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DEPOSITIONAL STYLE AND TECTONIC IMPLICATIONS OF THE MOGOLLON RIM FORMATION (EOCENE), EAST-CENTRAL ARIZONA

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Abstract—The Mogollon Rim formation is an alluvial braidplain deposit that blanketed part of the southern Colorado Plateau and Transition Zone province in east-central Arizona during the Eocene. These coarse clastics were shed northeastward off the flanks of the actively rising Laramide Mogollon highland onto a locally channeled but regionally flat erosion surface that bevels increasingly older early Teritiary(?) through Precambrian rocks toward the southwest. Evidence for contemporaneous uplift is recorded by facies relationships across several northwest-trending intrabasinal faults that cross the Transition Zone. Regional transport of sediment was generally eastward toward the Baca basin in New Mexico. At least three large trunk streams from the Mogollon highland distributed discrete lithologic suites of clasts across a broad alluvial braidplain. The source area extended west and southwest beyond the present Tonto basin and Globe-Miami mining district. Deposition began with the widespread distribution of a coarse boulder conglomerate across the moderately channeled bedrock surface. As bedrock lows were filled, clast size diminished, and arkosic sand dominated the rivers. The alluvial plain was deposited in a semiarid climate, but the source area was sufficiently humid to support large-volume rivers. Paleocurrents suggest a 31° northward rotation of paleoslope following deposition of the basal conglomerate. Increasingly tuffaceous sandstones in the upper member signal incipient mid-Tertiary magmatism in latest Eocene time. The basal contact serves as a datum for post-depositional structural lowering of the Transition Zone. The previously active northwest-trending faults in the area were later reactivated with the opposite sense of movement, causing the Mogollon Rim formation in the Transition Zone to be downfaulted and downwarped at least 760 m to the south.

INTRODUCTION

Late Laramide uplift of the ancestral Mogollon highland in central Arizona resulted in deposition of coarse fluvial clastics northeastward onto the southern periphery of the Colorado Plateau (Peirce et al., 1979; Young and Hartman, 1984). This assemblage is commonly called the "Rim gravels" (Cooley and Davidson, 1963) and is named after the Mogollon Rim, the south-facing escarpment and regional drainage divide that defines the southern physiographic edge of the Colorado Plateau (Peirce, 1984) (Fig. 1). Middle to late Tertiary extension in the Basin and Range Province subsequently rifted the Laramide Mogollon

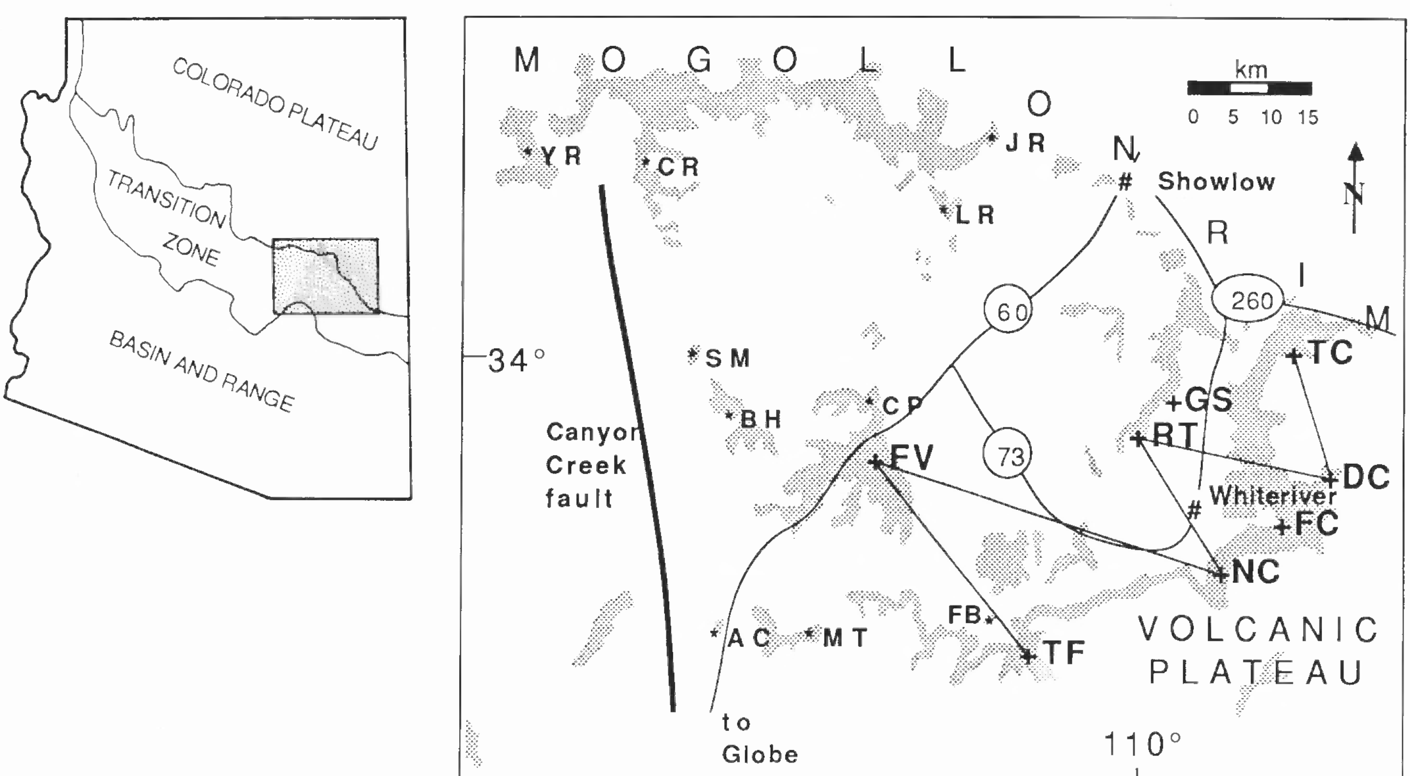

FIGURE 1. Locality and outcrop map of early Tertiary alluvial sediments in the study area. Measured sections are designated with large letters; other localities discussed in text are designated with small letters: AC—Ash Creek, BH—Blue House Mountain, CR—Chediski Ridge, CP—Cibeque Peak, DC—Deep Creek, FC—Firebox Creek, FV—Flying V, FB—Forks Butte, GS—Gla She Spring, JR—Juniper Ridge, LR—Limestone Ridge, MT—Mormon Tank, NC—Nash Canyon, RT—Round Top, SM—Spotted Mountain, TC—Trout Creek, TF—Tick Flat, YR—Young Road.

highland and ultimately induced a regional drainage reversal. The structural transition between the relatively undeformed Colorado Plateau and the highly deformed region to the south remains poorly understood due to lack of an adequate Tertiary datum linking the two provinces. In east-central Arizona, early Tertiary alluvial sequences are widely distributed on the Colorado Plateau and in the adjacent Transition Zone. Resolving the stratigraphic and temporal relationships between these sequences may elucidate the tectonic and paleogeographic evolution of the southern Colorado Plateau margin during the mid-Tertiary change from crustal shortening to crustal extension (Zoback et al., 1981).

This study examines previously undescribed exposures of the Rim gravels and Transition Zone gravels in order to test two contrasting paleogeographic models. The Transition Zone gravels are at significantly lower altitudes than the Rim gravels and rest on lower stratigraphic horizons in the Paleozoic and Precambrian section. Using present Paleozoic stratigraphic positions as datum levels, there is insufficient offset on known intervening faults to account everywhere for the lower altitudes. One model suggests that certain outcrops of lower elevation gravels may have been deposited by later streams flowing at lower altitudes relative to the Colorado Plateau (Peirce et al., 1979). The other model includes all outcrops in the same northeastward-flowing deposystem (Cather and Johnson, 1984) and explains variation in structural and stratigraphic position by either paleotopography on the underlying erosion surface (Peirce, oral commun., 1989) or post-depositional structural lowering (Spencer and Reynolds, 1986). This study attempts to resolve these contrasting ideas by taking a more detailed look at the depositional features in relation to Transition Zone structures and paleotopography.

The following discussion is divided into three parts. First, depositional facies and their arrangement in a series of measured sections along a transect are described to demonstrate depositional continuity using both facies relations and marker units. Second, depositional continuity is further tested by comparing paleocurrents, maximum clast size and provenance. Finally, structural features in this region are described and discussed in terms of their relation to sedimentation and the geologic evolution of this segment of the Transition Zone during early to middle Tertiary time.

REGIONAL SETTING

The study area lies within the Fort Apache Indian Reservation in east-central Arizona. It is bordered on the north by the Mogollon Rim, a south-facing, deeply embayed, erosional escarpment of Permian rocks (Peirce, 1984) (Fig. 1). Erosional remnants of unconsolidated Rim gravels are widely distributed along this part of the Mogollon Rim.

Toward the east, the middle to late Tertiary White Mountain volcanic field (Berry, 1976; Merrill and Pewé, 1977) covers part of the Transition Zone. It forms a volcanic plateau that merges with the Colorado Plateau and overlies thick, early Tertiary alluvial sequences. Headward erosion by southwest-flowing tributaries of the Salt River has produced a deep embayment ("Carrizo embayment," S. J. Reynolds, oral commun., 1987) in the western side of the volcanic plateau. The Carrizo embayment is rimmed on the east and south by a west-northwest-facing escarpment of early Tertiary alluvial clastics capped by volcanic rocks ranging in age from Miocene to Quaternary (Berry, 1976; Condit and Shafiqullah, 1985). This boomerang-shaped outcrop (here referred to as the "boomerang" transect) is the primary focus of this study because it reveals a continuous cross-sectional exposure of alluvial clastics from the Mogollon Rim southwestward to lower altitudes in the Transition Zone (Fig. 1).

The Flying V–Blue House Mountain–Spotted Mountain outcrops are early Tertiary alluvial sequences located between the Mogollon Rim and "boomerang" transect (Fig. 1). These clastics underlie basalt-capped buttes that are erosionally isolated in the center of the Carrizo embayment.

