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ASSESSMENT OF THE GEOTHERMAL POTENTIAL OF SOUTHWESTERN NEW MEXICO

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July 1981

New Mexico Energy Research and Development Program

NOTICE

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OF

SOUTHWESTERN NEW MEXICO

Final Report

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ABSTRACT

This report deals with research during 1978-80, funded jointly by U.S Geological Survey Extramural Geothermal Program grant 14-08-0001-G-630 and New Mexico Energy and Minerals Department Energy Research and Development Program grant EMD 78-2123, with contributions from National Science Foundation grant EAR 77-24501. The geothermal proposals covered four topics:

1. Geologic controls and geochemistry of geothermal waters of the Lightning Dock KGRA, Hidalgo County. The results of this study are due to be published in 1981 as New Mexico Bureau of Mines and Mineral Resources Circular 177, by W. E. Elston, E. G. Deal and M. J. Logsdon.
2. Compilation of a geologic map of southwestern New Mexico. This work has been completed by W. E. Elston and E. G. Deal and will be incorporated in a geological map of New Mexico, to be published in 1981 by the New Mexico Geological Society (R. E. Clemons, New Mexico State University, editor).
3. Geologic mapping and geomorphic evolution of the San Francisco-Duck Creek-Mangas Valley, between the Lower Frisco Hot Springs KGRA and the Cliff-Gila area. Mapping of the southern part by Winfried Leopoldt of this area has been completed. Work in the northern part by Randy Albright is scheduled for completion in 1981.
4. Geologic mapping of the area between the Gila Hot Springs KGRA and Mimbres Hot Springs. This work has been completed by W. E. Elston, D. J. Krier, S. R. Farris, with a major contribution (funded by the New Mexico Bureau of Mines and Mineral Resources) by W. R. Seager (New Mexico State University). The results are described in the present

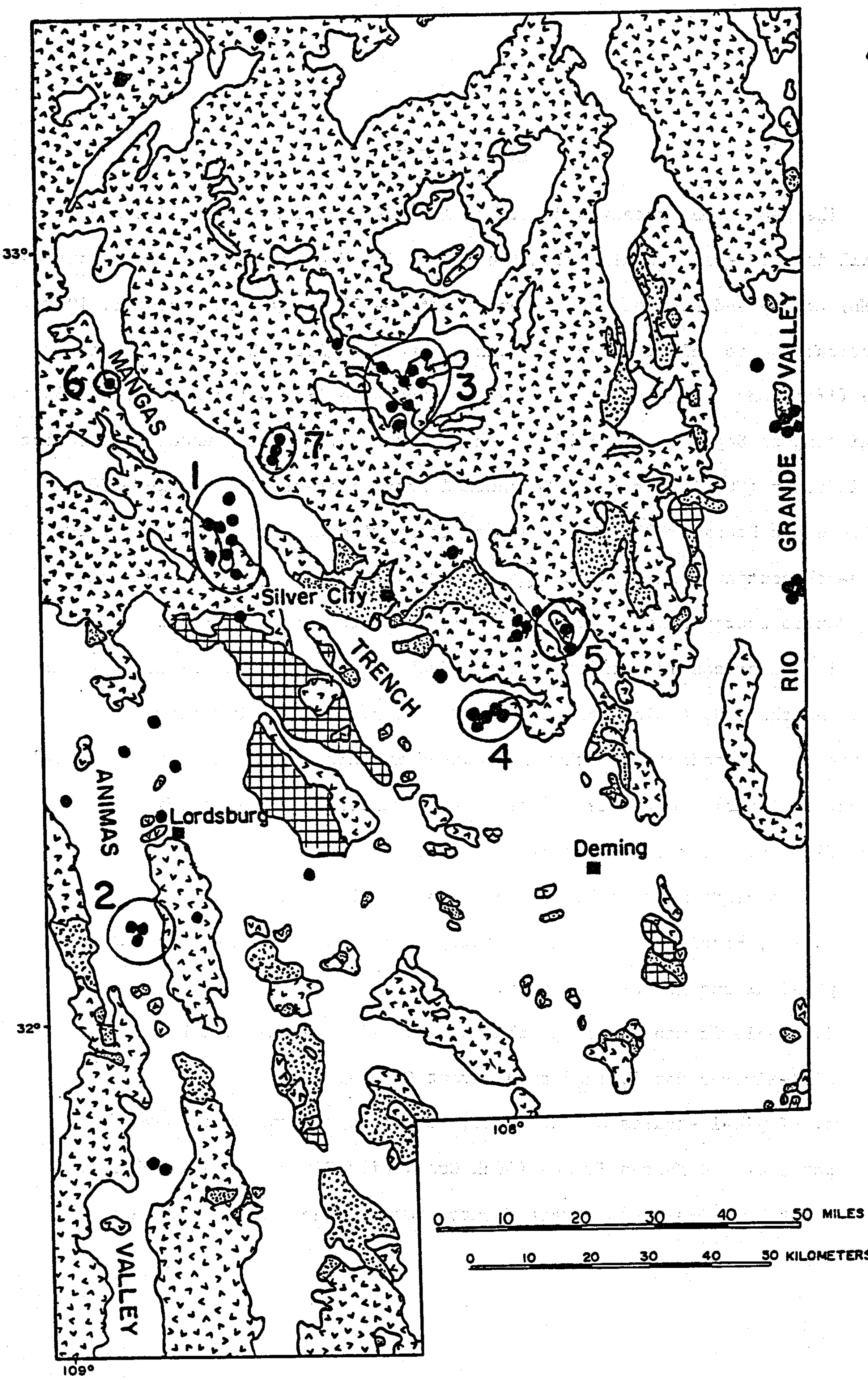
report. They suggest that both hot-spring occurrences are structurally controlled by the intersection of a major Basin and Range fault and the disturbed margin of an ash-flow tuff cauldron. Hydrothermal alteration in both areas is related to mid-Tertiary volcanism, not to modern hot springs. At Gila Hot Springs, the geothermal aquifer is a zone at the contact between the unwelded top of a major ash-flow tuff sheet (Bloodgood Canyon Rhyolite Tuff) and a succession of interlayered vesicular basaltic andesite flows and thin sandstone beds (Bearwallow Mountain Formation). Scattered groups of natural hot springs occur at intersections of this zone and the faults bordering the northeastern side of the Gila Hot Springs graben. Hydrothermal alteration of Bloodgood Canyon Rhyolite Tuff near major faults seems to have increased its permeability. At Mimbres Hot Springs, a single group of hot springs is controlled by the intersection of the Mimbres Hot Springs fault and a fractured welded ash-flow tuff that fills the Emory cauldron (Kneeling Nun Tuff). Gila Hot Springs and Mimbres Hot Springs do not seem to be connected by throughgoing faults. At both localities, hot spring water is used locally for space heating and domestic hot water; at Gila Hot Springs, water of 65.6°C (150°F) is used to generate electricity by means of a 10 kw freon Rankine Cycle engine. This is the first such application in New Mexico.

INTRODUCTION

The geothermal research described in this report began in 1978 and is still in progress. Funding from the New Mexico Energy and Minerals Department (EMD) Energy and Minerals Department grant 78-2123, began on August 1, 1978 (retroactive to July 1, 1978) and was extended to April 30, 1980. During the first year, additional funds became available from NSF grant EAR 77-24501. Beginning on September 1, 1979, matching funds were granted under U.S. Geological Survey (USGS) Extramural Geothermal Program grant 14-08-0001-G-630, extended to December 31, 1981. Beyond the period covered by this report, research continued in 1980-81 under the U.S. Geological Survey grant and New Mexico Energy Research and Development Program grant 68-R2102.

In the proposals submitted to the New Mexico Energy and Minerals Department and the U.S. Geological Survey in October, 1977 and December 1978, respectively, geothermal work was proposed in three KGRA's (Known Geothermal Resources Areas) and related areas in southwestern New Mexico (Fig. 1). Specifically, the following tasks were set:

1. Completion of geologic mapping of the Lightning Dock KGRA, Animas Valley, Hidalgo County and vicinity, correlation of geologic, geophysical and geochemical data.
2. Geologic mapping of geothermal anomalies in the Gila Hot Springs KGRA-Mimbres Hot Springs area, Grant County.
3. Topical studies of structure, stratigraphy, and hydrology of parts of the Mangas Trench (Duck Creek-Gila River-Mangas Creek-Lampright Draw Drainages) Grant County, between the Lower Frisco Hot


33°
32°
109°
108°
MANGAS
TRENCH
ANIMAS
VALLEY
RIO GRANDE VALLEY
Silver City
Lordsburg
Deming
1
2
3
4
5
6
7
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

EXPLANATION

- TERTIARY AND QUATERNARY VALLEY FILL
- MID-TERTIARY VOLCANIC ROCKS
- CRETACEOUS AND TERTIARY IGNEOUS ROCKS
- PRECAMBRIAN-MESOZOIC ROCKS
- ● HOT SPRINGS AND WARM WATER WELLS

GEOTHERMAL TARGET AREAS

1 CLIFF-GILA AREA
2 ANIMAS VALLEY (LIGHTNING DOCK KGRA)
3 GILA HOT SPRINGS KGRA-ALUM MOUNTAIN
4 FAYWOOD HOT SPRINGS
5 MIMBRES HOT SPRINGS
6 LOWER FRISCO HOT SPRINGS KGRA
7 TURKEY CREEK

Figure 1. Geologic sketch map of southwestern New Mexico, showing geothermal anomalies (from Summers, 1965) and KGRA's

Springs KGRA and Faywood Hot Springs, especially in the area around Cliff and Gila, N.M.

4. Compilation of geologic and tectonic maps of southwestern New Mexico.

This report deals specifically with task No. 2. Progress on the other tasks is briefly described in the next few paragraphs.

