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Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
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Ceil fall
Volcanics

Resurgent Cauldrons

ROBERT L. SMITH AND ROY A. BAILEY,

U. S. Geological Survey,
Washington, District of Columbia

Technical - Volcanology

SOCIETY OF

Dear Mr. Kurtz:

Ben Donegan told me you might be interested in this. You and others from Asarco are cordially invited

Sincerely,

Wolf Elston

File Technical Volcanology

RECEIVED
MAY 23 1973
S. W. U. S. EXPL. DIV.

May 14, 1973

Dear Mr. Kurtz,

In response to several requests for tours through the Mogollon-Datil Volcanic Field, an informal field trip will be run from Tuesday, May 29 through Saturday, June 2, 1973. You are cordially invited to come for all or any part of it. This invitation also applies to any of your associates who might want to come. The purpose of the trip is to examine our model of the Mogollon Plateau as the surface expression of a pluton. We will examine the various stages of volcanism and tectonism, with special emphasis on timing of events and their implication in plate-tectonic models and economic mineralization.

The first day will be led by Edmond G. Deal, who is completing a doctoral dissertation on the Mt. Withington Caldera in the San Mateo Mountains. I will lead the other three days, aided and abetted by anyone willing and able.

Please fill out the attached questionnaire, so that we can plan the trip and make sure that there are enough seats in vehicles. Please make your own motel reservations. We will be driving on dirt roads part of the time, but four-wheel drive is not required. An ordinary car will make it.

The itinerary shown here is tentative. If there is insufficient demand for any days or days, it (they) may be cancelled.

Tuesday, May 29: 1 PM

Meet at University of NM, Northrop Hall (Geology Bldg), Rm 316B, for an orientation session.

Accomodations: Many motels. Midtown Holiday Inn, Hilton Inn, Four Seasons Motor Lodge, Western Skies, area near campus: Hiway House, is inexpensive, ask for commercial discount (phone 505-268-3971).

Wednesday, May 30th: Leave Albuquerque at 8:00 AM for San Mateo Mountains. Examine Mt. Withington ash-flow tuff cauldron (resurgent dome, moat deposits, ring fractures and associated domes.)

Accomodations: Ranchman's Inn, Magdalena, NM (505) 854-9910.
Camping: Datil Campground

Thursday, May 31: Magdalena - Beaverhead - Mimbres - Silver City. Examine Railroad Canyon Rhyolite ash-flow tuff and traverse its possible source, the Corduroy Canyon Depression. Domes of tin-bearing Taylor Creek Rhyolite ("cauldron lava") near Beaverhead. Examine Rhyolite of Rocky Canyon (framework lava). Contrast between "framework rhyolites" (those that are derived directly from the inferred pluton) and "cauldron rhyolites" (associated with ash-flow tuff cauldrons, interpreted as derived from shallow secondary magma chambers). Limestone outcrops near Terry Canyon, an expression of the Santa Rita-Hanover Axis.

Accomodations: Holiday Inn, (505) 538-3711 or Drifter Motel, (505) 538-2916 Silver City. Camping: Cherry Creek or Walnut Creek Campgrounds.

Friday, June 1: Silver City - Pinos Altos - Gila Cliff Dwellings National Monument - Black Range - Groundhog Mine (near Vanadium, NM). Contrast volcanic section east and west of Santa Rita-Hanover Axis. Tadpole Ridge Quartz Latite ash-flow tuff; Alum Mountain-Copperas Peak andesitic center; fumarolic hydrothermal alteration; Bloodgood Canyon and Jordan Canyon Rhyolites; early basaltic andesites (Alum Mountain, Bear Springs) late basaltic andesites (Double Springs, Bearwallow Mountain).

Dated basaltic rocks interbedded with Gila conglomerate are indicators of timing of Basin and Range faulting. Megabreccias in vent zone of Kneeling Nun Quartz Latite ash-flow tuff are contrasted with differentiated outflow part of Kneeling Nun ash-flow tuff sheet.

Accomodations: Same as third day.

Reference: Elston, W. E. and Kuellmer, F.J., 1968, Road Log, second day, Arizona Geological Society Guidebook of Southern Arizona III, p. 266-294.

Saturday, June 2: Silver City, Gila, Glenwood, Mogollon, Mogollon Mountains. Altered area at mouth of Gila Canyon (near Gila, NM); Glenwood and Catwalk (Whitewater Creek Rhyolite and Cooney Quartz Latite ash-flow tuffs); Mogollon mining district; structure of Bursum Cauldron (Apache Spring Quartz Latite ash-flow tuff); framework and cauldron rhyolites. Return to Albuquerque.

I hope you will be able to join us. If you can't make the entire trip, come for part of it. Come when you can and leave when you must. If you have any questions, please call me at (505) 277-5339.

Sincerely,

Wolf

Wolfgang E. Elston
Professor of Geology

WEE:nar
Encl. -

will
I will not attend the volcanic field trip.

There will be_____persons in my party.

will
I/we will not provide our own transportation.

I/we can give rides to____more persons.

camping
I/we will be staying in motels.

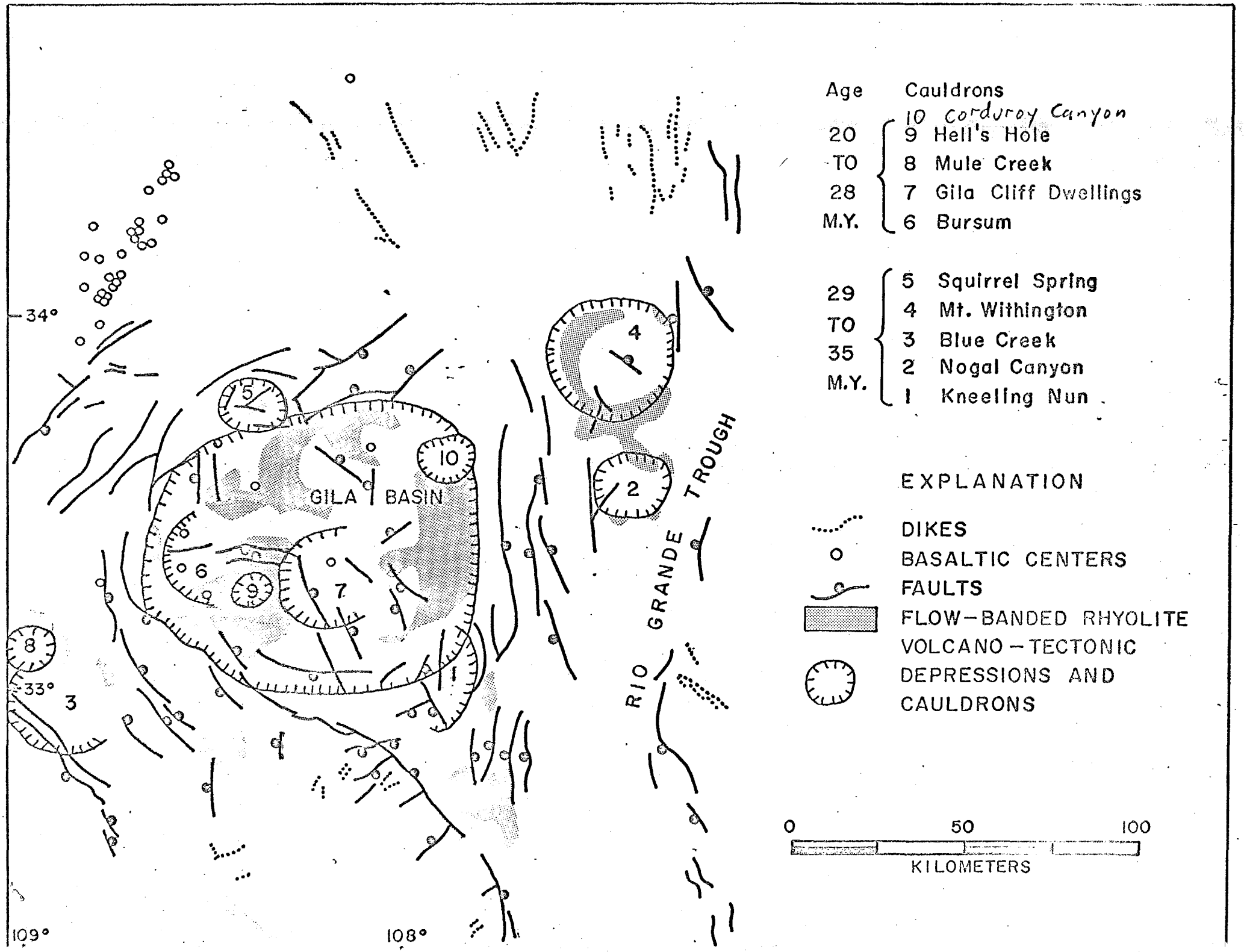
I/we will come for May 29
May 30
May 31
June 1
June 2

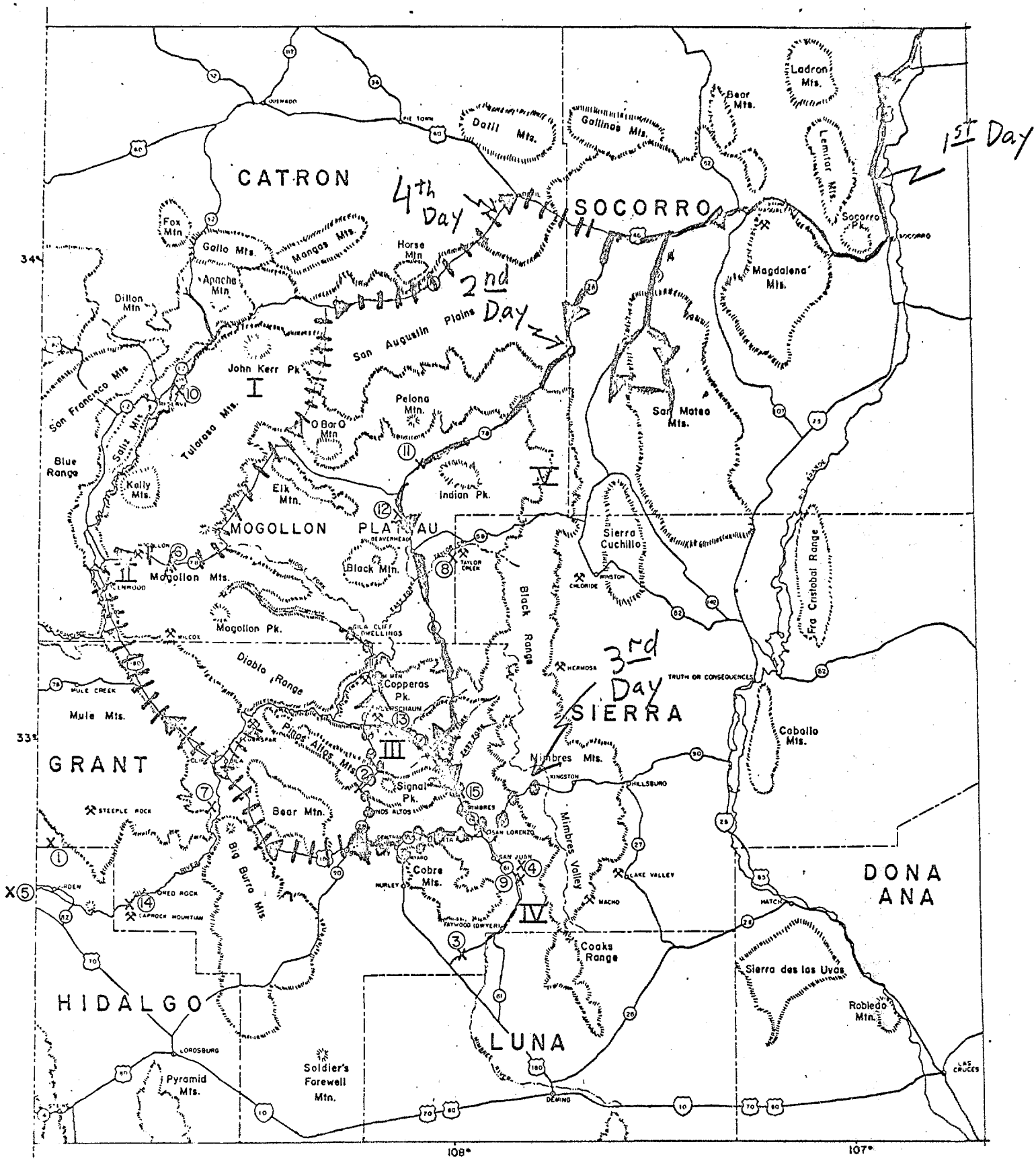
Remarks:

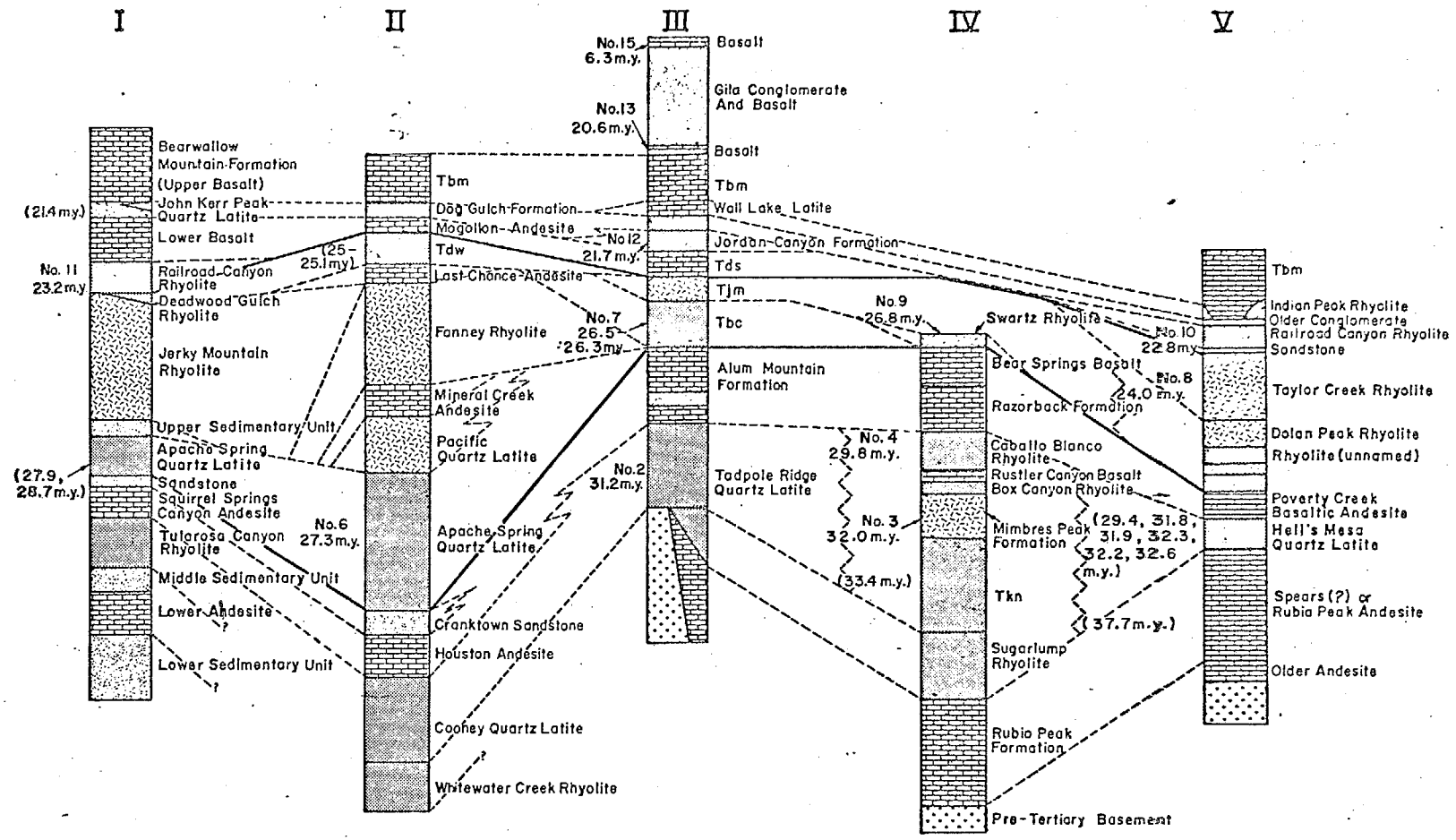
Name:_____

Address_____

Phone_____


Age
Cauldrons
10 Corduroy Canyon
20 TO 28 M.Y.
9 Hell's Hole
8 Mule Creek
7 Gila Cliff Dwellings
6 Bursum
29 TO 35 M.Y.
5 Squirrel Spring
4 Mt. Withington
3 Blue Creek
2 Nogal Canyon
1 Kneeling Nun
EXPLANATION
DIKES
BASALTIC CENTERS
FAULTS
FLOW-BANDED RHYOLITE
VOLCANO-TECTONIC DEPRESSIONS AND CAULDRONS
0
50
100
KILOMETERS
GILA BASIN
RIO GRANDE TROUGH
34°
33°
109°
108°


CATRON
SOCORRO
GRANT
HIDALGO
LUNA
DONA ANA
SIERRA
MOGOLLON PLATEAU
Datil Mts.
Gallinas Mts.
Bear Mts.
Ladron Mts.
Lemitar Mts.
Socorro Pk.
Magdalena Mts.
San Mateo Mts.
Sierra Cuchillo
Fra Cristobal Range
Caballo Mts.
Sierra des los Uvas
Robledo Mtn.
Cooks Range
Mimbres Mts.
Mimbres Valley
Black Range
Copperas Pk.
Signal Pk.
Cobre Mts.
Bear Mtn.
Big Burro Mts.
Pinos Altos Mts.
Diablo Range
Mogollon Mts.
Mogollon Pk.
Black Mtn.
Indian Pk.
Elk Mtn.
Pelona Mtn.
O Bar O Mtn
San Augustin Plains
Horse Mtn
Mangas Mts.
Gallo Mts.
Fox Mtn
Apache Mtn
Dillon Mtn
John Kerr Pk
San Francisco Mts
Tularosa Mts.
Saliz Mts.
Blue Range
Kelly Mts.
Mule Mts.
Pyramid Mts.
Soldier's Farewell Mtn.
Cookes Range
1st Day
2nd Day
3rd Day
4th Day
SCALE IN MILES
SCALE IN KILOMETERS
Location of samples in table I
Location of columnar section in figure 2
NEW MEXICO
108°
107°
34°
33°



EXPLANATION

Pre-Tertiary basement

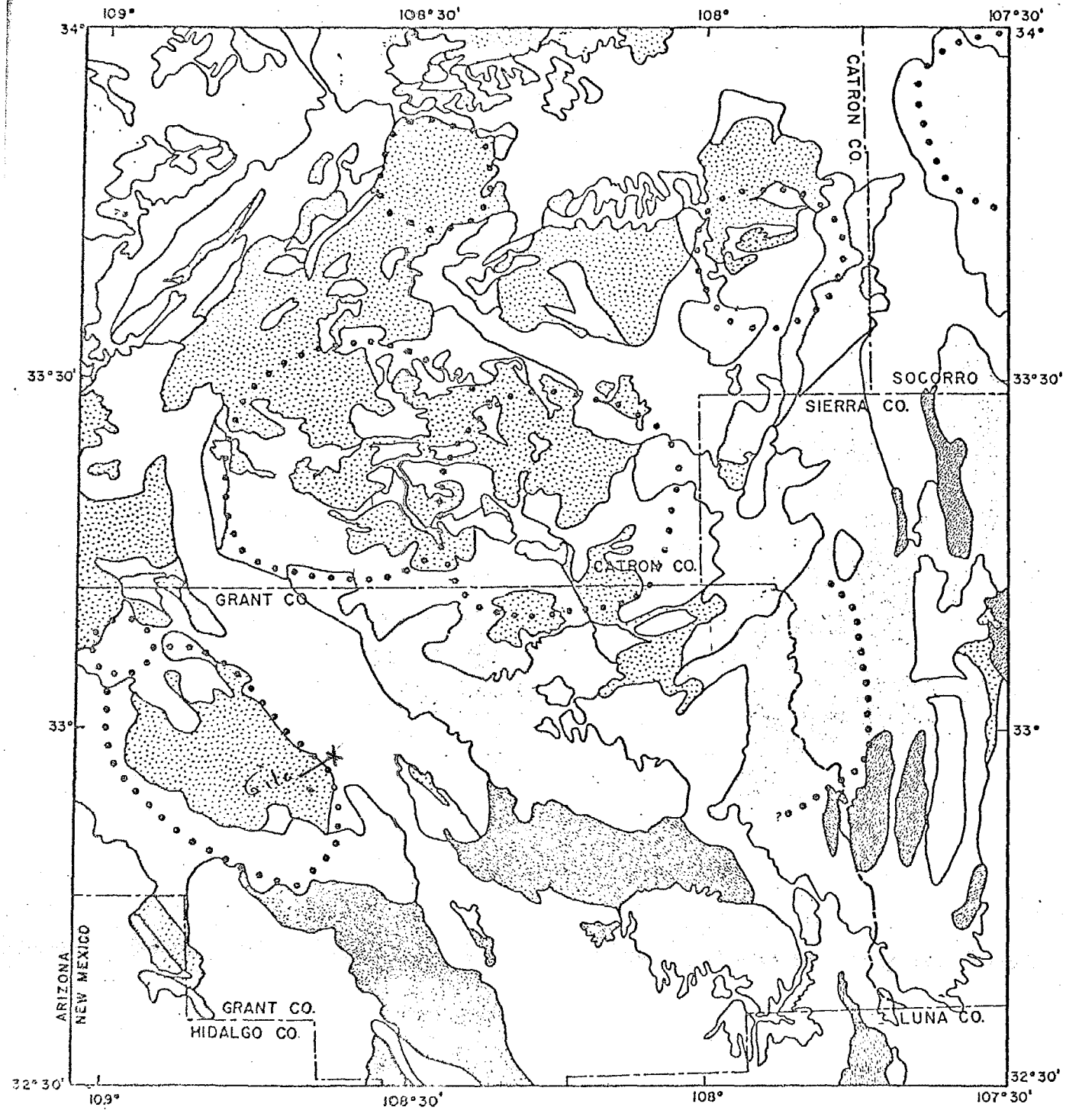
Mafic and intermediate lava flows

Felsic lava flows

Felsic ash-flow and air-fall tuffs

Clastic rocks

Tbm – Bearwallow Mountain Formation
Tdw – Deadwood Gulch Rhyolite
Tds – Double Springs Andesite
Tjm – Jerky Mountain Rhyolite
Tbc – Bloodgood Canyon Rhyolite
Tkn – Kneeling Nun Quartz Latite



