U. S. DEPARTMENT OF THE INTERIOR
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ENVIRONMENTAL GEOCHEMISTRY AND MINERAL RESOURCE POTENTIAL OF THE THREE RIVERS AREA AND GEOLOGY OF THE THREE RIVERS PETROGLYPH SITE, OTERO CO., NEW MEXICO

By

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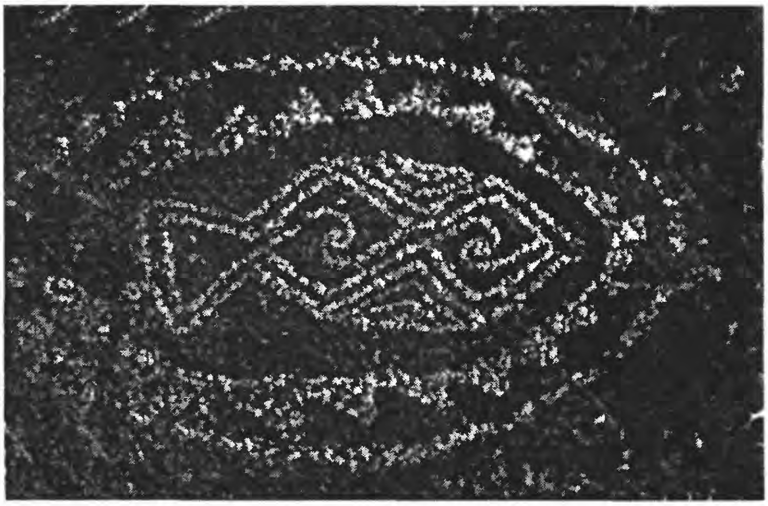

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INTRODUCTION

The Caballo Resource Area is a Bureau of Land Management (BLM) designated region that includes all of Sierra and Otero Counties, south-central New Mexico. Within this resource area of more than 21,000 square miles, nearly one fourth of the land is administered by the BLM. At the request of the BLM, geological and geochemical investigations were carried out at the Three Rivers Petroglyph Site and surrounding area, approximately 32 miles north of Alamagordo, New Mexico in northeastern Otero County (Fig. 1).

The BLM-administered Petroglyph Site contains more than 21,000 examples of rock art carved by Mogollon Indians between about 900 and 1200 A.D. The Site occupies about five square miles of land along Three Rivers, whose tributaries drain the western slopes of Sierra Blanca. This report discusses the geology of the Petroglyph Site and the mineral resources and environmental geochemistry of the Petroglyph Site and surrounding area.

GEOLOGY

Regional Setting

The Three Rivers area is located in the northeastern part of the Tularosa basin and lies within the Sacramento section of the Basin and Range physiographic province of Fenneman (1931). The study area is located near the eastern margin of the Rio Grande Rift; major rift-margin faults occur less than three miles west of the study area (Woodward and others, 1975). The Three Rivers area is located within a north-trending zone of Tertiary intrusive rocks that includes some of New Mexico's most important gold deposits. The intrusions and related volcanic rocks are alkalic in composition and the associated deposits contain both precious and base metals.

Sierra Blanca is a prominent peak east of the study area and marks the northern-most extent of the adjacent Sacramento Mountains. The nearly 12,000-foot-high Sierra Blanca is drained on its western flank by Three, Indian, and Golondrinas Creeks that comprise the headwaters of Three Rivers. The peak is underlain by numerous alkalic plutonic stocks and related volcanic rocks of Tertiary age (Moore and others, 1988; Seagerstrom and others, 1979; Thompson, 1972). Most of the upper Three Rivers drainage basin is underlain by the mid-Tertiary Walker Andesite Breccia (Seagerstrom and others, 1979). The Godfrey Hills which lie less than two miles northwest of the Petroglyph Site are also composed of the Walker Andesite that is overlain by the Godfrey Hills Trachyte of Thompson (1972). Black Mountain on the southwest flank of Sierra Blanca and directly east-southeast of the Petroglyph Site is underlain by igneous rocks that consist of hornblende syenite, quartz syenite, and numerous dikes of alkali gabbro and syenogabbro (Moore and others, 1988). Sedimentary rocks of Permian and Cretaceous age were intruded by igneous rocks of the Sierra Blanca region.

The area surrounding the Petroglyph Site is one of low relief and consists of coalecing alluvial fans whose source is the Godfrey Hills and Black Mountain to the east. Three Rivers drainage basin is located between the Godfrey Hills and Black Mountain and the main channel of the river is within the Petroglyph Site. Indian rock art carvings are preserved along the crest of a northwest-trending ridge that is the main physiographic feature at the Site.