A preliminary geologic map and report on the Lightning Dock KGRA and adjoining areas of the Pyramid Mountains had been completed under previous State and USGS grants and were submitted to the Energy and Minerals Department in January 1978. During the present grant, brief versions of the results were published (Deal and others, 1978; Elston and others, 1979) and preparation of a full report and colored geologic map began. Correlations of geophysical and geological data on the Lightning Dock KGRA were discussed in a paper by Smith (1978). The origin, distribution, and base temperature of thermal waters of the Lightning Dock KGRA were the subject of a geochemical study by Mr. Mark J. Logsdon, a UNM graduate student. The USGS Water Resources Division, Albuquerque, has cooperated in this study and mass spectrometer facilities of the USGS in Denver have been made available for δD and $\delta^{18}O$ determinations. Dr. G. P. Landis (USGS, Denver), Dr. R. O. Fournier (USGS, Menlo Park) and Professor H. D. Holland (Harvard University), have kindly offered advice on this project.

During the period of this report, 5 acres of greenhouses heated by geothermal waters for raising roses have been completed at the Lightning Dock KGRA and there has been considerable exploration and leasing activity by industry (see Fig. 10 in Smith, 1978).

Our work on the Lightning Dock KGRA will be published in 1981 as New Mexico Bureau of Mines and Mineral Resources Circular 177. The authors are W. E. Elston (University of New Mexico), E. G. Deal (formerly University of New Mexico, now Duval Corp.), and M. J. Logsdon (formerly University of New Mexico, now New Mexico Bureau of Mines and Mineral Resources).

Studies of the geologic structure and sedimentary fill of the southern part of the Mangas Trench near, Cliff and Gila, N.M., were completed in 1979-1980 by Mr. Winfried Leopoldt, a West German citizen and UNM graduate student (Leopoldt, 1981) The first stages of Mr. Leopoldt's work were supported by a stipend from the government of the German Federal Republic, later stages by NSF, USGS, and EMD. Work on the northern part, by Randy Albright, is in progress and is due to be completed in late 1981. Work to date has shown that the San Francisco-Duck Creek-Mangas Valley has had a long history of hot-spring activity, going back to the Pliocene. Considerable progress has been made in defining the geologic structure of the valley as well as stratigraphic succession and facies relationships of the water-bearing valley-fill sediments. Preliminary results suggest control of thermal waters by complex interactions of young faults and favorable sedimentary facies. The Mangas Trench is being given high priority because structure, thermal history, and reservoir characteristics favor the existence of geothermal resources. The market for geothermal energy should be favorable. The region is the center of the New Mexico copper industry (Kennecott Copper Corp. Chino mine and Hurley mill and smelter; Phelps Dodge Corp. Tyrone mine and mill), has several population centers (Silver City, Tyrone, Bayard), and some irrigated farm lands (Gila Valley).

The compilation of geologic and tectonic maps of southwestern New Mexico is being integrated with a project of the New Mexico Geological Society under the editorship of Dr. R. E. Clemons (NMSU). The compilation for Hidalgo County has been completed by Dr. E. G. Deal and for the Mogollon-Datil volcanic province (which includes the Gila Hot Springs-Mimbres Hot Springs and Mangas Trench areas) by Dr. W. E. Elston. This work was done at no cost to sponsoring agencies. Compilation is on a scale of 1:500,000; publication will be at a scale of 1:1,000,000.

GEOLOGY AND GEOTHERMAL WATERS OF THE GILA HOT SPRINGS KGRA - MIMBRES HOT SPRINGS AREA

Introduction

Preliminary geologic and tectonic maps of the region between the Gila Hot Springs KGRA and Mimbres Hot Springs were completed by W. E. Elston, S. R. Farris, and D. J. Krier (Figs. 2, 3). The purpose was to determine whether any throughgoing structures connect the two hot-springs localities, and whether the region between them might be favorable for further geothermal exploration. To date, no evidence has been found for any connecting structures. Each hot-spring occurrence appears to have separate structural controls. Both are on the margins of Oligocene caldera complexes. Mimbres Hot Springs is located directly on the inner margin of the well-documented Emory cauldron (Elston and others, 1975; Seager and others, 1978). Gila Hot Springs lies in a zone of structural complexity that has been interpreted as the margin of the Gila Cliff Dwellings cauldron (Elston and others, 1968; Ratté and Gaskill, 1975) but more regional work is needed to establish the validity of this interpretation.

The study area of about 1,200 km^2 (500 mi^2) is roughly triangular and is bounded on the east by the Black Range, on the southwest by the Pinos Altos Mountains, and on the north by the Gila Sag, the drainage basin of the East, Middle, and West Forks of the Gila River (Figs. 2, 3). Its geology had partly been mapped before, the southern end by Elston (1957) and the middle part by Kuellmer (1954) and Hedlund (1977). Dr. William R. Seager (New Mexico State University) kindly contributed his unpublished map, which was incorporated into figures 2 and 3. The northern end had partly been mapped by Aldrich (1974, 1976) but much of it was known only from reconnaissance mapping by Ratté and others (1975, 1979) and Elston and others (1976), which showed virtually nothing about structure and few details of distribution of rock units.

A preliminary appraisal of geothermal resources of the Gila Hot Springs area, by Summers and Colpitts (1981) contains logs of wells drilled for hot water. A private report by Du Mars (1979) discusses legal rights to geothermal resources of Gila Hot Springs. Within the scope of the current project, the area north of lat. 33°N. was mapped in detail by Donathon J. Krier and Stephen R. Farris, former UNM graduate students.

Stratigraphy

Pre-Cenozoic Rocks

Pre-Tertiary units consist of Precambrian crystalline rocks and a Paleozoic sedimentary section in which every system is represented, although the total thickness is only about 600 m (2,000 ft). Mesozoic rocks are represented by scattered remnants of Cretaceous Beartooth Sandstone. All pre-Tertiary rocks were faulted and invaded by porphyritic intrusions of intermediate composition during the Laramide disturbance.

Pre-Tertiary rocks crop out mainly on the southwestern margin of the mapped area, along the Mimbres fault. An isolated occurrence of Syrena Limestone (Pennsylvanian) occurs in sec. 19, T. 14 S., R. 11 W., near Terry

Canyon. It appears to have been brought to the surface by the Santa Rita-Hanover axis (Fig. 3); a structural high with a long history (Aldrich, 1974). The depth at which pre-Cenozoic rocks are buried in the rest of the area is not known. It is greatest within the margin of the cauldrons shown on figure 3, and shallowest on the upthrown side of the Mimbres fault. The average depth for the rest of the region is probably on the order of 1,500 m (5,000 ft).

Cenozoic Rocks

Oligocene and early Miocene volcanic rocks occupy most of the region between Gila Hot Springs and Mimbres Hot Springs and were emphasized in geologic mapping. Radiometric ages and brief petrographic descriptions are given in the explanation of figure 2; greater details, including chemical analyses, can be found in reports on individual areas (Krier, 1980; Farris, 1981; Kuellmer, 1954; Elston, 1957). All available chemical data were summarized by Bornhorst (1980).

In general, the volcanic stratigraphic column of the area consists of andesitic rocks that become increasingly mafic with time, interlayered with rhyolites that tend to become more felsic. The entire complex is overlain by Miocene and younger basin-fill sediments associated with minor basalt flows. Knowledge of detailed stratigraphy and distribution of rock units has made it possible to interpret the geologic structure. In the discussion that follows, the rock units shown in figure 2 are grouped together in a way that accentuates structural units.

Basal andesite: - The basal unit, the andesitic Rubio Peak Formation, is exposed only at the southern tip of the mapped area, outside the Emory cauldron. Farther south, its thickness varies from a few tens of meters to about 1,500 m (5,000 ft) and similar thicknesses presumably lie beneath younger rocks throughout the mapped area. Locally, it is overlain by patches of bedded sandy tuff of the Sugarlump Formation, but these rocks are not shown separately on figure 2.

Rocks associated with the Emory cauldron: - The main ash-flow tuff fill of the Emory cauldron, the Kneeling Nun Tuff, crops out throughout much of the eastern part of the mapped area (the west flank of the Black Range), where its thickness is about 1,000 m. In many places outside the cauldron margin, the Kneeling Nun Tuff is absent but thin outflow deposits occur locally along the Mimbres fault. Within the Emory cauldron, megabreccia lenses may mark a possible vent zone. Alternatively, they could have formed by collapse of segments of the caldera wall. Lavas and tuffs of the Mimbres Peak Formation have been interpreted as ring-fracture and moat deposits, respectively. The Pollack Rhyolite, which consists of shallow intrusions of porphyritic rhyolite and associated domes and flows, has been interpreted as a late-stage product of the Emory cauldron.

Caballo Blanco Tuff and associated rocks: - In the north fork of the Mimbres River and nearby drainages, the Kneeling Nun Tuff is overlain by an andesite flow unit (andesite of Turkey Cienega Canyon) and three ash-flow tuff sheets (Caballo Blanco Tuff, tuff of Terry Canyon, and tuff of Monument Canyon). Their sources are unknown but the units are important markers in geologic mapping. Only the Caballo Blanco Tuff has regional extent.

Alum Mountain Group: - The Alum Mountain Group consists of dark-colored rocks, mainly andesitic but ranging in composition from basalt to latite. It is the most widespread unit in the northern part of the mapped area and also caps much of the Black Range. The delineation of structures between Gila Hot Springs and Mimbres Hot Springs, which was a principal purpose of this study, was largely accomplished by defining and mapping subdivisions of the Alum Mountain Group (Krier, 1980). In the Copperas Block (Fig. 3), the Alum Mountain Group was divided into the Salt Creek Formation (lower basaltic andesite member, upper andesite member), the Gila Flat Formation (andesite and latite flows), and the basaltic andesite of Middle Mountain. In the Black Range and Mimbres Valley, it had earlier been divided into the Razorback Formation (lower andesite member, upper latite member) and the Bear Springs Basalt (Elston, 1957). Three eruptive centers for rocks of the Alum Mountain Group were discovered on the west side of the mapped area; a fourth is known at Alum Mountain, off the western edge of the map; a fifth is present near the southern tip of the map.