The study area is bounded on the west by the Canyon Creek fault (Fig. 1) and Sierra Ancha. Early Tertiary alluvial sequences in the study area overlie late Cenomanian marine sandstone and shale (Cobban and Hook, 1984) on the Mogollon Rim and progressively older Permian through Proterozoic sedimentary rocks south and southwest of the Colorado Plateau.

PREVIOUS WORK

Darton (1925) observed a "heavy boulder cap" overlying Cretaceous marine strata on the Mogollon Rim and gravel resting on lava-capped buttes within the Fort Apache Indian Reservation. McKee (1951) noted the widespread distribution of gravel deposits along the entire southern margin of the Colorado Plateau in Arizona and considered them Pliocene(?). Hunt (1956) discussed the provenance of "bouldery gravel deposits" on the Mogollon Rim west of Show Low and suggested a Late Cretaceous to Eocene age. Cooley and Davidson (1963) coined the term "rim gravel" for outcrops along the Mogollon Rim near Show Low and considered them correlative with the Late Miocene–Pliocene Bidahochi Formation that lies to the north. Cooley and Davidson (1963) and Merrill and Pewé (1977) correlated the Transition Zone outcrops beneath the White Mountain volcanic field with the volcaniclastic Datil Group in western New Mexico. Reconnaissance mapping of the region conducted between 1956 and 1969 defined the extent of Tertiary clastics in the area (Moore and Peirce, 1967; Wilson et al., 1969). Three 15′ quadrangle geologic maps in the northwestern part of the study area (Finnell, 1966a, b; McKay, 1972) are the most detailed maps in the region. On these maps, the Tertiary clastics are divided into "Rim gravel," those deposits clearly on the Mogollon Rim, and "younger gravel," similarly described deposits at lower elevations on ridges and buttes to the south. Peirce et al. (1979) proposed a two-stage depositional history that supported some of the mapping of Finnell (1966a) near Canyon Creek and constrained the age of Rim gravel on the Plateau between Eocene and middle Oligocene. During a reconnaissance study of the region, Johnson (1978) and Cather and Johnson (1984) described a partial section, measured paleocurrents and clast sizes in two areas, and tentatively correlated outcrops in this area with the Baca Formation of west-central New Mexico.

METHODS

Six stratigraphic sections were measured and described along the "boomerang" transect from the Mogollon Rim southwestward across the Transition Zone (Fig. 1). The type section was established at Trout Creek on the Mogollon Rim. Sections were measured to compare vertical and lateral lithofacies relations. Pebble counts, paleocurrents, maximum clast size, contact elevations and contact relationships were measured on the transect and at many other localities in the area. Structural features were mapped in sufficient detail to determine their relationship to sedimentation.

In the central and western part of the study area, two additional traverses were made along prominent ridges that extend from the Mogollon Rim south to gravel-mantled buttes at lower altitudes in order to compare clast composition, rounding and size. These traverses, down Limestone Ridge to Cibeque Peak and similarly down Chediski Ridge to Blue House Mountain, were conducted in order to compare Rim gravels with the Transition Zone "younger gravel" mapped by Finnell (1966a, b) and McKay (1972).

DEPOSITIONAL FACIES

Six facies are identified and described (Fig. 2). The vertical arrangement of these facies in the measured sections is displayed in Figure 3. White to light brown, fine- to coarse-grained arkosic sandstones and red-brown mudstones typify most measured sections. Bedding in sandstones is often indistinct, but horizontal bedding, planar crossbedding, trough crossbedding and low-angle crossbedding are present in all measured sections.

Facies A comprises framework-supported conglomerate with clasts that are commonly rounded to well-rounded, moderately sorted and imbricated (Fig. 2). Both sheet and ribbon geometries are present, and lateral continuity of some gravel beds is greater than 50 m. Horizontal to massive bedding is common; planar crossbeds are less abundant. Planar crossbed sets range up to 2.5 m in thickness, and individual crossbeds in some sets coarsen down the dipface from pebbly sands to

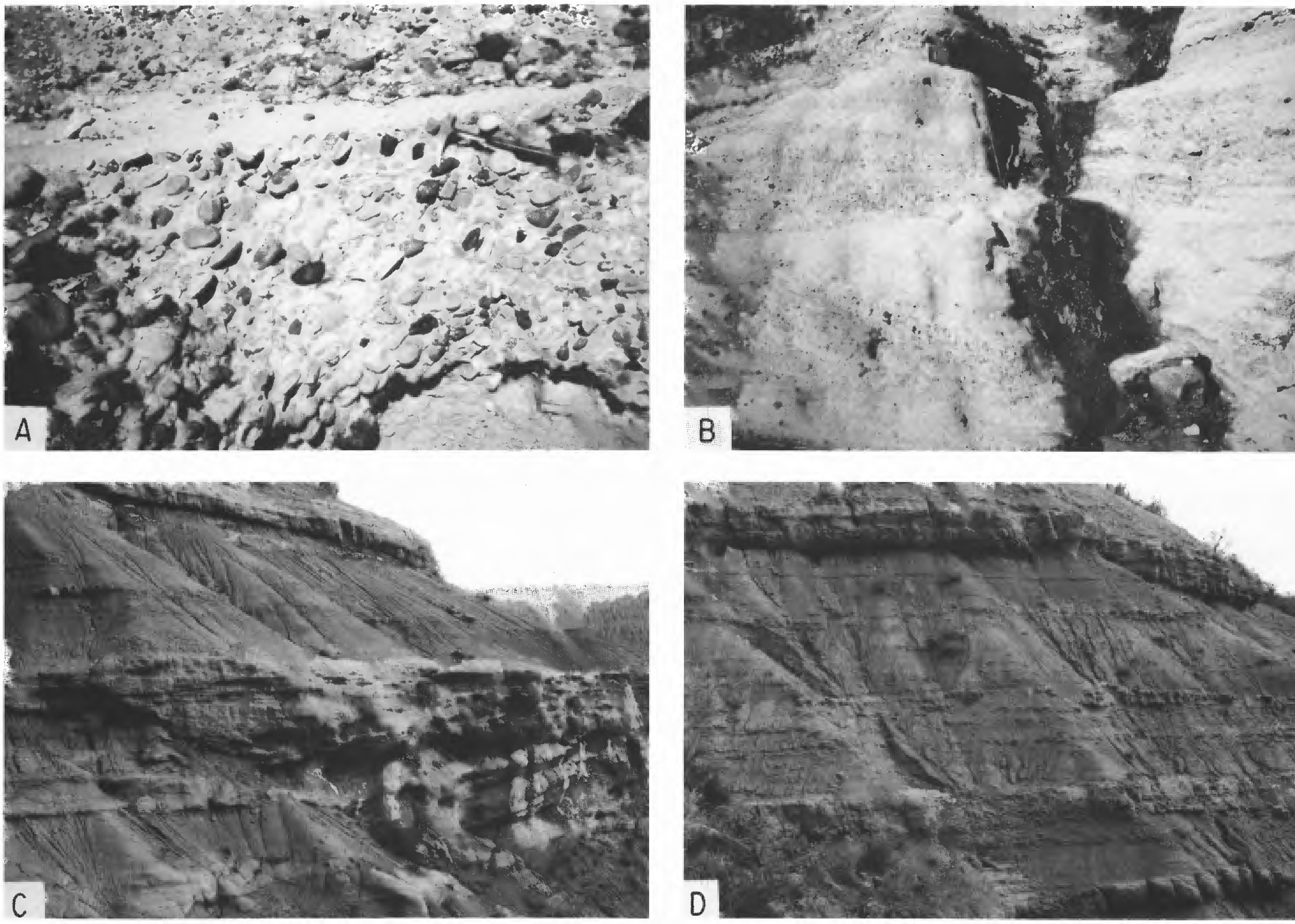

FIGURE 2. Outcrop photographs of facies. **A,** Facies A: mature, clast-supported, imbricated conglomerate with a thin lense of interbedded sandstone (rock hammer for scale). **B,** Facies B: planar crossbedded sandstones and conglomeratic sandstones with minor mudstone (1.5 m Jacob staff for scale). **C,** Facies C: 4-m-thick channel sand sheet rests on a scoured surface and laterally attentuates against a channel wall. Low angle crossbeds pass upward through the sandstone which is gradationally overlain by 5 m of sandy mudstone capped by a paleosol (no scale). **D,** Facies D: thin sandstone sheets (crevasse splay deposits) interbedded with, Facies E: floodplain mudstones (hat in lower left quadrant for scale).

cobbles. Thin lenses of channel sand (Fig. 2) and pedogenically altered mud commonly fill shallow scours within thick conglomerate sequences. The scarcity of steep-walled channels and predominance of horizontal to massive bedding may reflect deposition on longitudinal bars (Rust, 1972). Planar crossbedded gravels may have been deposited by transverse bars (Rust, 1972; Smith, 1970).

Facies B is a widely inclusive category of conglomeratic sandstones and sandstones in which mudstone is minor or not present (Fig. 2). Sandstones are typically sorted, subangular to subrounded, medium- to coarse-grained and frequently capped by a few thin beds of light brown to reddish brown mudstone. Bedding is usually planar crossbedded, horizontal or massive. Steep-walled channels, ribbon geometries and complex scouring and stacking of depositional units are common features. Many of these units may have originated as migrating bedforms such as transverse bars and linguoid bars in braided bedload streams (Rust, 1972).

Facies C is characterized by cyclic, sheet-like, fining-upward units that occur in both multistory and single story sequences (Fig. 2). A typical unit overlies an uneven erosion surface and consists of medium-grained sandstone gradationally overlain by a subequal thickness of ripple- and plane-laminated sandy mudstone. These sandstone-mudstone couplets vary from 2 m to 9 m in thickness and are at least several hundred meters in cross-channel width. Large-scale, enigmatic low-angle crossbeds with highly variable dip azimuth directions are common in the sandstones. Trough and planar crossbedding and horizontal bedding are also present. The overlying mudstones are frequently capped with red to red-brown burrowed paleosols that contain pedogenic carbonate nodules, clay skins and fine root casts. Rip-up clasts from these mudstones are commonly deposited in sandstone of the overlying unit. Facies C has characteristics of the classic meandering stream model (Allen, 1970) and is similar to descriptions of the fine-grained meanderbelt facies of the Baca Formation (Cather and Johnson, 1984). More detailed work is necessary, however, to determine paleosinuosity of the rivers which deposited these channel sandstones.

