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The Blanco Basin Formation (Eocene), San Juan Mountains region, Colorado and New Mexico

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THE BLANCO BASIN FORMATION (EOCENE), SAN JUAN MOUNTAINS REGION, COLORADO AND NEW MEXICO

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Abstract—A new principal reference section and four additional sections measured from the Eocene Blanco Basin Formation illustrate the variability of the depositional environments, composition and sedimentation patterns. Lithofacies associations show a wide range of depositional environments, from rare proximal mass-flow breccias to abundant pedogenically modified basinal overbank deposits. Conglomerate clast counts and sandstone point counts indicate a laterally and vertically variable composition influenced by both local provenance and progressive onlapping of the basin margins. Paleocurrent studies of Blanco Basin outcrops demonstrate that the San Juan sag, a Laramide foreland basin of the San Juan Mountains region, was a major pathway for sediment input into the San Juan Basin during late Paleocene-Eocene deposition of the San Jose Formation. Stratigraphic relationships and tectonic implications suggest that the upper part of the Blanco Basin Formation may be coeval with the Eocene El Rito Formation, but that the two were deposited in different basins separated by a drainage divide near Chama, New Mexico.

INTRODUCTION

The Eocene Blanco Basin Formation is a coarse, alluvial red-bed deposit found in isolated outcrops along the southwestern flanks of the San Juan Mountains in south-central Colorado and adjacent New Mexico. Outcrops of this formation are sparse, yet it is an important record of a part of the early Tertiary geologic history of the San Juan Mountains region. It was deposited in the San Juan sag, a Laramide foreland basin that lies buried beneath the extensive volcanic pile of the Oligocene San Juan volcanic field. The formation documents the relative timing of uplift events in the region during the latter part of the Laramide orogeny. Understanding of the timing and style of uplift, basin formation and the general paleogeography of the region are of economic importance because of the recently recognized petroleum potential of the San Juan sag (Gries, 1985, 1989).

Remoteness of outcrops, rarity of complete exposures and apparent absence of economic mineral resources are probably the primary reasons that the Blanco Basin Formation has not seen detailed study in the past. Earlier work was limited to regional reconnaissance of the formation as it was described, mapped and tentatively correlated with similar formations. This paper refines the definition of the Blanco Basin Formation through analysis of its contacts, thickness, lithofacies associations, conglomerate and sandstone petrology, and paleocurrents. Together, these reveal the stratigraphy, sedimentology and provenance of the formation.

General description

The Blanco Basin Formation (as exposed) is a relatively thin (<200 m), unconformity-bound braidplain deposit of probable Eocene age. It is composed of reddened, oxidized conglomerate, sandstone, and soft mudstone deposited by generally southwest-flowing streams. It is poorly consolidated and friable, with varying amounts of carbonate, hematite and clay making up interstitial material. Clastic material in the formation was derived from a number of different source rock types exposed in nearby active uplifts during the latter part of the Late Cretaceous to Eocene Laramide orogeny.

Location and setting

Outcrops of the Blanco Basin Formation are restricted to a narrow band along the southern flank of the San Juan Mountains in southwestern Colorado and adjacent New Mexico, where they are exposed beneath the volcanic units of the San Juan volcanic field (Fig. 1). Heavy vegetation and extensive Holocene landslides cover most of the formation. Reference sections discussed in this paper were measured on public lands; access to private lands is strictly controlled and discouraged. Although most outcrops have poor lateral extent, enough widely separated individual exposures exist to enable reconstruction of probable early Eocene paleogeography and depositional environments.

PREVIOUS WORK

The Blanco Basin Formation was first described and named by Cross and Larsen (1935, p. 48) for "prominent development about Blanco Basin, in the central part of the Summitville quadrangle." Blanco Basin (also the name of a small community) is a basin-shaped, glaciated valley surrounded on three sides by steep mountains, one of which is an exhumed laccolith weathered to a white ("blanco") color. Unfortunately, the outcrops of the formation in Blanco Basin are sparse and incomplete; most of the "prominent" outcrops in the area are volcaniclastic beds of the Oligocene Conejos Formation.

The type section of the Blanco Basin was described by Cross and Larsen (1935) from an unspecified location in the valley of the Rio Chama, in the southeastern corner of Archuleta County, Colorado. Supplemental sections were described by Larsen and Cross (1956) and Adams (1957; reprinted in Muehlberger, 1967). Other detailed descriptions of the Blanco Basin Formation and its tectonic significance are those by Dunn (1964a, b) and Muehlberger (1967). Many other authors have made brief mention of the Blanco Basin Formation, and where possible, these are cited elsewhere in this text.

STRATIGRAPHIC POSITION AND AGE

To date, no macrofossils have been recovered from the Blanco Basin Formation and no lithologies are suitable for radiometric dates. A palynologic assemblage from the lower part of the formation indicates a *possible* late Paleocene–early Eocene age (E. B. Robertson, written comm. 1990), but the assemblage was sparse, and has not been reproduced (Brister, 1990). The only evidence of the age of the formation is its stratigraphic position and inferred correlation with units of better known age.

The Blanco Basin Formation overlies rocks as high in the stratigraphic section as the upper member of the Animas Formation, which has been assigned a Paleocene age based on biostratigraphic criteria (Reeside, 1924; Newman, 1982; R. H. Tschudy in Ryder, 1985, p. 99). The lower contact of the Blanco Basin is everywhere unconformable. As exposed, the formation overlies progressively older strata from Paleocene in the center of the San Juan sag to Triassic towards basin margins. The degree of angular discordance at its lower contact increases towards basin margins (Fig. 2a). In the central part of the basin, the angularity between the Blanco Basin and Animas Formations is minor, and thus other criteria such as petrology, lithofacies, color and presence of organic matter are employed to distinguish between them.