Rocks associated with the proposed Gila Cliff Dwellings Cauldron: - Bloodgood Canyon Rhyolite Tuff forms great cliffs along the three forks of the Gila River and tributary drainages, in and beyond the northwestern corner of the map area. Its minimum thickness is about 250 m (800 ft) but its base is not exposed. South and southeast of Gila Hot Springs it thins abruptly to about 25 m (80 ft) and eventually pinches out. The massive cliff-forming facies has been interpreted as fill of the proposed Gila Cliff Dwellings cauldron and the thin apron to the south and southeast as an outflow sheet.

In the Diablo Range, west of the mapped area, great masses of flow-banded rhyolite interfinger with Bloodgood Canyon Rhyolite Tuff and give the impression of ring-fracture domes on a cauldron margin. They resemble the rhyolite of Rocky Canyon in the northeastern corner of the mapped area, which lies on Bloodgood Canyon Rhyolite Tuff outflow sheet at some distance from the inferred cauldron margin. However, they cannot be exact correlatives because the rhyolites of the Diablo Range have reversed paleomagnetic polarity, whereas the rhyolite of Rocky Canyon has normal polarity (Strangway and others, 1976). Between the outcrop areas of the rhyolite of Rocky Canyon and the rhyolite of the Diablo Range there are only a few rhyolite dikes but alteration is locally intense in rocks of the Alum Mountain Formation. This can be seen along State Highway 15, on the western edge of the mapped area (Fig. 3).

Two thin ash-flow tuff sheets locally separate the Alum Mountain Group from Bloodgood Canyon Rhyolite Tuff. They have been correlated with the rhyolite tuff of Davis Canyon and the quartz latite tuff of Shelley Peak, units that thicken greatly in the Sierra Diablo and Mogollon Mountains (Ratté and Gaskill, 1975). The basaltic andesite of Squaw Creek locally separates Bloodgood Canyon Rhyolite Tuff from rhyolite of Rocky Canyon. In the southern end of the mapped area, domes and flows of Swartz Rhyolite occupy approximately the same stratigraphic position as the Bloodgood Canyon Rhyolite Tuff.

<u>Bearwallow Mountain Formation</u>: - Basaltic andesite of the Bearwallow Mountain Formation caps the mid-Tertiary volcanic section in the northern end of the mapped area. North of Gila Cliff Dwellings National Monument, beyond the

mapped area, the unit can be divided into several members. It seems likely that the exposures of Bearwallow Mountain Formation around Gila Hot Springs and the junctions of the East and West Forks of the Gila River correspond to the basal Double Springs Member. The hot springs in this area issue from the contact between Bloodgood Canyon Rhyolite Tuff and the Double Springs Member of the Bearwallow Mountain Formation.

Late Cenozoic valley fill: - A period of faulting began in early Miocene time, toward the end of the period of volcanic activity represented by the Bearwallow Mountain Formation. It culminated in the main stage of Basin and Range faulting. Erosion of ranges caused the adjacent basins to be filled with sedimentary rocks of the Gila Group and, later, by Quaternary terrace gravels and alluvium. In the upper Mimbres Valley, basalt flows locally interfinger with the upper part of the Gila Group.

Geologic Structure

At least three stages of Phanerozoic tectonic activity can be recognized in the area covered by this report:

1. Laramide, bracketed between Upper Cretaceous sedimentary rocks and late Eocene to early Oligocene volcanic rocks. Porphyritic intrusions near the Mimbres fault, and some fault movements, belong to this period of activity; in the Santa Rita and Tyrone mining districts porphyries have been dated between about 74 and 56 m.y. (McDowell, 1971).
2. Mid-Tertiary, associated with volcanic activity, especially the collapse and resurgence of ash-flow tuff cauldrons between about 36 and 25 m.y.

3. Late Tertiary Basin and Range faulting. The main stage can be bracketed between the upper part of the Bearwallow Mountain Formation (about 21 m.y.) and basalt flows of the Mimbres Valley (about 7 m.y.), but minor activity may have continued into the Quaternary.

Laramide Structures

Laramide structures are not known to control thermal waters directly but they may control positions of later structures. The north-trending Santa Rita-Hanover axis, a regional uplift that bisects the mapped area (Fig. 3) is an example. It was active during emplacement of Laramide porphyries and has been reactivated repeatedly since then (Aldrich, 1974). The Mimbres fault may also have been active during Laramide tectonism.

Mid-Tertiary Structures

Collapse and resurgence of the Emory cauldron occurred around 34 m.y. ago, and was the main mid-Tertiary event on the eastern margin of the mapped area. The inner cauldron margin (Fig. 3) can be defined by the abrupt disappearance of the massive cauldron-fill facies of Kneeling Nun Tuff. At Mimbres Hot Springs, massive Kneeling Nun Tuff is present; about 250 m (800 ft) to the southeast, post-Kneeling Nun rocks (Mimbres Peak Formation) lie on pre-Kneeling Nun rocks (Rubio Peak Formation). Elsewhere, the cauldron margin is covered by younger rocks and can only be approximately located. In the Mimbres Valley and on the western flank of the Black Range south of Lat. 33°N., displacement on most faults east of the Mimbres fault is downward on the east side. This is the direction of collapse of the Emory cauldron. Farther north, on the west flank of the Black Range, displacement of faults is in the opposite direction. In the same area, arcuate trends of canyons (Monument Canyon, both forks of Powderhorn Canyon, both forks of McKnight Canyon, Dutchman Canyon, East Canyon, Shepard Canyon) may be related to fractures originally formed during progressive collapse of the Emory cauldron and are shown as photolineaments on figure 3. The present anticlinal structure of the Black Range began to develop during resurgence. The structure and evolution of the Emory cauldron was treated in more detail by Elston and others (1975) and by Seager and others (1978).

The Gila Cliff Dwellings cauldron is more problematical. Its age, and very existence are controversial (Ratté and others, 1979; Elston and others, 1976). Its inner margin can be broadly defined by a zone of drastic thinning of the 27 m.y.-old Bloodgood Canyon Rhyolite Tuff, but it is not known to be outlined by a set of arcuate faults. There was no resurgent doming and the present topographic expression is a broad basin, the Gila Sag, not an anticlinal mountain range like the Black Range. There is no central horst but a complex northwest-trending graben which terminates at its southeastern end in the Gila Hot Springs graben (Ratté and Gaskill, 1975), which lies at the northwestern end of the mapped area (Fig. 3).

Between the times of activity of the Emory and Gila Cliff Dwellings cauldrons, a group of andesitic volcanoes erupted in the north-central part of the mapped area. Their products became part of the Alum Mountain Group. Together with the rhyolite of Rocky Canyon, they are now exposed in an east-west trending mountain range which has no official name but was called the Diablo-Copperas Prong by Trauger (1965). The part within the mapped area is called the Coperas Block in this report (Fig. 3).

Late Tertiary (Basin and Range) Structures

During Basin and Range faulting, most earlier structures were rejuvenated. For example, it can be demonstrated that about one quarter of the present structural relief of the Black Range resulted from collapse and resurgence of the Emory cauldron and three quarters from reactivation of cauldron structures during Basin and Range faulting (Elston and others, 1975). All of the documentable movement of the Gila Hot Springs graben occurred during the Basin and Range episode. Other structures were only slightly reactivated and consequently were largely obliterated as topographic features. The Santa Rita-Hanover axis is an example.

The three main mountain ranges of the study area are a result of Basin and Range faulting. They are the Black Range on the east side, the Pinos Altos Mountains on its southwest side, and the Copperas Block, which cuts through the western part of the area in an east-west direction. Sediments of the Gila Group, eroded from these ranges, fill two major basins, the Gila Sag and the Sapillo-Mimbres Valley. The part of the Gila Sag that lies within the mapped area does not have well defined structural borders. Mid-Tertiary volcanic rocks of the Copperas Block dip beneath sedimentary fill on its south side.

The northwestern end of the Sapillo-Mimbres Valley is a well-defined graben, the Sapillo graben of Ratté and Gaskill (1975). On its north side, it abuts the Copperas Block along the Sapillo fault zone (Fig. 3). On the south side, the Mimbres fault zone and its westward continuations form its border with the Pinos Altos Mountains. The southeastern end of the Sapillo-

Mimbres Valley is a half graben. It is bordered on the west side by the Mimbres fault and on the east side by westward-dipping rocks of the Black Range dome, faulted down toward the east by the Mimbres Hot Springs fault and other ring-fracture faults of the Emory cauldron.

Hot Springs

Locations, Temperatures, and Chemical Composition

The hot springs at and near Gila Hot Springs are located on the northwestern end of the mapped area, those of Mimbres Hot Springs at its southwestern end. Data on locations, measured temperatures, and base temperatures calculated from geologic thermometry were kindly provided by Dr. C. A. Swanberg (New Mexico State University) and are listed in the Appendix. For the sake of completeness, data on the hot springs at Alum Mountain, just west of the mapped area, are included also.

Gila Hot Springs

Introduction: - Of the seven areas of thermal springs in the northwestern end of the study area, one is in the lower part of Black Canyon, five are on the East Fork of the Gila River near Lyon's Hunting Lodge, and one cluster is on the West Fork of the Gila River, near Gila Hot Springs. Another group is just west of the mapped area, north of Alum Mountain, in the main canyon of the Gila River below the junctions of its three forks. The locations shown on figures 2 and 3 were taken from Ratté and Gaskill (1975).

No significant deposits of sinter or travertine are associated with the springs, which are marked only by dense foliage on otherwise barren rock or by warm and soggy ground on canyon floors. In Black Canyon, there is only a single gushing spring, warm to the touch. Summers (1965) listed the discharge of three springs of the Gila Hot Springs area as 25, 100, and 10 gallons per minute, respectively.

