"Take note, passers-by, of the sharp erosions
eaten in my head-stone by the wind and rain -
Almost as if an intangible Nemesis or hatred
were marking scores against me,
but to destroy, and not preserve my memory."

Edgar Lee Masters
Spoon River Anthology

RECONNAISSANCE SURVEY OF NEOGENE CLASTIC SEDIMENTS IN THE SOUTHEASTERN MOGOLLON-DATIL VOLCANIC PROVINCE, NEW MEXICO

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ABSTRACT

Five Neogene basins along the eastern portion of the interior plateau of the Mogollon/Datil volcanic field were formed during the Basin and Range event, and later modified by internal faulting and arching. The lack of significant rotation in all of the blocks implies that uplift, rather than extension, was the dominant factor.

Basin fill (the Gila Conglomerate) consists of conglomerate, sandstone, siltstone, and mudstone that were deposited on extensive bajadas and in adjoining fluvial and lacustrine systems. These rocks occur in outcrops that are either predominantly 1) matrix-supported conglomerates, 2) clast-supported conglomerates, 3) mixed sandstones and conglomeritic sandstones, 4) massive siltstones and mudstones, 5) laminated sandstones and siltstones, or 6) tuffaceous sandstones. These outcrops are interpreted as scarp front, proximal bajada, distal bajada, flood basin, lacustrine, and reworked pyroclastic deposits, respectively.

Basin history shows a major period of faulting and basin development followed by a relatively long period of tectonic quiescence during which the four northern basins were overtopped and a low-gradient trunk drainage system formed. Later, deformation caused impoundment of the two northernmost basins and arching along the Continental Divide in the Mimbres/Sapillo trough.

Table of Contents

List of Figures

List of Tables

Introduction

This study focuses on Gila Conglomerate deposited as basin fill on the interior plateau of the Datil-Mogollon volcanic field. This area lies at the juncture of the Colorado Plateau, the Rio Grande rift, and the Sonoran Basin and Range.

The Gila Conglomerate in the study area has been inadequately described in the past. The purpose of this report is to further the understanding of these rocks and the circumstance of their deposition. In order to attain this goal I have attempted, in reconnaissance fashion, to interpret depositional environments, reconstruct paleodrainage patterns, and relate sedimentation to paleotectonics.

Considerable field work was necessary to accomplish this goal. Contours of remnant constructional surfaces were plotted to determine paleoslope. Paleocurrent measurements were taken from imbrication where available. Measured sections were compared to models to determine depositional environments. Selected traverses were hiked to determine field relationships.

From this information it was possible to draw conclusions concerning basin geometry, location of axial systems, and tectonic influences.

GEOLOGIC SETTING

The study area (see Figure 1) consists of a series of Neogene basins bordered by the Black Range on the east, the Pinos Altos Range to the south, and numerous volcanic peaks to the north and west including Granny Mountain, Black Mountain, O Bar O Mountain, and Pelona Mountain. This area represents a parcel of the Datil-Mogollon volcanic field which, in a gross sense, lies at the juncture of three major structures - the Colorado Plateau, the Rio Grande rift, and the Sonoran Basin and Range.

Geologic Background

Beginning about 43 Ma this structural intersection became volcanically active, generating expansive ignimbrite outflow sheets, huge calderas, resurgent domes, and towering stratovolcanoes - together producing tens of thousands of cubic kilometers of volcanic rock (Elston *et al*., 1976). All pre-existing rocks throughout the area were deeply buried by generation upon generation of igneous extrusives.

During Tertiary volcanism three overlapping volcanic suites were produced (Elston *et al*., 1976): calc-alkaline andesite to rhyolite (about 43-29 Ma), high-silica alkali rhyolite (about 32-21 Ma), and basalt and calc-alkalic basaltic andesite (about 37-0 Ma).

The first stage is best represented in the study area by the Rubio Peak Formation and the latitic and andesitic

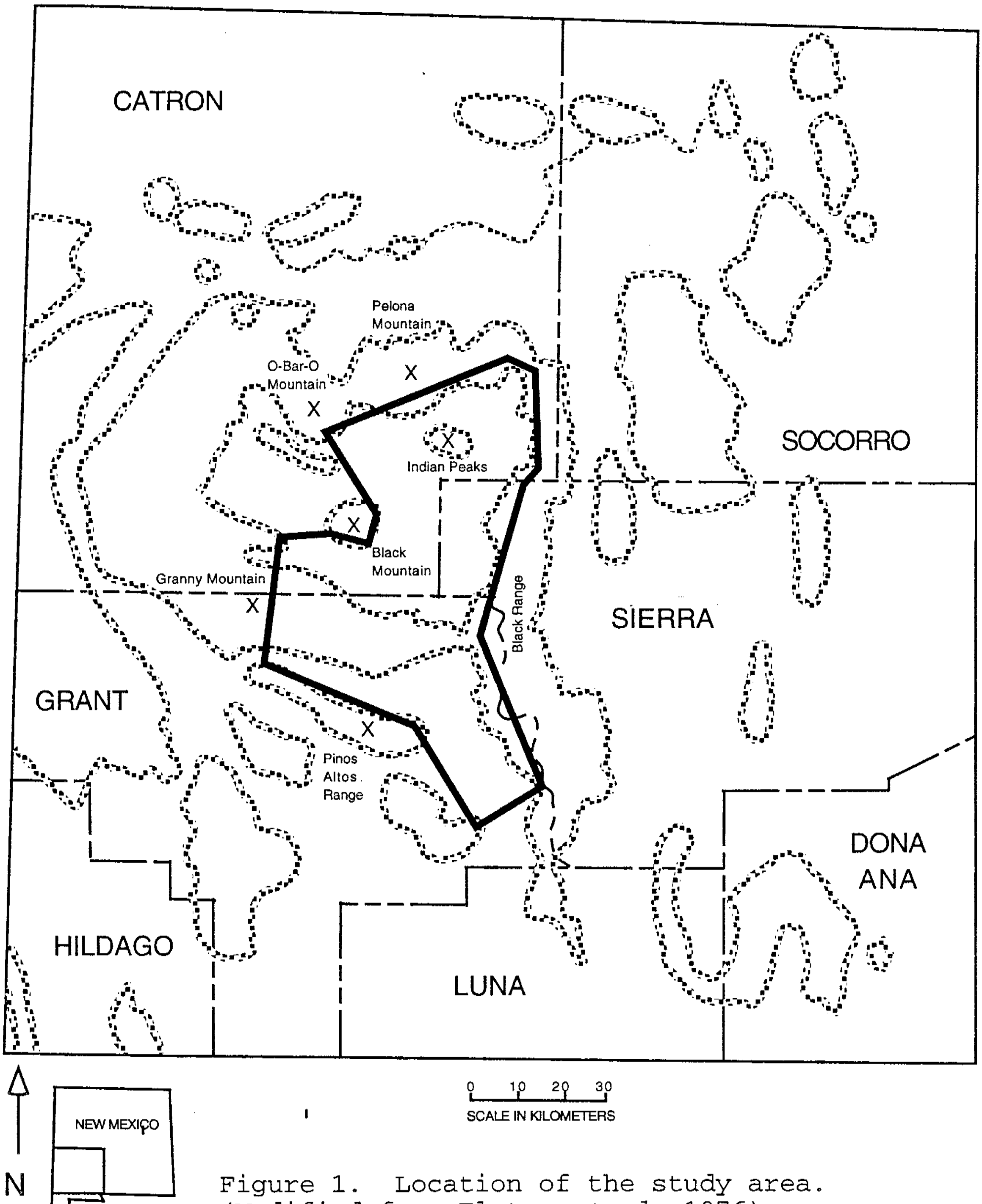


Figure 1. Location of the study area. (Modified from Elston *et al.*,1976).

lava flows of Gila Flat (Figure 2). Stage two is best represented by the Kneeling Nun Tuff, which flowed over widespread flat topography, extending from Silver City and Deming to Hillsboro and Winston. Also representative of this group are the Caballo Blanco Rhyolite Tuff, the Railroad Canyon Rhyolite Tuff, and the moonstone-bearing Bloodgood Canyon Tuff. The last major eruptions were in the early Miocene and produced the stratovolcanoes responsible for the Bear Springs Formation, Wall Lake Latite, Double Springs Andesite, and the ubiquitous Bearwallow Mountain Formation, a widespread and complex succession of dark-colored calc-alkaline rocks including basalt, basaltic andesite, andesite and latite. The Bearwallow Mountain Formation erupted about 21 Ma (Elston, 1976) and although there were several subsequent mafic eruptions they were inconsequential compared to the major outpourings of magma in the early Miocene.

This gigantic volcanic province has been described as the surface expression of a pluton by Elston *et al*. (1976). Their conclusion is supported by the presence of a regional gravity low (Wollard and Joesting, 1964) analogous to the gravity low beneath the San Juan Mountains of Colorado, which has been interpreted as the probable expression of a concealed batholith (Plouff and Pakiser, 1972).

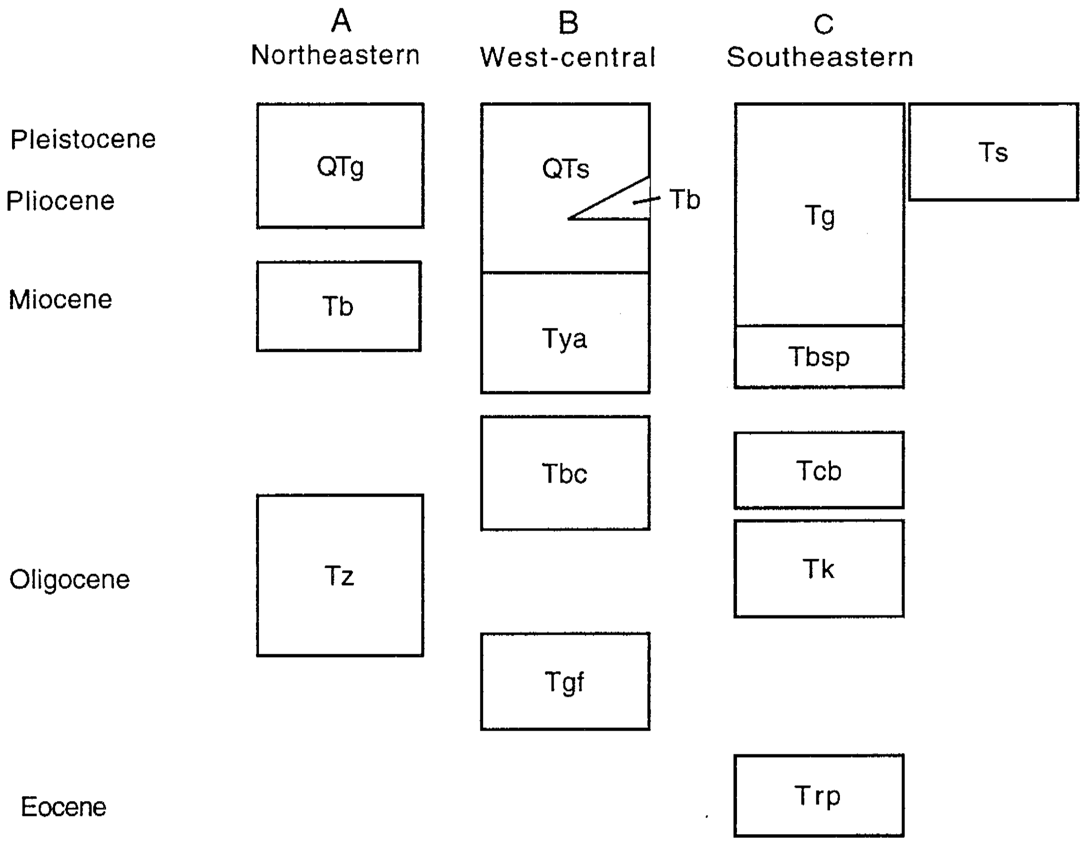


Figure 2. Generalized stratigraphic relationships across the study area.
(Column A from Elston *et al.* (1976).

QTg = Sedimentary Rocks, including the Gila Conglomerate

Tb = Younger Basaltic Andesite, primarily the Bearwallow Mountain Formation

Tz = Younger Rhyolite Ash-Flow Tuff, includes the Railroad Canyon Rhyolite Tuff

Column B from Ratte' and Gaskill (1975).

QTs = Sedimentary Rocks, mainly Gila Conglomerate

Tb = Alkaline Olivine Basalt Flows

Tya = Younger Andesitic and Latitic Lava Flows, includes the Bearwallow Mountain Formation, Wall Lake Latite, and the Double Springs Andesite.

Tbc = Bloodgood Canyon Rhyolite Tuff

Tgf = Latitic and Andesitic Lava Flows of Gila Flat

Column C from Seager *et al.* (1982)

Tg = Gila Group (outside the Rio Grande drainage)

Ts = Santa Fe Group (within the Rio Grande drainage)

Tbsp = Bear Springs Basalt

Tcb = Caballo Blanco Rhyolite Tuff

Tk = Kneeling Nun Tuff

Trp = Rubio Peak Formation)

Structural Relationships

Due to the widespread and mafic nature of the early Miocene volcanic formations, it is presumed that these were non-viscous, free-flowing lavas that filled local depressions and created a rather flat topography, broken only here and there by constructional topography at an eruptive center. This volcanic surface was subsequently modified and complicated by faulting associated with Basin and Range extension. According to Elston *et al.* (1976) the main mass of the Bearwallow Mountain Formation "...seems to have erupted while the stress field that caused Basin and Range faulting was developing." They point out that the flows were not diverted by fault blocks but that the vents were aligned along trends parallel to later faults. These faults developed synchronously with major Basin and Range events throughout southwestern North America, and they show high-angle normal slip associated with extension and collapse. The fault patterns are complex and may have been influenced by the residual effects of emptied magma chambers and thermo-tectonic collapse.

The study area lies across the eastern portion of the interior plateau of the Mogollon/Datil volcanic field. The interior plateau is defined by the Mogollon uplift to the south and west, the Black Range uplift to the east, and a series of ancient volcanos that border the downdropped Reserve graben and the Plains of San Agustin to the north.

The interior plateau forms a quasi-symmetrical dish-shaped highland that slopes gently upward towards its eastern and western margins. Along each margin is a major uplift, a boundary fault, and a down-dropped graben (Figure 3). On the east the Black Range uplift is bounded by an east-dipping fault zone that has dropped the outlying Winston graben with displacement up to 300 m (Coney, 1976). To the west the Mogollon uplift is bounded by a range-front fault that has dropped the outlying Glenwood/Mangas graben. The Mogollon Plateau is an asymmetrical domal horst (Coney, 1976) with relief greater to the west than the east. The boundary fault of the Glenwood/Mangas graben has juxtaposed Neogene sedimentary rocks against the oldest rocks of the Tertiary volcanic sequence. The fault plane dips 60 degrees toward the west (Coney, 1976). Estimates of displacement range from 400 m (Ferguson, 1927), 1500 m (Coney, 1976), and up to 1800 m (Leopoldt, 1981). It seems that displacement was much greater along the western boundary fault zone of the Mogollon uplift than along the eastern boundary fault zone. Thus, the interior plateau represents a structural highstand whose flanks have collapsed to the east, the west and, to some degree, to the south and north as well. This is perhaps due to the buoyancy of the pluton.

Sometime after the eruption of the Bearwallow Mountain Formation, movement along plateau-margin fault zones tilted the interior plateau down to the east or southeast (Coney,

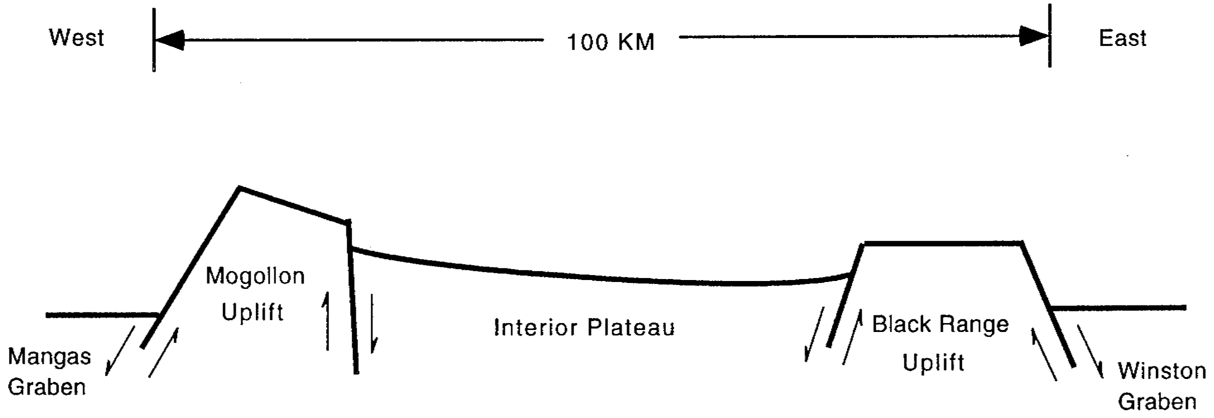


Figure 3. Generalized cross-section of southeastern Mogollon/Datil volcanic field

1976). Correspondingly, the central region collapsed along the western flank of the Black Range uplift. Faulting within the interior plateau, especially along the collapsed southern and eastern margins, formed downdropped basins in which deposits of alluvial fans, bajadas, braided stream systems and playas accumulated. This study focuses on these sedimentary rocks: the conglomerates, sandstones and mudstones that have inherited the name Gila Conglomerate, a term coined by Gilbert in 1875.

THE GILA CONGLOMERATE

Gilbert (1875), while working for the Wheeler Survey described four basins straddling the Arizona-New Mexico territorial line along the upper drainage of the Gila River. He applied the name Gila Conglomerate to the sedimentary fill in these basins. Since then usage has expanded westward, southward, and eastward until the meaning has become indistinct. Heindl (1958, 1962) proposed that the term be abandoned. In 1965, an arbitrary boundary delineating "Gila" deposits from the contemporaneous "Santa Fe" deposits was proposed by Dane and Bachman, but their distinction was based upon modern drainage, which may not reflect drainage during Gila deposition. Leopoldt (1981) described the term as a "formational wastebasket." In a figurative sense the term now resides in the niche occupied by the crazy grandfather. So what happened?

Development of Gila Nomenclature

Gilbert originally described four basins on tributaries of the upper Gila River - along the drainages of the Bonito Creek, Prieto Creek, the San Francisco River, and Gilita Creek (Figure 4). He used the term Gila Conglomerate to describe:

> A system of valley beds, of which conglomerate is the characteristic member, are exhibited in sections along the gorges of the upper Gila and its tributaries. The bowlders (sic) of the conglomerate are of local origin, and

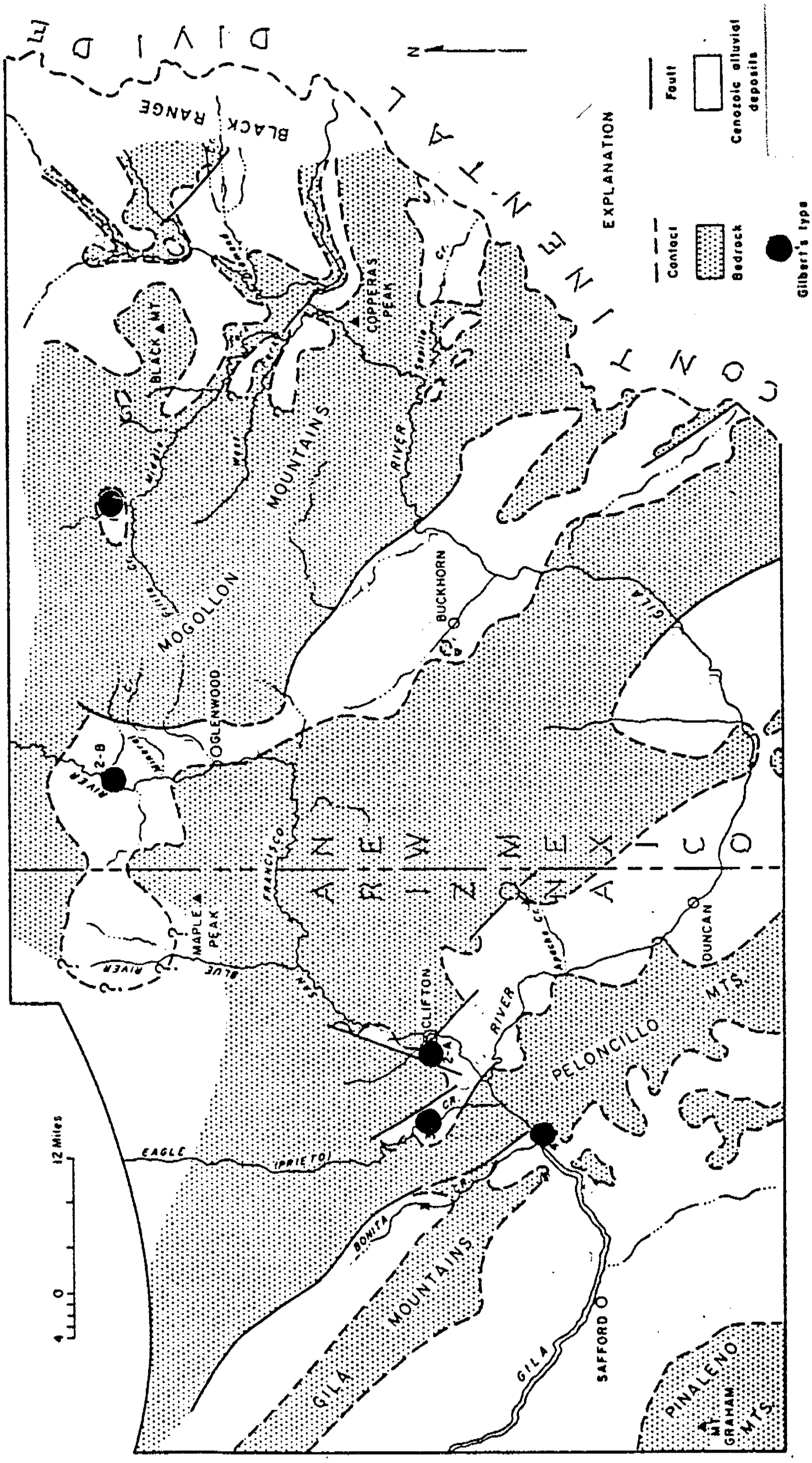


Figure 4. Map showing where Gilbert (1875) defined the Gila Conglomerate. (Modified from Heindl, 1962)

> their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand, and trass, and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points, by Mr. Howell and myself, that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than one hundred miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend eighty miles; on the Prieto, ten; and on the Bonito, fifteen. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels that occupy the troughs, and floor the desert plains. Below the Bonito it merges insensibly with the detritus of the Pueblo Viejo Desert. It is indeed one of the 'Quaternary gravels' of the desert interior, and is distinguished from its family only by the fact that the water courses which cross it are sinking themselves into it and destroying it, instead of adding to its depth.

Gilbert probably had a different concept of the Quaternary than we do today, but it is difficult to understand assigning to the "Quaternary gravels" 1,500 feet of sediments that have been deposited, indurated and subsequently downcut into deep canyons. Also, within the modern usage, his criterion for separating the Gila Conglomerate from other Quaternary gravels is unworkable. The author has observed streams downcutting banks fifteen feet or more and, although the walls of the canyon are composed of indurated conglomerate, the sediments that are being cut into on the valley floor are clearly modern. Should these "bowlders", sand, mud, and soil be called Gila

Conglomerate because they are being incised? Also, by including interbedded trass (an antiquated word for light-colored tuff) and basalts, which Gilbert says can predominate over the conglomerate, he has planted the seeds of a separate ambiguity. Several of the older volcanic units contain interbedded conglomerates, which are not related to the sedimentary regime which filled the basins. And what does he mean by "merges insensibly"?

Since Gilbert's pioneering work usage of the term Gila Conglomerate has been expanded westward, southward, and eastward. Ransome, in his 1903 study of the Globe Copper District of Arizona, took the name down the Gila River. He reiterated the locally derived nature of the valley deposits and suggested that they originally accumulated in lowlands separated by mountain ridges and "... never formed a continuous deposit over the whole region." He speculated as to the possible occurrences of pluvial lacustrine sediments within the basins. Ransome did not quibble with Gilbert's opinion of the age of the deposits, saying that "... there is no good reason for questioning this conclusion." He did point out that the Gila Conglomerate is distinctly older than present stream deposits and assigned it to the early Pleistocene.

Lindgren, in 1905, invoked the name Gila Conglomerate in the Clifton-Morenci District of Arizona. When it came to the age of the sediments he used negative reasoning to deal with the issue, stating, "No fossils have been found in the formation. Mr. Gilbert, followed by Mr. Ransome, assigns an early Quaternary age to it, and no evidence from this region conflicts with this conclusion."

A series of USGS Water Supply Papers (Meinzer, 1913; Schwennesen, 1917, 1918, 1919) carried the name to the Sulphur and San Simon valleys in Arizona and to southern Grant County, New Mexico, while further entrenching the term near Globe, Arizona. Paige used the term in a 1916 folio of the Silver City, New Mexico area. Schrader, in a 1915 USGS bulletin, said that sediments in southernmost Arizona near Nogales probably include a representative of the Gila Conglomerate of Gilbert. He pointed out that currently bajadas are aggrading near the higher mountains while degrading farther away, and that basins simultaneously may maintain constructional and destructional processes, thus confounding Gilbert's criterion. Nonetheless, he assigned the sediments in this area to the Quaternary, yet he did make a distinction between older detrital deposits and younger alluvium.

Ransome (1919) included gypsiferous silt in the Gila Conglomerate, and stated that the deposit was "fluviolacustrine." Once again he accepted Gilbert's Quaternary age, stating, "The present investigation has brought out no evidence requiring a revision of this supposition, unless the great thickness and deformation of the beds southwest of Gila River are considered incompatible with assignment to the youngest of geologic periods."