EXPLANATION

Miocene, Pliocene, Pleistocene and Holocene	Basin fill *Gila Conglomerate and minor basalt; terrace gravel, alluvium; felsic volcanic rocks near 108°52'32" W, 33°7'30" N; post-21 m.y.*	TERTIARY AND QUATERNARY
Miocene	Basaltic andesite *Third volcanic cycle, may include some rocks of second volcanic cycle near Arizona line; 20-22 m.y.*	TERTIARY
	Rhyolite *Third volcanic cycle; 21-23 m.y.*	
Oligocene and Miocene	Rhyolite and andesite *Second volcanic cycle; 23-28 m.y.*	
Eocene(?) and Oligocene	Andesite, quartz latite, and rhyolite *First volcanic cycle; 28-38 m.y.*	
	Basement rocks, undivided *Precambrian crystalline rocks, Paleozoic and Cretaceous sedimentary rocks, late Cretaceous and early Tertiary igneous rocks*	
	Cauldron margin	

MILES
0 5 10 15 20
0 8 16 24 32
KILOMETERS

TERMINOLOGY AND DISTRIBUTION OF ASH FLOWS OF THE MOGOLLON – SILVER CITY – LORDSBURG REGION NEW MEXICO[1]

By

Wolfgang E. Elston
University of New Mexico

INTRODUCTION

The New Mexico part of Field Trip No. 1 of the 1968 meeting of the Cordilleran Section, Geological Society of America, will traverse at least three distinct ash-flow provinces: (1) The western part of the Mogollon Plateau, seen late on the first day and on the morning of the second day in the Mogollon and Pinos Altos Mountains and around the Gila Cliff Dwellings National Monument, Stops 9-14; (2) the Mimbres province, seen on the afternoon of the second day, Stops 15-18, and (3) the southwestern corner of New Mexico, seen on the morning of the third day, Stop 19 (Fig. 1).

All three provinces have been studied in piecemeal fashion, resulting in confused terminology and correlation. This article will attempt to clarify old stratigraphic terms, define new ones not previously published, and suggest correlations. It is a progress report and an expression of one man's opinions. The only point on which all workers agree is that a great deal more needs to be done.

In preparing this summary, I have benefitted greatly from discussion with my co-workers, especially Dr. Peter J. Coney, Middlebury College, and Mr. Rodney C. Rhodes, University of New Mexico. They have permitted me to draw freely from their field observations, but I take sole responsibility for interpretations.

HISTORICAL BACKGROUND

G. K. Gilbert (1875) first described the great quantities of rhyolites among the Tertiary volcanic rocks of southeastern Arizona and southwestern New Mexico, and Lindgren (*in* Lindgren, Graton and Gordon, 1910) first recognized a prevailing sequence of andesite-rhyolite-basalt. He explained it by invoking fractionation of andesite magma into rhyolitic and basaltic fractions by liquid immiscibility, a process popular in his native Sweden in pre-Bowen days. Andesites tend to fill deep basins between major Laramide porphyry centers such as Morenci and Santa Rita. Because the pioneer geologists were mainly concerned with mining camps they failed to see the thickest andesite sections, leading to the myth of a bimodal rhyolite-basalt province that has lingered into our day.

Most of the older geologists regarded Tertiary volcanic rocks as overburden of Laramide metal deposits and wall rock of Tertiary ones. None were volcanologists and none recognized ash flows, although some, like Paige (1933) wondered how supposedly viscous rhyolite "lavas" could travel tens of miles down gradients of less than 100 feet per mile.

In 1950 the New Mexico Bureau of Mines and Mineral Resources began a systematic program of detailed mapping of selected areas of volcanic rocks and reconnaissance mapping of wider area. This work involved not only permanent members of its staff but graduate students and their professors. The then Director of the Bureau, Eugene Callaghan, had previously become familiar with "welded tuffs," as ash-flow tuffs were generally called between the publication of Iddings (1899) and Smith (1960), in the Great Basin. He introduced a great many geologists (myself included) to their existence and problems. His own concepts were summarized in 1953. Simultaneously with work by members of the State Bureau of Mines, the U.S. Geological Survey undertook detailed geologic mapping in the Santa Rita – Silver City mining area under the late Robert M. Hernon and William R. Jones. After a promising start, most of this work, both state and federal, was not completed and had ceased by the late 1950's. My current program began in 1964 and is oriented

1. Research supported by NASA grant NGR-32-004-011.

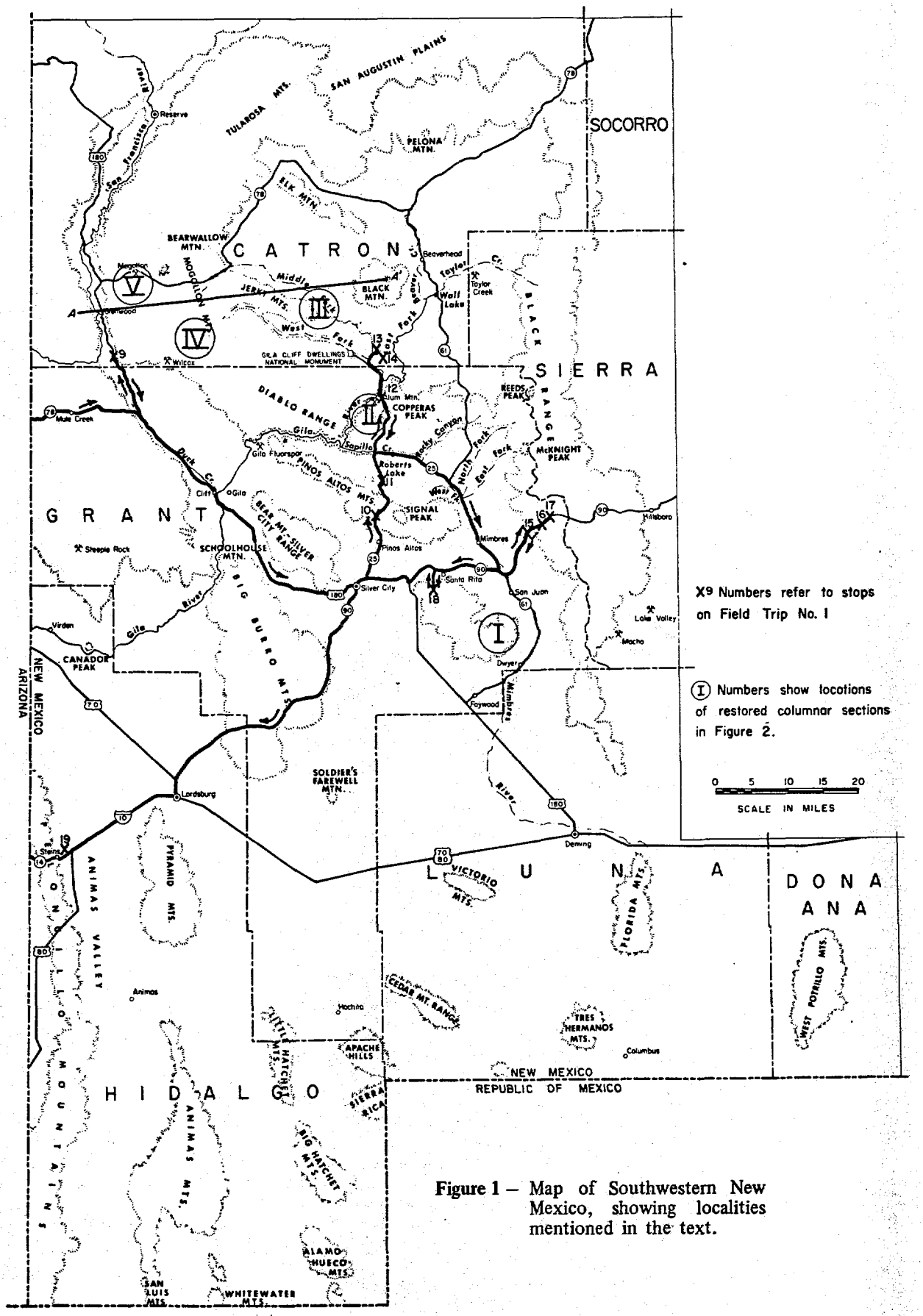


Figure 1 – Map of Southwestern New Mexico, showing localities mentioned in the text.

toward the role of large-scale volcanism in the evolution of crusts of this and other planetary bodies. Its purpose has been explained elsewhere (Elston, 1964, 1965).

The Mogollon Plateau and Mimbres Provinces

Work prior to 1960 is summarized on the Geologic Map of New Mexico (Dane and Bachman, 1965). The discussion which follows relates to symbols on this map, because it is the basic reference work which most geologists would use. Eight volcanic rock units are shown in the Mogollon Plateau and Mimbres Provinces, and all can be seriously questioned. This criticism is not directed against the persons who compiled the map, but against the circumstances under which it was done. Actual field work was either detailed mapping by graduate students, who commonly lacked the necessary experience, or reconnaissance mapping by professionals who had insufficient time to cover the vast and difficult terrain assigned to them. As a participant in both programs, I can attest to the shortcoming of the material handed to the compilers, who were themselves unfamiliar with the region.

Another factor was the lack of K-Ar dates; long-range correlations were largely a matter of guesswork. In general, the compilers correlated rock types, keeping close to the well-known sequence of andesite-rhyolite-basalt. Exceptions were recognized but could not be evaluated. As a result the map units are compromises, rationalized on the explanation sheet by disclaimers.

The first K-Ar dates from southwestern New Mexico were published in 1964 (Weber and Bassett, 1964, Burke and others, 1964). Thirteen additional dates, obtained during the past two years at the Geochronology Laboratory, University of Arizona, are so important that it will take an entire article to explain them (Bikerman, Damon, and Elston, in preparation). However, the raw data were made available by Damon and others (1966) and are used here.

The symbols used on the Geologic Map of New Mexico (Dane and Bachman, 1965) for the Mogollon Plateau and Mimbres Provinces are, in order of age:

(1) Kv: This symbol is correctly applied to Cretaceous andesite breccias around Pinos Altos, which are intruded by mineralized porphyries of Laramide age, confirmed by a K-Ar date (McDowell, 1966). Southeast of Morenci, Arizona, boulders of andesite and dacite in sediments containing plant fossils of latest Cretaceous age (Erling Dorf, personal communication, Pradhan and Singh, 1960) shows that the assignment of Cretaceous age to a broad belt of apparently older volcanics is not without grounds. However, a K-Ar age of 34.7 ± 1.0 m.y. was obtained from this region (Damon and others, 1966). It is not yet known whether the discrepancy is due to a mid-Tertiary period of hydrothermal alteration associated with mineralization in the Steeple Rock mining district or, more likely, to an error in reconnaissance mapping by Elston (1960). The rocks in question contain only a few thin ash flows.

(2) Ta: This symbol is locally used for Tertiary "andesite, basalt, and latite flows and pyroclastic rocks." The intention seems to have been to separate the andesites below thick rhyolitic sections, known since the days of Lindgren. Unfortunately, the map explanation goes on to state that "the unit includes the Rubio Peak Formation of Hernon and others (1953) and generally equivalent beds." Now, in its type area, the Rubio Peak Formation intertongues with the overlying Sugarlump Rhyolite Tuff (Fig. 2, column I), assigned to the Datil Formation by Dane and Bachman (1965). It is therefore not clear how rocks designated as Ta should be distinguished from the andesite and latite facies of the Datil Formation (Tdl and Tda of Dane and Bachman (1965).[1] Further, some rocks designated as Ta and, especially, Tdl may well be Cretaceous, but evidence is lacking.

(3) Td – Datil Formation. Since the bulk of known ash flows are designated as part of the Datil Formation, this term requires special consideration. The term itself is unfortunate because it refers to the Datil Mountains, in Socorro County, but the type section of 1,824 feet of sediments and volcanics measured by Winchester (1920) is 30 miles to the east, in the Bear Mountains (about 30 miles northeast of the northeast corner of Figure 1). Since then, the type section has been redefined three times: By Wilpolt and others (1946), who removed the basal 685 feet of sedimentary rocks, mainly reddish sandstone, and placed them in a separate formation, the Baca; by Tonking (1957), who extended the Datil upward to include additional units, especially rhyolite ash flows, but also a capping basalt; and by Willard (1959) who removed the basalt. A full account of these transactions is given by Weber (1964). Willard and others (1961) extended the term Datil southward from the type locality for 100 miles, to the Pinos Altos Mountains. Dane and Bachman (1965) extended it southward another 40 miles, to just north of

1. Author's personal note: I originally named the Rubio Peak Formation and mapped its type locality (Elston, 1953). The subsequent history of the name is explained in a generous footnote in Hernon and others (1964).

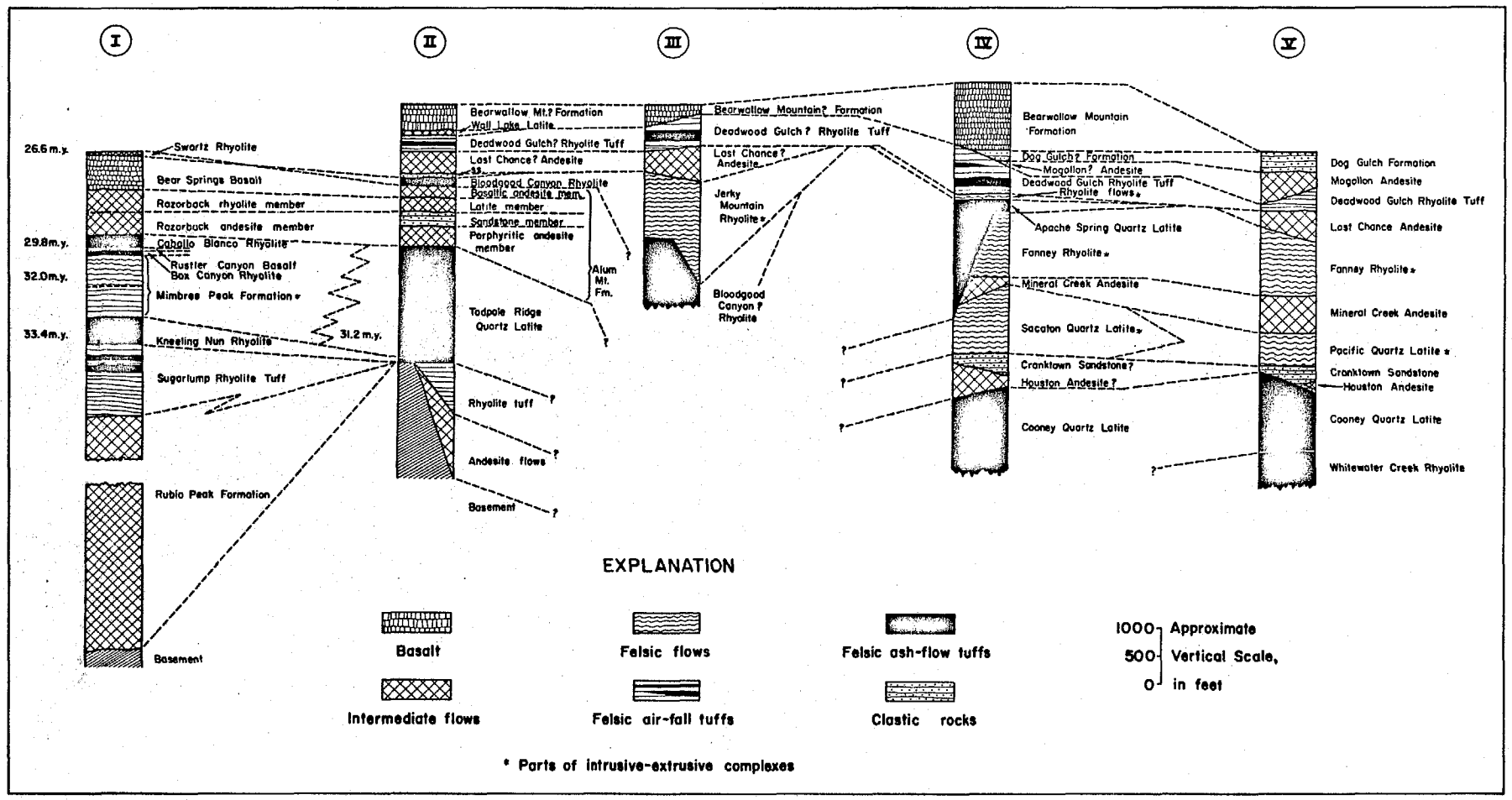


Figure 2 – Tentative correlation chart of Tertiary volcanic rocks of Mogollon Plateau and Mimbres Provinces, New Mexico. Section I is in Mimbres Province, Sections II to V are in Mogollon Plateau Province. See Figure 1 for locations. Sources of data: Section I – Elston (1957); Section II – W.E. Elston, unpublished field work; Section III – P.J. Coney and W.E. Elston, unpublished field work; Section IV – R.C. Rhodes, unpublished field work; Section V – Ferguson (1927).

Deming. It has also been carried eastward across the Rio Grande and westward to the Arizona line.

The intention of the compilers is clear: The term Datil Formation was to designate the rhyolites and quartz latites, characterized by thick ash-flow cooling units, that separated older andesite from younger basalt. It was generally believed that the rhyolitic rocks were roughly contemporaneous and probably Miocene. The age was based on flimsy structural and paleontological evidence: The Datil is profoundly unconformable with rocks deformed during the Laramide orogeny, yet it is cut by Basin-and-Range faults. No identifiable fossils have yet been extracted from the Datil, but the jaw bone of a *Brontotherium* found in gravels associated with possibly pre-Datil andesite in the northern Black Range was tentatively dated as Oligocene by J. F. Lance (personal communication). Unfortunately, the discoverer, Mr. Charles B. Hutchins, died shortly after his discovery, and the site of his find cannot be located. The specimen is at the University of New Mexico. A lower limit was determined by post-Datil fossil conifers in the Black Range near Kingston, said to be early Miocene to early Pliocene (Kuellmer, 1954, p. 29).

Like everybody else, I used the term Datil for the major ash flows and associated rocks in 1964 and 1965. By that time, K-Ar dates had shown the bulk of the Datil to be Oligocene. Field work on the Mogollon Plateau had revealed stratigraphic complexities and I concurred in a suggestion by R. H. Weber to raise the Datil from formation to group status (Elston, 1965, p. 170-171).

Since 1965, additional field work and new K-Ar dates have thrown an entirely new light on the Datil. It represents not one but at least three cycles of rhyolitic eruptions. The age of the type section was bracketed between approximately 38 and 29 m.y., well within the Oligocene. Rocks of about the same age range will be referred to as *Datil (restricted sense)* in the rest of this article. Rocks that are clearly younger, or which have not yet been dated, will be referred to as *Datil (broad sense).*

Recent K-Ar dates have shown that the ash flows of the Mimbres province (Figure 2, column I) are Datil (restricted sense) in age. On the other hand, great sections from the interior of the Mogollon Plateau province (Figure 2, sections III, IV, and V) are distinctly younger.