Facies D consists of 0.5- to 1-m-thick, tabular, horizontally bedded units which grade upward from fine- or very fine-graind sandstone to silty claystone. These thin sheets of sandstone are either stacked in multiple sequences or occur as single units enclosed within mudstones (Fig. 2). The geometry of these sand sheets and their association with floodplain sediments suggests crevasse splay deposition on floodplains.

Facies E is composed of red brown to light brown silty claystone, clayey siltstone and silty, very fine sandstone ranging up to 17 m thick. These horizontally bedded, ripple cross-laminated or massive sequences commonly include interbedded crevasse splay deposits of Facies D (Fig. 2). Erosion surfaces and pedogenic features are uncommon. Deposition appears to have occurred by the vertical accretion of suspended fines on floodplains. Facies D and E comprise the upper part of Facies C fining-upward couplets but also occur separately.

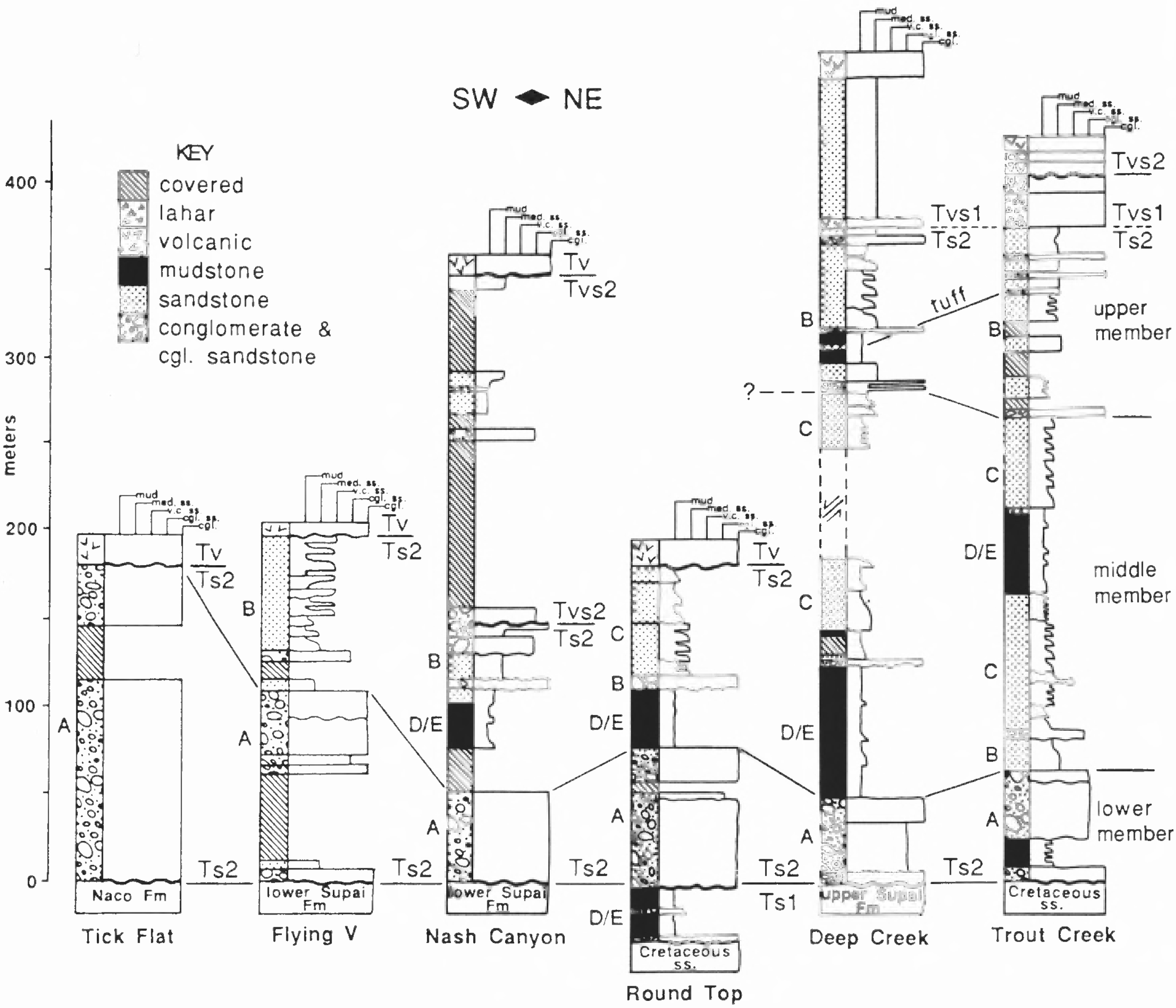

FIGURE 3. Measured sections on a transect across the Transition Zone (Fig. 1). Tie lines define the three informal members at the uneroded Deep Creek and Trout Creek sections. Tie line between upper Deep Creek and Trout Creek is the dated tuff (Table 1). Ts1—early Tertiary(?) red beds, Ts2—Mogollon Rim formation, Tvs1—gradationally overlying volcaniclastics (lower Datil Group equivalents), Tvs2—unconformably overlying volcanic conglomerate sequence, Tv—Tertiary volcanics. Letters to the left of columns refer to facies described in text. Trout Creek type section is located in secs. 4, 9 and 10, T7N, R24E, McNary 7.5′ quadrangle.

DESCRIPTIONS OF MEASURED SECTIONS

Trout Creek is the type section for what is here informally named the Mogollon Rim formation. It is selected as the type section for two reasons: (1) its stratigraphic and geomorphic position on the Mogollon Rim clearly places it in the same depositional system as the Rim gravel deposits farther west on the Colorado Plateau and (2) it is the thickest and best exposed outcrop in the region. Reference sections at the Round Top and Deep Creek localities (Fig. 1) provide good exposures of the lower and upper parts of the section, respectively.

At Trout Creek the Mogollon Rim formation is 375 m thick and divided into three members that grade into one another (Fig. 3). The section rests on a low-relief erosion surface that bevels more than 120 m of Upper Cretaceous marine strata to a feather edge southwestward from Trout Creek to Round Top (Moore and Peirce, 1967; Peirce et al., 1979). The lower member consists of clast-supported gravels and conglomeratic sandstones. The middle member is composed mostly of cyclic fining-upward sequences of sandstone and mudstone. Crevasse splay and overbank fines are abundant, whereas gravels are uncommon. The upper member is dominated by sandstones that are moderately conglomeratic and increasingly tuffaceous upsection. Conglomerate clast size and abundance abruptly decrease above the lower member. An interbedded sequence of tuffaceous sandstone and volcanic debris-flow gradationally overlies the Mogollon Rim formation at Trout Creek and Deep Creek. The contact is drawn at the base of the first sandstone or conglomerate bed that contains greater than 50% volcanic clasts. These volcaniclastics are, in turn, unconformably overlain by a sequence of volcanic conglomerate and sandstone intercalated with mafic volcanic flows (Fig. 3).

The Round Top section is a composite of outcrops at Round Top and Gla She Spring (Fig. 1). At Round Top, a unique 30 m section of fine-grained early Tertiary(?) red beds unconformably overlies Cretaceous sandstone and underlies the coarse basal conglomerate of the Mogollon

Rim formation (Fig. 3). The lower contact of the red-bed sequence is flat and unconformable, but the upper contact is a highly irregular erosion surface with at least 4 m of local relief. A thin basal conglomerate in the red-bed sequence is overlain by four fining-upward units in which a half meter of very fine or fine sand is overlain by 5 to 7 m of red to orange-red mudstone. Three 1.5-m-thick beds of purple, buff or red, pebbly, planar crossbedded sandstone are interbedded midway through the sequence. Reduction spots are common, and bedding is subhorizontal and structureless in the mudstones. These red beds are not included in the Mogollon Rim formation because of their contrasting lithology and strongly erosional contact with the overlying facies A boulder conglomerate.

The Deep Creek composite section is composed of lower section outcrops at Firebox Creek and upper section outcrops at Deep Creek (Fig. 1). The base of the section unconformably overlies a slightly channeled erosion surface cut on the Corduroy Creek Member of the Permian Supai Formation (Winters, 1963). The two partial sections are on opposite sides of a N60°W-trending structure, here called the Brushy Mountain fault, that drops the section 170 m to the southwest (Figs. 4, 5A). Distinctive lithofacies and an interbedded ash-fall tuff serve to correlate the section across the fault.

Several features confirm correlation of the Deep Creek and Trout Creek sections. A similar three-member pattern of grain-size variation is recognizable in both sections (Fig. 3). The gradational upper contacts with the overlying volcaniclastic sequence are similar and rest at the same altitude. An ash-fall-tuff marker bed is interbedded in the middle part of the upper member at both localities. These tuff beds have similar phenocryst composition, occupy a similar stratigraphic position relative to the upper gradational contact (Fig. 3) and have nearly the same K-Ar age at both localities.

Along the "boomerang" transect from Firebox Creek to Tick Flat (Fig. 1), the Mogollon Rim formation is dropped down across several more faults (Fig. 4) and overlies progressively older Pennsylvanian and Permian strata toward the southwest. In the vicinity of Nash Canyon, the upper section is eroded and unconformably overlain by a 200-m-thick volcanic conglomerate and sandstone sequence similar to the unconformably overlying sequence at Trout Creek (Fig. 3). The Mogollon Rim formation grades laterally from a wholly conglomeratic sequence to sandstone-dominated sequence in the 10 km northeast of the Tick Flat section. Thinning of the sequence to the southwest is partly due to post-depositional erosion but is primarily due to depositional onlap of a paleohighland to the southwest (see below).