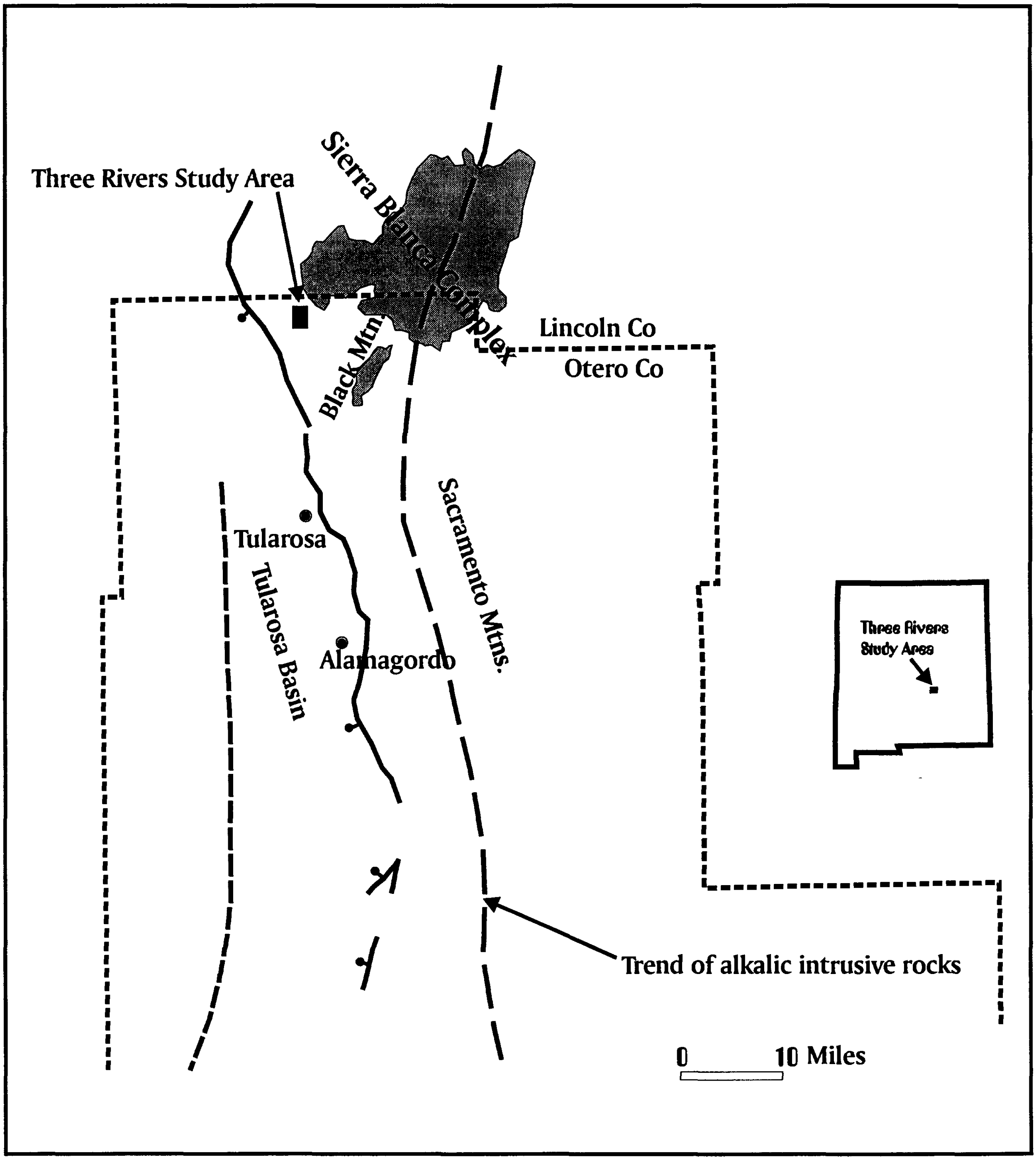

Figure 1. Location map showing the Three Rivers area

Geology of the Three River Petroglyph Site

Most of the rock units within the boundaries of the Petroglyph Site consist of surficial deposits (Fig. 2). Stream floodplain alluvium fills the active channel of Three Rivers and was also deposited in wide ephermal stream channels that drain the west side of the Godfrey Hills. Stream gravels that cap low terraces adjacent to Three Rivers represent older stream floodplain deposits. Alluvial and fluvial deposits ranging from silt to cobble gravel were deposited in narrow, anastomozing stream channels and on broad alluvial slopes. Thick deposits of caliche cap the higher parts of the petroglyph ridge and are characterized by white, calcareous deposits containing angular fragments of the underlying sill. Colluvium is well developed on most bedrock surfaces, is generally abundant in calcium carbonate, and is typically one to two feet thick; deposits labeled Qck (Fig. 2) overlie Cretaceous sedimentary rocks: those labled Qci overlie Tertiary intrusive rocks. Talus deposits derived mainly from igneous rocks that cap the petroglyph ridge cover much of the west side of the escarpment. Young alluvial fan deposits encircle the main ridge within the Petroglyph Site and overlie older, broad and now partly dissected alluvial fans shed from the nearby Godfrey Hills.

Sedimentary rocks exposed at the Petroglyph Site consist of the Cretaceous Mesa Verde Group. The Mesa Verde is poorly exposed within the boundaries of the study area; the best and most complete exposures are along the west side of the northwest-trending ridge (Fig. 2). The sedimentary rocks consist of an interlayered sequence of predominantly yellow-colored sandstone, siltstone, and shale. Sandstone ranges from olive-tan, platy, fine-grained lithic arenite interlayered with informational mud chip conglomerate to tan-white, medium-grained, cross-bedded quartz arenite with calcium carbonate cement. Some sandstone beds contain abundant marine shell fragments. Shale and siltstone are typically yellow-brown, locally sandy and calcareous, and poorly exposed.

The main body of igneous rock within the Site underlies the elongate ridge that contains the prehistoric Indian petroglyphs. The rock is a dark green fine-grained trachybasalt that contains hornblende phenocrysts up to two inches long. A well developed patina of manganese oxide or desert varnish coats most exposed surfaces of the rock outcrops. The surface coating is easily scratched and provided prehistoric Indians an accessible medium upon which to make petroglyphs.

The main ridge is an elongated trachybasalt sill intruded into the Cretaceous sedimentary rocks. Maxium thickness of the sill is around 30 feet. The sill is associated with several smaller concordant to plug-like bodies intruded both above and below the main intrusive (Fig. 2). Baked sedimentary rocks at the contacts of the sills are common and extend no more than a few feet from the intusive contact. Quartz veins and evidence of hydrothermal alteration and mineralization associated with these intrusions were not observed. The sill is latest Eocene in age; ^{40}Ar/^{39}Ar age of the main sill, obtained during this study, is 36.32±0.35 million years.

KNOWN MINERAL RESOURCES OF THE REGION

Some of New Mexico's largest gold deposits occur along a north-south belt roughly along the boundary between the Great Plains physiographic margin, the Rio Grande rift on the south and Rocky Mountains physiographic province on the north (McLemore, 1996). These deposits