Bryan (1926) examined deformed valley fill in the San Pedro Valley of Arizona and called it Gila Conglomerate. He included in the unit fine-grained deposits such as red clays, soft white limestone, yellow sandy clays, diatomaceous earth, and gypsum. He, along with Gidley (1926), cited vertebrate fossils of a late Pliocene fauna near the top of the formation, and suggested that deposition was completed at this time, with subsequent uplift and deformation. Ferguson (1927) briefly mentioned Gila Conglomerate near Mogollon.

Knechtel (1936, 1938) studied sediments in the same area covered by Schwennesen's (1917) Water Supply Paper - the linear trough formed by the Gila and San Simon valleys (Safford basin). Knechtel concluded that lake beds dominate the valley trough. His lacustrine depositional interpretations were based upon the presence of diatom floras, limestone beds containing freshwater molluscan fossils, extensive layers of tuff presumed to be lain down in quiet water, and the predominance of clay beds. Schwennesen did not include lake sediments within the Gila Conglomerate, rather he conceived of them draping over the older conglomerate. Knechtel refuted Schwennesen's cross-sectional model, citing bore hole data and the laterally interfingering nature of the sediments. He proposed a new model, in which the lake beds are time equivalent and laterally continuous with the coarser beds on the mountain flanks.

Knechtel (1936) then invoked Gilbert's original statement:

> Beginning at the mouth of the Bonita, *below which point their distinctive characters are lost*, [Knechtel's italics] they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita.... Below the Bonito it merges insensibly with the detritus of the Pueblo Viejo Desert.

From this Knechtel (1936) concluded that "the Gila Conglomerate as a geologic formation must include both lake beds and fanglomerates, the two phases having originated simultaneously." So, like Bryan and Ransome before him, Knechtel added lake sediments to the Gila Conglomerate, thus including such lithologically diverse units as conglomerates containing twelve-foot boulders derived from proximal debris flows on steep slopes to fine-grained limestone deposited in shallow playas. Knechtel found himself in the fundamental trap of the facies concept and chose the route of temporal continuity rather than lithologic similarity.

Knechtel (1936, 1938) also contributed new fossil data, specifically a late Pliocene vertebrate assemblage collected from numerous localities along the Gila/San Simon trough, now referred to as the Safford Basin. He correlated his observations with the findings of Bryan (1926) and Gidley (1922, 1926) in the San Pedro Valley, two basins to the southwest. Knechtel inferred that "many of the thick valley deposits that have been ascribed to the Gila Conglomerate belong in reality to a common period of deposition." But, he added this disclaimer, "However, some of the deposits along the upper Gila River and its tributaries that were included by Gilbert in the Gila Conglomerate may be Pleistocene."

Seventeen years later Schwartz (1953) expressed uncertainty as to the correlation of deposits along the northern San Pedro River with those described by Gilbert and took a cautious approach. He referred to the Gila (?) conglomerate and gave it a Pliocene (?) and Pleistocene (?) age. Gilluly (1956), working in the central San Pedro valley, basically accepted Knechtel's (1936, 1938) correlation, but mentioned the possibility of two distinct sedimentary series and noted some scattered outcrops of conglomerate that might be older than the type locality at Bonita Creek.

About this time Heindl (1952), in an article in the Arizona Geological Society guidebook for southern Arizona titled simply "The Gila Conglomerate", described the term as controversial and concluded, "It may be suggested that the use of the term 'Gila Conglomerate', through its application to several basins, to a variety of deposits (including lake beds), and to more than a single cycle of deposition, has inhibited understanding of the depositional and structural history of the basin deposits in this area."

Heindl (1952), in questioning the application of the term 'Gila Conglomerate' to several basins, stated:

> The textural similarity of the conglomerates and the common presence of lake beds in the centers of the troughs point to deposition under similar environments. Fossil evidence from the upper lakebed members shows that some of the like [sic] deposits in the several basins were contemporaneous. The question is whether textural similarity and contemporaneity of the upper members is sufficient evidences to place the deposits of several basins in a single unit. A single unit implies areal continuity, which has not been demonstrated on the surface or at depth.... In addition, the basic assumption that the development of the ranges and troughs follows a single structural pattern or was contemporaneous throughout the region has not been incontrovertibly established.

Heindl (1952) offered his interpretation of the depositional conditions in which he described a system composed of: (a) a variable width zone of fanglomerates, some locally derived, grading into (b) a transition zone which is generally abrupt, (less than 200 yards {180 m} wide), but which can exceed a mile (1.6 km), grading into (c) playa deposits with gypsum, freshwater limestone and diatomaceous beds. Other than adding the transition zone this is the same package described by Knechtel (1936). Heindl cited late Pliocene to early Pleistocene fossils found on surface exposures, as had other authors, but Heindl ventured that is was "possible that the deposition of Gila Conglomerate began before late Pliocene times."

Heindl (1952) also pointed out that within these basins are conglomerates that are more tightly cemented, that contain clasts that cannot be clearly demonstrated as locally derived, and that are structurally deformed. He noted that some authors separate the more steeply dipping conglomerate units from the Gila Conglomerate (Ross, 1925a, b; Knechtel, 1936) while other authors include angularly discordant beds with flat lying beds. Essentially, Ross and Knechtel separated the older Whitetail Conglomerate (at the base of the middle Tertiary volcanic pile) from those conglomerates that are interbedded with the volcanic pile. It is uncertain whether Gilbert intended to include these beds, but it seems that he did not (see Gilbert, 1875).

Heindl (1954) divided Cenozoic alluvial deposits along the upper Gila River drainage basin into two divisions: an upper unit that is locally derived and deposited in basins that approximate modern valleys and is discontinuous with the lower unit, which is a group of deposits that differ in having been deformed, intruded and mineralized and whose texture and composition suggest deposition in basins not now evident.

In his 1958 doctoral thesis Heindl examined the term Gila in several contexts - its current use as a regional formation, the possibility of its being restricted to a specific unit, and its use as a term with group status. He concluded that, "... in none of these ways is the use of the term Gila advisable at this time and it is recommended that its use be abandoned as rapidly as possible until the time when field data justify its definition as a group or series name." He stressed the use of smaller, more definite alluvial units and suggested a fresh approach that is "... uncomplicated by attempts to show the relationship of one alluvial unit to the whole of the Gila Conglomerate..." Whereupon Heindl offered a slew of bed names stating, "Although it is obvious that these proposals will result in a nomenclatural plethora, it is believed that this multiplicity of names will serve to clarify our knowledge of Cenozoic history in this region."

Following publication of Heindl's ideas, many workers began to distance themselves from the term Gila Conglomerate. Wargo (1959), a colleague of Heindl at the University of Arizona, sidestepped the issue, referring to "Stage Three gravels" when describing the fanglomerate, stream deposits, and lake beds within the Schoolhouse Mountain Quadrangle, although he said that "The term 'Gila Conglomerate' is probably justified in the case of Stage Three gravels." Davidson (1961) took a novel approach in his study of the Gila/San Simon valley trough, by now known as the Safford Basin. He simply termed the sediments as terrace gravel, and alluvium, deformed conglomerate or gravel, and basin fill. He only used the phrase "Gila Conglomerate" once, and that was to note that one of Gilbert's type sections lay within the area. Cooper and

Silver (1964) referred to older alluvium which they describe as "equivalent" to the Gila Conglomerate.

Heindl (with McCullough, 1961) in a USGS Water Supply Paper, stated that he had shown that "the use of the term 'Gila Conglomerate' is impractical in any detailed investigation of valley-fill deposits...." In a 1962 paper titled "Should the term 'Gila Conglomerate' be abandoned?", he suggested that units within each individual basin be given formational status and that these formations be broken down to members where possible. Then he proposed that "... as early as substantiating field mapping defines the formations in individual basins, the Gila be raised to group status...."

In a USGS Bulletin concerning the lower San Pedro Valley, Heindl (1963) raised the Gila to group status. He included "deposits derived from uplifted ranges that partly filled the depressed areas between them as a result of the most recent major structural deformation. The Gila group includes deposits in depositional or normal-fault contact with bedrock in adjacent mountains and represents a nearly continuous aggradational sequence." He excluded "(1) deposits clearly related to the most recent major cycle of degradation; (2) somewhat older deposits that are clearly younger than the highest erosional surface cut on the basin fill; and (3) highly deformed alluvial deposits, similar to those of the Cloudburst formation and the Mineta formation of Chew (1952), that are clearly related to rocks that are older than the basin fill or are in marked angular unconformity with the basin fill."

Leopoldt (1981, p. 12), in his master's thesis stated: "Heindl (1963) had raised the Gila Conglomerate to group status, without defining a solid lithostratigraphic classification. His outstanding reconnaissance reexamination of the Gila Conglomerate and all earlier work did not justify this at that time premature definition of the Gila Group. Lacking in stratigraphic detail and a definite stratigraphic classification, Heindl's work effectively added to the general confusion by including (1) a greater geographic area and (2) a wider faunal range a greater period of time [sic]. The Gila Conglomerate problem simply became the bigger Gila Group problem."

At present the usage of the Gila Group is entrenched in Arizona. While that was happening the term Gila Conglomerate was becoming widely accepted in southwestern New Mexico, due primarily to extensive reconnaissance mapping at the 1:126,720 scale by Willard (1957), Weber and Willard (1959a; 1959b), Elston (1960), Willard, Weber and Kuellmer (1961), and Willard and Stearns (1971). Weber and Willard (1959a, 1959b) mapped deposits in the contiguous Reserve and Mogollon quadrangles and included lacustrian clays and silts as well as interbedded thin rhyolite tuffs within the Gila Conglomerate. Elston (1960) included diatomite within the Gila Conglomerate and mentioned angular unconformities within the unit in the Virden area. Willard *et al.* (1961) also used the term Gila Conglomerate and included interbedded rhyolite tuffs in the Alum Mountain quadrangle.

Gillerman (1964) used the term Gila Conglomerate in western Grant County. He described consolidated to semi-consolidated conglomerates and interbedded sandstones in which, "The beds are mostly tilted, in places reposing at angles up to 65 degrees...."

As usage of the term Gila Conglomerate expanded eastward, there arose a conflict with the Santa Fe nomenclature of the Rio Grande depression. Willard (1957) referred to the "Gila Conglomerate-Santa Fe group" in the Luera Springs area. Willard (1959), in the NMGS guidebook, states, "In the field-trip area [northern Catron County] beds with these very general characteristics have been called Santa Fe in the Puertocito, Dog Springs and Magdalena area. Similar beds are extensive in Catron County south of the field-trip area and have been traced somewhat discontinuously into the area of the upper Gila River, Gilbert's type area for the Gila Conglomerate. Hence, it would appear that the term Gila Conglomerate probably should have been used in this southwestern part of New Mexico, especially outside the Rio Grande depression." In order to diffuse this squabble an arbitrary boundary delineating

"Gila" from the contemporaneous "Santa Fe" was erected by Dane and Bachman (1961, 1965). As pointed out earlier, their distinction is based upon modern drainage, which may not reflect drainage during Gila/Santa Fe time.

Indeed, in some areas this distinction is tenuous at best. Hernon *et al.* (1953) mapped sedimentary rocks along the Mimbres River and referred to them as the Mimbres Conglomerate to which they assigned a Miocene(?), Pliocene, and Pleistocene(?) age. At roughly the same time Elston (1952) and Jicha (1954) correlated conglomerate farther down the Mimbres with the Santa Fe Formation. Jones *et al.* (1967) refused to accept either the Gila Conglomerate or Santa Fe Formation along the Mimbres River, referring to these sedimentary deposits as the "semiconsolidated gravel deposits in the Mimbres River valley." Such "Mimbres" nomenclature has been abandoned and the area was mapped by Dane and Bachman (1965) as Gila Conglomerate. Yet as recently as 1989 Elston states, "The valley-fill sediments of the Mimbres Valley (and its westward continuation, the Sapillo Valley) straddle the Continental Divide. They are the connecting link between the older parts of the Gila Group to the west and the Santa Fe Group to the east."

To further muddy the already murky water, the USGS in 1966 (Cohee and West, 1966) recognized the term Gila Formation based upon Morrison's (1965) work in the Duncan and Candor Peak area. This designation has largely been ignored. Elston and Netelbeek (1965), for the 16th annual NMGS field trip, used both Gila Conglomerate and Gila Formation in their introduction to the unit, but deferred to Gila Conglomerate in the road log. Trauger (1972) continued to use the term Gila Conglomerate in Grant County. (Leopoldt, 1981, erroneously reported Elston and Netelbeek, and Trauger as preferring Gila Formation.) Ratte′ (1980, *et al.*, 1982) also continued to use the term Gila Conglomerate along the Arizona/New Mexico border, while Seager *et al.* (1982) used Gila Group along the Mimbres drainage, although they did not break out formations.

So this is basically where we stand. We have a term that was originally defined by Gilbert to describe locally derived valley beds of which conglomerate is the characteristic member. Usage was expanded by Ransome, Knechtel, and many subsequent workers to include such varied lithologies as rhyolite tuffs, gypsiferous silts and limestone. These lithologies were included because these deposits accumulated in conjunction with each other and are time-stratigraphic. Yet correlation among different basins has been inconclusive. These conundrums led Heindl to instigate a campaign that would effectively scuttle the term in Arizona. In New Mexico the term is still in common usage to describe the loosely related basins whose modern drainage empties into the Colorado River or closed basins west of the Rio Grande above Hatch, and west of the Sierra de las Uvas.

For the purpose of this study I will use the term Gila Conglomerate in this sense: locally derived, largely post-volcanic, semi-consolidated to consolidated, alluvially deposited fanglomerates, conglomeratic sandstones, and finer-grained sandstones and siltstones that are contained in the basins described herein. These deposits consist of debris weathered from volcanic rocks on adjacent highlands and swept into basins on bajadas and piedmonts which merged basinward. These rocks are characteristically poorly sorted. Strata are generally sub-horizontal and undeformed, though locally can dip as much as 25 degrees. No attempt will be made to divide this unit into distinct formations or members.

Previous Investigations in the Study Area

Previous detailed work on the valley fill within the study area has been meager. Hernon *et al.* (1953) and Jones *et al.* (1967), briefly described sediments along the Mimbres River which they referred to as the Mimbres Conglomerate, a term eventually abandoned. Heindl, in his 1958 doctoral thesis, took a cursory look at deposits along the Diamond Creek, Beaver Creek, and Gila Cliff Dwellings areas. He divided these sediments into the Dry Diamond beds, the Hunting Lodge beds, and the Montoya tuffaceous beds. But as Leopoldt (1981) pointed out, Heindl failed to clearly define his lithostratigraphic classifications, and the distinctions between these beds is cloudy. Lambert (1973) devoted three pages of his thesis to the Gila Conglomerate near San Lorenzo.

Thirty-minute quadrangle reconnaissance maps of portions of the study area were made by Willard (1957), Willard *et al.* (1961), and Willard and Stearns (1971), but these maps were almost exclusively concerned with delineating formational contacts. Ratte′ and Gaskill (1975) performed a more detailed reconnaissance of the central portion of the study area, but again the primary treatment of basin fill was restricted to delineating formational boundaries. Seager *et al.* (1982) performed a similar treatment that covers the southeastern corner of the study area.

Within the study area six quadrangles have been mapped at the 1:24,000 scale; five in the upper Beaver Creek area (Richter, 1978, 1987; Richter *et al.*, 1986a, 1986b; Lawrence and Richter, 1986) and one along the Mimbres River (Moore, 1987). Once again, these maps barely begin to address the nature of the Gila Conglomerate.

Elston and Netelbeek (1965), Elston *et al.* (1965), Clemons *et al.* (1980) and Elston (1989) menton Gila Conglomerate in road logs.

Age of the Gila Conglomerate

The oxidizing depositional environments and the generally coarse-grained nature that characterize the majority of the sedimentary rocks in the study area are not conducive to fossil preservation. There are some fine-grained deposits, but to my knowledge they have not been adequately prospected. The only published fossil evidence within the study area is by Tedford (1981), who reported oreodont remains from the western slope of the Black Range at the head of Taylor Creek that suggest a late Arikareean (early Miocene) age for the enclosing sediments.

In the outlying Glenwood/Mangas trough Leopoldt (1981) reported a fossil rhinoceros (*Teleoceras fossinger* Cope) originally dated as Miocene by Cope (1884), and redated by J. F. Lance (Heindl, 1958, p. 44) as mid-Pliocene. Leopoldt (1981) stated that Lance's interpretation "is no longer valid, because American rhinoceroses are believed to have become extinct in the early Pliocene."

In Gila Conglomerate (Gila Group) basins in Arizona, fossil evidence is predominately Pliocene (Gidley, 1922, 1926; Knechtel, 1936, 1938; Wood, 1960; Lindsay, 1978).

The period of deposition in the study area can be roughly bracketed by two volcanic events. The uppermost Bearwallow Mountain Formation intertongues with fine-grained basal Gila Conglomerate sediments at Lake Roberts. K-Ar dates are 20.6 +/- 0.5 Ma (Elston *et al.*, 1973). Near

Mimbres, an undissected constructional surface is capped with basalt dated 6.3 +/- 0.4 Ma by Elston *et al.* (1973). The basalt near Lake Roberts shows dips between ten and twenty degrees while the basalt near Mimbres is almost horizontal. This suggests that faulting and deposition in this Mimbres/Sapillo area was primarily a Miocene event. These ages are also in agreement with dates in basins adjacent to the study area. Elston *et al.* (1973) reported basal Gila Conglomerate interbedded with Bearwallow Mountain Formation basalt near Red Rock and Virden. The basalt was given a K-Ar date of 20.6 +/- 1.5 Ma. Ratte′ *et al.* (1984) reported basalt flows interbedded in the Gila Conglomerate along the San Francisco River which they dated at 5.5 Ma.

Paleoclimate

Ransome (1903) pointed to an arid climate during Gila time by arguing that depositional processes during Gila sedimentation compare favorably with modern processes. He stated that the "freshness" of the coarser clasts and their angular shape indicated that this detritus came from slopes where "mechanical disintegration strongly preponderated over rock decay - a characteristic of the region at present time."

Lindgren (1905) also argued for an arid climate on the basis of physical evidence. He stated that the Gila Conglomerate was deposited during a time in which "disintegration progressed rapidly in the mountains... from which intermittently torrential streams brought down vast masses of the crumbling rock. The climatic conditions were then probably very similar to what they are at present."

Ransome (1919), in describing the Globe area during Gila time, noted that the mountain ranges were perhaps higher and the valleys were deeper. Consequently, the stream grades were steeper and their erosive powers were greater than they are now. He allowed the possibility that the higher mountains generated greater precipitation, but held that "the general character of the deposit points to a decided preponderance of mechanical disintegration over rock decay and to an arid rather than humid climate."

Bryan (1926), without elaborating on his own reasoning, endorsed Ransome's conclusions and stated that arid conditions were "obvious". Blissenbach (1954), addressing alluvial fans in general, maintained that "the climatic conditions most favorable for the development of fans appear to range from moderately arid to semiarid."

At this time I should point out a bias in early geological thinking concerning alluvial fans. Nilsen (1982) sums it up well:

> "For many years the only modern fans studied in detail were from arid and semiarid regions. As prominent and conspicuous as these fans are, they may be characteristic only of their particular climates, whereas a large number of ancient alluvial fans may have been deposited in temperate and humid climatic conditions."

Ransome (1903) postulated that - based on angularity and "freshness" - mechanical disintegration dominated over rock decay, ergo arid climate. Freshness is a function of the rate of erosion vs. the rate of chemical weathering. On steep slopes detritus would be flushed out quickly, especially if adequate precipitation was available to move it and bury it with a succeeding deposit. Angularity, Ransome's other criterion, is a function of conditions of transportation. This would vary according to discharge and slope. These two factors are unknown, but certainly the local relief would have had to have been greater. Gila basins were typically narrow and poorly-integrated, the constituents of the Gila Conglomerate spent little time in transit and covered only short distances before being buried, and thus would be angular regardless of the climatic scheme. Considering the short transport distance, a more humid interpretation is not incompatible.

The previous arguments concern physical principles. Krynine (1937) stated that inorganic sedimentary features result from dynamic processes which may operate in several different environments and "are to be interpreted with more difficulty than the organic record..." Unfortunately, fossil evidence within the study area is restricted to fragmentary material from an early Miocene oreodont (Tedford, 1981). Any paleoecological implications, however, are difficult to assess.

Miocene fossil evidence is scant in the regions adjacent to the study area. However, Meyer (1983), in the vicinity of Socorro, analyzed fossil plants from the lower Popotosa Formation (Miocene) and concluded that the assemblage was adapted to dry climatic conditions. Any regional paleoclimatic interpretations based upon this flora are sketchy because of the confounding effects of relief and altitude. Presently, the higher elevations in the region receive not only abundant summer rains, but up to sixty inches of snow on the average, while lower elevations only 20 km away may receive less than ten inches of precipitation yearly, and the ecological communities vary drastically.

The author believes that little can be definitively concluded about paleoclimate within the study area. However, the presence of calcareous paleosols within Gila Conglomerate in the study area indicates that, for at least portions of the depositional history, the area was subject to long, dry periods.

METHODS

The objective of this field study was to attempt, in reconnaissance fashion, to interpret depositional environments, reconstruct paleodrainage patterns and to relate sedimentation to tectonics. Gila sediments deposited in the study area cover an expansive and poorly accessible area; therefore, it was necessary to devise a "hit and skit" system based upon garnering data that are significant at this scale of investigation. Outcrops were often analyzed *in toto*. This approach biases the analysis toward recognition of lateral changes, but vertical changes, though de-emphasized, were recorded when apparent. Also, certain traverses were treated with greater thoroughness, in some cases to determine how much control is optimal, or in places where the basin is more complex. This is particularly the case in the Sapillo/Mimbres area.

The initial step in this study was map analysis. Formation boundaries were compiled from the maps of Ratte′ and Gaskill (1975), Elston *et al*. (1976), and Seager *et al*. (1982). Based on field confirmation, the map by Willard *et al*. (1961) proved to be inaccurate in the southeast quarter and was disregarded. Contacts were transferred to 1:100,000 scale USGS topographic maps (Hatch, Mogollon Mountains, San Mateo Mountains, Silver City, Truth or Consequences, Tularosa Mountains) and twenty-seven pertinent 7 1/2 minute quadrangles.

Contours of geomorphic surfaces that are assumed to be paleo-constructional surfaces were mapped using vehicular reconnaissance and topographic analysis. These surfaces are broad, flat, low-slope surfaces that are only slightly modified by erosion, are concordant across the modern incised drainage, and beneath which the bedding is near parallel to the topographic surfaces. There is no evidence for a widespread erosional surface below the capping material. Due to the absence of an erosional surface under the capping gravels and the concondant nature of underlying strata, it is assumed that these surfaces roughly correspond to paleo-surfaces of maximum aggradation which were abandoned following incision (i.e., they are not pediments). In this sense these surfaces correlate to the "morphostratigraphic units" of Frye and Willman (1962). Contours of constructional surfaces give a general sense of the paleoslope of ancient piedmont surfaces. Results from this technique might be questionable in older and/or more highly deformed terranes, but in the study area the Gila beds are generally undeformed, conformable and concordant, and rarely deviate much from the horizontal.

What follows is a list of information that was recorded for various outcrops.

1) Lithofacies. Units present in the outcrop were characterized according to Miall's (1978) classification (Table 1). Facies encountered in the field were primarily

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to *Ss, Sh, Sp*	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

Table 1. Lithofacies and sedimentary structure of fluvial deposits (from Miall, 1978).

Gms, Gcs, Sh, and Fl, with a minor component of Fr and P.

2) Grain size distribution. The outcrop was estimated for volume percent of a) boulders, b) cobbles, pebbles and granules, c) sand, and d) mud. The arithmetic average of the ten largest clasts was recorded and the average size of the coarse fraction (>2 mm) was estimated. These will be referred to as maximum clast size and average clast size, respectively.

3) Imbrication. Paleoflow was determined by visual estimation. Analysis concentrated on blade- and disk-shaped pebbles and cobbles. No data were recorded unless I was confident of a clear pattern. Once again, the scale of this project precluded a detailed statistical analysis. A discussion of this method is included at the end of this section.

Also noted where conspicuous were the following.

4) Bedding style. This category includes horizontal or inclined stratification, cross-bedding, massive bedding, laminations, channels and scours.

5) Vertical sequences and cycles. Gross vertical changes in clast size and bed thickness were recorded when present.

6) Clast shape. Clasts were grossly represented as rounded or angular, and spherical or flat. In many cases the outcrop contained a mixture of clast shapes and no effort was made to determine the proportions.

7) Paleosoils, carbonate layers, and root traces.

8) Clast composition. The widespread, yet at the same time diverse nature of some of the volcanic formations provides numerous sources for similar rock types. Many of the clast populations were heterogeneous with a wide variety of clasts, but my lack of detailed knowledge of the pre-Gila volcanic stratigraphy and the scale of this project precluded detailed pebble counts. However, when the outcrop was dominated by a single clast type, or if an unusual clast type was present, this was recorded.

From the above information it was possible to determine the following.

1) Depositional environments. Lithofacies, bedding, vertical sequences and cyclicity data were compared to contemporary models.

2) Proximal-distal relationships. This is inferred from maximum clast size, average clast size, rounding, and constituent grain size distribution and compared to depositional settings.

3) Provenance and paleoslope. Imbrication and limited clast composition data were compared to proximal-distal relationships and constructional contours.

A Brief Discussion of Clast Imbrication

At this time it is appropriate to review the various opinions on pebble imbrication in continental deposits. In

1893, Becker noted that flat pebbles dip upstream and rod-shaped pebbles are found lying across the channel. Twenhofel (1932) and Fraser (1935) concurred on both points, while Johnson (1922) and Krumbein (1940, 1942) found fluvially-deposited pebbles with long axes parallel to flow and dipping upstream. In 1953, Murray and Schlee studied recent terrace gravels and concluded that long axes dipped upstream sub-parallel to streamflow. In 1954, Land and Carlson stated, "It was also noticed that the elongated cobbles were usually arranged with their longest dimension to right angles to the direction of flow..." Douglass (1962) studied the structure of sedimentary deposits from two braided rivers and concluded that the average orientation of the long axis of cobbles, pebbles and coarse sand grains is normal to the current direction with flat pebbles inclining upstream. Johansson (1963) found long axes to be both parallel to flow and at right angles to flow. He postulated that when tractive forces were dominant long axes were parallel to flow, but when gravity was dominant, such as on foresets dipping greater than 20 degrees, long axes were normal to flow. There is no equivocation that clasts dip upstream, but there is disagreement of ninety degrees with respect to the average orientation of the long axis.

