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Stratigraphy and provenance of upper Cretaceous and Paleogene strata of the western Sierra Blanca Basin, New Mexico

Steven M. Cather
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STRATIGRAPHY AND PROVENANCE OF UPPER CRETACEOUS AND PALEOGENE STRATA OF THE WESTERN SIERRA BLANCA BASIN, NEW MEXICO

STEVEN M. CATHER
New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Abstract—A sampled reference section about 1200 m thick in the western Sierra Blanca basin contains strata ranging in age from Late Cretaceous to late Eocene–early Oligocene(?). Stratigraphic units include, in ascending order, the Crevasse Canyon Formation (probably the Ash Canyon Member), the Cub Mountain Formation, the Sanders Canyon Formation (new name), and the Walker Andesite Breccia of the Sierra Blanca Volcanics. With the exception of a disconformity at the base of the Cub Mountain Formation, which represents a lacuna that spans at least the entire Paleocene, contacts between the stratigraphic units appear to be gradational. A marked similarity in detrital composition between the Crevasse Canyon Formation and the lower part of the Cub Mountain Formation suggests that much of the basal Cub Mountain was recycled from underlying Cretaceous rocks. Provenance data from the upper part of the Cub Mountain Formation document the unroofing of Paleozoic and crystalline basement sources as Eocene tectonism proceeded. The increased influx of volcaniclastic grains in the distally derived sandstone and mudstone of the Sanders Canyon Formation records the onset of Tertiary volcanism in areas to the south and southwest. Debris-flow breccias of the Sierra Blanca Volcanics at the top of the reference section herald the beginning of local volcanism nearby to the east or southeast.

INTRODUCTION

The Sierra Blanca basin contains the only extensive exposures of Upper Cretaceous and Paleogene rocks within a broad region of central and southeastern New Mexico, yet these strata have been relatively little studied. This report describes the stratigraphy and sedimentary petrology of a reference section in the western Sierra Blanca basin (Fig. 1). Lithostratigraphic data from the study area are compared to those from better-known areas to the west and southwest, and the provenance and tectonic implications of these data are discussed.

The first systematic investigation and mapping of the stratigraphy in the study area was by Weber (1964), although earlier workers (Wegemann, 1914; Griswold, 1959) had described aspects of the regional stratigraphy. In a master's thesis, Arkell (1983) remapped and described the geology of the study area and substantially revised the stratigraphy initially proposed by Weber (1964). A preliminary study by Lucas et al. (1989) of the Eocene Cub Mountain Formation, however, supported the earlier stratigraphy and placement of contacts as advocated by Weber (1964). The present report is based on, and supports, Weber's concept of the local stratigraphy, but divides it more finely and proposes a few nomenclatural changes.

A reference section through Upper Cretaceous and Paleogene strata along Chaves Draw and Chaves Canyon (Fig. 2) in the western Sierra Blanca basin was mapped and sampled by the writer during July 1990. Stratigraphic thicknesses and position of samples within the reference section were determined from cross section. Due to the long traverse and the presence of minor structural complications along the reference section, thicknesses and sample positions can only be considered as approximations. The reference section is about 1200 m thick and was sampled at stratigraphic intervals ranging from about 10 to 110 m (Fig. 2). Petrographic thin sections were prepared from 30 sandstones and from three volcanic clasts.

STRATIGRAPHY

The study area encompasses strata of Late Cretaceous, Eocene and early Oligocene(?) age. No Paleocene beds are known to be present. Four lithostratigraphic units of formational rank are present along the reference section: the Upper Cretaceous Crevasse Canyon Formation (probably the Ash Canyon Member), the Eocene Cub Mountain Formation, the late Eocene(?) Sanders Canyon Formation (new name), and the Walker Andesite Breccia of the late Eocene–Oligocene Sierra Blanca Volcanics.

Upper Cretaceous rocks

Early workers assigned continental and marine strata of Late Cretaceous age in the western Sierra Blanca basin to the Dakota Sandstone, Mancos Shale and Mesaverde Formation (or Group). Arkell (1986) and Cobban (1986) subsequently recognized the paralic and continental rocks of the Tres Hermanos Formation within the Mancos, and divided the Mesaverde Group into the Gallup Sandstone and the Crevasse Canyon Formation. The distribution of these recently recognized Cretaceous units, however, has not been mapped in the western Sierra Blanca basin. The reference section described in this report encompasses only the uppermost part of the Cretaceous section in the study area.

Crevasse Canyon Formation

The reference section begins at an arbitrary point within the Crevasse Canyon Formation, about 240 m below the contact with the superjacent Cub Mountain Formation. The total thickness of the Crevasse Canyon Formation in the western Sierra Blanca basin is not known. Although Arkell (1986) estimated a thickness of 180–240 m for the unit, I consider much of what he mapped as Cub Mountain Formation (Arkell, 1983)

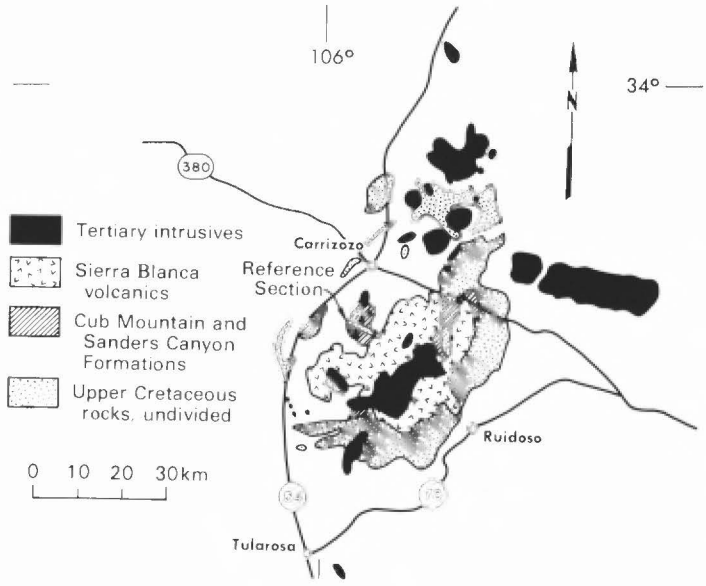


FIGURE 1. Map showing location of reference section and outcrop areas of Upper Cretaceous and Paleogene rocks in the Sierra Blanca basin and vicinity (modified from New Mexico Geological Society, 1982).