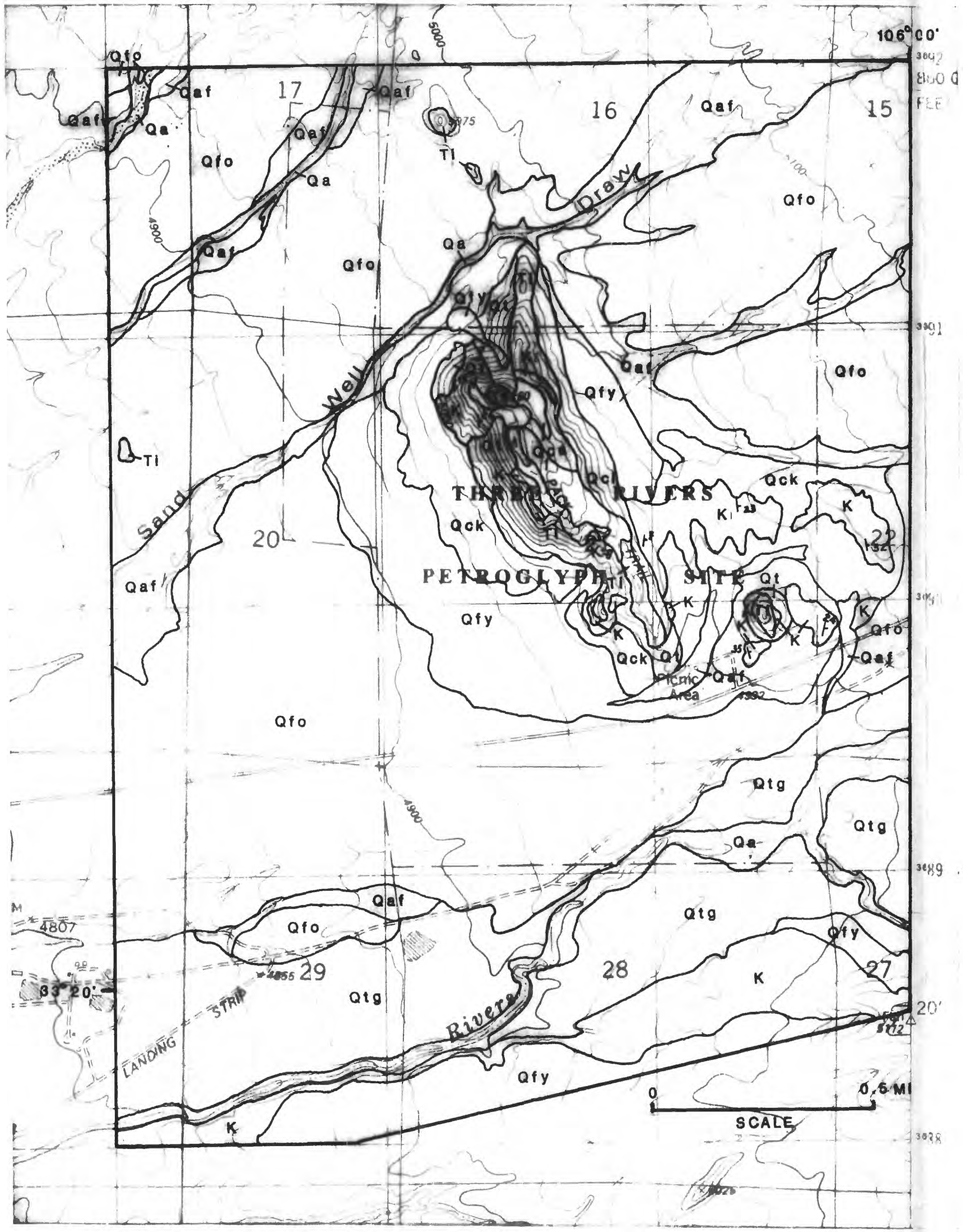

Figure 2—Geologic map of the Three Rivers Petroglyph Site

Map Explanation

Qa	Stream floodplain alluvial deposits
Qaf	Alluvial and fluvial deposits
Qca	Caliche
Qck	Colluvial deposits developed on Cretaceous sedimentary rocks
Qci	Colluvial deposits developed on Tertiary igneous rocks
Qt	Talus deposits
Qfy	Young alluvial fan deposits
Qtg	Stream terrace gravel deposits
Qfo	Old alluvial fan deposits
Ti	Eocene trachybasalt intrusive rocks
K	Cretaceous Mesa Verde Group sedimentary rocks
—	Geologic contact
┴ 23	Strike and Dip of Bedding

have similar characteristics that define a class of ore deposits referred to as Great Plains Margin deposits by North and McLemore (1986, 1988).

Great Plains Margin (GPM) deposits contain both precious and base metals, but precious metals, especially gold, are typically high compared to other metal deposits in the state. These deposits consist of six deposit types: (1) placer gold, (2) porphyry copper-gold (± molybdenum) and gold,(3) gold-silver and polymetallic veins and breccia deposits, (4) copper, lead/zinc, and/or gold skarns or carbonate-hosted replacement deposits, (5) iron skarns and replacement bodies, and (6) thorium-REE-fluorite epithermal veins and breccias. Mineralization is usually associated with silica-saturated (monzonite) or oversaturated (quartz monzonite) rocks of Eocene or Oligocene age (Segerstrom and Ryberg, 1974; McLemore and North, 1987; McLemore and others, 1991; Thompson, 1991). Lamprophyre dikes or sills are common in areas containing mineralized rocks, but their association to deposits is unknown.

Placer gold deposits—Placer gold deposits are low grade, disseminated deposits consisting of small sized gold. In New Mexico, they generally occur in late Tertiary to Recent alluvial fan deposits, bench or terrace gravel deposits, river-bars, and stream deposits or as residual placers formed directly on top of lode deposits typically derived from Proterozoic, Cretaceous, and Tertiary source rocks (McLemore, 1994a). Gold also concentrates above cemented gravels and clay layers within the gravel deposits, which constrain downward migration of gold particles. Most deposits are thin and less than 45 ft below the surface (Lindgren and others, 1910; Johnson, 1972).

Copper-molybdenum-gold porphyry deposits—Copper-gold and/or gold porphyries, locally with significant quatities of molybdenum (Cox and Singer, 1986, 20c, 21a) are found in some GPM deposits in New Mexico. Disseminated molybdenum and copper minerals occur in the Rialto stock in Lincoln County, northeast of Three Rivers, but the low grades and proximity to a wilderness area has hampered development (Thompson, 1968). At the Mudpuppy-Waterdog prospect in the Nogal-Bonito mining district, northeast of Three Rivers, a copper-gold porphyry deposit is hosted by a syenite to monzonite stock that is concentrically zoned from outer propylitic to argillic to inner phyllic alteration to a core of silicified and oxidized breccia (Fulp and Woodward, 1991).

Alkaline-related gold-silver and polymetallic veins and breccia deposits—Many polymetallic veins are associated with gold-bearing breccia deposits and quartz veins in many GPM districts (McLemore, 1996). Breccia fragments of igneous and/or sedimentary rock are typically highly altered and vary in size, ranging from large blocks 10's of feet in diameter to clay-sized particles. The origin of these breccia deposits is related to igneous intrusion and associated volcanism. Brecciation was followed by flooding of hydrothermal fluids forming cement of the breccia fragments and quartz veins that may carry base and precious metals..

Copper, lead-zinc, and gold skarns or carbonate-hosted replacements—Numerous GPM districts host copper, lead-zinc, and gold skarn deposits in New Mexico (Cox and Singer, 1986, 18a, b, c). Most skarns are copper skarns, but they contain considerable gold concentrations. Most gold skarns occur as carbonate-hosted deposits in Ordovician to Permian limestones (White, 1991; Giles, 1991). The skarns typically occur in metasomatized limestone adjacent to or in the vicinity of an intrusive contact with stocks, dikes, and/or sills.

Iron contact metasomatic-replacement and skarn deposits—Numerous iron skarn and replacement deposits (Cox and Singer, 1986, 18d) occur throughout the GPM alkaline igneous rock belt. Most deposits are small and insignificant (Griswold, 1959; Kelley, 1949) and none are economic gold deposits.

The iron deposits consist of hematite and magnetite and occur as lenses or irregular bodies in limestone and as veins filling fractures, faults, and along bedding planes adjacent to Tertiary intrusions. Calc-silicate minerals are rare.

