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Introduction and history

Five miles northwest of Las Vegas, New Mexico, in the eastern foothills of the southern Rocky Mountains, the east-flowing Gallinas River cuts a water gap through the Dakota Sandstone hogback, locally known as the Creston. The village of Montezuma, built on a Gallinas River terrace, lies immediately west of the water gap. The Montezuma Hot Springs rise a half-mile west, upstream from the Montezuma post office. The area studied covers the Gallinas valley from the post office upstream to the village of Hot Springs and the tributary valleys of the Gallinas entering from the south and north. The hot springs were known to early Indian tribes who roamed the east slope of the Rocky Mountains, and the area was considered a treaty zone where even hostile tribes could meet in friendship and peace. According to nomadic Indian legend, the Mexican Indian chief Montezuma bathed here (Las Vegas Daily Optic, 1885).

When the opening of the Santa Fe trail brought settlers and merchants west, the Donaldson brothers acquired the lower Gallinas Canyon through a grant from the Mexican Government in 1840, and proceeded to build a six-tub bathhouse on the site. In 1846 General Kearney had a 30-by-100 ft adobe hospital constructed at the springs to care for his ailing troops. The hospital was in use until 1862. About this time, several other bathhouses were constructed.

After 1852 the hot springs changed hands many times, selling at prices ranging from \$300 in 1852 to \$102,000 in 1879 when controlling interest was bought by the Santa Fe Railway. The Hot Springs Company, an eastern consortium, walled in twenty of the fifty-odd springs and piped the hot water into a spacious \$18,000 bathhouse. Because of Santa Fe Railway tourist promotions, and the popularity of public bathing enjoyed at that time, the new bathhouse was a resounding success. There were tub, mud, vapor, and medicated baths priced from 50¢ to \$1.00 (see fig. 1 for an indication of the grandeur of the area in 1882). During this time the Santa Fe Railway ran a spur line past Montezuma to the six ice ponds that supplied refrigerator-car ice for vegetables in transit from California to the eastern markets. The same trains also brought passengers to the hotels at Montezuma.

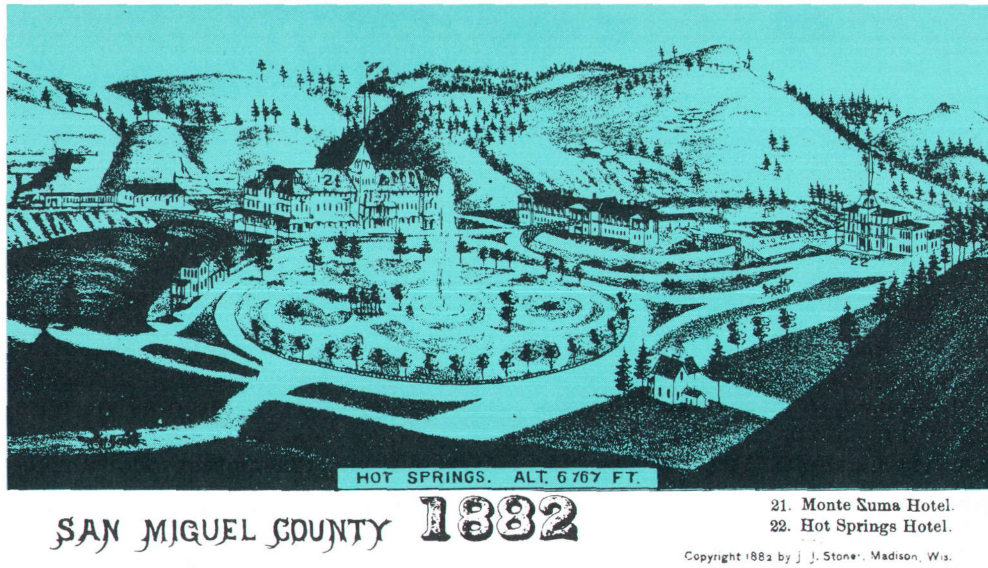


FIGURE 1—MONTEZUMA, NM (FORMERLY CALLED HOT SPRINGS), 1882.