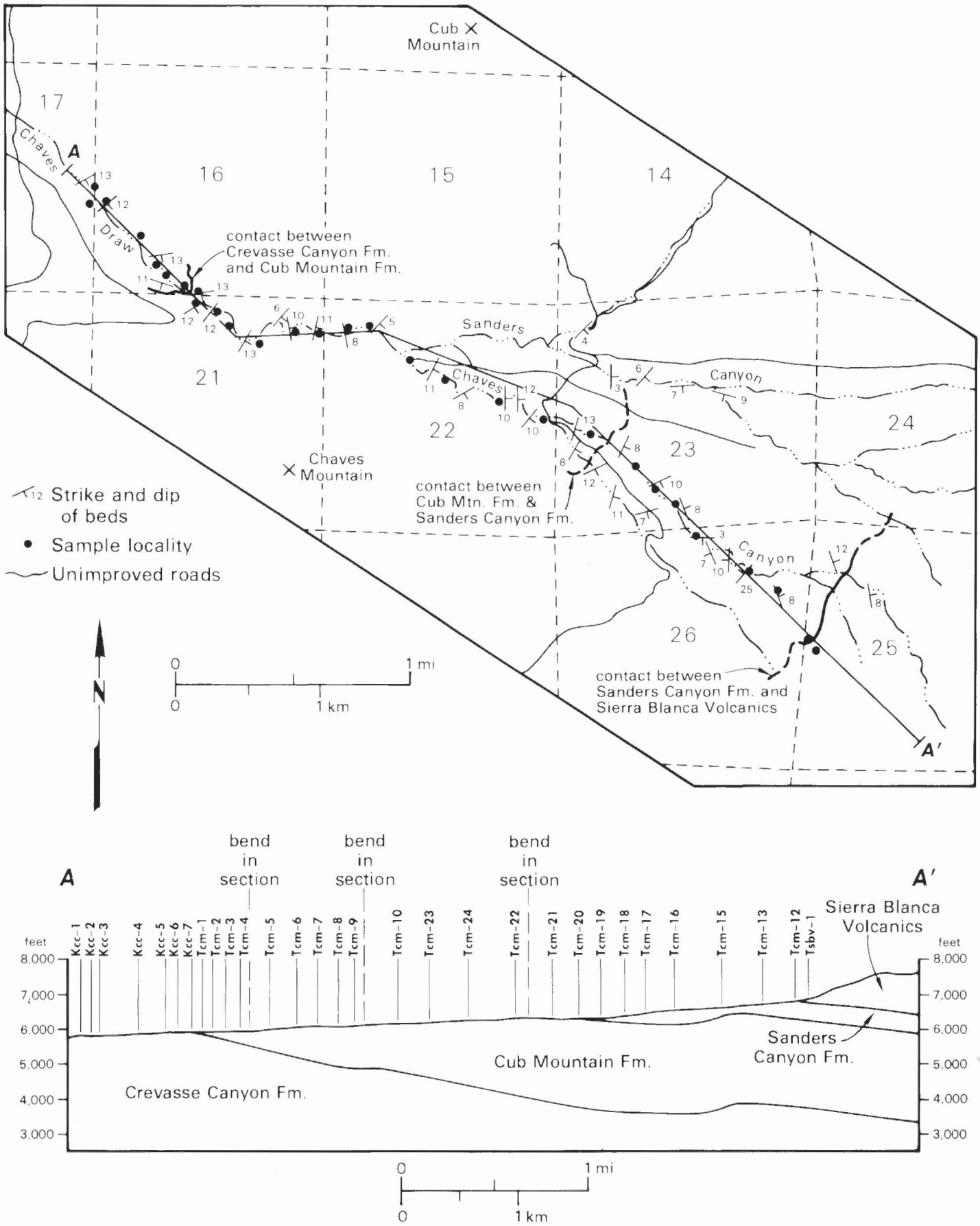


FIGURE 2. Map and cross section along reference section, showing sample locations and contacts.

to be Crevasse Canyon (see also Weber, 1964, and Lucas et al., 1989, for similar opinions).

Average conglomerate/sandstone/mudstone ratio in the Crevasse Canyon Formation is about 1/40/59. Pebbles were observed as scattered clasts in sandstones within the upper 110 m of the unit and consist dominantly of well-rounded quartzite, chert and felsic volcanics. Maximum clast size is 3 to 4 cm; most clasts are 0.5 to 2 cm.

Fluviatile sandstones and mudstones compose the majority of the Crevasse Canyon Formation. Mudstones are typically grayish green except where they are locally oxidized beneath the basal Tertiary unconformity. Most sandstones are medium to fine grained and light olive to grayish green in color. Many of the coarser-grained and more laterally continuous sandstones have been oxidized by ground water and display light-orange hues and liesegang bands.

The upper part of the Crevasse Canyon Formation in the western Sierra Blanca basin, including most or all Cretaceous rocks within the reference section, appears to be correlative with the Ash Canyon Member of the Truth or Consequences area. This correlation is based on several lines of evidence:

Stratigraphic position. The Ash Canyon member occupies the uppermost part of the Crevasse Canyon Formation, above the finer-grained, locally coal-bearing lower and medial parts of the formation in both the Truth or Consequences area and the western Sierra Blanca basin. The Ash Canyon, however, is erosionally cut out beneath the basal Tertiary unconformity in the northern and eastern parts of the Sierra Blanca basin, where the Cub Mountain overlies older Cretaceous rocks (Kelley and Thompson, 1964; Kelley, 1971).

Conglomeratic nature. The Ash Canyon Member is the only pebble-bearing unit known in the Mesaverde Group in southern New Mexico. Furthermore, the pebble suites in the Truth or Consequences area (Bushnell, 1953; Melvin, 1963; Wallin, 1983) are similar to those in the reference section. In both areas, pebbles are well rounded and consist dominantly of quartzite, chert and felsic volcanics.

Sandstone composition. The composition of detrital grains in sandstones within the pebbly Mesaverde sequences near Truth or Consequences and in the westem Sierra Blanca basin appear to be fundamentally similar (Fig. 3; also see provenance section).

Down-dip depositional trends. Paleoflow during Ash Canyon deposition in the Truth or Consequences region was generally northeastward (Wallin, 1983), toward the Sierra Blanca basin. Sandstone/mudstone ratio, abundance of conglomerate, and maximum clast size in the western Sierra Blanca basin are substantially lower than in the Truth or Consequences area, as would be expected in the distal reaches of the coastal-plain system. In contrast to the type area of the Ash Canyon Formation, paleoflow during late Mesaverde time in the western Sierra Blanca basin was southeastward (Fig. 4), approximately parallel to the trend of post-Turonian shorelines in the area (Molenaar, 1983). The geologic significance of this seemingly anomalous paleocurrent trend is not known.

The age of the Ash Canyon Member can only be loosely constrained. In the Truth or Consequences area, a lower age limit of late Turonian–early Coniacian is imposed by the presence of *Lopha sannionis* in the Gallup Sandstone (Wallin, 1983), although about 450 m of strata intervene between the Gallup and the base of the Ash Canyon Member. The upper age limit is provided by dinosaur remains of Lancian (Maastrichtian) age in the McRae Formation, which disconformably overlies the Ash Canyon Member (Lozinsky et al., 1984; Wolberg et al., 1986; Gillette et al., 1986). In the Sierra Blanca basin, the age of the Ash Canyon is bracketed by very late Coniacian inoceramids present in the middle part of the Mesaverde Group (Cobban, 1986, p. 76) and Eocene vertebrates in the overlying Cub Mountain Formation (Lucas et al., 1989). Taken together, data from both areas allow a latest Coniacian to Maastrichtian age range (about 88 to 66 Ma) for the Ash Canyon, although it is quite possible that the unit is somewhat time-transgressive between the two areas.

Paleogene rocks

Weber (1964) employed the term "Cub Mountain Formation" to describe all of the strata between the Mesaverde Group and the Sierra Blanca Volcanics in the study area. He noted that the lower part of the Cub Mountain consists of arkosic sandstone and mudstone with minor

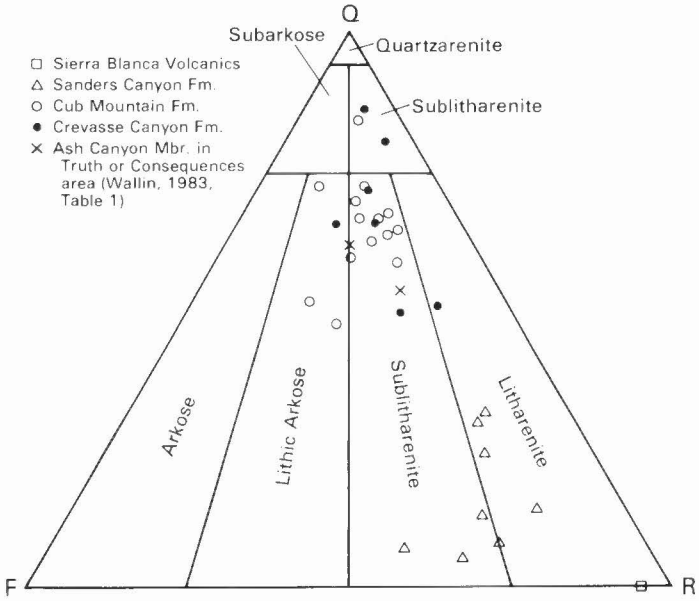


FIGURE 3. QFR plot of point-counted sandstones from reference section (after Folk, 1974). Q = quartz (excluding chert); F = feldspar plus granite/gneiss rock fragments; R = all other rock fragments.