Thorium-rare-earth elements-fluorite and niobium vein deposits—Thorium-rare-earth elements-fluorite epithermal veins and breccias (Cox and Singer, 1986, 11d) occur throughout the GPM area (McLemore, 1996). They typically occur as tabular bodies, narrow lenses, and breccia zones along fractures, faults, and shear zones and vary from a few feet to over 900 feet long and from less than an inch to 9 feet wide (Staatz, 1985, 1986; Perhac, 1970; McLemore and Phillips, 1991; McLemore and Guilinger, 1993; Schreiner, 1991, 1993). The deposits are typically spotty, discontinuous, of variable grade, and contain local concentrations of REE, yttrium, thorium, uranium, niobium, and gold (McLemore and others., 1988a,b). Bastnaesite was produced from the Gallinas district, north of Three Rivers (Griswold, 1959). Gold is typically low, rarely exceeding a few parts per million in concentration.

Three Rivers area

The study area has probably been prospected for a variety of metals, but to date, no known development or production has occurred. Alkaline igneous rocks are present in the vicintiy of the study area and, as discussed above, are known in New Mexico to have potential for deposits of gold and silver deposits. The closest mining took place in the Three Rivers district, several miles to the east. The Tularosa district, approximately 10 miles southeast of the study area, contained sandstone-hosted red-bed type copper mineralization. The production is not known but was probably small (Anderson, 1957).

Three Rivers mining district

The Three Rivers mining district is one of several districts in the Sierra Blanca area. The largest, most productive districts are located northeast of the Petroglyph Site in Lincoln County. The Three Rivers district extends to Black Mountain on the south to Three Rivers Canyon on the north in Lincoln County; the district includes much of the upper Three Rivers drainage basin. The Three Rivers Petroglyph Site lies about seven miles west of the mining district. Many of the mines and prospects are on the Mescalero Apache Indian reservation (Table 1). Three minor prospects are located near and within the southwestern portion of the White Mountian Wildereness Area. In 1943, H. Stain shipped 87 tons of 58 % Fe and 0.138 % P from deposits on the east side of Black Mountain in sec. 18, T12S, R11E (Harrer and Kelly, 1963; Kelley, 1949). Additional, but minor prospecting for replacement iron-copper and volcanic-epithermal vein deposits has occurred (Table 1). Production, if any, from these deposits is unknown.

Replacement iron deposits are the most important mineral deposits in the Three Rivers district. The largest known replacement iron deposit is in sec. 18 T12S, R11E, where magnetite and hematite with barite, azurite, malachite, and calcite are found in a tabular zone approximately 600-700 ft long and 20 ft wide (Kelley, 1949; Harrer and Kelly, 1963). The zone strikes N40°W. The host rock is San Andres Limestone and the deposit occurs near a porphyritic dike

TABLE 1. Mines and prospects in the Three Rivers district, Otero County, New Mexico. *—mine or prospect is on the Mescalero Apache Indian Reservation (see Moore et al., 1985 and NMBMMR file data for description). See Tables 2 and 3 for chemical analyses (sample numbers are in parenthesis under mine name/alias).

MINE NAME/ALAIS	LOCATION	LATITUDE	LONGITUDE	COMMODITIES	DEVELOPMENT	HOST	TYPE OF DEPOSIT	REFERENCES
Three Rivers (Apache, Nogal, Swain, Iron Mine Draw, GD1073M, GD2231M, 9845-1-3)*	NW18 12S 11E	33° 16' 15"	105° 55' 25"	Fe, Ba, Cu	pits	Permian San Andres Limestone, Teritary Black Mountain Stock	replacement iron	Kelley (1949), Moore et al. (1988), NMBMMR file data
unknown (GD2091R, GD2093R, 9843-1-8)*	19 12S 11E	33° 15' 30"	105° 55' 5"	Fe, Cu	pits	Teritary Black Mountain Stock	replacement iron	NMBMMR file data, Moore et al. (1985)
unknown	23 12S 10E	33° 15' 5"	105° 56' 30"	Fe, Cu	pits	Teritary Black Mountain Stock	replacement iron	NMBMMR file data
unknown	13 12S 10E	33° 16' 15"	105° 55' 45"	Fe	pit	Permian San Andres Limestone	replacement iron	NMBMMR file data
unknown (Three Rivers Canyon, 682-693)	34,35 10S 10E	33° 23' 41"	105° 52' 39"	Ag, Cu, Pb, F	shaft, pits	Tertiary Walker Breccia Andesite	volcanic-epithermal	Segerstrom et al. (1979), FN 10/18/96
unknown (9844-1-2)*	NE26 11S 10E	33° 19' 35"	105° 52' 15"	Cu	pit	Tertiary Black Mountain stock	volcanic-epithermal	NMBMMR file data
unknown (Barber Canyon, GD5051A,BM)*	NW34 11S 10E	33° 18' 45"	105° 53' 45"	Cu, Ag	adit	Tertiary Black Mountain stock	volcanic-epithermal	Moore et al. (1985)
unknown (GD1066M, GD1220M)*	19, 20 12S 11E	33° 15' 55"	105° 54' 20"	Cu, Ag	pit	Tertiary Black Mountain stock	volcanic-epithermal	Moore et al. (1985)

Table 1 (cont.)

unknown (GD1070M)*	NW22 12S 10E	33° 16' 5"	105° 54' 30"	Cu, Fe	pit	Tertiary Black Mountain stock	volcanic-epithermal	Moore et al. (1985)
unknown (GD004M, MW049M, 9842-1-2)*	20, 21 12S 11E	33° 15' 15"	105° 53' 40"	Cu	pits, 40 ft shaft	Permian San Andres Formation	volcanic-epithermal	NMBMMR file data, Moore et al. (1985)
unknown	NW22 12S 10E	33° 15' 54"	105° 57' 43"	unknown	10 ft pit	Permian Yeso Formation	unknown	FN 10/18/96
unknown (Horse Camp Spring)	N15 12S 10E	33° 16' 35"	105° 57' 33"	unknown	pits, now caved	Cretaceous	unknown	FN 10/18/96
unknown	NW16 12S 10E	33° 16' 37"	105° 59' 30"	unknown	pit, now caved	Cretaceous	unknown	NMBMMR file data

which strikes northeast. Iron content varies (Harrer and Kelly, 1963). Copper is low, 0.01% Cu (Table 2). The deposit may contain several tens of thousands of tons of iron ore (Moore and others., 1985). Smaller replacement iron deposist are found in sec. 23, T12S, R10E and sec. 19, T12S, R11E. In sec. 23, magnetite and hematite occurs in small tabular bodies in San Andres Limestone along a porphyry dike.