In 1903 declining profits forced the bathhouses to close, and in 1904 a Gallinas River flood broke six ice-pond dams upstream, destroying the bathhouses (Reinerts, 1966). Only a ruined swimming pool remained at the flooded area. Of all the splendid bathing facilities, only a lone cobblestone bathhouse built at a later date still stands—although it has been stripped of its water pipes.

On the slope north of the springs the abandoned Montezuma Hotel still stands, surrounded by modern dormitories built between 1964 and 1971. This area has a unique history: In 1913 the Santa Fe Railway deeded the hot spring area to the Las Vegas YMCA, which, in turn, sold the property in 1920 to a Baptist group who operated a college there from 1922 to 1932. In 1937 the Baptists sold the property to the Committee of North American Bishops of the Roman Catholic Church, who built the dormitories and converted the hotel into a seminary for Mexican novices. The seminary was closed in 1972, and has remained closed except for a brief moment of glory as a motion-picture set (The Evil, 1977), and a stint as La Raza Unida's short-lived school during the winter of 1973-74.

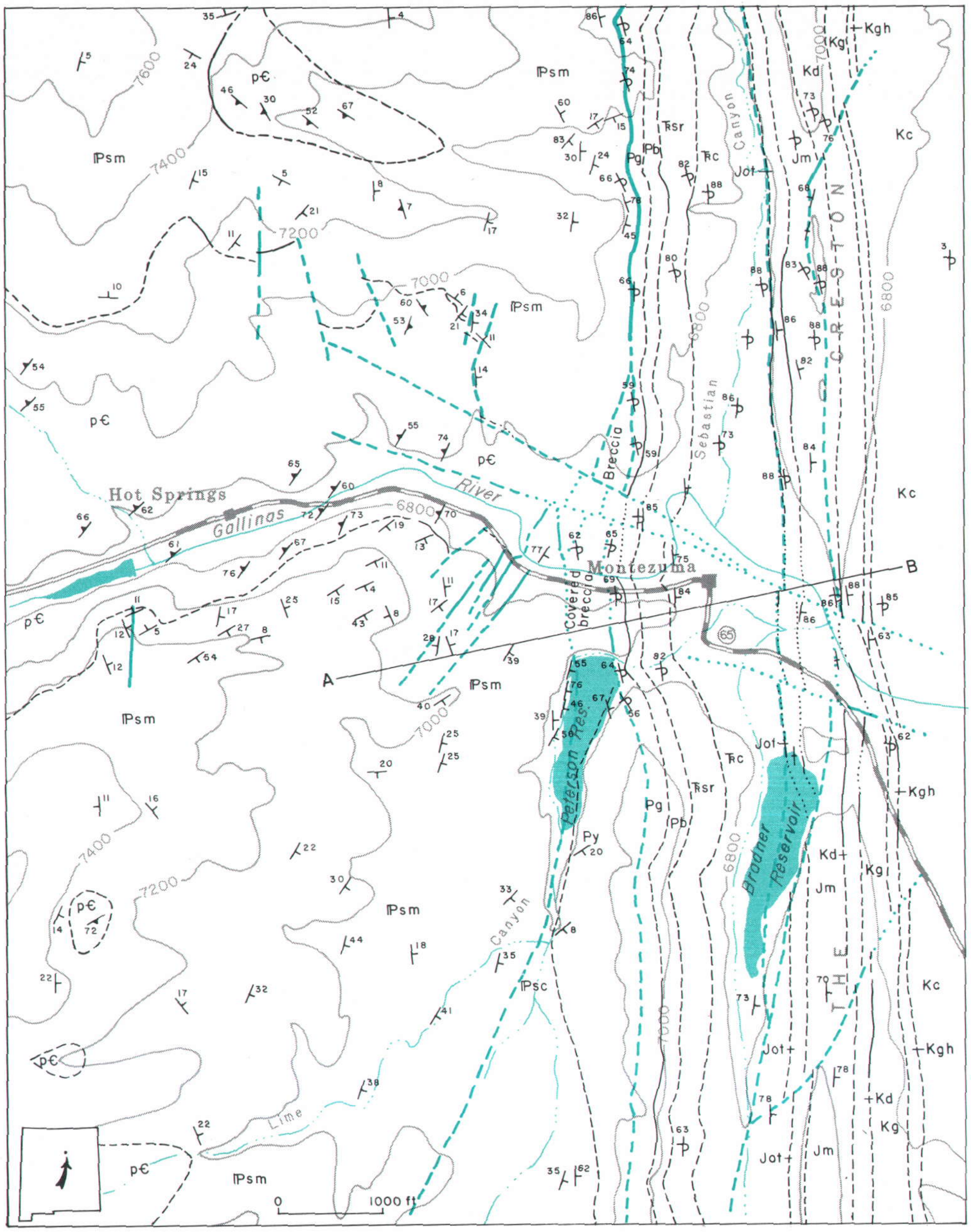
Structure

The location of the hot springs is determined by the spectacular geology of the area. An abbreviated stratigraphic column appears in table 1. The geologic map (fig. 2) indicates the general geology and the location of the geologic cross section (fig. 3). An interpretation of the general geology of the area has been proposed by Baltz (1972).

The outstanding structure in this area is the north-south trending Las Vegas syncline, whose axis is approximately a mile east of the area mapped (fig. 4). The eastern part of the area (fig. 2) represents the vertical-to-overturned west flank of the Las Vegas syncline. The most easterly prominent north-south hogback is an outcrop of resistant Dakota Sandstone and Morrison Formation (the Creston). West of the Creston the sequence of older rocks creates valleys or hogbacks, depending upon their resistance to erosion and the amount of brecciation due to faulting that has occurred (See figs. 2 and 3.)

Sebastian Canyon and Bradner Reservoir are strike valleys in the Chinle Formation. The next prominent hogback to the west has very resistant orthoquartzite of the Glorieta Sandstone as its spine.

The low area occupied by Peterson Reservoir was less resistant to erosion due to a 300-ft wide breccia zone developed along a 2,000-ft-throw reverse fault that brings Pennsylvanian limestone on the west in contact with Glorieta Sandstone (Permian) on the east. This zone, referred to as the Peterson Reservoir breccia zone,



Base from USGS

FIGURE 2—GEOLOGIC MAP OF THE MONTEZUMA AREA. Section A-B in fig. 3; geologic units shown in table 1. Contour interval 200 ft.

Contact; dashed where approximately located

