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Geology of Cieneguilla Creek drainage basin in southwest Colfax County, New Mexico

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Regional setting

The Cieneguilla Creek drainage basin occupies the southern two-thirds of the Moreno Valley in the Sangre de Cristo Mountains of southwest Colfax County, New Mexico. Moreno Valley is part of a long north-south topographic and structural depression that extends southward from the Taos County line almost to Mora, New Mexico. The area of Cieneguilla Creek drainage basin is 75.2 sq mi. Highways US-64 and NM-38 provide access to this ranching and recreation area.

Altitudes in the Cieneguilla Creek drainage basin range from 8,194 ft along the valley floor to 11,086 ft on Agua Fria Peak; maximum relief is 2,892 ft. Climate in the valley is temperate-dry with average annual precipitation between 15 and 20 inches. Both Pleistocene and recent erosion are responsible for the present valley form. Clark (1966) recognized three terrace levels within the valley: The highest terraces, represented by the Valley of the Utes, are remnants of the Broad Valley Stage. The second or intermediate stage is represented by the dissected terraces in the southern part of the valley. The third and lowest terraces near Cieneguilla Creek are indistinguishable from modern stream terraces.

Cieneguilla Creek drains northward from its headwaters on the west flank of Agua Fria Peak to Eagle Nest Lake—then into Cimarron Creek, a tributary of the Canadian River. Numerous tributaries drain the upper valleys and peaks into Cieneguilla Creek. Approximately half the tributary drainageways contain perennial streams; the remainder contain ephemeral streams that flow during spring runoff. The perennial streams are fed by small bogs (cienegas) and springs that occur on the mountain flanks. Other springs occur on the valley floor or near its margins. Local ranchers have developed a number of springs for livestock watering and/or domestic water supply.

Tributaries on the west side of the valley have a dendritic drainage pattern in their upper reaches caused by easterly dipping Pennsylvanian strata, and a linear pattern in their lower reaches caused by downcutting in the soft alluvium of the old valley floor. Tributaries on the east side of the valley have both dendritic and rectangular patterns caused by Tertiary volcanic rocks and variously dipping Permian-Pennsylvanian strata.

In the Cieneguilla Creek drainage basin, Precambrian, Mississippian, Pennsylvanian, Permian, Triassic, and Tertiary rocks crop out along the margins of the basin; Quaternary and Holocene alluvial deposits cover the central portion of the basin.

The basin is broken and segmented by numerous thrust, normal, and transverse faults that expose the Precambrian in the northern part of the basin and the Sangre de Cristo Formation (Permian-Pennsylvanian) and the Magdalena Group (Pennsylvanian) in the central and southern parts. Fig. 1 shows the overall geology and structural relationships in the basin.

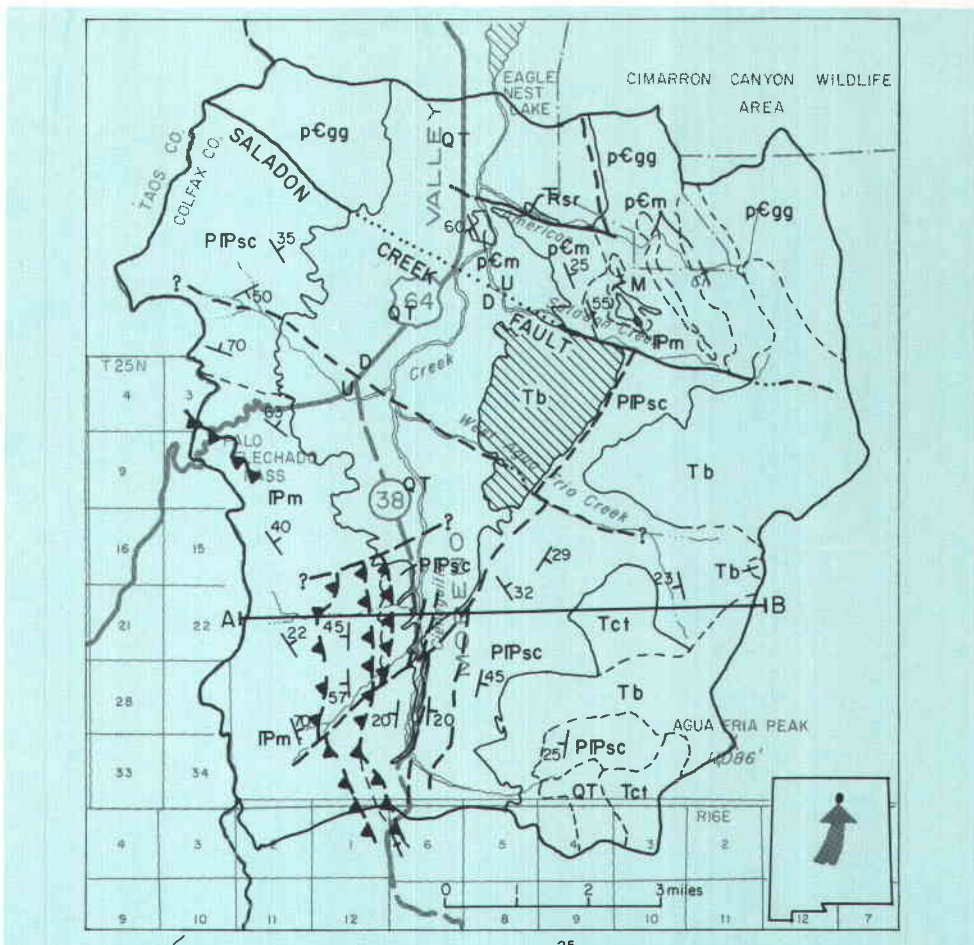

FIGURE 1—Geologic map of Cieneguilla Creek drainage basin.