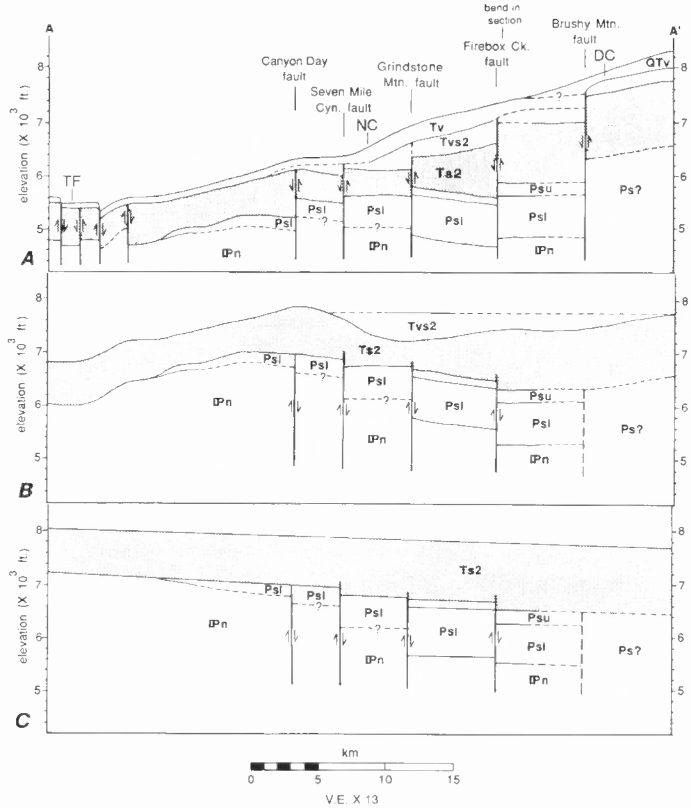

FIGURE 5. Cross section A–A′ (Fig. 4) along the "boomerang" transect shows: A, progressive down-faulting of the Mogollon Rim formation (Ts2) to the southwest across the Fort Apache fault zone. Overlying Miocene basaltic andesites (Tv) are not significantly offset by faults. B, reconstruction of the basal contact of Mogollon Rim formation across these faults restores the earlier southwest-up episode of displacement and reveals the amount of deformation attributable to downwarping. A paleovalley filled with volcanic conglomerate (Tvs2) is cut in the upper Mogollon Rim formation. C, unwarping of the section by restoring Mogollon Rim formation to an assumed depositional slope of 0.002 m/m for the upper surface and 0.005 m/m for the basal contact. The section overlies increasingly older strata to the southwest: Psu—Permian upper Supai Formation, Psl—Permian lower Supai Formation, ℙn—Pennsylvanian Naco Formation.

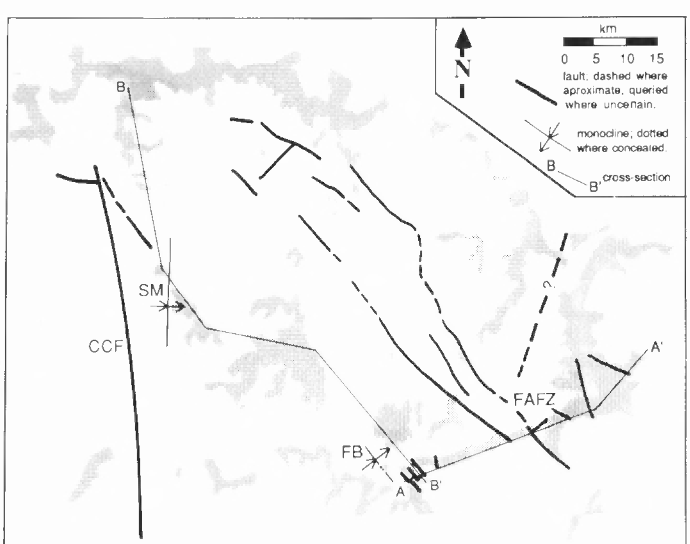

FIGURE 4. Structure map showing Canyon Creek fault (CCF), Fort Apache fault zone (FAFZ), Forks Butte monocline (FB), Spotted Mountain monocline (SM), cross sections A–A′ (Fig. 5) and B–B′ (Fig. 10). Folds at Spotted Mountain and Forks Butte predate deposition of the Mogollon Rim formation. Fort Apache fault zone and Canyon Creek fault are high-angle reverse faults which show evidence for an earlier episode of uplift to the west-southwest and later reactivation with opposite sense (after Moore and Peirce, 1967).

Southwest of Tick Flat, Tertiary gravel deposits with southerly-derived basement clasts locally overlie the same ancestral erosion surface, here cut in lower Paleozoic through upper Proterozoic sedimentary rocks. These outcrops rest at the same range of altitudes as the Mogollon Rim formation between Firebox Creek and Tick Flat. Deposits at Mormon Tank and Ash Creek (Fig. 1) are composed of subrounded to rounded boulder conglomerate. At Mormon Tank, a 49-m-thick sequence rests on lower Paleozoic limestone, and at Ash Creek, a clast-supported boulder deposit fills a 137-m-deep paleochannel cut in Proterozoic Troy Quartzite.

The Flying V section is part of an extensive outcrop of basalt-capped early Tertiary clastics centrally located in the study area between the "boomerang" transect and the Mogollon Rim (Fig. 1). This outcrop rests at the same range of altitudes and overlies the same erosionally beveled Pennsylvanian-Permian strata as the Mogollon Rim formation between Firebox Creek and Tick Flat. The measured section is a 195-m-thick fining-upward sequence dominated by mature, clast-supported conglomerate in the lower half and sandstones in the upper half (Fig. 3). Sandstones are coarser and less mature than those which typify sections to the northeast. Both fining-upward and coarsening-upward crossbedded sandstone sequences occur. Uncommon occurrences of very coarse and angular shallow trough-crossbedded sandstone beds suggest rapid deposition from a nearby source, but debris-flow deposits are not present. Scour-and-fill structure and narrow, conglomerate-filled channels are common in the upper section. Mudstones comprise a small percentage of the section and are often pedogenically altered and laced with root casts and burrows. Well-indurated petrocalcic paleosols are interbedded in the basal conglomerate and form a resistant limestone unit up to 8 m thick at the top of the section.

PALEOCURRENTS

Paleocurrent data were gathered from clast imbrication, dip azimuth of planar crossbeds, axes of trough crossbeds and orientation of channel walls. Data were compiled separately for the basal conglomerate and the overlying deposits where possible. Mean paleocurrent vectors at particular localities for the basal conglomeratic member range from 22° at Trout Creek to 69° at Young Road. Upper-section Mogollon Rim formation mean paleocurrent vectors vary from 359° at Deep Creek to 58° at Flying V Canyon. At sites where upper-section data were obtained, paleocurrents are systematically deflected toward the north when compared to the basal conglomerate (Fig. 6). The grand mean paleocurrent vector is 53° for the basal conglomerate and 22° for the upper part of the section. This 31° upsection counterclockwise shift of the grand mean vector is interpreted to reflect a significant change in regional paleoslope during the period of deposition. A continuation of this counterclockwise rotation in paleoslope is apparent in the 338° grand mean vector (Fig. 6) of the unconformably overlying volcanic conglomerate (Tvs2 of Fig. 3).

MAXIMUM CLAST SIZE VARIATION

Maximum clast size in the basal conglomerate provides a measure of variation in stream competence across the area during the initial stages of deposition. The bouldery basal conglomerate ranges from 4 m to about 110 m in thickness and is present at nearly all outcrops in the study area. Upper section gravels are invariably and distinctly smaller on average than those at the base. The mean maximum size is calculated from the intermediate diameters of the ten largest clasts in the basal conglomerate at a given locality. One outsized Proterozoic quartzite clast at the Flying V locality (450 cm) was not included in calculations because it represents an extreme flood event uncharacteristic of the fluvial system. Isopleths show a systematic decrease in clast size toward the northeast ranging from 90 cm at Ash Creek to 18 cm south of Trout Creek (Fig. 7). This is consistent with paleocurrent data for the basal conglomerate (Fig. 6). Lobate patterns in the isopleths may denote concentrations of larger clasts in bedrock paleochannels or may simply be abberations in sampling or outcrop preservation. Regardless, the even distribution of the coarse basal conglomerate and the systematic decrease in clast size across the area suggests deposition by a laterally continuous northeast-flowing alluvial system across a regionally low-relief bedrock surface.

It has been recognized by previous workers that clast size diminishes in the downstream direction in alluvial systems according to a log distribution. Sternberg's Law expresses this relationship in terms of downstream reduction in maximum weight of clasts (Blatt et al., 1972). The expression can also be written in terms of maximum size as follows (Lindholm et al., 1979):

$$Do/D = \exp(as)$$

where Do is the initial length of the clast in a stream; D is the length after transport of distance s; and a is the coefficient if size reduction that reflects the physical characteristics of the clasts and transporting fluid. The coefficient a is compiled from other sources by Lindholm et al. (1979) for depositional modes ranging from alluvial fan to fluvial deposits. Values for a in this study average 0.03, placing the Mogollon Rim formation within the middle range for fluvial deposits. This is consistent with the style of deposition and supports the hypothesis that all outcrops studied are part of the same depositional system.

PROVENANCE

Pebble counts were conducted in the basal conglomerate and in upsection locations across the study area for three purposes: (1) to determine if similarity in gravel composition across the area supports the correlation of outcrops, (2) to more closely constrain the location of sediment sources and (3) to look for systematic lateral or vertical compositional variations that could provide insight into the erosional evolution of the source area.