Fault; dashed where approximately located; dotted where concealed; U, upthrown; D, downthrown

Strike and dip of beds

Strike of vertical beds

Strike and dip of foliation

is best observed at the Peterson Reservoir dam.

The area west of the breccia zone is composed of Precambrian rocks with a thin capping of generally east-dipping Pennsylvanian strata that contain a few minor folds and many normal faults of small displacement. Many of these features appear in figs. 2 and 3.

The suggested sequence of events that created this unusual geologic structure is shown in a series of sketches (fig. 4) believed to represent the area along the geologic cross section (fig. 3).

Hot springs

The hot springs, which are the only thermal springs in the Pecos River basin, have been studied repeatedly (Summers, 1976). They extend westward 1,500 ft along the sloping river terrace on the south bank of the Gallinas River. The surface is covered by alluvium, and slopes 8° from the high river terrace (on which NM-65 is built) down to the floodplain of the Gallinas. The springs all lie east of the village of Hot Springs.

The entire slope over which the springs flow is a bog, thickly covered with grass that remains green even in the winter months. Stagnant pools that never freeze form in the more level areas. These pools are covered with a thick layer of algae and are inhabited by numerous species of frogs, snails, and other aquatic creatures.

Eventually the hot water trickles down to the Gallinas River, but in the process, most of the heat is dissipated into the ground and air. The average temperature of the hottest water issuing from the springs is 56° C (Bejnar, 1967) and an average chemical analysis of the water in parts per million is as follows (Summers, 1965): Ca 7.9, Mg 2.2, Na 168, K 168, HCO_3 79, CO_3 15, SO_4 50, Cl 157, F 20, NO_3 0.1, and total solids 534. The water exudes both the taste and the stench of hydrogen sulfide (rotten eggs).

Rain and melting snow on the high Sangre de Cristo Mountains to the west percolate as ground water through the joints, faults, and permeable rocks to gradually work their way downward to lower country by gravity. As these waters move eastward, they percolate to considerable depth until they encounter the wide Peterson Reservoir fault breccia zone. The breccia contains much rock material that has been pulverized to fine, clay-sized particles—thus it is practically impermeable to the continued eastward movement of the ground water. As this effective dam stretches at least 3 mi north and 5 mi south of Montezuma, it holds back a large volume of water. Topographically, Gallinas Canyon is the lowest area behind the dam; therefore the backed-up water moves, due to hydrostatic head, to the surface along joints and faults in the older rocks, and seeps to the surface through the alluvium.