METHODS AND PREVIOUS WORK—Detailed (1″=500′ and 1″=2,000′) property maps supplied by Coe and Van Loo Consulting Engineers, Inc., were used as the base for the geologic map. In addition to low and high altitude aerial photos, additional stratigraphic and structural information was interpreted from bore holes drilled and tested for water supply, as well as seismic profile interpretations of the lower part of the valley prepared by Charles Reynolds and Associates, Inc.

Ray and Smith (1941) and Smith and Ray (1943) discussed the geology of the Moreno Valley and the neighboring Cimarron Mountains. Wanek and Read (1956) briefly studied the area and suggested various forms of faulting as the origin for the Moreno Valley. Robinson and others (1964) described and mapped the Philmont Scout Ranch immediately east of Cieneguilla Creek drainage basin. Clark (1966) mapped the Eagle Nest Quadrangle immediately north of the area covered. Goodnight (1973) mapped the geology of the central Cimarron Range.

Stratigraphy

PRECAMBRIAN—Precambrian rocks crop out in the northern part of the basin north of the Saladon Creek Fault. South of the fault they are buried by younger rocks to depths ranging from 3,000 ft beneath the uplifted margins of the valley to as much as 13,000 ft in the depressed central area. (Table 1)

Precambrian rocks consist of metamorphosed sedimentary rocks, granite gneiss, and migmatites. The metasediments are predominantly quartzite with accessory muscovite, magnetite, and hornblende; and muscovite schist with accessory chlorite, ferro-tremolite, and sillimanite. Outcrops display apparent relict bedding. The granite gneiss is predominantly orthoclase and quartz with accessory biotite. The biotite is partially segregated within the granite gneiss imparting a pseudofoliation. Migmatite is confined to zones between the granite gneiss and the quartzite of the metasediments.

The metasediments and granite gneiss are assigned to the Precambrian on the basis of correlation with rocks of similar lithology, metamorphic grade, and known age relationships in other parts of the Sangre de Cristo Mountains (Callender and others, 1976). The granite gneiss intruded the metasediments, perhaps after some metamorphism. Erosion prior to Mississippian time created the surface on which the overlying Mississippian sediments were deposited.

MISSISSIPPIAN–Mississippian rocks crop out in the basin north of Saladon Creek fault, occurring as isolated erosional remnants lying unconformably upon Precambrian granite gneiss. These Mississippian rocks consist of a basal arkosic conglomerate, silicified limestone, chert, and light-gray, crossbedded sandstone. The basal conglomerate is brown and consists of cobbles of granite gneiss and quartzite in a matrix of poorly sorted, coarse-grained, arkosic sand. The basal conglomerate is overlain by very hard, gray-to-brown bedded chert and silicified limestone. The overlying limestone breccia that Clark (1966) reports immediately northwest of the basin is not observed here. The chert and silicified limestone are overlain by light-brown, slightly crossbedded, medium-grained sandstone with clay and calcium carbonate cement. Total thickness of the Mississippian rocks is 25.5 ft.

PENNSYLVANIAN—Pennsylvanian rocks, unconformably overlying the Mississippian and Precambrian, belong to the Magdalena group. Miller and others (1963) subdivide them into the Flechado Formation (Morrowan to lower Des Moinesian) and the Alamitos Formation (Middle to Upper Des Moinesian).

South of Saladon Creek fault the *Flechado Formation* crops out in the southwestern quadrant of the basin. North of the Saladon

PERIOD	FORMATION		DESCRIPTION	THICKNESS (ft)
Quaternary and Tertiary	Valley fill and Recent alluvium	(QT)	Complexly interbedded sands, gravels, silts and clays.	0′-425′+
Tertiary	Basalt flows	(Tb)	Dark-gray, dense, vesicular basalt.	900′
	Crystal tuff	(Tct)	Light-gray to white ash flow tuff with phenocrysts of sanadine. and biotite.	±1000′
Triassic	Santa Rosa Sandstone	(ŦRsr)	Light-gray to buff sandstones and limestone pebble conglomerates.	±65′
Permian	Sangre de Cristo Formation	(P₽sc)	Complexly interbedded red-brown, gray to gray-green, purple, tan, and buff sandstones, siltstones, shales, lenticular limestones and channel conglomerates.	±3400′
Pennsylvanian	Alamitos Formation	(₽m)	Interbedded black to gray sandstones, siltstones, shales and limestones.	±4300′
	Flechado Formation		Interbedded black to buff sandstones, siltstones, shales, limestones and occasional conglomerate stringers.	±4200′
Mississippian	Mississippian	(M)	Basal arkosic conglomerate overlain by silicified limestone, chert and sandstone.	25.5′
Precambrian	Metasediments	(p€m)	Interbedded quartzite and muscovite schist.	2000′+
	Granite gneiss	(p€gg)	Red to pink granitic intrusive.	