The hot springs seem to be controlled by three factors: (1) border faults of the Gila Hot Springs graben, especially on its northeastern side, (2) the contact between Bloodgood Canyon Rhyolite Tuff and the Bearwallow Mountain Formation, and, more speculatively, (3) the margin of the Gila Cliff Dwelling cauldron.

Stratigraphic controls: - Springs emerge from both Bloodgood Canyon Rhyolite Tuff and Bearwall Mountain Formation, but always within a few meters of their mutual contact. The uppermost part of the Bloodgood Canyon Rhyolite Tuff is poorly welded and permeable. The Bearwallow Mountain Formation consists of vesicular and scoriaceous basaltic andesite flows and thin (to 50 cm) interlayered baked sandstone beds. The sanidine cryptoperthite ("moonstone") crystals that are characteristic of Bloodgood Canyon Rhyolite Tuff have lost their characteristic iridescence through alteration and now have silky luster. Other rocks have few signs of alteration that are obvious in the field.

The modest amount of present-day hydrothermal alteration is in striking contrast to that of an earlier time. Between Sapillo Creek and Alum Mountain, the Salt Creek Formation of the Alum Mountain Group is intensely altered to clays, zeolites, and sulfates (Fig. 3). Alteration barely extends upward into the Gila Flat Formation of the Alum Mountain group and Bloodgood Canyon Rhyolite Tuff is entirely unaffected. This intense alteration, which gives Alum Mountain its name and is so conspicuous along State Highway 15, seems to have resulted from ancient hot springs related to one or more vents for the lower part of the Alum Mountain Group. The hot springs became extinct before eruption of the Bloodgood Canyon Rhyolite Tuff, about 28 m.y. ago.

For present-day geothermal waters, sandy and scoriaceous layers in the basal part of the Bearwallow Mountain Formation and, especially, the relatively unwelded uppermost few meters of Bloodgood Canyon Rhyolite Tuff seem to have acted as the aquifer. The main part of the Bloodgood Canyon Rhyolite Tuff is densely welded and finely recrystallized so that primary permeability would be controlled by fractures. Alteration of the glassy to microcrystalline matrix of the tuff may increase permeability. There is no evidence that conglomerate of the Gila Group, which fills the Gila Hot Springs graben, acted as an aquifer.

Structural controls: - The Gila Hot Springs graben (Fig. 3) trends southeastward from the Gila H t Springs for about 17 km (10 mi) and is between 3 to 5 km (2 to 3 mi) wide. Off the map, northwest of Gila Hot Springs, the faults become more numerous, fan out, and form a complex group of horsts and grabens that can be traced for a further 30 km (20 mi) across the Gila Cliff Dwellings cauldron (Ratté and Gaskill, 1975).

The Gila Hot Springs graben is bordered on the northeast by a set of four major northwest-trending vertical faults, all down to the southwest. These are linked together by several short and more west-trending faults. Faults decrease in number and stratigraphic separation southeastward from Gila Hot Springs. The most continuous one dies out just southeast of the junction of Apache Creek and Black Canyon.

The main fault on the northeast side of the Gila Hot Springs graben cuts through several meanders of the East Fork of the Gila River, about 3.2 km east-southeast from Gila Hot Springs. Excellent exposures in cliffs are marked by moderately gouged rock and vertical slickensides. Stratigraphic separation of the fault is 120 m or more, as measured by the displacement of the contact between the Bloodgood Canyon Rhyolite Tuff and the overlying basaltic andesite of the Bearwallow Formation. The fault dies out to the southeast, in rocks of the Bearwallow Mountain Formation. Northwest of the mapped area, it becomes one of a set of 10 or more sub-parallel northwest-trending faults and can be traced for another 12 km (8 mi).

The other vertical faults that border the northeast side of the Gila Hot Springs graben are southwest of the main fault. One of them was mapped from the neighborhood of Gila Hot Springs, across the East Fork of the Gila River, and southeastward along Black Canyon. At the junction of Black Canyon and Apache Creek, this fault has a stratigraphic separation of about 75 m; it dies out to the southeast, in rocks of the Gila Group. Other faults exposed at Gila Hot Springs either join the more continuous faults or die out in the southeast within about 3 km (2 mi).

The Gila Hot Springs graben is bounded on the southwest by a single vertical fault, down on the northeast side. Its maximum stratigraphic separation can be estimated in places where pre-Gila rocks are exposed within the graben. East of Highway 15, where the fault crosses Jordan Canyon, stratigraphic separation is no more than a few tens of meters. Three or four kilometers to the southeast, the fault dips steeply northeast or is vertical; its stratigraphic separation is still limited to a few tens of meters. Farther to the southeast, the fault dies out within rocks of the Alum Mountain Group.

The northwesterly trend of the Gila Hot Springs graben is reflected in the alighment of parts of major drainages, such as Apache Creek, Black Canyon, and the East Fork of the Gila River. Hot-spring activity along the northern boundary faults of the Gila Hot Springs graben dies out toward the southeast, as does the northern margin of the graben. The faults continue to the northwest, beyond the mapped area, but the country there is part of the Gila Wilderness and not likely to be developed for geothermal energy. The exposed rocks in this area are Bloodgood Canyon Rhyolite Tuff and older units: the apparent aquifer at the Bloodgood Canyon-Bearwallow Mountain contact has been eroded away.

No known faults are associated with the thickening of Bloodgood Canyon Rhyolite Tuff, from about 25 m at Alum Mountain to more than 250 m in the Gila Sag. Nevertheless, most of the hot springs are located on the flexure at which this thickening occurs and which has been related to the margin of the Gila Cliff Dwellings cauldron. If the Gila Hot Springs graben had originally been part of a fault zone transverse to the cauldron, its dying out to the southeast, beyond the cauldron margin, would be explained. However, most of the graben formed later than cauldron collapse, because the late Tertiary Gila Group has been displaced by border faults.

Conclusions: - The volume of thermal waters in the Gila Hot Springs KGRA is sufficient for local use in residences and recreational facilities. Springs and wells controlled by major faults seem to tap a geothermal reservoir of modest temperature, yield and thickness, at the Bloodgood Canyon-Bearwallow Mountain contact. The source of thermal waters is unknown, but the possibility of deep convective circulation of meteoric water through faults, joints, and altered zones in the Bloodgood Canyon Tuff, and older rocks should be considered. Proximity to a cauldron margin could explain the presence of fractures which would allow deep circulation.

Up to now, no evidence has been found for substantial amounts of hot water in conglomerate of the Gila Group within the Gila Hot Springs graben. The thickness of the Gila Group within the graben is less than 75 m (250 ft) and no springs seem to issue from its base. The thickness of the aquifer at the Bloodgood Canyon-Bearwallow contact is a few tens of meters at most and the volume of water in shallow reservoirs appears to be modest.

The border faults of the Gila Hot Springs graben seem to play a dual role in controlling hot springs . They feed deeply convecting waters into the aquifer and they cause the aquifer to intersect the present land surface. As faults die out toward the southeast, hot-spring activity diminishes and disappears. To the northwest, faults continue into the Gila Wilderness but the aquifer has been eroded away.

Natural hot water has long been used for heating the home, greenhouse and business of the Doc Campbell family at Gila Hot Springs. In 1980 Doc Campbell installed a 10 kilowatt generator, the first use of natural hot water for generating electricity in New Mexico. Two shallow wells near the generator, in SW¼ NW¼ NE¼, sec. 5, T. 13 S., R. 13 W., produce water at 64.9°C (148.8°F) from a depth of 11.5 m (37.8 ft) and 65.8°C (150.4°F) from a depth of 6.4 m (21.0 ft), respectively. These wells are within a few meters of a major fault. Three deeper wells were drilled a short distance away. The Campbell et al No. 1 well, in N½ NE¼ NW¼, sec. 5, T. 13 S., R. 13 W., yielded about 20 to 25 gallons per minute. Its total depth is 286.3 m (939.2 ft); water temperature at the bottom was 58°C (136.4°F) and the flow about 75 to 95 liters (20 to 25 gallons) per minute. For the lower 210 m (700 ft), the increase in temperature was 13.9°C per 100 m (7.67°F per 100 ft). The Campbell et al No. 2 well, in NE¼ NW¼ NE¼, sec. 5. T. 13 S., R. 13 W., was drilled to a depth of 84.5 m (277 ft). At a depth of 81 m (265 ft), there was a heavy flow of water, estimated at about 950 liters per minute (250 gallons per minute) with a temperature of 61.0°C (141.8°F). The third deep well was drilled at a trailer park in NE¼ NW¼, sec. 5, T. 13 S., R. 13 W.; water temperature was 41.7°C (106.1°F) at 132.9 m (436.2 ft). All of the wells bottomed in Bloodgood Canyon Rhyolite Tuff except for the Campbell et al No. 1, which seems to have drilled into andesite (presumably of the Alum Mountain Group) below 62.5 m (205 ft). Well logs were listed by Summers and Colpitts (1980); additional details were supplied by Doc Campbell (personal communication, 1981).

The generator uses about 19 liters (5 gals) per minute of hot water at 65.5°C (150°F) per kilowatt; the condensor 23 liters (6 gals) of cold water per minute. The generator is a freon Rankine cycle engine built by Gerotor Power Systems of Batavia, Ohio. Spent water is returned to the Gila River; the use of hot water for generation of electricity is non-consumptive.

Local uses of geothermal water are likely to remain modest at Gila Hot Springs, because of the sparse population. Most of the surrounding country is Wilderness or Primitive Area and it seems unlikely that population and market for geothermal energy will rise substantially in the next few years.