Within the Datil (restricted sense) several distinct ash-flow provinces can be recognized, presumably from different sources. In the Mimbres province (Figure 2, column I), the Kneeling Nun Quartz Latite has its source in a megabreccia zone on the west flank of the Black Range, described in the road log of Field Trip No. 1 for the afternoon of the second day. Its age was determined by McDowell (personal communication). The Caballo Blanco Rhyolite also thickens toward the Black Range, but its source is unknown. It can be traced southwestward for 50 miles, to the Knight Peak graben separating the Gold Hills from the Big Burro Mountains (Figure 1). Both are differentiated compound cooling units that become more calcic and less quartzose toward the top. North of Santa Rita, a north-trending Laramide structural high that controls (or is caused by) the mineralized Santa Rita and Hanover-Fierro stocks existed as a physical topographic barrier in Oligocene time. The Kneeling Nun and Caballo Blanco Formations butt up against it and abruptly pinch out; west of the high an entirely different section takes their place. This is the Tadpole Ridge Formation (new name), roughly contemporaneous with the Kneeling Nun – Caballo Blanco section (Figure 2, column II). Its name is derived from Tadpole Ridge on the western end of the Pinos Altos Mountains; its source is unknown, and what little is known about its lithology is described in the road log of Field Trip No. 1, Stop 10. Farther north, ash flows of great thickness but unknown source or age occur along the western foot of the Mogollon Mountains. The best-known section consists of the Whitewater Creek Rhyolite and Cooney Quartz Latite, at least 2,000 feet thick, of the Mogollon mining district (Ferguson, 1927). Attempts at K-Ar dating have failed so far, because of regional chloritization. They may well be Datil (restricted sense), but this cannot be proved at present. Farther north yet, the older of two rhyolite ash-flow sequences mapped within the Datil (broad sense) at the western end of the San Augustin Plains by Stearns (1962) and shown on his map as $Tdrp_1$ probably ties in with the Datil (restricted sense).

In Figure 2, section I is locally capped by a thin rhyolite flow breccia, the Swartz Rhyolite. K-Ar dating has shown that this insignificant unit is roughly equivalent in age to massive ash flows originating in local cauldrons within the Mogollon Plateau. They are the Apache Spring Quartz Latite (new name), and Bloodgood Canyon Rhyolite (new name). Stratigraphic relationships and ages are shown in Figure 2, structural relationships in Figure 3.

The Apache Spring Quartz Latite is a massive cooling unit, at least 2500 feet thick within its source, the Bursum cauldron (new name, after Bursum road, New Mexico Highway 78), currently being studied by R. C. Rhodes. The cauldron is 12-15 miles in diameter; the Apache Spring Quartz Latite is largely confined to the cauldron and is differentiated, becoming more mafic toward the top. Outliers of

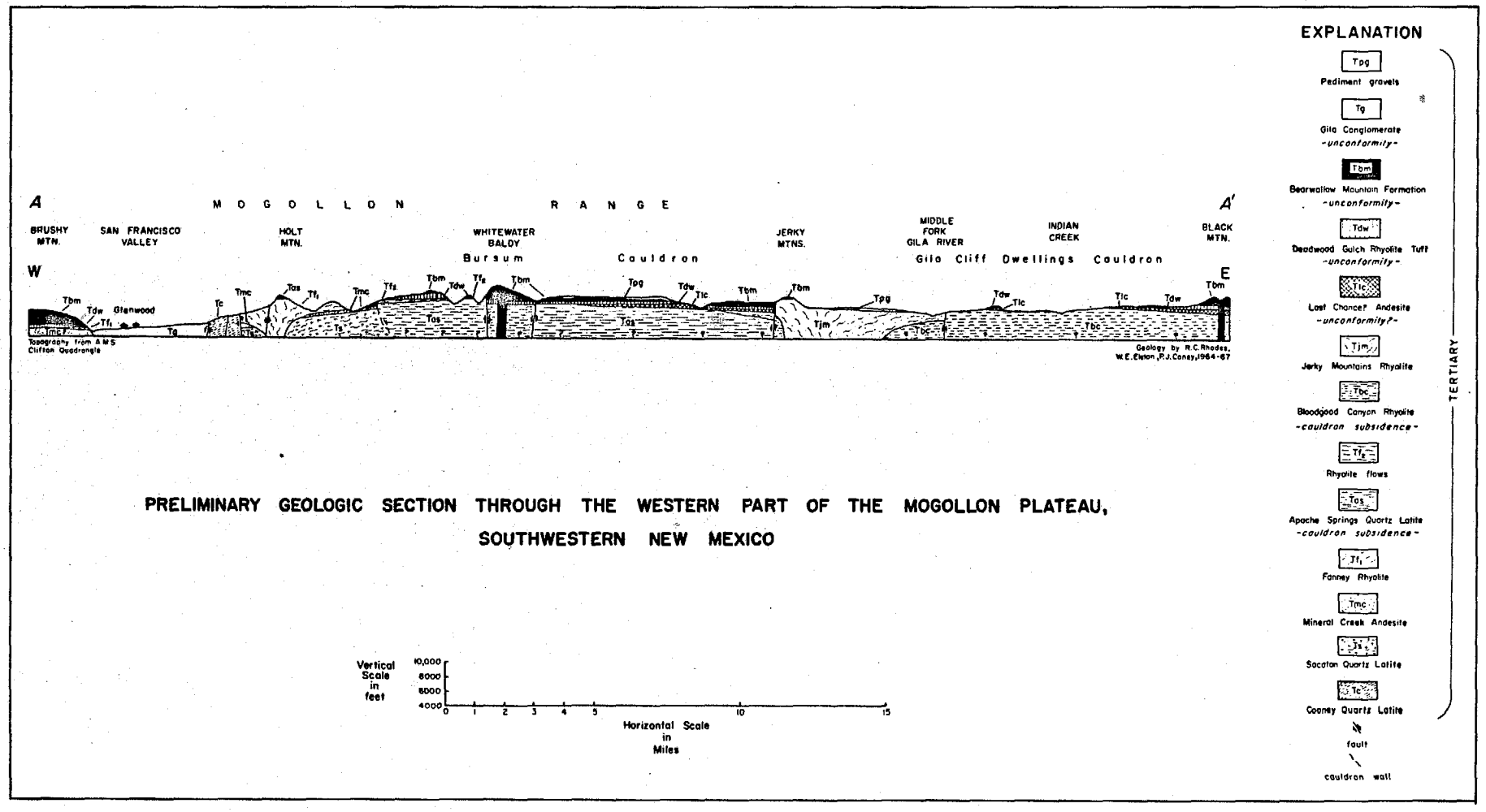


Figure 3 – Geologic section across western part of Mogollon Plateau province, along line AA', Figure 1.

Apache Spring locally crop out on the western crest of the Mogollon Range and form the basal part of the upper of the two ash-flow units mapped by Stearns (1962) to the north and designated $Tdrp_2$. In an earlier publication (Elston, 1965), written before K-Ar dates had become available, I incorrectly correlated the Apache Spring Quartz Latite with the Kneeling Nun and Tadpole Ridge Quartz Latites, referring to them collectively as "biotite-rich two-feldspar rhyolites and quartz latites." The name Apache Spring is derived from a locality in sec. 36, T. 11 S., R. 18 W.

The new term *Bloodgood Canyon Rhyolite* replaces the term *Moonstone Tuff* coined by Wargo (1959), and used by Elston (1965) and Elston and Coney (1967). The unit is at least 2,000 feet thick in its poorly delineated source cauldron, of which the Diablo Range and Jerky Mountains seem to form the western rim. The canyon for which it is named is a tributary of Little Creek, and drains the northeastern flank of the Diablo Range in secs. 5 and 6, T. 13 S., R. 14 W. Gila Cliff Dwellings National Monument is near the edge of the suspected source cauldron, which is hereby called the Gila Cliff Dwellings cauldron (new name). The relatively unwelded top of the Bloodgood Canyon Rhyolite is exposed in the parking area on the east side of the Gila River, near the Cliff Dwelling.

The Bloodgood Canyon Rhyolite is a massive ash-flow compound cooling unit characterized by conspicuous phenocrysts of rounded quartz and sanidine cryptoperthite ("moonstone"). Biotite is scarce and plagioclase absent. Pumice fragments, nearly spherical in shape, are conspicuous at the top and grade into flattened and somewhat elongated streaks near the base. In this respect, the Bloodgood Canyon Rhyolite resembles the Superior Dacite, seen on the first day of Field Trip No. 1.

Unlike the Apache Spring Quartz Latite, the Bloodgood Canyon Rhyolite spilled copiously out of its source cauldron. To the southwest, its distal edge has been located in the Pinos Altos and Silver City ranges, in the northern end of the Big Burro Mountains, and west of Cliff. To the north, its ultimate extent is unknown, but it forms the upper part of the $Tdrp_2$ unit of Stearns (1962). To the northwest, it forms cliffs several hundred feet high around Reserve, where it clearly breaks down into several individual ash-flow units. West of Reserve, rocks resembling Bloodgood Canyon Rhyolite occur in the Blue Mountain Primitive Area (P. E. Damon and J. C. Ratte, personal communication). Thus the entire sheet seems to have a minimum diameter of 85 miles, with the northern end yet to be discovered. However, there are unresolved problems in tracing its extent to the east, and in slightly conflicting age dates from widely separated localities (26.3±0.8 and 23.2±0.7 m.y., Bikerman, Damon, and Elston, in preparation). It is therefore not yet clear whether all rocks tentatively included in the formation did, in fact, originate from a common source and in a single eruptive cycle spanning several million years.

Wherever the margins of the Bursum and Gila Cliff Dwelling cauldrons were seen, the outcrops of the contained ash-flow tuff end abruptly, usually in fault contacts against great elongated protrusive domes of quartz latite or flow-banded rhyolite. The Apache Spring Quartz Latite abuts against the Sacaton Quartz Latite (new term, in part equivalent to the Pacific Quartz Latite of Ferguson, 1927, type locality Sacaton Mountain in Wilcox Mining District) Locally, outliers of Apache Spring lie on the post-Sacaton Fanney Rhyolite of Ferguson (1927) (Fig. 3). In many places an unnamed Fanney-like rhyolite overlies the Apache Spring.

In the Middle Fork of the Gila River, west of Black Mountain, Bloodgood Canyon Rhyolite plunges beneath a single-feldspar flow-banded rhyolite, the Jerky Mountains Rhyolite (new name, after the Jerky Mountains which are largely made up of this formation). In the Diablo Range the flow-banded rhyolite bordering the Gila Cliff Dwelling cauldron may be post-Bloodgood Canyon, but this is still uncertain because no unfaulted contact has yet been found.

Only the western margins of the Bursum and Gila Cliff Dwellings cauldrons are known. Eastward, the contained ash flows (Apache Spring and Bloodgood Canyon, respectively) dip underneath younger rocks in the inner basin of the larger Mogollon Plateau volcano-tectonic structure (see discussion by R. C. Rhodes at Stop No. 5, Field Trip No. 1, and preceding notations in road log). Masses of flow-banded rhyolite, resembling the Fanney and Jerky Mountain formation, are known from Elk Mountain, the country east and west of Pelona Mountain, and the western flank of the Black Range. Their relation to ash flows and cauldron structures is not yet known.

The break between the Datil (restricted sense) and the Apache Spring-Bloodgood Canyon ash flows of the Mogollon Plateau probably involved a series of geologic events including eruption of basaltic and andesitic rocks in the Mimbres Province (Figure 2, column I) and intrusion of mineralized porphyry bodies at Magdalena, dated at about 28 m.y. (Weber and Bassett, 1964). The dual nature of the rhyolites in the Datil (broad sense) west of the type locality was clearly recognized by Stearns (1962), who mapped several sedimentary and volcanic units of intermediate composition between his two rhyolite ash-flow units ($Tdrp_1$ and $Tdrp_2$). One of the

intervening andesites (Tda_2) strongly resembles the "Turkeytrack Porphyry" of southeastern Arizona.

After the eruption of the Bloodgood Canyon Rhyolite and associated rocks, the Mogollon Plateau province was bevelled to low relief, and unconformably covered by relatively thin but persistent beds of sand and gravel, interlayered with a third "Datil" sequence of rhyolite tuff. It consists of airfall tuff, and sandy tuff as well as poorly-welded ash flows. The unit has tentatively been traced into the Deadwood Gulch Rhyolite of the Mogollon mining district (Ferguson, 1927), and is shown as Deadwood Gulch(?) Rhyolite in Figure 2. Its pyroclastic parts are highly felsic, rich in pumiceous glass but poor in phenocrysts. Neither the age nor source of the formation are known. In the higher parts of the Mogollon Range the Deadwood Gulch(?) reaches a maximum thickness of about 1,000 feet; thicknesses from a feather edge to 400 feet are more usual. The fine-grained sandy beds are its most persistent constituents. The units can be traced over an area from the Gila Cliff Dwellings to Beaverhead, Glenwood, and further west. Its ultimate limits are unknown.

At least one flow-banded dome-forming rhyolite is known to be younger than the Deadwood Gulch(?) Rhyolite: The highly porphyritic (quartz and sanidine phenocrysts) flow-banded Taylor Creek Rhyolite (new name), well known for its association with cassiterite deposits in the Taylor Creek tin mining district after which it was named. It forms an arcuate outcrop belt from the vicinity of Pelona Mountain, along the western side of the Black Range, as far south as South Diamond Creek. Locally, flows and flow breccias issuing from the domes are interbedded with moonstone-bearing rhyolite ash flows. The belt of Taylor Creek Rhyolite forms the youngest and innermost known member of the roughly concentric arcuate protrusive bodies interpreted as the surface expression of a ring-dike complex 75 miles (125 km) in diameter (Elston, 1964). The world over, ring-dike complexes with associated rhyolite ash flows, usually preserved in the central volcano-tectonic depression, are commonly associated with tin mineralization. Examples occur in Australia, Southwest Africa, Nigeria, the Sudan, the Iberian Peninsula, Brazil, and elsewhere.

To summarize: The Datil (broad sense) can be subdivided into at least three major ash-flow sequences in the Mogollon Plateau province. (1) The Datil (restricted sense), (2) the Apache Spring – Bloodgood Canyon sequence, and (3) the Deadwood Gulch(?) – Taylor Creek sequence. Each sequence is associated with arcuate elongated belts of intrusive-extrusive ("protrusive") composed of flow-banded rhyolite or quartz latite which tend to become progressively younger toward the center of the Mogollon Plateau. If seen at a deeper erosion level, they would constitute a ring-dike complex. Andesite and latite flows and pyroclastics occur at various horizons.

On the Geologic Map of New Mexico the Datil (broad sense) outcrop area on the Mogollon Plateau Province is enlivened by a complex color scheme, representing numerous facies. On the other hand, equivalent rocks in the Mimbres Province are shown as undivided Datil Formation, Td. The uninitiated might suppose that the compilers had much information on the Mogollon Plateau Province and little on the Mimbres Province. The exact reverse is true: The Mogollon Plateau had, at the time of compilation, been covered by only the most rapid reconnaissance mapping, and there had been virtually no petrographic work. Several bulletins of detailed geology had been published on the Mimbres Province (Kuellmer, 1954, Jicha, 1954, Elston 1957) and they contain petrographic descriptions based on hundreds of thin sections, supplemented by a number of superior chemical analyses.

(4) QTb: The unit shown on the Geologic Map of New Mexico as QTb is now known to consist of numerous rock types of varying ages. None are Quaternary and few are true basalt. The andesite-rhyolite-basalt cycle has already been mentioned several times, and it now appears that the capping basaltic sequence of one rhyolite can be time-equivalent to the basal andesite of another. Each of the three rhyolite sequences that make up the Datil (broad sense) is indeed capped by dark-colored rocks that range in composition from rhyolite to basalt. The Datil (restricted sense) section of the Mimbres province is capped by the Razorback - Bear Springs section (Fig. 2, column I), approximately equivalent in age (and partly in lithology) to the Alum Mountain Formation (new name, after Alum Mountain, Stop 12 on Field Trip No. 1) of the Pinos Altos - Gila Cliff Dwellings area (Fig. 2, column II). The Apache Spring - Bloodgood Canyon rhyolite ash-flow sequence of the Mogollon Plateau Province is capped by a basaltic andesite tentatively correlated with the Last Chance Andesite at Mogollon (Ferguson, 1927), but possibly younger. It is shown as Last Chance(?) Basaltic Andesite in Fig. 2, columns II and III. The Deadwood Gulch - Taylor Creek sequence is locally capped by the Wall Lake Latite (new name; the dam of Wall Lake south of Beaverhead is anchored on this rock) and, more generally, by the Bearwallow Mountain Formation (new name, after a prominent peak north of Mogollon which is littered with basaltic bombs).

In addition, isolated basalts, not related to rhyolite sequences in any systematic manner, occur in various places (e.g., Rustler Canyon Basalt in Fig. 2, column I). The younger basalts intertongue with the base of the Gila Conglomerate.

(5) QTr: The symbol QTr is used for rhyolites younger than the most prominent basalt sequence in any particular area. No ash flows are included under the symbol. It includes the post-Bear Springs Swartz Rhyolite of the Mimbres Province (Fig. 2, column I), of late Oligocene or early Miocene age (26.6±0.8 m.y., Damon and others, 1966), and a group of northwest-trending post-Bearwallow Mountain rhyolite domes, flows, glassy rocks, and non-welded pyro clastics near Mule Creek dated at 18.6 m.y. (Weber and Bassett, 1964). Not shown on the Geologic map of New Mexico are domes of latite that appear to be younger than the Bearwallow Formation. The upper part of Eagle Peak, east of Reserve, is an example. The latite is given the new name of Pelona Latite. Pelona Mountain (see Fig. 1 for location) is an eruptive center of a basalt tentatively assigned to the Bearwallow Mountain Formation. A dome of latite partly fills a circular valley that still retains characteristics of a crater or caldera of Bearwallow Mountain age.

(6) Qb: All rocks discussed so far are older than the main stage of Basin-and-Range faulting and the main mass of Gila Conglomerate. The only Qb in the Mogollon and Mimbres Provinces is a nearly flat-lying olivine basalt flow near Mimbres, just below the top of the Gila Conglomerate, seen on the afternoon of the second day of Field Trip No. 1. It has recently been dated as 6.3±0.4 m.y., or Pliocene (Damon, personal communication). No true Quaternary volcanic rock, has yet been identified in the Mimbres or Mogollon provinces, although virtually undissected basalt cinder cones, maars and lava fields are common on both sides of the Mexican border.

(7) Qvr: Supposedly post-Gila rhyolite flows at the southern end of the Knight Peak graben are based on a mapping error. A graduate student mistook terrace gravels derived from Datil (restricted sense) rocks for bedrock.

(8) Tv: This symbol is used to indicate "extrusive rocks of varied composition and age." It should clearly have been used more freely.

A Note on the Southwestern Province

On the Geologic Map of New Mexico (Dane and Bachman, 1965) certain symbols change along a line roughly following U. S. 70 west of Deming. This division is not as arbitrary as might seem at first glance. South of U. S. 70 lies the Basin-and-Range province, the Sonoran and Mexican geosynclines, and the highway roughly follows the postulated Texas lineament. The Pennsylvanian Florida archipelago of Kottlowski (1960) and the Cretaceous Burro uplift of Elston (1958) are just north of the highway.

A complicated debate concerning the existence and identification of early Cretaceous rocks (Kv) in the southwestern province need not concern us here, since the rocks in question contain no ash flows.

Ash flows are widespread in the southwestern province, and many local names have been assigned. The Geologic Map of New Mexico has divided them into a lower and an upper unit, Tvl and Tvu, respectively. The dividing marker is a massive and widespread quartz latite cooling unit, called Gillespie Quartz Latite by Zeller and Alper (1965) and Steins Mountain Quartz Latite by Gillerman (1958). Where identifiable it forms the base of Tvu. On Field Trip No. 1, the Steins Mountain Quartz Latite can be seen from Stop 19. Tvl includes not only rocks that would be included in the lower part of the Datil (broad sense) farther north, but possibly also late Cretaceous andesites like those around Pinos Altos and andesites designated elsewhere as Ta. Tvu includes rocks that are probably equivalent to the upper part of the Datil (broad sense) and, possibly, younger yet.

Since the Steins Mountain Gillespie Quartz Latite is not everywhere present, the Tvl - Tvu boundary cannot be drawn consistently. In the absence of even a single K-Ar date, correlation with eruptive phases in the Mimbres and Mogollon province is impossible. Alper and Poldervaart (1957) presented evidence, from similarity in chemical composition and zircon populations, that the Animas Quartz Monzonite stock in the Animas Mountains is the unroofed source of the pre-Gillespie Oak Creek Quartz Latite ash-flow tuff. Aside from this, little is known about the volcano-tectonic history of the area. The scarcity of post-ash flow basalts (QTb) is noteworthy but remains unexplained. Quaternary(?) basalt flows occur near Hachita and Animas.