In 1957, Unrug (p. 255-256) suggested that particle size is an important factor, with smaller particles less well oriented than larger particles because they have a tendency to fill void spaces. He also reported that the angle of inclination of particles decreases downstream and presumably correlates with stream gradient and size.

The 1965 Sedimentary Petrology Seminar concluded from 298 particles larger than 32 mm on two modern gravel bars that size and flatness has "little effect on orientation", which contradicts Unrug's (1957) opinion. However, their data support his conclusion that angle of imbrication decreases downstream.

Rust (1972) isolated populations of pebbles on the Donjek River and measured the upstream dips of the AB planes of discs and the azimuths of A axes of elongated pebbles. From his data he concluded that the "highest degree of preferred orientation of elongate pebbles is obtained from populations of large pebbles isolated on sand beds. Smaller size or increased concentration of the pebbles reduces the degree of preferred orientation. With flat pebbles, a stronger upstream imbrication mode is developed when pebbles are in contact."

Systematic investigation of gravel fabric began in 1932 with Richter's work on a till. Wadell (1936) worked on esker and outwash delta deposits and developed the method later modified by Krumbein and Pettijohn (1938). This method requires drawing horizontal and vertical lines on the pebble, exhuming it from the outcrop, reorienting it with the aid of a goniometer, and plotting it.

Schlee (1957) provides a good summary of early work in sedimentary fabric. In this paper he is quick to point out that Krumbein and Pettijohn's method is "tedious", "laborious", and "time consuming", requiring approximately 1 and 1/4 hours to mark 50-75 pebbles. Douglass' (1962) conclusions were based upon measurements of two samples containing 100-200 pebbles down to 2 cm in length. He points out that the "number of particles measured was relatively small, owing to lack of time." Schlee proposed using only pebbles that were rod- or disc-shaped, according to Zingg's (1935) classification. He said, "Presumably, by eliminating the more spherical pebbles which tend to come to rest with their long axes in most any direction, a clearer fabric pattern will be obtained with fewer measurements in less time." He measured rod- and disc-shaped pebbles in two modern streams and from his data he concluded that discoid pebbles become imbricated, dipping upstream, and that rod-shaped pebble's A axes (long axes) exhibited a wide arc, dipping upstream.

From the in-depth discussions contained in these papers several points become clear.

1) Orientation of the long axis is variable, perhaps due to avalanching, traction, or movement above the bed.

2) Less normal-to-current variance is introduced when readings are taken from larger (elongated) pebbles isolated

on sand beds. Less parallel-to-current variance occurs from flat pebbles in contact.

3) Disc-shaped pebbles tend to imbricate, dipping upstream.

4) Detailed statistical analysis of grain orientation on a reconnaissance project is unwieldy.

Even with the above points in mind the method is not always straightforward, but when used with caution can yield satisfactory results. Gathering paleocurrent data from imbrication has been described as an "art form" (Cather, 1992, personal communication).

LITHOSTRATIGRAPHIC UNITS, FACIES MODELS AND DEPOSITIONAL SETTINGS

The Gila Conglomerate within the study area consists of conglomerate, sandstone and mudstone. Outcrops can be characterized as either predominantly A) matrix-supported conglomerates, B) clast-supported conglomerates, C) mixed sandstones and conglomeratic sandstones, and, D) non-conglomeratic sandstones and mudstones, which in turn have three distinct manifestations.

The following descriptions of these rock packages refer to the facies classification scheme of Miall (1977, 1978; herein Table 1) and its modifications by Rust (1978). The reader is referred to Miall (1982) for a comprehensive review of this system. For the purpose of this report, lithofacies are defined as rock packages that are pervaded by a distinct facies. It should be understood that different rock types are often interbedded and can grade laterally with each other.

Matrix-supported Conglomerates

The matrix-supported conglomerate lithostratigraphic units are characterized by well-indurated rocks containing poorly sorted, angular, blocky clasts often exceeding 60 cm in maximum dimension (Figure 5). These deposits correspond with Miall's Gms facies. The matrix-supported conglomerates in the study area show a bimodal range of matrix volume.

Figure 5. Coarse, poorly sorted, matrix-supported conglomerates in Rocky Canyon. (Hammer for scale).

The matrix-poor end member shows a modicum of contact between larger (10-60 cm) clasts, though the clasts do not form a framework (Figure 6). However, these rocks are often found in association with a lesser component of true framework conglomerate, Miall's facies Gm (Figure 7). Lithostratigraphic units dominated by the matrix-poor end member correspond to the facies assemblage GI of Rust (1978), which he interprets as alluvial fan deposits. Characteristics of these outcrops satisfy at least seven of the ten criteria proposed by Bull (1972) for identifying ancient alluvial fans and fifteen of the twenty-three criteria proposed by Nilsen (1982), including poor sorting, rapid particle size decrease downfan, a limited suite of sedimentary structures, oxidization, and a dearth of organic and fossil material. These sediments approximate the 'Trollheim Type' depositional style of Miall (1978, after Hooke 1967). Blair and McPherson (1993) question the accuracy of Hooke's model, particularly the continuum of proximal-fan debris flows with distal-fan fluvial facies. They state that "[the] facies model with debris flows in the proximal area and waterlain deposits distally is not characteristic of the fan on which it is based", and that this facies pattern has yet to be documented on any modern fan. However, in the case of the study area, these types of ancient deposits are intimately related.

Matrix-poor conglomerates are located exclusively along

Figure 6. Coarse, poorly sorted, matrix-supported conglomerate in Rocky Canyon. (Dan Mancano for scale).

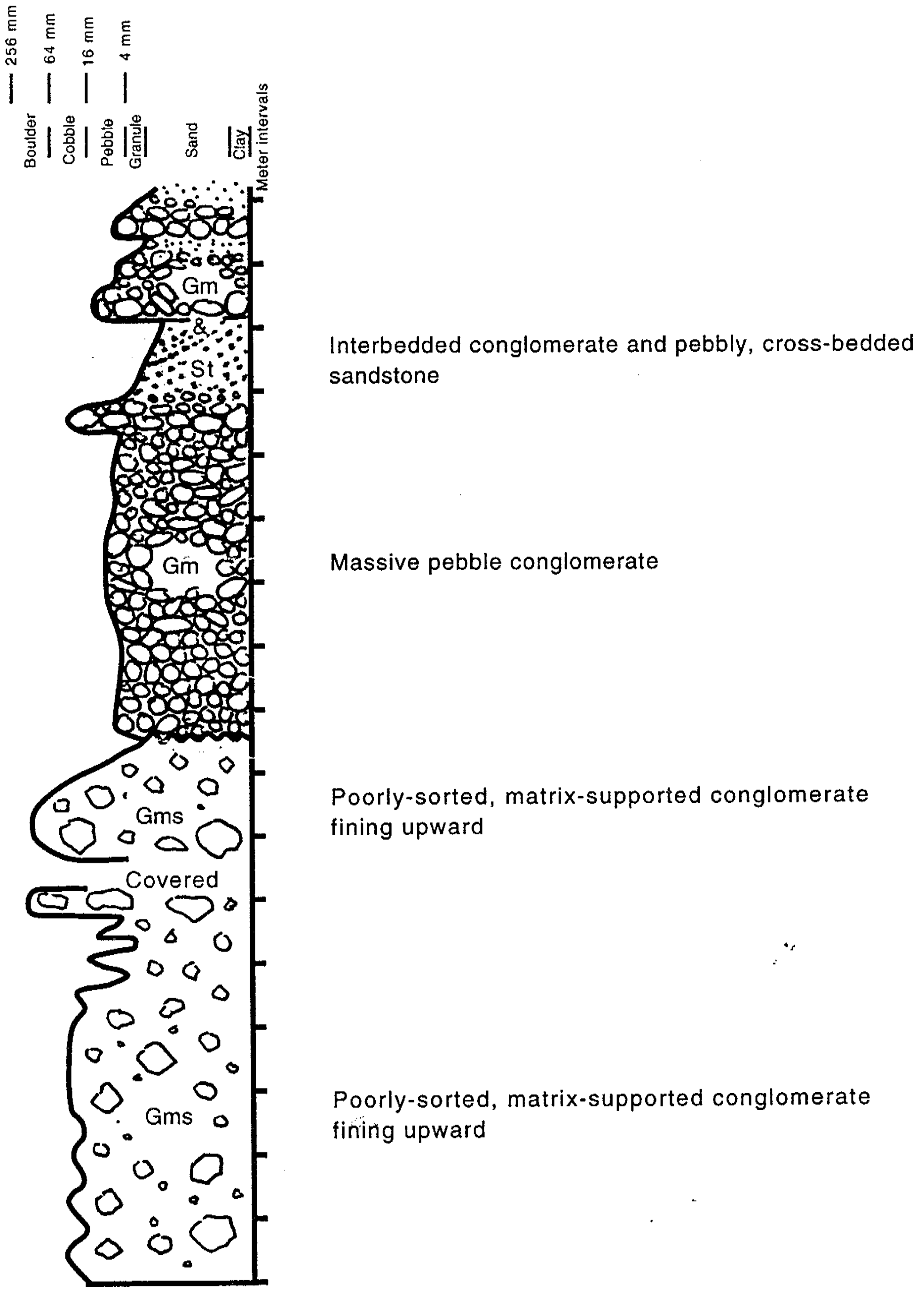


Figure 7. Measured section in which the lower portion is dominated by well-indurated, matrix-supported conglomerates containing poorly-sorted, angular clasts. Outcrop is interpreted as scarp front deposits. (Section is located along the north of the Railroad Canyon basin, NW1/4, Sec 16, T9S, R13W).

fault-bounded margins of basins within the study area. These deposits are interpreted as having been largely formed by mass movement or sediment gravity flow on an extreme slope, such as a scarp front and are herein informally referred to as the scarp front facies.

The matrix-rich end member contains smaller (5-10 cm) 'floating' clasts. These rocks are commonly found at basal contacts which have been exposed along canyon floors. Implications of this occurrence are not clear. Perhaps this texture is due to availability of sediments (Cather, personal communication, 1993).

Clast-supported Conglomerates

Clast-supported conglomerate lithofacies units are dominated by crudely stratified, clast-supported, well-imbricated cobble and boulder conglomerate that is often situated in well developed erosional scours 5 to 50 m wide and located in close proximity to fault-bounded margins of basins. Figure 8 illustrates this type of deposit. These beds compare to Miall's Gm facies. Horizontally bedded sandstones (facies Sh) are commonly present in the unit, but to a lesser degree than the conglomerate (Figure 9).

This assemblage is analogous to Rust's GII facies assemblage which represents proximal braided rivers on alluvial plains and also compares to the 'Scott Type' deposits of Boothroyd and Ashley (1975). The high boulder

Figure 8. Large channel containing imbricate gravels in Corduroy Canyon. (Spare tire for scale).

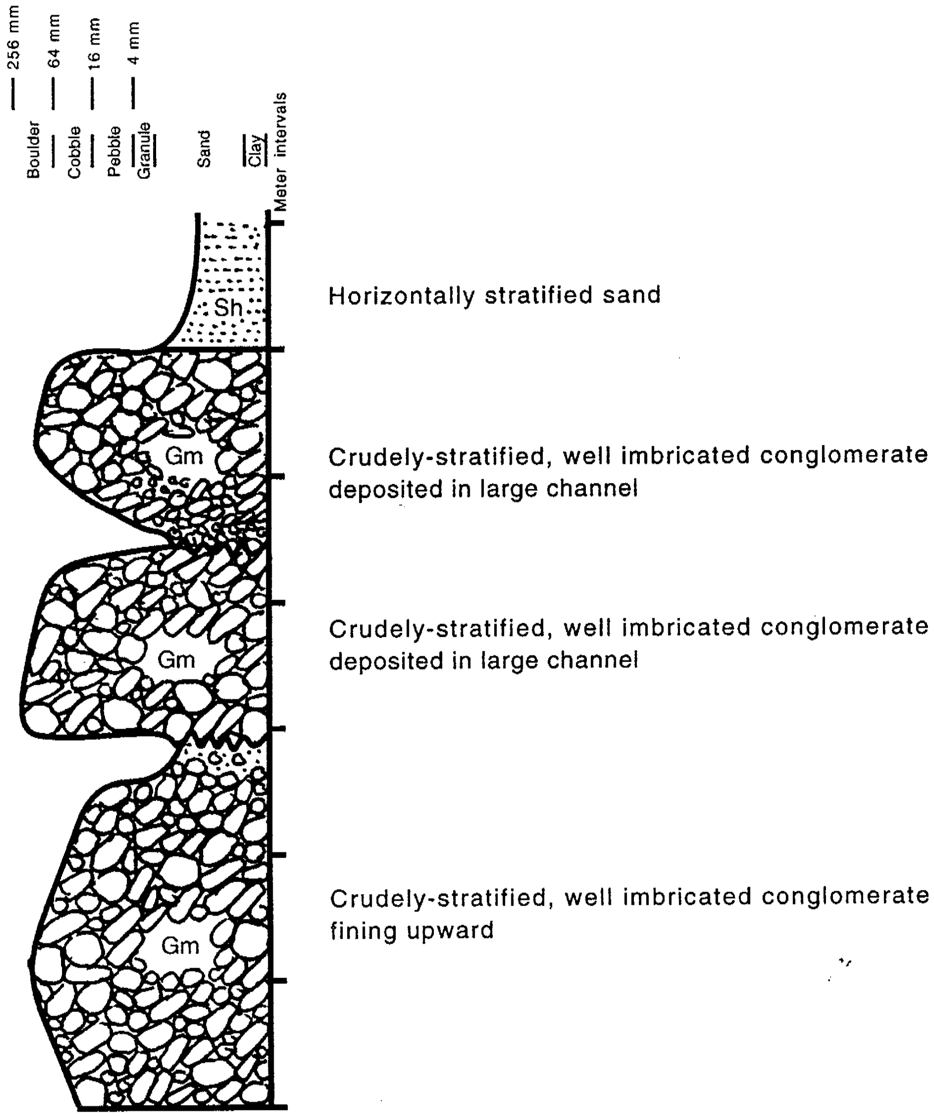


Figure 9. Measured section dominated by crudely stratified, well imbricated, boulder and pebble conglomerate deposited in well-developed erosional scours. Outcrop is interpreted as proximal bajada deposits. (Section is located in Corduroy Canyon west of Squaw Creek, SE1/4, Sec 29, T9S, R11W).

and cobble to sand ratio indicates a rolling bedload in turbulent upper flow regime conditions such as in a highly competent flood discharge confined within an incised channel (Blair, 1987). Hence it is interpreted that this coarse detritus was deposited in incised channels on the bajada as either longitudinal bars or lag deposits. They are herein referred to as proximal bajada deposits.

Mixed Sandstones and Conglomeratic Sandstones

The mixed sandstone and conglomeratic sandstone lithofacies units are characterized by tabular, flat-based beds that are laterally extensive (Figure 10). These beds are dominated by coarse sand and pebbles, though cobbles and rare boulders are present. The pebbles are often concentrated in stringers bounded by massive sand (Figure 11). Horizontal beds of sand are stacked above and below interspersed beds of coarser material (Figure 12), although this material is not as coarse as that of the previously described facies (max 25 cm). The gravel/sand ratio shows a gradation between deposits proximal to basin margin faults (high ratio) and those distal to the margins (low ratio). Rocks in this association are the most widespread lithofacies units throughout the study area.

In a very generalized sense these beds are represented by Miall's facies Sh and Gm and fall under Rust's heading SI for proximal braided rivers and alluvial plains. Miall

Figure 10. Flat-based laterally extensive beds of mixed sand and gravel along Sapillo Creek.

Figure 11. Stringers of gravel bounded by massive sand in Railroad Canyon (dark beds in top 1/4 of photograph).

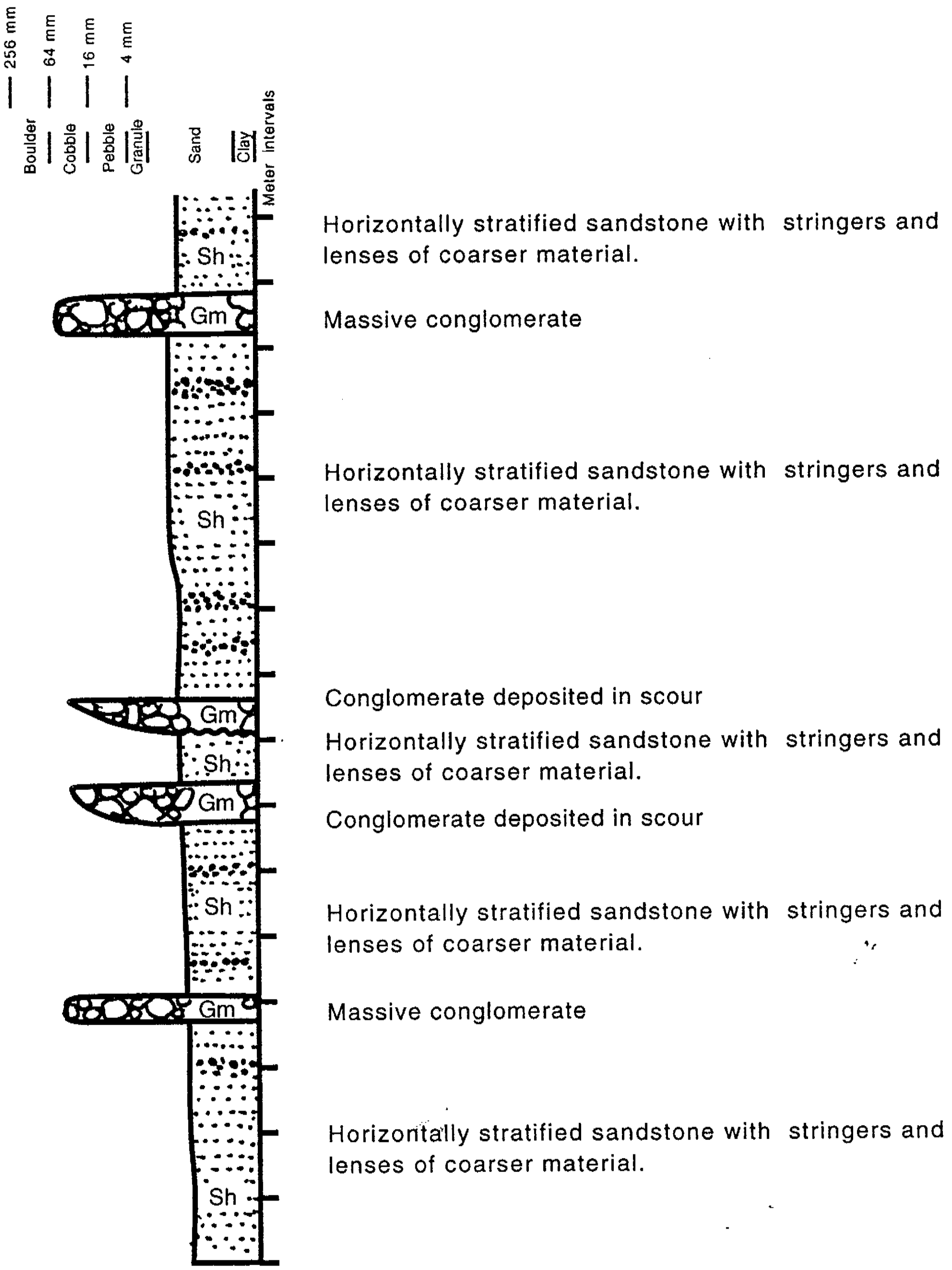


Figure 12. Measured section of mixed sandstone and conglomeratic sandstone. Sandstone beds are tabular, flat-based, laterally extensive, and contain stringers of granules, pebbles, and rare cobbles and boulders. Outcrop is interpreted as distal bajada deposits. (Section is located in the SE1/4 of Sec 28, T8S, R12W).

links facies Sh with planar bed flow and facies Gm with longitudinal bars and lag deposits. It is herein interpreted that the horizontally bedded sands were deposited during high discharge events as non-channelized sheetflood which buried coarse deposits which lay in abandoned shallow channels of ephemeral streams on a low-slope bajada.

Non-Conglomeratic Sandstones and Mudstones

The predominantly sandstone-mudstone association has three distinct manifestations within the study area: A) as thick sections of poorly indurated, apparently structureless sandstone and mudstone, B) as well indurated, extensively laminated sandstone and mudstone, and C) as sandstone that is distinctly tuffaceous. These deposits do not readily fit into Miall's scheme and they are simply too fine-grained to bear any resemblance to the "Platte", "Donjek", "South Saskatchewan", "Bijou Creek", "Scott", or "Trollheim" models. Herein these deposits are referred to as axial deposits based on their fine-grained nature in relation to other deposits in the study area.

The most widespread axial deposits in the study area consist of thick sections (10 - 20 m) of mudstone interbedded with much thinner (0 - 3 m) tabular beds of sandstone that pinch out laterally. These deposits form tall debris-covered slopes that preclude detailed stratigraphic work (Figures 13, 14, & 15). These units are interpreted as having been deposited in a flood basin where a low gradient and standing water allowed clays to settle from suspension. Herein, they will be referred to as flood basin deposits.

Outcrops composed of horizontally bedded and laminated silt, sand and mud were found along the north shore of Lake Roberts (Figure 16). These beds exhibit strong lateral continuity and are bounded by sharp contacts. Alternating groups of beds are colored brilliant red and stark white hues. These beds are unusual for Gila Conglomerate in that they are strongly laminated and are deeply colored, and outcrops of this type were found nowhere else in the study area.

Several lines of evidence suggest that these are lake deposits, but this conclusion is far from certain. Lake deposits are difficult to characterize definitively. Miall's classification scheme, in its current form, does not address lacustrine systems. Picard and High (1972) pose the following questions about lacustrine deposits in general:

> Is there a characteristic lacustrine sequence or facies pattern? Is there a lacustrine biota? Is there a lacustrine assemblage of minerals or sedimentary structures? Are texture, geochemistry, paleocurrent patterns or lithology ever definitive of lacustrine environments?"

Their answer to each question is "no".

With this in mind it is herein conjectured that these are lake deposits based upon the following lines of

Figure 13. Mud slopes along Military Trail.

Figure 14. Mud slopes near the Turkey Track.

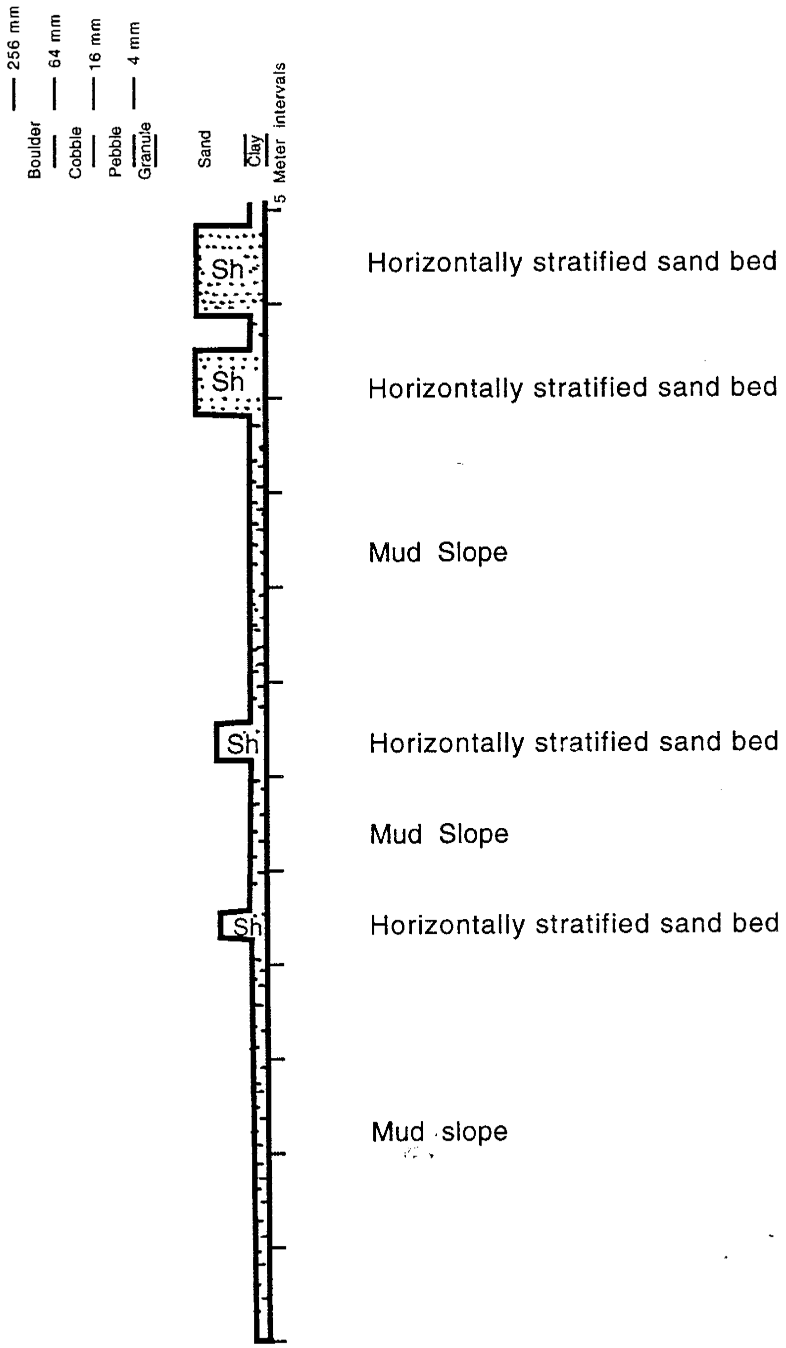


Figure 15. Thick section of poorly indurated mudstones interbedded with resistant tabular beds of sandstone that pinch out laterally. Outcrop is interpreted as flood basin deposits. (Section is located along the Military Trail, SE 1/4, Sec 31, T14S, R12W).