Mimbres Hot Springs

Introduction: - Mimbres Hot Springs consists of a group of about 30 closely clustered springs in NW¼ sec. 13, T. 18 S., R. 10 W., at the intersection of the inner wall of the Emory cauldron and the Mimbres Hot Springs fault. The geology of the area surrounding the springs was described by Elston (1957) and the hydrology by Bushman (1955). Hot water is used for heating and domestic water in a large residence. Its flow exceeds 100 gallons per minute.

Stratigraphic controls: - The principal hot springs issue from fractures in massive cauldron-fill facies of Kneeling Nun Tuff. Only about 250 m southeast of the springs, rhyolite of the Mimbres Peak Formation (younger than Kneeling Nun) rests on andesite of the Rubio Peak Formation (older than Kneeling Nun). Kneeling Nun Tuff is not present, nor is it present on the southern tip of the mapped area, where State Highway 61 crosses the Mimbres fault. This is typical of the margins of ash-flow tuff cauldrons; the main ash-flow tuff unit is generally absent or patchy on the former caldera rim.

Because Kneeling Nun Tuff has a densely welded and recrystallized matrix, it is likely to have fracture permeability only. If Sugarlump Tuff is present beneath Kneeling Nun Tuff, it could be a more substantial aquifer. However, the thickness of Kneeling Nun Tuff that would have to be penetrated to reach the Sugarlump Tuff is unknown, as are the lateral extent and attitude of the Sugarlump Tuff. These problems can only be partly solved by surface geology. About 15 km south of Mimbres Hot Springs, up to 420 m (1,400 ft) of air-fall and ash-flow tuff, water-deposited sandy tuff, and tuffaceous sandstone of the Sugarlump Formation separate Kneeling Nun Tuff from the Rubio Peak Formation. In much of the Black Range, Sugarlump Tuff is thin or absent. From scanty exposures near the place where State Highway 61 crosses the Mimbres fault, it can be concluded that Sugarlump Tuff is likely to be only a few tens of meters thick at Mimbres Hot Springs, if it is present at all. The thickness of Kneeling Nun Tuff is likewise unpredictable because of proximity to a cauldron margin. Finally, an aquifer is unlikely to have much lateral extent, because of slumping at the cauldron margin and slicing by branches of the Mimbres Hot Springs fault.

Structural controls: - At different times, the Mimbres Hot Springs fault acted as a marginal fracture of the Emory cauldron and as one of the Basin and Range faults that define the Mimbres Valley half graben. Its early history is unknown. It is not know whether it was active prior to eruption of the Emory cauldron and during cauldron collapse and filling. It was certainly active during resurgence, because it controls rhyolite ring-fracture domes of the Mimbres Peak Formation. Most of its movement occurred as part of the Basin and Range episode; it displaces the Bear Springs Basalt and is buried by the upper part of the Gila Group.

For most of its exposed length south of Mimbres Hot Springs, the Mimbres Hot Springs fault has carried the top of the Razorback Formation on the east side down against the base of the Mimbres Peak Formation, for a stratigraphic separation of about 600 m (2,000 ft). At Mimbres Hot Springs, the fault splits into several branches, so that slices of Kneeling Nun Tuff and andesite of the Rubio Peak Formation came to be inserted into the fault zone. The rocks of Mimbres Peak Formation are hydrothermally altered. This is characteristic of ring-fracture and moat deposits of resurgent cauldrons. Alteration occurred during and after resurgence in mid-Tertiary time and is not the result of modern hot-spring activity.

The southern end of the Mimbres Hot Springs fault is buried by the Gila Group. A spring near its southward projection, Carisa Tubs in Carisa Canyon (SE¼ SW¼ sec. 31, T. 18 S., R. 19 W.) is cold. However, the waters of Carisa Tubs are anomalously high in fluorine (5.2 ppm), which is a characteristic of thermal waters. The fault probably continues north of Mimbres Hot Springs (Fig. 2) but the very name of the next canyon, Cold Springs Canyon, suggests that no warm waters have been detected there.

Conclusions: - Mimbres Hot Springs occupies a unique position at the only exposed intersection of the southwestern margin of the Emory cauldron and a major fault. Elsewhere, the margin is buried by younger rocks. To the east, it is not seen again until the Lake Valley area; to the northwest it has not yet been located in the present incomplete state of mapping. Fractures associated with the intersection of a cauldron margin and a major fault probably provide the opportunity for tapping deeply convecting heated waters. Unfortunately, structural complications make it difficult to assess the volume of the geothermal aquifer by surface geology. Fracture permeability of the

Kneeling Nun Tuff alone should provide sufficient hot water for residential use in the immediate vicinity. Only drilling could show whether sufficient hot water could be developed to justify piping to farms and residences of the Mimbres Valley, and 4 km (2½ mi) distant. From present indications, development of a major geothermal reservoir would be difficult, because no thick, shallow, and continuous aquifer is known and because the hot springs are remote from population centers.

Geothermal Possibilities of the Region Between Gila Hot Springs and Mimbres Hot Springs

Throughgoing faults run parallel to many of the valleys of the Basin and Range province and it could be expected that examples would be found as a result of this study, parallel to the northeast side of the Mimbres Valley. Such northwest-trending faults, if they exist, could link the Mimbres Hot Springs fault with the Gila Hot Springs graben and would guide exploration for geothermal anomalies between the two known hot-spring occurrences. Unfortunately, no throughgoing faults were found.

Indications of northwest-trending faults were indeed found on the northeast side of the Mimbres Valley. However, major faults are dominated by the north-trending Emory cauldron, which makes up the core of the Black Range, and photolineaments suggest arcuate collapse structures of the Emory cauldron. There is no evidence at present for major faults crossing the western margin of the Emory cauldron and heading northwestward from Mimbres Hot Springs to Gila Hot Springs (Fig. 2).

Southeast of Gila Hot Springs, the dying out of faults bordering the Gila Hot Springs graben has already been described. As the faults die out, so does hot-spring activity. The Copperas Block is associated with east-trending faults which prevent any simple linkage between faults northwest of Mimbres Hot Springs and southeast of Gila Hot Springs. The Copperas Block is also a reflection of Oligocene volcanic centers. Near its western end, several andesitic centers have been located and others may be present. On its eastern end, rhyolite of Rocky Canyon welled up in enormous masses, and related intrusions may lie beneath much of the Copperas Block. During Basin and Range extension, the block seems to have acted as a massif that separated the Gila Sag from the Sapillo-Mimbres Valley and prevented throughgoing northwest-trending faults from developing between Mimbres Hot Springs and Gila Hot Springs.

Discussion

Geothermal activity in the Mimbres Hot Springs and Gila Hot Springs areas seems to reflect local structural conditions that allowed water to circulate deeply and rise in a heated condition. There is as yet no evidence for regional structures to link the two areas. Both hot-spring areas are at the intersections of major faults and earlier ash-flow tuff cauldrons. At Mimbres Hot Springs, there is good geologic evidence for the proximity of a cauldron wall and for activity of a major fault during resurgence. At Gila Hot Springs the evidence for a cauldron margin is weaker.

It should be emphasized that there is no suggestion of invoking mid-Tertiary cauldrons as heat sources for modern hot springs. The proposed connection between cauldrons and hot springs would be purely one of structural control. It should not come as a surprise that cauldron margins are associated with intensely disturbed ground which permits deep circulation of fluids. The cauldrons of the study area are very large indeed and their eruption and collapse must have been cataclysmic. The directed explosion at Mount St. Helens on May 18, 1980 accompanied the eruption of approximately 1.5 km^3 of ash. The volume of the Kneeling Nun Tuff that erupted during the collapse of Emory cauldron was 1,000 times greater. After the Mount St. Helens eruptions, a few centimeters of ash fell on nearby cities. In the Gila Sag, the Bloodgood Canyon Rhyolite Tuff forms massive cliffs 250 m (800 ft) high in the canyons of Little Creek and the West and Middle Forks of the Gila River.

In neither hot-springs area are there indications for a major geothermal reservoir. At Gila Hot Springs, the aquifer seems to be a relatively thin ($\sim$10 m) permeable stratigraphic zone on both sides of the contact between Bloodgood Canyon Rhyolite Tuff and the Bearwallow Mountain Formation. The controlling fault zone, which borders the northeast side of the Gila Hot Springs graben, dies out toward the southeast and heads into the Gila Wilderness toward the northwest. At Mimbres Hot Springs, fractures in massive Kneeling Nun Tuff appear to be the source of thermal waters. To date, no further indications of hot water have been found farther to the north and south along the controlling Mimbres Hot Springs fault, although anomalous fluorine contents persist in cold waters for several kilometers to the south. In both areas, hydrothermal alteration is widespread but occurred during mid-Tertiary volcanic activity, not as a result of modern hot springs.

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Dr. William R. Seager and Dr. Chandler A. Swanberg, New Mexico State University, generously contributed information although their work was not directly related to the project covered by this report. Dr. Seager provided much information for figures 2 and 3, between Lats. 32°45' and 33°00' N. Much of our knowledge of the Emory cauldron, critical to the interpretation of Mimbres Hot Springs, comes from his work and that of Dr. R. E. Clemons (New Mexico State University).

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APPENDIX

Locations, measured temperatures, calculated base temperatures, and chemical analyses of waters from Mimbres Hot Springs, Gila Hot Springs, and Alum Mountain, Grant County, New Mexico. Data kindly furnished by Dr. C. A. Swanberg, New Mexico State University.

Table 1. Temperature and location of springs and wells of the Gila Hot Springs-Mimbres Hot Springs areas: T_1 = actual temperature; T_2 = estimated Na-K-Ca temperature; T_3 = estimated silica temperature; L_1 = map or quadrangle name; L_2 = latitude and longitude location; L_3 = township and range location.