There are three possible sources of heat: The most likely source is the presence of a slightly higher than normal geothermal gradient. This natural heat increase with depth is normally about 1° C/100 ft, but in volcanics or folded and faulted areas, the gradient may be up to 10 times as great. As the area to the west of the hot springs has been folded and faulted, it is reasonable to assume that there is enough geothermal heat to increase the local geothermal gradient to 4° C/100 ft. Assuming an annual average surface water temperature of 12° C added to this gradient, the ground water would need to percolate to a depth of only 1,100 ft to reach the hot-springs temperature of 56° C. The elevation of the hot springs is 6,740 ft, whereas the mountains immediately to the west rise to 10,470 ft. The difference of 3,730 ft would permit the ground water to percolate to a depth of at

TABLE 1—ABBREVIATED STRATIGRAPHIC COLUMN AT MONTEZUMA, NEW MEXICO. Geologic symbols are those used in figs. 2 and 3.

PERIOD	FORMATION	DESCRIPTION	THICKNESS (FT)
QUATERNARY AND TERTIARY	Pediment and river gravels	Mixture of Precambrian and younger sedimentary rock clasts	40 max.
	Carlisle Shale **(Kc)**	Mostly dark-gray shale with sparse yellow-brown sandstone beds in upper half of formation	400
CRETACEOUS	Greenhorn Limestone **(Kgh)**	Alternating beds of medium-gray limestone with olive-gray shale	63
	Graneros Shale **(Kg)**	Medium-dark-gray shale with calcareous cement	225
	Dakota Sandstone **(Kd)**	Three units: Lower, pale-grayish-orange to very light gray sandstone, conglomeratic to fine grained, locally crossbedded. Middle, dark-gray carbonaceous shale. Upper, grayish-yellow to grayish-olive sandstone including coaly fragments	103
JURASSIC	Morrison Formation **(Jm)**	Upper half, grayish-olive shale. Lower half, grayish-orange-pink, medium-grained sandstone alternating with thinner beds of siltstone and shale	415
	Todilto Limestone **(Jot)**	Medium-dark-gray, thin-bedded limestone interbedded with thin greenish-gray beds of siltstone and shale	20
	Ocate (Entrada) Sandstone **(Jot)**	Medium-grained grayish-yellow to pale-orange, flat to crossbedded, friable sandstone	127
TRIASSIC	Chinle Formation **(TRc)**	Various shades of red siltstone ranging from medium red to grayish red, with alternating pale-olive to pale-red sandstones and conglomerates	1202
	Santa Rosa Formation **(TRs)**	Pale-reddish-brown to yellowish-gray sandstones and conglomerates interbedded with thinner layers of pale-olive to grayish-red shale	323
PERMIAN	Bernal Formation **(Pb)**	Pale-reddish-brown, thin-bedded siltstone, shale, and sandstone interbedded	118
	San Andres Limestone **(Pg)**	Pale-yellowish-brown, dolomitic, dense limestone	6
	Glorieta Sandstone **(Pg)**	Grayish-orange, fine-to-medium-grained, bimodal, very resistant sandstone	93
	Yeso Formation **(Py)**	Faulted out in Gallinas Canyon	
PENNSYLVANIAN	Sangre de Cristo Formation **(IPsc)**	Faulted out in Gallinas Canyon	
	Madera Formation **(IPsm)**	Dark-yellowish-brown to light-olive-gray, thin-bedded, fossiliferous limestone interbedded with pale-red to yellowish-orange thinner bedded shales	137
	Sandia Formation **(IPsm)**	Light-gray to dark-gray, fine-grained to coarsely crystalline limestone interbedded with pale-olive to dark-gray shale	172
PRECAMBRIAN	Precambrian **(p€)**	Metasediments plus migmatites, pegmatites, gneisses, schists, granites, and amphibolites	2,000+