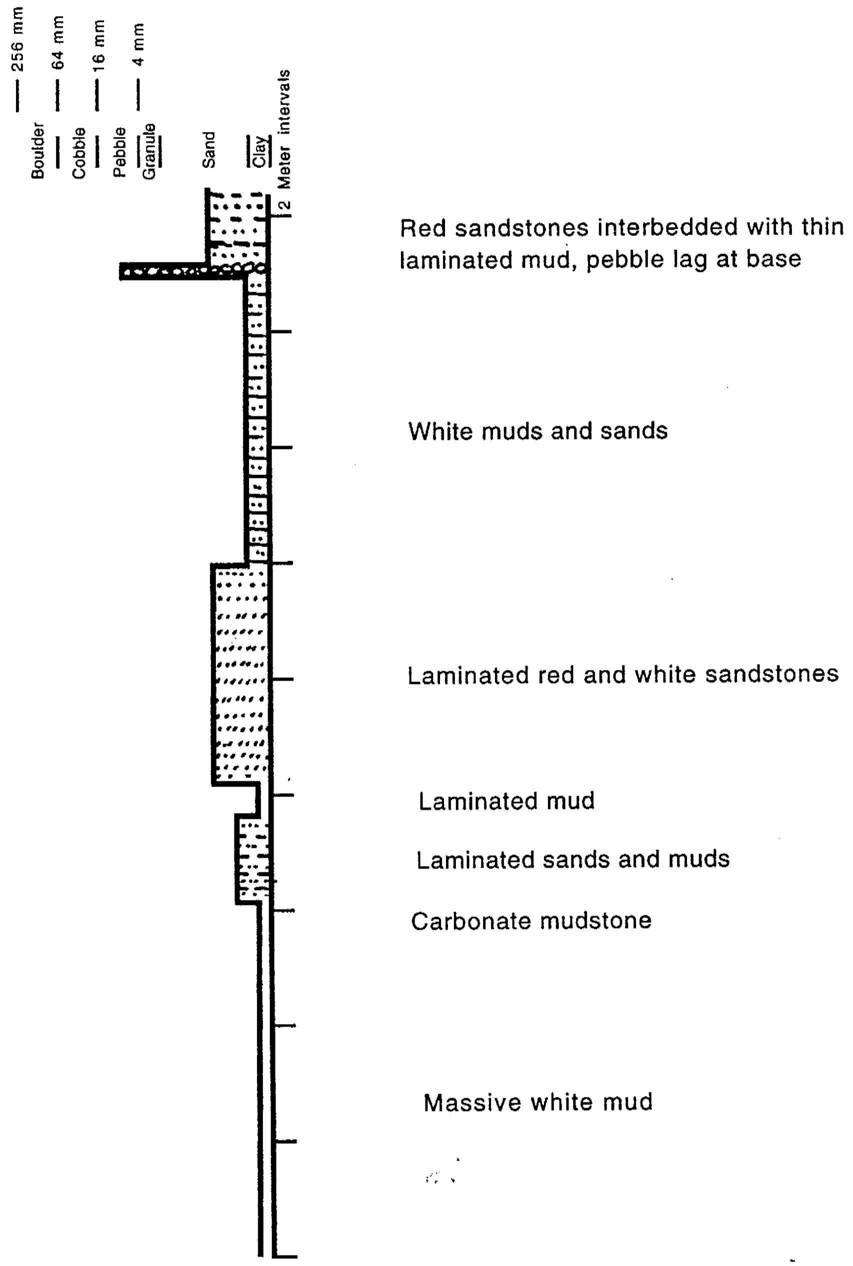


Figure 16. Measured section of thin-bedded and extensively laminated sandstones and mudstones. Beds exhibit strong lateral continuity and are bounded by sharp contacts. Outcrop is interpreted as lacustrine deposits. (Section is found above the north shore of Lake Roberts, SW1/4, Sec 35, T14S, R13W).

evidence:

a) Lateral continuity of stacked thin beds bounded by sharp contacts strongly suggests that deposition occurred in a quiet water environment that was not subject to subaerial erosion. The lack of coarse material and the sharp contacts indicate an influx of suspended load sediments in storm events. Such deposition might likely occur on the bottom of a lake.

b) At one outcrop (SW1/4, Sec. 35, T14S, R13W) the sediments are cut by a substantial clastic dike (Figure 17). The clastic dike indicates that a substantial thickness of unconsolidated sediment was saturated during the time of emplacement. Such a situation might exist on and beneath the floor of a lake.

c) The change in color might reflect submergence and emergence. Such effects might have been induced climatically on a shallow lake.

The third variety of finer-grained deposits includes two peculiar types of tuffaceous, sand-dominated facies: A) those in which beds lack internal stratification and contain sparse floating clasts which are deeply weathered, and B) those in which beds show large-scale low angle crossbedding (Figure 18). Both of these types are found only in narrow zones (< 15m) in extreme proximal settings, directly against fault-bounded margins.

The origin of these deposits is problematic. Crews

Figure 17. Clastic dike cutting through horizontally bedded laminated sandstone and siltstone near Lake Roberts.

Figure 18. Large-scale, low-angle crossbedding in tuffaceous unit along upper drainage of East Diamond Creek.

(1990) worked in the Reserve graben (a basin to the west of the study area that also contains Gila Conglomerate) and described a facies similar to type A. He says:

> This association, together with the apparent lack of sedimentary structures, suggests a high energy mass flow origin that contrasts strangely with the fine-grained texture of the facies. One possibility is that the massive sandstone facies reflects a peculiar source-rock lithology whose breakdown products did not include gravel, or, if gravel was produced, the clasts were too soft to survive transport.

The above conclusion is in keeping with the deeply weathered nature of the clasts, but does not explain the location of the unit against the fault margin, which is probably due to tectonic influences (see section on tectonic models. Crews' (1990) reasoning also applies to type B, though the large scale cross-bedding implies a stronger fluvial influence that was probably responsible for the complete reduction of the fragile clasts to sand. These units are interpreted as reworked pyroclastic deposits.

In summary six characteristic rock packages were recognized in the field and interpreted as the following:

1) Scarp front
2) Proximal bajada
3) Distal bajada
4) Flood basin
5) Lacustrine
6) Reworked pyroclastic

Reworked pyroclastic deposits are found only in narrow zones abutting fault margin. Scarp front deposits are proximally situated, but the width of the zone may extend up to a mile (1.6 km) from the fault. Proximal bajada deposits are not extensive. The most widespread types of deposits are distal bajada and flood basin deposits. Lacustrine deposits are found exclusively near Lake Roberts.

FIELD RELATIONSHIPS AND INTERPRETATIONS

Five basins were delineated based upon present distribution of the Gila Conglomerate and Gila constructional surfaces. Within these individual basins Gila constructional surfaces are at considerably lower elevations than the surrounding topographic highs. In the absence of major post-depositional deformation and tilting, or drastic faulting, this observation implies that these highs acted as barriers to distribution of sediments during Gila time. The basins occupy discrete lower portions of catchment areas - thus in a crude sense the modern topography bears similarities to ancient topography.

The following are designated as separate basins (see Figure 19):

(1) The Mimbres/Sapillo trough
(2) The Western Slope of the Black Range
(3) The Gila Hot Springs sag
(4) The Railroad Canyon basin
(5) The Adobe Ranch depression

Field relationships will be discussed individually for each basin and sub-basin. Discussions will proceed in this general pattern: constructional contours, structure, paleocurrents, and lithological relationships. This will be followed by interpretations.

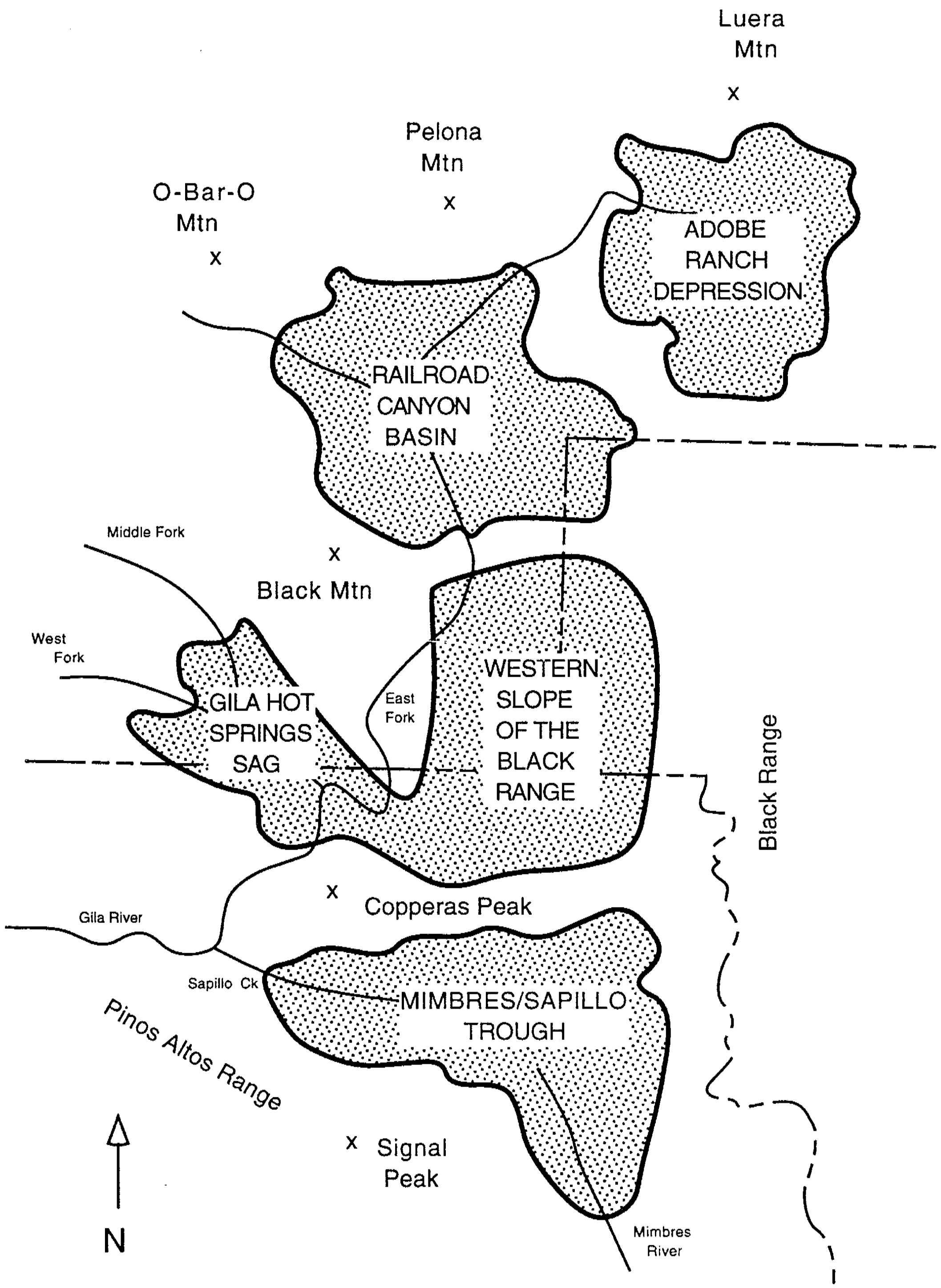


Figure 19. Basins within the study area.

The Mimbres/Sapillo Trough

The Mimbres/Sapillo trough (Figure 20) is bounded by the Black Range on the east, the Gila Flats to the north, and the Pinos Altos Range to the southwest. Whereas the Gila Flat is a relatively flat lying volcanic flow surface with an average elevation above 7200 ft (2200 m), the Pinos Altos Range is dotted with peaks reaching between 8000 ft (2440 m) and 9000 ft (2740 m), and the Black Range is an immense north-south trending range that consistently reaches elevations above 9000 ft (2700 m).

The Mimbres/Sapillo trough is now a broad valley that gently arches across the continental divide. The modern axial systems - Sapillo Creek to the west and the Mimbres River to the south - are bounded by bold cliffs of Gila Conglomerate. The interplay between weathering, jointing and bedding in the Gila Conglomerate produces spectacular canyon walls that rise over 250 ft (75 m) near the Ponderosa Ranch (see Figure 10). At Gatton's Park the bases of opposing canyon walls are over a mile (1.5 km) apart. Tributary canyons are incised at roughly right angles to the axial system. These side canyons form precipitous narrow boxes in their upper reaches. Gradients along the Sapillo axis are around 50 feet per mile (9 m/km) and along the Mimbres axis are also around 50 feet per mile (9 m/km). Gradients of the larger side canyons, such as Rocky Canyon and the northern fork of the Mimbres, reach 150 feet per

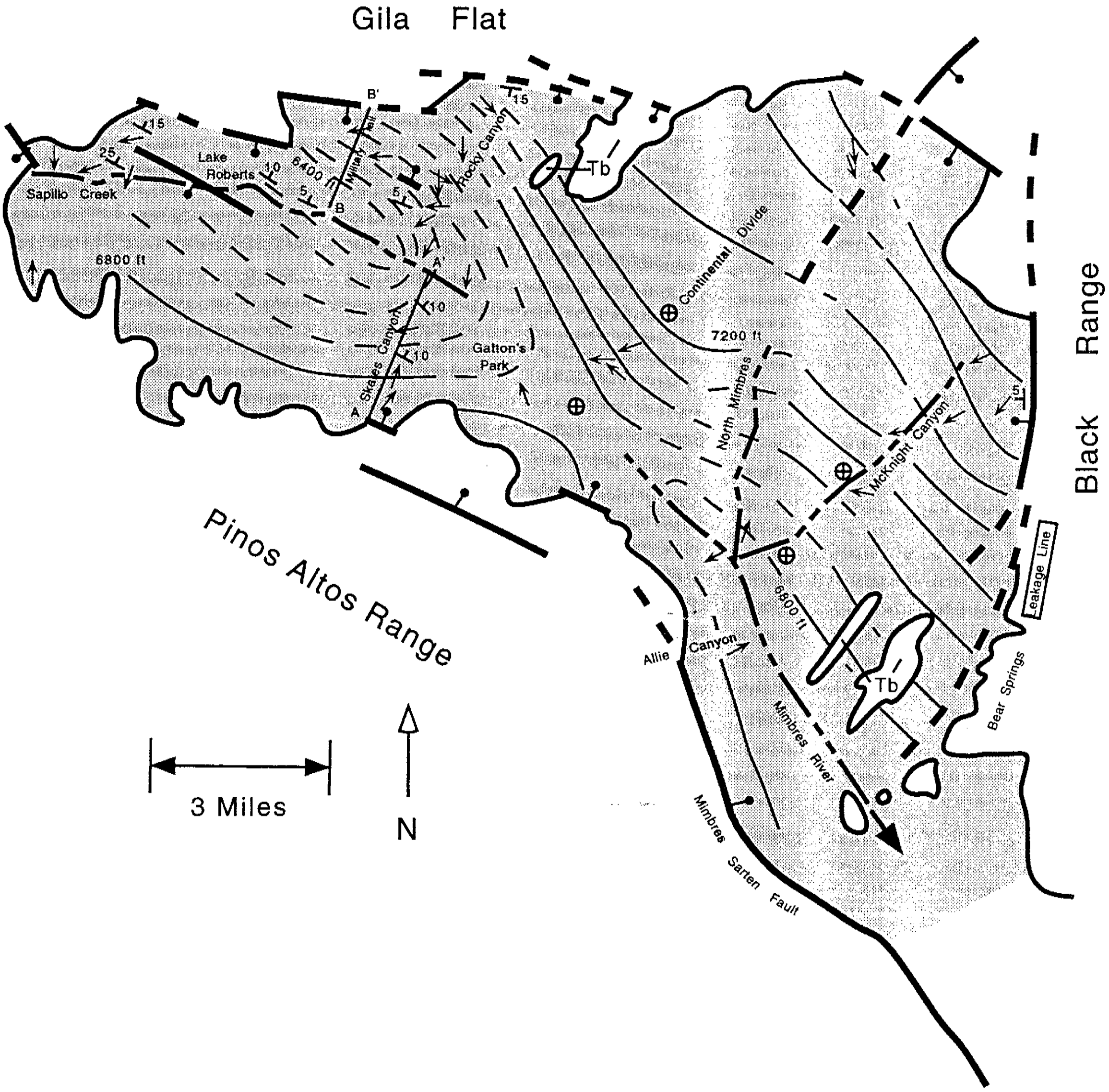


Figure 20. Map of the Mimbres/Sapillo trough, including faults (bold lines, dashed where inferred), contours of constructional surfaces (thin lines, dashed where inferred), and paleocurrent measurements (arrows). (Tb = alkaline olivine basalt flows. Contour interval = 100ft. Line A-A′ and line B-B′ are for Figure 21. Structure modified from Ratte′ and Gaskill, 1975, Elston *et al.*, 1976, Farris, 1980, and Moore, 1987).

mile (27 m/km) in the upper reaches.

The elevation at Lake Roberts is 6036 ft (1840 m), the saddle of the continental divide is about 6640 ft (2025 m), the base of the canyon walls at Gatton's Park are at 6600 ft (2010 m), only 40 ft (15 m) below the continental divide. Near the northeastern basin margin Gila deposits are found as high as 8000 feet (2440 m). Gila formational thicknesses in the Sapillo Creek graben are estimated to be between 250 and 300 meters (Ratte' *et al.*, 1979).

A look at constructional surface contours (Figure 20) reveals two important observations:

1) The constructional surfaces grade away from an embayment in the Black Range in the upper reaches of the present Mimbres River and describe a large fan-shaped wedge. Constructional surfaces in this area are above 7500 feet (2290 m).

2) A depression exists along the northern margin of the basin near Military Trail. This area sits in the low point of the constructional contours at an altitude of 6400 ft (1950 m).

Figure (20) also shows major structural elements. The Mimbres fault zone is the best expressed structure in the southern portion of the basin. It represents the eastern boundary of the Silver City-Santa Rita structural high and extends at least eighty miles (130 km). To the south it is continuous with the Sarten fault, which runs along the eastern flank of Cooke's Peak. Near San Lorenzo the fault zone bends to the west and splays apart toward Meadow Creek in the Pinos Altos Mountains. The fault dips generally northeast, is an old, reactivating, structure, and uplift along the fault has been less active northward of Swartz (Elston and Netelbeek, 1965; Jones *et al.*,1967; and Lambert, 1973).

Along the southeastern boundary of the basin is what I have termed the Bear Springs leakage line. The Bear Springs Basalt represents the late-stage basalts on this side of the Black Range and eruptive centers are arranged in a linear fashion, possibly along a prevolcanic fault zone. Along the northern extension of this leakage line the author and S. S. Hart (in Ratte' *et al.*, 1979) mapped faults downthrown to the west, toward the basin.

The northern boundary of the basin is formed by the Gila Flat. The edge of the flats is delineated by a series of faults that are generally east trending, down to the south, including the North Star fault of Aldrich (1976).

There is a fault system that cuts along the southwestern shore of Lake Roberts. Elston *et al.* (1976) noted an ancient fanglomerate derived from the scarp produced by this fault, and also noted that this fault system affects the present topography and drainage. Along the north shore, the author observed surface fracturing, north-trending calcite veins, and small down-to-the-south faults within the Gila Conglomerate. This evidence, coupled with the juxtaposition of lower fine-grained Gila deposits interbedded with 20 Ma basalt against coarser deposits, shows that this fault zone has been active following deposition.

Stratal dips along the Continental Divide and the Mimbres drainage (eastern portion of the basin) are near horizontal. Dips within the Sapillo Creek area (western portion of the basin) are generally to the northeast. Beds west of Lake Roberts show the greatest tilt (> 15 degrees). This general trend shows that post-depositional deformation in the basin has been most influential to the west.

Figure (20) shows paleocurrent measurements. Arrows give a general trend down paleoslope (as determined by constructional contours) and exhibit a tendency to turn toward the west.

The Skates Canyon transect (Figure 21) illustrates general trends in lithology moving away from bounding faults. Along the fault the rocks are composed of angular, poorly sorted, poorly bedded, matrix-supported, and essentially monomict clasts, but the character of the clasts changes quickly downslope to boulders and cobbles that are more diverse, clast supported, and generally smaller. Further downslope, the sand/gravel ratio increases and clasts becoming less angular and the bedding better defined. The mixed sandstone and conglomeratic lithofacies represents

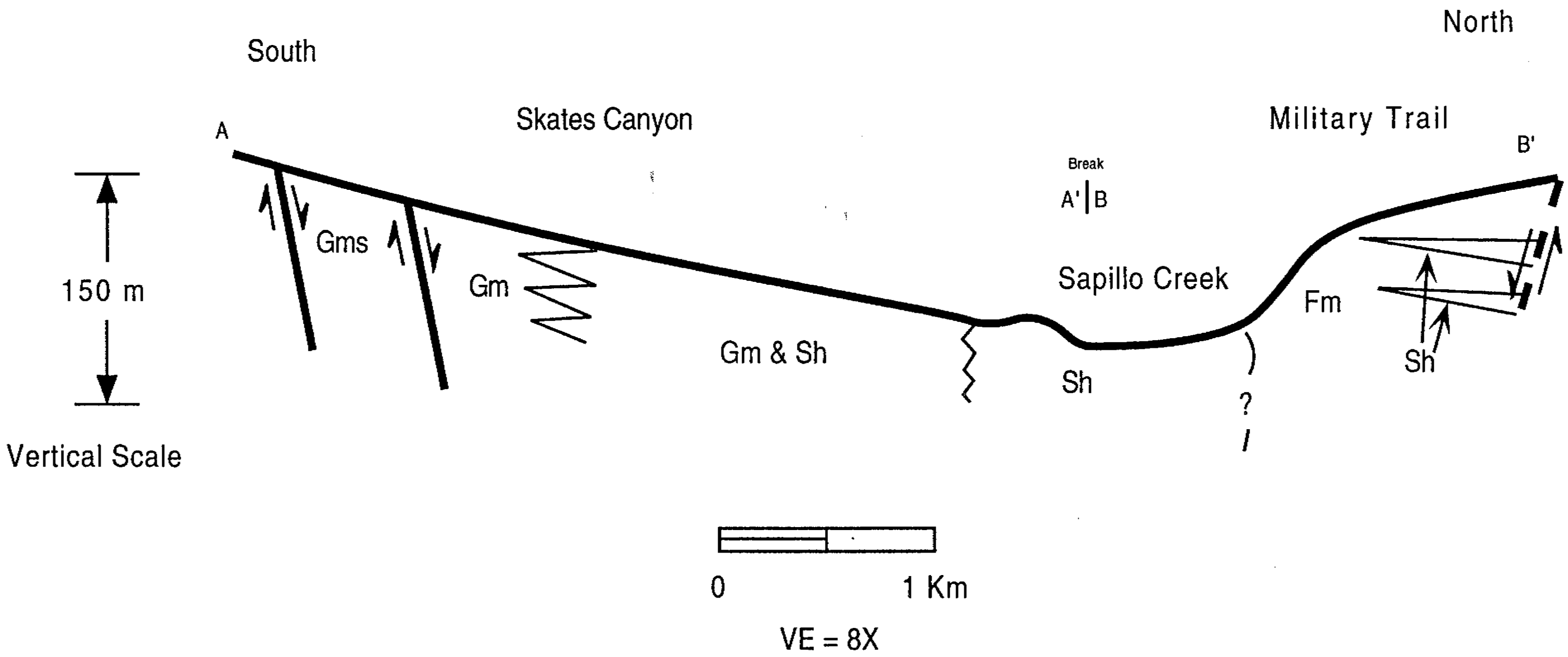


Figure 21. Composite cross section from Skates Canyon (south) to Military Trail (north) showing lateral changes in lithology. (Section is located on Figure 20).

the widest zone on this transect and its character is rather uniform. Further downslope there is a somewhat abrupt decrease in the coarser component and the outcrop is dominated by sand and, to a lesser degree, mud.

A transect up Rocky Canyon differs from this pattern in one primary aspect of the facies transitions - the width of the matrix- and clast-supported zone, which together extend almost a mile from the contact with the volcanic formations that provided the large angular boulders (see Figures 5 and 6). These boulders often exceed 60 cm. Further away from the fault there is a near-vertical intrabasinal fault in the mixed sandstone and conglomeratic lithofacies of Rocky Canyon (SE1/4, Sec 32, T14S, R12W), with displacement decreasing upsection, which indicates a growth fault. Another curious feature lies near the Gila Conglomerate/ volcanic contact. Deposited within the conglomerate is a large, rectangular, structureless section of brilliant white tuff (Figure 22). The tuff has been given an Ar/Ar date of 28.886 +/- 0.099 (McIntosh, 1993, personal communication). Aldrich (1972) reported this unit as faulted in, but due to the lack of fault traces in the underlying beds and the angular geometry, I prefer to think of this as arroyo fill consisting of recycled older pyroclastic material.

A transect up McKnight Canyon yielded a pattern somewhat similar to the Skates Canyon transect, excepting that there are no axial sandstones or mudstones along the

Figure 22. Rectangular channel filled with white tuff in Rocky Canyon. (Dan Mancano for scale).

basin interior and the mixed sandstone and conglomeratic sandstone lithofacies covers an even broader zone. Another difference is that upon approaching the bounding fault you pass out of the matrix-supported deposits and encounter a modest outcrop of tuffaceous sandstones, then the fault.

It is interesting to note the presence of complexly flow-banded, dome-shaped accumulations of lavas juxtaposed against Gila Conglomerate along bounding faults (Figures 23 and 24). Such domes were found at the head of McKnight Canyon, Rocky Canyon and Skates Canyon, as well as canyons in the basin to the north. Perhaps further study might reveal the relationship between the domes and the faults.

Significant accumulations of finer-grained sediments were found only in the western half of the basin. Finer-grained, axial-type deposits in the Sapillo Creek area are located in three concentrations: along the Military Trail, from the base of Skates Canyon to the Continental Divide at Gatton's Park, and at Lake Roberts.