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SECOND DAY, TUESDAY, APRIL 9

Leaders: Wolfgang E. Elston and Frederick J. Kuellmer
(We are indebted to the New Mexico Geological Society and to field trip leaders W.W. Baltosser, R.M. Hernon, W.R. Jones, F.J. Kuellmer, W.E. Elston, R.W. Weber and F.D. Trauger for permission to use portions of the road log for their Sixteenth Field Conference).
Driving Distance: 145 miles
Logged Distance: 144 miles
Starting Time: 8:00 A.M.
Assembly Point: Holiday Inn Motel

GENERAL STATEMENT

The second day's trip is northward from Silver City to Gila Cliff Dwellings National Monument, returning by way of the Sapillo and Mimbres Valleys, the west flank of the Black Range, and the Santa Rita-Central mining district. For the first 9 miles, from Silver City through Pinos Altos, the caravan traverses a terrace of Upper Cretaceous Colorado Shale and Cretaceous-Tertiary andesite breccia, cut by porphyritic stocks, innumerable dikes, and veins. The next 17 miles are across the complexly faulted Pinos Altos Range, composed of Tertiary volcanic rocks and Gila Conglomerate, and down to Sapillo Creek. For the following 7 miles the route ascends Copperas Peak, probably a Tertiary andesitic volcano, from which one may obtain a sweeping view of the vast Gila Wilderness. From there, for the next 12 miles the caravan descends into the Upper Gila Basin, probably a large volcano-tectonic sink, to wind up at Gila Cliff Dwellings National Monument. After backtracking to Sapillo Creek the route for 28 miles is through the Sapillo and Mimbres Valleys, past Roberts Lake and across the Continental Divide, with extensive views of late Tertiary Gila Conglomerate and Quaternary terraces on the way. A side trip will go to the west flank of the Black Range, where the vent area of the Kneeling Nun Quartz Latite ash-flow tuff will be examined. The last leg of the trip, from San Lorenzo back to Silver City, is through the heart of the most productive metal-mining district in New Mexico, in which mineralization is controlled by Laramide porphyry bodies intruded into Paleozoic and Cretaceous sedimentary rocks. A stop at the base of the Kneeling Nun ash-flow tuff, which changes from a poorly welded rhyolite, to intensely welded quartz latite in the basal 100 feet, will conclude the day.

Segmental Mileage	Cumulative Mileage	
0.0	0.0	STARTING POINT on right side of New Mexico Highway 25 at junction with U.S. Highway 180, opposite Shamrock station on the left, heading north towards Pinos Altos.
0.2	0.2	Cross gully. Dike in Colorado Shale on the right.
0.4	0.6	TURN LEFT on New Mexico Highway 25 at Ranch Club. Ridge at 10 o'clock is a resistant dike in Colorado Shale. Dikes in dike complex trend northeast and constitute more than 50 percent of the exposed rock. Outcrops of Colorado Shale are characterized by their yellow to buff weathered color.
1.2	1.8	Crest of topographic rise. Ahead, "W" Mountain marks southern edge of Pinos Altos Range; consists of Colorado Shale and Cretaceous-Tertiary andesite breccia intruded by dikes and Tertiary monzonite intrusive stocks.
0.9	2.7	Light-colored dike of andesite porphyry on the right. Silver City Range, at 9 o'clock on horizon, contains a well-exposed northeast-dipping section of Paleozoic and Cretaceous sedimentary rocks, resting on the Precambrian.

0.4	3.1	Porphyritic dike in road cut.
0.1	3.2	Inferred contact between Colorado Shale and overlying Cretaceous-Tertiary andesite breccias.
0.1	3.3	Side road on right to Hickel place. Contact between Cretaceous-Tertiary andesite breccia and intrusive Tertiary monzonite.
0.2	3.5	Cross gully. Exposures of monzonite on the right. Road parallels general trend of dikes in this area.
0.6	4.1	Cross arroyo. Road cut on left at curve exposes monzonite cut by dike.
0.2	4.3	Poorly exposed Cretaceous-Tertiary andesite breccia cut by Cretaceous-Tertiary augite-biotite monzonite and dikes.
0.2	4.5	Gully along contact of monzonite and Tertiary Pinos Altos stock, composed of hornblende quartz monzonite porphyry.
0.1	4.6	Road cut on the right in weathered, highly fractured hornblende quartz monzonite porphyry. Silver Hill at 10 o'clock is mainly andesite breccia cut by dikes. Mine dumps near base of Silver Hill. Road from here to Pinos Altos is on Pinos Altos stock.
0.2	4.8	At 3 o'clock, Cooks Peak on skyline, seen through a gap in the Cobre Mountains, was a famous landmark for early travelers in this region. It consists of a granodiorite porphyry stock. Cobre Mountains consist of Tertiary volcanics including several ash-flow cooling units of which the Kneeling Nun Quartz Latite, Box Canyon Rhyolite and Caballo Blanco Rhyolite are the most prominent. Smelter stack at Hurley visible at 5 o'clock from just beyond this mileage point.
0.2	5.0	Old mill site on the left.
0.3	5.3	Road curves to left. Side road junction on right. Numerous mine dumps on slopes ahead. Dark-colored dumps to the left are in diorite on the Pacific claims, whereas light-colored dumps to the right are from the Pinos Altos quartz monzonite stock. The Pacific Mine was credited in 1905 with total production of over $1,000,000 (Lindgren, et al., 1910, p. 298). The values were mostly in copper and gold, with some silver.
0.5	5.8	Road cuts in Pinos Altos stock.
0.6	6.4	Southwest corner of old Gopher (Golden Giant) claims. Gopher shaft, on the right, is 520 feet deep. Extensive tunnels extend from the 400 foot level and from four other levels. (Paige, 1910, p. 120). Values were mostly in gold and silver. Water level in the shaft was at 46 feet in 1954. Official Scenic Historic Marker states: "The Pinos Altos Mountains rise to an elevation of over 9000 feet. The Continental Divide crosses the highway at this point. Elevation 7067 feet. In this area are extensive gold, silver, and copper deposits mined as early as 1803. Pinos Altos was southwestern New Mexico's first gold camp and once the seat of Grant County." Metal production of the Pinos Altos district prior to 1950 has been estimated at $9.7 million. Gold and zinc were the most important metals mined (Anderson, 1957).

0.2	6.6	Road curves to left at large two-story house. Road trends due north in front of house. Main crest of Pinos Altos Range ahead. Headwaters of Bear Creek in valley at 10 o'clock. At 9 o'clock are workings of Aztec-Asiatic claims. The Aztec-Asiatic veins are extensions of the Pacific claim and are similar in character. Mina Grande, Mogul, and Kept Woman Mines produced gold, silver, copper, lead, and zinc.
0.1	6.7	Fork in road. BEAR LEFT on Alternate New Mexico Highway 25. Caravan passes through old town of Pinos Altos. PLEASE DRIVE SLOWLY.
0.1	6.8	Bridge. Cross arroyo in headwaters of Bear Creek.
0.1	6.9	TURN RIGHT. Follow pavement past Pinos Altos Mercantile and Buckhorn Saloon on right; oldest schoolhouse in Grant County on left. The Tatsch family is responsible for restoration of many of the historic buildings in Pinos Altos. Once almost a ghost town, Pinos Altos has recently been revived by an influx of people, including a number of artists, who appreciate its scenery, climate, and historic atmosphere.
0.5	7.4	Cross Bear Creek on Pinos Altos stock. First gold discovery was made in placer gravels in creek bed. According to reports, some placers are still being worked occasionally and small amounts of gold are being recovered. Old placer claims are still valid and not open to the public, except locally for a fee.
0.1	7.5	Old mine adit on right.
0.1	7.6	Road junction on the right. KEEP STRAIGHT AHEAD.
0.5	8.1	Cross side gulch. House on left is one of the early adobe structures in this area.
0.2	8.3	Cattle guard. Gila National Forest Boundary. CAUTION! NARROW, WINDING ROAD AHEAD. Outcrops of Pinos Altos hornblende quartz monzonite porphyry stock.
0.3	8.6	Cretaceous-Tertiary andesite breccias and mafic dikes cut by apophyses of Pinos Altos stock.
0.2	8.8	"Early Grant County" style miner's cabin on slope to the right. Pinnacles of Tertiary Tadpole Ridge Quartz Latite ash flows ahead.
0.2	9.0	Base of Tadpole Ridge ash flow sequence here is a vitrophyre resting unconformably on the late Cretaceous-early Tertiary igneous sequence. Ash flow tuffs are more than 1000 feet thick. According to Elston (this guidebook) they are essentially the same age as the Kneeling Nun—Caballo Blanco section of the Black Range—Santa Rita area to be visited this afternoon, but belong to a different volcanic province. The two provinces are separated by a physical barrier, the north-trending Santa Rita—Hanover—Fierro axis. Note zone of king-size spherulites at top of vitrophyre. These rhyolite ash flows can be distinguished from the younger Bloodgood Canyon sequence exposed near the Cliff Dwellings by an abundance of biotite and the absence of moonstone (sanidine cryptoperthite) and rounded quartz. For details of volcanic section on this log of the trip, see accompanying paper by Elston (Fig. 2, Column II).
0.1	9.1	Fault. Vitrophyre downthrown against Cretaceous-Tertiary andesite breccias and mafic dikes.

0.1	9.2	Placer mining tailings in creek bed on the left.
0.1	9.3	Bridge across Mill Creek. Outcrops of stony quartz latite ash flows with vitrophyric base.
0.1	9.4	Gold placers on the left. Terrace gravels in road cut on the right.
0.4	9.8	Bridge crossing Little Cherry Creek.
0.6	10.4	STOP 10 - Time: 20 minutes - Curve, trail to Ben Lilly Memorial marker at left. Plaque located on north side of outcrop about 50 yards west of highway reads as follows:

1856 – Ben V. Lilly – 1936

Born in Alabama and reared in Mississippi, Ben V. Lilly, in early life, was a farmer and trader in Louisiana, but turned to hunting of panther and bears with a passion that led him out of the swamps and canebrakes, across Texas, to tramp the wildest mountains of Mexico, and finally to become a legendary figure and dean of wilderness hunters in the southwest. He was a philosopher, keen observer, naturalist, a cherisher of good hounds, a relier on his rifle, and a handicraftsman in horn and steel. He loved little children and vast solitudes. He was a pious man of singular honesty and fidelity and a strict observer of the Sabbath. New Mexico mountains were his final hunting range and the charm of the Gila Wilderness held him to the end.

Erected in 1947 by friends.

The Tadpole Ridge Quartz Latite (see accompanying photograph) has not yet been studied in detail. It consists of numerous ash flows; four cliff-forming columnarly-jointed welded zones separated by relatively unwelded benches can be seen from this point. Biotite from a sample collected at Ben Lilly Memorial gave a K-Ar age of 31.2±0.9 m.y. (Damon et al., 1967). Because of faulting no complete section has been measured, but total maximum thickness must be 1,000 to 2,000 feet. The source(s) of the unit is (are) unknown, but it has not been found east of the Santa Rita–Hanover–Fierro axis. (Figure 8)

The lower members contain phenocryst of oligoclase-andesine, sanidine, biotite, little or no quartz except in a narrow resistant ledge. Occult quartz becomes more abundant toward the top of the formation which grades into rhyolitic rock. Differentiation within individual members has not yet been studied. Planar structures consisting of crystal-lined vapor-phase cavities with alteration halos are more obvious than collapsed pumice fragments. Only the lowest member has a vitrophyric base.

Figure 8 – Typical ash-flow tuff member of Tadpole Ridge Quartz Latite, west side of Cherry Creek. –Photograph by W.E. Elston

A few tuffaceous sandstone members are present at the top of the formation, which interfingers with the basal porphyritic andesite member of the Alum Mountain Formation.

Along the highway the Tadpole Ridge Quartz Latite lies unconformably on pre-Tertiary rocks, but toward the west, along Bear Creek, several hundred feet of bedded rhyolite air-fall tuff and sandy water-laid tuff and older purple-brown andesite progressively wedge in beneath the Tadpole Ridge Quartz Latite.

0.4	10.8	Descending into Cherry Creek Canyon. Note gradation in tall columns of welded ash flow tuff from sheeted zone above to massive pinnacles below.
0.1	10.9	Fresh road cut in tuff on right shows lighter color more Felsic composition(?), and less indurated character than more highly welded portions seen previously.
0.8	11.7	Cross Cherry Creek.
0.1	11.8	Entrance to Cherry Creek campground on right. Annual precipitation in this area averages about 21.3 inches a year, (47 years of record at Pinos Altos).
1.4	13.2	Entrance to McMillan campground on right.
0.6	13.8	Abundant xenoliths of a wide variety of volcanic rock types shown in road cut in rhyolite tuff.
0.7	14.5	Red andesite interlayered with quartz latite tuff in creek floor on the right. Entering the Membres fault zone, which trends WNW between here and the Gila Canyon, SE from here to the Cook's Range, and has been traced south in the subsurface from the Cook's Range to the Mexican border; a distance of over 100 miles. Displacement in the Tertiary volcanics alone is up to 9,000 feet, the cumulative displacement since the beginning of Laramide deformation is far greater.

The northeast block of the Mimbres fault has moved down relative to the southwest block. In the Silver City–Santa Rita mining area the fault marks the northeastern limit of the mineralized pre-Tertiary rocks.

At this locality, the base of the Alum Mountain Formation has been faulted against the Tadpole Ridge Formation. Elongated domes of flow-banded rhyolite are locally intruded in the fault zone.

0.2	14.7	Cattle guard. Redstone Cabin of U.S. Forest Service on the left.
0.2	14.9	ROAD FORK. Keep left on road to Gila Cliff Dwellings.
0.2	15.1	Fault. Thin-bedded tuffaceous sandstones of Tadpole Ridge Quartz Latite on the south are in fault contact with flows and breccias of the porphyritic andesite member of the Alum Mountain Formation, downthrown on the north.
0.3	15.4	At curve, Meadow Creek road junction. Northwest-trending fault crosses highway. Flowbanded intrusive rhyolite plug domes lie to east of road. Route ahead passes through altered andesites.

0.2	15.6	Intrusive rhyolite on the right.
0.1	15.7	Sharp bend in road. Outcrops of red porphyritic andesite of Alum Mountain formation.
0.7	16.4	In road cut on left, andesites of Alum Mountain formation in depositional contact on rhyolite ash flow. Ash flow is the downfaulted top to the Tadpole Ridge Quartz Latite.
0.3	16.7	At curve, fault in side gulch crosses road alignment. Fine-grained dark latite member of the Alum Mountain formation exposed on hill slope to the right.
0.3	17.0	Head of Trout Creek.
0.3	17.3	On right, sandstone member of Alum Mountain formation with porphyritic Andesite member below and dark Latite above. This sandstone may be a tongue of a thick sandstone section exposed below mafic andesite east of Signal Peak. The sandstone there forms a thick wedge on the edge of the structural and buried topographic high that separates the Mogollon Mountains and Black Range–Mimbres Valley ash flow provinces.
0.1	17.4	Bridge. Dark latites on slopes to the right, beyond which route crosses another outcrop belt of red andesite.
0.6	18.0	Snow Creek Cabin road on left. Fault zone. Small banded rhyolite intrusive body in gully on left.
0.2	18.2	Bridge across Trout Creek. Olivine basalt faulted against porphyritic andesite of Alum Mountain formation in a fault zone nearly ¼ mile wide. Bloodgood Canyon Rhyolite below the basalt rests on basaltic agglomerate with sandy matrix. Dark Latite member of Alum Mountain formation nearly faulted out of this section. Buff sandstones and pumiceous sandstones are interbedded with the basal part of the basalt.
0.3	18.5	Late Tertiary basalt in road cuts on right.
0.4	18.9	Pine Flat. Fault. Top of Bloodgood Canyon Rhyolite crops out beyond piles of crushed stone to the right. Late Tertiary basalt on both sides of the road beyond curve.
1.2	20.1	Fault(?). Bloodgood Canyon formation on right is the thin end of a great wedge that is about 2,000 feet thick northwest of the Gila Cliff Dwellings. There, the moonstone-bearing tuff is intensely welded and forms spectacular 700-foot cliffs in the canyons of the West and Middle Forks of the Gila River. This ash flow sequence is younger than the one we passed in Cherry Creek (23.2 to 26.5 m.y., see discussion in yesterday's log at 91.3 miles). It is distinctly younger than the known range of the type–Datil or the rocks of the Black Range–Mimbres–Santa Rita area. Overlying basalt crops out ahead capping the crest of a narrow spur ridge.
1.8	21.9	Approximate contact of Gila Conglomerate with underlying basalt.
0.4	22.3	STOP 11 - Time: 15 minutes - Trout Creek Canyon on the left; Trout Creek is one of the principal tributaries of Sapillo Creek. A fault of westerly to west-northwesterly trend has downthrown Gila Conglomerate on the south side against

andesite and calcic latite flows and breccias of the Alum Mountain formation on the north side of the canyon. Post–Bloodgood Canyon basalts and basaltic andesites directly overlie the andesite–latite sequence on Horse Mountain and Wild Horse Mesa at the mouth of Trout Creek. The intervening thick section of moonstone–bearing Bloodgood Canyon Rhyolite ash flow and Jerky Mountain Rhyolite of the eastern part of the Mogollon Mountains and the Diablo Range (in the distant view to the west and northwest) is missing here due to eastward thinning and pre-basalt erosion. The basaltic sequence is in turn truncated by the unconformity at the base of the Gila Conglomerate, consequently the Gila in the immediate vicinity rests directly upon the Alum Mountain andesite–latite sequence. The section extending from the Alum Mountain andesites and latites through the Jerky Mountain Rhyolite was assigned to the Datil Formation (Weber and Willard, 1959; Willard et al., 1961). More recent work by Elston and associates indicates that they are younger than the known age range of the Datil Formation. This seems to account in part for the preservation of primary volcano tectonic structures on the Mogollon Plateau, but not elsewhere.

0.4	22.7	CAUTION! USE LOW GEAR. Road ahead descends into Sapillo Creek Canyon with steep grades and sharp curves.
0.5	23.2	Cattle guard.
0.5	23.7	Andesites of Alum Mountain formation exposed in road cuts.
0.2	23.9	Granny Mountain dead ahead (post–Bloodgood Canyon basalt). CAUTION! SHARP CURVE TO RIGHT, FOLLOWED BY SHARP CURVE TO LEFT.
0.7	24.6	CAUTION! DANGEROUS CURVE TO RIGHT.
0.3	24.9	Depositional contact of Gila Conglomerate on red porphyritic andesite of Alum Mountain formation. Gila dips about 10 degrees northeast.
0.9	25.8	Cross floor of side canyon. Basalt Gila Conglomerate in road cut on right.
0.2	26.0	Bridge over Sapillo Creek. Fault that crosses canyon just beyond the bridge dropped Gila against red andesite. A complicated fault zone extends from this point for about 2 miles along the route ahead. The Gila Primitive Area borders the road on both sides. The southeastern corner of the Gila Wilderness Area is about 1½ miles to the northwest.
0.1	26.1	Road junction. TURN LEFT on New Mexico 527, leaving New Mexico Highway 25. Gila Conglomerate rests in depositional contact on andesite in slopes to left.
0.4	26.5	Major fault ahead. Reversed dips in Gila are due to drag.
0.1	26.6	Entering main part of fault zone, and continuing for about the next 1.2 miles. This zone forms part of the ring or polygon of fractures surrounding the Mogollon Plateau, which we are about to enter. The ring fractures control only a few small rhyolite dikes along the highway (compared with enormous masses east and west) instead, a major andesite and latite eruptive center (near Alum Mountain) is located on the fracture zone and is surrounded by intense hydrothermal alteration.
0.2	26.8	Elongated rhyolite intrusive in road cut on left is locally mineralized, containing specularite and pyrite. Flow banding dips about 45 to 50 degrees northeast.