TABLE 1—GENERALIZED STRATIGRAPHIC COLUMN, CIENEGUILLA CREEK DRAINAGE BASIN.

ALSO IN THIS ISSUE:

COMING SOON:

- Proterozoic tectonics of New Mexico
- Red Rock talc deposits
- Geology and paleontology, Tortugas Mtn.
- Depositional environments, Chinle Formation

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Creek fault the Flechado occurs as erosional remnants unconformably overlying Mississippian rocks. The Flechado is only partially exposed in the basin; some of our knowledge of the formation comes from areas immediately west of the basin.

The Flechado consists of interbedded sandstones, conglomerates, siltstones, and some limestones. The sandstones are light to dark brown, medium to coarse grained, arkosic to feldspathic, and locally conglomeratic. They are medium to thin bedded and friable to hard, depending on the degree of induration, the cement being clay with some calcium carbonate. The conglomerates (light gray with fine- to medium-grained quartzite pebbles) occur as thin-bedded stringers within the sandstones. Beds range in thickness from several inches to about 2.5 ft and display poor lateral continuity. The siltstones are light brown to brown, slightly sandy to sandy, micaceous, and often feldspathic. The cement is clay and calcium carbonate in nearly equal proportions except near limestone beds where the cement is primarily calcium carbonate. The limestones, thin- to thick-bedded, black, fossiliferous, and argillaceous, are locally nodular and discontinuous, especially in thin-bedded zones in the lower part of the section.

The Flechado Formation grades upward into the overlying Alamitos Formation. The contact is placed at the base of a prominent limestone containing the brachiopod *Anthracospirifer rockymontanus*. Thickness is approximately 4,200 ft.

The *Alamitos Formation* crops out south of Saladon Creek fault. Exposures occur in a relatively narrow zone west of Cieneguilla Creek. East of the outcrops, the Alamitos occurs as subcrop beneath alluvial cover in the western part of the basin floor. North and east of the valley fill the Alamitos occurs beneath the Sangre de Cristo Formation.

The Alamitos consists of interbedded sandstones, siltstones, limestones, and shales; lithology is similar to the underlying Flechado Formation. Individual beds are clearly traceable for several miles; the limestones and numerous sandstones are the most prominent layers.

The contact between the Alamitos Formation and the overlying Sangre de Cristo Formation is transitional and is placed at the first red bed. Thickness ranges between 4,300 and 4,500 ft.

PERMIAN-PENNSYLVANIAN—The *Sangre de Cristo Formation,* partially concealed by valley fill as well as Tertiary volcanic rocks, crops out south of Saladon Creek fault and conformably overlies the Pennsylvanian sediments. Several boreholes penetrated parts of the Sangre de Cristo, intersecting conglomerates, sandstones, sandy siltstones, and micaceous clayey shales.

The conglomerates are light gray to brownish gray, very sandy, and contain very fine to coarse-grained pebbles of Precambrian quartzite, schist, and granite gneiss as well as Pennsylvanian limestone and sandstone pebbles. Beds are lenticular channel fillings ranging from 5 to 40 ft wide and from 3 to 20 ft thick, forming isolated prominent outcrops on steep hillsides.

The thick- to very thin bedded and locally flaggy to fissile sandstones are light gray to magenta to brown, very coarse to fine grained, arkosic to feldspathic, slightly micaceous, and locally conglomeratic, silty, and shaly. The siltstones are gray and greenish gray to red brown and maroon, slightly sandy to sandy, slightly micaceous to micaceous, and slightly calcareous. They are thin bedded to fissile and contain brownish- gray to bright, blood-red, lenticular nodular, micritic limestone beds. The siltstones form very poor outcrops and are exposed only in roadcuts and some stream cuts.

The shales are green gray to brownish red and magenta, slightly micaceous to micaceous, and are fissile to thin bedded. They form slopes without outcrops. The shale beds appear to be extremely variable and grade laterally into siltstone and sandstone. Fresh exposures of shale are found only in roadcuts. Lateral variability is the rule rather than the exception; individual beds are difficult to trace for any distance. In some horizons the change from one rock type to another occurs over several hundred to several thousand feet. The exposed thickness of the Sangre de Cristo Formation is approximately 3,400 ft.

TRIASSIC—Rocks of Triassic age crop out in the northern part of the basin on the north bank of American Creek and may occur as isolated outcrops at a few localities north of American Creek, probably overlying Permian rocks. The only beds exposed are correlated with the *Santa Rosa Sandstone* (Upper Triassic) and consist of interbedded light-gray limestone pebble conglomerates and buff to yellow-gray sandstone. The limestone pebble conglomerates are light gray to gray, crossbedded, with rounded, worn pebbles of limestone and shale in a matrix of very slightly sandy, sparry limestone. Thickness ranges from 18 to 21 ft.

The sandstones are buff to yellow gray, crossbedded, coarse to fine grained, slightly calcareous, feldspathic and are locally flaggy. Thickness ranges from 5 to 22 ft. The Santa Rosa is approximately 65 ft thick where exposed.