Volcanic-epithermal vein deposits—South of Three Rivers Canyon in Lincoln County (sec. 34, 35, T10S, R10E), three shafts and two pits expose small volcanic-epithermal veins in Walker Andesite Breccia that contain quartz, fluorite, malachite, azurite, and calcite (Table 1). The veins are up to 1 ft wide in a zone 5 ft wide, 20-50 ft long, and exhibit banding and crustification of quartz. Argillic alteration consisting of chlorite, kaolinite, illite, and quartz is common. One sample reportedly assayed 0.3-0.5 oz/ton Ag and 0.57% Cu (Table 3; Segerstrom and others., 1979). Additional volcanic-epithermal veins are scattered throughout the Black Mountains (Table 1; Moore and others., 1985), but are low in gold and silver (Tables 2 and 3).

ASSESSMENT OF ENVIRONMENTAL GEOCHEMISTRY AND MINERAL RESOURCE POTENTIAL OF THE THREE RIVERS AREA

In the Spring of 1996, field work was carried out in support of a mineral resource and environmental geochemical investigation of the Three Rivers study area which surrounds the Three Rivers Petroglyph Site, on lands administrated by the U. S. Bureau of Land Management, Las Cruces, New Mexico.

Three Rivers, in its upper reaches, is the only perennial stream in the study area, therefore water quality is an important issue. Because of the importance of water quality, the determination of water chemistry and the processes responsible for the controls on the mobility and attenuation of elements in water is the focus of the environmental geochemistry investigation.

Three Rivers Area

The Three Rivers area, which includes the Petroglyph Site is characterized by small Tertiary-age dikes and sills that intrude Triassic and Cretaceous sediments. Much of the surface is low relief and consists of coalescing alluvial fans whose source is the Godfrey Hills and the western flank of Black Mountain to the east.

The study area lies within the northern Chihuahuan desert. The climate is semi-arid with hot dry summers and mild winters. Average annual precipitation (Fig. 3) is around 12 inches. About 60 % of the precipitation occurs during May through September as thunderstorms (Hood and Herrick, 1965). Vegetation is mostly mixed desert scrub and desert grassland.

The upper reaches of Three Rivers is the only perennial stream in the study area. A dendritic pattern of ephemeral streams is present and after storms, these ephermal streams may flow for short periods of time. These ephermal streams drain into Three Rivers and the Tularosa Basin. Regional ground water flow, based on ground water surface elevations (Fig. 4), is to the Tularosa Basin to the west. The source of recharge to the water bearing formations is local precipitation and runoff from the upper western slopes of the Sierra Blanca massif to the east.

TABLE 2. Chemical analyses of samples collected from mines and prospects in the Three Rivers district (J. W. England, R. G. Erickson, J. R. Brooks, and R. J. Thompson, December 6, 1962, unpublished report, NMBMMR file data). See Table 1 for location (sample numbers are in parenthesis under mine name/alais). —analyses not determined. *—from replacement iron deposits, the remainder samples are from volcanic-epithermal veins.

NO.	Fe %	Mn%	Cu%	Pb%	Zn%	TiO_2%	SiO_2%	Al_2O_3%	P_2O_5%	S%	CaO%	MgO%	LOCATION
9842-1	13.3	0.22	2.52	0.02	—	—	—	—	—	—	—	—	20, 12S, 11E
9842-2	0.9	1.30	0.04	0.02	—	—	—	—	—	—	—	—	21, 12S, 11E
9843-1	6.2	—	0.01	—	—	—	—	—	—	—	—	—	19, 12S, 11E
9843-2	3.4	—	0.01	—	—	—	—	—	—	—	—	—	19, 12S, 11E
9843-3	5.4	—	0.01	—	—	—	—	—	—	—	—	—	19, 12S, 11E
9843-5	3.4	—	trace	—	—	—	—	—	—	—	—	—	19, 12S, 11E
9843-6	45.2	0.25	0.01	—	0.15	0.62	9.9	3.0	0.014	0.08	0.1	3.9	19, 12S, 11E
9843-7	65.8	0.28	nil	—	0.05	0.05	4.0	0.7	0.022	0.01	0.2	1.3	19, 12S, 11E
9843-8	11.7	—	0.01	—	—	—	—	—	—	—	—	—	19, 12S, 11E
9844-1	5.6	—	0.01	—	—	—	—	—	—	—	—	—	26, 11S, 10E
9844-2	6.4	—	0.01	—	—	—	—	—	—	—	—	—	26, 11S, 10E
9845-1	62.8	0.09	0.01	—	0.10	0.06	5.0	0.5	0.026	0.17	0..1	nil	13, 12S, 10E
9845-2	5.8	—	0.01	—	—	—	—	—	—	—	—	—	18, 12S, 11E
9845-3	5.5	—	0.01	—	—	—	—	—	—	—	—	—	18, 12S, 11E

TABLE 3. Chemical analyses of selected samples collected from mines and prospects in the Three Rivers district. See Table 1 for location (sample numbers are in parenthesis under mine name/alais).

NO.	Au oz/ton	Ag oz/ton	Cu%	Pb%	Zn%	SAMPLE DESCRIPTION	REFERENCE
682	<0.02	0.50	0.57	—	—	grab of dump	Segerstrom et al. (1979)
683	<0.02	0.40	—	—	—	40-ft chip	Segerstrom et al. (1979)
684	<0.02	0.30	—	1.14	1.55	stockpile	Segerstrom et al. (1979)
685	<0.02	0.30	—	1.08	—	30-ft chip	Segerstrom et al. (1979)
689	<0.02	0.30	—	0.44	—	grab of dump	Segerstrom et al. (1979)
693	<0.02	0.30	—	0.58	—	grab of dump	Segerstrom et al. (1979)
GD1073M	<0.02	<0.02	0.015	—	0.003	—	Moore et al. (1985)
GD2231M, A	<0.02	0.02	0.002	—	—	—	Moore et al. (1985)
GD2231M, B	<0.02	<0.02	0.003	—	—	—	Moore et al. (1985)
GD1066M	0.23	0.04	0.7	0.001	0.0015	—	Moore et al. (1985)
GD1220M	0.11	<0.02	0.2	0.003	—	—	Moore et al. (1985)
GD1070M	<0.02	<0.02	0.01	0.001	0.003	—	Moore et al. (1985)
GD5051A	<0.02	0.03	0.005	0.02	0.05	—	Moore et al. (1985)
GD5051B	<0.02	0.58	0.003	0.03	0.07	—	Moore et al. (1985)
MW049M	<0.02	<0.02	0.7	0.005	0.07	—	Moore et al. (1985)
GD004M	0.002	<0.02	1.5	0.003	0.050	—	Moore et al. (1985)