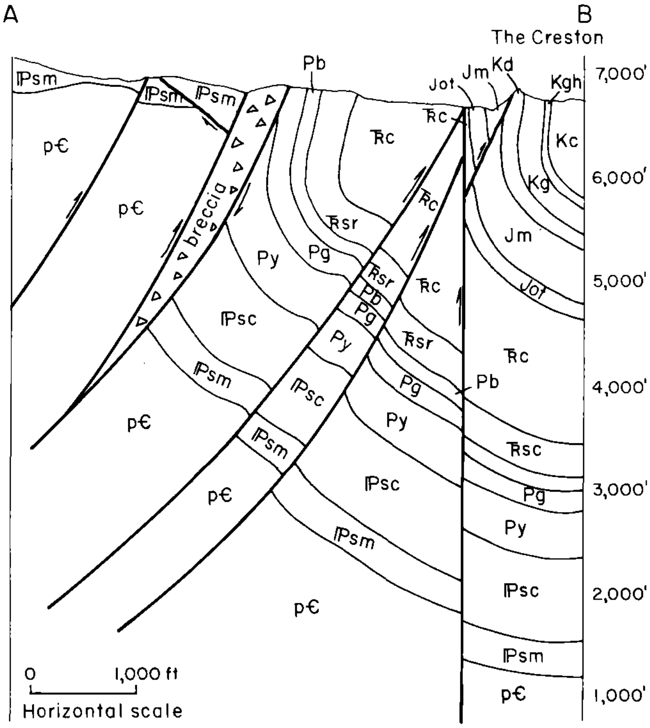


FIGURE 3—GEOLOGIC CROSS SECTION A-B ACROSS GALLINAS RIVER AT MONTEZUMA, NM. Location shown on fig. 2; geologic units in table.

least 1,100 ft and still have sufficient gradient to migrate east to the lower elevations at the hot springs, and continue east to the plains.

The relatively recent uplift of the basement rock may provide an alternative or additional source of this heat. The Precambrian rocks in the Montezuma area were deeply buried until the Laramide orogeny, and thus may retain some of their original heat. These rocks moved to the surface during the Miocene and post-Miocene rejuvenation of the Rocky Mountains, and crop out, among other places, to the west of the hot springs area. Subsurface water passing through—or adjacent to—these Precambrian rocks could have its temperature raised to 56° C.

A third possible source is related to the volcanism that has occurred in northeastern New Mexico during the last 8 m.y. Although the nearest volcanic cone is 25 mi northeast of Montezuma, several lamprophyre dikes cutting Cretaceous rocks are exposed 6 mi northeast of the hot springs. Magma, related to the volcanics, may exist near the percolation zone, heating ground water that rises due to thermal differentiation. This magma may extend under and to the west of the hot springs, and contribute significant heat to the spring water.

It is unlikely that the Montezuma Hot Springs could be developed as a geothermal source for a large electrical generation plant. For such a plan to be effective, the area would need a large volume of super-heated steam at a temperature of at least 400° F (202° C), and a pressure of 150 psi (Summers, 1968). These conditions are not present at Montezuma Hot Springs.

The springs, however, could be utilized to a much greater degree than they are at present. A roofed-over swimming pool could become a center for year-round bathing; and some of the hot water could be pumped to supply radiator heat and hot water for buildings in the ☞

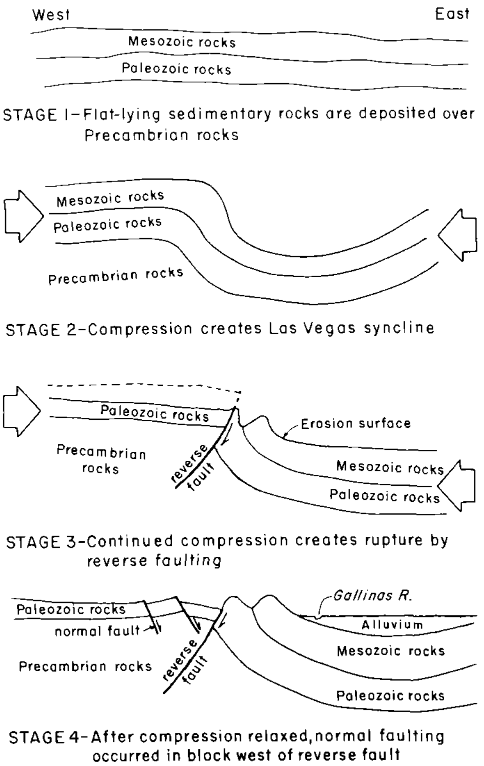


FIGURE 4—GENERALIZED SECTION TAKEN DUE EAST FROM POINT **A** OF CROSS-SECTION LINE.

vicinity. The most commercially feasible, simple enterprise would be a series of greenhouses located below the hot springs and heated year round for growing vegetables and flowers.