The greatest concentration of finer-grained Gila deposits is along the ridge north of the Military Trail, to the south of Gila Flat (Figure 25). This ridge is composed of 200 ft (60 m) of mudstone with interbedded, thin, laterally extensive sand/gravel units that pinch out to the south. These sand/gravel beds thicken to to the north and show a general upward coarsening trend. Collectively, these deposits extend in a wide zone (up to 1.5 km) along the

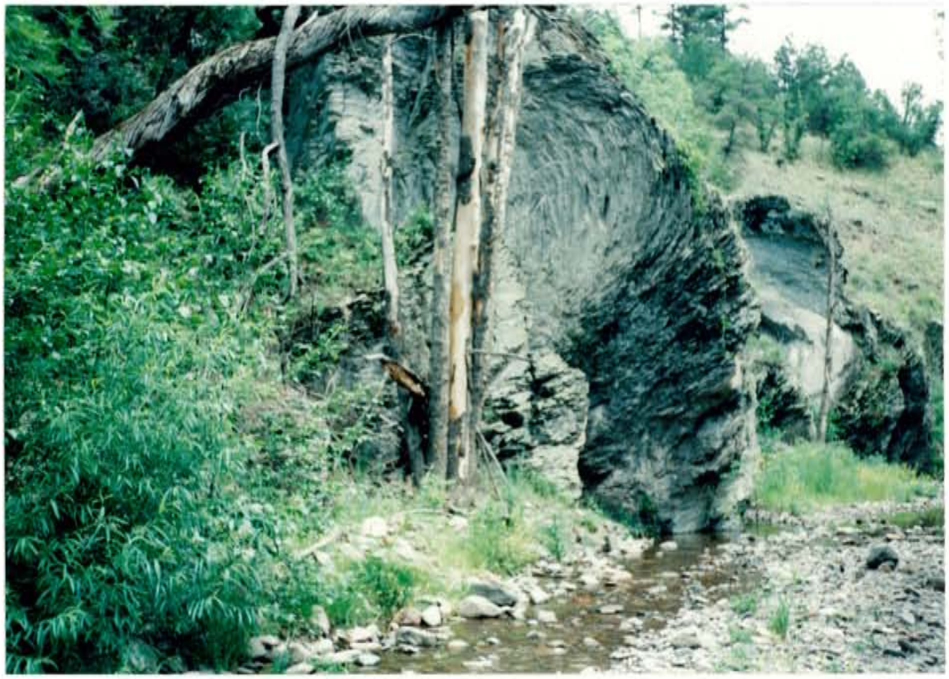


Figure 23. Foliated rhyolite dome at the Gila Conglomerate/volcanic fault contact in Skate's Canyon.

Figure 24. Foliated rhyolite dome at the Gila Conglomerate/volcanic fault contact in Rocky Canyon.

Figure 25. Thick mudstone along the Military Trail. (Note constructional surface on horizon).

basin margin with a shallow (5 degree) tilt toward the north, back toward the basin margin.

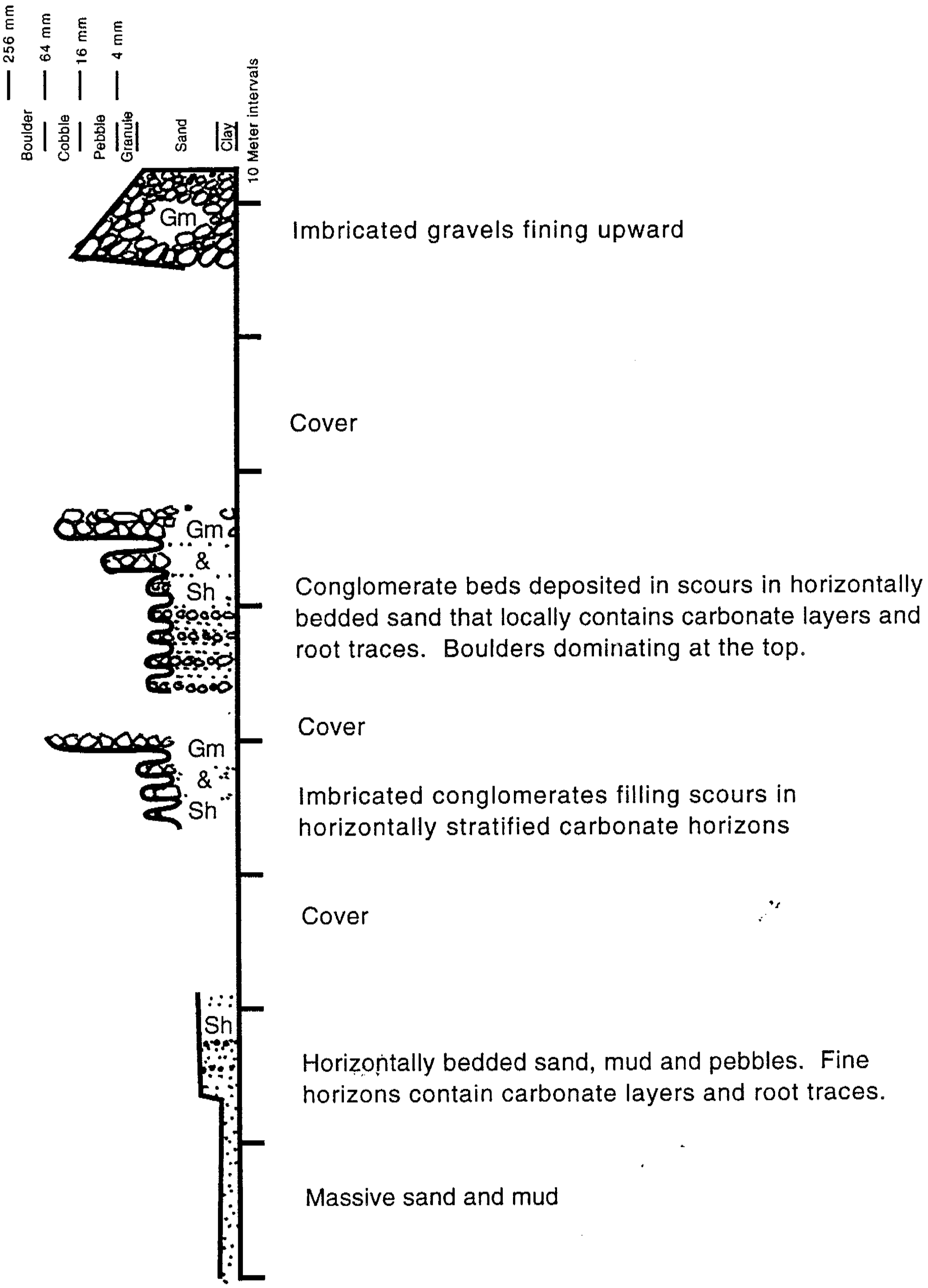
Other finer-grained outcrops occur in a band from the mouth of Skate's Canyon to Gatton's Park and the saddle of the Continental Divide. Finer-grained sediments at the mouth of Skate's Canyon were deposited in massive, thickly-bedded poorly indurated mudstones and sandstones. Bold cliffs of conglomerate and sandstone along the perimeter of Gatton's Park are underlain by muddy slopes at least 20 m thick. It is inferred that the Gatton's Park area at one time was host to a substantial deposit of mud and sand that has been consequently excavated. This could explain the unusual arcuate geomorphology at Gatton's Park. If the former (now removed) deposits in this area were underlain by mud (as are the conglomerates along the rim), the erosional scarp would have readily retreated, creating the arcuate scarp that exists today.

Outcrops surrounding the north end of Lake Roberts are predominately fine-grained, composed of moderately indurated sandstone and mudstone. These beds exhibit well developed lamination, are brilliantly colored, and rocks of this type are found nowhere else in the study area. At one locality (SE corner, Sec 34, T14S, R13W), these deposits are cut by a large clastic dike (see Figure 17). Finer-grained deposits at Lake Roberts are stratigraphically lower than those along the Military Trail, which are lower than those in Gatton's

Park.

Finer-grained beds are occasionally found directly associated with coarse beds. This relationship is best represented along the saddle of the continental divide at the headwaters of the Mimbres River and Sapillo Creek (Figure 26). This outcrop features two distinct facies: A) an amalgam of structureless fine-grained beds, horizontally stratified sandstones (Figure 27) and thin (1 - 5 cm) zones of carbonate (Figure 28); and B) coarser beds of sand and gravels, often deposited in channels scoured into root mottled silt (Figure 29). Locally, the pebbly sand units are crossbedded. Cross-bedding is rare in Gila sediments except in this relationship, where, though not abundant, it is characteristic. These fine and coarse units are intercalated, with finer-grained facies dominating downsection and coarser facies dominating upsection. Collectively, these diverse beds form a crude, erratic, upward coarsening sequence.

As you move up the divide from Gatton's Park to the northeast you encounter boulder beds at 6860 ft (2090 m). This transition is somewhat abrupt but includes at least two upward coarsening cycles. From 6900 ft (2100 m) to 7000 ft (2130 m) boulders make up approximately 75 percent of the outcrop and can be as large as 25 cm across. The lower boulder beds are scoured into thin (1-5 cm) layers of carbonate in the underlying mudstone and sandstone.



Imbricated gravels fining upward

Cover

Conglomerate beds deposited in scours in horizontally bedded sand that locally contains carbonate layers and root traces. Boulders dominating at the top.

Cover

Imbricated conglomerates filling scours in horizontally stratified carbonate horizons

Cover

Horizontally bedded sand, mud and pebbles. Fine horizons contain carbonate layers and root traces.

Massive sand and mud

Figure 26. Measured section showing coarse deposits related to fine deposits. (Section is located along the Continental Divide, Sec 23, T15S, R12W.

Figure 27. Horizontally stratified sandstone and siltstone along the Continental Divide (center, Sec 23, T15S, R12W).

Figure 28. Resistant carbonate layer along the Continental Divide (center, Sec 23, T15S, R12W).

Figure 29. Gravels deposited in channels scoured in root-mottled silt along the Continental Divide (center, Sec 23, T15S, R12W. Plastic fish for scale, 16 cm).

Downstream from Lake Roberts, near where Sapillo Creek exits the basin (Center, Sec 31, T14S, R13W), is evidence of a large channel (Figure 30) filled with alternating fluvial sandstones that show characteristics of a point bar (low angle accretionary surfaces), probably indicating an axial system not on the piedmont. The channel trends east-west, but the direction of flow could not be determined from the outcrop.

What follows is the interpretation of this data.

Constructional surfaces reveal a large fan-shaped wedge from an embayment in the Black Range in the upper reaches of the present Mimbres River, and this embayment seems to be a major gateway for sediments into the basin. Leeder and Gawthorpe (1987) noted that "large drainage systems frequently take advantage of transfer-fault zones and areas between *en echelon* fault terminations so that larger-than-average cones may preferentially form in such locations." That appears to be the case here. Paleocurrent data indicate that sediments were borne off this giant fan and distributed to the west, towards Gatton's Park.

Sediments were also provided by basin-margin faults to the north and southwest. The transects down Skates Canyon, Rocky Canyon, and McKnight Canyon provide general trends in lithofacies changes moving away from bounding faults. These changes are interpreted as the transition of depositional environments from scarp front to proximal bajada to distal

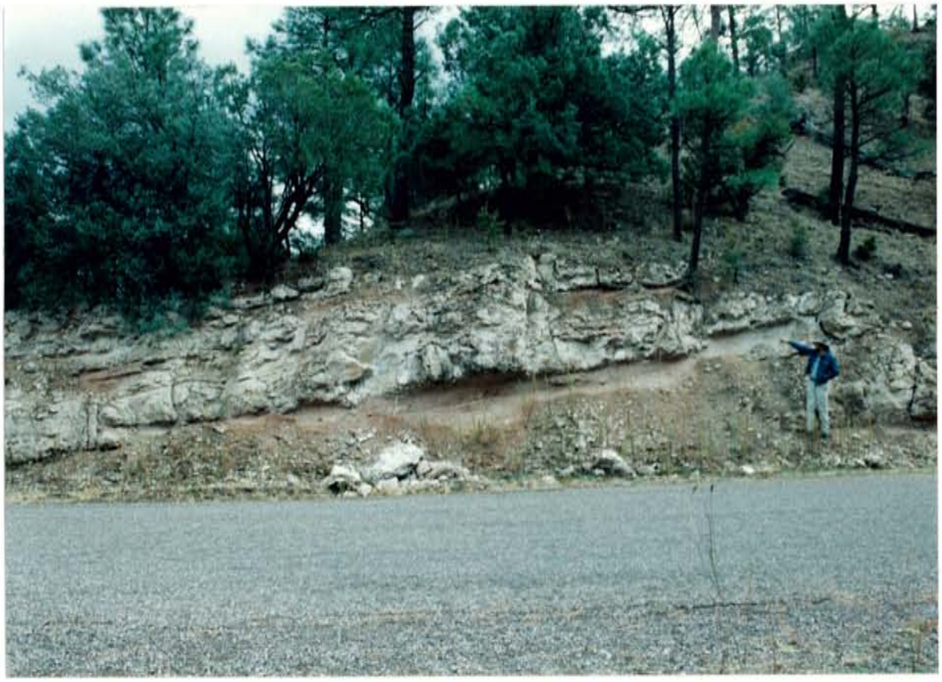


Figure 30. Channel deposits along Sapillo Creek. Note low-angle accretionary surface. (NE1/4, Sec 31, T14S, R12W).

bajada.

Field data from the Lake Roberts area suggest that intrabasinal faulting both postdates and was contemporaneous with major tectonism. The fine-grained deposits on the north of the Lake are cut by a substantial clastic dike (see Figure 17). Collision and Thompson (1989) stated, "Where the intruded host sediment is fine-grained (e.g. sand or silt), and was laid down in relatively quiet conditions an external shock may have been needed to liquefy temporarily the source bed." Such a shock could have been supplied by movement along this fault during early Gila depositional history. It appears that the fault was active contemporaneous with deposition, and subsidence along this fault might be responsible for the localization of lake deposits and sediments near here, both past and present.

Constructional contours indicate that the Military Trail area was situated at the topographic low immediately prior to the beginning of degradation of the basin. The great thickness of mudstone beds along the ridge north of the Military Trail are tilted north, back toward the basin margin. These beds probably represent a time when active tectonism kept the topographic low confined to this margin of the basin. It is inferred that the master fault for the western part of the basin was along the southern rim of Gila Flat. The term master fault is used in the sense that this fault system remained active for sufficient time to control topographic lows and to tilt the basin.

The distribution of the fine-grained facies may represent succeeding events, i.e. an initial event that concentrated fines near Lake Roberts followed by major basin margin collapse to the north, near the present Military Trail.

The only concentrations of finer-grained deposits in the western half of the basin are found exclusively along the western basin-margin fault. These fine-grained deposits, however, are neither thick nor areally extensive. These deposits are probably related to early tectonic subsidence and were quickly buried by the prograding eastern piedmont. This, along with the high altitudes to which the sediments aggraded, and the sheer volume of the sediments suggests that the rate of uplift along the Black Range was rapid; great relief was incurred in a brief time, then ceased. Relative movement was accomplished without a great deal of tilting on the downthrown block. This was then followed by a major westward progradation to the distant reaches of the basin.

The general upward coarsening trend in the deposits along Military Trail and the Continental Divide also represent progadation out into the basin. The presence of mudrock and fine sandstone in the lower units along the Continental Divide suggests low gradients. Carbonate layers and root mottling suggest paleosol development, which implies long periods of depositional inactivity. It is plausible that these sediments were overbank and crevasse splay deposits laid down as the prograding streambeds elevated. The lower units might represent the progradation of a low, flat, sand apron out onto the basin floor, a harbinger of the coarse clastic wedge that followed, when rapid tectonism waned and coarse sediments filled the structural depression.

The Western Slope of the Black Range

The basin along the western slope of the Black Range (Figure 31) is bounded by the Black Range to the east, the Gila Flat to the south, North Mesa to the west, Black Mountain to the northwest, and Kemp Mesa to the north,. Black Mountain (9287 ft, 2830 m) was a major Miocene eruptive center, producing large quantities of mafic lavas of the Bearwallow Mountain Formation at the onset of Basin and Range faulting (Elston, 1976). Kemp Mesa and North Mesa probably represent major outflows of lava derived from the Black Mountain stratovolcano.

This basin is characterized by extensive flat topped mesas formed from a major westward dipping constructional (piedmont) surface. These mesas top out at about 7400 ft (2250 m). This surface is dissected by deep, sub-parallel, westward-draining canyons cutting back into the Black Range. In Black Canyon and along Squaw Creek the streams have cut

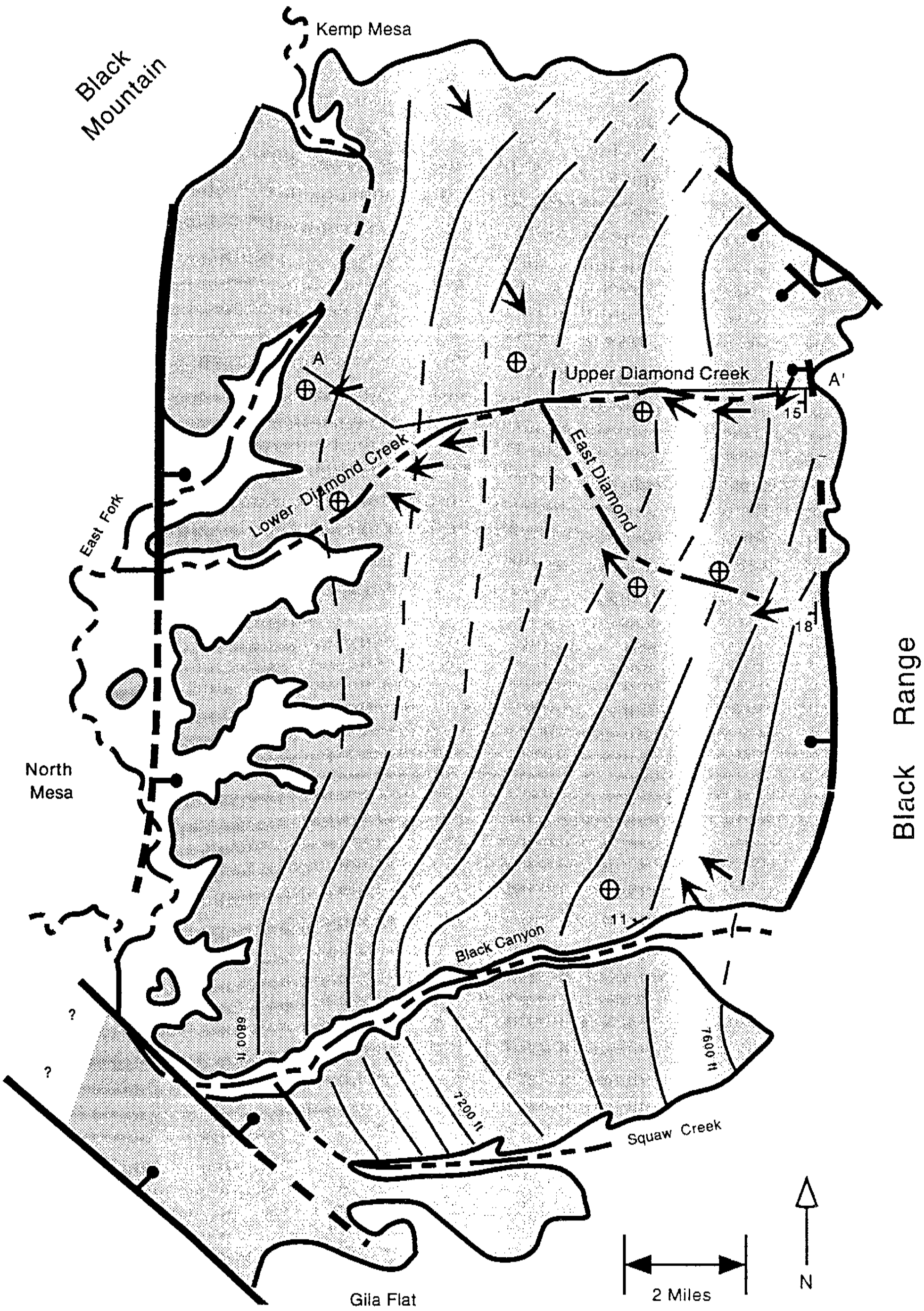


Figure 31. Map of the basin along the western slope of the Black Range, including faults (bold lines, dashed where inferred), contours of constructional surfaces (thin lines, dashed where inferred, contour interval = 100ft.), and paleocurrent measuresments (arrows). (A-A' = line of section for Figure 32. Structure modified from Ratte' and Gaskill, 1975).

completely through Gila deposits into the underlying volcanics.

The structure that is most influential on sedimentation is the Black Range uplift along the eastern margin of the basin. Constructional surfaces grade away from this front, dropping 800 ft (250 m) within six miles (10 km). Also, Gila formational thickness diminishes appreciably away from this front, decreasing from >800 ft (250 m) on the east to <60 ft (20 m) to the west. At this point the formation is erosionally truncated by the broad valley of the East Fork of the Gila River. The interior of the basin is relatively undeformed. Stratal dips are near horizontal, except in a narrow zone along the range-front fault zone, where Gila strata tilt down away from the margin at 15 to 20 degrees. This fault zone is on the same trend as the range-front fault zone that defines the eastern edge of the Mimbres-Sapillo basin, and may represent a northern extension. Paleocurrent data shows a strong trend away from the Black Range front in agreement with constructional contours.

A transect up Diamond Creek (Figure 32) reveals a distinct distal/proximal pattern in Gila sedimentation - with a twist at the end. Along the western margin, where the formation is most distal from the Black Range front, there are outcrops that contain mudstones grading upward into bedded sand units containing pebble and boulder stringers, with pebbles more common than boulders. These

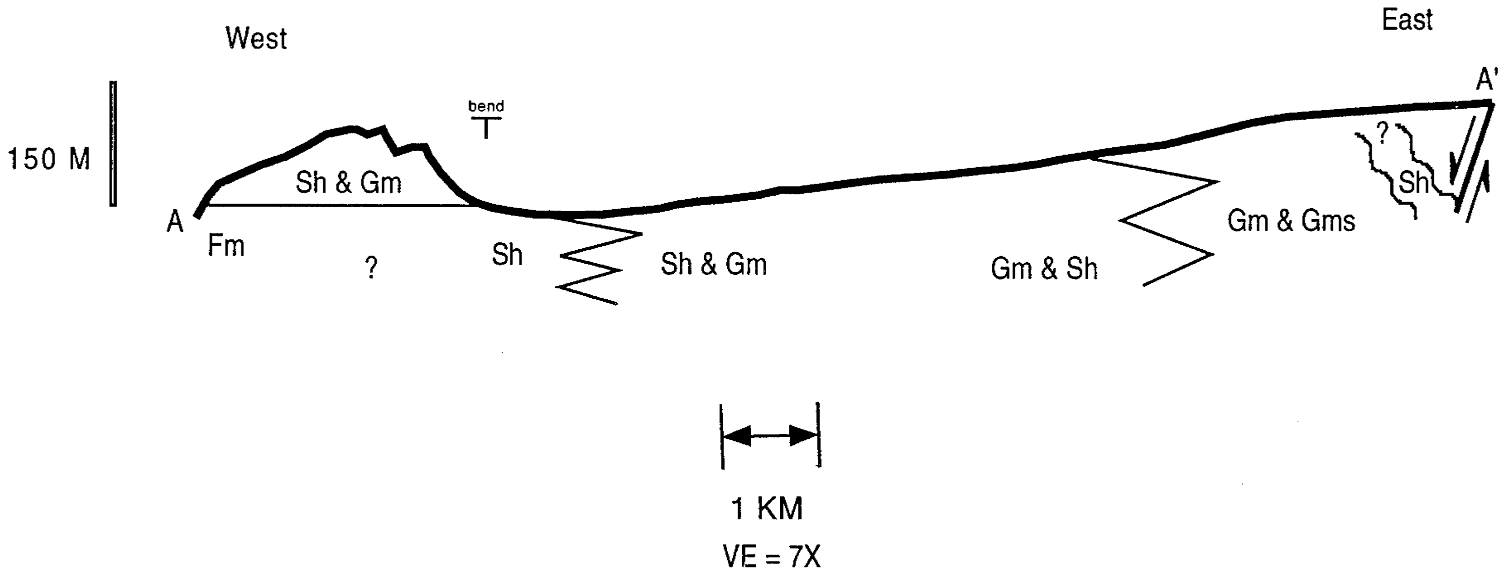


Figure 32. Cross section along Diamond Creek showing lateral changes in lithology. (Section is located on Figure 31).

bedded sand > pebble > boulder units (bajada units) are persistent across the majority of the basin. Outcrops along most of lower Diamond Creek contain less than 5 percent boulders. But upon approaching the Black Range front along both East Diamond Creek and Upper Diamond Creek there is a rapid increase in the coarse fraction. This transition occurs within approximately 3 km from the master fault. Along Upper Diamond Creek, (NE corner Sec 33, T11S, R11W), there is a well-developed zone of superimposed migrating channels containing very coarse units with boulders >40 cm.

Up to this point grain size has become steadily and decidedly coarser, but within 50 m of the master fault there is a radical decrease in grain size. Abutting the master fault are discrete tuffaceous sand units. Figure 18 shows crossbedded tuffaceous sands near the bounding fault on East Diamond Creek. The tuffaceous unit along Upper Diamond Creek contains monomict clasts floating in a tuffaceous matrix and is overlain by beds of normally graded boulders (Figure 33).