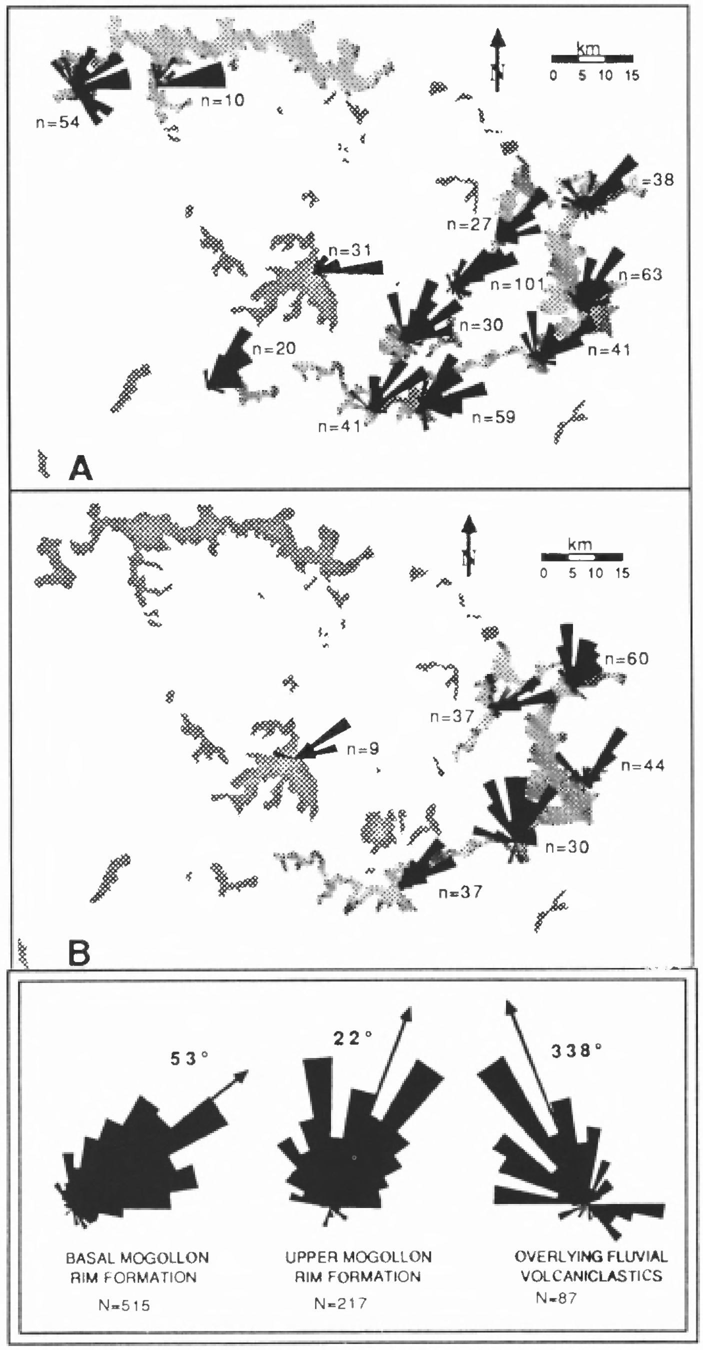

FIGURE 6. Paleocurrent rose diagrams of the A, basal conglomerate and B, upper section of the Mogollon Rim formation. Grand mean vectors are shown below for these two data sets plus the unconformably overlying volcanic conglomerate sequence (Tvs2).

Similar gravel lithologies occur at virtually all sites across the region, but the relative proportions vary between outcrops. Between 80 and 99% of clast types at all localities consist of limestone, chert, quartzite, granitoids, volcanic porphyry, diabase and metavolcanic rocks. Minor clast types include argillite, vein quartz, aphyric volcanics, greenstone, conglomerate, sandstone, schist and tuff.

A minimum transport distance for gravels is constrained by the dis-

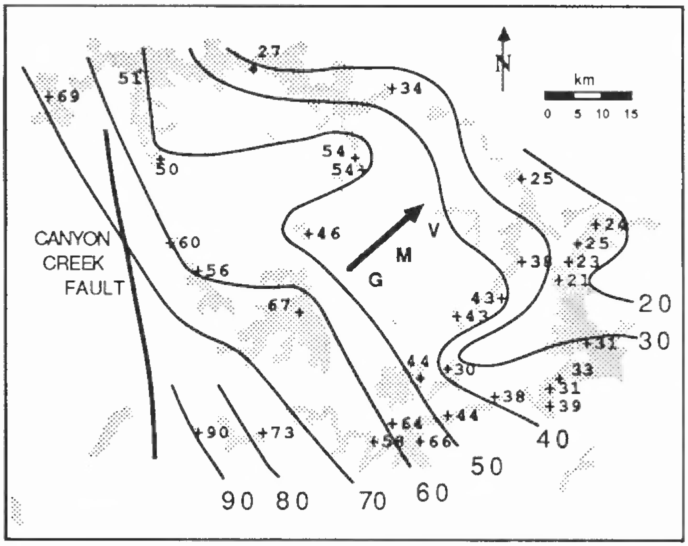

FIGURE 7. Isopleths of the average maximum clast size (cm) of the basal conglomerate show a northeastward diminishment pattern consistent with the grand mean paleocurrent vector for the basal conglomerate (GMV).

tinct source regions for two commonly observed gravel lithologies. The first type consists of red and purple quartzites characteristic of the Lower Proterozoic Mazatzal Group (Trevena, 1979). Extensive exposures of these strata are in the Mazatzal Mountains and Tonto basin area 60 to 80 km west of the study area (Wilson et al., 1969; Karlstrom and Conway, 1986). The second type consists of red, green and gray latite, dacite and andesite porphyry clasts. The absence of metamorphic fabrics and alteration features in this suite distinguishes it from the Lower Proterozoic metafelsites and greenstones. Phenocryst content generally ranges from 10% to 65% and is predominantly anhedral to subhedral white plagioclase with minor hornblende, pyroxene or biotite. The petrography indicates an extrusive or possibly shallow intrusive origin. Whole rock K-Ar ages on three porphyritic clasts sampled from the Round Top section are dated at 54.6 ± 1.2, 56.8 ± 1.2 and 66.7 ± 1.4 my (Peirce et al., 1979). A likely source for these lithologies is the Laramide porphyry-copper mining district 60 to 100 km southwest of the study area (Peirce, 1986). Paleocurrents in the Mogollon Rim formation point "upstream" to the Globe-Miami mining district where K-Ar dates on Laramide intrusives range from 56 to 68 my (Creasey, 1980). These volcanic porphyry clasts may be the extrusive equivalents of the mineralized intrusives.

Provenance and paleocurrents in the proximal region indicate that at least three trunk streams once delivered compositionally discrete clast suites through paleocanyons in the nearby mountain highlands. One stream began in volcanic porphyry terrain southwest of Tick Flat, and a second drained a quartzite-limestone dominated terrain southwest of Flying V (Fig. 8). The latter may have flowed through the 1400+ m deep northeast-trending paleocanyon that parallels the course of the modern Salt River along the southern periphery of the Sierra Ancha (Faulds, 1986a; Peirce, 1982). These two suites merge in sections farther to the northeast (Fig. 8). A third source stream is required for the extensive Rim gravel outcrops in the northwestern part of the study area near Young Road and Chediski Ridge (Fig. 1). These outcrops contain Hells Gate Rhyolite clasts derived from a unique source area several tens of kilometers to the west (Conway and Wrucke, 1986). The third trunk stream must have traversed the northern flank of the Sierra Ancha and originated at least as far west as the northern Tonto basin.

All outcrops exhibit a similar systematic upsection variation in the relative proportions of different gravel types (Fig. 8). Precambrian and volcanic porphyry lithologies increase in abundance upsection relative to Paleozoic lithologies which comprise 23 to 90% of the basal conglomerate and 17 to 62% of the upsection conglomerates. Precambrian

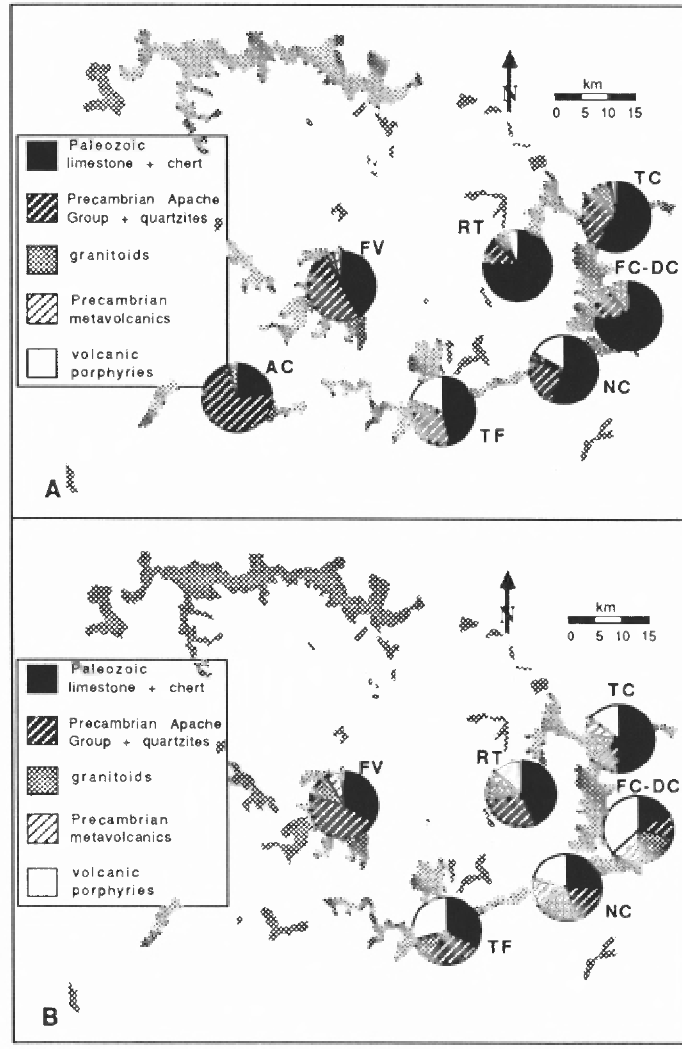

FIGURE 8. Distribution of clast lithologies: A, clast lithologies in the basal conglomerate are dominantly Paleozoic. The greater percentage of Precambrian quartzite lithologies toward the west and volcanic porphyry lithologies toward the southwest suggests two separate source streams entering the basin. B, upsection clast lithologies. The increase in Precambrian basement and volcanic porphyry clasts at the expense of Paleozoic clasts indicates progressive unroofing of basement during deposition.

lithologies constitute 5 to 38% of the basal conglomerate and 23 to 57% of upsection conglomerates. The average percentage of Precambrian metavolcanics and granitoids increases upsection from 6 to 20%. This indicates that crystalline basement was partly exhumed in the source area prior to initial deposition (Conway and Wrucke, 1986) and was progressively unroofed during the period of deposition.