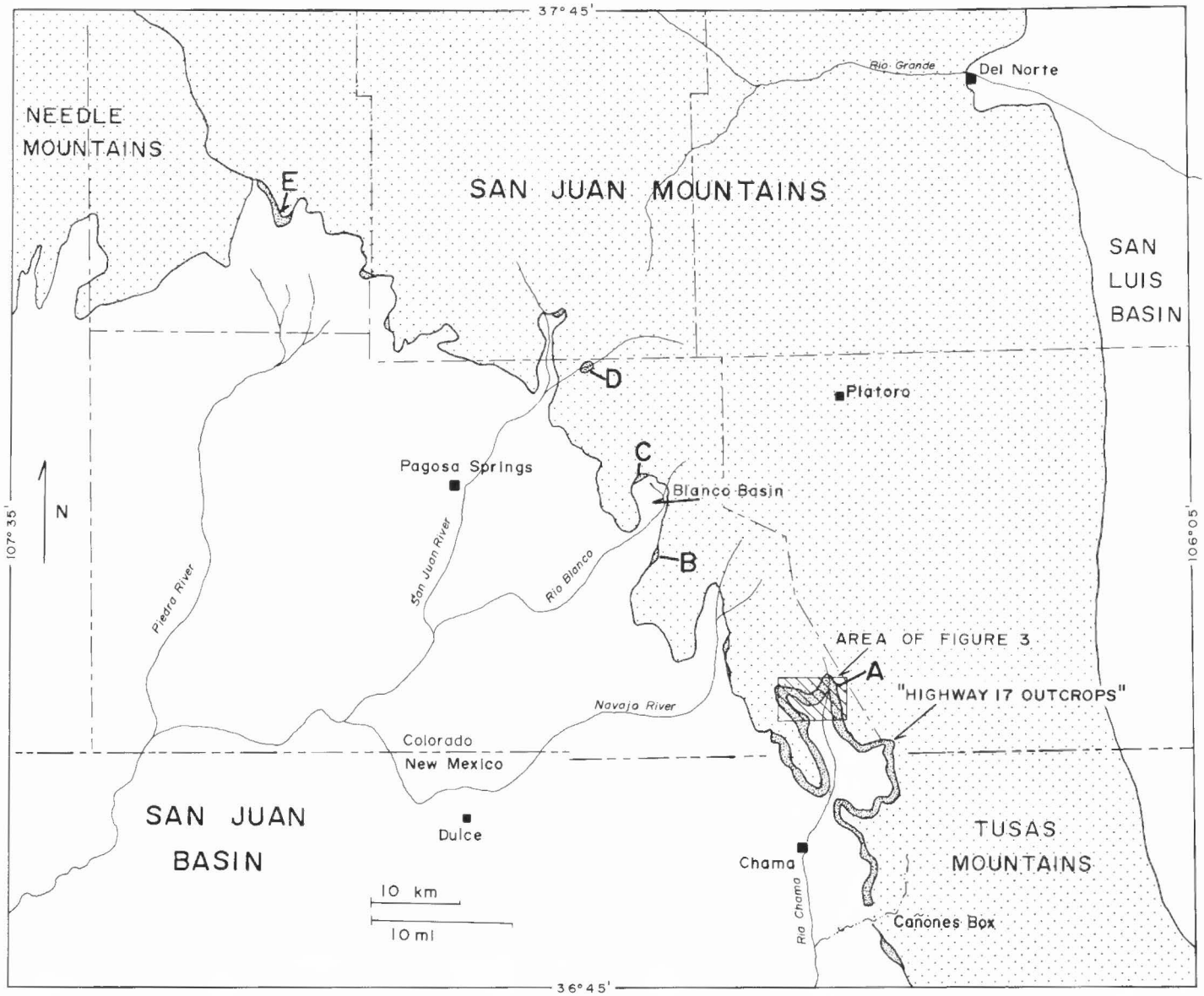


FIGURE 1. Regional location map. Blanco Basin Formation (dark stippled pattern) crops out at scattered locations along southwestern flank of San Juan Mountains (light stippled pattern). Bold letters (A, B, C, D, E) show locations of reference sections discussed in text.

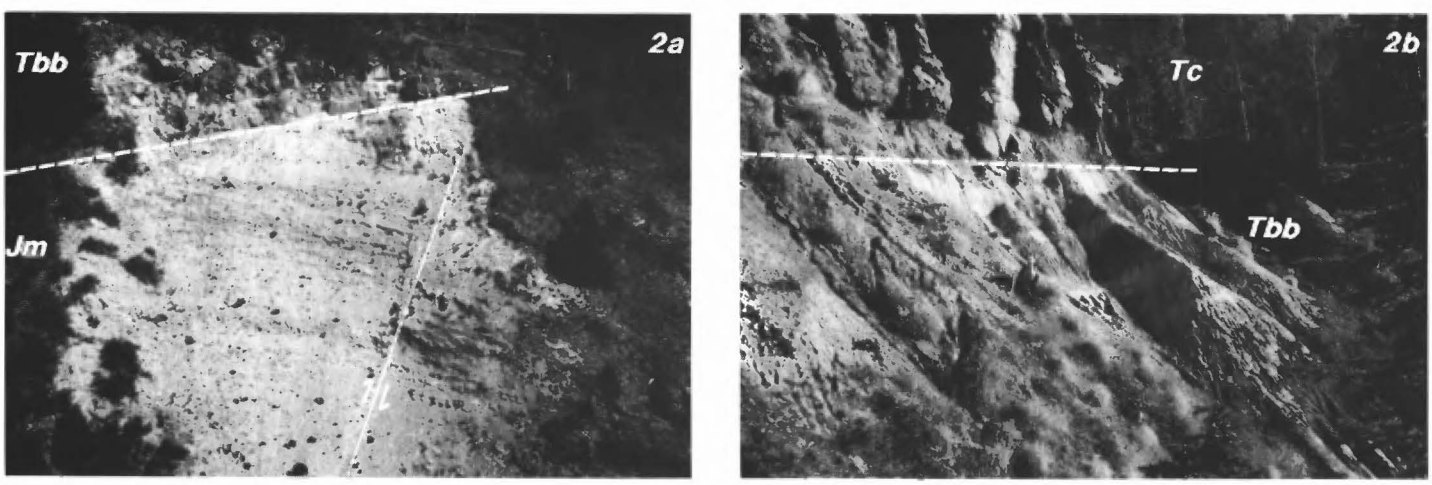


FIGURE 2. Upper and lower contacts of the Blanco Basin Formation. a. Angular unconformity between Blanco Basin Formation (Tbb) and Morrison Formation (Jm) visible from New Mexico Highway 17, near state line, north of Chama, New Mexico. b. Contact between Blanco Basin Formation and Oligocene Conejos Formation (Tc) at Oil Creek, Colorado (location "C" on Fig. 1).

The Blanco Basin Formation is overlain by the Conejos Formation, which has a K/Ar age of 35 to 30 Ma (Lipman et al., 1970). Apparent conformity between the two formations at some localities was described by Cross and Larsen (1935), but they also mentioned that the Blanco Basin was in places erosionally thinned prior to deposition of overlying units. Later regional mapping demonstrated that an erosion surface of probable latest Eocene age was developed across the Blanco Basin and older formations (Steven, 1975). This surface cuts strata as low in the section as the Lewis Shale (Upper Cretaceous) along the northeastern flank of the Archuleta anticlinorium. Folding of the Blanco Basin and older strata over the Archuleta anticlinorium occurred in the middle(?) Eocene (Dunn, 1964a, b). Fig. 2b illustrates a rare excellent exposure of the upper contact.

Numerous authors have suggested that the Blanco Basin is a piedmont facies of the lower Eocene San Jose Formation (e.g., Baltz, 1953, 1967; Barnes, 1954; Van Houten, 1957; Muehlberger, 1967; Dunn, 1964a, b; Lucas, 1984), but direct correlation is impossible due to post–Blanco Basin folding and erosion in the vicinity of the Archuleta anticlinorium. Smith (1988) showed that paleocurrent indicators at one outcrop north of Chama, New Mexico, demonstrated southwest flow towards the San Juan Basin. This paper contributes additional data to support this observation. Smith (1988) also demonstrated that the Regina, Llaves and Tapicitos Members of the San Jose Formation were derived from northern and northeastern sources; thus they may correlate with the Blanco Basin, at least in part.

Dunn (1964a) briefly compared the sandstone compositions of the San Jose and Blanco Basin Formations. Lucas (1984) suggested Dunn's study provided possible criteria for correlation of the Blanco Basin Formation with the Cuba Mesa Member of the San Jose Formation. However, as demonstrated in this paper, compositional variability of the Blanco Basin Formation is highly location-dependent, and detailed petrographic studies of the nearest San Jose Formation outcrops are needed before any correlations can be claimed with confidence. However, the similarities between some members of the San Jose Formation and the Blanco Basin Formation in lithology, stratigraphic position and general sedimentologic trends indicate that they correlate at least in part.

Other formations with which the Blanco Basin has been correlated are the Telluride Conglomerate and El Rito Formation. The relationship of the Blanco Basin Formation and the El Rito Formation is discussed later in this paper. The Telluride Conglomerate (Cross and Larsen, 1935) occurs in outcrops along the western margin of the San Juan Mountains. Its sediments were shed westward and northwestward (Steven and Hail, 1989) from the Needle Mountains area (part of the Laramide San Juan uplift) during the Eocene(?), whereas part of the Blanco Basin was derived from the Needle Mountains area but shed south to southeast. The two formations probably reflect sedimentary response to the same uplift event.

REFERENCE SECTIONS

In order to understand the characteristics of the formation, I briefly visited most outcrops reported in the literature (exceptions were some private lands where permission for access could not be obtained). Reference sections were measured from the best exposed and accessible outcrops in order to document vertical and lateral variations of the formation.

Principal reference section

A new principal reference section and locality are proposed here because Cross and Larsen's (1935) description of the type section along the Rio Chama was not detailed enough to determine its exact location. The principal reference section occurs on public land and is easily accessible in good weather via a gravel road (Fig. 3). The principal reference section (Fig. 4; called section "A" in this paper) is the thickest section of the formation (194 m) and appears to be the most representative single section.

Cross and Larsen (1935, p. 48) described three informal members:

> . . . an upper cliff-forming white sandstone with some horizontal fluting; a middle member that crops out as broken cliffs and is made up of alternating beds of white sandstone and red shale, giving a general pinkish outcrop; and a lower bright-red member of muddy sandstone and shale that is soft and gives poor exposures.

This subdivision applies well to outcrops along the Rio Chama near the principal reference locality, but has less application to most outcrops away from the Rio Chama area. For this reason, these members are not extended to other areas. The general trend of coarsening upward of sandstone and conglomerate units and upward-decreasing abundance of mudstone units implied in Cross and Larsen's three members, however, is a common feature in most complete sections of the formation in outcrop.

Other reference sections

Measured sections B and C (Fig. 5) were erosionally thinned prior to deposition of the Conejos Formation, but are included here because their upper and lower contacts are exposed, and because of sedimentologic and petrographic differences from section A. Section D (Fig. 6) shows the greatest contrast in lithofacies types with section A. Section E (Fig. 6) demonstrates paleodrainage from a different uplift source. Sections B and C are best accessed by foot travel, whereas D and E are easily visited by passenger car.