Field	Lab #	T_1 °C	T_2 °C	T_3 °C	L_1	L_2	L_3	Name
Gila 4	SW31	58.2	74.5	106.8	Dwyer	107°50.1'W 32°44.9'N	T18S R10W Sec 13 NW 1/4 NW 1/4	Mimbres Hot Springs
Gila 5	SW32	62.8	76.3	119.8	Gila National Forest	108°12.5'W 33°12.0'N	T13S R13W Sec 5 NE 1/4 NW 1/4	Gila Hot Springs
Gila 6	SW33	66.3	77.3	120.5	Gila National Forest	108°12.6'W 33°12.0'N	T13S R13W Sec 5 NE ½ NW ½	Gila Hot Springs
Gila 7	SW34	64.8	74.4	128.9	Gila National Forest	108°14.2'W 33°14.0'N	T12S R14W Sec 24 SE 1/4 SE 1/4	Hot Springs
Gila 8	SW35	43.6	62.2	128.9	Gila National Forest	108°12.7'W 33° 9.8'N	T13S R13W Sec 17 SW 1/4 NE 1/4	Hot Springs
Gila 9	SW36	N/A	44.4	110.3	Gila National Forest	108°00.5'W 32°34.6'N	T20S R11W Sec 8 SW 1/4 SW 1/4	Well
Gila 10	SW37	N/A	48.4	111.2	Gila National Forest	108°00.2'W 32°35.1'N	T20S R11W Sec 8 NW 1/4 SE 1/4	Well
Gila 11	SW38	N/A	55.0	105.9	Gila National Forest	108° 2.5'W 32°33.8'N	T20S R11W Sec 18 SW 1/4 SW 1/4	Well

Table 1. (Continued)

Field	Lab #	T_1 °C	T_1 °C	T_1 °C	L_1	L_2	L_3	Name
MFG1	SW161	31.0	34.6	102.7	Alum Mountain	108°15.8'W 33°17.0'N	T11S R14W Sec 35 SW 1/4 SE 1/4 (unsurveyed)	Spring
MFG2	SW162	37.0	19.4	107.2	Alum Mountain	108°15.9'W 33°17.4'N	T11S R14W Sec 35 SW 1/4 NE 1/4 (unsurveyed)	Spring
MFG3	SW163	36.0	31.4	107.5	Alum Mountain	108°15.9'W 33°17.4'N	T11S R14W Sec 34 NE 1/4 SE 1/4 (unsurveyed)	Spring
MFG4	SW164	26.0	22.6	105.4	Alum Mountain	108°15.0'W 33°16.4'N	T12S R14W Sec 1 SW 1/4 SW 1/4 (unsurveyed)	Spring

Table 2. Major cations and anions for springs and wells

Field #	Lab #	TDS	pH	mg/l Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
Gila 4	31	320	8.97	2.4	<.006	91.7	1.2	20.4	67.1	14.5	84.0
Gila 5	32	408	8.19	10.6	0.1	123.0	3.1	0	108.6	99.4	69.6
Gila 6	33	416	8.15	10.4	0.2	129.7	3.1	0	115.9	100.1	67.2
Gila 7	34	548	7.92	15.4	0.1	151.5	3.5	0	131.1	104.3	118.0
Gila 8	35	516	8.08	18.4	0.8	141.9	2.7	0	125.0	115.7	93.6
Gila 9	36	320	8.15	31.6	13.0	28.9	3.5	0	227.5	1.4	24.0
Gila 10	37	344	7.84	32.0	18.1	24.8	4.3	0	213.5	17.0	16.2
Gila 11	38	428	7.82	39.8	13.2	47.1	5.1	0	236.6	8.5	50.4
MFG2	162	188	8.07	19.2	1.6	41.8	0.8	0	128.1	4.2	31.7
MFG3	163	192	8.09	16.8	1.6	43.7	1.2	0	139.7	3.9	28.3
MFG4	164	168	8.15	14.8	1.5	37.5	.8	0	131.2	3.2	19.2

Table 3. Analyses of iron, fluoride, boron, phosphorous, and silica

Field #	Lab #	Fe (ppm)	F (ppm)	B (ppm)	P (ppm)	SiO_2 (ppm)
Gila 4	31	< .10	16.00	0	0	55.56
Gila 5	32	< .10	8.70	.03	0	72.27
Gila 6	33	< .10	8.70	.02	0	73.31
Gila 7	34	.22	9.50	.07	0	85.89
Gila 8	35	1.25	8.70	.11	.01	85.89
Gila 9	36	.29	.61	.01	0	59.73
Gila 10	37	3.11	.66	.01	0	60.78
Gila 11	38	< .11	3.00	.01	0	54.53
MFG1	161	.37	4.86	.05	.20	51.0
MFG2	162	.42	5.28	.02	.16	56.0
MFG3	163	< .10	5.28	.07	.09	56.5
MFG4	164	< .10	5.07	0	.09	54.0

Table 4. Analyses of nitrogen species, nickel, lead, antimony, selenium, strontium, and zinc

Field #	Lab #	NO_3+NO_2 (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Sr (ppm)	Zn (ppm)
Gila 4	31	0.00	<.13	.051	<.6	.004	<.02	<.028
Gila 5	32	.29	<.13	.024	<.6	.005	.02	.06
Gila 6	33	.19	<.13	.021	<.6	.005	.02	.06
Gila 7	34	.19	<.13	.021	<.6	.006	.03	<.028
Gila 8	35	0.00	<.13	.021	<.6	.006	.02	.05
Gila 9	36	--	--	--	--	--	--	--
Gila 10	37	--	--	--	--	--	--	--
Gila 11	38	--	--	--	--	--	--	--

Table 5. Analyses of cadmium, cobalt, chromium, copper, mercury, hydrogen sulfide, lithium, manganese, molybdenum, ammonium, silver aluminum, arsenic, barium, and bromine

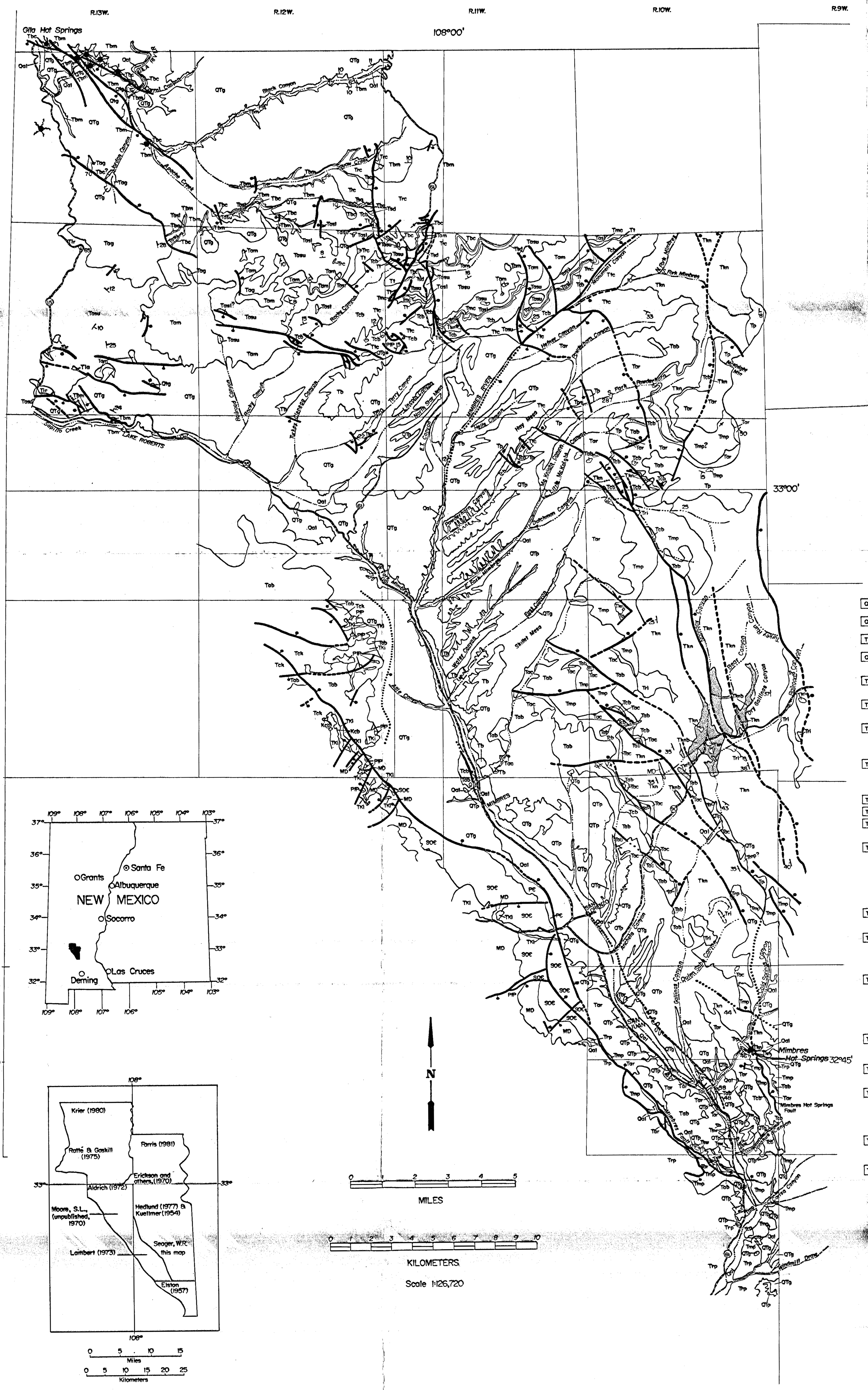
		ppm														
Field #	Lab #	Cd	Co	Cr	Cu	Hg	H_2S	Li	Mn	Mo	NH_4	Ag	Al	As	Ba	Br
Gila 4	31	<.02	<.18	<.1	<.12	.0006	--	.11	<.063	<.45	<.05	<.07	<1.10	.006	<.20	<.06
Gila 5	32	<.02	<.18	<.1	<.12	.0033	--	.26	<.063	<.45	<.05	<.07	<1.10	.007	<.20	<.06
Gila 6	33	<.02	<.18	<.10	<.12	.0007	--	.26	<.063	<.45	<.05	<.07	<1.10	.008	<.20	<.06
Gila 7	34	<.02	<.18	<.10	<.12	.0005	--	.43	<.063	<.45	<.05	<.07	<1.10	.006	<.20	<.06
Gila 8	35	<.02	<.18	<.10	<.12	.0006	--	.31	<.063	<.45	<.05	<.07	3.10	.009	<.20	<.06
Gila 9	36	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gila 10	37	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gila 11	38	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 6. Calculated Na-K-Ca-Mg temperatures