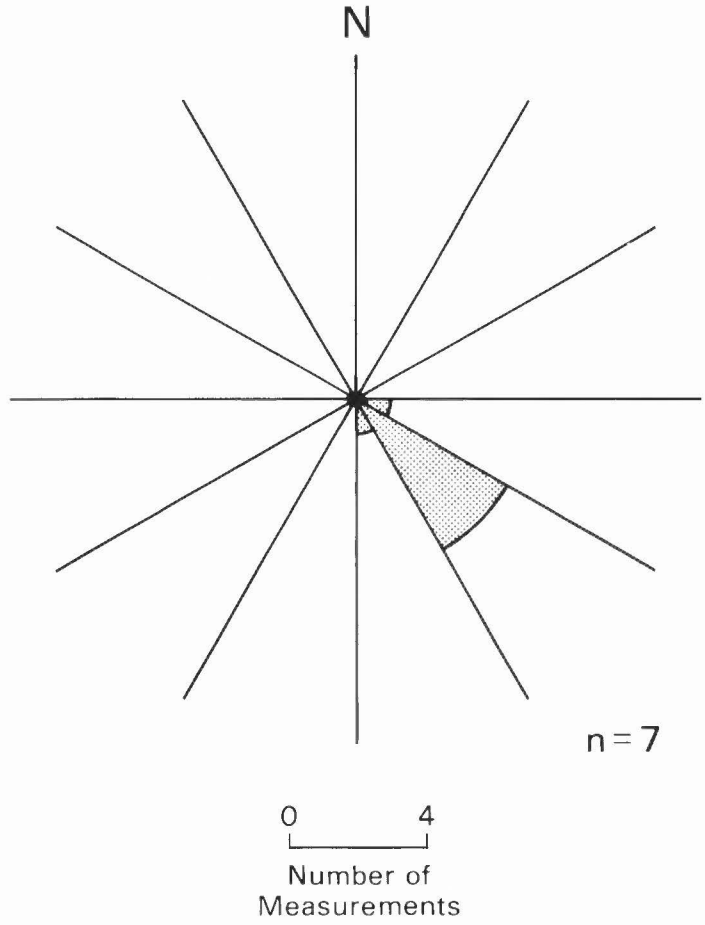


FIGURE 4. Paleocurrent rose diagram from Crevasse Canyon Formation in study area, based on pebble imbrications.

conglomerate that gives way upsection to volcaniclastic rocks, thus providing criteria for subdividing the Cub Mountain Formation into lower and upper members (Weber, 1964, p. 105). In this report, I propose raising the upper volcaniclastic part of Weber's Cub Mountain Formation to formational rank (hereafter termed the Sanders Canyon Formation; see below). I will restrict usage of the Cub Mountain Formation to the lower, largely nonvolcanic part of Weber's unit. The proposed Cub Mountain/Sanders Canyon terminology is similar to existing formation-rank nomenclature for homotaxial Paleogene sequences elsewhere in New Mexico (El Rito–Blanco Basin/Conejos, Galisteo/Espinaso, Baca/Spears, Love Ranch/Palm Park–Rubio Peak). The Sanders Canyon Formation grades abruptly upward into the locally derived volcaniclastic breccias of the Sierra Blanca Volcanics that compose the upper part of the reference section.

Cub Mountain Formation

Bodine (1956) introduced the term "Cub Mountain Formation" in the Capitan area, although a footnote inadvertently omitted from his report would have credited the concept of the unit to R. H. Weber, who in 1964 published a description of the type section. The reference section described in this report includes much of Weber's (1964) type section, except in the upper part where, due to the availability of better exposures, the reference section follows Chaves Canyon and an unnamed tributary instead of Sanders Canyon (Fig. 2). The thickness of the Cub Mountain Formation, in the restricted sense of the unit used in this report (i.e., the lower, essentially non-volcaniclastic part of Weber's unit), is about 760 m. This thickness is greater than that of any other late Laramide basin-fill sequence in New Mexico, with the possible exception of the more than 2000 m of Eocene(?) strata penetrated by an oil test in the Potrillo basin near Las Cruces (Thompson, 1982; Seager and Mack, 1986).

The lower contact of the Cub Mountain Formation in the reference section is disconformable and is marked by conspicuously coarse conglomerate and pebbly sandstone (Fig. 5) that overlie sparsely pebbly sandstone and mudstone of the Ash Canyon Member in SE¼ SW¼ sec. 16, T9S, R10E. Maximum clast size in the basal Cub Mountain is about 8–10 cm, compared to 3–4 cm in the Ash Canyon Member. Clast compositions of the two units are fundamentally similar (dominantly quartzite, felsic volcanics and chert), but minor amounts of sandstone, siltstone, limestone, silicified wood, granite and diorite pebbles also were observed in the Cub Mountain Formation. Abundance of pebbles in the Cub Mountain decreases markedly upsection; pebbles other than intraformational mudclasts seem to be absent in the upper half of the unit.

Conglomerate/sandstone/mudstone ratio is about 5/85/10 in the basal part of the Cub Mountain, whereas mudstone and subordinate sandstone dominate the upper part of the unit. Such overall upward-fining trends occur in most late Laramide (Eocene) basinal sequences in New Mexico (cf. Cather and Johnson, 1984; Gorham and Ingersoll, 1979; Smith, 1988; Logsdon, 1981; Seager et al., 1986). Sandstone compositions indicate unroofing of basement-cored uplifts during Cub Mountain time (see provenance section). Mudstone is typically purplish-gray in the basal 50 to 60 m of the unit, and becomes dominated by reddish hues above. The Cub Mountain was deposited entirely by fluvial processes, by both bed-load and mixed-load fluvial systems. Paleocurrent data (Fig. 6) indicate that these rivers flowed dominantly toward the northeast.

The Cub Mountain Formation was regarded by most early workers to be Late Cretaceous and/or early Tertiary in age, based entirely on stratigraphic position and perceived regional correlations. Lucas et al. (1989) documented the first fossils from within the Cub Mountain. These vertebrate remains were collected from the lower part of the unit and are of unequivocal Eocene age, probably late Wasatchian–early Bridgerian. The age of the upper part of the Cub Mountain remains unknown, although timing of the transitional contact with the superjacent Sanders Canyon Formation is arguably late Eocene on the basis of regional stratigraphic trends (see below).

Sanders Canyon Formation

The new stratigraphic term "Sanders Canyon Formation" is herein proposed to encompass the fine-grained volcaniclastic sandstone and mudstone formerly included in the upper part of the Cub Mountain Formation by Weber (1964) and most subsequent workers. The type section is designated in Chaves Canyon and an unnamed tributary canyon (Fig. 2), and is encompassed by the reference section. The unit is named for Sanders Canyon, which lies a short distance north of the type section. The Sanders Canyon Formation is exposed locally throughout much of the Sierra Blanca basin, except in the southeastern part of the basin where the unit is erosionally cut out beneath the Sierra Blanca Volcanics (Moore et al., 1988).



FIGURE 5. Conglomerate and pebbly sandstone in basal Cub Mountain Formation.