The upsection increase in volcanic porphyry gravels is problematic. If these clasts are all Paleocene it is not likely that an upsection increase is due to contemporaneous eruption because radiometric ages are too old for the probable middle Eocene age of deposition (see below). There is no known middle Eocene volcanic complex southwest of the vicinity that could have been a contemporaneous source. If these rocks were largely intrusive, a simple unroofing model could explain their greater upsection abundance. If these rocks were largely extrusive, their greater upsection abundance could reflect headward erosion of source streams into previously untapped porphyry terrain. None of these hypotheses can be excluded, however, until the lower age limit for the Mogollon Rim formation is better constrained and the age and mode of emplacement for the various types of source-area porphyries is better understood.

CORRELATION OF OUTCROPS ACROSS THE TRANSITION ZONE

Stratigraphic data and field observations support correlation of the Mogollon Rim formation along the length of the "boomerang" transect from Trout Creek southwestward to Tick Flat. The data also support correlation of the Mogollon Rim formation with the Rim gravels northwestward along the Mogollon Rim from Trout Creek to the Chediski Ridge–Young Road area (Fig. 1). The Flying V–Blue House Mountain sequence is centrally located in the study area between the "boomerang" transect and Rim gravel outcrops. This sequence occupies the same structural and stratigraphic position as the Mogollon Rim formation between Firebox Creek and Tick Flat. In addition, formation thickness, facies relations, lithology, paleocurrents, maximum clast sizes and maturity of gravels are very similar between these two outcrops. A well-indurated pedogenic carbonate unit up to 8 m thick locally caps the Tertiary clastic sequence in both areas. Provenance differs between the two localities, but this may be attributable to source area variation in nearby highlands. The many similarities and the absence of significant differences between the Flying V sequence and Mogollon Rim formation along the "boomerang" transect support correlation of these sequences.

To further test correlation of the Flying V–Blue House Mountain sequence with the Mogollon Rim formation, two transects were conducted from the Flying V area northward along gravel-capped ridges to higher altitudes on the Mogollon Rim. One transect was conducted from Flying V through Blue House Mountain and Spotted Mountain to Chediski Ridge. A second was conducted from Flying V northward through Cibeque Peak, along Limestone Ridge to Juniper Ridge (Fig. 1). On these transects, discontinuous outcrops of Tertiary clastics overlie increasingly younger Paleozoic strata at progressively higher altitudes toward the Mogollon Rim. Poor preservation and exposure of outcrops precludes a comparison of facies relations, but gravel maturity, provenance, paleocurrents (Fig. 6) and maximum clast size (Fig. 7) are remarkably similar along these transects. Sedimentologic features documenting the existence of more than one deposystem are not present. Variation of outcrop altitude between the two areas is more likely attributable to either large-scale paleotopography on the underlying erosion surface or subtly expressed, post-depositional structural lowering.

COMPARISON WITH THE BACA FORMATION AND EAGAR FORMATION

Stratigraphic position, transport direction, provenance, lithology and inferred continuity of paleoenvironments have been used to correlate the Mogollon Rim formation (formerly "Mogollon Rim gravels") with the Eagar Formation and Baca Formation of eastern Arizona and west-central New Mexico (Cather and Johnson, 1984; Johnson, 1978). This study supports depositional continuity of these formations but provides a more detailed and considerably different description of the depositional system in this region. The Mogollon Rim formation is not wholly conglomeratic as depicted by Cather and Johnson (1984) in their reconnaissance study of the area. Framework-supported gravels comprise between 40% and 95% of the proximal Flying V and Tick Flat sections but only 4% to 18% of the more distal sections between Nash Canyon and Trout Creek. The sequence is much thicker than previously described, and arkosic sandstone and siltstone are the dominant constituents of all but the Tick Flat section. Using the terminology and criteria (percent gravel) of Cather and Johnson (1984), the Trout Creek–Deep Creek–Round Top region shows an upsection evolution from proximal fan through distal fan and, finally, middle fan facies. The term "fan" is not used here because paleocurrents do not suggest a distributary system of streams resulting in fan morphology. The Eagar and Baca formations exhibit an overall fining-upward trend (Cather and Johnson, 1984). With regard to size of gravels, abundance of gravels and mudstone percentage, the Mogollon Rim formation also generally fines upward but coarsens again in the upper member.

AGE CONSTRAINTS

The Mogollon Rim formation is Eocene in age, but the initiation of deposition is poorly constrained. K-Ar ages of 54.6 ± 1.2 and 56.8 ± 1.2 my on volcanic clasts (Peirce et al., 1979) sampled 40 m above the base of the Round Top section limits the Mogollon Rim formation to no older than early Eocene. The correlative Baca Formation attains its greatest outcrop thickness of 580 m about 155 km east of Trout Creek in the Datil Mountains area (Cather and Johnson, 1984). A Uintan mammal discovered 40 m above the base of the Baca Formation in this area (S. G. Lucas, oral commun., 1989) indicates that deposition in west-central New Mexico began by middle Eocene time.

The minimum age of deposition is better constrained. A biotite air-fall tuff interbedded in the Mogollon Rim formation 337 m above the base of the Trout Creek section yielded a K-Ar date of 37.6 ± 0.8 my. A similar biotite air-fall tuff interbedded in the upper Deep Creek section was dated at 37.5 ± 0.8 my. The two tuffs are 38 and 67 m, respectively, below the gradational contact with the overlying lower Datil Group equivalent and may record the same eruptive event. These ages are similar to the approximate 39 my age assigned to the onset of Datil Group deposition in west-central New Mexico.

The unconformity between the lower Datil Group equivalent and overlying volcanic conglomerate sequence at Trout Creek (Fig. 3) represents most of Oligocene time. A 24.8 ± 0.5 my age was obtained on a mafic flow interbedded near the base of the Trout Creek volcanic conglomerate (Table 1). The thicker and very similar northwest-flowing fluvial sequence at Nash Canyon fills a deep paleovalley cut in the Mogollon Rim formation. The outcrop at Trout Creek lithologically correlates with the upper part of the Nash Canyon sequence, indicating that the base of the latter is older than 24.8 my. A K-Ar age of 28.0 ± 0.6 my on rhyolite which intrudes the Mogollon Rim formation at Round Top (Peirce et al., 1979) indicates that volcanics were erupted locally during the late Oligocene.

RELATIONSHIPS TO STRUCTURAL FEATURES

Evidence for contemporaneous faulting

A series of northwest-trending, high-angle faults, here called the Fort Apache fault zone, crosses the central part of the study area (Fig. 4). Some of these faults dip to the southwest, but others are indeterminate. They die out to the northwest and do not offset units along the Mogollon Rim (Moore and Peirce, 1967). Most of these faults downdrop the Mogollon Rim formation along the "boomerang" transect in a step-like manner to the southwest. An earlier and opposite sense of displacement on some faults is evident in those areas where the basal conglomerate overlies distinctly older Paleozoic or Precambrian strata on the southwestern side of a given fault (Fig. 5). This relationship clearly documents an earlier period of movement during which underlying strata on the upthrown southwest block were more deeply beveled prior to deposition of the basal conglomerate.

Several observations indicate that the earlier uplift and beveling episode was partly contemporaneous with deposition of the basal conglomerate. These features are most clearly expressed at Firebox Creek fault where: (1) on the southwest side, an additional 27 m of the Permian Supai Formation was eroded prior to deposition of the Mogollon Rim formation; (2) the basal conglomerate member abruptly thickens on the northeast side; (3) chaotic facies on the northeast side reflect locally unstable topography; and (4) cobble lithologies and clast size at the basal contact lack the expected stratigraphic continuity across the fault (Fig. 9).

A characteristic feature of the basal conglomerate member is that both maximum clast size and relative abundance of Paleozoic clasts systematically decrease upsection. Oddly, the maximum clast size measurement at the basal contact on the southwestern side (paleoupstream) of the Firebox Creek fault is distinctly smaller than on the northeastern side. Basal measurements made on the southwestern side, however, closely match measurements taken from the upper part of the doubly thickened section on the northeastern side. A comparison of the relative abundances of clast lithologies across the fault shows a similar relationship (Fig. 9). It seems reasonable to assume that, at any given time during deposition of the basal conglomerate, both the maximum size and the relative percentage of clast lithologies should have been consistent over this short reach of the river system. If the Mogollon Rim formation is restored to its original configuration across Firebox Creek