LITHOFACIES TYPES

Lithofacies of the Blanco Basin Formation are highly variable within and between individual outcrops. The lithofacies present were dependent upon distance between sources and depositional sites, and specific environments of deposition, at least two of which are recognized. In general, facies are similar to those typical of humid subaerial alluvial fans and braidplain deposits. Descriptive terminology in common usage for such facies is that of Miall (1977, 1978, 1984), Rust (1978) and Rust and Koster (1984). This terminology has been modified slightly in Table 1 in order to group various lithofacies types recognized from the Blanco Basin Formation. For a detailed discussion of lithofacies types common to the formation see Brister (1990).

The depositional environments of the Blanco Basin Formation are discussed here in terms of lithofacies associations, which are listed in order of relative abundance.

TABLE 1. Lithofacies abbreviations defined.

Lithofacies	Depositional Environment
Gms = matrix-supported gravel	mass-flow deposits
Gm = massive gravel	braided stream longitudinal bars
Gp = planar bedded gravel	braided stream transverse bars
Gt = trough cross-stratified gravel	erosional channel fill
Sh+Sp = horizontal bedded and planar cross-stratified sand	sandy braid bars
St = trough cross-bedded sand	Channel and crevasse splays
Fl = horizontally laminated fines	overbank deposits
Fm = massive fines	paleosols, bioturbated overbank deposits

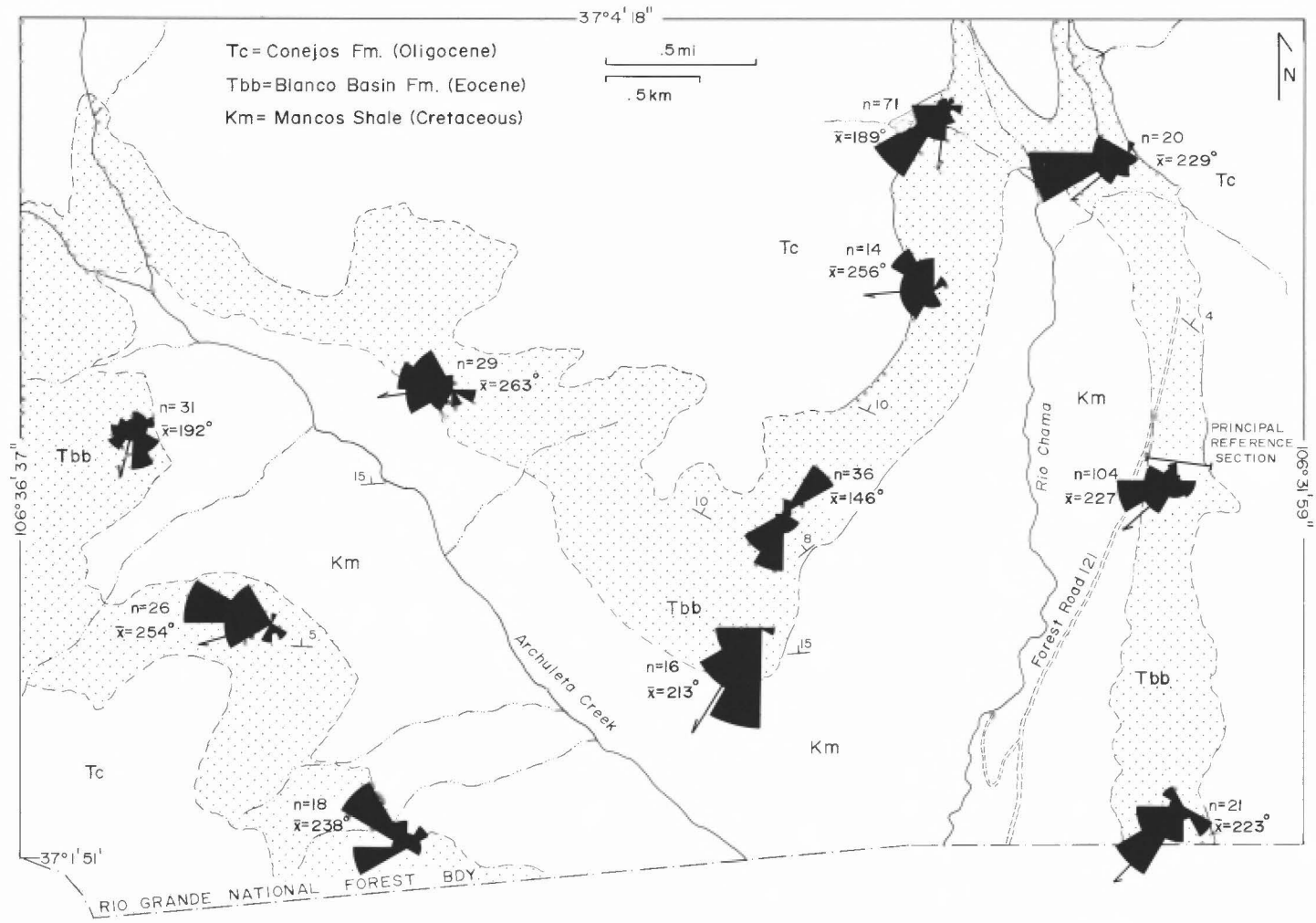


FIGURE 3. Simplified geologic map of principal reference locality in Archuleta County, Colorado, showing paleocurrent rose diagrams for Blanco Basin Formation. Formation contacts dashed where covered and inferred. Mapped area lies within U.S. Geological Survey Archuleta Creek 7.5' quadrangle, Colorado.

Lithofacies association Gm and Gms

The Gm (massive gravels) and Gms (matrix-supported gravels) association was only found north and east of Chama, New Mexico, mostly east of NM-17. It appears to be limited to proximal areas subject to occasional muddy debris-flow deposition caused by high storm runoff. Streams originating in adjacent low mountainous areas constantly reworked debris; thus facies Gm predominates. No point sources (canyons at head of fan) for alluvial fans have been recognized from the existing deposits. This association is identical to the Trollheim-type model of braided stream deposits (Miall, 1978). The limited contribution of Gms to this lithofacies association needs emphasis because statements by Dunn (1964a, b) may be misconstrued as indicating that mudflow facies are volumetrically important in outcrops of the formation. Recent drilling along the eastern margin of the San Juan sag, however, has discovered that locally the Blanco Basin may contain more extensive Gms-type facies.

Lithofacies association Gm, Gp, Gt and Fm

The Gm, Gp (planar bedded gravels), Gt (trough cross-stratified gravels), and Fm (massive fines) association is common in the upper parts of reference sections A and E and characterizes proximal braided-river deposits. Even though this association is found close to basin margins, mean paleocurrent indicators at the principal reference locality (Fig. 3) reflect nearly unidirectional flow over a large area, with no evidence of diverging flow from a point source. This indicates that either alluvial fans do not extend far into the basin, or that fans are very broad with such extremely low gradient that diverging flow cannot be determined from the outcrops examined. This association is similar to the Scott-type model of modern braided rivers (Miall, 1977).

Lithofacies association Fm, Gt, Gp, Fl, St, Sh and Sp

The association of Fm, Gt, Gp, Fl (laminated fines), St (trough cross-stratified sands), Sh (horizontal bedded sands), and Sp (planar cross-stratified sands) is characteristic of the lower portion of sections A and E, and sections B and C (upper parts of these sections have been removed by erosion). It grades upward into the lithofacies association discussed above. The finer grained nature of this association could be evidence that it is a more distal association than that above, but fine grain size may also reflect high rates of local tectonically induced subsidence, or fine-grained source rocks, or both. The basal part of section A contains significant amounts of reworked sedimentary material and much of the fine material in this section may come from erosional beveling of the thick Mesozoic shaly formations (i.e., Mancos Shale, Morrison Formation) at basin margins. In sections B and C, which are interpreted to be more geographically distal, this association lacks significant thicknesses of gravelly lithofacies. This braidplain lithofacies association is similar to the Donjek-type model of Miall (1977).