A more complicated, industrial generation of electricity on a small scale might be accomplished through the use of heat engines. Apparently the temperature differential between the hot spring waters and the cold water of the Gallinas River is great enough to make heat engines economically feasible, although a substantial capital investment would be necessary for their installation.

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Mining, milling, and smelting operations in southwest New Mexico

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The ultimate goal of mining and mineral-processing operations in southwest New Mexico is the production of a relatively pure metal or nonmetallic mineral. Most metals occur in chemical combination with other elements to form minerals. These minerals are dispersed throughout generally valueless rock-forming minerals (gangue) to form ore — rock masses of sufficient size and value to be processed economically. These ore bodies occur in the surrounding rock or waste and vary in size from very high-grade ore deposits a few inches thick in some precious-metal mines to low-grade ore deposits hundreds of feet thick in porphyry copper mines. The mining process removes the ore from the surrounding waste rock; milling separates the valuable minerals from the gangue; and smelting breaks down the minerals to yield the pure metal. Various company operations use different equipment and procedures to accomplish these steps.

At present, some of the major mines, mills, and smelters in southwestern New Mexico are shut down as a result of depressed copper and zinc prices. Although significant quantities of nonmetallic minerals such as fluorspar were produced in the past, present production is limited, except for the Mathis lime plant midway between Hanover and Central.

Most of the major operators provide for some form of public access. During the summer Kennecott Copper Corporation normally conducts tours of its operations at Hurley for the general public. As a rule, given advance notice, both Kennecott and Phelps Dodge Corporation at Tyrone are able to arrange special group tours. Other operators vary in their policies regarding public tours. In addition, Phelps Dodge, Chino, and Tyrone have readily accessable public lookouts at the pits.

The potential hazards of abandoned mines are significant and many. ***Do not enter abandoned mines, pits, or workings.*** Children in all mining areas should be under careful supervision at all times.

Mining

In general, mining operations can be divided into two categories: underground and open-pit. Open-pit mining is the method of choice in areas where ore deposits occur at or near the surface. Deposits of this type occur at Santa Rita and Tyrone as large, low grade ore bodies. Underground mining methods are used to recover ore in narrow, nearly vertical veins and chutes (in the case of the Groundhog mine at Vanadium); or when the ore body is covered by too much overburden to remove economically (in the case of UV Industries). Both conditions are present in the area.

There are three major open-pit mines in the district. UV Industries at Fierro, Kennecott Copper Corporation at Santa Rita, and Phelps Dodge at Tyrone. In the pits, ore and waste are first broken by drilling holes up to 14 inches in diameter and 60 ft deep at a predetermined distance back from the edge of the bench. The holes are loaded with explosive, then blasted. The broken rock is loaded into trucks by electric shovels—some of which can move up to 25 tons at a time (fig. 1). Such shovels, at present, cost in excess of a million dollars. Trucks used in the pits have capacities from 40 to 150 tons each, and there is a trend towards even larger trucks.

With the present ore grade at Chino and Tyrone, about 3 tons of waste must be moved for each ton of ore mined. Allowing for milling and smelting losses, this means about 700 lbs of rock must be blasted, loaded, and hauled for each pound of copper produced. The Chino mine produces about 23,000 tons of ore per day, Tyrone about 46,000 tons.

Because most of the underground mines in the district have been closed down due to depressed metal prices, UV's Continental Mine at Fierro is currently the only one of its kind in operation. ASARCO's (American Smelting and Refining Company) Groundhog unit at Vanadium and Federal Resources Corporation's Bonney Mine at Lordsburg can be expected to open if lead, zinc, and copper prices rise. Several small underground mines ship limited amounts of precious-metal bearing fluxing ore to the ASARCO smelter at El Paso, and a few other mines produce fluorspar on an intermittent basis.