CENOZOIC—Rocks of Cenozoic age include:

1) A volcanic sequence of Pliocene (?) age.

2) Valley-fill deposits whose age is indeterminate, but post-volcanic.

3) Alluvium of Holocene age.

The *volcanic rocks* include basalt flows and an ash-flow crystal tuff. The flows cover much of the highland area east of the valley and overlie both the Sangre de Cristo Formation and the Precambrian. Agua Fria Peak is probably a vent or near a vent inasmuch as the topographic position of the basalt suggests that the basaltic lava flowed away from the peak, probably reaching as far as Ocate Mesa.

The ash-flow tuff is a white to light-gray, unwelded to slightly welded, lithic crystal tuff composed of sanidine crystals and biotite fragments in a glass matrix with occasional quartz grains. The biotite flakes give the tuff a salt-and-pepper appearance; the biotite content increases from north to south. In the southeast corner of the basin, the tuff contains lithic fragments of Precambrian granite gneiss and purple sandstone of the Sangre de Cristo Formation. The ash-flow tuff is locally 1,000 ft thick.

The basalt flows are black, hard, dense, and vesicular, with aggregates of olivine, magnetite, and biotite. Feldspars are not apparent in specimens examined under a hand lens. The basalts flow from the crest of Agua Fria Peak in all directions and form a basalt-capped mesa between West Agua Fria Creek and Saladon Creek. The combined thickness of the basalt flows averages 900 ft.

The *valley-fill* deposits include a variety of sediments that have accumulated in structural and topographic depressions. Beds or lenses of clay, silt, sand, and gravel are intimately interbedded. Clays are light brown to gray, slightly sandy and occasionally gravelly. Silts are gray to gray brown, slightly micaceous, slightly feldspathic, and are the least common of the fill materials. Sands are gray to brown, fine to very coarse grained, with variable matrix. Individual grains are quartz and fragments of feldspar, basalt, granite gneiss, and limestone. Gravels are light brown to gray brown and consist of pebbles of quartzite, granite gneiss, schist, limestone, sandstone, basalt, crystal tuff, and occasional pieces of siltstone and pegmatite. Thickness of the valley fill deposits ranges to more than 420 ft.

Alluvium consists of sand, silt, and gravel that forms stream-bed deposits as well as bar deposits along the banks of the present drainages. Sands are medium to coarse grained and silty; gravels contain medium-sized pebbles and are sandy; silts are slightly sandy and slightly clayey. Lithologies of the pebbles in the gravels are similar to those of the valley fill because of stream erosion of the nearby valley-fill terraces. Alluvium has a maximum thickness of about 15 ft.

Structural geology

The Sangre de Cristo Mountains are broadly arched with a slight asymmetry to the east; the western boundary of the mountains is defined by normal faulting and some tear faulting that brings older rocks into contact with Tertiary volcanics and valley fill of the Rio Grande rift. The eastern edge is marked by reverse faulting, low-angle thrust faulting, normal faulting, and folding. The Moreno Valley covers an area near the eastern flank of the Sangre de Cristo Mountains within a zone of considerable structural complexity. Volcanism in the Red River area extends southward along portions of the easternmost ridges of the Sangre de Cristo Mountains, concealing parts of the complex structure (Clark, 1966).

PRECAMBRIAN DEFORMATION—Weakly foliated granite gneiss and an incomplete sequence of folded metasediments provide evidence of Precambrian deformation in the basin. Relict bedding in the metasediments is parallel to the foliation of the granite gneiss; a north-northwest strike with a northeast dip is the usual orientation, although marked di-

(continued on page 13)

that drive the thermal transport processes within coal blocks. Mass transfer is initially limited by the relatively low permeability of the naturally occurring material. Pore geometries in coal suggest that mass transfer channels are near 50 nm. These pores are typically filled by absorbed moisture; moisture removal changes permeability by $10^{2.5}$. Once moisture is removed, other absorbed gases, CH_4, CO_2, etc., flush from the interior volume. These combined gases, during the drying steps, control preliminary heat transfer. Modeling studies suggest that heat transfer mechanisms switch from conduction to convection as permeability is changed from 0.01 md to 5 md, those variations in mass transfer resistance formed during coal drying. Results that predict heat transfer rates in blocks of subbituminous coals during the initial drying stages of in situ processing are described. (ERA citation 03:042119)

ELECTRICITY FROM HOT DRY ROCK GEOTHERMAL ENERGY: TECHNICAL AND ECONOMIC ISSUES, *by J. W. Tester, G. E. Morris, R. G. Cummings, and R. L. Bivins, Los Alamos Scientific Lab., NM, 1979, 27 p.* **LA-7603-MS** *Price code: PC A03/MF A01*

Extraction of energy from hot dry rock would make available a nearly unlimited energy source. Some technical problems and possible economic tradeoffs involved in a power generating system are examined and possible solutions proposed. An intertemporal optimization computer model of electricity production from a hot dry rock geothermal source has been constructed. Effects of reservoir degradation, variable fluid flow rate, and drilling operations are examined to determine optimal strategies for reservoir management and necessary conditions for economic feasibility. (ERA citation 04:029813)