Lithofacies association St, Sh + Sp, Fm, Fl

This is the most distal lithofacies association of the Blanco Basin Formation. It is found at reference section D and is interpreted as a

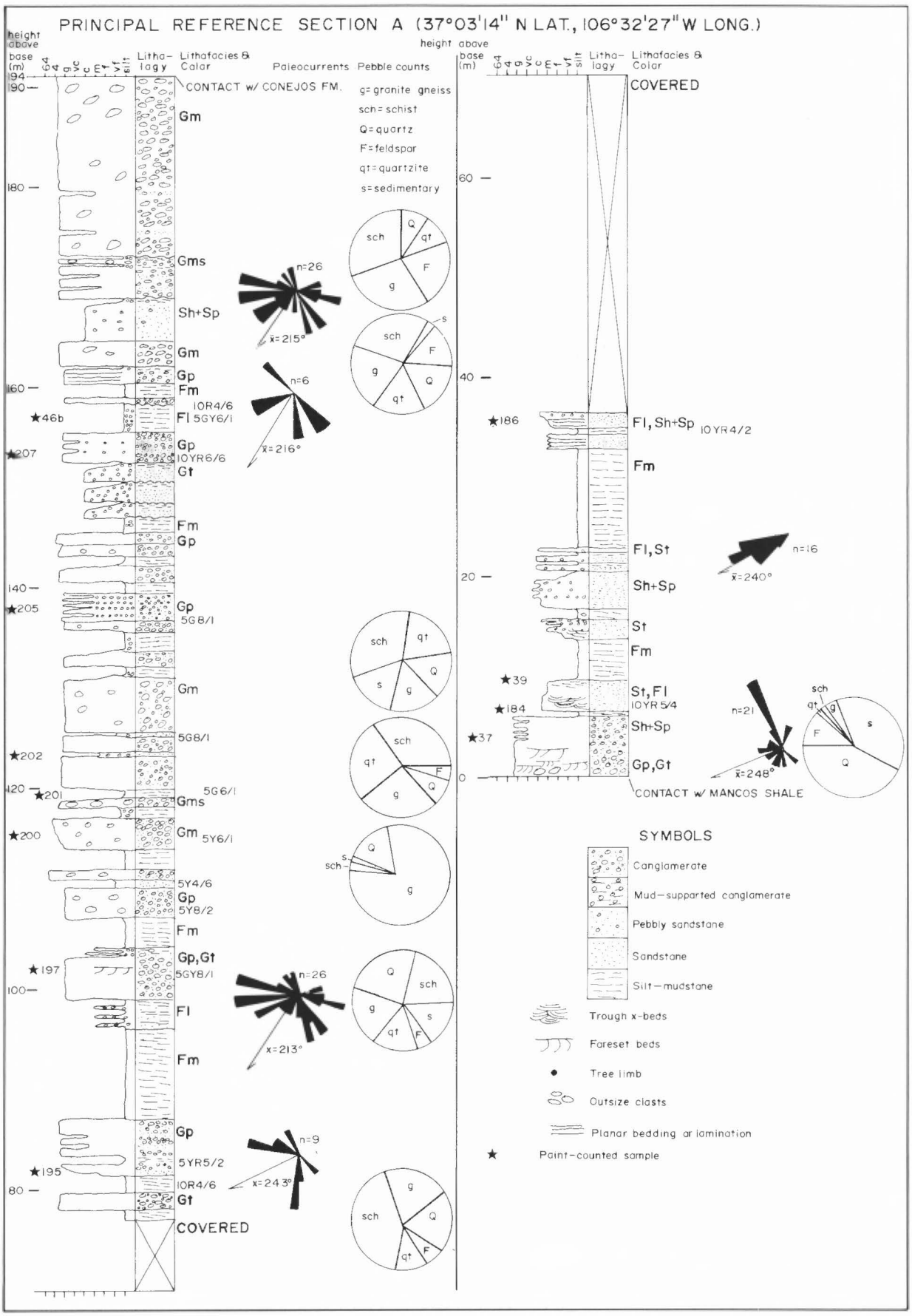


FIGURE 4. Measured section of the Blanco Basin Formation; principal reference locality, Rio Chama, Archuleta County, Colorado. Abbreviations explained in Table 1. Rock color codes are industry standard.

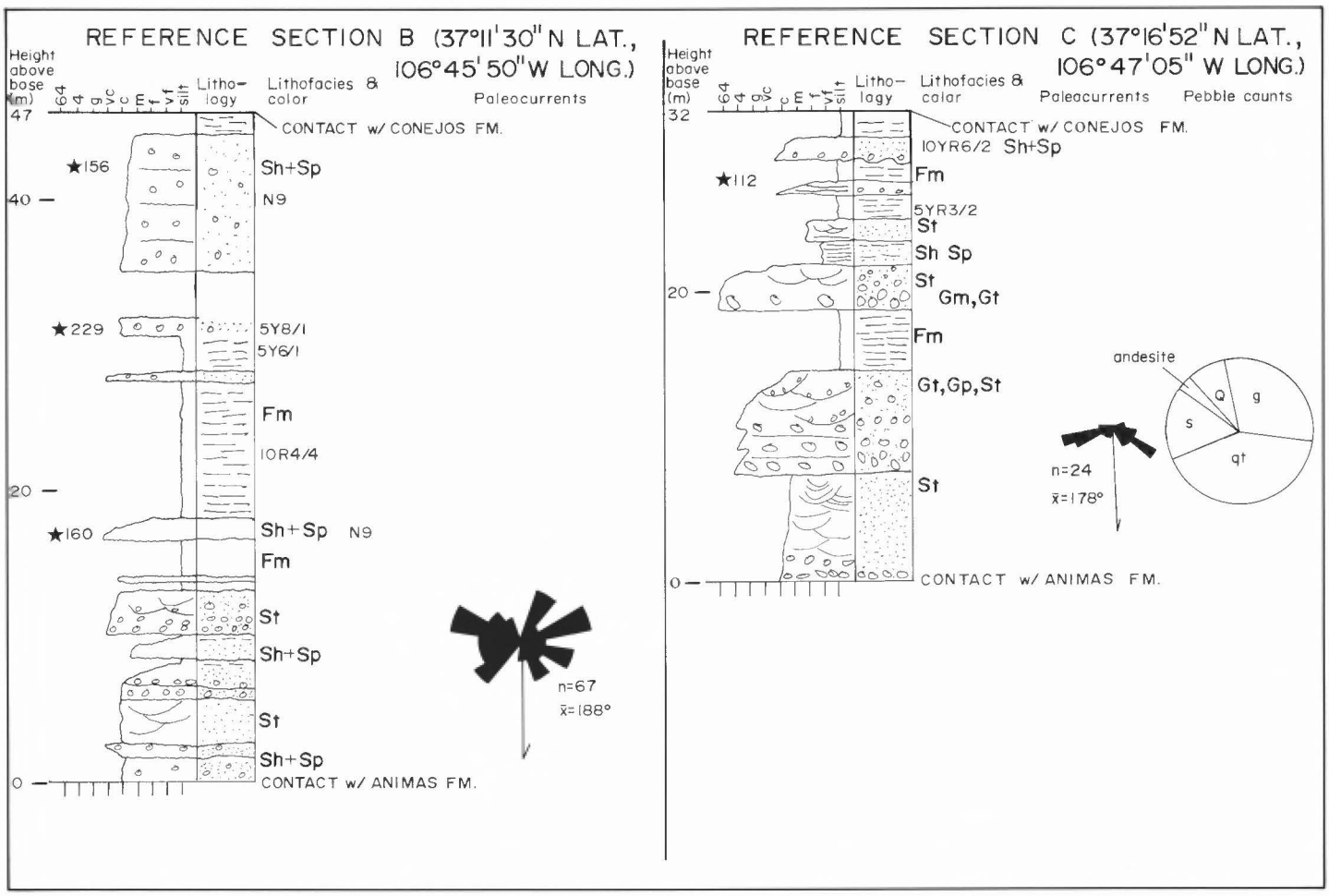


FIGURE 5. Measured sections B and C, Blanco Basin Formation. Symbols explained in Fig. 4; abbreviations as in Table 1.

coarse, sand-dominated, braided, trunk-stream system draining the interior of the depositional basin (San Juan sag). This association is dominated by lithofacies St and is lacking in gravel facies. This lithofacies association is similar to the South Saskatchewan–type model of sandy braided rivers of Miall (1978).

PALEOCURRENTS

Paleocurrent rose diagrams shown in Fig. 7 were derived primarily from pebble imbrications, with lesser contributions from parting-step lineations, crossbeds and trough orientations. Several general observations can be made. First, mean paleocurrent directions appear to converge obliquely towards a central axis that trends towards the San Juan Basin, confirming Smith's (1988) observation that one or more major trunk streams drained into the San Juan Basin from the San Juan sag region. This paleodrainage pattern is important evidence supporting correlation of the Blanco Basin Formation with the San Jose Formation of the San Juan Basin and shows that the Archuleta anticlinorium was not an emergent uplift feature during Blanco Basin deposition.

