N, R35E, Union County, New Mexico.