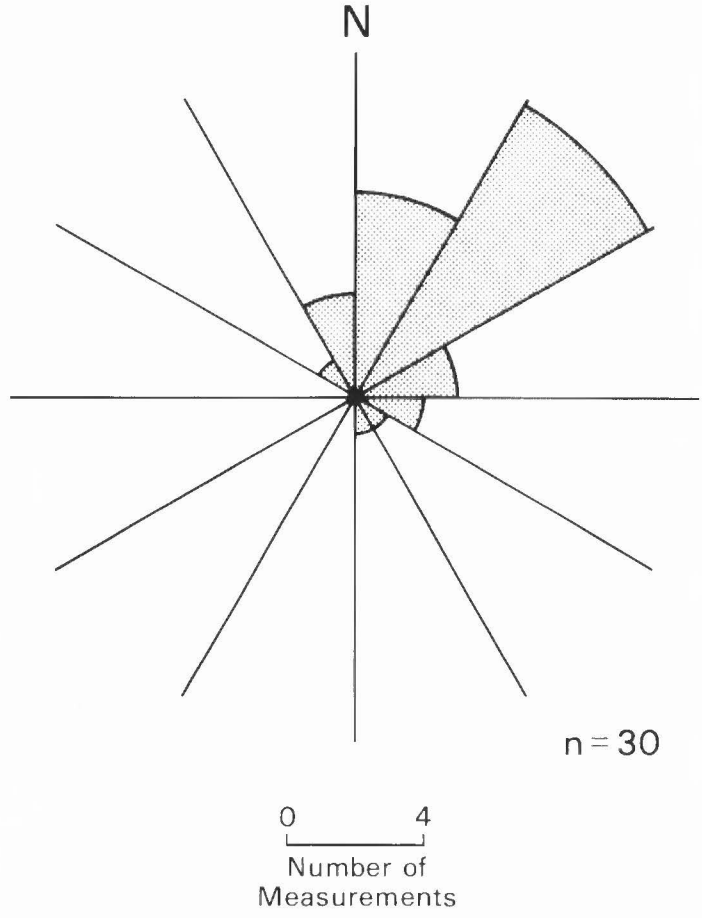


FIGURE 6. Paleocurrent rose diagram for the Cub Mountain Formation in the study area, based on pebble imbrications and parting-step lineations.

The Sanders Canyon Formation transitionally overlies the largely non-volcanic strata of the Cub Mountain Formation. The contact is defined by the upsection change from reddish colors of the Cub Mountain to the dominantly grayish-purple hues of the Sanders Canyon Formation; this color change corresponds to a modal increase to greater than about 25% framework-fraction volcanogenic detritus and a concomitant decrease in quartz content (see Fig. 3 and provenance section).

The average sandstone/mudstone ratio in the Sanders Canyon Formation is about 30/70, and decreases somewhat upsection. Conglomerate is minor, consisting mainly of intraformational mudclasts and rare interfingering lenses of pebbles and cobbles of Sierra Blanca Volcanics near the top of the unit. Total thickness of the Sanders Canyon is about 150 m at the reference section. Although based on only two measurements of clast imbrication, paleoflow appears to have been north-northeastward during deposition of the Sanders Canyon Formation. This is in general agreement with measurements from the unit made by the writer elsewhere in the Sierra Blanca basin. The Sanders Canyon Formation appears to have been deposited largely by mixed-load fluvial systems.

Constraints on the age of the Sanders Canyon Formation are indirect, as no fossils have been collected and no clasts dated from the unit. Based on petrologic similarities (see provenance section) and paleoflow evidence for derivation from the southwest, a tentative correlation between the Sanders Canyon Formation and the Palm Park–Rubio Peak andesites of southwestern New Mexico may be inferred. If correct, this correlation implies a late Eocene age for the onset of Sanders Canyon deposition, based on isotopic ages from the Palm Park Formation (40–43 Ma; Seager and Clemons, 1975). A maximum age of about 38 Ma can be inferred for the overlying Sierra Blanca Volcanics (Moore et al., 1991, this volume).

Sierra Blanca Volcanics

Volcaniclastic breccias and minor sandstone and conglomerate of the basal Sierra Blanca Volcanics (Walker Andesite Breccia of Thompson, 1972) compose the uppermost 50 m of the reference section, which ends at an arbitrary point within the formation. These volcaniclastic rocks were largely deposited by debris flows, although in other parts of the basin the basal Sierra Blanca Volcanics are dominated by flow breccias and associated lavas (T. B. Thompson, written comm., 1991). The Sierra Blanca Volcanics are at least 1020 m thick (Thompson, 1964), and may have been significantly thicker prior to Neogene erosion. The Sierra Blanca Volcanics range in age from about 38 to 26 Ma (Moore et al., 1991, this volume).

The contact between the Sierra Blanca Volcanics and the underlying Sanders Canyon Formation is defined by the first upsection occurrence of greater than 50% volcaniclastic breccia or conglomerate. The contact is poorly exposed but appears to be gradational in the study area. In at least two places, fluvial deposits containing outsized pyroxene-bearing volcanic pebbles and cobbles were observed within the dominantly fine-grained, upper Sanders Canyon Formation. The large size and pyroxene-bearing nature of these clasts are atypical of the Sanders Canyon Formation but are similar to clasts in the overlying Sierra Blanca Volcanics (see provenance section). It seems plausible that the fine-grained strata of the upper Sanders Canyon Formation represent the deposits of a north-northeast-flowing, axial fluvial system that was being pushed westward across the basin by the prograding volcanic apron of the Sierra Blanca Volcanics. More petrographic data and paleocurrent information, however, are needed to test this hypothesis and to further evaluate the nature of the contact. Although the contact between Sanders Canyon Formation and the Sierra Blanca Volcanics also appears to be gradational in the northeast part of the Sierra Blanca basin (see Day 2 road log and supplemental road log by Cather and Elston, 1991), the basal contact of the Sierra Blanca Volcanics clearly becomes unconformable in the southeast part of the basin, where the unit overlies Upper Cretaceous rocks (Moore et al., 1988).

PROVENANCE

A systematic assessment of changes in detrital composition of the strata in the reference section was attempted by the examination and point counting of thin sections from 30 sandstones and three conglomerate clasts (Fig. 7). At least 200 framework grains were counted from each sandstone thin section (see Appendix) using traditional (QFR) point-counting techniques. Thin sections were stained with sodium cobaltinitrite to facilitate identification of feldspars. To minimize grain-size effects, an attempt was made to sample only medium- to fine-grained sandstones wherever possible. Point-count data for grains with probable diagnostic significance were apportioned into provenance categories indicative of crystalline basement, sedimentary and volcanic sources (see below). Because all of these diagnostic grain types may have been through earlier, unrecognized sedimentary cycles, the relative abundance of primary versus recycled detritus in the reference section is poorly constrained. My approach here is to use the upsection *variation* in diagnostic grain types to infer temporal changes in the source regions. Upsection abundance of monocrystalline, nonundulatory quartz, polycrystalline quartz and monocrystalline undulatory quartz were also tabulated.

Differences between means of provenance parameters were calculated among the stratigraphic units using the t-test. Because of the scarcity of sandstone in the basal Sierra Blanca Volcanics, this unit is omitted from the following statistical comparisons. Additionally, I have divided the Cub Mountain Formation into upper and lower halves to allow evaluation of possible unroofing of uplifts, as evidence for such unroofing has been documented in Eocene deposits elsewhere in New Mexico (Cather, 1980; Seager et al., 1986). [Note: In this report, the probabilistic significance of the difference between means was determined using the t-test and is designated by "p." For example, the statement "$p = 0.01$" indicates a one percent chance that the difference between two means is due simply to the random sampling of a homogeneous population. The terms "statistically significant" and "statistically insignificant" represent the cases where $p \leq 0.05$ and $p > 0.05$, respectively.]