Second, paleocurrents near basin margins appear to be oriented obliquely to the margins (as opposed to perpendicular) and vary little within sections at individual localities. Therefore, extensive high-gradient alluvial fans are not indicated by this data. This is supported by the overall distribution of lithofacies associations discussed above. Third, exposures of the formation along the eastern side of the basin and recent drilling data (Brister, 1990) demonstrate the presence of an uplifted area east of the San Juan sag. Paleocurrent and provenance data suggest that the present Needle Mountains area was another uplifted area on the western side of the basin.

CLAST COMPOSITION AND PROVENANCE

Detritus in the Blanco Basin Formation is mainly arkosic. Common minerals (in decreasing abundance) are quartz in a variety of monocrystalline and polycrystalline types, orthoclase, microcline, biotite, sodic plagioclase, muscovite, heavy minerals (particularly opaques) and perthitic intergrowths of plagioclase and K-feldspar. Most of these minerals owe their origin to plutonic and metamorphic rocks in basement-cored uplifts that were present along the eastern and western margins of the San Juan sag. Lithic fragments from these terranes, plus sedimentary and volcanic lithic fragments from Mesozoic and lower Tertiary sources, are also important constituents. On average, clay, cement, and alteration and replacement minerals compose approximately 28% of the sandstones examined. Clay occurs as both authigenic and detrital material and calcite is the most common cement, followed by hematite.

Conglomerate and sandstone clast compositions from several outcrops were found to vary significantly, but in a predictable fashion, both laterally between outcrops, and vertically within measured sections. Study of clast compositions in the Blanco Basin Formation and comparison with other formations for correlation purposes must consider such variation. Point-counts of sandstones (mostly medium grain size) were carried out to document these compositional changes. Twenty-nine samples from the measured sections in Figs. 4, 5 and 6 were point-counted (500 points per sample), using parameters tailored to maximize provenance data (Table 2). See Brister (1990) for point-count data and description of method used.

Fig. 8 illustrates the compositional characteristics of the formation at the principal reference section. Overall, the samples reflect a strong input of local Precambrian detritus, both in feldspars from granitic

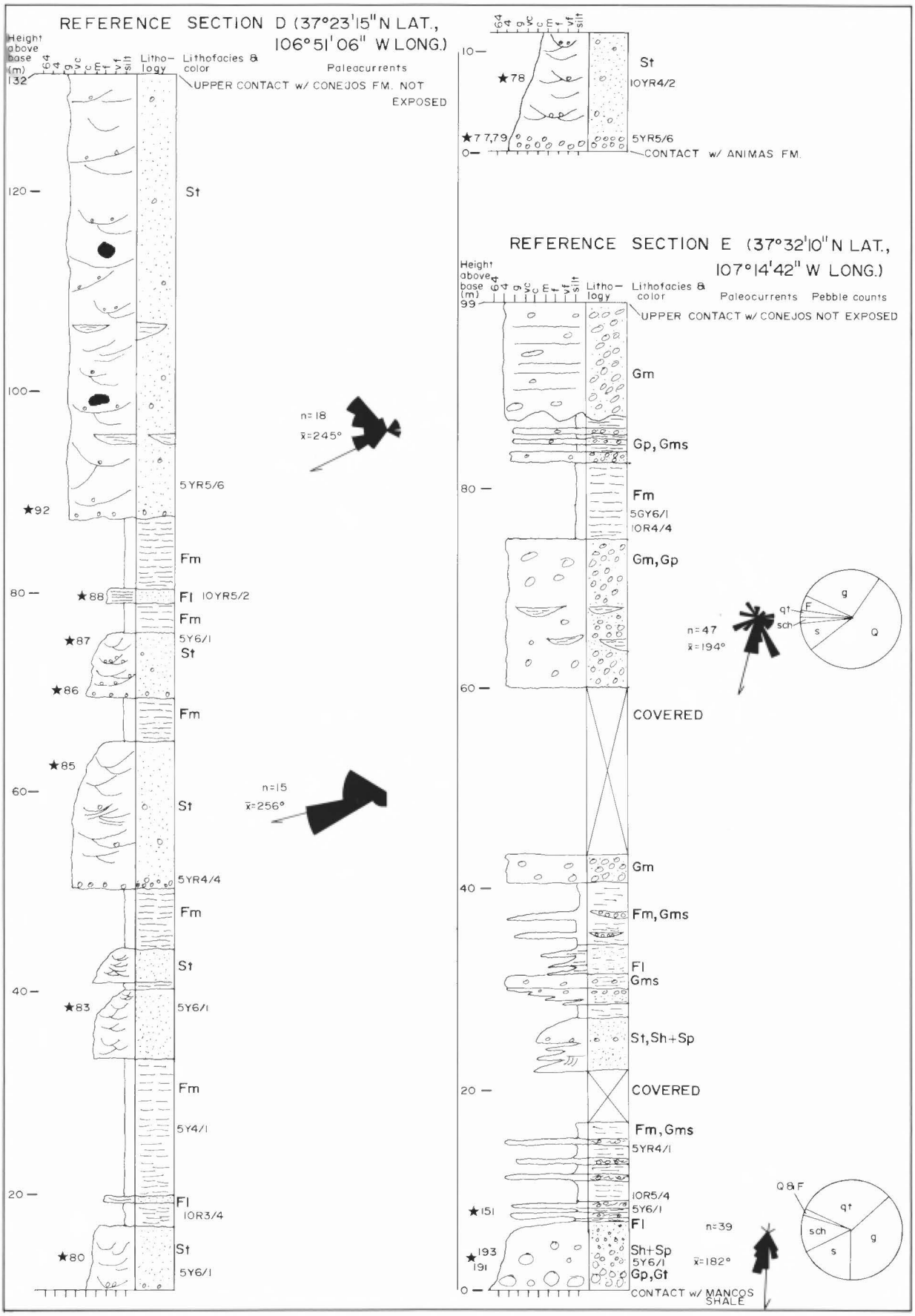


FIGURE 6. Measured sections D and E, Blanco Basin Formation. Symbols explained in Fig. 4; abbreviations as in Table 1.