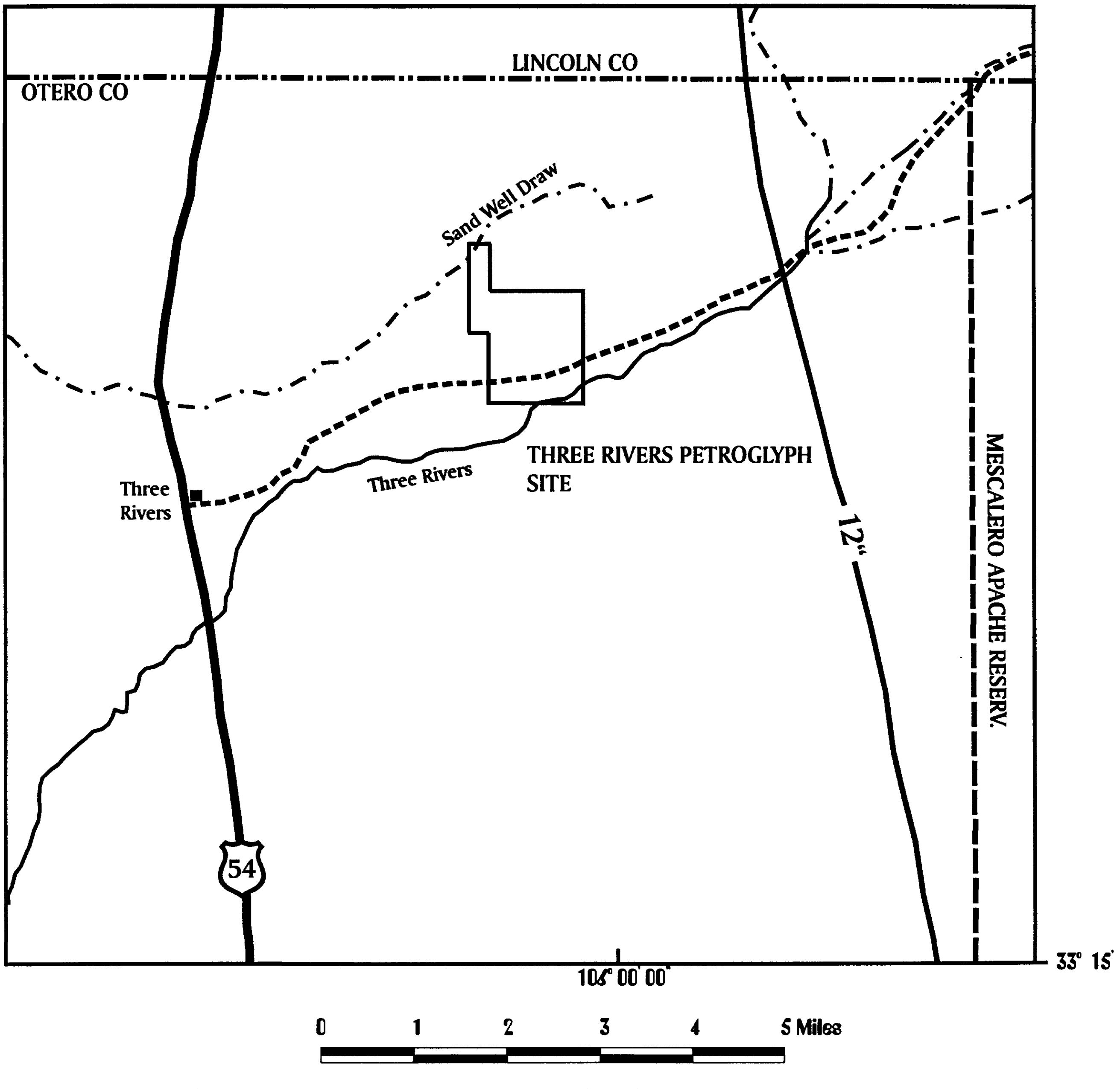

Figure 3. Map showing showing precipitation in the Three Rivers study area. From New Mexico State Engineer Office (1956, p.7)

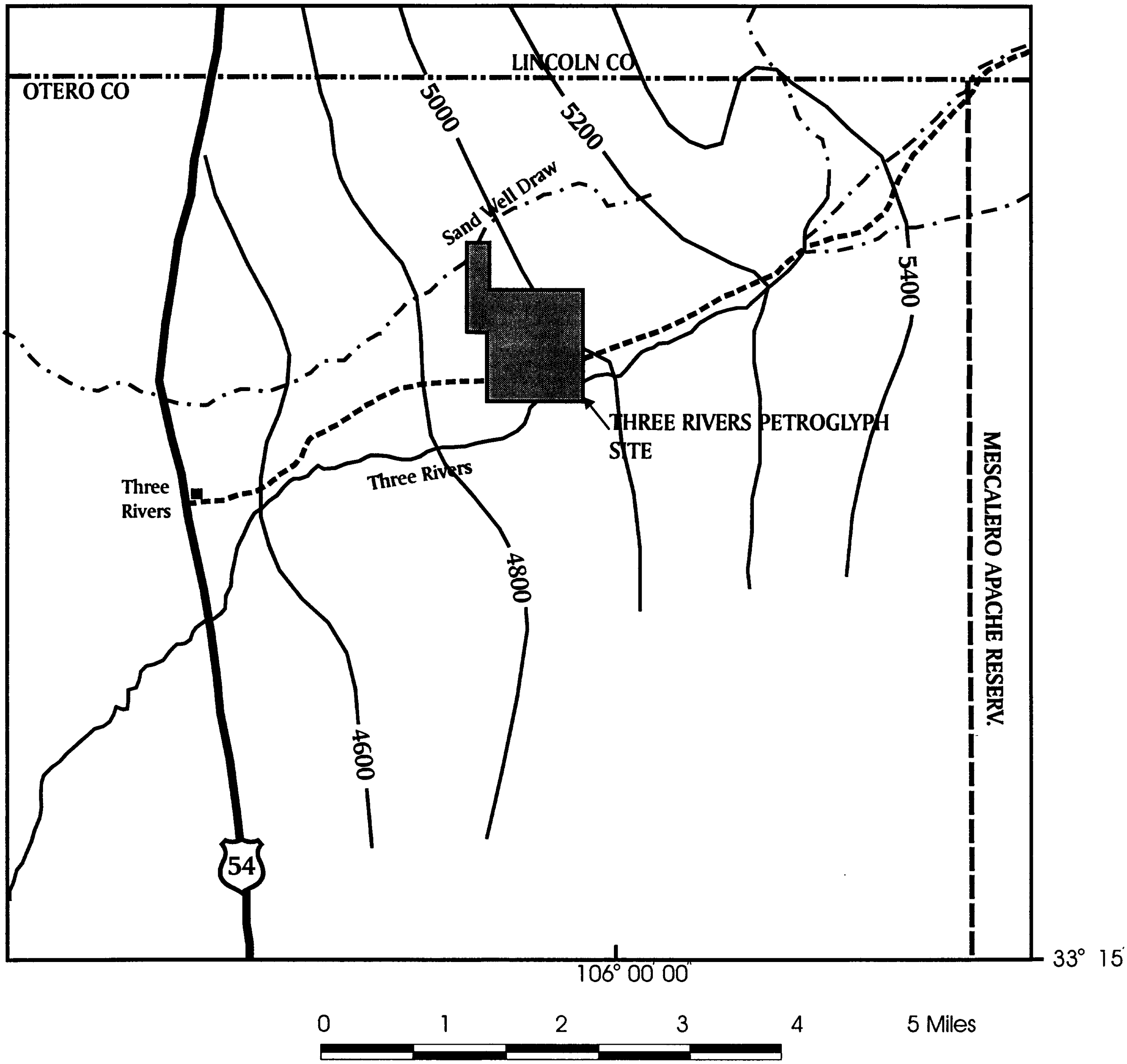

Figure 4. Map showing showing contours on the water table in feet in the Three Rivers study area