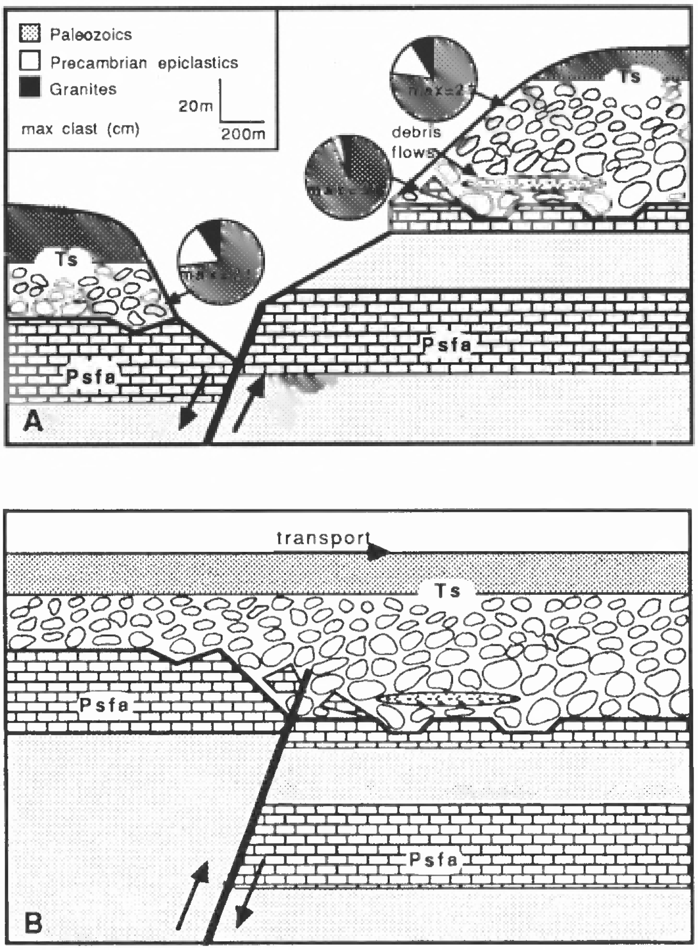

FIGURE 9. A, cross section perpendicular to the strike of Firebox Creek fault. Maximum clast size, clast compositions, and upsection facies changes in the basal conglomerate allow reconstruction B, A, of the Mogollon Rim formation (Ts) to its original stratigraphic position prior to downfaulting. Greater structural elevation of the Fort Apache Limestone (Psfa) on the southwest side of the fault indicates an earlier history of southwest-side uplift. Thickening of basal conglomerate in paleodownstream direction across the fault reflects contemporaneous uplift during deposition of the basal conglomerate member.

fault using these "clast-matching" criteria rather than the basal contact, the abrupt upsection facies change from conglomerate to fines correlates very closely (Fig. 9). Thus, the doubling in thickness of the basal conglomerate member across the fault is probably due to contemporaneous faulting and depositional onlap rather than to irregularity on the underlying erosion surface.

Other structures of the Fort Apache fault zone, here named Canyon Day fault, Seven Mile Canyon fault and Grindstone Mountain fault, display evidence for greater uplift and erosion on the southwestern block prior to deposition of the Mogollon Rim formation (Fig. 5). Where exposures are adequate, some of these faults also display evidence for contemporaneous faulting. Brushy Mountain fault could not be evaluated because the base of the Tertiary section is not exposed.

The total amount of southwest-up faulting can be quantified for a given fault by measuring the stratigraphic separation in the underlying Paleozoics after palinspastically restoring the Mogollon Rim formation. Greater accuracy is obtained by utilizing the clast-matching criteria outlined above. Although poor exposures cause some uncertainty in estimates, reconstruction across these faults indicates at least 234 m of cumulative southwest-up offset of which the final 79 m (34%) was contemporaneous with deposition. Canyon Day and Grindstone faults show negligible evidence for contemporaneous movement, whereas Seven Mile Canyon and Firebox Creek faults show 32% and 42% contemporaneous movement, respectively.

Palinspastic restoration of the Mogollon Rim formation

Deformation of the Mogollon Rim formation can be evaluated from two cross sections of the area. The first is drawn parallel to depositional dip between Tick Flat and Deep Creek (Figs. 4, 5); the second is drawn parallel to depositional strike between Chediski Ridge and Tick Flat (Figs. 4, 10).

Palinspastic restoration of the Mogollon Rim formation parallel to depositional dip is accomplished in two steps: (1) restoration of the Tertiary base across faults (Fig. 5B) and (2) restoration of crustal warps by imposing an assumed depositional slope (Fig. 5C). In the first step, the earlier phase of contemporaneous faulting is taken into account. In the second step, the underlying erosion surface is "unwarped" to form a gentle northeasterly dipping paleoslope of low relief. Low paleotopographic relief is justified by field observations and the down-dip orientation of the cross section. Depositional slopes of analogous alluvial braidplain sequences and braided river systems include: the Ogallala Formation = 0.0014 to 0.0020 m/m, North Platte River = 0.00135 m/m (Goodwin and Diffendal, 1987); River Durance = 0.0025 m/m (Doeglas, 1962); and proximal wet alluvial fans in general = 0.001 to 0.004 m/m (Galloway and Hobday, 1983). The upper surface of the Mogollon Rim formation is reconstructed using an average slope of 0.002 m/m. A value of 0.005 m/m is assigned to the basal conglomerate, which must have had a steeper slope in order to transport boulder-sized material. The convergence of these two assumed slopes toward the southwest is consistent with the present thickness of the Tick Flat section (Fig. 5C), suggesting that little erosion of the section has occurred. This palinspastic reconstruction raises the structurally lowest Tick Flat section 736 m from its present position. About 50% of the 736 m is attributed to faulting and 50% to southwestward downwarping.

The second cross section strikes southeastward along depositional strike from Chediski Ridge on the Mogollon Rim to Tick Flat (Figs. 4, 10). The first step in palinspastic reconstruction requires raising the Tick Flat section 736 m in accord with the first reconstruction (Fig. 5). This restores the base of the Tick Flat section to only 24 m below the base of the Chediski Ridge section. The second step is to determine whether the intervening lower altitude Flying V–Blue House Mountain outcrops occupy a paleovalley cut in the underlying Paleozoics or a post-depositional structural sag between Tick Flat and the Mogollon Rim.

A deep paleovalley in the Flying V area does not seem likely. It would require the Flying V sequence to have originally been over 577 m thick, three times its present thickness, in order to laterally onlap adjacent paleohighs at Chediski Ridge and Tick Flat. It would also require large boulders high in the Flying V section to correlate with coarse basal conglomerate on adjacent paleohighs. In the complete sections at Trout Creek and Deep Creek, however, total thickness does not exceed 375 m, and coarse gravel sizes occur only in the basal 50 m. Three observations suggest that the underlying erosion surface was originally at about the same relative altitude along depositional strike between Tick Flat and Chediski Ridge: (1) the ubiquitous occurrence of large boulders exclusively in the lowest 4 to 100 m of all Mogollon Rim formation measured sections, (2) the widespread distribution of this basal conglomerate across the area and (3) the consistency of maximum clast size measurements of the basal conglomerate along depositional strike (e.g., see 60 cm isopleth, Fig. 7). Local channels with depths up to several tens of meters are present, but broader scale paleotopography with relief exceeding 100 m is not discernible.

Evidence for southward downwarping of the Mogollon Rim formation is present in the Flying V outcrop. Paleocurrents in the basal conglomerate are east-northeasterly, but the basal contact gradually loses altitude to the south-southwest. Assuming an original east-northeast paleoslope of 0.005 m/m, the average post-depositional south-southwestward tilting of the Flying V outcrop is about 0.9°. The average angle of tilt needed to structurally lower the Blue House Mountain sequence from the altitude of Chediski Ridge is 1.1° to the south-southeast (Fig. 10). The similarity of these two calculations supports the hypothesis of southward downwarping of the Mogollon Rim formation in this part of the Transition Zone.

With present knowledge, the underlying erosion surface in this area

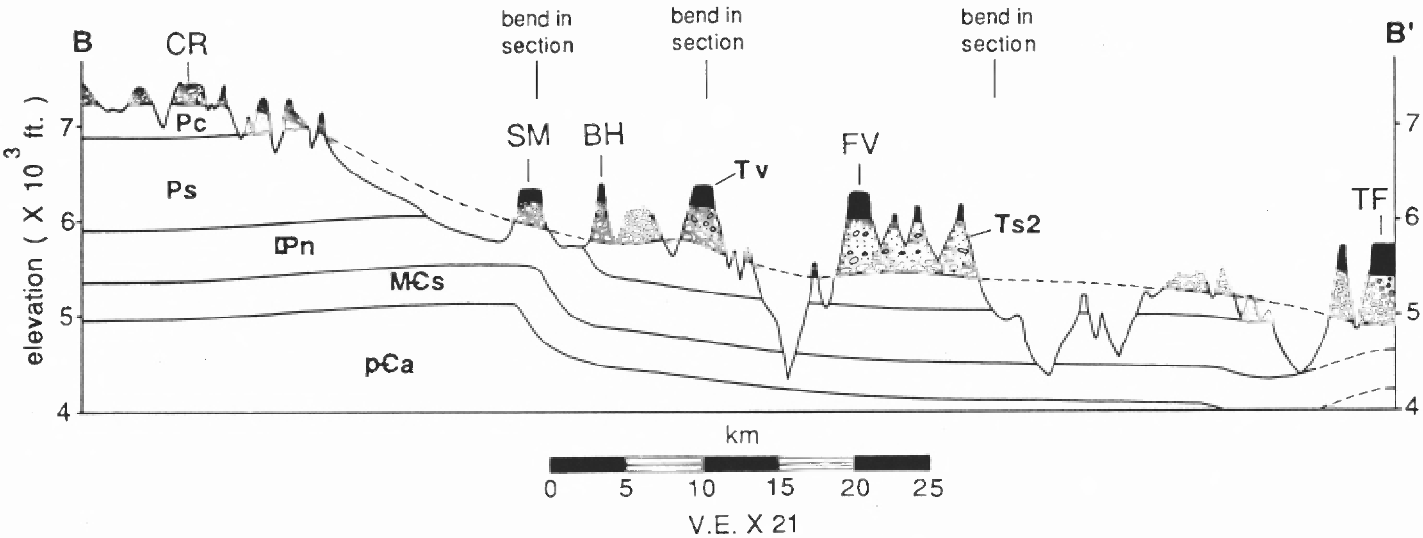

FIGURE 10. Cross section B–B′ is parallel to depositional strike and extends from Chediski Ridge on the Mogollon Rim southeastward to Tick Flat (Fig. 5). The southward-slope of the Mogollon Rim formation is primarily due to post-depositional downwarping. p€a—Upper Proterozoic Apache Group and Troy Quartzite, M€s—Mississippian through Cambrian sedimentary rocks, IPn—Pennsylvanian Naco Formation, Ps—Permian Supai Formation, Pc—Permian Coconino Sandstone, other abbreviations as in Figures 1 and 5.

appears to have been regionally flat along depositional strike. The second step to palinspastically restore the Mogollon Rim formation in Figure 10 is to simply raise the basal contact to an equal altitude along the length of the cross section. Because no faults cross this transect and paleotopography appears minor, the base of the Mogollon Rim formation in Figure 10 reflects the amount of post-Eocene southward downwarping of the Transition Zone. About half of this structural relief is accommodated by faulting between Deep Creek and Tick Flat (Fig. 5). This requires faults of the Fort Apache fault zone to increase in displacement along strike to the southeast. The similarity in structural relief between Tick Flat and both Chediski Ridge and Deep Creek indicates that structural relief parallel to the southern edge of the Colorado Plateau between Deep Creek and Chediski Ridge has not changed discernibly since the close of Eocene time.