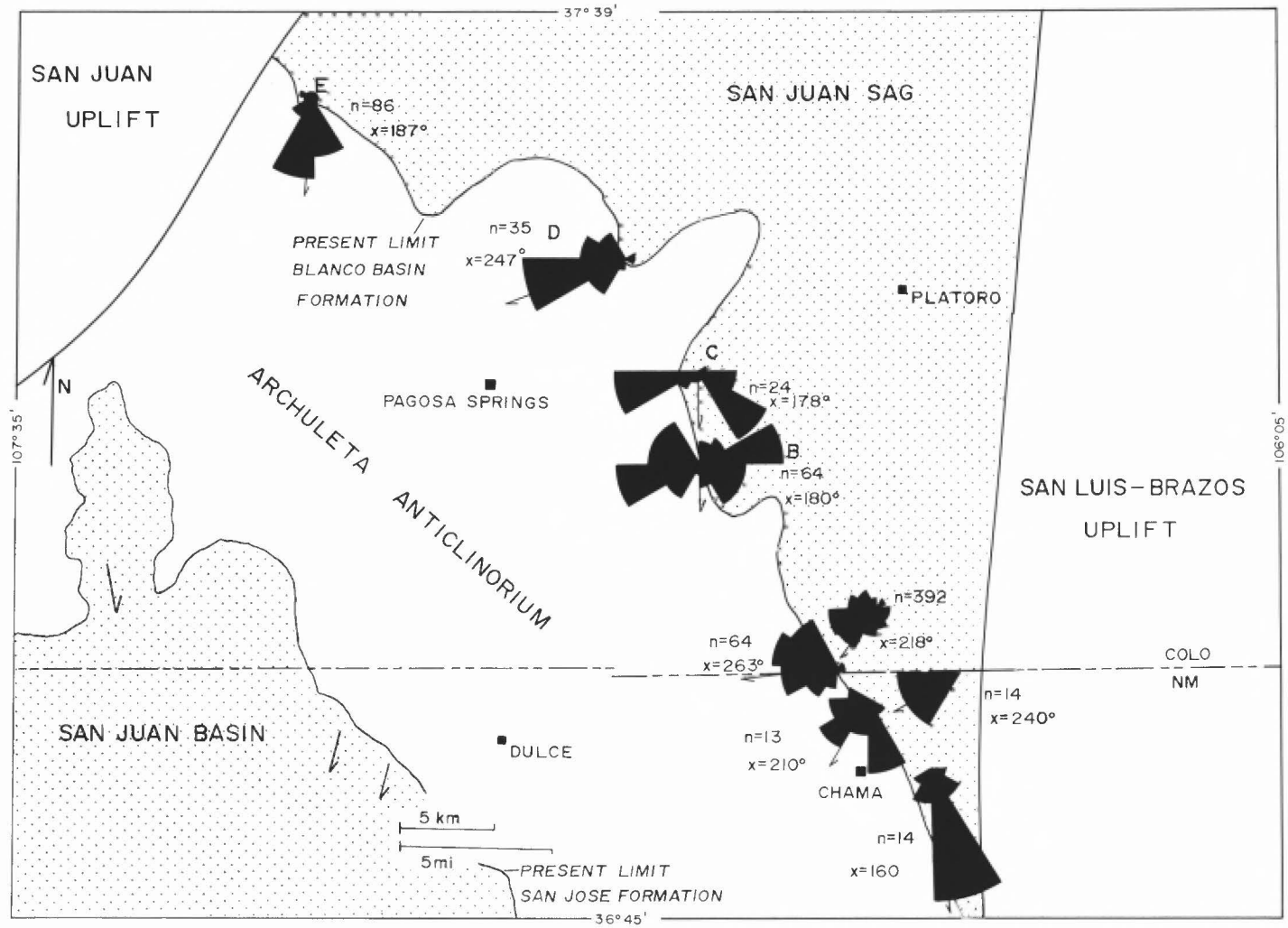


FIGURE 7. Regional tectonic elements and paleocurrent patterns. Blanco Basin Formation is stippled pattern in San Juan sag (much of it covered by younger strata); San Jose Formation is stippled pattern in San Juan Basin. Paleocurrent means for San Jose Formation are from Smith (1988).

TABLE 2. Point-count parameters defined.

```
Qt = total quartz = Qm + Qp
  Qm = total monocrystalline quartz
  Qp = total polycrystalline quartz

Ft = total feldspar = Fp + Fk + Fi
  Fp = total plagioclase
  Fk = total k-feldspar
  Fi = total intergrown plagioclase
       and k-feldspar

Lt = total lithic fragments and
     polycrystalline quartz = L + Qp
L = total lithic fragments = Lv + Ls + Lm
  Lv = total volcanic rock fragments
       (unmetamorphosed)
  Lm = total schistose rock fragments
  Ls = total sedimentary rock fragments
```

sources and in dominance of quartzitic and schistose rock fragments relative to sedimentary or volcanic sources.

Section A is near the eastern margin of the San Juan sag and adjacent to the Laramide Brazos uplift. This section overlies Cretaceous Mancos Shale, but the Blanco Basin Formation oversteps progressively older Mesozoic formations closer to the uplift. Correspondingly, the lowermost conglomerates (see pebble counts, Fig. 4) contain recycled mollusc shell fragments (from Mancos Shale), and sandstone clasts originating from the Cretaceous Dakota Sandstone and Burro Canyon Formation and the Jurassic Morrison Formation and Entrada Sandstone. Similarly, sandstones near the base of the section contain recycled, well-rounded quartz grains from these same Mesozoic sources, as seen in enrichment in quartz in ternary plots on Fig. 8.

Once the Mesozoic rocks were onlapped and became partially covered by a blanket of Blanco Basin sediments, they became less important contributors of Blanco Basin detritus. Sandstones low in the Mesozoic section, however, must have been continuously re-exposed at faults along the basin margin near the principal reference section because they are identified in minor amounts throughout most of the section.

Another vertical compositional variation is the upsection increase of plagioclase feldspar relative to total feldspar. Plagioclase is most common in granite-gneiss rock fragments near the top of the formation at that location. The overall arkosic composition of most samples shows the dominance of granitic detritus compared with all other inputs. Perhaps the increase in plagioclase represents increasing input of a granitic source enriched in plagioclase relative to other granitic sources.

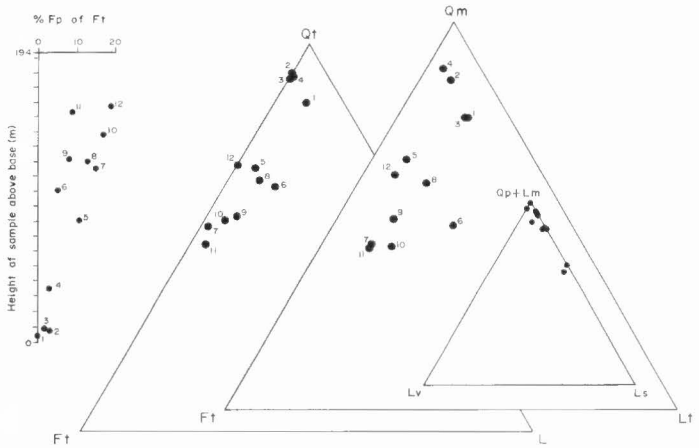


FIGURE 8. Ternary diagrams illustrating compositional variation of Blanco Basin Formation at principal reference section A. Numbers indicate relative height above base of section. Symbols explained in Table 2.

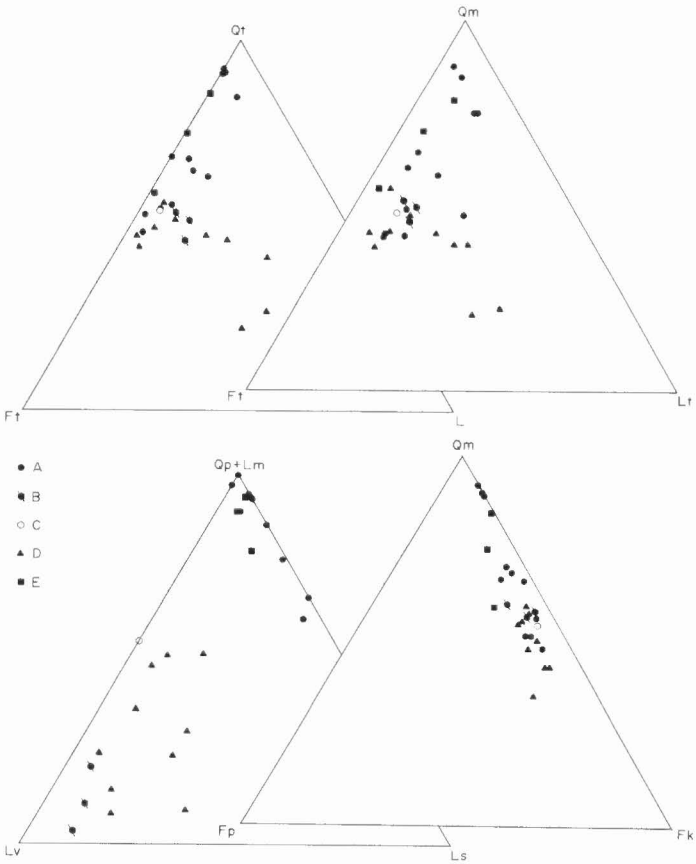


FIGURE 9. Ternary diagrams illustrating lateral compositional range of Blanco Basin Formation. Data collected from measured sections A through E. Symbols explained in Table 2.

A few volcanic clasts were observed at section A. These differ greatly in appearance from those found at other sections, in that they are highly sericitized and are recognizable only by ghost phenocrysts. They probably came from the Precambrian Moppin complex (Bauer and Williams, 1989) metavolcanic source because of their degree of alteration, their presence in a few samples scattered throughout the measured section, and the presence of metavolcanic rocks exposed nearby in the Tusas Mountains.

Metaquartzite, schist, gneiss and granite are present in different, widely spaced Precambrian terranes in the Tusas Mountains, east and southeast of the principal reference section (e.g., Muehlberger, 1967; Wobus, 1985; Bauer and Williams, 1989). However, there is no indication from paleocurrents (Fig. 4) that section A was the site of coalescing drainages. Because similar mixed-clast compositions can be observed in outcrops directly adjacent to the inferred margin of the uplift, mixing of these clasts must have occurred in areas upon the uplift. This may suggest the uplift was of low relief with an extensive drainage network atop it, as supported by observations discussed above from paleocurrents and lithofacies distributions.