0.2	27.0	Leaving intrusive rhyolite. Altered zones ahead.
0.5	27.5	Prominently altered volcanics of the andesite–latite sequence of the Alum Mountain formation. Hydrothermal alteration, very possibly solfataric in character, has profoundly altered the rocks in the vicinity of Copperas Canyon and Alum Mountain (seen later at Stop No. 12). Bleaching and variegated staining by iron oxides resulting from almost total destruction of the original minerals by hypogene and supergene processes has obscured the original structures and textures of the rocks. The nature of the alteration is poorly known, but includes extensive argillization, with halloysite (endellite) as one of the conspicuous products, pyritization, and local silicification. Alunite is prominent in the Alum Mountain zone, where it is associated with abundant alunogen and halotrichite.
0.3	27.8	Crossing Copperas Canyon. Crags of silicified volcanics on the right.
0.3	28.1	Entering northwest–trending fault zone.
0.2	28.3	Tongue of silicified rhyolite (?) on right. Road cut ahead in highly altered volcanics.
0.3	28.6	Abandoned clay pit, formerly worked by Reese Mining and Manufacturing Co. Inc. on the right. Argillized volcanics utilized in the manufacture of brick and tile in a plant at Silver City, in 1964-65.
0.6	29.2	Northwest–trending fault zone with associated intense alteration.
0.8	30.0	Northwest–trending fault zone cutting porphyritic andesite.
0.4	30.4	Fault.
0.4	30.8	Cattle guard. Fault zone. Copperas Peak at 10 o'clock (elevation over 7800 feet). Buck Hannen Mountain at 12:30 o'clock.
0.3	31.1	Tuff, sandstone, and conglomerate intercalated with andesite. Buck Hannen Mountain contains intercalated vitrophyres and fine–grained andesite flows. All of these rocks are tentatively included in the Alum Mountain formation.
0.5	31.6	Bedded tuffs dipping 17° NE. Entering small structural basin, probably a caldera about one mile in diameter.
0.4	32.0	Tuffs here dip 23° SSW as result of dip reversal across structural basin.
0.4	32.4	Center of basin.
0.6	33.0	Spectacular road cut on left exposes highly contorted flow banding in partially devitrified vitrophyre at contact with volcanic conglomerate on the western inner rim of the caldera.
0.3	33.3	STOP 12 - Time: 20 minutes - PARK ON LEFT. This point (altitude 7450 feet) provides a scenic view of the Gila Wilderness Area, the first such area designated by the U.S. Forest Service (1924), containing nearly 500,000 acres that are protected from commercial exploitation. The headwaters of the three forks of the Gila River lie within a structural and topographic basin rimmed on the west by the Mogollon Mountains, on the north by a series of isolated peaks and broad divides, on the east by the Black Range, and on the south by the Pinos Altos Range. Elevations range from a little over 4600 feet where the Gila River

debouches from the mountains on the west, to 10,892 feet on the summit of Whitewater Baldy in the Mogollon Mountains.

Exposed rocks consist of a thick sequence of Tertiary volcanics and associated intrusives, and clastic sediments derived therefrom. Below is the Alum Mountain formation of andesite flows and flow breccias, succeeded upward by dark-colored latite flows and breccias that crop out in both walls of the Gila Canyon from just below the junction of the East and West Forks southwestward and southward across the divide into the lower reaches of Sapillo Creek. The overlying Bloodgood Canyon Rhyolite ash flow tuff, visible on cliffs across the Gila, thickens rapidly from a wedge edge in the south wall of the Gila Canyon west of its junction with Sapillo Creek and southwest of this point, northward into the Diablo Range. In the Diablo Range, a thick "protrusive" mass of flow–banded rhyolite appears probably below Bloodgood Canyon Rhyolite, a segment of the ring–dike complex postulated by Elston. The exact stratigraphic relations of this unit are uncertain and it has not yet been named. Lithologically it resembles the post–Bloodgood Canyon–Jerky Mountain Rhyolite.

Locally, the Bloodgood Canyon Rhyolite is lapped on conformably by basaltic andesite flows, flow breccias, and minor pyroclastic equivalents that blanket the upper slopes of the north wall of the Gila Canyon in and about Brushy Mountain. They probably correlate with the Bearwallow Mountain Formation which caps the high peaks and eastern slopes of the Mogollon Mountains, and makes up the broad cone of Black Mountain some 17 miles to the north. Basinward, additional flows and ash flows wedge in between Bloodgood Canyon Rhyolite and Bearwallow Canyon(?) basaltic andesite.

Overlapping all of the volcanic assemblage, and locally interfingering with the late basalts, is an extensive blanket of mudstone, sandstone, and conglomerate composed of volcanic detritus, with local lenses of interbedded rhyolite tuff. This sequence constitutes the Gila Conglomerate, to which frequent reference will be made at subsequent points along today's route. The widespread distribution of the Gila Conglomerate within the structural basin of the headwaters of the Gila River reflects a characteristic relationship of the Gila River with structural, as well as topographic, basins elsewhere in southwestern New Mexico and southeastern Arizona.

The Gila Conglomerate and older rocks have been cut by high-angle faults of prevailingly northwesterly trend, paralleling the trend of the frontal faults along the western border of the Mogollon Mountains at this latitude.

0.4	33.7	Small fault in road cut on right. Just beyond the fault is a trail, on the right, to the Gila River.
0.2	33.9	Cattle guard.
0.2	34.1	Volcanic breccias and minor tuffs of Alum Mountain formation on the right.
0.2	34.3	View to west shown in panorama photo. (Figure 9).
0.5	34.8	Platy andesites in road cut. Good view across drainage basin of the upper Gila River toward Black Mountain and Beaver Points (Bearwallow Mountain(?) basalts, and andesites), a volcanic center near the center of the basin that preserves some of its original morphology. Note analogy with large lunar crater–raised walls, depressed inner floor, central peak.

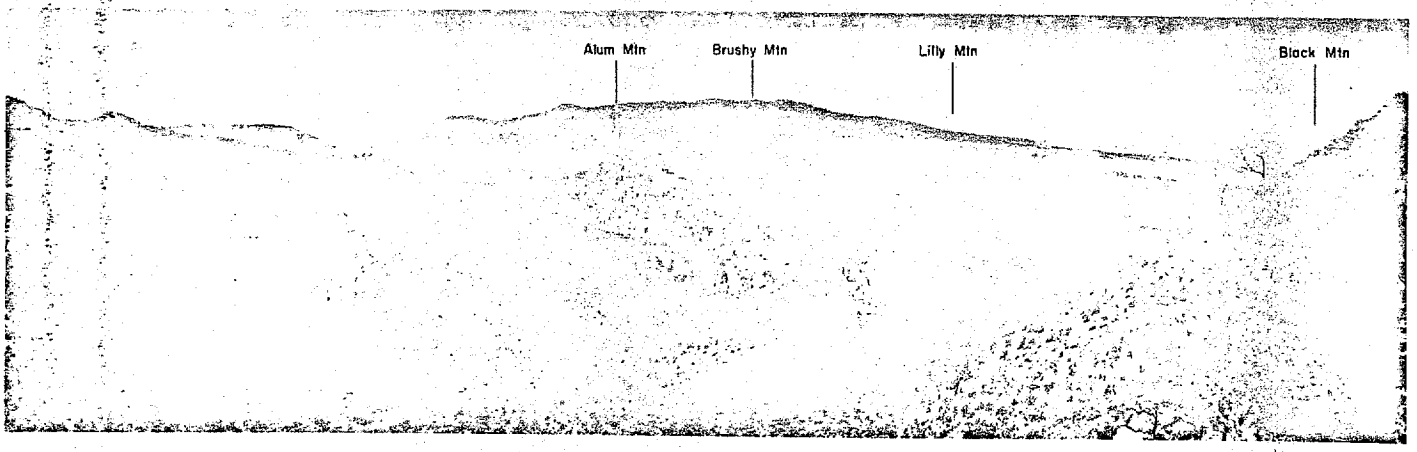


Figure 9 – Panoramic view across Gila Canyon of southern rim of Mogollon Plateau. Rocks in foreground and lower slopes of Brushy Mountain are part of the Alum Mountain Formation, hydrothermally altered. Cliff just below wooded top of Brushy Mountain consists of Bloodgood Canyon Rhyolite ash-flow tuff. Top of Brushy Mountain is Bearwallow Mountain (?) Basalt. Lilly Mountain in background consists of post-Bloodgood Canyon, pre-Bearwallow Mountain Jerky Mountains Rhyolite. All rocks dip northward into the Gila Sag, interpreted as a volcano-tectonic depression. Black Mountain (right background) is a volcano near the center of the Gila Sag. – Photographs by F.D. Trauger, U.S. Geological Survey

0.9	35.7	Cliffs of Bearwallow Mountain(?) Formation and Bloodgood Canyon Rhyolite at 12 o'clock on north side of the East Fork of the Gila River.
0.4	36.1	Unconformable contact of Gila Conglomerate on andesite of Alum Mountain formation.
0.8	36.9	Scenic view point of the Gila River on the left. Gila Conglomerate in road cuts ahead.
0.5	37.4	Cliffs of Gila Conglomerate on right; note jointing. A series of northwest–trending faults cuts the canyons of the forks of the Gila River.
0.3	37.7	Excellent exposures of the Gila Conglomerate in road cuts on left.
0.6	38.3	XSX Ranch at 3 o'clock. Basalt underlies Gila Conglomerate in canyon at 9 o'clock.
0.1	38.4	Well-rounded terrace gravels resting on Gila Conglomerate.
0.5	38.9	Basalt overlain by terrace gravels on left.
0.1	39.0	Road junction on right to Lyon's Lodge. Lyon's Lodge lies at the foot of a spectacular cliff of Bloodgood Canyon Rhyolite ash flow tuff, the only place where a really good exposure of this immense compound cooling unit is accessible by road within the Gila Basin. Unfortunately, the road is impassable by bus, although at times of low water it can easily be forded in a sedan – columnar joints, widened by weathering, hide numerous pre-historic cliff dwellings.
0.1	39.1	Bridge over Gila River at junction of East and West Forks.
0.4	39.5	Gila Conglomerate resting on basalt in road cut on left.
0.4	39.9	Cattle guard. Pinnacles of Gila Conglomerate across river on right. Major fault beyond pinnacles brings Bloodgood Canyon Rhyolite and overlying Bearwallow Mountain(?) basalt in contact with Gila.

0.1	40.0	Cattle guard. Gila Hot Springs on right across river. Water issues from many large and small orifices, only a few of which have been developed. The aggregate visible discharge was estimated to be about 100 gpm in 1962. The orifices are located in a large fault zone. Water issues at temperatures that are constant at about 147°F. Other hot springs are located in this general area, and increments of hot water are added to the river locally, by seepage, in amounts sufficient to raise the temperature of the river water by several degrees. A characteristic of the hot springs waters in this area is a relatively low content of total dissolved solids, 414 ppm for Gila Hot Springs, a high pH, up to 8.2 and relatively large amounts of fluorides and silica; some of the thermal discharge may be juvenile water.
0.3	40.3	Doc Campbell's Vacation Center (store). Bloodgood Canyon Rhyolite beyond the store. Downfaulted blocks of Gila Conglomerate overlying Bearwallow Mountain(?) basalt. Faults cross route diagonally to the left. For many years Doc acted as Superintendent of Gila Cliff Dwellings National Monument–at $1.00 a year. There was no paved road to the Monument until 1966.
0.2	40.5	Road cut. Terrace gravels overlying rhyolite tuff.
0.1	40.6	Cattle guard. County Line. Leaving Grant County, entering Catron County.
0.2	40.8	Basalt overlying Bloodgood Canyon Rhyolite. Because of hot-spring activity in this area the rocks are altered and sanidine lacks the "moonstone" irridescence.
0.2	41.0	Little Creek. Gila faulted against basalt across canyon on the right.
0.4	41.4	Cross distributary of West Fork of Gila River.
0.3	41.7	Bluffs of Gila Conglomerate on right. Faulted Gila on basalt visible through tributary canyon notch.
0.9	42.6	Cross dry wash.
0.5	43.1	Heart Bar Ranch. Now a game farm of the State Department of Game and Fish.
0.2	43.3	Fork left to Gila Cliff Dwellings. Go straight ahead, past Visitor Center.
0.1	43.4	Bridge across Gila River.
0.2	43.6	Visitors Center on right. Continue on service road closed to the general public.
0.3	43.9	Entrance to Forest Service trailer park on right.
0.1	44.0	STOP 13 - Time: 20 minutes - Looking up the Middle Fork of the Gila River at this point, one sees a basal section of dark andesite flows. About 6 miles upstream, the Bloodgood Canyon Rhyolite ash flow tuff crops out underneath this unit. Regional reconnaissance mapping by Peter J. Coney and Wolfgang E. Elston originally suggested that the andesite approximately correlates with the Last Chance Andesite of the Mogollon mining district (Ferguson, 1927) but recent work has indicated it may be younger. The notch above the layered, chocolate–colored andesite is made by thin conglomerate and a little pumiceous rhyolite tuff. Only a few feet thick at this point, this unit thickens systematically to the north and northwest.

A short distance upstream, the rhyolite tuff develops columnar joints and takes on the appearance of a poorly welded pumiceous ash flow. Good exposures of the rock can be seen along New Mexico 61 north of Beaverhead, 15 miles to the north. The unit thickens to about 400 feet on the west side of Black Mountain. It has tentatively been correlated with the Deadwood Gulch Rhyolite (Ferguson, 1927), although toward Mogollon massive, columnarly jointed zones disappear and bedded pumiceous tuff takes their place. It appears to reach its maximum thickness of around 1,000 feet in the highest part of the Mogollon Range, which we saw yesterday from Leopold Vista. The Deadwood Gulch Rhyolite has not yet been dated but it lies on older rocks with a pronounced angular conformity. The persistence of thin sediments at the base of the Deadwood Gulch Rhyolite, and the angular conformity, indicate that the Mogollon Plateau was bevelled to an area of low relief prior to its deposition. Much of the present relief developed subsequent to eruption of the Deadwood Gulch Rhyolite and even subsequent to the deposition of the Gila Conglomerate. The Gila Conglomerate not only fills part of the inner basin of the Mogollon Plateau, it also forms a structural basin with marginal dips commonly around 10° and locally as high as 30°. The differential movement between the floor and the mountainous rim of the Mogollon Plateau occurred in many stages over a long, but as yet unknown, period of time. Some stages of subsidence can clearly be correlated with eruption of major ash flow cooling units such as the Bloodgood Canyon Rhyolite and the earlier Apache Spring Quartz Latite ash flow tuff. Others, such as the post-Gila stage cannot be associated with any known ash flow. Active hot-spring activity and a Bouguer anomaly of about -30 milligals (Woolard and Joesting, 1964) show that the area is still active and has not yet reached isostatic equilibrium.

The thin conglomerate and tuff representing the southern terminus of the Deadwood Gulch Rhyolite at this stop is overlain by a hypersthene latite flow tentatively correlated with the Wall Lake Latite south of Beaverhead. Farther north, this flow is in turn overlain by olivine–bearing basalt from Black Mountain tentatively correlated with the Bearwallow Mountain formation.

0.3 44.3 STOP 14 - Time: 15 minutes - End of road. Garbage dump.

This point affords a good view of the Diablo Mountains to the west, which are made up of a huge mass of flow-banded rhyolite, so far found only in fault contact with the Bloodgood Canyon Rhyolite, interpreted as one of the inner arcuate intrusions surrounding the volcano–tectonic basin within the Mogollon Plateau. If the weather is clear, the 800-foot vertical cliffs made by Bloodgood Canyon Rhyolite ash flow along the West Fork of the Gila and Little Creek, one of its tributaries, can be seen. (Figure 10)

In the canyon of the Middle Fork, about 10 miles northwest from here (as the crow flies, not as the river winds) the Bloodgood Canyon Rhyolite dips underneath a great mass of flow-banded Jerky Mountains Rhyolite, the same age or younger than the rhyolite of the Diablo are. Incomplete field work by Peter J. Coney farther north indicates that the Jerky Mountains Rhyolite can be followed into Elk Mountain, a ridge that trends northwesterly from Black Mountain (the central volcanic peak of the Mogollon Plateau) toward the rim of Mogollon Plateau. Block faulting, including graben formation, with a northwesterly trend is prominent around Elk Mountain. As yet, no evidence has been found for resurgent doming within the Mogollon Plateau, but the Elk Mountain region suggests a possible analogy with a domes and grabens well known from the interiors of smaller cauldrons, such as Jemez (Valles), New Mexico; Timber Mountain, Nevada; and Creede, Colorado.

Because of lack of time, we will not be able to visit the Gila Cliff Dwellings. The earliest known occupation of the site was around A.D. 450. Subsequently, it became one of the centers of the Mogollon culture. It was abandoned for unknown reason around A.D. 1300.

Turn around and return to junction of New Mexico highways 25 and 527.

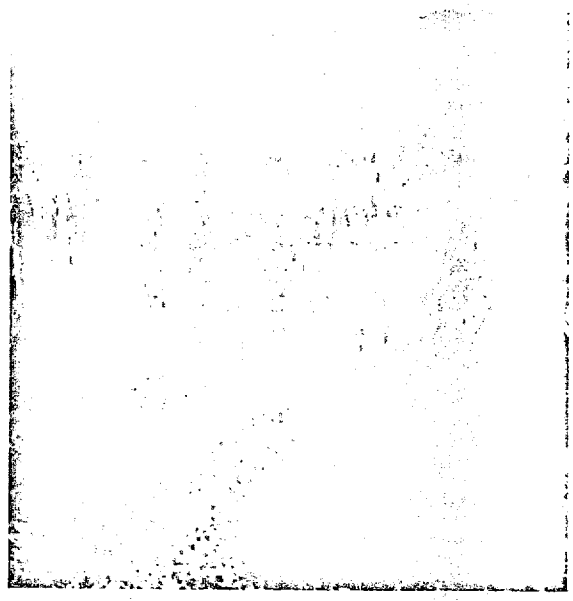


Figure 10 – Cliffs of Bloodgood Canyon Rhyolite ash flow tuff on Middle Fork of Gila River, south of Black Mountain. –Photograph by W.E. Elston, from aircraft piloted by J.F. McCauley, U.S. Geological Survey

18.2	62.5	Junction of New Mexico highways 527 and 25 at Sapillo Creek. TURN LEFT ON highway 25.
0.3	62.8	Lower Gila Conglomerate in road cuts on left.
0.2	63.0	Cross north-northwest-trending fault, down thrown on west side.
0.3	63.3	Dip. Cross Salt Creek. Lower Gila here dips up to 25° NE.
0.5	63.8	Bridge.
0.1	63.9	Cross Fault.
0.1	64.0	Bridge. Old meerschaum(sepiolite)mines about 1 mile up tributary canyon to the left. Sepiolite occurs in veins cutting Gila Conglomerate and is therefore late Tertiary in age. The gangue is quartz and small crystals of iceland spar calcite. The occurrence is very different from the usual association of sepiolite with serpentinite.
0.1	64.1	Cattle guard.
0.5	64.6	Site of abandoned milling town of Meerschaum across Sapillo Creek to the right. A series of northwest–trending faults repeats the upper part of the Gila Conglomerate.
0.2	64.8	Bridge. Upper Gila Conglomerate dips 10° ENE.
0.4	65.2	At 10 o'clock, basalt within lower Gila faulted against upper Gila.
0.2	65.4	Fault (as above) crosses route. Gila basalt in lower Gila faulted against upper Gila.
0.1	65.5	Bridge.
0.2	65.7	Cross wash.

0.1	65.8	Reddish sandstone in lower Gila.
0.1	65.9	Red clastic dike along fracture in Gila Conglomerate on left.
0.1	66.0	Lake Roberts ahead on the right. Sapillo Creek is impounded by a dam set on an intra–Gila basalt or basaltic andesite, the resistant outcrop of which has resulted in local constriction of the canyon walls.
0.8	66.8	Cross gulch. Upper Gila dips 20° NE.
0.4	67.2	Cross tributary wash. Entrance to campgrounds of Lake Roberts on right.
0.2	67.4	Terrace gravels, sands, and silts in road cut on the left.
0.2	67.6	Cross Sapillo Creek.
0.6	68.2	At 10 o'clock, excellent cliff exposures of Gila Conglomerate showing well developed bedding and conspicuous jointing. Canyon here follows the approximate strike of the Gila. Fault in canyon at western end of cliff.
0.4	68.6	Cross tributary wash.
1.4	70.0	Mouth of Rocky Canyon to left.
0.4	70.4	Cross Sapillo Creek channel.
0.2	70.6	Massive, less indurated facies of the upper part of Gila Conglomerate in the slopes of Skates Canyon to right.
0.2	70.8	Side road to Skates Canyon on right.
0.5	71.3	Massive Gila in cliffs at 2 o'clock.
0.5	71.8	Lower end of Gattons Park at the mouth of Terry Canyon.
0.1	71.9	Cross channel of Sapillo Creek.
0.8	72.7	Lower end of Gattons Park at 3 o'clock. A basalt flow near the top of the Gila Conglomerate on the skyline has been dated at 6.3±0.4 m.y. (Damon, personal communication) and must be close to the minimum age of the Gila Conglomerate in this area. It is nearly flat-lying and probably younger than the main stages of Basin-and-Range faulting. A basaltic andesite cut by Basin-and-Range faults and interbedded with basal Gila or pre-Gila sediments in the Gila Valley about 60 miles southwest from here gave a whole–rock age of 20.6±1.5 m.y. These ages bracket both the Gila Conglomerate and Basin-and-Range faulting.
0.4	73.1	Entering upper Gatton Park. GOS Ranch to left. Valley is carved in Gila Conglomerate.
0.1	73.2	Cattle guard.
1.9	75.1	Continental Divide. Sign gives elevation of 6500 feet, but it actually must be about 6640 feet, as indicated by a bench mark below this point. Eroded Gila to the left. Entering Mimbres River drainage. Is this really the Continental Divide? The Mimbres River drains into a closed basin of the Basin and Range Province near Deming.