TIME DOMAIN SURVEY OF THE LOS ALAMOS REGION, NEW MEXICO, *by Williston, McNeil and Associates, Inc., Lakewood, CO, 1979, 52 p.* **LA-7657-MS** *Price code: PC A04/MF A01*

A time domain electromagnetic sounding survey of the region surrounding the city of Los Alamos, New Mexico, was carried out. Results show that a linear trough, trending northeast-southwest runs beneath the city. The southern boundary is somewhat to the south of the city, the northern boundary was not established. The geoelectric section consists of three layers; the total thickness of the section is in excess of 3,000 m. Resistivities of the second layer are as low as 2.5 omega m. If the salinities are in the region of 7,000 ppm, the resistivities could indicate that water with a temperature of 150°C may be found at a depth of 3,000 m. (ERA citation 04: 029773)

DATA ACQUISITION FOR THE HOT DRY ROCK GEOTHERMAL ENERGY PROJECT, *by R. G. Lawton and E. H. Horton, Los Alamos Scientific Lab., NM, 1979, 7 p. CONF-790505-2* **LA-UR-79-812** *Price code: PC A02/MF A01*

The data acquisition system for the Hot Dry Rock Geothermal Energy Project at Fenton Hill, in northern New Mexico, has evolved to a computer-controlled system complete with visual displays and emergency alarms. The system is comprised of two units. One unit monitors all surface facilities and during an energy extraction experiment is on-line 24 hours a day. The other system is used for specialized downhole experiments. The data acquisition system is operator oriented so that a minimum crew can maintain the system. (ERA citation 04:036208)

GEOTHERMAL STUDIES IN SOUTHWEST NEW MEXICO, *by Chandler A. Swanberg, New Mexico Energy Institute, Las Cruces, NM, 1976, 69 p. NMEI-3* **PB-295 836/1WE** *Price code: PC A04/MF A01*

The research consists of three parts: (1) a detailed water chemistry study of thermal and nonthermal waters in Doña Ana County, (2) a reconnaissance water chemistry study of the hot springs of southwest New Mexico, and (3) a detailed gravity and magnetic study of the Lightning Dock KGRA (Known Geothermal Resource Area) in the Animas Valley of southwest New Mexico.

GEOTHERMAL APPLICATION FEASIBILITY STUDY FOR THE NEW MEXICO STATE UNIVERSITY CAMPUS, *by Narendra N. Gunaji, Edward F. Thode, Lokehs Chaturvedi, Arun Walvekar, and Leo LaFrance, New Mexico Energy Institute, Las Cruces, NM, 1978, 127 p., NMEI-13* **PB-295 846/OWE** *Price code: PC A07/MF A01*

The present project exploring the use of geothermal energy on campus was prompted by the belief, based on geochemical survey, that a substantial geothermal resource exists on NMSU property, not far from the main campus. The purpose of the project was to better define the potential resource and to examine alternatives for its use from a technical-economic standpoint.

AN APPRAISAL STUDY OF THE GEOTHERMAL RESOURCES OF ARIZONA AND ADJACENT AREAS IN NEW MEXICO AND UTAH AND THEIR VALUE FOR DESALINATION AND OTHER USES, *by Chandler A. Swanberg, Paul Morgan, Charles H. Stoyer, and James C. Witcher, New Mexico Energy Institute, Las Cruces, NM, 1977, 98 p. NMEI-6-1* **PB-295 859/3WE** *Price code: PC A05/MF A01*

This report is an appraisal investigation of the geothermal resources of a portion of the Lower Colorado River Region of the U.S. Bureau of Reclamation. The study area includes most of Arizona, part of western New Mexico west of the continental divide, and a small part of southwestern Utah. Almost 300 water samples have been collected from the study area and chemically analyzed.

GEOTECHNICAL STUDIES OF GEOTHERMAL RESERVOIRS, *by H. R. Pratt and E. R. Simonson, Terra Tek, Inc., Salt Lake City, UT, 1976, 56 p. Microfiche copies only.* **TID-28703** *Price code: MF A01*

It is proposed to delineate the important factors in the geothermal environment that will affect drilling. The geologic environment of the particular areas of interest are described, including rock types, geologic structure, and other important parameters that help describe the reservoir and overlying caprock. The geologic environment and reservoir characteristics of several geothermal areas were studied, and drill cuttings were obtained from most of the areas. The geothermal areas studied were: (1) Geysers, CA, (2) Imperial Valley, CA, (3) Roosevelt Hot Springs, UT, (4) Baca Ranch, Valle Grande, NM, (5) Jemez Caldera, NM, (6) Raft River, ID, and (7) Marysville, MT. (ERA citation 04:029819)

Cieneguilla Creek

(continued from page 3)

vergences occur where metasediments are strongly folded.

Exposures are poor and age relationships are obscure although most data suggest invasion of the metasediments by the granite prior to the last Precambrian metamorphism. The age of the Precambrian rock deformation in the Picuris area southwest of Moreno Valley is estimated at 1.3 b.y. (billion years) by Miller and others (1963); several Precambrian events in the Sangre de Cristo Mountains are dated between 800 million and 1.7 b.y. (Callendar, Robertson, and Brookins, 1976). Precambrian exposures in the basin are limited and geochronology has not been done. Of the several dated events above, it is impossible to determine which may be represented by the Cieneguilla Creek Precambrian rock sequence; at least two are present.