Quartz types

All of the genetic types of quartz (Folk, 1974), except possibly volcanic quartz, are present in the reference section. In this analysis, chert is considered to be a sedimentary rock fragment. Quartz is a major component of sandstones of the Crevasse Canyon and Cub Mountain Formations, but decreases dramatically upsection due to dilution by quartz-poor volcanogenic detritus (Fig. 3). As shown in Fig. 3, the range of QFR values for the Crevasse Canyon and Cub Mountain is approximately the same. The relatively low abundance of quartz in the Sanders Canyon Formation reflects the admixture of volcaniclastic materials with Cub Mountain–type detritus. Such transitional lithologies occur at the base of the Tertiary volcanic sequence elsewhere in New Mexico (Seager and Mack, 1986; Cather et al., 1987). At the reference section, the basal breccias of the Sierra Blanca Volcanics appear to be essentially quartz-free.

Blatt and Christie (1963) noted that monocrystalline, nonundulatory quartz grains are significantly more stable, both mechanically and chemically, than polycrystalline or undulatory varieties. In this study, an index of "quartz maturity" was tabulated for each sandstone which was point counted, using the ratio of nonundulatory quartz/total quartz. Nonundulatory quartz is defined as monocrystalline quartz which exhibits straight or slightly undulose extinction (i.e., less than 5° of stage rotation; Folk, 1974, p. 73; Basu et al., 1975). Theoretically, an upsection decrease in nonundulatory quartz/total quartz ratio may indicate increasing contributions from basement sources or from older, immature sandstones. Although such an upsection trend appears to exist (Fig. 7) within the Crevasse Canyon and Cub Mountain Formations, this trend is not statistically significant (Table 1), probably due to the wide variation of values within the units. Mean nonundulose quartz/total quartz ratio for the Sanders Canyon Formation, however, is significantly higher than either the upper or the lower parts of the Cub Mountain Formation (Table 1). This may be explained in large part by a decrease in basement-derived quartz, as it corresponds stratigraphically with a statistically significant decrease in other basement-derived grains (see below). It is

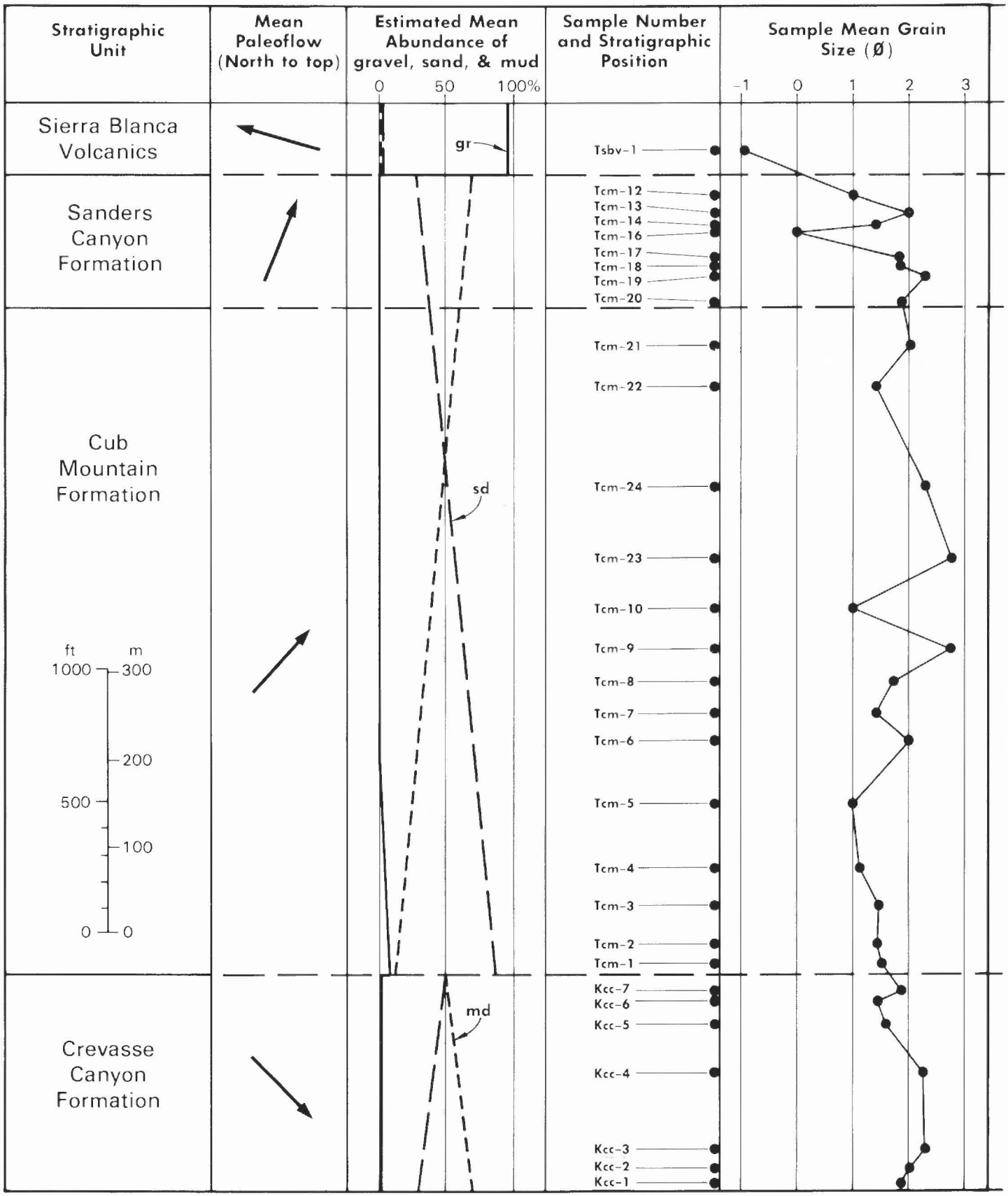
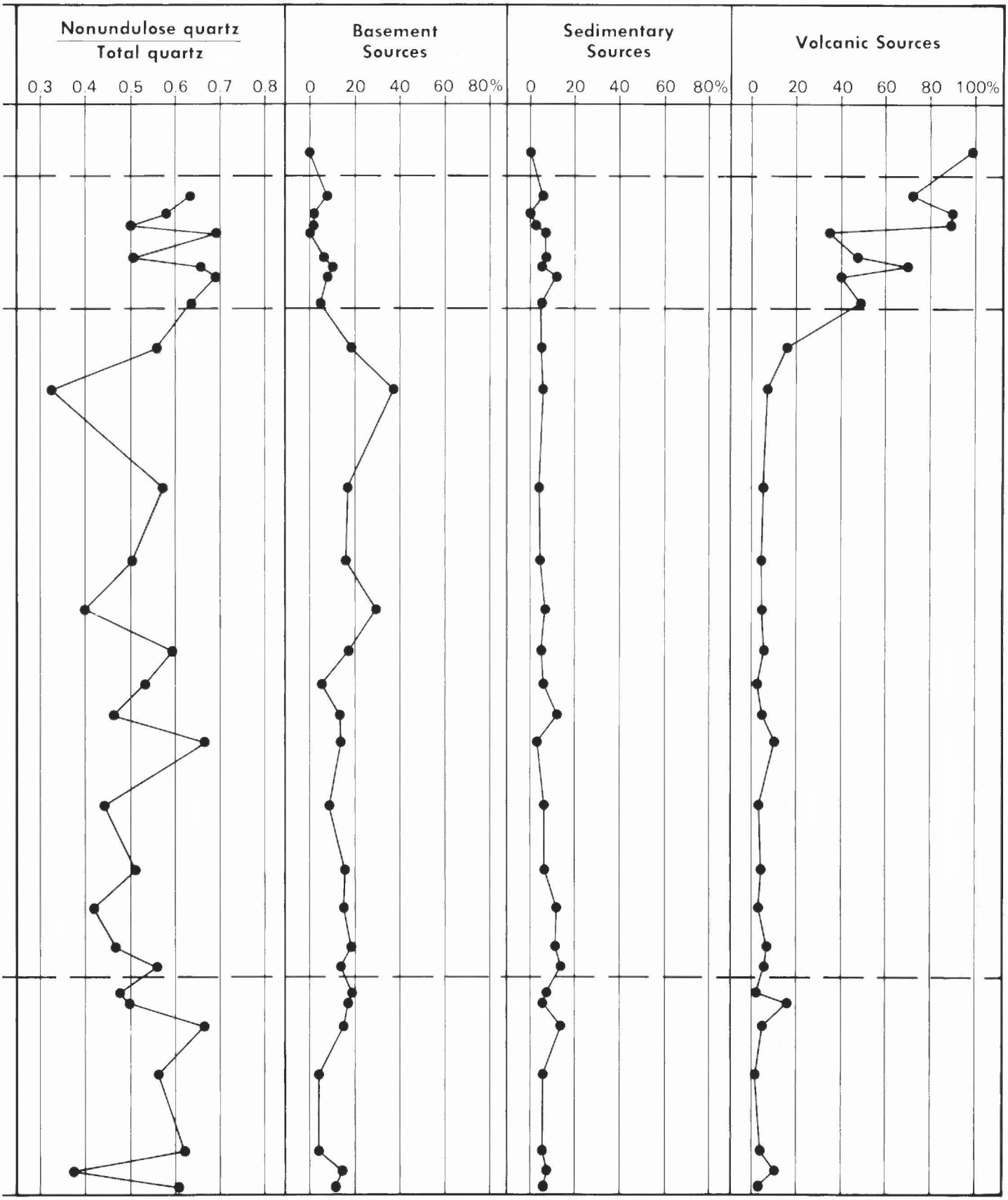