In its simplest form, this is the pattern when approaching the master fault: 1) a pervasive broad zone of horizontally bedded sands with subequal amounts of gravel and boulders, 2) a zone of clast size increase, beds of clast-supported cobbles and boulders begin to dominate, channels conspicuous, 3) a boulder zone with numerous poorly sorted, matrix-supported, debris-flow deposits, and 4) a

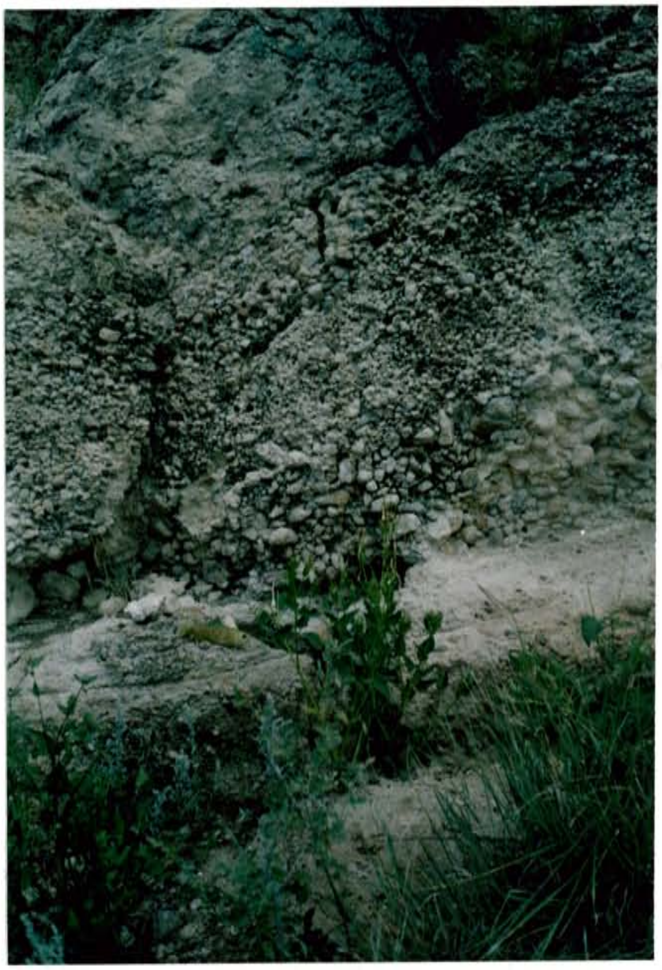


Figure 33. Well sorted, normally graded boulder beds overlying tuffaceous unit along Upper Diamond Creek.

narrow zone abutting the master fault that is composed of sandy, tuffaceous, fluvial deposits. The transitions from zone to zone are better characterized as somewhat abrupt, rather than grading evenly.

Across the basin rhyolitic clasts predominate over basaltic clasts, suggesting that Black Mountain to the west (the nearest potential source of basaltic clasts and still an imposing landform 22 million years after its last major eruptions) did not make a significant contribution and the preponderance of sediments in this basin were derived from the east, off the Black Range. It might be worth noting the occasional occurrence of peculiar white clasts that were not observed anywhere else in the study area. These clasts are composed of a very fine, aphanitic, dense groundmass with a very few scattered, barely discernible crystals. On a fresh surface the rock is white and it is either an altered tuff, or, more likely, an altered lava (W. C. McIntosh, personal communication, 1993). The location of the source rock would aid in interpreting sediment dispersal patterns, but is unknown.

Transects up the branches of Diamond Creek yielded similar results to those along the Black Range front to the south. The Gila Conglomerate is thickest along the fault, but fine-grained beds are neither observably thick nor horizontally extensive, and there is no tilting toward the fault margin. The presence of axially oriented channels stacked away from the fault zone suggests that the axial system was trapped only briefly, then migrated away from the master fault. Lack of basaltic clasts show that the hanging wall did not make a significant contribution.

The structural history of this basin is not apparent, but the following scenario is plausible. After initial collapse along the eastern margin, the collapsed edge was subsequently entrained by adjacent uplift in the Black Range (rising as a result of tectonic unloading due to faulting in the Winston graben) and the basin platform gradually tilted away from the footwall. With increased tilting, subsidence on the block transferred from east to west and sediments prograded rapidly across the basin. In this setting both blocks appear to have been rising along this belt, though one block initially collapsed.

The Gila Hot Springs Sag

The area around the Gila Hot Springs is rugged country with narrow canyons deeply incised by three major perennial streams - the East, West and Middle forks of the Gila River (Figure 34). The West and East forks converge at an elevation of 5557 feet (1690 m). This spot represents the lowest basal Gila contact in the study area as well as the staging point for assembling the drainage of the Interior Plateau before it exits through a single deep gorge and spills into the Mangas graben to the southwest.

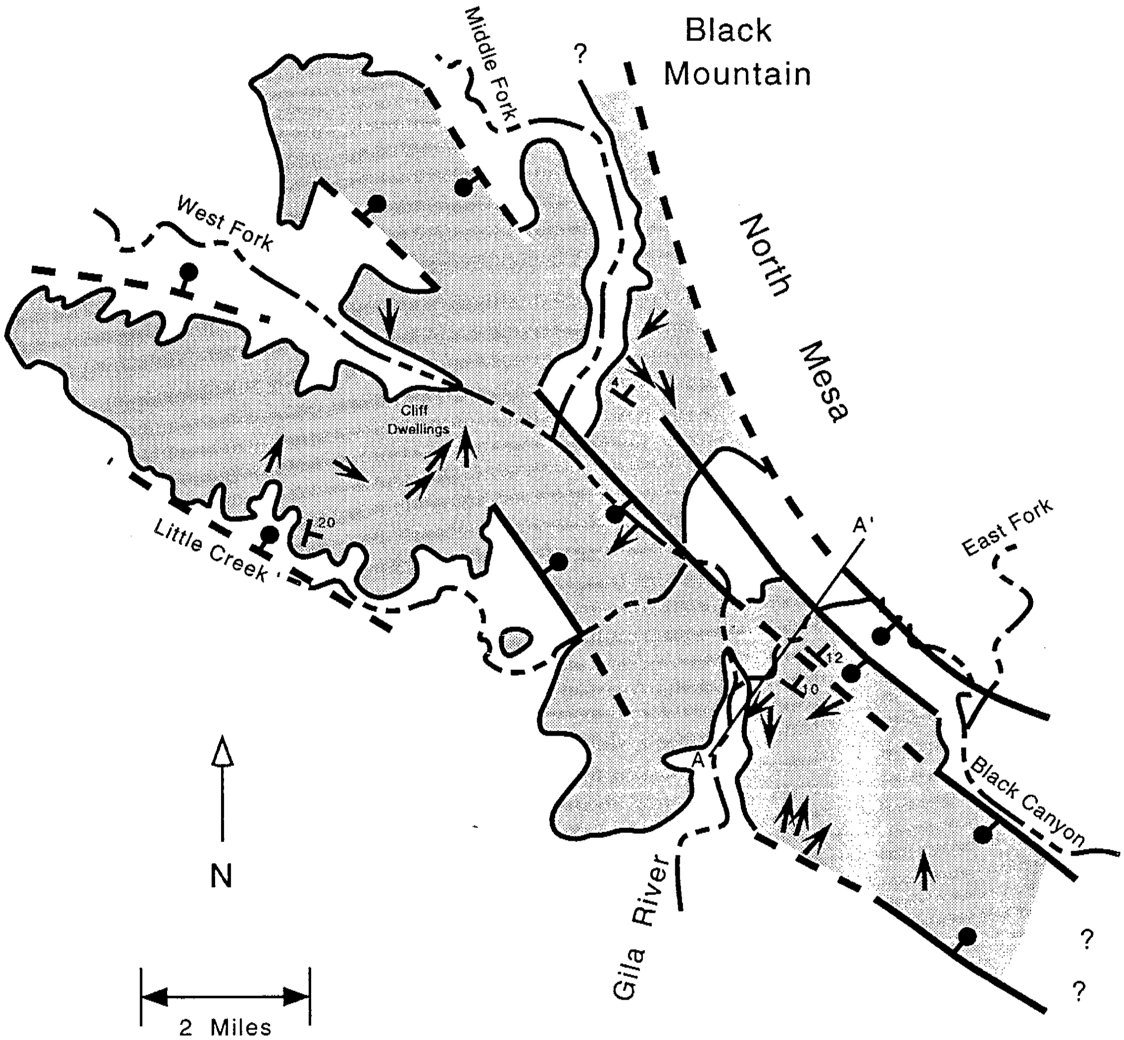


Figure 34. Map of the Gila Hot Springs sag, including faults, (bold lines, dashed where inferred), and paleocurrent measurements (arrows). (A-A' = section line for Figure 36. Structure modified from Ratte' and Gaskill, 1975).

Figure 35 (from Ratte′ and Gaskill, 1975) shows the intensity of the faulting in this basin. Faults are normal, typically high-angle, subparallel (trending NNW), and control the location of no less than ten hot springs in this area. The depositional basin is delineated on the northeast by a fault scarp that rises to 6600 ft (2000 m), forming a flank of North Mesa. Movement along this fault has displaced the Bearwallow Mountain Formation in excess of 600 ft (180 m) above the top of the Gila Conglomerate. It is possible that this is the master fault for this basin, but this could not be verified because the base of the scarp is buried under a coalescing series of modern alluvial fans. Older Gila deposits exposed near the base of these fans are sandy with a paucity of coarse material. Another major fault cleaves through the middle of the basin, through the Gila Hot Springs, and cuts through the Black Canyon to the southwest, where it offsets the basal contact of the Gila by more than 400 ft (120 m). Numerous faults splay off the major faults and doubtless there are more that are as yet undocumented.

Constructional surfaces are of limited utility in this area. Post-depositional faulting has displaced the various blocks and aggressive erosion has obliterated any vestige of an original surface throughout most of the basin. Paleocurrent data were of little help as no clear trend emerged. To further confound matters faulting has in many

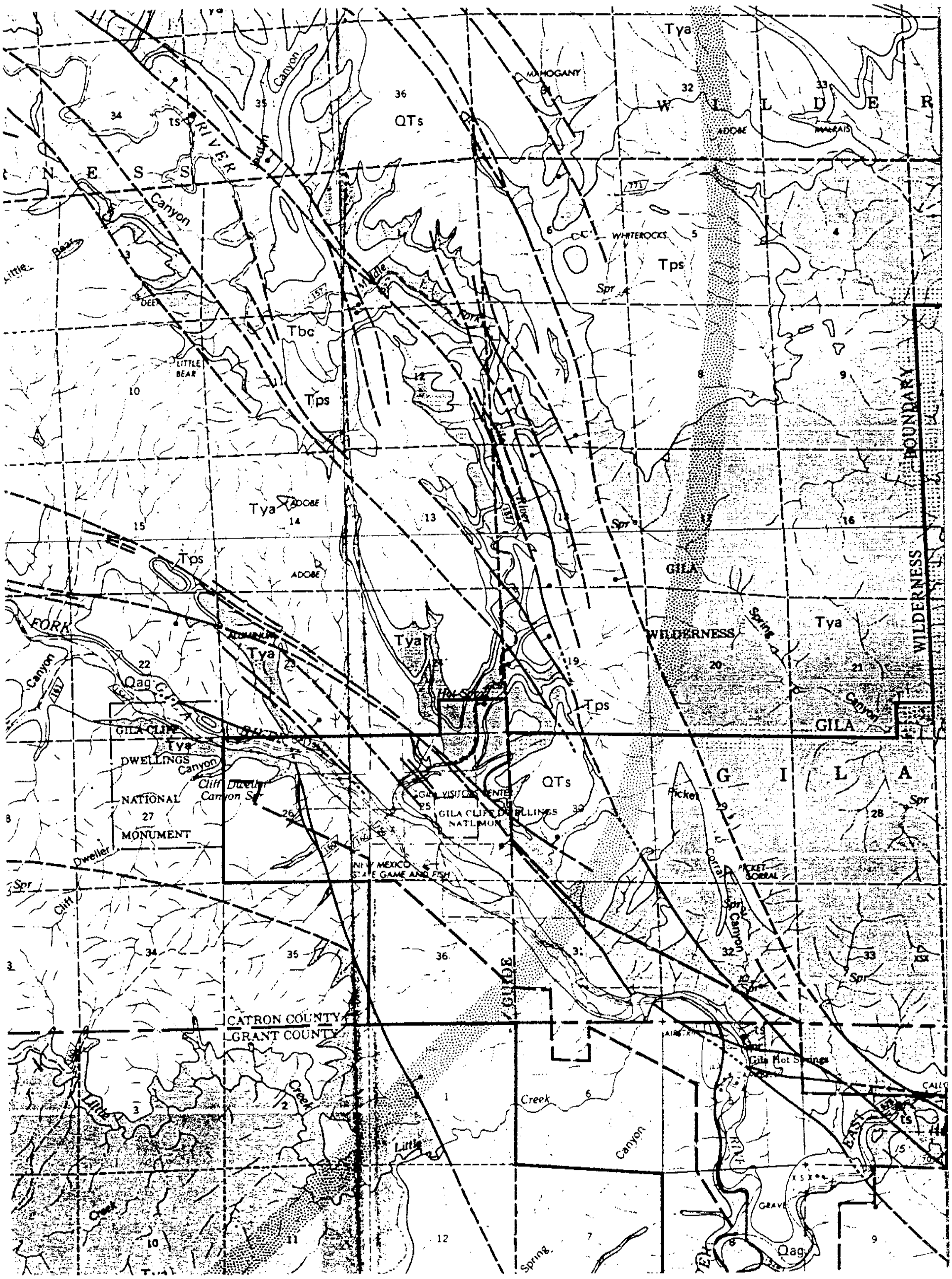


Figure 35. Gila Hot Springs portion of Ratte' and Gaskill's 1973 map.

places juxtaposed younger Gila Conglomerate against older Gila and, until these beds are correlated, stratigraphic trends can be confused with horizontal trends. Correlating these beds could prove difficult because individual distinctive Gila beds are not very persistent horizontally. In light of all this the author must confess a lack of clear understanding concerning the original geometry of this basin.

Despite the confounding circumstances, some observations should be noted. The very erosion that has destroyed constructional surfaces has provided a window to the basal contact, which is not commonly exposed in other sections of the study area. Basal contacts dip generally northeast, toward the North Mesa scarp and total displacement of lower contacts show an asymmetric pattern of collapse (Figure 36).

The basal Gila Conglomerate at the Cliff Dwellings is composed of buff, massive, fine-grained, poorly sorted sandstone and mudstone with lenses of conglomerate and "floating" clasts. This basal sandy unit contains a regolith of the underlying vesicular basalt. Fifteen feet (5 m) above the contact the basal unit is capped by a granule and cobble bed. The lower bed is very typical of basal Gila where it is exposed - "floating" outsized clasts in a massive sandstone matrix. This texture was observed at several localities within this basin as well as along

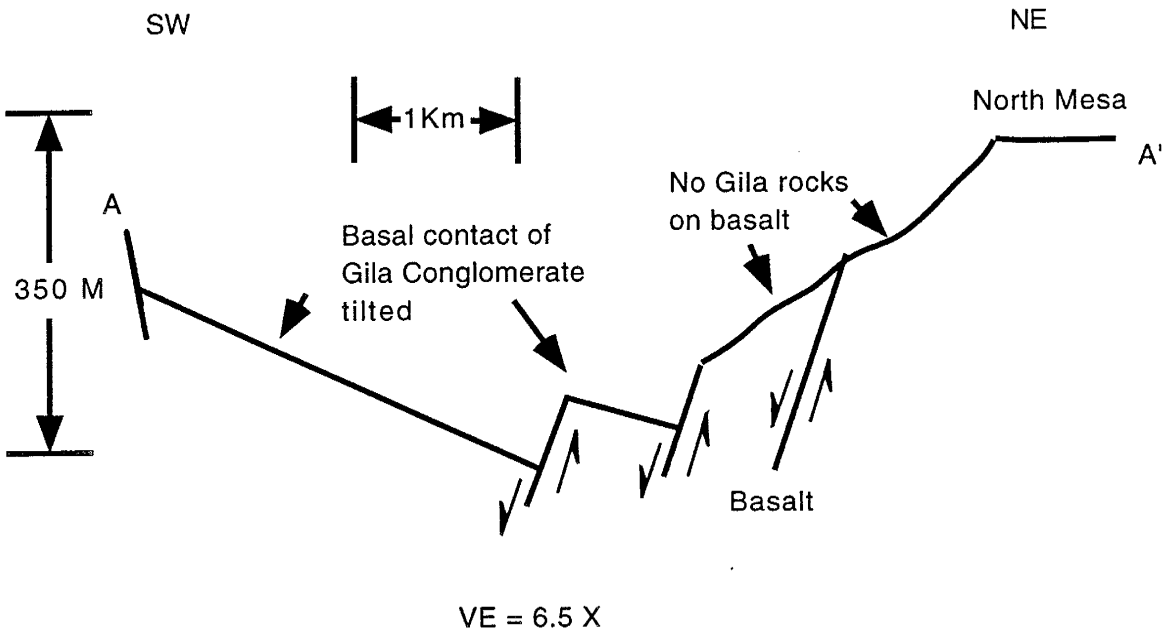


Figure 36. Generalized cross section across the Gila Hot Springs sag showing contacts of basal Gila Conglomerate with underlying basalts. (Section is located on Figure 34).

Meerschaum Canyon in the Mimbres-Sapillo basin (N Sec. 33, T14S, R13W), and in the Black Range basin (W Sec. 31, T11S, R12W), showing a similarity of initial depositional conditions within the separate basins.

Proceeding southwestward and upsection from the basal units at the Cliff Dwellings the sediments become more gravelly, and at the top of the section show low-angle trough cross-bedding in pebbly sandstones. Farther southwestward from this point (downsection through a covered interval) along the formational boundary that parallels Little Creek are monomict conglomerates, massive, poorly sorted, matrix-supported, with basaltic boulders often exceeding 40 cm. These are interpreted as scarp front deposits, implying that there had at one time been sufficient relief along this southwestern margin of the basin to produce such debris flows.

Also, along the southern basin-margin just east of the Gila River are very coarse Gila Conglomerate deposits (max 40-50 cm). These deposits are clast supported, poorly sorted, and well imbricated, and are interpreted as proximal bajada fanhead deposits.

This area is rife with internal faulting and in many cases it is difficult to determine the time frame of the faulting (though many are post-depositional), thus interpretations are sketchy. The basal Gila Conglomerate/Bearwallow Mountain Formation contact steps down to the northeast, creating an asymmetrical depression. Although this area has been previously described as a graben (Ratte′ and Gaskill, 1975) it is actually more like a half-graben with the dominant fault along North Mesa.

There is a continuous band of Gila Conglomerate outcrops that connects the southern portions of the Gila Hot Springs sag and the basin along the western slope of the Black Range. The relationship between the two basins is uncertain. It is possible that they were once a single U-shaped basin that wrapped around the basalt outflows that formed North Mesa. An alternative possibility is that there were initially two separate basins that later overtopped to form a single basin.

The Railroad Canyon Basin

This basin is situated between the northern Black Range to the east, Black Mountain to the southwest, Pelona Mountain to the north, and Indian Peaks to the northeast (Figure 37). This is a zone of transition, both in the biota and the geomorphology as expressed in terms of availability of outcrop. Here rainfall is scant, being orographically depleted, and whereas the basin is heavily forested to the south, the northern portion can only support grasslands. Outcrop is abundant in the eastern canyons of the basin, and in a thin belt along the northern margin of the basin; but exposure of lithified sedimentary rock is

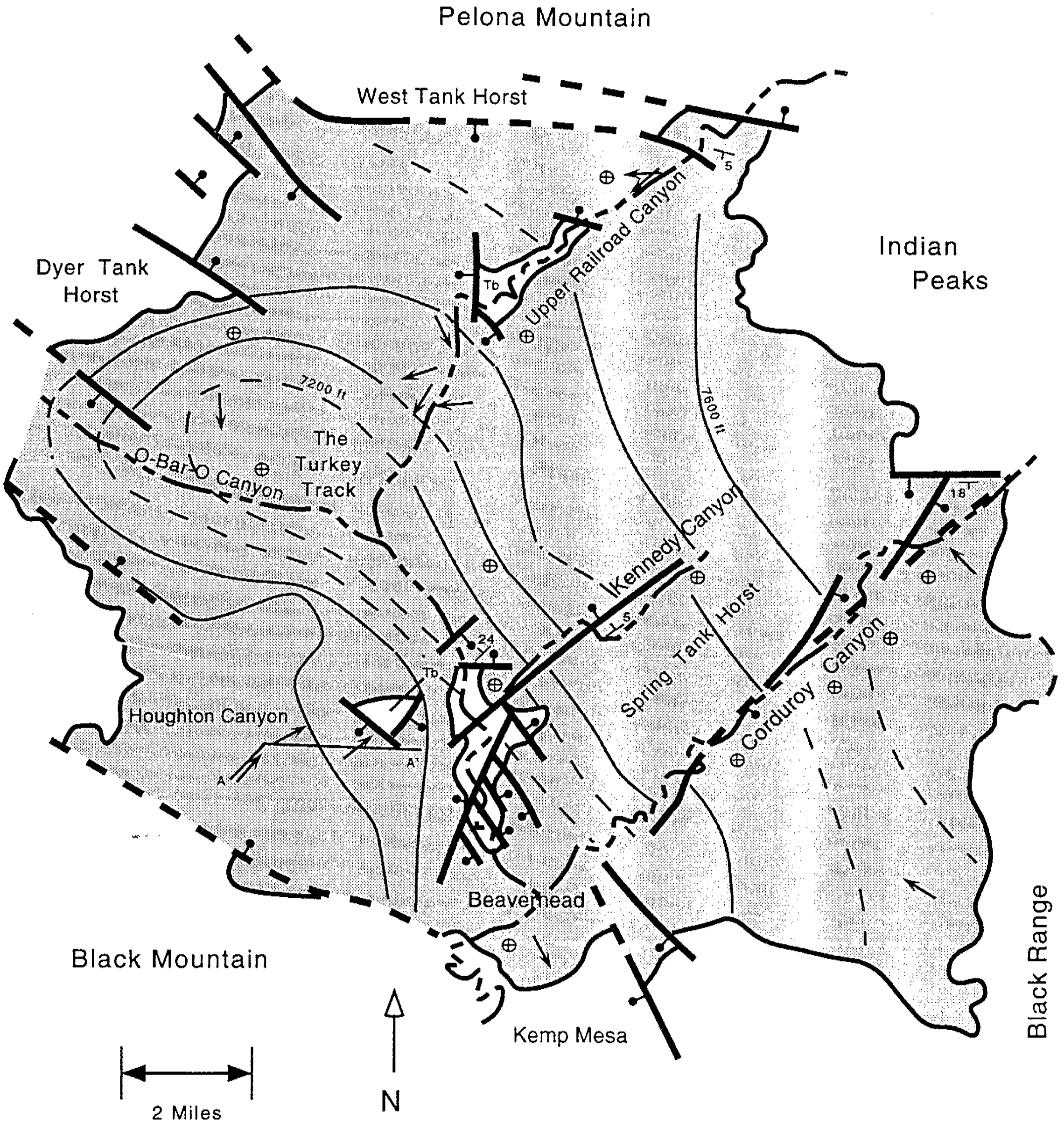


Figure 37. Map of the Railroad Canyon basin, including faults (bold lines, dashed where inferred), contours of constructional surfaces (thin lines, dashed where inferred, contour interval =100ft), and paleocurrent measurements (arrows). (Tb = Bearwallow Mountain Formation. A-A′ = line of section for Figure 39. Structure modified from Richter, 1978, 1985, Richter *et al.*,1986, and Lawrence and Richter, 1986).

sparse in the western and central portions which are blanketed by unconsolidated debris (Figure 38).

Contours of constructional surfaces form a quasiconcentric pattern centered around the Turkey Track (a term used by local ranchers for the intersection of roads in Sec. 16, T9S, R13W). This could be due to the modification of the constructional surface during recent erosional events. However, the fact that this area is only weakly degradational (at best!) it is likely that the effects of erosion are minor and superimposed on the previous topogaphic low of the basin fill. Limited paleocurrent data, pointing toward the Turkey Track, supports this conclusion.

Major topographic features surrounding the basin are volcanic, rather than tectonic, in origin and include the stratovolcanoes of Black Mountain, O Bar O Mountain and Pelona Mountain (Elston *et al.*, 1976), the rhyolitic flow dome complexes of Indian Peaks and Taylor Creek (Richter *et al.*, 1986), and the basalt flows of Kemp Mesa.

This is not to say that this is not an area of complex faulting. The basin has been modified by three horsts. The West Tank horst, an elongate structure that stretches westward from Indian Peaks, brings up Bearwallow Mountain Formation basalts and could possibly have been involved in the generation of Gila sediments, but this is uncertain. The Dyer Tank horst is parallel to the western part of the

Figure 38. Photograph of the central portion of the Railroad Canyon basin blanketed by unconsolidated debris.

West Tank horst. The Spring Tank horst is defined by faulting along Kennedy Canyon and Corduroy Canyon. It tilts to the southwest, where it is truncated by a series of antithetic faults. Uplift of these horsts is on the order of 80 to 150 feet (25 to 45 m) and appears to be largely post-depositional, showing no evidence of pre- or syn-Gila movement, such as localized coarse deposits or growth faulting. The Spring Tank horst positively offsets Gila constructional contours. The internal faults within the basin locally show evidence of drag both on the downthrown block (e.g. north 1/2, Sec 6, T10S, R12W), and on the upthrown block (e.g. center, Sec 33, T9S, R12W). The drag on these blocks flattens out in a short distance from the fault. These horsts have brought up the underlying volcanics, increased stream gradients and caused entrenchment of meanders across them. At times the Spring Tank horst undoubtedly acted as a hinderance to the exit of sediments from the basin.

The northwestern portion of the basin contains a series of small faults aligned parallel with the trends of the antithetical faults in the southern portion of the basin and those in the Gila Hot Springs sag on the opposite side of Black Mountain.