MESOZOIC-CENOZOIC DEFORMATION—Deformation began with the Laramide Orogeny in latest Mesozoic time and continued intermittently throughout the Cenozoic. Initially, broad open folding of late Paleozoic and Mesozoic sediments was the principal deformational pattern. As east-west compression increased, faulting became more pronounced and high-angle reverse and low-angle thrust faults were formed. During Cenozoic time normal faulting with north-south as well as northwest-southeast and northeast-southwest trends was dominant. The southern end of the basin exhibits the most complex deformation (fig. 1).

FOLDING—Folding is not pronounced. Anticlines and synclines east of Cieneguilla Creek are broad, open folds with minimum relief; the anticlines and synclines are minor flexures in the Moreno Valley synclinorium, as suggested by Ray and Smith (1941). The synclines are filled in part by volcanics (basalt and ash-flow tuff) from Agua Fria Mountain and in part by Quaternary deposits of sand, gravel, and slope debris. Small folds associated with thrust faulting on the west side of the valley were mapped. We recognized structural terraces and overturned bedding in several places, but tracing structures along strike is difficult due to excessive tree cover and forest litter. Some structural features can be traced because of street development in the Angel Fire properties area.

FAULTING—Faulting in the southern part of Cieneguilla Creek drainage basin is intense. Three types are evident: the oldest, high-angle reverse or low-angle thrust faults; intermediate age normal faults, and younger transverse faults.

High-angle and low-angle reverse faults are confined to a 1½- to 2-mile-wide zone in the southwestern part of the basin. The zone strikes in a northerly direction and is partially concealed by valley fill (fig. 2). Clark (1966) recognized similar structures in the same relative position north of the basin. In addition, a complex structural zone between Mora and Las Vegas may be a similar southern continuation.

Normal faults are best exposed in the eastern half of the valley. Previous work north of the basin by Clark (1966) and geophysical evidence obtained from seismic reflection lines run by Charles Reynolds and Associates, Inc. (1978) suggest normal faulting is present throughout the valley rather than being confined to a particular area. The normal faults strike in a northerly direction similar to the older reverse or thrust faults.

Transverse faults strike transversely across the valley either west-northwest or east-northeast, and are found throughout the drainage basin; they disappear along the southern boundary of the mapped area. Their movements are usually normal, but they differ

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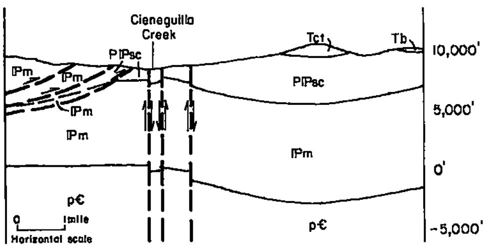

FIGURE 2—GEOLOGIC CROSS SECTION A–B ACROSS CIENEGUILLA CREEK.

from the northerly striking normal faults in that relative movement is not exclusively dip slip. The net slip is a different direction and magnitude for each fault. Interrelationships of these fault types contribute to the shape and size of the basin.

REVERSE FAULTS—High-angle reverse faults predominate although a few low-angle thrust faults have been mapped. Older Pennsylvanian and Mississippian marine sedimentary rocks are thrust over younger Pennsylvanian marine and Permian-Pennsylvanian continental sedimentary rocks (fig. 2). The faults dip 45° to 65° west.

Stratigraphic throws on individual faults range from several tens of feet to several hundreds of feet. Throws of several thousand feet have been estimated north of the map area by Clark (1966). We cannot confirm such displacements in the Cieneguilla Creek area because of lack of outcrops, although fault traces are visible on low-altitude air photos or on oblique color photos of the west side of the valley taken from mountains on the east side. We inferred the position of some thrust faults by examining the western side of the valley and noting changes in soil color associated with changes in topography. Seismic reflection lines by Charles Reynolds and Associates, Inc. yield data in good agreement with the inferred fault positions. We calculated an apparent stratigraphic displacement of 1,000 ft for one inferred fault. Topography and geophysical data suggest a substantial breccia zone along the slippage plane.

A thrust fault exposed along road cuts in Palo Flechado Pass reveals a considerable amount of brecciation as well as overturning of brittle limestone and calc-argillite beds. Similar brecciation and overturning of beds occurs in several places along the southwestern side of the basin.

NORMAL FAULTS—Normal faults are high angle (dips >70°). Most common in the eastern half of the valley, their abundance and steplike pattern result in slumping of portions of the basalt flows. Geophysical evidence suggests that normal faults are widely distributed throughout the valley rather than being confined to either side. Many of these faults are obscured by valley fill, landslide, or talus, although Clark (1966) reports faults cutting valley fill north of the map area.

The normal faults strike northeast and north-northeast nearly parallel to the thrust fault zones found in the western half of the valley. Seismic reflection data suggest that some normal faults may offset the thrust faults. Clark (1966) noted that the principal trend directions for normal faulting north of the basin are east-northeast and north-northeast—closely paralleling observed trends in the basin proper.