Methods for collection and analysis of samples

Waters were collected from 4 wells, 5 springs, and Three Rivers (Fig. 5) within the ACSC area during April 25-26, 1996. Generally, wells were pumping prior to arrival at the site. If the wells were not pumping, they were allowed, if possible, to pump for 15 minutes before collecting the sample. Temperature, pH, and conductivity were measured at the site. Samples were collected into high-density polyethylene acid-washed bottles. For the dissolved cation analyses, a 60-ml sample was filtered through a 0.45 µm-membrane filter and acidified with reagent-grade concentrated nitric acid to pH<2. A second 60-ml sample was collected and acidified without filtering to determine total cations in solution. A 125-ml sample was filtered but not acidified for anion analyses. The samples were stored in an ice chest and kept cool until analyzed.

Upon return to the laboratory, alkalinity as HCO_3^-, was determined by titration with H_2SO_4 using a Grans plot technique (Orion Research, Inc.,1978). Ca, Mg, Na, K, and SiO_2 were determined by flame atomic absorption spectrophotometry (Perkin-Elmer Corp.,1976). Sulfate, chloride, nitrite + nitrate, and fluorine were determined by Water Resource Division (W. D'Angleo-analyst) by ion chromatography (Fishman and Pyen, 1979). The remaining elements (Table 4) were analyzed by ICP-MS by ACTLABS, Wheatridge, Colorado.

Stream sediments were collected by compositing the sample across the width and depth of the active drainage channel. The drainages were dry at the time of collection. In the laboratory, the samples were sieved at 0.180 µm and the less than fraction analyzed by instrumental neutron activation analysis or inductively coupled plasma emission (Table 6) after total digestion by ACTLABS, Wheatridge, Colorado.

Results of the geochemical survey of the Three Rivers area surrounding the Petroglyph Site

Few rock outcrops are exposed in the Three Rivers area. Therefore a geochemical survey utilizing water and stream sediment samples was carried out. The chemical analyses for the 10 water samples (Fig. 5) collected from wells, springs, and one stream are shown in Table 4 . The waters are high in dissolved solids. Conductivity ranges from 1504 to 5090 µS/cm. The pH values range from 7.16 to 8.18. The waters are fresh to slightly saline and classified according to the dominant cation and anion. All ten sampes are Ca^{2+}- SO_4^{2+} dominant waters. The U.S. Public Health Service (1962) recommends that a drinking water supply should contain less than 250 ppm sulfate or chloride, where better water is not available. Using this classification, the well waters are of poor quality for domestic use, but better water is not available. The waters are used mostly for watering livestock. The most objectionable element in the well waters is sulfate followed by chloride. Moderate concentrations of nitrate, up to 4.4 ppm (Table 4) are present in the waters. This may be due to leaching of cattle waste. Cattle will congregate around wells and springs. Leaching of nitrate from cattle waste during runoff after storms and leaking of nitrate into the ground water in the vicinity of the well may account for the high values. Addition investigation would be needed to document this.

The concentrations of the heavy metals is generally low. The highest concentrations is manganese, with values up to 720 ppb, zinc, with values to 380 ppb, and iron, with values to 124 ppb. The remaining heavy metals are lower in concentrations. Of the base metals, only Cu, Mo, Cr, and U occur in anomalous concentrations above normal background abundances (Table 4).