Laramide folds and regional northeast tilt

Large monoclinal folds deform the Paleozoic sequence east of Spotted Mountain (Moore and Peirce, 1967; Finnell, 1966a) and at Forks Butte (Fig. 4) near the confluence of the Black and White rivers. In these two localities, east-facing, north and northwest-striking monoclines with about 240 m and 360 m of structural relief, respectively, were beveled to a surface of moderately low relief prior to deposition of the Mogollon Rim formation. Minor thrust faults and smaller open folds of similar style deform the Paleozoics in highway roadcuts south of the Flying V section. The style of deformation is similar to Laramide folds on the Colorado Plateau north of the study area (Kelley, 1955).

A regional north-northeastward tilt is superimposed on pre-Tertiary rocks of the Colorado Plateau and Transition Zone. It is, in part, inherited from an epeirogenic event which tilted and beveled the Phanerozoic sequence prior to southwestward advance of the Late Cretaceous seaway across northeastern Arizona (Harshbarger et al., 1957). Following retreat of the seaway, Late Cretaceous strata on the Mogollon Rim were tilted northeastward and beveled prior to deposition of the early Tertiary(?) red beds and overlying Mogollon Rim formation (Peirce et al., 1979).

DISCUSSION

The Mogollon Rim formation was deposited on an Eocene erosion surface of low to moderate relief that bevels large Laramide-style folds and increasingly older Cretaceous through Precambrian rocks to the south and west. The fluvial system that beveled the erosion surface must have been significantly different from the fluvial system responsible for Mogollon Rim formation deposition. Regional planation was presumably accomplished by laterally migrating streams which were neither incising canyons nor significantly aggrading their river beds through geologic time. This scenario suggests an extended period of equilibrium during which the surface drainage system was not subjected to significant climatic or tectonic change (Gresens, 1981). The early Tertiary(?) fluvial red-bed sequence underlying the Mogollon Rim formation at Round Top may be the only tangible evidence for these landscape-leveling streams. Pebbles of Precambrian basement in this mudstone-dominated sequence indicate that the Mogollon highland had already undergone significant uplift and incision. The red-bed sequence may therefore represent a period of pedimentation following Laramide deformation. A similar low relief Eocene pediment, observed in many parts of the western Cordillera, is interpreted to signify waning Laramide tectonism (Epis and Chapin, 1975; Gresans, 1981; Potochnik and Damon, 1986).

The Mogollon Rim formation and its correlatives represent a significant pulse of fluvio-lacustrine sedimentation in a very broad and shallow basin that evidently had no pre-Eocene history of Laramide subsidence. Aggradation of coarse clastics on the underlying erosion surface signals a fundamental change in climatic or tectonic regime. Although contemporaneous uplift played an important role, climate change could also have influenced deposition. A pronounced global cooling (Stanley, 1986) and drying trend occurred toward the end of the Eocene (Frakes and Kemp, 1973). For the southern Rocky Mountains, the change from a humid subtropical climate in the early to middle Eocene to a seasonably dry subtropical climate during the later Eocene was accompanied by the onset of seasonal drought (Meyer, 1983). Pervasive pedogenic caliche horizons in the proximal outcrops probably formed in a semiarid to arid climate (Cather and Johnson, 1984; Machette, 1985). Mammalian fauna in the correlative Baca Formation indicate a savanna-type climate (Schiebout and Schrodt, 1981). Despite these indications of dry climate, sedimentary structures and sediment maturity in the Mogollon Rim formation document deposition by turbulent stream flow. The absence of debris flows and sieve deposits typical of arid region alluvial fans (Bull, 1972) indicates that precipitation must have been abundant in the source region. If the highland source area was sufficiently humid, large perennial streams could be maintained despite semiarid conditions on the braidplain. Significant volumes of deeply weathered regolith stored in the Mogollon highlands during the more humid early to middle Eocene conceivably would have been vulnerable to denudation following widespread climate-induced vegetation loss during later Eocene time.

Although climate change may have increased sediment supply, several observations point toward active tectonism as the primary cause of deposition. Southwest-side uplift on faults of the Fort Apache fault zone was contemporaneous with deposition of the basal conglomerate. The Canyon Creek fault (Fig. 1), eastern boundary of the Laramide Apache uplift (Davis et al., 1982), shows evidence for 1400 to 1750 m of west-side-up displacement prior to Oligocene time (Finnell, 1962; Faulds, 1986b). Abundant quartzites and sparse granitic clasts in the basal conglomerate indicate that large areas of Precambrian Apache Group and Mazatzal Group, but relatively small tracts of crystalline basement had been exhumed at the onset of deposition. Progressively deeper erosion of the source area is reflected in the increasing upsection abundance of Precambrian granitic and metavolcanic clasts and by the great volume of arkosic sand in the middle and upper members. The concurrent upsection increase in volcanic porphyry clasts may reflect active headward erosion of source streams into previously untapped Laramide porphyry terrain during active uplift of the region.

Two observations indicate that regional northeast tilting may have accompanied faulting and the onset of deposition: (1) the low variance in northeast paleocurrent vectors is an indication that rivers were not significantly deflected or ponded by contemporaneous faulting along northwest trends; and (2) the Mogollon Rim formation coarse basal conglomerate overlying early Tertiary(?) red-bed mudstone reflects a profound increase in stream competence and thus paleoslope. Regional tilting and beveling, like the earlier episode of faulting, appears to have begun before aggradation of the basal conglomerate because underlying fluvial red beds and preexisting regolith were apparently skimmed from most of the study area before deposition began. In addition, about two-thirds of the earlier, fault-produced topographic relief on the Fort Apache fault zone was apparently beveled before the beginning of deposition.

Despite the influx of voluminous volcaniclastic detritus at the end of the Eocene, the Mogollon highlands continued to supply basement-derived detritus for the northeastward-flowing river system. The northwestward-flowing late Oligocene volcanic conglomerate which unconformably overlies this sequence does not contain clasts typical of the Mogollon Rim formation. Although fluvial transport continued onto the Colorado Plateau, the Mogollon highland source area to the southwest must have been erosionally or structurally lowered so that by 24.8 million years ago it was no longer a sediment source for this area. Subsequent structural lowering of the Transition Zone relative to the Colorado Plateau probably disrupted the volcanic conglomerate system prior to emplacement of widespread mafic flows in the Transition Zone. These flows overlie the Mogollon Rim formation and volcanic conglomerate and appear to have originally rested in buttress unconformity against the downwarped Colorado Plateau edge (Fig. 10). Moreover, these flows are not significantly offset by the Fort Apache fault zone (Fig. 5A). One of these flows caps Blue House Mountain and yielded a K-Ar date of 21.9 ± 1.9 my (Peirce et al., 1979). From these relations, downwarping and consequent interruption of drainage onto the Colorado Plateau in this part of the Transition Zone appears to have taken place mostly between 24.8 and 21.9 my ago. This interpretation must remain tentative, however, until further work is completed. Structural differentiation south and west of the study area continued throughout the remainder of the Basin and Range extensional disturbance.

SUMMARY

The Rim gravels on the southern edge of the Colorado Plateau in east-central Arizona are erosional remnants of a fluvial braidplain sequence, here informally named the Mogollon Rim formation. This Eocene sequence ranges up to 375 m thick and once blanketed at least 7000 km^2 of the southern Colorado Plateau and Transition Zone west of the White Mountains. It was deposited on a regionally low- to moderate-relief erosion surface cut on early Tertiary(?), Cretaceous, Paleozoic and Precambrian sedimentary rocks. Laramide-style folds with several hundred meters of structural relief were beveled to low relief prior to deposition of the Mogollon Rim formation. Several northeast-flowing trunk streams contributed sediment from a highland source that extended at least as far south as the Globe-Miami district and as far west as the Tonto basin. Deposition of the basal conglomerate member began during an episode of southwest-up faulting on intrabasinal, northwest-trending, high-angle faults. Faulting appears to have been accompanied by regional northeast tilting. Following deposition of the distinctive, clast-supported basal conglomerate across the underlying erosion surface, the river system became less competent and began depositing mostly sandstone and mudstone. Rejuvenation of stream competence and a 31° northward shift in paleoslope occurred during deposition of the slightly coarser upper member. Sparse air-fall tuffs in the upper member are the earliest evidence for the voluminous tuffaceous sandstones and volcanic debris flows which eventually dominated the arkosic system during latest Eocene time. In the late Oligocene, northwest-flowing streams locally incised the Mogollon Rim formation and deposited a volcanic conglomerate sequence across the Transition Zone and onto the Colorado Plateau.

The basal conglomerate of the Mogollon Rim formation serves as a structural datum across the Transition Zone during the subsequent period of continental extension. Many of the northwest-trending reverse(?) faults active during initial deposition were later reactivated in the opposite sense. Southwestward structural lowering of the Transition Zone at least 760 m relative to the Colorado Plateau occurred by both faulting and downwarping. Lowering occurred after deposition of the 24.8 my volcanic conglomerate sequence and appears to have been mostly complete before mafic flows as old as 21.9 my were emplaced across much of the Transition Zone. Further field work and radiometric dating will more accurately constrain the interrelations of volcanism, erosion, sedimentation, and deformation on the southern edge of the Colorado Plateau during the advent of Tertiary extensional tectonism.

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