Stratigraphic throws along the normal faults range from a few tens of feet to several hundreds of feet. Normal faults cut both folds and reverse faults along the western side of the basin as well as slightly deformed to undeformed strata in the central and eastern part.

Displacement along the normal faults causes oversteepening of the valley walls resulting in large and small landslide failures and large slump blocks that obscure the bedrock relations. Seismic reflection data and test drilling verify the landslide block interpretation.

Throw on individual normal faults is difficult to assess due to slumping of the faulted beds and extreme lateral variability in the Sangre de Cristo Formation where normal faulting is best exposed. Clark (1966) reports vertical displacements from a few feet to as high as 9,000 ft on the eastern side of the Moreno Valley north of the basin. Seismic reflection data suggest displacements of a few feet to several hundred feet in the southern part of the map area. Major displacements of 5,000 ft or more have not been demonstrated on the normal faults although a displacement of twice that magnitude is calculated for one of the transverse faults.

A number of normal faults are continuous for several miles along their strike. One such fault is cut off by the Saladon Creek fault in the northern part of the map area (fig. 1). Inadequate outcrops and lack of key horizons prevent identification of the normal faults within the Precambrian basement rock; thus their relation to earlier structures is unknown. The broad outlines of the valley are related to normal faulting in the late Tertiary.

Normal faulting and its associated slumping create pervious channels and impervious barriers. Springs and bogs occur in the areas of greatest disturbance—usually within several tens of feet of the surface trace of the fault and/or near the toe of a slump block. In most cases where a slump is associated with a fault, springs are found near the fault rather than at the toe of the slump block. Normal faulting and slumping are responsible for the locations of nearly all springs in the basin. The majority of the springs are in the southernmost part of the map area and drain into several of the tributaries of Cieneguilla Creek.

TRANSVERSE FAULTS—High-angle transverse faults cut the valley in three directions; northwest-southeast and northeast-southwest strikes are the most common, while an east-west strike occasionally occurs in the southernmost part of the valley. The faults offset the valley margins, creating a zigzag pattern. Dips of the transverse faults approach 90° as determined by surface trends and geophysical data.

The transverse faults have pronounced stratigraphic throws; the Saladon Creek fault brings Precambrian basement into contact with the Permian-Pennsylvanian Sangre de Cristo. This juxtaposition represents a stratigraphic throw of 10,000–12,000 ft. Other such faults have displacements from several tens of feet to several hundreds of feet.

The transverse faults are well defined and may be traced for several tens of miles before being intersected by another fault or having magma intruded along them during a post-faulting period of volcanism.

The transverse faults are the youngest of the faulting events, cutting both the thrust faults and the normal faults. The transverse faults exert a pronounced control on tributary drainage patterns to Cieneguilla Creek, more so than the normal faulting or thrust faulting. Some springs are located along the strikes of the transverse faults, but only where such a fault intersects either a normal fault or a thrust fault.

Geologic history

The earliest events recorded in the basin are the deposition of large quantities of quartzose and feldspathic sandstones, and interbedded shales and siltstones during middle Precambrian time. The provenance of these sediments is unknown and exposures are so limited that their source direction is indeterminate.

Following the accumulation of the sediments, regional stresses resulted in a widespread, intense orogeny. Activity probably began between 1.3 and 1.7 b.y. ago and continued nearly to the end of the Precambrian. This period of deformation produced a metamorphic grain which remains recognizable today.

The metamorphism changed the quartzose and feldspathic sandstones to micaceous quartzite and pure quartzite; converted the siltstones to gneissic quartzite; and the shales to sillimanite and ferro-tremolite mica schist. Similar lithologic types are described by Clark (1966) in the region north of the mapped area. During this orogenic event, granite was intruded into the metasediments, creating zones of migmatite along the contacts. Continuing stress after intrusion imparted a mild foliation to the granite parallel to relict bedding in the metasediments.

Evidence for early Paleozoic deposition, uplift, and erosion is not present, but by earliest Mississippian time a broad surface had been cut across the old Precambrian terrain, allowing deposition of a shallow marine limestone sequence. Subsequently, the Mississippian limestone was partially dissolved, producing caverns and a karst topography. Intermittent and irregular deposition of clastic debris on the karst surface created a series of complex depositional episodes toward the end of the Mississippian.

Latest Mississippian or earliest Pennsylvanian time is marked by an orogenic event that produced numerous narrow mountain chains and adjacent deep basins in Colorado and northern New Mexico. The Uncompahgre-San Luis element of the ancestral Rocky Mountains supplied detritus to the Pennsylvanian Rowe-Mora Basin, which includes the present Cieneguilla Creek drainage. Depositional environments were fairly shallow and rapidly subsiding, allowing considerable thicknesses of strata to accumulate during the Pennsylvanian. Abundant fauna preserved in the Rowe-Mora Basin indicates ages from Morrowan (Lower Pennsylvanian) to Upper Des Moinesian (middle Upper Pennsylvanian). As deposition continued into late Pennsylvanian, the shoreline gradually moved eastward toward the center of the basin; however deposition of continental strata continued without cessation from Upper Pennsylvanian through Permian. Several hundreds to thousands of feet of fluvial sands, silts, shales, and gravels with some isolated lacustrine and lagoonal limestone deposits were deposited throughout most of the Permian. Near the end of the Permian, deposition ceased and erosion of the continental deposits began. This hiatus extended through latest Permian and lowermost Triassic.