Some authors (S. S. Hart in Ratte′ *et al.*, 1979, and R. C. Rhodes in Elston *et al.*, 1970) have postulated the existence of a fault along the northern Black Mountain front. Although this is likely, it was not possible for the author to directly ascertain this because the front is blanketed by modern fans and transverse drainages make only shallow cuts into the unconsolidated alluvium and colluvium and do not penetrate to bedrock. However, a traverse up Houghton Canyon (Figure 39) reveals a general upward coarsening trend as it obliquely approaches the northern front of Black Mountain. Very coarse clast-supported conglomerates are found near Beaverhead, and although the contact with the basalts is buried, these coarse deposits support the inference of a fault along the northern front of Black Mountain.

Whereas potential sources for clasts on the east side of the basin are exclusively rhyolitic domes, sources to the west are dominantly andesitic/basaltic stratovolcanoes (with the primary exception of the unnamed peak in section 1, T9S, R14W, which is a rhyolitic flow dome complex). A map of relative clast composition (Figure 40) shows that, quite predictably, the coarse fraction of the Gila Conglomerate deposited on the southern and western flanks of Indian Peaks is exclusively rhyolitic, while andesitic/basaltic clasts begin to appear as you move toward the west. The zone of mixing occurs along upper Railroad Canyon. Along the modern drainage (northeast 1/4, Sec 6, T9S, R12W) is an exposed coarse-fill channel cut into bedrock basalt (Figure 41). Moving downstream along upper Railroad Canyon, outcrops show

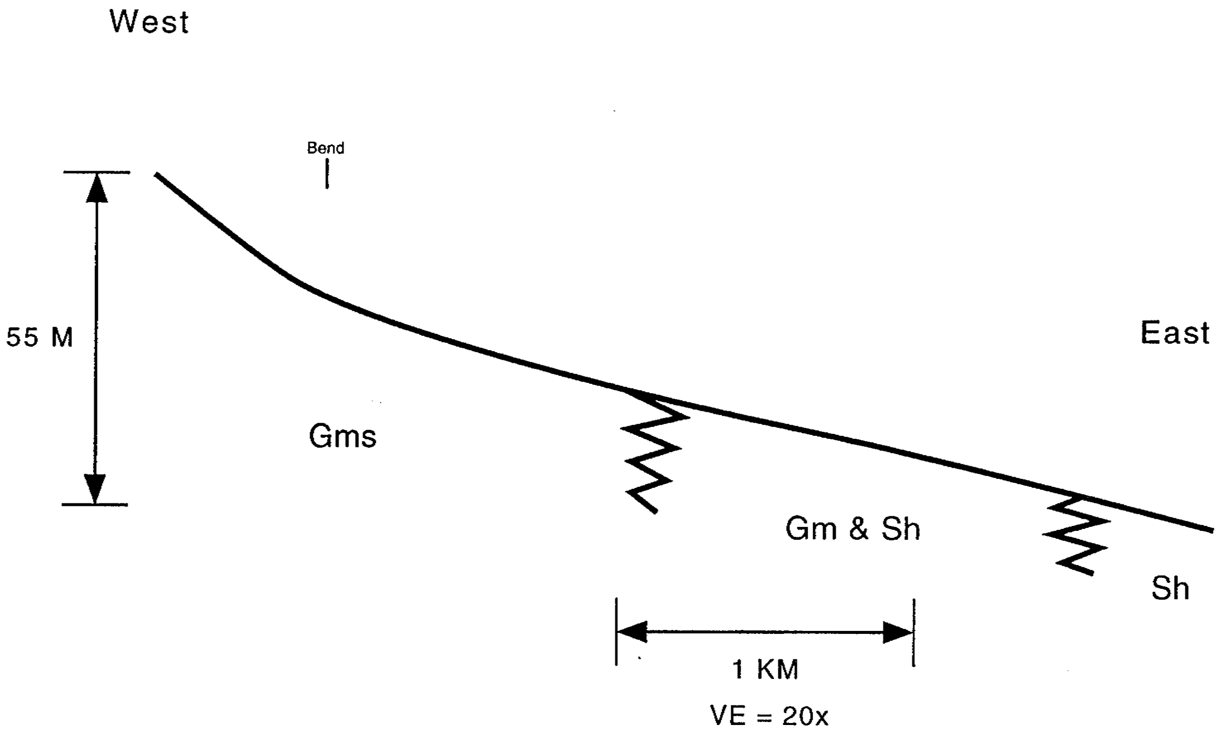


Figure 39. Cross section along Houghton Canyon showing lateral changes in lithology. (Section is located on Figure 37).

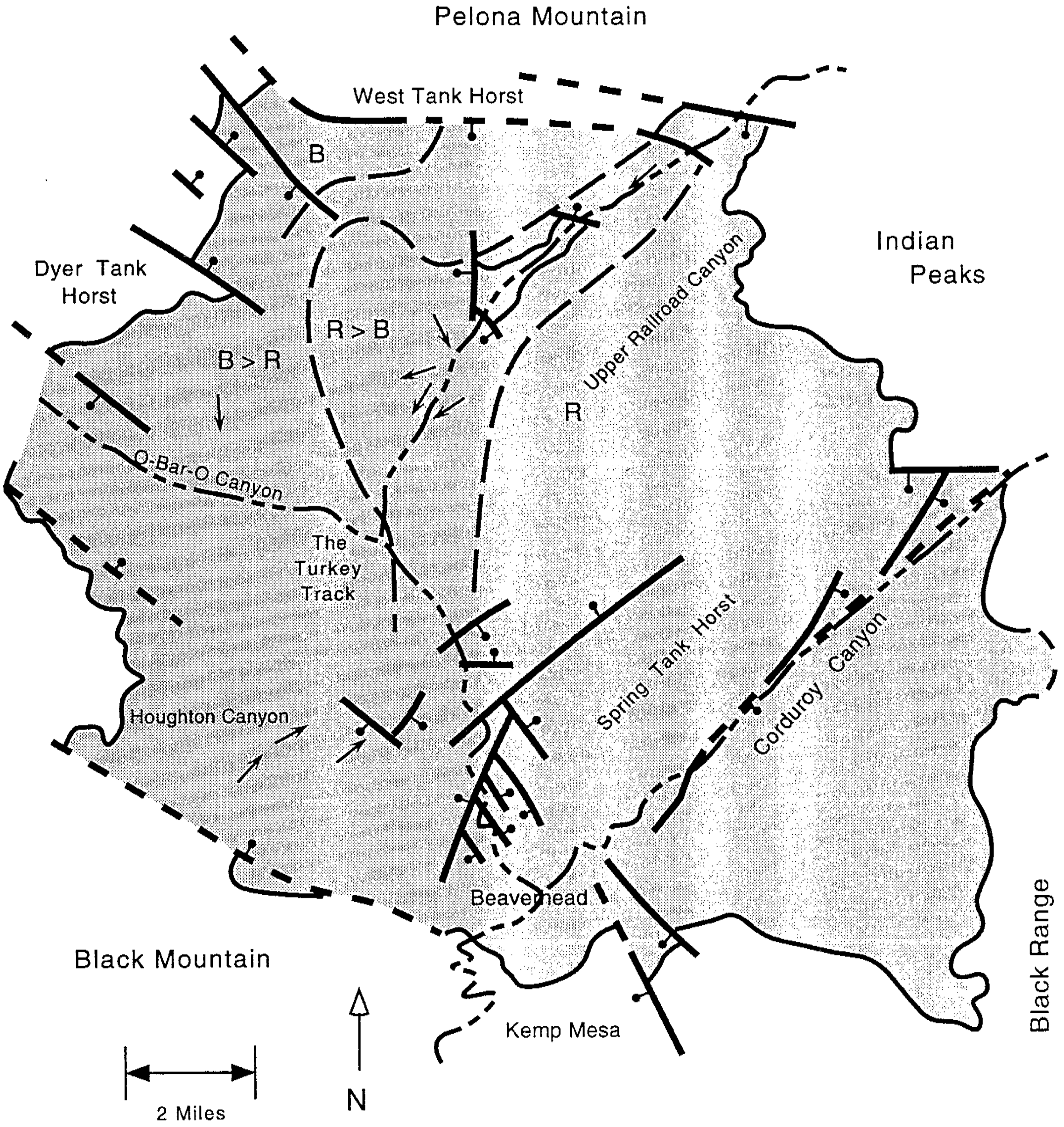


Figure 40. Map of the Railroad Canyon basin showing relative clast composition across the northern portion of the basin. (R = rhyolite, R > B = rhyolite predominating over basalt, B > R = basalt predominating over rhyolite, B = basalt. Faults are shown by bold lines, dashed where inferred. Arrows indicate paleocurrent measurements. Data from the author and from Richter, 1978, 1985, Richter *et al.*, 1986, and Lawrence and Richter 1986).

Figure 41. Gila Conglomerate deposited in channel cut in underlying volcanics in upper Railroad Canyon.

an increase in channelization and, although boulders are present, sand and pebbles dominate. Beds show sparse, low-angle crossbedding (Figure 42).

Interpretation of this basin is significantly different from the previously described basins. Clast composition data show that a zone of mixing occurs along upper Railroad Canyon and it is probable that this modern drainage is heir to prior drainage that existed between two extensive bajadas. The conclusion that a pre-Gila paleovalley existed is further supported by the presence of a coarse-fill channel cut into bedrock basalt. Channelization and low-angle crossbedding in sand and pebble deposits suggests that this area was a low-gradient, axial fluvial system deriving sediments from the opposing fans that hemmed it in between them. It is also possible that Corduroy Canyon is situated in a paleovalley, as indicated by substantial coarse deposits in large channels.

Much unconsolidated sediment remains in the north and center of the basin. There is little in the way of relict coarse material, suggesting that little such material was deposited in this area. It is herein conjectured that this area represents poorly-exposed flood-basin deposits, such as overbank and crevasse splay deposits.

The Railroad Canyon basin appears to be a non-tectonic basin controlled by the outlying eruptive centers and structures that dammed drainage for a time sufficient to

Figure 42. Low-angle crossbedding in Gila Conglomerate along upper Railroad Canyon.

impound a considerable amount of fine-grained sediments. It is possible that two independent events were responsible for the disruption of drainage. It seems that the outflow basalts of Kemp Mesa acted as a barrier to Gila sedimentation, as evidenced by sediments that onlap from both the north and the basin to the south (western slope of the Black Range). The modern trunk drainage has cut a deep (500 ft., 150 m), narrow canyon that sharply meanders through the breach. The cliffs are topped with rounded, poorly consolidated cobbles, boulders, and gravels of basaltic andesite and according to Richter *et al.* (1986) may be gradational with the Gila Conglomerate. This evidence leads to the conclusion that the basin topped over with sediments, then began to drain to the south, and subsequently the outlet incised deep meanders into the underlying volcanics as base level was lowered.

Trunk drainage across the Spring Tank horst (upstream from Kemp Mesa) is also deeply incised in meanders. At present, the ephemeral V-Cross Lake sits at the upstream margin of this structure. The Turkey Track area at the present time is only weakly degradational, and it is plausible that this basin has only recently been re-integrated following impoundment by the post-depositional Spring Tank horst.

The Adobe Ranch Depression

The Adobe Ranch Depression is the northernmost basin in the study area and is bounded by the Continental Divide to the north and east, and Indian Peaks to the southwest (Figure 43). The Continental Divide along the northern and eastern boundaries of the Adobe Ranch depression is a close approximation of Gila Conglomerate formational contact with the Bearwallow Mountain Formation to the north and the Railroad Canyon Rhyolite tuff to the east. The divide is barely perceptible where it forms the northern margin, while it forms an erosive front along the east.

Whereas exposure is scarce in portions of the Railroad Canyon basin, there is a wholesale lack of outcrop across the entire Adobe Ranch depression, and therefore, treatment of this basin will be brief.

This area was named the Corduroy Canyon depression by Elston *et al*. (1970). They discussed flow directions in outlying rhyolites that radiate from the topographic depression and they speculated that the depression might be a cauldron, but concluded that there was no direct geological or geophysical evidence to lend support to their idea. Rhodes and Smith (1972) mentioned the Corduroy Canyon depression but were unable to provide any new evidence for a cauldron. Fodor (1976) invoked fault patterns that "vaguely suggest subsidence." Fodor's choice of the adverb is apropos. He noted that "features commonly characteristic of

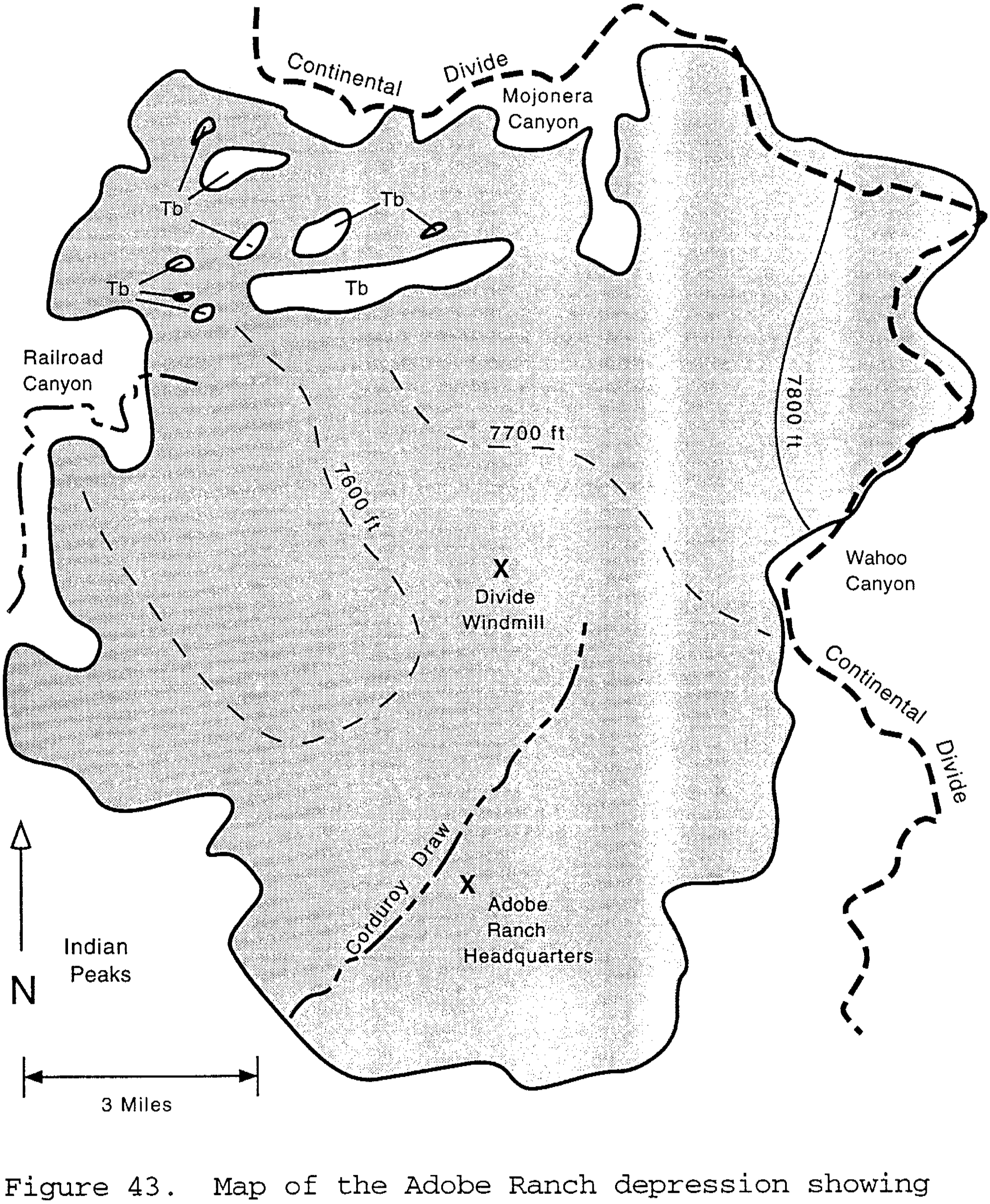


Figure 43. Map of the Adobe Ranch depression showing contours of constructional surfaces (thin lines, dashed where inferred, contour interval = 100ft. Tb = Tertiary basalt).

cauldrons, however, such as a resurgent dome, mudflows, and moat deposits, have not been observed in this area." Elston (1984) proposed a cauldron that did not resurge, but noted that such a proposed structure is poorly documented.

Regardless of the origins of this basin, calling it the Corduroy Canyon depression is a misnomer. Corduroy Canyon lies outside the domain of the depression and the word "canyon" implies streambeds and outcrop, which are virtually nonexistent across the entire basin. The gently rolling topography is draped with a veneer of alluvium, and, in fact, it is not directly obvious if there is any Gila Conglomerate beneath this veneer. Willard (1957) originally mapped the basin as "Gila Conglomerate-Santa Fe group", though it is not clear how he made this distinction. Fodor (1976) mapped the area as "Qtg, Qal." Richter *et al.* (1986) mapped the southwest quarter of the basin as "QTal?", describing this unit as: "Very poorly exposed grayish-red to reddish-brown unconsolidated mud, silt and sand... underlies most of the low hills [and] the extensive low relief country... but everywhere the unit is mantled by a thin veneer of cobbles and gravel.... Unit was apparently deposited in and around an intermittent lake basin that formed prior to development of Corduroy Canyon or at times when Corduroy Canyon was blocked."

With these things in mind I would like to make two observations.

1) Elevations across the Adobe Ranch depression average over 7600 feet (2300 m). This basin sits at a higher elevation than all the other late Tertiary basins that surround it, including the topographically closed Plains of San Agustin to the northwest. Although the Plains of San Agustin contain the remnants of a Pleistocene lake system, the San Agustin basin is probably much older. In 1958-1959 a 2000 foot bore-hole was drilled down into the playa (Foreman *et al.*, 1959). The lower 1000 feet of section closely resembles Gila Conglomerate in texture, color, and structure, and the author believes that this section represents related deposits.

2) Drainage is peculiar in this basin. There is a medial divide and drainage exits either through Railroad Canyon north of Indian Peaks or through Corduroy Canyon south of Indian Peaks, both of which flow into the East Fork of the Gila River (Pacific drainage). The Alamosa system, which drains into the Rio Grande (Atlantic drainage) is encroaching from the east, principally through Wahoo Canyon and Stone Canyon. Mojonera Canyon, which empties into the internally-drained Plains of San Agustin, is making inroads from the northwest. Thus, the scant precipitation that fall on this basin is being contested by three entirely separate drainage systems.

Due to the non-existence of outcrop and subsurface data the evidence for this basin is inconclusive. Perhaps the only insight to be gained from this basin is that of a modern analogue for other basins that had yet to experience degradation.

DISCUSSION

Tectonic Models

Before interpreting the relationships between the basins in the study area, it is worthwhile to introduce a few current avenues of thinking with regards to extensional basins. Recently many workers have begun to abandon the symmetrical horst/graben representations that were prevalent in the 60's and 70's (see Illes, 1981) and to re-emphasize asymmetry in basin architecture. Bally (1982) brought the point to bear:

> "In recent years, after having looked at a number of seismic reflection profiles from various areas, I have been impressed with the dominant asymmetry of rift systems. Half-grabens are the rule, and reflection seismic evidence for symmetrical grabens is virtually absent... In hindsight, it is puzzling why the concept of more or less symmetrical grabens has dominated the geological literature for decades."

Five years later Leeder and Gawthorpe (1987) presented a number of predictive tectono-sedimentary facies models in which various asymmetrical subsidence vectors were explored. Figure 44 illustrates their models for continental half-grabens with interior drainage (A), and axial through drainage (B). Note that the lacustrine and alluvial deposits are located over the zone of maximum subsidence.

Blair (1987), working in nonmarine half-grabens in Mexico noted cyclicity in the sediments and postulated that the cyclicity resulted from shifts in the rates of basin

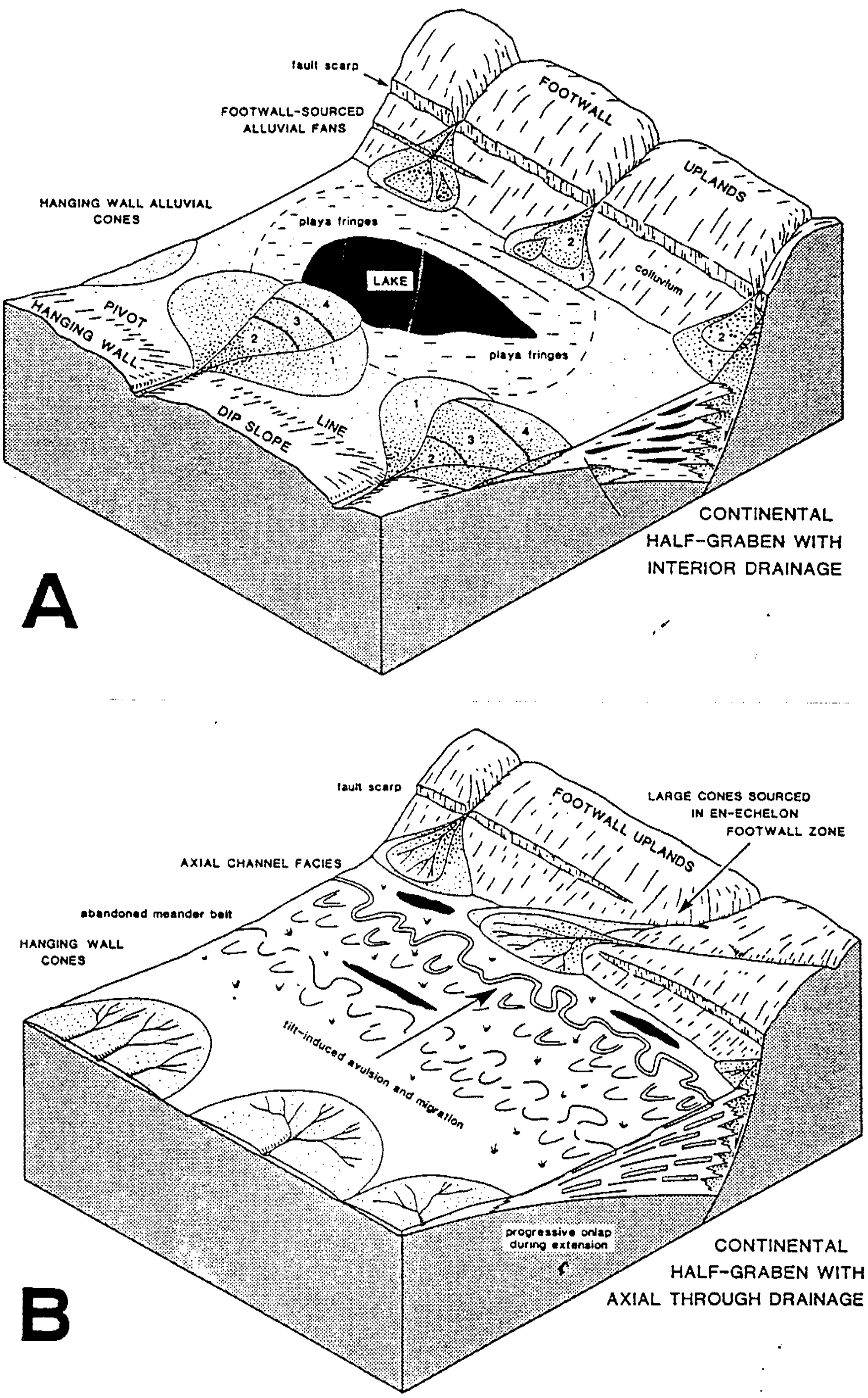


Figure 44. Models for continental half-grabens with A) interior drainage, or B) axial through drainage (from Leeder and Gawthorpe, 1987).

subsidence. He stated, "lacustrine or fluvial environments responded more quickly to periods of active tectonic subsidence and migrated over the fans to occupy the basin-margin depression. Aided by a decrease in basin subsidence, alluvial fans eventually prograded and displaced the fluvial or lacustrine environments away from the basin margin."

Blair and Bilodeau (1988) took issue with the traditional concept that the appearance of coarse-grained basin fill is related to tectonic rejuvenation of the source area. They contended the reverse: that fine-grained deposits overlying coarse-grained deposits are the best indicators of renewed tectonic activity and that progradations of extensive coarse-grained clastic wedges are indicators of periods of tectonic quiescence.

This unorthodox model was tested by Mack and Seager (1990) on Pliocene-Pleistocene sediments of the Rio Grande rift. In two asymmetrical basins the axial-fluvial facies was found to be concentrated near the footwall scarp and transverse piedmont systems on the hanging-wall dip slope occupied a much wider outcrop belt. In a symmetrical basin the axial-fluvial facies was found to occupy a wide belt in the center of the basin and to encroach on both margins. In all three basins a tongue of fanglomerate prograded over the axial-fluvial facies near the end of rapid tectonism. They concluded that their evidence supported two-phase models for asymmetrically subsiding basins - models that delineate a tectonically active period when axial-fluvial systems migrate to the topographic low at the axis of maximum subsidence, and a post-orogenic phase when coarse sediment progrades away from the footwall block, displacing the axial system.

Crews (1990) attempted to construct a numerical model that focuses on the interplay between the evolution of topography, sediment production and subsidence. Uplift provides sediment flux, promoting syntectonic progradation, whereas subsidence inhibits syntectonic progradation as it creates a void that must be filled before progradation can occur. The output of the model is an estimation of the ratio of sediment flux to subsidence in tectonic and non-tectonic phases. The primary assumption of the model is that maximum subsidence occurs adjacent to the location of maximum uplift. The model predicts the occurrence of thick, areally-restricted, slowly prograding footwall-derived sedimentation during syntectonic phases and thin, widespread, rapidly prograding sedimentation during the post-orogenic phase (Figure 45).