0.2	75.3	Junction of New Mexico Highway 61 on left, which is a part of the Outer Loop Drive via Beaverhead (Highway 61 is an excellent access route to the inner volcano-tectonic depression of the Mogollon Plateau) Bench mark, 6599 feet. Route passes down headward drainage of West Fork of Mimbres River through a valley cut in the ubiquitous Gila Conglomerate. Warning: Don't attempt the Outer Loop Drive without lots of gas. There are no gas stations between Mimbres and Glenwood, a 6 to 8 hour drive!
1.3	76.6	Terrace gravels overlying Gila Conglomerate on spur to right.
0.4	77.0	Entrance to Camp Thunderbird on right. This is the Pilgrim Fellowship camp of the Congregational Churches.
1.1	78.1	Excellent exposures of Gila Conglomerate in cliffs to left. Note etched relief of bedding.
0.2	78.3	Road junction on left. Confluence of North, East, and West Forks of Mimbres River.
0.5	78.8	Mouth of Cottonwood Canyon on right. Dead timber on hill slopes resulted from drought of the early 1950's. Dendroclimatic studies by Schulman (1956, p. 67) indicate that the current drought, which began in New Mexico about 1943, is the most severe since that of the late 1200's.
0.4	79.2	Gaging station to left.
0.3	79.5	Mimbres Ranger Station on right. The 6.3 m.y. old basalt flow interbedded with gently northward–dipping Gila Conglomerate is visible on skyline at 10 o'clock.
0.2	79.7	Cattle guard. Leaving Gila National Forest.
1.6	81.3	SLOW! Wash-out ahead at mouth of Allie Canyon.
0.2	81.5	Cattle guard.
0.3	81.8	Terrace gravels in road cut on right overlie highly conglomeritic facies of the Gila Persistent terrace levels which become more prominent further down the Mimbres Valley.
0.4	82.2	Bridge.
0.3	82.5	Terrace gravels on Gila Conglomerate in road cut on right.
0.2	82.7	Bridge.
0.4	83.1	Entrance to Bear Canyon Lake on right. Bear Creek is perennial in part of its upper reaches; the lake is maintained by underflow.
0.2	83.3	Rhyolite ash flow tuff on the right is correlative with Caballo Blanco Rhyolite of Dwyer quadrangle, K-Ar age of 29.8±0.8 m.y. (Damon, et al., 1967). For correlation, see Figure 2, Column I in article by Elston, this guidebook. Although the Caballo Blanco Rhyolite is the youngest ash flow of the thick rhyolite section in the Black Range–Mimbres Valley–Santa Rita area, it is older than three major ash flow units that took part in development of the Mogollon

Plateau; the Apache Springs Quartz Latite, Bloodgood Canyon Rhyolite and Deadwood Gulch Rhyolite. The Mogollon Plateau ash flow province is therefore largely younger than the volcanics to the south and the type—Datil to the north.

0.2	83.5	Bridge. Bear Canyon dam to right. Caballo Blanco Rhyolite ash flow tuff at bridge abutment. The Caballo Blanco is characterized by abundant phenocrysts of doubly terminated smoky quartz, sanidine, biotite, and sparse plagioclase. Its maximum known lateral extent is 45 miles (from the North Fork of the Mimbres to the Knight Peak graben) thickening systemetically northwestward toward a probable source in the Black Range. The maximum thickness of typical Caballo Blanco is about 350 feet. Toward the Black Range, other ash flows appear above and below, giving a total thickness of about 600 feet.
0.8	84.3	Terrace gravels abutting rhyolite tuff in road cuts on right.
0.2	84.5	Caballo Blanco on right. Fault contact of tuff with Bear Springs(?) Basalt just ahead.
0.2	84.7	Basalt on Caballo Blanco tuff on right.
0.1	84.8	Ranch house on right. Volcanics here swing westward away from the Mimbres Valley.
0.6	85.4	Mouth of Shingle Canyon on right.
0.1	85.5	Entering town of Mimbres.
0.2	85.7	Bridge.
0.3	86.0	Mimbres Post Office and store. Route from here to San Lorenzo is largely over Quaternary terrace gravels.
0.4	86.4	At 2 o'clock, trace of Mimbres fault along which Precambrian rocks and overlying Paleozoic section are faulted against Gila Conglomerate. Northwestern continuation of this fault seen earlier today at head of Cherry Creek.
0.8	87.2	Bridge. Cooks Peak at 1 o'clock. Probable continuation of Mimbres fault crosses Crooks Range to the left of Cooks Peak.
0.3	87.5	Bluffs of Gila Conglomerate at 9 o'clock. Hillsboro Peak (elevation 10,011 feet) on skyline.
1.4	88.9	Lower Paleozoic strata in cliffs to right.
1.1	90.0	Village of San Lorenzo to the left.
0.4	90.4	Junction of road to San Lorenzo on left.
0.2	90.6	EXTREME CAUTION! Junction with New Mexico Highway 90 on the left. TURN LEFT on New Mexico 90.
0.6	91.2	From 7 to 12 o'clock scarp formed of upthrown block on southwest side of Mimbres Valley fault. At 11 o'clock, lower brownish slopes are of Precambrian spotted greenstone; dark brown outcrops are of Bliss formation, note 2 ledges

marking resistant sandstone beds; ledges of gray limestone above Bliss are the early Ordovician El Paso Formation; high dark–brown cliff capping escarpment is late Ordovician Montoya limestone. At 10 o'clock on south (left) side of canyon note several down–faulted blocks capped by the Montoya cliff.

0.5 91.7 Bridge.

0.1 91.8 Fork in highway. Follow State Highway 90 on Left Fork

0.3 92.1 Bridge across Mimbres River. Tertiary consolidated gravels and unconsolidated terrace gravels ahead for the next four miles. The Tertiary gravels are identical with those we've been seeing for the past two days. However, since we have crossed the Continental Divide, some people apply the term Santa Fe Conglomerate instead of the term Gila Conglomerate. However, the Mimbres River flows neither into the Atlantic nor the Pacific, but ends in an interior basin near Deming, New Mexico. Also, the gravels are continuous, extending across the Continental Divide, from the Mimbres into the Sapillo Valley, as well as from the Mimbres Valley eastward across the southern Black Range into the Rio Grande Valley (Home of the Santa Fe Group alluvial sediments). The distinction here appears purely arbitrary. Let's leave this problem to the stratigraphers and get on with the job of worrying about ash flow.

4.0 96.1 Fault, on the left side of the highway, a sliver of Caballo Blanco Rhyolite ash-flow tuff is exposed unconformably underneath Gila (?) (Santa Fe?) Conglomerate and faulted against a basaltic andesite, probably equivalent to the Bear Springs Basalt and bracketed between the 26.6±0.8 m.y. date for the overlying Swartz Rhyolite and the 29.8±0.8 m.y. date for the underlying Caballo Blanco, (Damon, et al., 1967). It is clearly older than the post–Bloodgood Canyon basalts and basaltic andesites of the Gila Cliff Dwellings area. (Figure 11)

To the right across the valley, a depositional contact between Bear Springs Basalt and Caballo Blanco Rhyolite can be seen. About 20 feet of sandstone intervene between the two units.

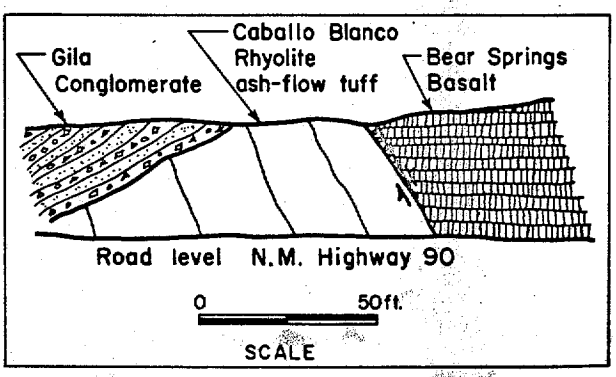


Figure 11 – Field relations at mile 96.1, (second day) from a sketch by W.E. Elston

0.3 96.4 For the next 1.9 miles, a descending section of Bear Springs Basaltic Andesite, reddish sandstone, Caballo Blanco Rhyolite Tuff and Kneeling Nun Quartz Latite ash flow tuff is exposed in low cuts on the left side of the highway. Contact relationships and thicknesses are difficult to judge because of faulting. The Kneeling Nun Quartz Latite tuff is the main objective of this part of the field trip. The road traverses what appears to be the vent area of this extensive ash flow cooling unit. Kuellmer (1954) estimated its minimum thickness at 1300 feet; its maximum thickness in the vent area is much greater but cannot be accurately measured because no base is exposed and the section may be repeated by faulting. The ash flow tuff shows rectangular jointing in some places and high–angle, closely–spaced (10 in. or less) sub–parallel jointing elsewhere along this stretch of the road. Three main phases can be recognized along the highway and a stop will be made at each:

1. Massive ash flow tuff with planar structures dipping 20 to 40 degrees southwesterly, rectangular jointing, abundant xenoliths generally less than 30 mm in size, and sparse vapor-phase cavities.

2. Xenolith or chaotic megabreccia zone, containing accidental rock fragments ranging in size up to 80 feet in length. The xenoliths may be surrounded by reaction rims of stony rhyolite. Black vitrophyre masses intimately interpenetrate both the tuff and the fragments of the xenolith zone on a large and small scale. The vitrophyres may be cut by ramifying fractures along which normal tuff material has formed. The long axes of xenoliths tend to be vertical (Elston). The rocks comprising the xenoliths are in order of decreasing abundance: (a) Andesite of the type immediately underlying the Kneeling Nun Quartz Latite. Andesite makes up approximately 90% of the xenoliths. (b) Red shale and sandstone of the Permian Abo Formation. (c) Limestone from the Pennsylvanian Magdalena Group (d) Limestone and shale from the Mississippian Lake Valley and Devonian Percha Formations. (e) Granitoid rocks. According to Kuellmer (1954), the xenolith zones extend more than 3 miles long in a north–south direction and up to half a mile wide. Within the normal ash flow tuff regional dip of planar structures is 20 to 40° SW; whereas in the xenolith zone, dips as steep as 82° have been recorded. In many places the volume of xenoliths exceeds the volume of Kneeling Nun Quartz Latite matrix.

3. A phase of massive ash flow tuff densely welded and characterized by subparallel vertical joints only inches apart and more widely spaced southwest-dipping joints.

Later this afternoon, after leaving the Black Range, we will see, in the Bayard area 20 miles to the southwest, the Kneeling Nun Quartz Latite as it appears away from the vent area. There it is a typical columnar–jointed quartz latite ash flow compound cooling unit with a pumiceous rhyolitic base.

1.9	98.3	Xenolith zone.
0.3	98.6	"Normal" Kneeling Nun, lacking large xenoliths.
0.4	99.0	Enter Gila National Forest.
0.7	99.7	STOP 15 - Time: 20 minutes - Kneeling Nun Lookout. Examine massive phase of Kneeling Nun Quartz Latite tuff. No large xenoliths are present. The rock is a grayish–pink welded tuff containing abundant fragmented phenocrysts of sanidine, quartz, and biotite, all of which are 2 mm and less in size. Sparse, small (2 in. and less) xenoliths of andesitic material and several granitoid xenoliths (14 in. and less long) may be seen. The lighter–colored lenses forming a planar structure are abundant, as well as less obvious cognate (?) fragments, blocky and ellipsoidal in shape, with coarser phenocrysts (to 5 mm).

When this unit was mapped in 1950, published descriptions of welded tuffs emphasized properties demonstrating their air-borne nature. Many of the properties of the Kneeling Nun tuff in this vicinity such as the lack of obvious pumice fragments, the abundance of crystal fragments (up to 69%), the near lack of bedding or sorting, linear gas cavities, the uniform regional dip of planar structures coupled with great irregularities within the xenolith zone, irregular vitrophyre masses, and closely–spaced sub–parallel vertical joints seemed to deviate from those emphasized for ash falls. Today it is recognized on the basis of work by Ross and R.L.

Smith, Boyd and others, that proximity to an eruptive center and great thicknesses of particulate ash flows can produce the intensity of welding and crystallization found in this area. Furthermore, subsequent work by Kuellmer, Elston, Giles and others demonstrates the continuity of this rock with distant Kneeling Nun welded tuff areas.

The layered, columnarly–jointed part of the Kneeling Nun Quartz Latite can be seen in the distance. The formation was named after a single weathered-out column that overlooks the Chino Mine at Santa Rita.

The moonstone–sanidine pegmatite of Grant County, New Mexico, described briefly by Kelley and Branson (1947) and Kuellmer (1954, p. 79-81) is found about three miles north–northwesterly from this stop. The pegmatites are not zoned, contain sanidine crystals as much as 24 inches long, large dipyramidal quartz and biotite. The fracture–filling pegmatitic lenses are within a miarolitic porous rhyolite porphyry injected into the Kneeling Nun Tuff. Mineral similarities; intimate spatial distribution of the pegmatite, porphyry, and tuff; lack of zoning; porous nature of the porphyry matrix; and geographic proximity to the xenolith zones suggest a vapor–rich late–stage fumarolic and intrusive origin, consanguineous with the Kneeling Nun tuff.

0.7 100.4 Numerous exposures of xenolithic rock for the next mile. In places the exposures in road cuts approach absolute chaos.

1.0 101.4 Cattle guard. STOP 16 - Time: 20 minutes - Examine xenoliths of various lithologic types and reaction rims. A partial description of the STOP is found under item 2 of the 96.4 mileage entry. Except for the road cuts, the mapped boundaries between xenolith zones and massive Kneeling Nun tuff are somewhat arbitrary. The tuff here is petrographically like that of the previous stop except for fresh brown biotite which shows less or no crinkling and no hematitic rims. Many of the contacts between tuff, xenoliths, or vitrophyre are marked by a slightly browner or orange–brown rim of a stony tuff which contains lenticular planar structures. The planar structures on a stony rim about a xenolith may be parallel to the xenolith contact. Phenocrysts in the rims are identical to those in the tuff proper. The rim matrix is cryptocrystalline with radial or spherulitic finely intergrown fibers radiating outward from crystal fragments and very fine dendrite–shaped intergrown masses. (Figure 12a, Figure 12b)

The xenoliths of andesitic volcanic rocks differ only slightly from the original rock. The matrix is more opaque (ferric oxides), contains small secondary spheroidal masses of intergrown quartz, sericite, and zeolites, thin veins of quartz and fresh biotite, and small sericite grains.

The rims are enriched in Si and K, and lower in Na relative to the vitrophyres. This shift in composition makes the stony rims more rhyolitic than the vitrophyre. This crystallization is believed to have been facilitated by both volatiles contained in the xenoliths and volcanic gases.

0.1 101.5 Massive Kneeling Nun without large xenoliths for next 0.3 miles. Shortly after the road starts down hill a large sugarloaf–like spire of rhyolite porphyry may be seen at about 2 o'clock, looking down into the valley. The porphyry is a small plug intrusive into the Kneeling Nun tuff and consists of white sanidine phenocrysts (to 2 + cm in length) and quartz dipyramids set in a white xenomorphic–granular, friable matrix. The intrusive resembles the porphyry of the Rabb Canyon pegmatite area except that the sanidine has a white silken luster instead of a blue moonstone chatoyance.

Figure 12a – Xenolith zone in Kneeling Nun Quartz Latite. The ramifying light-colored bands are Kneeling Nun; the grey areas are xenoliths, consisting of andesite in the foreground. The large xenolith directly behind the fence at the back of the vehicle is Paleozoic sedimentary rock, largely converted to hornfels. Its bedding is vertical.

Figure 12b – Closeup of single andesite xenolith in Kneeling Nun Quartz Latite, showing reaction rim, and vitrophyre below xenolith. Note hammer for scale. –Photographs by W.E. Elston

0.3	101.8	Narrow xenolith zone, massive Kneeling Nun beyond.
0.8	102.6	Bridge across Gallinas Creek. Enter "Devil's Backbone Geological Area" (no kidding, that's what the Forest Service sign says). The Devil's Backbone is a deep gorge with precipitous cliffs made up of the phase of Kneeling Nun Quartz Latite tuff characterized by closely–spaced sub–parallel vertical joints. The matrix of the rock locally takes on a glassy appearance.
0.6	103.2	Bridge across Gallinas Creek. STOP 17 - Time: 20 minutes - Examine closely–fractured phase of massive Kneeling Nun Quartz Latite tuff. The rock is a crystal–rich tuff with abundant phenocrysts of sanidine, quartz, and biotite (1–2 mm. size) and abundant fragments of andesitic(?) volcanic rocks (10 cm and less). Toward the west end of the gorge, there are sparse blocks of andesite (and andesite–lined cavities) up to about 15 feet in diameter. The closely–spaced joints trend north–south, and range from vertical to 70 degrees dip. At the east end of the gorge, a second set of fractures marked by rubble zones, hematite–stained joints, and/or a gash–vein type of bending of the vertical joints strikes about N20W, and dips 48° W. At the west end of the gorge (mileage: 102.6) rubble zones and less prominent joints trend about N50W and dip 28° NE. (Figure 13)

Exactly 5.5 and 5.6 miles east of the bridge at this stop (0.4 and 0.6 miles westward from Emory Pass) are dikes of a green vitrophyre intruded into the andesitic volcanic rocks. The green vitrophyres are slightly to considerably devitrified along the contact and contain 10% phenocrysts of sanidine, quartz, and granophyric intergrowths. The only other occurrence of granophyric phenocrysts, in a glassy matrix, of which Kuellmer is aware, is the African rift valleys. No time for this trip to go there. If you have a chance visit these outcrops sometime. The glass is clearly intrusive.

		Turn around and return to San Lorenzo.
12.6	115.8	Fork of New Mexico Highways 61 and 90. Take Highway 90, left fork.
0.3	116.1	Mimbres fault; Mimbres valley fill on east side is in fault contact with Precambrian on west side.
0.3	116.4	Top of Precambrian greenstone, base of Bliss Sandstone. The exposed section was measured and made available by Messrs. Robert M. Hernon and William R. Jones.

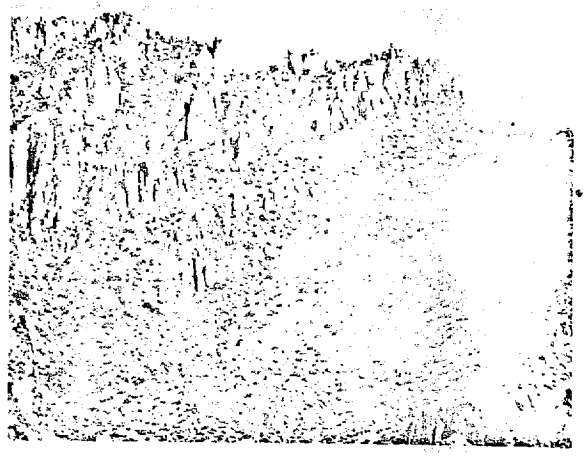


Figure 13 – Closely-jointed xenolith-poor Kneeling Nun in Devil's Backbone area. –Photograph by W.E. Elston

Ordovician:	
Montoya Group	103 + feet
Aleman Formation – cherty and dolomitic limestone	70 ± feet
Upham Dolomite – cliff	21 feet
Cable Canyon Sandstone	12 feet
El Paso Group	559 feet
Bat Cave Formation – limestone with dolomite and sandstone near top: cherty beds, siliceous laminae, scattered fossils	400 feet
Sierrite Limestone	159 feet
Cambrian:	
Bliss Sandstone – shaly and sandy dolomite, shale, conglomerate, sandstone, abundant glauconite	146 feet
Precambrian – spotted greenstone	

0.1	116.5	Reddish–brown, cross–bedded sandstone of Bliss in road cut on right.
0.15	116.65	Top of Bliss Sandstone, base of El Paso limestone, 50 to 100 feet above highway. High ledge on north (right) side of road is chert horizon in lower part of Montoya.
0.15	116.8	Large fault crosses road. Paleozoic section downdropped on south (left) side of road. Fault passes down canyon to the east. At 9 o'clock Montoya "limestone."
0.3	117.1	At 11 o'clock thick sill of quartz monzonite porphyry lies above Montoya; base of sill crosses road at 93.7 miles.
0.2	117.3	Silurian Fusselman Dolomite on right.
0.1	117.4	Sill.
0.5	117.9	Bridge. Late Devonian Percha Shale on left showing flat dip to west.
0.1	118.0	Rhyolite intrusive (soda rhyolite of Lasky) mixed with Percha Shale on left.