Field #	Lab #	Temp C°
Gila 4	SW31	27.977
Gila 5	SW32	76.266
Gila 6	SW33	77.246
Gila 7	SW34	73.637
Gila 8	SW35	62.113
Gila 9	SW36	44.387
Gila 10	SW37	48.329
Gila 11	SW38	54.978
MFG1	SW161	34.528
MFG2	SW162	19.385
MFG3	SW163	31.348
MFG4	SW164	22.517

DEPARTMENT OF GEOLOGY
UNIVERSITY OF NEW MEXICO

GILA HOT SPRINGS TO
MIMBRES HOT SPRINGS



Base map enlarged from AMS Clifton, Tularosa, Las Cruces and Silver City 2-degree maps

Compiled by Stephen R. Farris, 1979

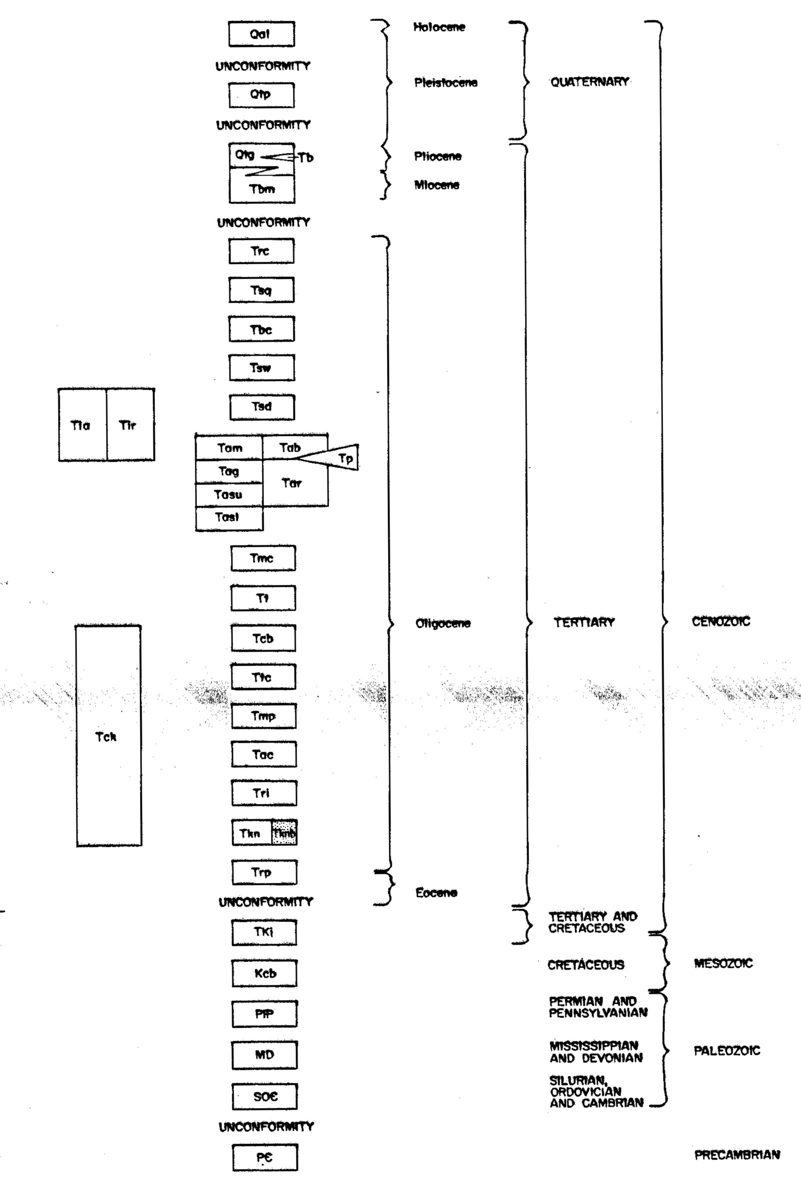
PRELIMINARY GEOLOGIC MAP OF THE COUNTRY BETWEEN GILA HOT SPRINGS AND MIMBRES HOT SPRINGS, GRANT AND CATRON COUNTIES, NEW MEXICO

BY
Wolfgang E. Elston, William R. Seager,
Stephen R. Farris, and Donathon J. Krier

1981

Figure 2

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qal ALLUVIUM (QUATERNARY)—Gravel, sand, and silt, unconsolidated, in modern drainages

QTp PEDIMENT AND TERRACE GRAVEL (PLIOCENE? TO QUATERNARY)—Gravel, unconsolidated, clasts generally rounded. Includes some fanglomerate

Tb ALKALI OLIVINE BASALT (PLIOCENE)—Vesicular olivine basalt, interlayered with Gila Group. Age 6.5±0.4 m.y. (Elston and others, 1973)*

QTg GILA GROUP (MIOCENE TO PLEISTOCENE?)—Conglomerate, fanglomerate, and sandstone, semi-consolidated; lower member well bedded and sorted, upper member massive with poorly sorted angular clasts

Tbm BEARWALLOW MOUNTAIN FORMATION (MIOCENE)—Andesite and basaltic andesite flows, dark gray to black, commonly vesicular. The most mafic flows contain microphenocrysts of olivine altered to iddingsite

Trc RHYOLITE OF ROCKY CANYON (OLIGOCENE TO MIOCENE?)—Rhyolite flows and domes, gray, flow banded, and minor tuffaceous units, with sparse phenocrysts of quartz, sanidine, biotite, and oligoclase

Tsq BASALTIC ANDESITE OF SQUAW CREEK (OLIGOCENE)—Basaltic andesite flows and breccias, dark brown to black, vesicular; phenocrysts of olivine are altered to iddingsite. New name; type locality is in upper Apache Creek, W½ sec. 36 (unsurveyed), T. 13 S., R. 12 W., 2.5 km (1.5 mi) southwest of upper Squaw Creek

Tbc BLOODGOOD CANYON RHYOLITE TUFF (OLIGOCENE)—Rhyolite ash-flow tuff, moderately to densely welded, with phenocrysts of quartz, chatoyant sanidine ("moonstone") and biotite. Age 27.0±0.8 m.y. (Elston and others, 1973)*

DIKES (OLIGOCENE)

Tla Hornblende andesite dike in Salt Creek, northwest of Roberts Lake

Tlr Crystal-poor and altered rhyolite dikes near western boundary of mapped area

Tsw SWARTZ RHYOLITE (OLIGOCENE)—Rhyolite flows, domes, and breccia flows, with abundant phenocrysts of quartz, oligoclase-andesine, sanidine, and quartz. Age 27.3±0.8 m.y. (Elston and others, 1973)*

Tsd RHYOLITE TUFF OF DAVIS CANYON AND QUARTZ LATITE TUFF OF SHELLEY PEAK (OLIGOCENE)—Tuff of Davis Canyon: Rhyolite ash-flow tuff, white, with lithic fragments and sparse phenocrysts of chatoyant sanidine, quartz, and minor biotite. K-Ar ages 29.0±0.7* (sanidine) and 30.9±0.7* (biotite) m.y. Tuff of Shelley Peak: Quartz latite ash-flow tuff, pink, with abundant phenocrysts of brassy biotite and andesine. K-Ar ages 28.1±0.7* (sanidine) and 29.1±0.7* (biotite) m.y.; zircon fission-track age 27.4±2.4 m.y. Ages determined in 1975 by R.F. Marvin and C.W. Naeser, cited by Ratté and Gaskill (1978)

ALUM MOUNTAIN GROUP

Tab BEAR SPRINGS BASALT (OLIGOCENE)—Basaltic andesite, black, vesicular, with iddingsite replacing olivine. Crops out in the Black Range, Lower Mimbres Valley and Cobre Mountains

Tam BASALTIC ANDESITE OF MIDDLE MOUNTAIN (OLIGOCENE)—Lower part: Basaltic andesite, black, vesicular, with iddingsite replacing olivine. Upper part: black, glassy, non-porphyritic. Crops out in the region between the Mimbres Canyon and Gila Hot Springs. New name; type locality between Middle Mountain, center sec. 8 (unsurveyed), T 14 S., R. 12 W., and center of western boundary of sec. 7, T. 14 S., R. 12 W.

Tag GILA FLAT FORMATION (OLIGOCENE)—Andesitic and latitic flows, dark gray, with phenocrysts of plagioclase, pyroxene, biotite and/or hornblende; glassy to microcrystalline. Age 30.4±1.0 m.y. (Ratté and Gaskill, 1975)*

SALT CREEK FORMATION (OLIGOCENE)—New name. Type locality for upper member: sec. 26, T. 14 S., R. 13 W., hill with 7212 ft elevation, 2.5 km (1.5 mi) north of Roberts Lake. Type locality for lower member: NE¼ sec. 15 (unsurveyed), T. 14 S., R. 12 W., about 2 km (1.3 mi) southeast of Loco Mountain.