The first Mesozoic deposits (Upper Triassic) consist of sandstones, interbedded limestone pebble conglomerates, and red-brown shales; much of the material is derived from the underlying Pennsylvanian and Permian strata (Clark 1966). Intermittent erosion and deposition are reflected by disconformities that separate Upper Permian from Triassic, and Triassic from Jurassic rocks. Upper Jurassic beds are, in turn, separated from the *Dakota Formation* (Lower Cretaceous) by disconformity indicating a brief period of nondeposition and erosion prior to the Cretaceous marine transgression.

Cycles of marine transgressions and regressions accumulated a considerable thickness of black shale with some limestone beds in the Raton Basin, north and east of the map area. Toward the end of the Late Cretaceous, local uplifts, possible forerunners of the Laramide Orogeny, expanded the areas of the transgressive and regressive cycles, resulting in interbedded black shales and gray to buff channel sandstones. Finally, the sea withdrew entirely, depositing the Trinidad Sandstone as the last regressive unit.

The Laramide folding and upwarping that marked the end of Cretaceous time strongly compressed the basin into a series of west-dipping thrusts and folds. As the orogeny subsided during the Eocene, erosion accumulated coarse clastics in parts of the southern Cieneguilla Creek drainage basin. Sometime during the Oligocene a great period of volcanism and intrusion began, extending through the Miocene and into the Pliocene. Numerous stocks and batholiths were intruded and basalt, rhyolite, and andesite flows as well as tuffaceous materials were erupted to the north, east, and southwest of the mapped area. Normal and transverse faulting concurrently formed the Rio Grande depression to the west and displaced the earlier thrust and reverse faulting in the Cieneguilla Creek drainage basin. Locally, Precambrian rocks were exposed by the faulting, their erosion contributing to the thicknesses of alluvial fill.

Late in Pliocene time, basalt flows formed the resistant peaks of Agua Fria Mountain as well as extensive cover over adjacent areas; Ocate Mesa and numerous smaller lobes are remnants of this former flow sheet. During this time, the Cieneguilla Creek drainage was part of the south-flowing Coyote Creek system.

During the Pleistocene, headward erosion of Cimarron Creek disrupted the upper Coyote Creek drainage pattern. Cimarron Creek captured the flow of upper Coyote Creek, diverting it northward to form the present basin. Three periods of stability during the lowering of base level for Cieneguilla Creek created terrace levels which can still be identified in the Cieneguilla Creek drainage.

Clark (1966) reported Pleistocene glacial deposition north of the mapped area around Wheeler Peak. Glaciation may have contributed to the sedimentation history of the northern half of the Moreno Valley (Clark, 1966). Evidence of glacial activity is not discernible in the basin. The present basin is the result of continued adjustment to the base level of Cieneguilla Creek and the drainage system of the Cimarron River.

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An occurrence of red beryl in the Black Range, New Mexico

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A locality for red beryl in rhyolite was found on May 23, 1979 by P. E. Haynes while prospecting for the Virgin Mining Company. The locality, on the west side of the Black Range in the Gila National Forest of northwestern Sierra County, New Mexico, has been named the Beryllium Virgin prospect.

General geology and structure

The rocks in the region, mid-Tertiary or younger, are comprised of rhyolite, basalt flows, and clastic sediments. Of primary interest are extensive outcrops of flow-layered, purple-brown to pink, porphyritic rhyolite. Phenocrysts are abundant, accounting for about 40 percent of the rock. One to three percent of the rhyolite consists of vesicles which, in part, are lined with several oxide and silicate minerals, including beryl (Fries and others, 1942; Lufkin, 1972).

The porphyritic rhyolite is cut by numerous north-trending fissures; rocks adjacent to the fissures are highly fractured. These fissures and fracture zones provided a channel for escaping vapors during the cooling of the lava. These gaseous emanations were responsible for much of the mineralization in the area.

The Beryllium Virgin prospect, in sec. 22, T. 10 S., R. 11 W., Sierra County, New Mexico, has at least two distinct north-trending fracture zones. Both are mineralized and run parallel to one another; each has its own distinct mineral assemblage.

Mineralogy

Red beryl occurs in the fracture zone on the east side of the mining claim. A more highly mineralized zone, devoid of beryl, lies on the western side of the claim. Adjacent to this zone are veins of massive hematite that contain crystalline grains of bixbyite and cassiterite. The following descriptions cover the characteristics and associations of the different minerals of interest found at the Beryllium Virgin prospect.

BERYL—$Be_3Al_2(Si_6O_{18})$—The red beryl from the Black Range of New Mexico is the third known source for red beryl found in rhyolite. Specimens from two other localities, the Thomas Range and the Wah Wah Mountains in Utah, have larger, more colorful, and more abundant crystals. Microprobe analysis of the Utah crystals (Nassau and Wood, 1968)

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