Fig. 9 shows samples from all five measured sections plotted on ternary compositional diagrams. On Qt:Ft:L and Qm:Ft:Lt diagrams (see Table 2 for abbreviation definitions), most samples are tightly grouped and are dominated by arkosic detritus from adjacent Precambrian-cored uplift areas. Exceptions are samples from the lower part of section A and from section D. As previously discussed, the lower samples from section A show influence from recycled Mesozoic sandstone sources. Samples from section D plot toward lithic poles on the diagrams due to presence of volcanic and sedimentary lithic fragments. Sedimentary clasts in this section are primarily mudclasts and the volcanic fragments are strongly weathered volcanic clasts. Most mafic minerals and many feldspars in the volcanic clasts have been removed, altered to clay or replaced by secondary minerals, causing the clasts to take on a more felsic appearance. These clast types probably reflect recycling of andesitic-dacitic detritus from the Animas Formation, which this Blanco Basin section overlies.

The Qp + Lm:Lv:Ls plot illustrates compositional differences with distance from surrounding uplifts. Samples from sections A and E, which lie near plutonic-metamorphic-cored uplifts, show predominance of metamorphic clasts. Where sections lie closer to the basin axis, these clasts are overshadowed by reworking of the volcaniclastic rocks from the Animas Formation and destruction of schistose clasts during the longer transport.

The Qm:Fp:Fk ternary diagram shows that quartz and alkali feldspar clearly dominate over plagioclase. Samples containing volcanic lithic grains are not enriched in plagioclase feldspar, a dominant mineral in the recycled Paleocene andesite rock fragments. Thus, volcanic sources contributed little to the overall feldspar content of the rock and gave only a minor contribution of detritus.

The presence of volcanic rock fragments in sections B, C and D requires discussion. Dunn (1964a, p. 36) stated that "volcanic detritus is notably lacking" from the formation, but noted that volcanic rock fragments reworked from the Animas Formation were minor constituents in his thin section descriptions. Fig. 9 confirms their presence as minor constituents. Volcanic pebbles in the formation are rare and generally concentrated near the base of the formation. They are most abundant in section B, where they occur as small, white, clayey pebbles. Thin sections reveal these pebbles to be rhyolite, with rare phenocrysts of quartz and alkali feldspar.

TECTONIC IMPLICATIONS

The tectonic implications of the Blanco Basin Formation have been previously discussed by Muehlberger et al. (1960), Dunn (1964a, b), Muehlberger (1967) and Brister (1990; also see Brister and Cather, this volume). The most important tectonic implications deal with timing of Laramide tectonic events. Due to the scarcity of excellent, complete exposures of the formation, the following observations are necessarily derived from a few key outcrops.

The unconformity at the base of the Blanco Basin Formation represents a time of regional degradation accompanying renewed uplift of the San Juan sag region. This period of uplift marks the beginning of what may have been the strongest pulse of Laramide tectonism in the southern Rocky Mountain region (Chapin and Cather, 1981). Once subsidence of the San Juan sag was able to outpace regional uplift, the Blanco Basin Formation onlapped the unconformable surface (Muehlberger, 1967) in the same manner that the San Jose Formation onlapped progressively older, tilted strata along the margins of the San Juan Basin (Baltz, 1967). This implies that the beginning of Blanco Basin depo-

sition was diachronous, and thus the lower parts of the formation along the axis of the San Juan sag and towards its southwestern connection with the San Juan Basin are probably older than near its other margins. It is also likely that while deposition was going on at one site, erosion was going on in areas more proximal to uplift areas. It follows then that the youngest basal deposits of the formation would be nearest to the basin margins. This may have important implications when attempting correlation with the San Jose Formation. Onlap of the unconformable surface through time is supported by compositional data from section A indicating "shutting off" (near the base) of marginward sources through time, or, in other words, eventual blanketing of sources.

Eventual onlapping of the uplift margins is depicted in Fig. 10, designed from outcrop relationships along NM-17 north of Chama, New Mexico (see Fig. 2a for related photograph). Note that the uppermost and coarsest facies are interpreted to transgress faults that truncate older Blanco Basin strata. In general, it is these younger beds, which postdate earlier fault movement, that can be traced southward to Cañones Box, where there has been some confusion over the Blanco Basin Formation–El Rito Formation transition.

Lithofacies associations, paleocurrents and apparent mixing of clasts in drainage nets prior to entering the basin of deposition are all evidence of low to moderate topographic gradient over the uplift areas. Perhaps the western flank of the Brazos uplift during the time of Blanco Basin deposition was an elevated, deeply eroded, but not deeply incised foothills region.

The pattern of overall coarsening upwards and gradual upwards decrease in abundance of fine-grained deposits may best be explained by a process described by Allen (1978). When basin subsidence and sediment accumulation is rapid, alluvial suites will be dominated by fine-grained overbank deposits with single or weakly multistory sand bodies, such as in the lower part of the Blanco Basin Formation. However, when subsidence and sediment accumulation are slow, thick and laterally extensive sand bodies can develop, as in the upper part of the Blanco Basin Formation. A greater degree of reworking removes finer-grained material to more distal areas and leaves behind the coarse, redistributed material. The uppermost gravels depicted in Fig. 10 would therefore mark waning basin subsidence and perhaps the "beginning of the end" of detrital input into the San Juan sag and San Juan Basin. They might also mark the beginning of renewed regional uplift, perhaps associated with the rise of the Archuleta anticlinorium.

BLANCO BASIN–EL RITO TRANSITION

It is significant that the lower, mud-rich part of the Blanco Basin Formation not only thins rapidly eastward as described above, but also thins southeastward from the type locality. South of the latitude of Chama, New Mexico, the Blanco Basin Formation is composed of only the upper, conglomeratic unit of the principal reference locality. It is in this vicinity that the transition between the Blanco Basin and El Rito Formation exists.

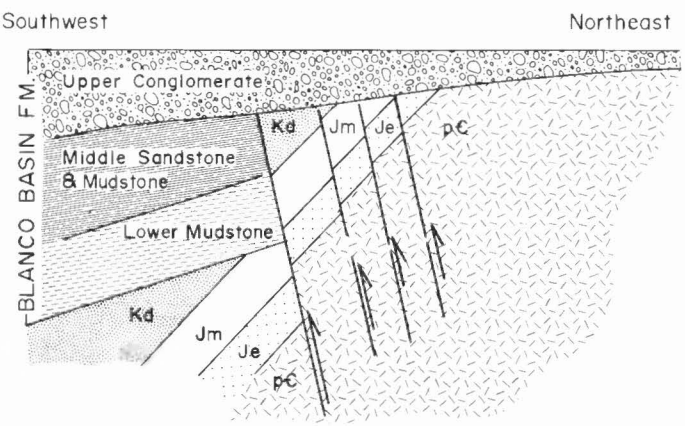


FIGURE 10. Schematic cross section interpretation of relationships between the Blanco Basin Formation and contemporaneous faults at basin margin, "NM-17 outcrops" Fig. 1. Horizontal and vertical dimensions not drawn to scale. Kd = Dakota Sandstone, Jm = Morrison Formation, Je = Entrada Sandstone.

The relationship between the two formations has been the subject of some discussion. The El Rito Formation (Smith, 1938) is a coarse, reddened, conglomeratic unit which crops out in the Tusas Mountains and southern Chama Basin (Smith et al., 1961; Bingler, 1968). Logsdon (1981) demonstrated that the El Rito Formation was deposited by southward-flowing stream systems headed in the Laramide Brazos and Nacimiento uplifts, and suggested that it is the upstream equivalent of the Eocene Galisteo Formation (Gorham and Ingersoll, 1979). The El Rito Formation at its type locality differs substantially from the Blanco Basin Formation at its type locality, particularly in clast composition, abundance of some lithofacies types, and paleoflow directions.

Lucas (1984) suggested that the El Rito Formation is younger than the Blanco Basin Formation, based on regional stratigraphic relations. Paleocurrents measured from the vicinity of the El Rito Formation type locality show southward transport into a basin developed between the Nacimiento-Gallina-Archuleta anticlinorium and the southern Brazos–Sangre de Cristo uplift (Logsdon, 1981; Ingersoll et al., 1990). According to Dunn (1964a, b), however, the Blanco Basin (at least in part) predated the rise of the Archuleta anticlinorium.