Tasu UPPER MEMBER—Andesite flows, light to dark gray, with phenocrysts of plagioclase, augite, enstatite, hornblende; resorbed crystals of quartz rimmed with augite, glomeroporphyritic clusters of plagioclase; matrix microcrystalline to glassy

Tasl LOWER MEMBER—Basaltic andesite flows, black, vesicular, with microphenocrysts of iddingsite and plagioclase; matrix consists of plagioclase laths with intergranular augite

Tar RAZORBACK FORMATION (OLIGOCENE)—Undifferentiated. Upper member: Gray aphanitic flow-cleaved latite lavas with sparse phenocrysts of oligoclase-andesine, enstatite, and oxyhornblende in a microcrystalline trachytic or glassy matrix. Lower member: Andesite flows, dark gray, with resorbed crystals of quartz rimmed with augite, and glomeroporphyritic aggregates of oligoclase. Microcrystalline groundmass of andesine, augite, enstatite, and olivine altered to iddingsite.

Tp POLLACK QUARTZ LATITE (OLIGOCENE)—Quartz latite flows, maroon, light gray, and brown, coarsely porphyritic, with phenocrysts of andesine, sanidine, quartz, and biotite, interpreted as late-stage ring-fracture domes of the Emory cauldron

Tmc RHYOLITE TUFF OF MONUMENT CANYON (OLIGOCENE)—Rhyolite ash-flow tuff, white, crystal-poor, with sparse phenocrysts of quartz and biotite, poorly welded. New name; type locality is in center of sec. 18 (unsurveyed), T. 14 S., R. 10 W., on northwest side of Monument Canyon.

Tt QUARTZ LATITE TUFF OF TERRY CANYON (OLIGOCENE)—Quartz latite ash-flow tuff, pink to brown, crystal-rich, with phenocrysts of plagioclase, sanidine, and biotite, moderately to densely welded. New name; type locality is in NW¼ sec. 21 (unsurveyed), T. 14 S., R. 11 W., on both sides of Terry Canyon, about 600 m (2000 ft) east of State Highway 61

Tcb CABALLO BLANCO RHYOLITE TUFF (OLIGOCENE)—Rhyolite ash-flow tuff, white to buff, with abundant coarse phenocrysts of smoky quartz, sanidine, plagioclase, and biotite, poorly to moderately welded. Age 30.6±0.8 m.y. (Elston and others, 1973)*

Ttc ANDESITE OF TURKEY CIENEGA CANYON (OLIGOCENE)—Basaltic andesite lava flows, gray to brown, with phenocrysts of resinous brown pyroxene and olivine altered to iddingsite

Tmp MIMBRES PEAK FORMATION (OLIGOCENE)—Flow-banded rhyolite flows, domes, and dikes; bedded pumiceous tuff; generally crystal poor with phenocrysts of quartz, sanidine, oligoclase, and biotite. Interpreted as ring-fracture domes and moat deposits of the Emory Cauldron. Age 32.8±1.0 m.y. (Elston and others, 1973)*

Tac VOLCANICLASTIC ROCKS OF ANCHETA CANYON (OLIGOCENE)—Tuffaceous sandstone and volcaniclastic conglomerate, orange or pink, bedded

Tri INTRUSIVE PORPHYRITIC RHYOLITE—Crystal-rich coarsely porphyritic intrusive rhyolite, flow banded, with prominent phenocrysts of quartz and sanidine, lesser plagioclase and biotite, in a xenomorphic-granular matrix.

Tkn **Tknb** KNEELING NUN QUARTZ LATITE TUFF (OLIGOCENE)—Quartz latite to rhyolite ash-flow tuff, buff to purple; crystal rich, with phenocrysts of oligoclase-andesine, sanidine, biotite, quartz and hornblende, densely welded. Interpreted as fill of the Emory cauldron. Age 34.3±1.0 m.y. (McDowell, 1971)* Tknb—Megabreccia

Tck KNEELING NUN QUARTZ LATITE TUFF, VOLCANICLASTIC ROCKS OF ANCHETA CANYON AND CABALLO BLANCO RHYOLITE TUFF (OLIGOCENE)—Undifferentiated

Trp RUBIO PEAK FORMATION (OLIGOCENE)—Andesite and latite lava flows, brown to purple, with phenocrysts of plagioclase, hornblende, and augite. Age 38.1 ± 0.8 m.y. (P.E. Damon, unpublished)

TKi INTRUSIVE ROCKS (CRETACEOUS TO EOCENE)—Stocks, dikes and sills, mainly porphyritic rocks of intermediate composition, undifferentiated

Kcb BEARTOOTH SANDSTONE AND COLORADO SHALE (CRETACEOUS)—Undifferentiated. Beartooth Sandstone: Orthoquartzite. Colorado Shale: Marine Shale

PIP OSWALDO, SYRENA, AND ABO FORMATIONS (PENNSYLVANIAN AND PERMIAN)—Undifferentiated. Oswaldo and Syrena Formations: Mainly limestone. Abo Formation: Red sandstone

MD PERCHA SHALE AND LAKE VALLEY LIMESTONE (DEVONIAN AND MISSISSIPPIAN)—Undifferentiated. Percha Shale: Nodular limestone and black fissile shale. Lake Valley Limestone: Crinoidal and cherty limestone

SOЄ BLISS SANDSTONE, EL PASO LIMESTONE, MONTOYA GROUP, AND FUSSELMAN DOLOMITE (CAMBRIAN, ORDOVICIAN, AND SILURIAN)—Undifferentiated. Bliss Sandstone: Orthoquartzite. El Paso Limestone: Limestone. Montoya Group: Dolomite and Sandstone. Fusselman Dolomite: Dolomite

PЄ CRYSTALLINE ROCKS (PRECAMBRIAN)—Undifferentiated. Greenstone schist and granite

*All K-Ar dates published before 1977 have been corrected for the new IUGS constants, according to the method of Dalrymple (1979)

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CONTACT

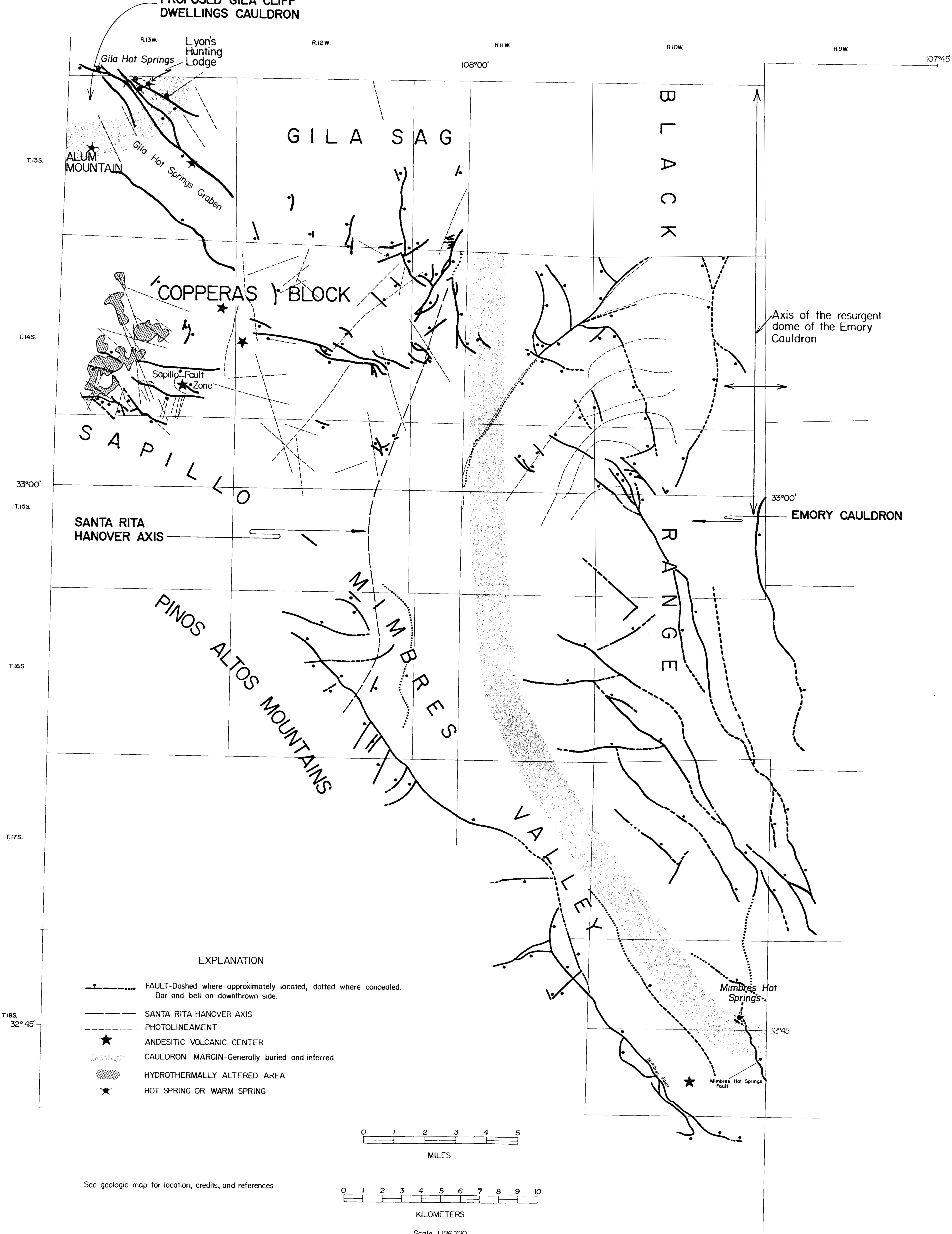
FAULT—Dashed where approximately located, dotted where concealed. Bar and ball on downthrown side

STRIKE AND DIP OF INCLINED BEDS

HOT SPRINGS OR WELLS

Foliation

Figure 3



TECTONIC SKETCH MAP OF THE COUNTRY BETWEEN GILA HOT SPRINGS AND MIMBRES HOT SPRINGS, GRANT AND CATRON COUNTIES, NEW MEXICO

BY

Wolfgang E. Elston, William R. Seager, Stephen R. Farris, and Donathon J. Krier

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