FIGURE 7. Diagram showing variation in grain size and petrologic characteristics of sandstone samples from the reference section. Sample locations are shown in Fig. 2.


Nonundulose quartz
Total quartz
0.3 0.4 0.5 0.6 0.7 0.8
Basement Sources
0 20 40 60 80%
Sedimentary Sources
0 20 40 60 80%
Volcanic Sources
0 20 40 60 80 100%

also plausible that significant amounts of volcanic-quartz were inadvertently counted as nonundulose quartz because evidence for their volcanic heritage was obscured by abrasion that destroyed their characteristic bipyramidal shapes and embayed margins. This explanation seems unlikely, however, due to the rarity or absence of volcanic quartz in the suspected source rocks, the basal andesites of the southern Mogollon-Datil field (W. E. Elston, oral comm., 1991).

Basement sources

Diagnostic grains apportioned to this category include granite/gneiss fragments, quartzose and micaceous metamorphic-rock fragments, microcline, orthoclase, untwinned plagioclase and muscovite. The abundance of basement-derived grains is relatively constant between the Crevasse Canyon Formation and the lower part of the Cub Mountain, but increases in the upper Cub Mountain (Fig. 7). Basement-derived grains abruptly decrease in abundance upsection at the base of the Sanders Canyon Formation. With the exception of that between the Crevasse Canyon and lower Cub Mountain, all differences between means for basement-derived grains among the units are statistically significant (Table 2).

Sedimentary sources

Grains allocated to this category include chert, sandstone rock fragments and carbonate rock fragments. Mudstone rock fragments were not included because many of these grains are clearly intraformational and thus are not reliable indicators of provenance. Sedimentary-derived detritus appears to decrease slightly upward through most of the reference section (Fig. 7). The only statistically significant change between adjacent units, however, is the decrease in abundance that occurs between the lower and upper parts of the Cub Mountain Formation (Table 3).

Volcanic sources

Volcanic-derived grains include volcanic-rock fragments, biotite, amphibole, pyroxene, olivine and sanidine. All twinned plagioclase was also included in this category, although evidence shows that minor amounts of plagioclase (both twinned and untwinned) in the lower part of the reference section were derived from basement sources. Volcanogenic detritus is of relatively constant abundance in the Crevasse Canyon and Cub Mountain Formations, but increases dramatically in abundance at the base of the Sanders Canyon Formation (Fig. 7). The abrupt increase between the upper Cub Mountain and the Sanders Canyon is the only statistically significant change in volcaniclastic grains that occurs between adjacent units in the reference section (Table 4).

PROVENANCE SUMMARY

The Crevasse Canyon Formation shows evidence for derivation from diverse source terranes that exposed basement, sedimentary and volcanic lithologies. Estimation of the relative contributions from these rock types, however, is hindered by lack of knowledge concerning the amount of recycled grains and the relative durabilities of the various grain types. The presence of volcanogenic grains in the Crevasse Canyon Formation in the study area is compatible with recent observations from the Mesaverde Group in other areas (Wallin, 1983; Johansen, 1986; Cumella, 1983). Paleocurrent and provenance data from the Mesaverde Group throughout much of New Mexico favor derivation from orogenic areas in southern Arizona and southwestern New Mexico (Johansen, 1986; Cumella, 1983).

Following an episode of non-deposition and erosion that produced a lacuna which encompasses at least the entire Paleocene, deposition resumed in the Sierra Blanca basin in the Eocene. Within the statistical resolution of the present study, the detrital composition of sandstone and conglomerate in the lower Cub Mountain Formation is essentially identical to that of the underlying Crevasse Canyon Formation. The identification of these stratigraphic units therefore depends primarily on their depositional characteristics rather than their detrital composition. In my experience, the most useful identifying characteristics of the Cub Mountain Formation are: (1) the presence of coarse- and very coarse-grained sandstone or pebbles exhibiting maximum sizes greater

TABLE 1. Significance level of difference between means for nonundulose-quartz/total-quartz ratio among stratigraphic units.

	Upper Cub Mountain Formation	Lower Cub Mountain Formation	Crevasse Canyon Formation
Sanders Canyon Formation	$p = 0.02$	$p = 0.04$	$p = 0.20$
Upper Cub Mountain Formation		$p = 0.40$	$p = 0.25$
Lower Cub Mountain Formation			$p > 0.50$

TABLE 2. Significance level of difference between means for basement-derived detritus among stratigraphic units.

	Upper Cub Mountain Formation	Lower Cub Mountain Formation	Crevasse Canyon Formation
Sanders Canyon Formation	$p < 0.001$	$p = 0.001$	$p = 0.03$
Upper Cub Mountain Formation		$p = 0.02$	$p = 0.02$
Lower Cub Mountain Formation			$p > 0.50$

TABLE 3. Significance level of difference between means for sedimentary-derived detritus among stratigraphic units.

	Upper Cub Mountain Formation	Lower Cub Mountain Formation	Crevasse Canyon Formation
Sanders Canyon Formation	$p > 0.5$	$p = 0.09$	$p = 0.05$
Upper Cub Mountain Formation		$p = 0.05$	$p = 0.02$
Lower Cub Mountain Formation			$p > 0.5$

TABLE 4. Significance level of difference between means for volcanic-derived detritus among stratigraphic units.