The physical boundary between the Blanco Basin and El Rito Formations is ill defined, due to sparse outcrops and incomplete sections between the type localities of the two formations. Muehlberger (1968) noted interfingering (suggesting contemporaneity) between the two formations at outcrops in the vicinity of Cañones Box, southeast of Chama. Unfortunately Muehlberger's criteria for separating the two formations was compositional and did not take into consideration transport directions. Compositional criteria need not be diagnostic of either formation. For example, quartzite clasts tend to dominate in the El Rito drainage basin, but such clasts are also common components of the Blanco Basin at many locations.

No marked interfingering was observed in the vicinity of Cañones Box. The lateral transition from mixed granitic-schistose-quartzitic composition to almost exclusively quartzitic composition appears to be relatively abrupt adjacent to the covered (but inferred) contact between schistose metavolcanic and metaquartzite Precambrian terranes mapped by Muehlberger (1967, 1968). Outcrops of the formations are poor and lateral relationships cannot be traced over substantial distances.

Paleocurrents measured south of Cañones Box (southeasternmost rose diagram shown on Fig. 7) indicate south to southeast rather than southwest transport. Thus, a drainage divide may have existed in this general area, separating the San Juan sag to the north from the El Rito basin to the south. It is probably no coincidence that this possible drainage divide follows a major terrain boundary in the Precambrian, and is the site of northwest-trending faults and folds attributable to the Laramide orogeny (Muehlberger, 1967, particularly plate 2; 1968). It is not difficult to imagine an exposed, erosion-resistant, quartzite ridge making up the "backbone" of part of this divide.

This discussion implies that the El Rito Formation south of Cañones Box and the upper conglomeratic part of the Blanco Basin Formation near Chama are more or less contemporaneous and the result of the same middle(?) Eocene tectonic event. However, these units were deposited into basins separated by a low topographic divide.

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REFERENCES

Adams, G. E., 1957, Geology of the Chama area, Rio Arriba County, New Mexico [M.A. thesis]: Austin, University of Texas, 95 p.

Allen, J. R. L., 1978, Studies in fluviatile sedimentation: an exploratory quantitative model for the architecture of avulsion-controlled alluvial suites: Sedimentary Geology, v. 21, p. 129–147.

Baltz, E. H. Jr., 1953, Stratigraphic relationships of Cretaceous and early Tertiary rocks of the east-central part of the San Juan Basin [M.S. thesis]: Albuquerque, University of New Mexico, 101 p.

Baltz, E. H. Jr., 1967, Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan Basin, New Mexico: U.S. Geological Survey, Professional Paper 552, 101 p.

Barnes, H., 1954, Stratigraphy and geologic structure of the Cretaceous rocks on the northern flank of the San Juan Basin, Colorado and New Mexico [Ph.D. dissertation]: Baltimore, Johns Hopkins University, 139 p.

Bauer, P. W. and Williams, M. L., 1989, Stratigraphic nomenclature of Proterozoic rocks, northern New Mexico—revisions, redefinitions, and formalization: New Mexico Geology, v. 11, p. 45–52.

Bingler, E. C., 1968, Geology and mineral resources of Rio Arriba County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 91, 158 p.

Brister, B. S., 1990, Tertiary sedimentation and tectonics: San Juan sag–San Luis Basin region, Colorado and New Mexico [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 267 p.

Chapin, C. E. and Cather, S. M., 1981, Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountain area; *in* Dickinson, W. R. and Payne, W. D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 173–198.

Cross, W. and Larsen, E. S., 1935, A brief review of the geology of the San Juan region of southwestern Colorado: U.S. Geological Survey, Bulletin 843, 138 p.

Dunn, D. E., 1964a, Evolution of the Chama basin and Archuleta anticlinorium, eastern Archuleta County, Colorado [Ph.D. dissertation]: Austin, University of Texas, 114 p.

Dunn, D. E., 1964b, Tectonic significance of the Blanco Basin Formation: Geological Society of America, Special Paper 76, p. 271.

Gorham, T. W. and Ingersoll, R. V., 1979, Evolution of the Eocene Galisteo Basin, north-central New Mexico: New Mexico Geological Society, Guidebook 30, p. 219–224.

Gries, R. R., 1985, San Juan sag: Cretaceous rocks in a volcanic-covered basin, south-central Colorado: The Mountain Geologist, v. 22, p. 167–179.

Gries, R. R., 1989, San Juan sag: oil and gas exploration in a newly discovered basin beneath the San Juan volcanic field; *in* Lorenz, J. C. and Lucas, S. G., eds., Energy frontiers in the Rockies: Albuquerque Geological Society, New Mexico, p. 69–78.

Larsen, E. S. and Cross, W., 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geological Survey, Professional Paper 258, 303 p.

Lipman, P.W., Steven, T. A. and Mehnert, H. H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by potassium-argon dating: Geological Society of America Bulletin, v. 81, p. 2329–2352.

Logsdon, M. J., 1981, A preliminary basin analysis of the El Rito Formation (Eocene), north-central New Mexico: Geological Society of America Bulletin, v. 92, p. 968–975.

Lucas, S. G., 1984, Correlation of Eocene rocks of the northern Rio Grande rift and adjacent areas: implications for Laramide tectonics: New Mexico Geological Society, Guidebook 35, p. 123–128.

Miall, A. D., 1977, A review of the braided river depositional environment: Earth Science Reviews, v. 13, p. 1–62.

Miall, A. D., 1978, Lithofacies types and vertical profile models in braided river deposits: a summary; *in* Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 597–604.

Miall, A. D., 1984, Principles of sedimentary basin analysis: New York, Springer-Verlag, 490 p.

Muehlberger, W. R., 1967, Geology of Chama quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 89, 114 p.

Muehlberger, W. R., 1968, Geology of Brazos Peak quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 22, 7 p.

Muehlberger, W. R., Adams, G. E., Longgood, T. E. and St. John, B. E., 1960, Stratigraphy of the Chama quadrangle, northern Rio Arriba County, New Mexico: New Mexico Geological Society, Guidebook 11, p. 93–102.

Newman, K. R., 1982, Biostratigraphy of Fruitland, Kirtland, and Animas formations (Cretaceous and Paleocene), northern San Juan Basin, Colorado: Geological Society of America, Abstracts with Programs, v. 14, p. 344.

Reeside, J. B., 1924, Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin, Colorado and New Mexico: U.S. Geological Survey, Professional Paper 134, 70 p.

Rust, B. R., 1978, Depositional models for braided alluvium; *in* Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 605–625.

Rust, B. R. and Koster, 1984, Coarse alluvial deposits; *in* Walker, R. G., ed., Facies models (2nd ed.): Toronto, Geological Society of Canada, p. 53–69.

Ryder, R. T., 1985, Oil and gas potential of the Chama–southern San Juan Mountains wilderness study area, Colorado; *in* Mineral resources of the Chama–southern San Juan Mountains wilderness study area, Mineral, Rio Grande, Archuleta, and Conejos counties, Colorado: U.S. Geological Survey, Bulletin 1524, p. 81–121.

Smith, C. T., Budding, A. J. and Pitrat, C. W., 1961, Geology of the southeastern part of the Chama Basin: New Mexico Bureau of Mines and Mineral Resources, Bulletin 75, 57 p.

Smith, H. T. U., 1938, Tertiary geology of the Abiquiu quadrangle, New Mexico: Journal of Geology, v. 46, p. 933–965.

Smith, L. N., 1988, Basin analysis of the lower Eocene San Jose Formation, San Juan Basin, New Mexico and Colorado [Ph.D. dissertation]: Albuquerque, University of New Mexico, 166 p.

Steven, T. A., 1975, Middle Tertiary volcanic field in the Southern Rocky Mountains: *in* Curtis, B. F., eds., Cenozoic history of the Southern Rocky Mountains: Geological Society of America, Memoir 144, p. 75–94.

Steven, T. A. and Hail, W. J., 1989, Geologic map of the Montrose 30′ × 60′ quadrangle, southwestern Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1939, scale 1:100,000.

Van Houten, F. B., 1957, Appraisal of Ridgway and Gunnison "tillites," southwestern Colorado: Geological Society of America Bulletin, v. 68, p. 383–388.

Wobus, R. A., 1985, Changes in the nomenclature and stratigraphy of Proterozoic metamorphic rocks, Tusas Mountains, north-central New Mexico: U.S. Geological Survey, Bulletin 1571, 19 p.



Cathedral Cliff southeast of Shiprock with minette dike in foreground is one of the intrusives of Oligocene age associated with Shiprock. Exposures of Mancos Shale in left middleground. Photograph taken the morning of 12 April 1992. Copyright © Paul L. Sealey, 1992.