0.8	119.1	Bridge.
0.3	119.4	Breccia border between Percha Shale and rhyolite plug.
0.1	119.5	Top of Percha Shale, base of Mississippian Lake Valley Limestone to left.
0.3	119.8	Bridge. Percha Shale in road cuts. At 2 o'clock distant ledge is lower cliff–forming member of the Lake Valley which overlies the Percha Shale. Ten degrees westerly dip. Valley underlain by Percha Shale.
0.5	120.3	Top of Percha Shale, base of Lake Valley Limestone to right of road.
0.2	120.5	Bridge. Beyond bridge (west) is crinoidal member of the Lake Valley Limestone, locally called Hanover Limestone, the chief host rock for zinc ores of Central Mining District. Large white chert nodules and crinoidal composition are distinguishing features; at the south end of the Hanover–Fierro Stock contact, metasomatically replaced by almost pure andradite garnet. Base of Pennsylvanian Oswaldo Limestone, basal parting shale (±15 feet) on south (left) side of road; note chert nodules in limestone are black.
0.3	120.8	Base of thick later quartz diorite sill; locally, because of its persistent stratigraphic position called the "Marker Sill."
0.3	121.1	Top of Marker Sill. Contact dips gently southwest. Side road to left. At 9 to 11 o'clock, prominent cliff is Kneeling Nun Quartz Latite welded ash flow tuff.
0.5	121.6	Cross contact of Oswaldo Limestone into Syrena Limestone, Syrena has 40-foot shale bed at base (both Pennsylvanian).
0.9	122.5	Dip Sign: Syrena–Oswaldo contact crosses road diagonally. For about one mile road is on Oswaldo Limestone with gentle southwest dip. Bench Mark U-126 on right side of road, center of dip. Elevation 6,602.483 feet.
0.4	122.9	Cattle guard. Ridge on left is capped by Beartooth Quartzite (Upper? Cretaceous, approximately Dakota–equivalent). Dips gently south.
0.2	123.1	At 10 o'clock, Chino Pit (copper), Kennecott Copper Corporation. Trail on right side of highway follows latite dike. Dike cutting Oswaldo Limestone. (Figure 14)
0.2	123.6	Road to right leads to Georgetown. This was an active silver mining district around the turn of the century. Several (inactive) mines, a few deer, and a couple of claim jumpers are all that one may find there today.
0.1	123.7	Road cut in southeast–dipping, severely altered Syrena Limestone.
0.4	124.1	At 10 o'clock, head frame of Oswaldo No. 2, zinc operation of Kennecott Copper Corporation. Mine workings mainly in Oswaldo and Hanover limestones, 300 to 400 feet below collar.
0.2	124.3	Large north–trending granodiorite dikes cross road, altered Syrena Limestone at surface.
0.1	124.4	Magnetite lenses mined from shallow open pit on right side of road in altered Syrena.

0.1	124.5	Santa Rita Store (abandoned) and Post Office. Road intersection. Kearney mine of American Zinc headframe at 1 to 2 o'clock.
0.4	124.9	At 11 o'clock, head frame of Princess Shaft of U.S. Mining, Smelting and Refining Company.
0.1	125.0	Side road on right to Kearney–Pewabic Zinc Mines of Empire (New Jersey) Zinc Company. (Road crosses Kearney breccia pipe 0.1 mile from main highway).
0.05	125.05	Altered Syrena and Oswaldo Limestones intruded by granodiorite dikes. One of the better zinc producing structures of the district.
0.05	125.1	Contact of Wimsattville basin fill and Oswaldo Limestone. Tertiary Wimsattville Formation underlies the bowl-shaped area ahead. Bull Hill at 2 o'clock is a later Tertiary low–quartz plug which intruded the Wimsattsville Formation. Igneous rock is almost completely altered to clay; a few veinleta of alunite and sparse pyrite have been noted in the mass.
0.2	125.3	Beautiful bedding in tailings form New Jersey Zinc Company mill. The present is not always the key to the past.
0.1	125.4	At 2 o'clock, Bull Hill.
0.2	125.6	Railroad crossing; Hanover Wash. New Jersey Zinc Company Mines at 3 o'clock. Railroad cut on left is Wimsattville Formation dipping 20-30° S. Latite dikes also exposed in cut. The Wimsattville basin fill has remarkably steep dip (up to vertical to overturned) at the edge of the basin; dips flatten toward the center. Rocks are massive fanglomerate at base, finer–grained and bedded toward top. Roughly circular basin has been ascribed to anything for meteorite impact to rapid subsidence accompanying formation of Hanover contact–metasomatic zinc deposit.
		Junction of New Mexico highway 90 and New Mexico 356. Turn left on New Mexico 356.
0.4	126.0	Edge of Wimsattville Basin.
0.1	126.1	Escarpment of Beartooth Quartzite on left cross drainage.

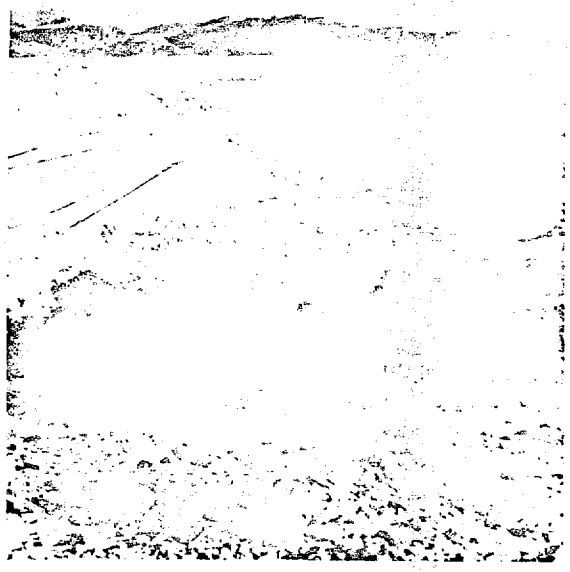


Figure 14 – Chino copper mine of Kennecott Copper Corporation – largest mine in New Mexico. Note skip–haulage system on far wall. Hills in background are of Tertiary volcanic rocks (mainly Kneeling Nun Quartz Latite ash-flow tuff) which unconformably overlie the mineralized Laramide porphyry body. Much of the oxidation and secondary enrichment is pre–volcanic, and preserved from erosion by the volcanic rocks that once blanketed the ore body. –Photograph by W.E. Elston

0.7	126.8	Curves in road. Exposures of Colorado Shale intruded by dike swarm.
0.4	127.2	Kneeling Nun Quartz Latite forms cliff from 8:30 to 12.
0.5	127.7	Road cuts in Colorado Shale with dikes and sills.
0.7	128.4	City limits of Vanadium. Turn left, cross railroad tracks.
0.2	128.6	Cobre loading point. Kneeling Nun Quartz Latite above Cretaceous sediments at 3 o'clock.
0.2	128.8	Road forks. Turn right, cross railroad tracks and bridge across Bayard Canyon.
0.1	128.9	Crossroad. Keep going straight ahead. The valley ahead of us follows the trace of the mineralized Groundhog Fault. The Groundhog Mine, owned by Asarco, is one of the leading producers of lead and zinc in New Mexico.
0.1	129.0	Road forks. Take right fork on dirt road. Left fork leads to No. 1 Shaft of Groundhog Mine.
0.2	129.2	STOP 18 - Time: 30 minutes - Park at former main office Asarco Groundhog Mine. On foot, follow lower road through gate, for about 1/8 mile, cross Bayard Canyon and follow left fork of road (the better of the two forks, it leads to Groundhog No. 5 shaft up Lucky Bill Canyon to second gate for another 1/8 mile. The base of the Kneeling Nun Quartz Latite is well exposed to the right. The basal Kneeling Nun is a slopeforming, poorly consolidated rhyolite overlain by welded cliff–forming rock. About 100 feet above the base, the rock is a quartz latite. The change in composition is gradational and independent of the degree of welding. Above the basal 100 feet, the next 500 feet are a nearly homogeneous quartz latite. At the top of the section rock becomes slightly more rhyolitic.

ASH-FLOW TUFFS OF THE COBRE MOUNTAINS

By

David L. Giles
Harvard University

Lucky Bill Canyon extends southeast for about 2 miles into the Cobre Mountains. The pinkish-white-to-red cliffs and slopes that surround all sides are of the Kneeling Nun Quartz Latite, a partially-to-densely welded crystal-rich ash-flow tuff. The valley floor is here on a small window through the Kneeling Nun into the underlying tuffaceous sandstones of the Sugarlump Tuff. Looking up the canyon, at 10 o'clock is the headframe of American Smelting's Groundhog No. 5 shaft; about 2 miles directly over the hill from the shaft is the south rim of Kennecott's Chino pit. The peaks in the background toward the head of the canyon, from 10:30 to 2 o'clock, are capped by scattered patches of Bear Springs Basalt. Underlying rocks are in descending order: cliffs of Caballo Blanco Rhyolite ash-flow tuff, Rustler Canyon Basalt, Box Canyon Rhyolite; slopes of thin local clastics and vitrophyre possibly equivalent to the Mimbres Peak Formation, the thick upper partially welded zone of the Kneeling Nun Quartz Latite ash-flow tuff (see

Figure 15). At 4 o'clock is an excellent exposure of the Kneeling Nun/Sugarlump contact (Figure 16).

Figure 15 – Base of Kneeling Nun Quartz Latite ash-flow tuff, near mouth of Lucky Bill Canyon. Ts–Sugarlump Tuff, Tkn–Kneeling Nun Quartz Latite. Note darkening of color and increase in degree of welding upward in the Kneeling Nun Quartz Latite. –Photograph by W.E. Elston

The Cobre Mountains consist of three broadly defined, predominantly volcanic sequences: a lower and very thick andesite and latite (Rubio Peak Formation), a middle pyroclastic sequence with related flows and clastics, and the upper andesites and basalts. The Caballo Blanco and Sugarlump are the upper and lower members, respectively, of the middle pyroclastic sequence. Regional homoclinal dips in the Cobre Mountains are gently to the southwest; in the northern part of the range the average is around 10°. The strata in this area are also broken by a series of small north–northeast trending normal faults. Relative displacements vary, but the cumulative effect has been one of a progressive downthrow to the west. The Groundhog No. 5 shaft is on a small horst bounded by several of these faults cutting across the canyon. The pattern of downthrow sharply terminates at the mouth of Lucky Bill Canyon; San Jose Mountain (opposite Bayard Canyon) is on a large uplifted block that forms the footwall of the northeast trending Groundhog Fault, a major structural feature of the area. Because of faulting, the middle pyroclastic sequence is best preserved in the northwestern part of the range, and is admirably exposed in Lucky Bill Canyon.

The dominant exposures in the canyon are of the compound cooling unit of the Kneeling Nun, which in this area is around 420' thick. Five distinct and genetically related flow units have been recognized in the sheet; the upper four comprise the top 150'. The basal flow unit (270' thick) is a simply zoned cooling unit. It has a partially welded top and base (the grayish-pink slope formers) and a thick middle zone of dense welding (the bold red cliffs). Partings have been recognized in this flow unit, but they are scattered and discontinuous. The variations in welding are gradational and this part of the sheet has been interpreted as the result of a continuous eruptive episode.

Phenocrysts in the unit range from 25 to 60%, and consists of quartz, sanidine, sodic plagioclase, biotite, opaque oxides, and trace amounts of sphene, zircon, hornblende, and clinopyroxene. The groundmass has been completely crystallized (devitrified), and there is a well-developed vapor-phase zone. The unit shows strong vertical compositional zoning that ranges from a basal quartz latite crystal-vitric tuff to an overlying latite crystal tuff. Variations may be abrupt but they are systematic, and consist of an upward increase in the number and size of phenocrysts, and in the proportion of ferromagnesian and plagioclase phenocrysts, with an accompanying decrease in the amount of quartz and the alkali feldspar/plagioclase ratio. Examples of such variation in the Lucky Bill Canyon section are the upward decrease in quartz from 36 to 5% (of phenocrysts) and of the alkali feldspar/plagioclase ratio from 2.0 to 0.25. Detailed studies have been carried out on major

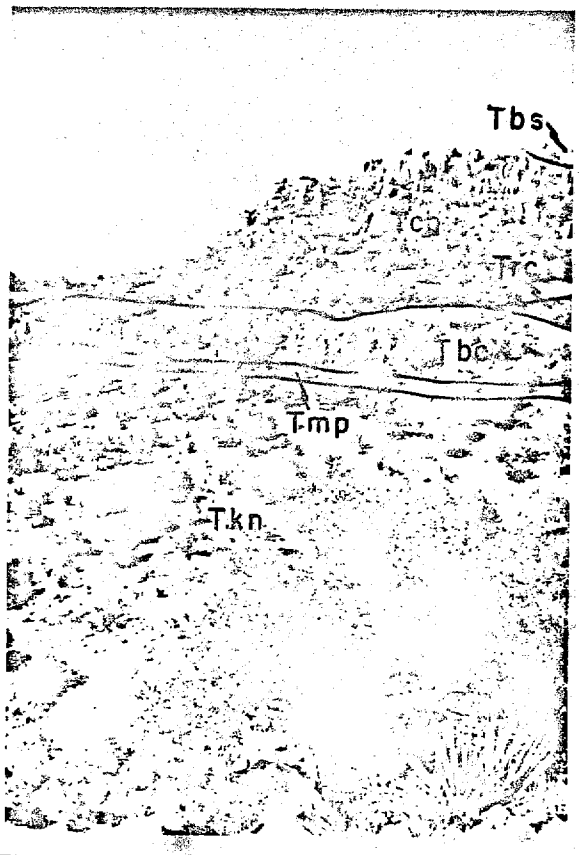


Figure 16 – Upper part of Tertiary rhyolite section in Cobre Mountains, head of Lucky Bill Canyon. Tkn–Poorly welded top of Kneeling Nun Quartz Latite ash-flow tuff; Tmp–Mimbres Peak Formation (vitrophyre and sandstone); Tbc–Box Canyon Rhyolite ash-flow tuff; Trc–Rustler Canyon Basalt; Tcb–Caballo Blanco Rhyolite ash-flow tuff; Tbs–Bear Springs Basalt. –Photograph by W.E. Elston

and trace elements in biotites and their matrix. The chemical data substantiates and complements the modal indications of a systematic vertical compositional zonation. Examples for biotite are the upward increase in Cu, Sr, Ba, and Ca, and a decrease in Rb and Mn.

All of the data is consistent with the explanation of an upward gradation and differentiation of progressively silicic and less crystal-rich melt within the pre-eruptive Kneeling Nun magma chamber. The rhyolitic material in the upper part of the chamber was erupted first, followed by more latitic material from increasingly lower levels. Eruption and deposition were more or less successive and continuous, at least for the lower two-thirds of the sheet (basal flow unit) – effectively resulting in an inverted replica of the compositionally zoned magma.

In the writer's interpretation, the initial compositional zoning in the Kneeling Nun magma resulted from protracted crystal settling concurrent with upward volatile (and alkali?) migration or transfer. The migration rate of water and other volatiles (whether in solution or as a separate phase) was not very high, and crystallization was well advanced prior to any upper level saturation. Further crystallization in this upper level – corresponding to the basal parts of the sheet – thus took place in a melt that had been previously zoned by crystal fractionation. Late-stage crystallization was simultaneous throughout the chamber, but at differing rates due to the vertical upward decrease of crystallization temperatures. The basal one-third of the sheet (for a distance of 60' to 80' above the Kneeling Nun – Sugarlump contact) represents crystal and water-rich residual silicate-melt equilibrium. The upper two-thirds (or so) of the unit represent lower-level magma that was in part crystal cumulate, and had in part crystallized more completely.

The Caballo Blanco Rhyolite which is compositionally zoned similarly to the Kneeling Nun (Basal rhyolite to capping quartz latite), has also been studied in detail. The general petrogenesis is identical to that of the Kneeling Nun.

0.2 129.2 STOP 18 (cont.)
Return to bus.

3.6	133.8	Return to Hanover the way we came, via New Mexico 356. Turn left on New Mexico 90 and continue towards Silver City. On the way, note the Kneeling Nun (the natural monument, not the ash flow) and the dumps from the Chino Mine, the largest mine in New Mexico. Production from this porphyry copper deposit, owned by Kennecott Copper Corporation, is 22,000 tons per day of ore and about twice as much waste.
0.4	133.2	Cattle guard. Western edge of Wimsattville Formation.
0.2	133.4	Road cut parallels Tertiary dikes; Oswaldo Limestone in walls of cut.
0.2	133.6	Road crosses quartzose dike.
0.05	133.65	Road crosses later Tertiary quartzose dike, 30 feet wide.
0.25	133.9	At 3 o'clock Humbolt Mountain is capped by Beartooth Quartzite, which is underlain by Abo Sandstone (Permian) and Syrena Limestone (Pennsylvanian). Outcrops on both sides of road are of the Oswaldo Formation.
0.8	134.7	Edge of Copper Flat stock in contact with the Oswaldo Formation which is here tightly folded into series of anticlines and synclines concentric with the stock margin. Clay pit in altered stock on left side of road. Idle Copper Flat mines from 1 to 2 o'clock. Road crosses eastern margin of Copper Flat stock, the main part of which underlies the shallow basin on the right side of the road. Oswaldo Formation is domed, dipping away from the intrusive at about 35° on the left side of the road.
0.3	135.0	Southern contact of stock with the Oswaldo Formation.
0.1	135.1	Cross top of Oswaldo Formation into the Syrena Limestone.
0.1	135.2	Historic marker says: "Kneeling Nun, 3 miles (to east). Most famous of many historic landmarks in the Black Range country is the Kneeling Nun, so named for its resemblance to a nun kneeling in prayer before a great altar. Many legends have grown up around the giant monolith, which rests near the summit of the Santa Rita range." Both the nun and the altar are quartz latite welded tuffs. All "legends" concerning the Kneeling Nun are of recent origin; G. K. Gilbert (1875) referred to the landmark as the Kneeling Jesus!
0.2	135.4	Road on dip slope of Syrena. 11 o'clock in middle distance is Lone Mountain. 12 o'clock is the Big and Little Burro Mountains. The Silver City Range is at 2 o'clock on the horizon and the Pinos Altos Range at 3:30 and 5 o'clock.
0.4	135.8	Syrena Formation in road cut.
0.2	136.0	Left side of road, Syrena underlies Beartooth Quartzite; Abo missing. The unconformity at the base of the Beartooth Quartzite accounts for the progressive cutting out of Paleozoic formations toward the west. In the Big Burro Mountains the Beartooth Quartzite lies on Precambrian.
0.1	136.1	Top of Beartooth Quartzite.
0.3	136.4	Sandstone and shale of the Colorado Formation in right road cut dips 10° SW.

0.1	136.5	Road curves to right. Extension of St. Helena, Eighty-eight, and Peerless No. 2 vein follows highway on right side to the northeast for about 0.5 mile. Vein dips 70° E; it is in later quartz diorite sill.
0.1	137.2	At 2 o'clock is Peerless Mine (inactive), most westerly mine of the Central Mining District. Mine is in a wide belt of narrow fissures which strike north–northeast through the sill and which contain quartz, pyrite, gold, and some lead and zinc sulfides.
0.1	137.3	Road cut in later quartz diorite sill.
0.2	137.8	Side road. Fort Bayard on right; Central to left. All outcrops are the later quartz diorite sill.
0.2	137.5	Turn right on U.S. Highway 180 to Silver City, New Mexico.
0.35	138.15	Later quartz diorite sill or laccolith. Contact dips gently west. The sill is 2000 to 3000 feet thick and underlies a large area on both sides of the road for about a mile east and west from this point. The town of Central and the Fort Bayard Hospital are on this sill.
0.25	138.4	Contact of the Colorado Formation and later quartz diorite sill.
0.05	138.45	At 3 o'clock, 200 feet from highway, light colored rocky hill is outcrop of rhyolite porphyry plug. Large sanidine crystals occur in this plug. North trending fault crosses road in valley, with downdropped block on west side.
0.25	138.7	At 9 o'clock from road edge to top of hill is white tuffaceous sand and rhyolite crystal tuff.
0.3	139.0	Road cut in shale and sandstone of the Colorado Formation dipping gently eastward.
0.35	139.35	Lone Mountain at 9 o'clock.
0.4	139.75	Good exposure in road cut of sandstone and black fissile shale of the Colorado Formation intruded by dikes and sill of basic dike complex.
0.25	140.0	Dikes in Colorado Formation on right. Arenas Valley ahead.
0.6	140.6	Drive-in theater on right.
0.5	141.1	Colorado Formation with dikes.
0.3	141.4	Dike complex on left (south) side of road.
0.55	141.95	Side road to right.
0.1	142.05	The contact between the Colorado Formation and the overlying andesite breccia is on the north (right) side of the highway. The andesite breccia underlies the terrain from the near highway to the foot of the Pinos Altos Range, and consists of subhorizontal andesite, rhyolite tuff and basaltic andesite. South (left) of the highway the Colorado Formation extends for 1 to 2 miles, where it is overlapped by the Gila Conglomerate (Pliocene). Isolated patches of the andesite breccia occur south of the highway. Dike complex with small inclusions of

		Colorado Formation next 0.6 miles. This is common in the Fort Bayard quadrangle.
0.55	142.6	Highway crosses Maud Canyon.
0.6	143.2	Dikes in Colorado Formation for the next 0.8 miles.
0.8	144.0	At 2 o'clock, Bear Mountain; at 3 o'clock, Gomez Peak, cone-shaped is a quartz monzonite plug; at 4 o'clock Pinos Altos Mountain; zinc-lead limestone replacement deposits are on west side of the highest peak.
		STOP AT HOLIDAY INN.