	Upper Cub Mountain Formation	Lower Cub Mountain Formation	Crevasse Canyon Formation
Sanders Canyon Formation	$p < 0.001$	$p < 0.001$	$p < 0.001$
Upper Cub Mountain Formation		$p = 0.40$	$p > 0.5$
Lower Cub Mountain Formation			$p > 0.5$

than about 3–4 cm in the basal part of the unit; and (2) the presence of variegated, commonly red, mudstone.

Relative to the lower part of the unit, the upper Cub Mountain Formation contains significantly more basement-derived grains and significantly less recycled sedimentary detritus. Also, the first significant upsection occurrence of carbonate rock fragments was noted in the upper Cub Mountain. Taken together, these data document the unroofing of late Laramide basement uplifts during Eocene time. The lower part of the Cub Mountain Formation appears to consist dominantly of recycled Upper Cretaceous detritus, but upper Cub Mountain sandstones contain evidence for increased contributions by basement sources and Paleozoic carbonates. A similar unroofing sequence has been documented by Seager et al. (1986) for the Love Ranch Formation, which may be a proximal equivalent of the Cub Mountain (Lucas et al., 1989).

The marked increase in volcaniclastic detritus in the Sanders Canyon Formation heralds the beginning of Tertiary andesitic volcanism in the source regions to the southwest. This detritus consists largely of phenocrystic plagioclase, amphibole, biotite and opaques, with rare sanidine occurring only as free grains. Groundmass textures are varied; felsitic, trachytic and vitric types were commonly noted. Although no detailed petrographic studies have been attempted in the presumed source rocks in the southeastern Mogollon-Datil field, the above phenocryst mineralogies are quite similar to those of the basal andesitic volcaniclastic rocks in the northeastern and eastern parts of the field (Cather, 1986; Cather and Folk, 1991).

Paleocurrent and petrologic data suggest that andesites to the southwest of the Sierra Blanca basin provided the volcaniclastic detritus to the Sanders Canyon Formation. Although the Palm Park–Rubio Peak rocks seem to be the most likely candidates, it cannot be ruled out that Eocene intermediate-composition intrusives near Orogrande (48.3 ± 1.8 Ma, 42.6 ± 2.2 Ma, C. E. Chapin, unpubl. K/Ar dates) and El Paso (47–48 Ma, Hoover et al., 1988) had extrusive equivalents that may also have supplied volcanic detritus to the Sanders Canyon.

Nonundulose-quartz/total-quartz ratio increases significantly and abundance of basement-derived grains decreases significantly in the Sanders Canyon Formation relative to the upper part of the Cub Mountain, yet abundance of sedimentary-derived grains remains approximately constant. These changes in detrital composition are indicative of diminishing contributions by basement sources concomitant with the onset of Tertiary volcanism in the source region, but with no accompanying abatement of detritial input from older sedimentary rocks. Indeed, the abundance of carbonate rock fragments, which must be derived largely or exclusively from Paleozoic strata, is significantly higher in the Sanders Canyon Formation than elsewhere in the reference section (see Appendix). The reasons for the changes in the non-volcanic part of Sanders Canyon detritus are not known but presumably reflect changes in lithologic availability within the source regions and/or modifications to the fluvial networks that drained these regions.

Clastic deposits in the reference section coarsen abruptly at the base of the Sierra Blanca Volcanics, in response to the onset of local volcanism and related sedimentation. Rocks of this unit in the study area are almost entirely debris-flow breccias that were derived from volcanoes nearby to the east or southeast. In addition to their coarseness and local derivation, the Sierra Blanca Volcanics differ mineralogically from the underlying Sanders Canyon Formation at the reference section in at least two ways: (1) the Sierra Blanca Volcanics appear to contain little or no non-volcanic detritus; and (2) non-opaque mafic minerals in the Sierra Blanca Volcanics are dominated by pyroxene (mostly clinopyroxene, many of which show sector zoning, and lesser amounts of orthopyroxene) with subordinate amphibole and rare olivine. In contrast, non-opaque mafic minerals in the Sanders Canyon Formation are dominantly amphibole and biotite; pyroxene and olivine are absent.

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APPENDIX—POINT-COUNT DATA FOR SANDSTONES FROM REFERENCE SECTION

Sample Number	Nonundulose Monocrystalline Quartz	Other Quartz	Granite/Gneiss Rock Fragments	Metamorphic Rock Fragments	Micro-cline	Ortho-clase	Untwinned Plagioclase	Musco-vite	Chert	Sandstone Rock Fragments	Carbonate Rock Fragments	Mudstone Rock Fragments	Volcanic Rock Fragments	Twinned Plagio-clase	Amphi-bole	Biotite	Pyroxene
Sierra Blanca Volcanics																	
Tsbv-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.7	4.3	0.0	0.0	4.7
Sanders Canyon Formation																	
Tcm-12	8.5	5.0	3.5	1.0	1.0	2.5	0.0	0.0	1.5	1.5	3.5	0.0	65.0	6.0	0.0	0.0	0.0
Tcm-13	5.3	4.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	2.7	41.3	41.3	1.3	0.0	0.0
Tcm-14	3.5	3.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.5	0.5	48.3	25.1	7.4	0.0	0.0
Tcm-16	5.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	5.0	0.0	61.0	24.5	1.0	0.0	0.0
Tcm-17	11.5	11.1	2.1	1.2	1.7	1.3	0.0	0.0	0.4	0.4	4.7	12.8	35.9	9.8	0.0	1.3	0.0
Tcm-18	8.3	4.4	2.0	0.0	3.9	3.4	0.0	0.0	2.9	0.0	0.5	2.5	57.8	13.2	0.0	0.0	0.0
Tcm-19	20.5	9.0	2.6	1.6	1.3	3.0	0.0	0.0	3.4	0.8	6.0	10.3	30.8	8.1	0.4	1.3	0.0
Tcm-20	19.6	11.7	2.8	0.0	0.0	0.9	0.0	0.5	2.3	0.0	1.4	10.3	40.2	8.4	0.0	0.5	0.0
Cub Mountain Formation																	
Tcm-21	33.5	26.5	8.0	3.5	3.0	5.0	0.0	0.0	2.5	1.0	1.5	1.0	11.0	4.0	0.0	0.5	0.0
Tcm-22	15.4	32.2	13.5	9.4	8.2	5.9	0.0	0.0	3.4	0.8	0.0	3.8	7.5	1.5	0.0	0.4	0.0
Tcm-24	40.7	30.9	2.9	6.9	2.9	2.9	0.0	1.5	1.0	1.5	0.0	3.4	2.5	2.4	0.0	0.0	0.0
Tcm-23	36.8	35.8	10.5	0.0	0.0	5.5	0.0	0.0	4.5	0.0	0.0	3.5	1.0	2.0	0.0	0.5	0.0
Tcm-10	19.3	29.9	15.9	3.9	5.8	4.4	1.9	0.0	4.3	3.4	0.0	3.9	1.0	3.9	0.0	0.0	0.0
Tcm-9	39.0	26.0	5.0	7.0	2.0	3.0	0.0	0.0	3.0	0.5	0.0	6.5	4.0	2.0	0.0	0.5	0.0
Tcm-8	45.6	38.4	1.5	0.0	1.5	2.4	0.0	1.0	5.8	0.0	0.0	2.4	1.0	0.5	0.0	0.0	0.0
Tcm-7	32.0	35.5	7.5	1.5	2.0	1.0	0.0	0.0	9.0	2.0	0.0	4.0	0.5	4.0	0.0	0.0	0.0
Tcm-6	41.0	20.5	2.0	5.5	2.0	2.5	0.0	0.0	2.0	2.5	0.0	6.5	7.0	5.5	0.0	0.0	0.0
Tcm-5	28.9	37.2	5.9	0.0	0.5	2.4	0.0	0.5	6.9	0.0	0.0	13.2	1.0	1.5	0.0	0.0	0.0
Tcm-4	34.6	30.3	5.3	6.7	1.0	1.4	0.0	0.0	6.3	0.5	0.0	10.1	1.9	1.9	0.0	0.0	0.0
Tcm-3	27.8	39.4	6.5	0.0	3.2	6.0	0.0	0.0	11.1	0.5	0.0	3.2	0.9	0.9	0.0	0.0	0.0
Tcm-2	29.0	33.5	7.5	5.8	2.0	3.5	0.0	0.0	11.0	1.0	0.0	0.0	5.5	1.5	0.0	0.0	0.0
Tcm-1	32.1	24.4	4.8	3.8	1.9	2.9	0.0	0.0	6.7	5.3	0.0	6.2	4.3	2.4	0.0	0.0	0.0
Crevasse Canyon Formation																	
Kcc-7	31.8	34.8	7.0	2.0	4.0	6.0	0.0	0.0	8.0	0.0	0.0	4.0	0.5	1.5	0.0	0.0	0.0
Kcc-6	25.0	25.0	8.5	3.5	1.5	4.0	0.0	0.5	8.0	1.0	0.5	5.5	14.0	2.5	0.0	0.0	0.0
Kcc-5	32.3	16.8	4.4	4.4	1.8	3.5	0.0	0.0	7.1	1.3	0.4	19.5	4.0	0.4	0.0	0.0	0.0
Kcc-4	46.7	35.5	2.3	0.0	0.5	0.9	0.0	0.5	5.6	0.0	0.0	2.8	0.0	0.5	0.0	0.0	0.0
Kcc-3	51.0	30.6	1.9	1.0	0.0	0.0	0.0	0.0	5.3	1.0	0.0	4.8	2.4	1.9	0.0	0.0	0.0
Kcc-2	23.5	38.0	4.5	2.0	2.0	4.5	0.0	0.5	7.5	0.5	0.0	6.5	8.0	2.0	0.0	0.0	0.0
Kcc-1	41.8	27.9	5.7	0.0	1.0	2.9	0.0	0.5	6.7	0.0	0.0	8.6	0.5	1.0	0.0	0.0	0.0