In summation the aforementioned models emphasize a zone of maximum subsidence which entrains the basin's axial hydrological system resulting in thick accumulations of fine-grained sediments along the active margin during prolonged rapid tectonism. This zone of maximum subsidence is represented as the intersection of the downward tilted

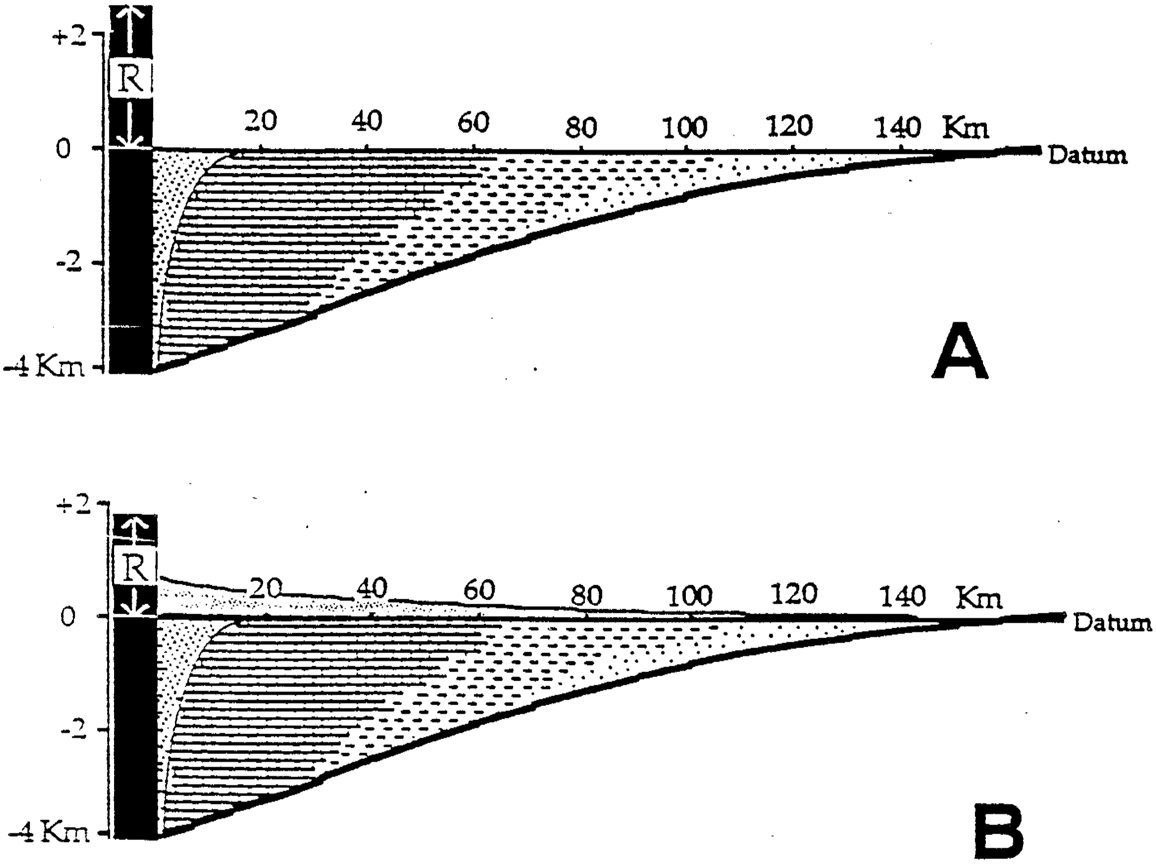


Figure 45. Synthetic stratigraphy of the basin formed in the example model run described by Crews, 1990. A: During this period, subsidence significantly outpaced sediment flux, causing the sediment shed from the rising uplift (stippled pattern) to be deposited in a narrow, slowly prograding band adjacent to the basin margin. B: Same basin, this time a period of tectonic quiescence. The lack of tectonic subsidence associated with this period means that the sediments shed from the mountain belt are free to construct an alluvial ramp above the datum. Rapid progradation is thus seen as a post-tectonic phenomenon. (From Crews, 1990).

block and the footwall.

In the study area, corespondence between field evidence and these models varies from basin to basin.

In the western Mimbres/Sapillo trough the deposits conform well to the models. Large accumulations of axial-type deposits occur along the southern rim of Gila Flat and it is inferred that the master fault for the western part of the basin was located here. Interbedded within these fine-grained deposits are sandstones which represent a net progradation outward from the basin margin and suggest waning tectonism (*a la* Leeder and Gawthorpe, 1987).

Deposits on the western slope of the Black range do not fit the models as closely as those in the western Mimbres/Sapillo trough. Transects up the branches of Diamond Creek and McKnight Canyon yielded similar results. The Gila Conglomerate is thickest along the fault, but fine-grained beds are neither observably thick nor horizontally extensive, and there is no tilting toward the fault margin. The presence of axially oriented channels stacked away from the fault zone suggests that the axial system was trapped only briefly, then migrated away from the master fault.

The basin architecture of the Gila Hot Springs sag is obscured by internal faulting, thus it is difficult to compare this basin to the models. The basal Gila Conglomerate contact steps down to the northeast, creating a asymmetrical depression with the dominant fault along North

Mesa, but Gila deposits along the fault margin are buried by modern alluvial fans.

This Railroad Canyon basin appears to be a non-tectonic basin (that is, a filled paleovalley), hence the extensional models outlined in this section do not strictly apply. Field evidence for the Adobe Ranch depression is too inconclusive to make even a tentative statement concerning basin models.

Paleotectonics

The existence of closely aligned fault swarms that post-date the main stage of Gila deposition suggests that basin structure was defined by at least two separate major events - the onset of Basin and Range faulting that defined the Gila basins, and the subsequent faulting that modified the basins. In almost all cases the blocks show little, if any, rotation and nowhere was angular unconformity observed.

The first event is temporally coincident with Basin and Range extension throughout the west. This event included major faulting that defined basin margins, such as along the western flank of the Black Range, the uplift of Gila Flat, and the Mimbres/Sarten fault. These faults do not appear to be temporally persistent, although that may not be the case with the Mimbres/Sarten fault.

The greatest concentration of post-Gila faulting surrounds Black Mountain, including faults in the Railroad Canyon basin on the northeast flank and faults in the Gila

Hot Springs sag on the southwest flank. Extensive modern deris-flow deposits mark both flanks.

Post- and syn-Gila strain in the Sapillo Creek area is documented by meerschaum veins crosscutting Gila Conglomerate, a growth fault in Rocky Canyon, and parallel calcite veins and small faults in the Gila Conglomerate near Lake Roberts. Local residents reported to the author that they have felt earth tremors near Lake Roberts.

The later faults were perhaps due to the buoyancy of the underlying pluton. The lack of rotation would hint that uplift and subsidence, rather than extension, have been the dominant factors.

Regional Implications

Gilbert (1875) originally stated of the Gila Conglomerate:

> "[It] is distinguished ... by the fact that the water-courses which cross it are sinking themselves into it and destroying it, instead of adding to its depth. It is in relation to the rivers that it is chiefly interesting; in the accumulation and subsequent excavation of the beds, there is recorded a reversal of conditions, that may have a broad meaning... There is no difficulty comprehending he present action, for it is the usual habit of swift-flowing streams to cut their channels deeper; but to account for the period of accumulation there must be assumed some condition that has ceased to exist."

That condition was reversed when the sediment supply could no longer overwhelm the transportational capacity of the streams. This circumstance could have been due to several influences, such as the integration of previously closed drainages, lowering of base level downstream, waning tectonism and subsidence, and/or climatic effects.

The widespread volcanism and intense faulting that characterized the middle and late Tertiary throughout the region undoubtedly caused major disruption of drainage. However, within the study area, the lack of closed basin deposits (playa or lake deposits) in the Gila Hots Springs sag, the Western Slope of the Black Range, and the Railroad Canyon Basin indicate that, 1) the basins overtopped and kept up with disruptive influences, or 2) previous drainage kept up with disruptive influences by downcutting. In either circumstance it appears that the drainage of these basins was well established by the time downcutting began.

Lowering of regional base level probably was not a factor in instigating downcutting. The headwaters of the Gila River gather near the Gila Hot Springs, flow southward through a deep canyon, pick up the drainage of Sapillo Creek, turn westward through a deep gorge, and eventually drain into the Mangas graben, a large, northwest-trending asymmetrical basin situated off the southwestern front of the Mogollon plateau. This area was studied by Leopoldt (1981), who described playa lake deposits in the center of the basin. According to Leopoldt, this lake freshened and considerably expanded in late Pliocene and early Pleistocene time. At this time the Safford lake system also expanded, nearly tripling in size (Cooley, 1968) and becoming by far the largest lake in the region. This would imply that base level was not being lowered.

A more likely explanation is waning tectonism. During active tectonism subsidence induced aggradation, but sediment supply was sufficient to keep pace. After tectonism, sediment supply dwindled, while erosion continued to flush detritus from the basin.

Climatic factors may also be responsible for inducing degradation. Plio-Pleistocene global climatic changes responsible for glaciation and the expanision of lakes may have provided higher levels of precipitation and increased the transportational capacities of streams.

Paleogeography

So what was the relationship between these basins? Perhaps the best place to begin is at the topographically lowest basin and the staging area for the modern drainage - the Gila Hot Springs sag.

The Gila Hot Springs sag has a very deep (>2000 ft, 600 m) outlet canyon and narrow floodplains and tributary canyons, indicating persistent downcutting. There are no lake sediments and no other substantial deposits of fine-grained sediments in this area, and it is likely that this was a through draining basin for a considerable period of time.

It is possible, but unlikely, that this basin drained into the Mimbres/Sapillo trough, which contains the largest collection of fine-grained sediments in the study area. The Gila Hot Springs sag has been heavily faulted after Gila deposition and has collapsed into its present structurally low position. Prior to this it might have drained toward the Black Range basin and collectively these two basins could have drained into the Mimbres/Sapillo trough. This would have been possible through one of three breaches in the Gila Flat: a) the broad saddle at the head of Copperas Creek (7200 ft, 2190 m), b) the narrow saddle to the west of Middle Mountain (7350 ft, 2240 m), and c) the broad saddle at Brannon Park (7550 ft, 2300 m). This does not seem likely, because Gila Conglomerate constructional surfaces nowhere in the vicinity exceed these elevations.

In contrast to the Gila Hot Springs sag, the western slope of the Black Range still bears the imprint of drainage during Gila depositional time. The relict bajada is expressed by broad flat mesas that slope to the west. This area is drained by parallel east-west streams incised into the former bajada. The western margin of the basin is truncated by the erosion of the East Fork of the Gila River, which cuts a broad, deep valley through this stretch. Interbedded mudstones along the margin of this valley suggest the former presence of an axial system. Thus, in this area, it appears that modern drainage is similar to paleodrainage.

The onlapping relationship of Gila sediments onto the broad lava flow at Kemp Mesa from the north suggests that the Railroad Canyon basin was initially isolated but overtopped. Subsequently, the ancestral axial drainage developed a highly-sinuous, meandering channel. This channel was later incised, suggesting lowered local base levels or uplift. Another retardant to the downcutting of the Railroad Canyon basin is the Spring Tank horst, which currently dams the V-Cross Lake, the only consequential lake in the study area unassisted by human engineering, attesting to the recency of this obstruction. It appears that the basins furthest upstream (Railroad Canyon and Adobe Ranch) were periodically impounded even after they overtopped.

In the Adobe Ranch depression the sedimentary budget has only recently switched from aggradational to degradational, and there is still a great deal of unconsolidated sediment in storage. Downcutting has been minimal, the system is only weakly degradational, and the area conveys the aspect of being in the earliest stage of exhumation. Richter *et al*. (1986) stated that the basin fill was "deposited in and around an intermittent lake basin that formed prior to the development of Corduroy Canyon or at times when Corduroy Canyon was blocked." Their first choice seems more likely because Corduroy Canyon is coincident with the southeastern fault that bounds the largely post-Gila Spring Tank horst. In a round about way, this further attests to the recency of this structure.

This leaves the Sapillo/Mimbres trough. The primary conundrum of this basin is the fact that currently the Continental Divide cuts through the middle of the basin and drainage empties in two opposite directions. This was certainly not the case during the bulk of Gila depositional time. So what happened? There are two possibilities: 1) the highly productive central clastic wedge prograded across the basin until it abutted the distant topographic wall, thus dividing the basin, or 2) central uplift arched the basin. In support of the second scenario, Elston *et al.* (1968) recognized a north-trending structure along the southern Mogollon plateau which they called the Santa Rita-Hanover axis. Aldrich (1972) traced this axis further north, bringing it up the spine of the modern divide as it crosses this basin. He concluded from joint patterns within the Gila Conglomerate that stresses were persistent through the early Quaternary and resulted from reactivation along the axis. Drainages on both sides of the divide parallel the axis and this pattern may be due to step faults shed off the uplift axis.

The steepest trunk stream gradient throughout the study area is along Sapillo Creek, just upstream from its confluence with the Gila River. This gradient is roughly 140 feet per mile, while other gradients in the study area are <50 feet per mile, except near headwaters. This anomalous gradient, coupled with the fact that the nickpoint along Sapillo Creek (near its confluence with the Gila) has not moved appreciably upstream, suggest that this system is far from equilibrium.

These observations lead to the following conjecture: originally this basin was impounded, then overtopped and drained westward, then arching divided the basin.

What follows is a synopsis of interpretations of geological events, although the lack of geochronologic constraints makes these reconstructions conjectural.

Approximately 21 Ma major faulting throughout the area tilted the interior plateau down to the east against the Black Range uplift (Figure 46). This plate fractured to the north and south of the Gila Flat uplift. Drainage south of the Gila Flat was impounded. Drainage north of Gila Flat exited to the southwest after being deflected by the lava flows of Black Mountain. It appears that the furthest upstream basins (Railroad Canyon and Adobe Ranch Depression) were impounded temporarily by the pre-Gila lava flows of Kemp Mesa.

After a relatively long period of tectonic quiescence the northern basins overtopped, and a low-gradient trunk drainage system developed tight meanders (Figure 47). Previously impounded drainage to the south overtopped and exited to the west.

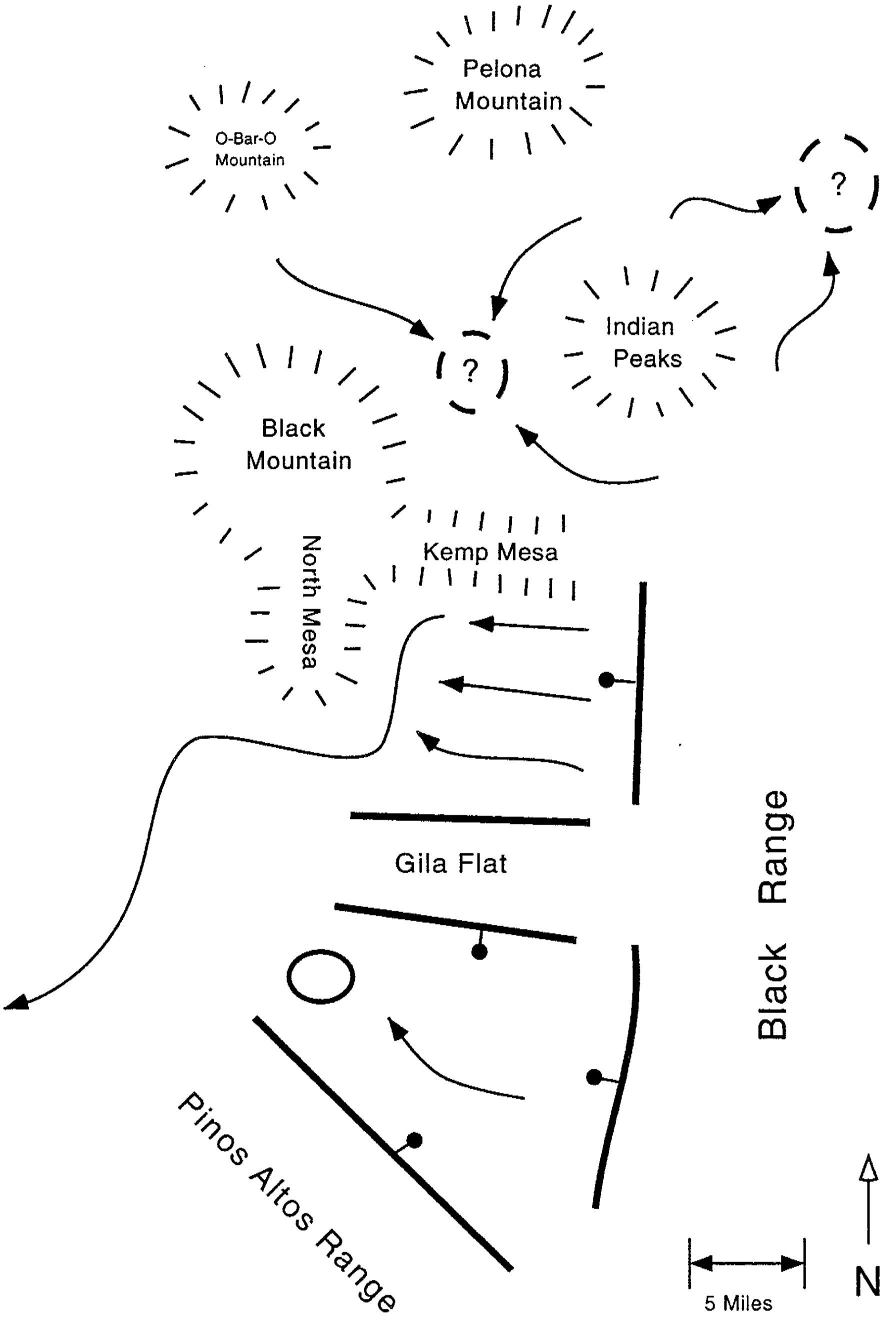


Figure 46. Paleogeography of the early stage of basin development. (Bold lines indicate active fault scarps).

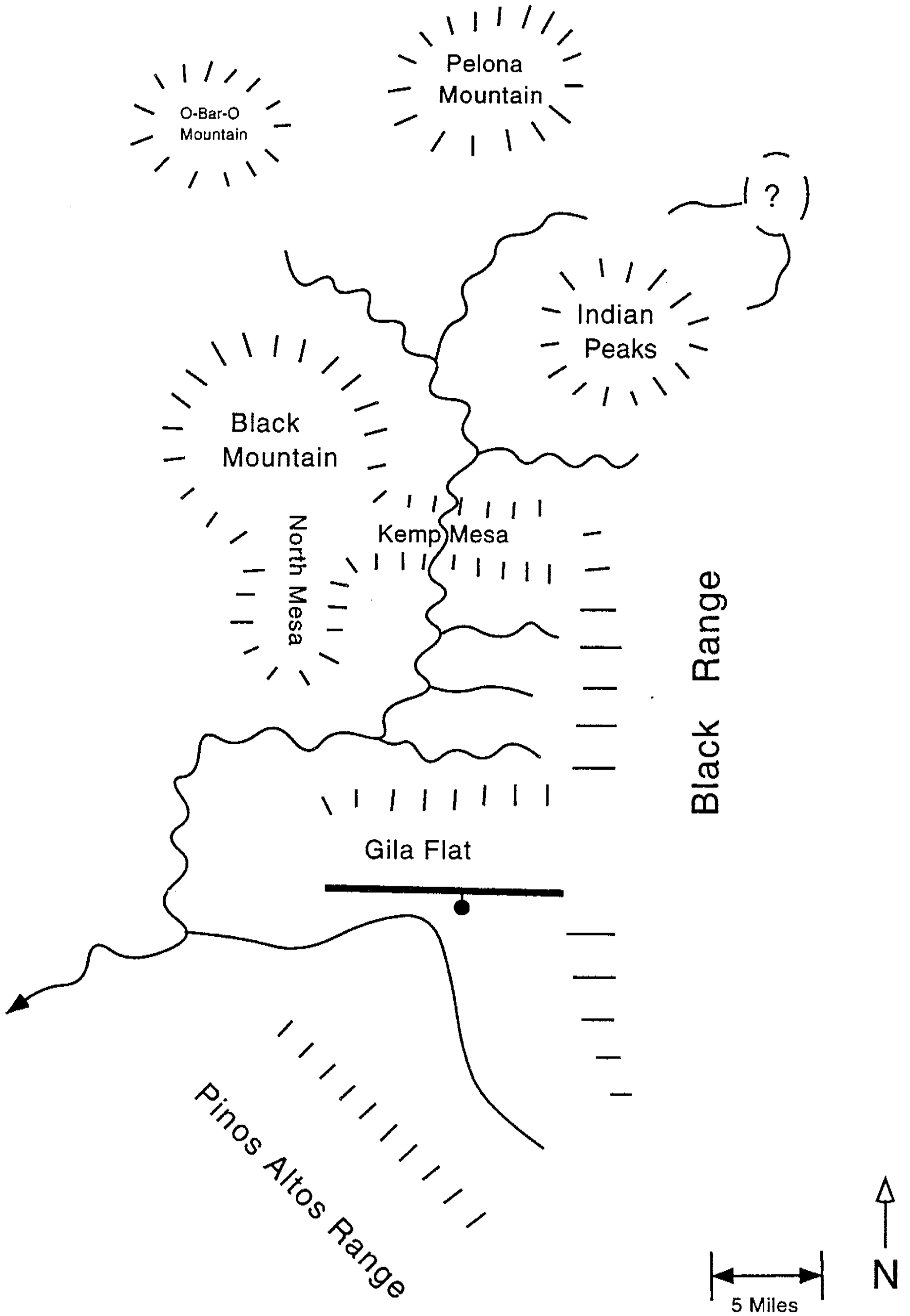


Figure 47. Paleogeography of the middle stage of basin development. (Bold line indicates active fault scarp).

Still later, deformation caused impoundment of the two northernmost basins and arching along the modern Continental Divide spilt the drainage in the Mimbres/Sapillo trough (Figure 48).

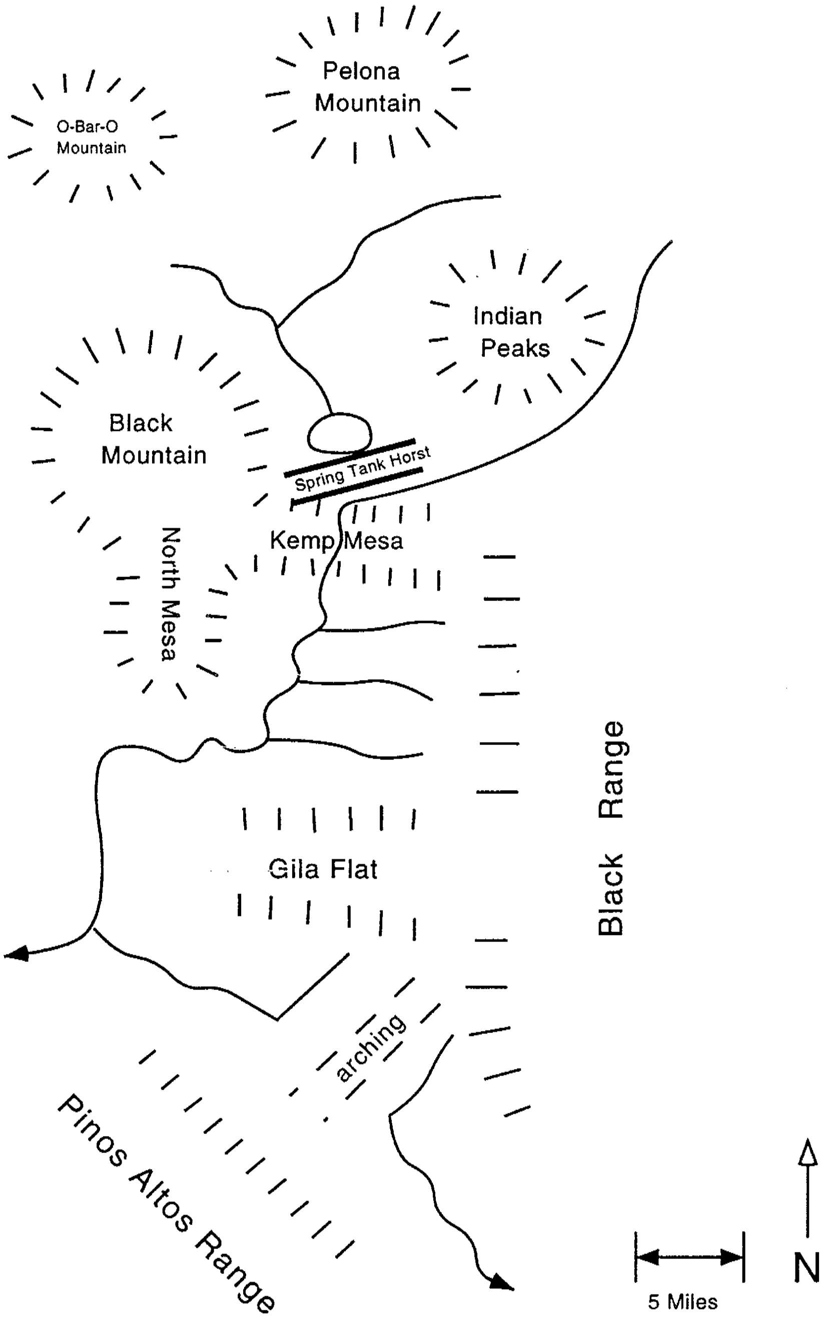


Figure 48. Paleogeography of the late stage of basin development. (Bold line indicates active fault scarp).

CONCLUSIONS

The study area shows at least two phases of tectonism during the Neogene Period. It appears that the Basin and Range event initiated basin development in the study area. Superimposed on this regime were later, more closely spaced faults. The lack of significant rotation in all the blocks would suggest that subsidence and uplift, rather than tilting has been the dominant factor.

The stratigraphy of the two northernmost basin is obscure due to lack of outcrop. In the southern basins, where outcrop is more abundant, the stratigraphy reveals a somewhat orderly pattern. In most cases, moving away from basin-margin faults are: 1) a thin zone of tuffaceous sandstone, 2) a zone of matrix-supported debris-flow deposited conglomerates that interfingers with 3) a zone of fluvially deposited clast-supported conglomerates that grades into a broad zone of interbedded conglomerates and sandstones, with the conglomerates less conspicuous away from the fault.

This progression conceptually fits the model of Leeder and Gawthorpe (1987), but in a restricted sense. The tuffaceous, fine-grained units along the basin margin faults are inconsequential compared to the predictions of the model. The transect along the Military trail better conforms to the model, having a significant quantity of finer-grained deposits found along the basin margin fault.

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This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Adviser

10/20/94

Date