VOLCANO-TECTONIC CONTROL OF ORE DEPOSITS, SOUTHWESTERN NEW MEXICO

by

WOLFGANG E. ELSTON

The University of New Mexico

PROGRESS REPORT ON THE MOGOLLON PLATEAU VOLCANIC PROVINCE, SOUTHWESTERN NEW MEXICO: NO. 2*

by

WOLFGANG E. ELSTON
University of New Mexico

PETER J. CONEY
Middlebury College

RODNEY C. RHODES
University of New Mexico

Section VI. Lunar and Terrestrial Analogs

RHYOLITE ASH-FLOW PLATEAUS, RING-DIKE COMPLEXES, CALDERAS, LOPOLITHS, AND MOON CRATERS*

Wolfgang E. Elston

Department of Geology, University of New Mexico

Regional Geology of the Mogollon-Datil Volcanic Province, New Mexico As A Guide to Mineralization: Wolfgang, Elston - GSA; Boulder, Colorado 5-73

This map shows the location of all the mining districts in southwestern New Mexico that are associated in one way or another with Tertiary volcanic rock. This morning I will just briefly discuss a few of these, the ones located to the northern end of this map, because some work has been done here for the last almost nine years now that has thrown some new light as to how this rather random distribution of data points is related to the regional volcano-tectonic structure. (Next slide, please.)

This is the USGS geological map of southwestern New Mexico. The area that I am going to discuss is the Mogollon-Datil volcanic field of mid-Tertiary age, more or less a mirror image of the San Juan field, which was the subject for discussion yesterday morning and again this morning in another session. This map was made before our project began in 1964 and if you related the mining district shown on the previous slide to this map, you would get no obvious correlations at all. The main purpose of our work has been to test the working hypothesis or hypotheses that there is a large pluton or batholith of 125 kms. or 75 miles from here to here, underlying this rather large structure here. As an intermediate erosion level this would be a rather large ring complex; as a near-surface erosion level, a net of calderas or cauldrons of rhyolite ash flow tuffs at the surface, of course a very large volcanic plateau. (Next slide, please.)

This is a rather simplified and crude geologic map of how we interpret this region now. When I talk of "we", I should mention the names of some of the associates in this project; Peter Koney, Rodney Rhodes, Eugene Smith, Edmund Beales, Douglas Cronin, Ron Foedder, James Aldrich. So, there are quite a number of people involved in this.

The rocks of the geologic map of New Mexico as shown in the Datil position have been broken down into three major volcanic cycles. The events are quite similar to those of the San Juan Mtns., the rocks of the area shown in blue are the pre-Tertiary rocks which included this area here, some economically very important Laramide porphyries that I won't discuss today. The earlier volcanic rocks which are about 29 to 38 M.Y. old begin with basal andesite which came from numerous centers scattered all over this region. Sometimes there is a basal conglomerate somewhat similar to the Telluride conglomerate of the San Juan at the base of the section. Next come still of the first volcanic cycle from quartz latite ash flow tuffs, basaltic andesites, then a major unconformity and the whole thing starts all over again a second time. The second cycle runs from about 24 to 28 or 29 M.Y. and then the third cycle repeats the whole thing from 20 to about 24 M.Y. As time goes on, the rhyolites become more alkalic, they change from two-feldspar quartz latites to single-feldspar rhyolites, the andesitic rocks become more iron-rich. There is conspicuous scarcity of basalt in this area throughout this entire time span. Not until about 20 million years do we see the beginning of Basin & Range block faulting and the eruption of true basalts, both tholeiite and alkali basalts. This is a very similar district to the one that Rudy Epis, Tom Stevens, and Pete Lipman talked about yesterday in another session. (Next slide, please.)

On this slide I have shown some of the more obvious tectonic elements; in blue we see the grabens of the basins of the Basin & Range Province, and here with the hatchure we can see the outline of the hypothetical pluton which is nowhere exposed as such, purely inferred. Then, shown here are the large rhyolite or quartz latite ash flow calderas or cauldrons. This is an old slide, from the previous, next slides will revise the picture just a little bit, not very much. You will see that the Rio Grande Trough, for example, this large basin in here, swings around the northeastern end of this hypothetical pluton, which acted apparently as a hard resistent knob which is not significantly cut by the Basin & Range fault blocks. This is very fortunate, because then we can study it. I am sure there are similar structures down here, but they are very difficult to work with, because they are all chopped up by Basin & Range faults. (Next slide, please.)

What is the evidence that this pluton actually exists? We have found that around on the edge of this structure there are two kinds of flow-banded rhyolite intrusions. Some of these, which we call "framework lavas", shown here, we interpret as being directly derived from the pluton. They include every one of the assemblages petrologically and they lie directly on the main liquid line of descent, petrologically. These so-called "framework lavas" here occur around individual rhyolite and quartz latite ash flow cauldrons or calderas and they are disequilibrium assemblages and appear to have formed within a kilometer or two of the surface. This two-story arrangement with a main pluton down here and then secondary magma chambers, which are the sources of the rhyolite ash flow tuffs that you see, explains one of the paradoxes in rhyolite ash flow tuffs. The isotope geochemistry says that these things are quite primitive and probably at the lower crust or upper mantle derivation, whereas phase equilibrium say that they crystallize very close to the surface or differentiate very close to the surface. That is another confirming piece of evidence that this model has some reality to it. But, it is much more complex in detail than what I am showing here. Another confirming piece of evidence is a recently completed gravity study by Douglas Cronin, who showed that in all the places where we have gone along margins of this pluton on the basis of the first occurrence of framework lavas, we start getting a very pronounced negative gravity anomaly. This is quite similar to the evidence presented by Tom Steven yesterday. (Next slide, please.)

This is an old map which shows the distribution of the framework and cauldron lavas. (Next slide, please.)

Now, when it comes to the mining districts you will see that the areas of alteration shown in blue and the mining camps are rather closely related to the margin, first of all of the hypothetical pluton, which is another piece of evidence, of course, that this model has some reality. We have purposely left this end open here because we don't have very much data and it is quite possible that the pluton swings around to take in these cauldrons here. We also don't know at this point whether the Magdalena Mining District will in any way lead us to it or not. (Next slide, please.)

On this map I coded the plutons by age and you will see that the, in general, the age of mineralization next to each cauldron or caldera is usually quite closely related, or known to the age of the adjacent caldera. There are some exceptions, for example, the Emma Mtns. area right here, to be dated by Jim Ratte of the USGS as 29 M.Y. and that is related to a small local andesitic volcano, not to this cauldron here. The relationship between these two cauldrons here is

somewhat in dispute. Jim Ratte is giving a paper this afternoon in which he will try to show you this relationship; don't get me wrong, it is quite possible he is right. These calderas or cauldrons are not all known to the same degree of certainty. This is a very well-documented one here, the Bursum Cauldron, this one here is being worked on right now by Edmund Beale, that is a very well-documented one, this one is pretty well documented, some of the others less so. Not all of them have been worked on by our group; for example, this one here was documented by Jim Ratte, these two here by Bill Seager and Russell Clemens of New Mexico State University. (Next slide, please.)

Just a couple of pictures to show you that this thing actually exists on the ground and not just on maps or in people's minds. This is the front of the Mogollon Range, seen from the west. (Can we have the preceding slide, again, please -- I would like to show where these pictures are located.) This slide shows the edge of the western side of the Mogollon Plateau as a whole here, the pluton, and also the west side of the Bursum Cauldron. The next slide I show after that will show the Emma Mtn. area. (Next slide, please.)

There is some pretty good conspicuous alteration here right in this area related to the framework lavas which make up the first range right in front of the range here. The second range of the cauldron lavas and the cauldron rocks themselves of the Bursum cauldron. (Next slide, please.)

This is the Emma Mtn. here that shows fumeralic-type alteration and what is apparently an andesitic bench zone. The rocks in the background here belong to the Gila Cliff Dwellings cauldron, where the margin of the cauldron runs somewhere through here. (Next slide, please.)

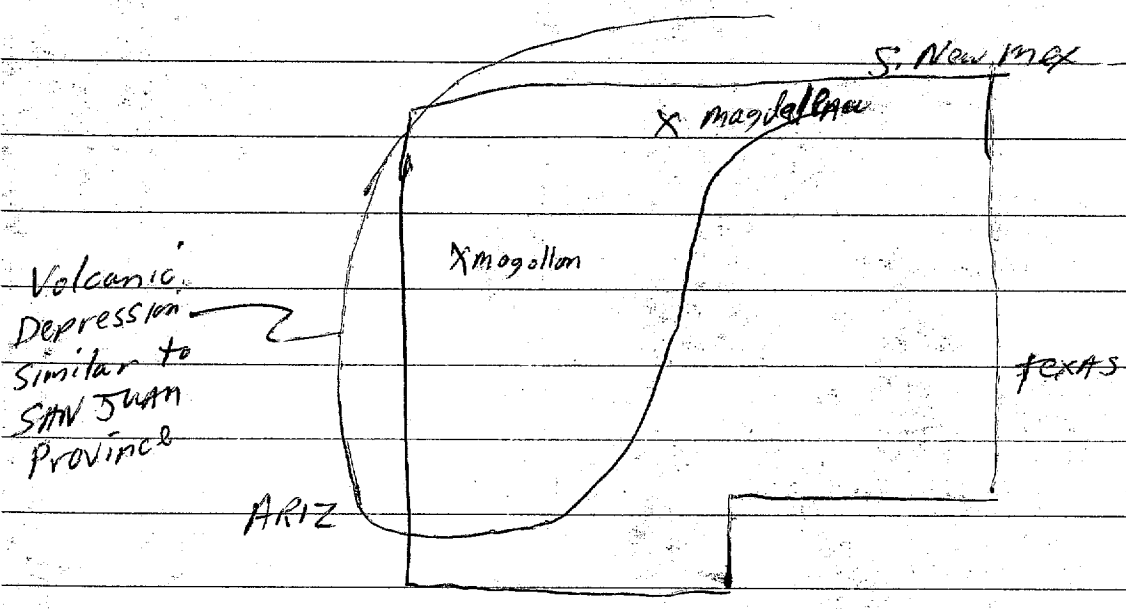
On this slide I have used the same color codes that I used on the map and I have shown the ages of the cauldrons, as far as they are known, and the kinds of mineralization we get. You will notice that in the big unconformity here, occurs about 40-50 M.Y., between the Laramide and Tertiary episodes. Prior to 50 M.Y. is a very important copper porphyry, as well as zinc and lead deposits. The basal andesites are related to some copper-lead-zinc mineralization. This is not too well documented as yet. The break between the first and second volcanic cycles occurred at about 28 M.Y. This was determined quite independently from any consideration of mineralization and this turns out to be also the age of the porphyries at Magdalena, (zinc-bearing). There are some other areas where there may be some lead deposits with this age also. The break between the second and third volcanic cycles corresponds with mineralization and the economically unimportant but mineralogically very interesting Taylor Creek Mining District (which is tin). It turns out that the age of mineralization is about 24-25 M.Y., is about the same as the mineralization at Questa, in northern New Mexico, and the Nogal-Ruidoso molybdenum district, in central New Mexico. The moly and tin are geochemically related. This is probably just a local expression of a much larger province. Finally, the precious metals mineralization as at Mogollon took place at about 21 M.Y., just prior to Basin & Range faulting, as far as we could determine, or prior to the eruption of the last group of basaltic andesites, that is like right here. After Basin & Range faulting we still have some minor mineralization that changes in character again to manganese oxides, small veins of manganese-oxides, fluorspar, and odd-ball things like meerscham, as well as other things like Iceland-spar. (Next slide, please.)

This is the same slide you have seen before; just to review what has been said here, we have a group of volcano-tectonic structures, volcanic calderas or cauldrons, the biggest one here is about 45 kms. in diameter, about 30 miles. These are very large structures superimposed upon a large pluton (this is our interpretation) along the margin of the pluton as a whole, and especially where the margins of a particular caldera intersect the margin of a pluton we have a structural environment that favors mineralization. These things have been determined over the last nine years, by an integrated program which involved mapping, detailed petrology, microscopic, electron microprobe mineralogy, gravity work, and something that is unique to our group, an attempt to map the flow directions of volcanic rock, especially ash flow tuffs or ignimbrites. We can determine from which caldera or cauldron this particular unit may have come. We hope in the future to be able to extend this kind of study down here to the Basin & Range Province where there are a great many more ore deposits or all the way into the great basin of Utah and Nevada. The techniques that we worked here should work elsewhere, although a lack of exposure would make it much more difficult.

Thank you very much.

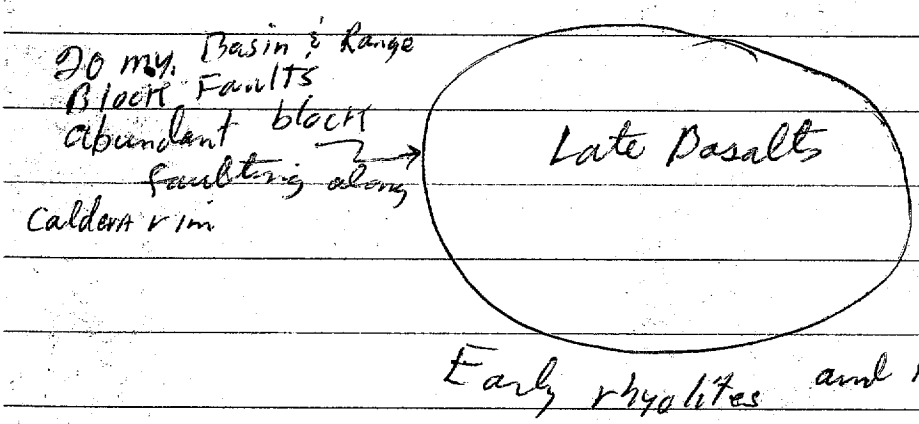
MAY 6, 1973
Boulder GSA

This information was recorded in the dark from Elston's rather poor slides! CEB

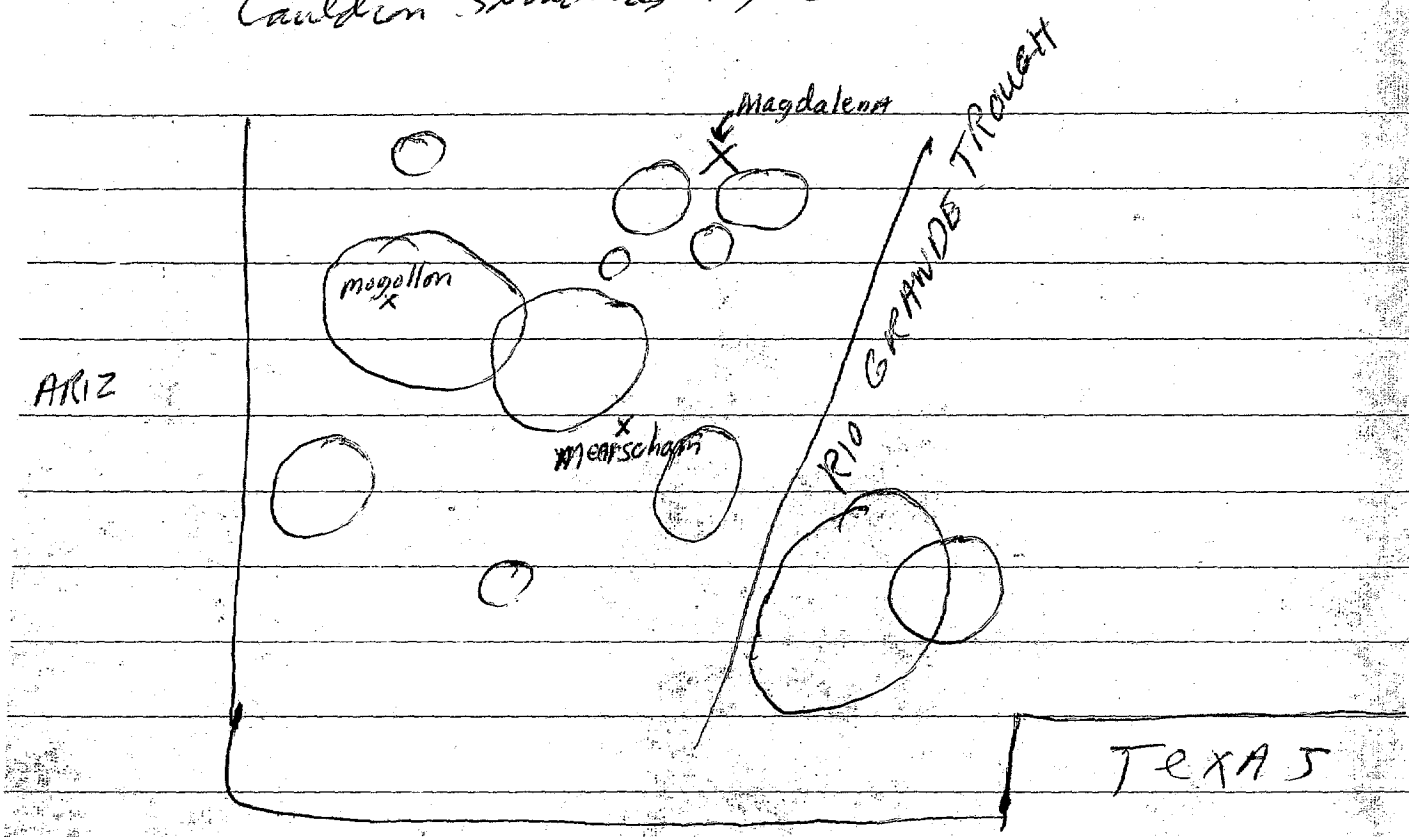


In Plan view the Caldera structures commonly look like this

"Basaltic Craters"

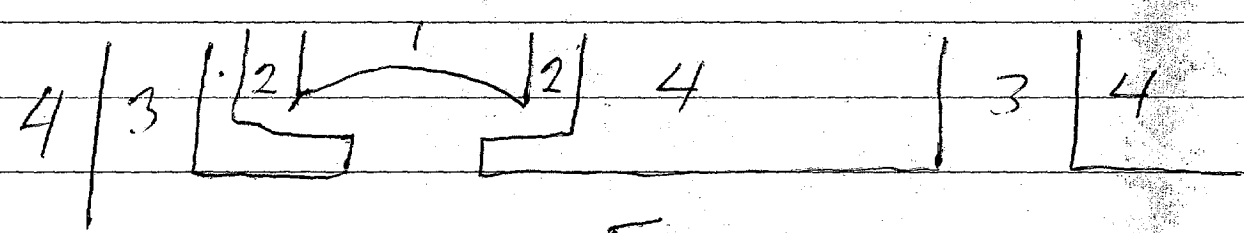


The circular-like features below were presented to be Cauldron structures by Elston. CSB



The following diagram is designed to show evidence for the existence of cauldron development. CSB

1. Resurgent Cauldron
2. Cauldron lake
3. Framework Lavas
4. Basement Rocks
5. Plutons



The following chart is designed to show Elston's Age data in relation to mining Districts and commodities. CSB

M.Y.	District	Commodity
42		Cu, Pb, Zn
34-38	Andesites	
29-34		
28	Magdalena	Zn, Pb?
24	Taylor Creek Questa	Sn, Mo
23		
21	Mogollon	Au, Ag
20	Basin & Range Faults Cap Rock	Meerscham

AMERICAN SMELTING AND REFINING COMPANY
ROCKY MOUNTAIN EXPLORATION DIVISION
1805 SOUTH BELLAIRE STREET. DENVER. COLORADO 80222

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January 10, 1972

TELEPHONE 303-757-5107

W. L. K.
JAN 13 1972

Mr. W.L. Kurtz
ASARCO
P.O. Box 5747
Tucson, Arizona 85703

Dear Bill:

Attached is a paper you may find of interest, delivered by Smirnov, presumably in support of his twofold classification of hydrothermal deposits, plutonic and volcanic.

One wonders about Safford in this scheme.

Very truly yours,

Stephen Von Fay (typ.n.)
Stephen Von Fay

SVF/pn
Enclosure
cc: JHCourtright
JSell

New file General Volcanology W.L.K.

W. L. K.

AUG 12 1971

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