APPENDIX (continued)

Sample Number	Sanidine	Olivine	Opaques	Unidentified Rock Fragments	Matrix*	Primary Porosity*	Secondary Porosity*	Carbonate Cement*	Hematite Cement*	Clay Cement*	Quartz Cement*	Zeolite Cement*	Mean Grain Size (φ)	Framework Points	Total Points
Sierra Blanca Volcanics															
Tsbv-1	0.0	0.9	1.4	0.0	0.0	0.7	0.0	5.1	0.0	0.0	0.0	20.5	-0.9	212	269
Sanders Canyon Formation															
Tcm-12	1.0	0.0	0.5	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	1.0	200	214
Tcm-13	0.0	0.0	2.7	0.0	6.0	1.2	0.0	1.2	0.0	1.2	0.0	1.2	2.0	225	252
Tcm-14	9.4	0.0	0.5	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.4	203	225
Tcm-16	1.0	0.0	0.5	0.0	0.0	0.0	0.0	28.4	0.0	1.4	0.0	0.0	0.0	200	285
Tcm-17	0.9	0.0	4.3	0.0	0.0	1.8	0.0	10.0	0.0	0.0	0.0	0.7	1.8	234	273
Tcm-18	0.0	0.0	0.5	0.0	1.3	0.0	0.0	12.3	0.0	0.0	0.0	0.0	1.8	204	236
Tcm-19	0.0	0.0	0.0	0.0	0.0	0.0	0.3	21.6	1.3	0.0	0.3	0.0	2.3	234	305
Tcm-20	0.9	0.0	0.0	0.0	0.0	0.0	0.0	10.2	0.0	2.4	0.0	0.0	1.8	214	245
Cub Mountain Formation															
Tcm-21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.9	0.0	0.0	0.0	0.0	2.0	200	227
Tcm-22	0.0	0.0	0.0	0.0	0.0	6.8	1.7	0.7	0.0	0.0	0.3	0.0	1.4	267	295
Tcm-24	0.0	0.0	0.5	0.0	0.0	4.1	0.0	1.4	0.4	0.0	1.4	0.0	2.3	204	220
Tcm-23	0.0	0.0	0.0	0.0	0.0	1.1	0.0	15.6	3.7	4.8	0.0	0.0	2.8	201	269
Tcm-10	0.0	0.0	0.0	0.0	0.0	0.9	0.5	2.3	0.0	0.9	0.9	0.0	1.0	207	219
Tcm-9	0.0	0.0	1.5	0.0	2.4	1.2	0.0	11.2	2.8	2.0	0.0	0.0	2.8	200	249
Tcm-8	0.0	0.0	0.0	0.0	0.0	1.2	0.8	13.5	0.0	4.6	0.4	0.0	1.7	206	260
Tcm-7	0.0	0.0	0.0	0.0	0.0	3.9	0.0	7.7	0.0	2.7	0.0	0.0	1.4	200	234
Tcm-6	0.0	0.0	1.0	2.5	3.5	2.2	0.0	7.9	0.0	3.9	1.3	0.0	2.0	201	229
Tcm-5	0.0	0.0	0.0	0.0	0.0	5.6	0.0	6.0	0.0	6.0	0.8	0.0	1.0	204	250
Tcm-4	0.0	0.0	0.0	0.0	0.4	5.1	4.7	1.6	4.4	1.2	0.4	0.0	1.1	208	253
Tcm-3	0.0	0.0	0.5	0.0	0.0	5.1	0.0	2.1	1.7	0.0	0.0	0.0	1.4	216	237
Tcm-2	0.0	0.0	0.0	0.0	0.0	0.0	1.1	20.0	0.0	8.4	0.4	0.0	1.4	200	285
Tcm-1	0.0	0.0	0.5	0.0	1.0	4.8	1.1	16.5	0.0	1.1	0.0	0.0	1.5	209	273
Crevasse Canyon Formation															
Kcc-7	0.0	0.0	0.5	0.0	7.4	5.5	0.0	1.9	1.5	5.1	0.0	0.0	1.8	201	256
Kcc-6	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.9	0.0	1.3	0.9	0.0	1.4	200	225
Kcc-5	0.0	0.0	0.4	0.0	3.1	5.4	0.0	8.1	0.0	0.0	0.0	0.0	1.6	226	261
Kcc-4	0.0	0.0	0.0	0.0	0.0	0.3	0.0	25.6	0.0	2.1	0.7	0.0	2.3	214	293
Kcc-3	0.0	0.0	0.0	0.0	0.0	10.3	2.9	1.6	0.0	0.4	0.0	0.0	2.3	206	244
Kcc-2	0.0	0.0	0.5	0.0	0.0	2.0	0.4	2.8	0.0	13.8	0.0	0.0	2.0	200	247
Kcc-1	0.0	0.0	1.0	0.0	0.0	4.9	0.8	0.0	0.0	6.2	2.9	0.0	1.8	208	244
														6,304	7,574

* percent of total points; all others are percent of framework points.





Hope springs eternal whether one be a prospector on a grubstake or a would-be investor on horseback. In the top view, these entrepreneurs of the pick and pan are doing it the hard way, setting out on foot, perhaps from Carrizozo bound for the White Oaks mines. A much easier way to find one's Golconda was to let the company provide the transportation as well as the facilities. All the investor had to do was to sign on the dotted line as these gentlemen must have done prior to their excursion to the Parsons mine near Nogal circa 1915. Top view courtesy of Robert W. Eveleth; lower view courtesy of Johnson Sterns, Carrizozo.