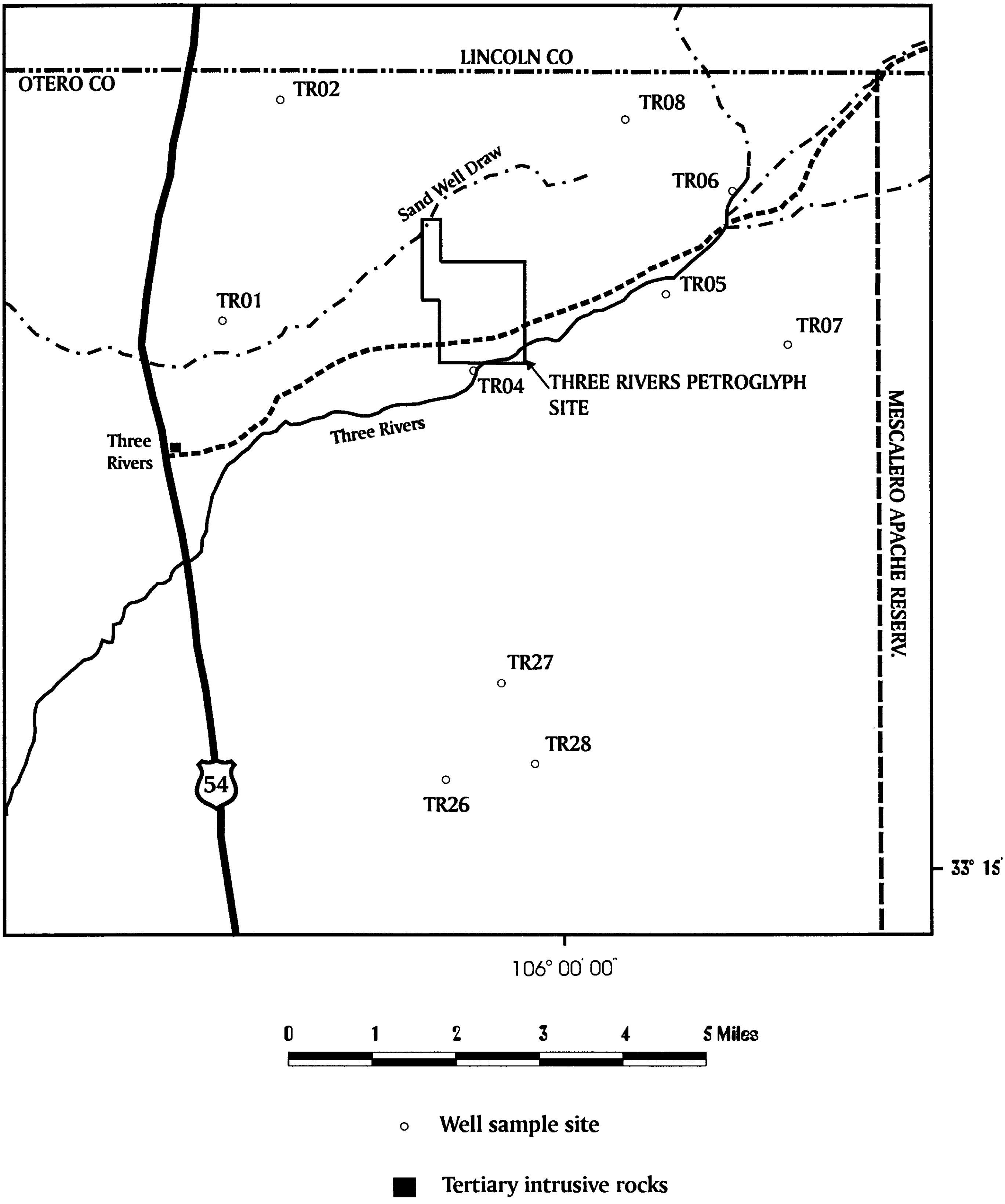

Figure 5. Map showing showing locations of sites sampled in the Three Rivers study area

Table 4. Chemical analyses of well waters collected in the Three Rivers area, south-central New Mexico

Site No.	Comments	pH	Conductivity uS/cm	Temperature Centigrade	Ca ppm	Mg ppm	Na ppm	K ppm	SiO2 ppm	Alkalinity ppm
TR01	Sand well	7.16	2420	20.2	380	62	170	1.9	25	183
TR02	New well	7.25	2040	19.7	240	61	150	3.9	28	141
TR04	Three Rivers	7.61	1990	18.6	330	45	110	0.9	24	281
TR05	Fall spring	7.72	3010	12.7	570	64	140	2.5	23	205
TR06	Crawford spring	7.38	1504	18.5	185	49	77	7.2	65	153
TR07	Golondrina well	8.14	1685	17.9	220	49	100	2.4	37	165
TR08	Crawford well	7.26	1620	24	220	61	56	7.2	73	140
TR26	Kitty spring	7.24	4800	19.9	670	180	370	7.2	24	177
TR27	Aguilar spring	7.28	5090	19.9	680	270	350	7.3	21	233
TR28	Crosby spring	8.18	4400	20.6	660	190	280	8.2	22	120

Table 4 (cont.)

Sulfate ppm	Cl ppm	F ppm	NO2+NO3 ppm	Cu ppb	Zn ppb	Li ppb	Al ppb	Cr ppb	Mn ppb	Fe ppb	Co ppb	Ni ppb
1000	220	0.3	3	8.2	45	27	52	23	5.8	122	1	4.2
750	210	0.9	2.6	6	305	41	17	12	5.4	133	0.6	5.3
720	190	0.6	<0.02	1.2	2	14	21	7	5.6	45	0.6	2.1
1200	390	0.2	<0.02	1.8	10	16	40	13	23	93	1.1	4.7
510	160	0.8	3	1.8	21	29	9	6	0.3	34	0.3	1.3
770	90	1	<0.02	2.4	9	15	19	5	8.9	114	0.5	< 0.02
560	180	0.6	4.4	17	380	26	22	6	3.6	47	0.4	1
2000	620	0.8	1.3	2	37	25	23	15	461	124	1.8	4.2
2200	780	0.9	<0.02	1.8	7	43	21	17	720	61	1.8	6.7
2000	620	0.9	0.73	2.1	8	26	18	15	3.2	53	1.1	4.4

Table 4 (cont.)

As ppb	Se ppb	Br ppb	Mo ppb	U ppb	Pb ppb	La ppb	Ce ppb	Pr ppb	Nd ppb	Tb ppb	Yb ppb	Lu ppb
1.8	4.3	360	3	5.3	1.7	34	60.0	9.7	23.0	4.3	3.2	4.2
1.1	7.4	419	5.4	4.1	1	4.7	8.4	1.9	3.0	0.9	0.8	0.83
1	4.1	276	8	4.1	0.8	1.7	3.3	0.6	1.2	0.3	0.3	0.34
1.6	4.5	517	2.8	3.1	0.8	2	3.9	0.8	1.3	0.4	0.3	0.45
1	6.6	262	3.3	2.8	0.6	0.39	0.8	0.1	0.2	0.1	0.1	0.13
1.3	1.5	134	10	2.9	0.5	0.58	1.1	0.2	0.4	0.2	0.1	0.09
1.3	5.9	276	4.1	4.1	3.3	0.48	1.0	0.2	0.4	0.1	0.2	0.09
4.5	5.2	707	12	8.6	0.9	1.5	3.8	0.4	1.3	0.3	0.2	0.23
2.8	3.4	797	5.7	3.6	0.7	0.95	2.1	0.3	0.6	0.2	0.2	0.2
2.7	5.6	675	9.7	7.1	0.9	2.7	4.0	0.7	1.8	0.3	0.2	0.1

When water is pumped from the wells, the water comes into contact with metal pumps, pipes, and rods, which may be the source for the anomalous values of Fe, Zn, Cu, and Mo in the well water. Most of the remaining trace elements are generally at background-type concentrations of less than 1 ppb, except for the rare earth elements (REE). The concentrations of REE La, Ce, Pr, Nd, Tb, Yb, and Lu are highly anomalous compared to average stream waters (Table 5). Most of the remaining trace elements are generally at background-type concentrations of less than 1 ppb.

In addition to the water samples, stream sediment samples were collected in fall, 1996 in the vicinity of well site TR01 (Fig. 5), which was anomalous in REE (Table 4). The high concentrations or REE in the well water suggest that the source is in the immediate vicinity and upstream from well site TR01 and that the source is a soluble REE-bearing mineral. No other water sources were available for sampling in the immediate area, therefore a stream sediment survey was carried out to determine the potential sources for REE mineralization (Fig.6).

The results of the detailed stream sediment survey is shown in Table 6. Copper concentrations in the stream sediments are low, a few sites are weakly anomalous in Pb and Zn, and the REE elements are probably above background values. The most significant geochemical anomaly is gold, which reaches a value of 0.4 ppm at site S01. Other sites are weakly anomalous in gold concentrations.

Stream sediments were also collected in 1976 as part of the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program. Geochemical data for 18 sites in the Three Rivers area were obtained from Hoffman and Buttleman (1994) and is shown in Fig. 7 and Table 7. Anomalous Zn is present at site N01 and anomalous Zn and Cu are present at site N18. Except for these two sites, the remaining sites contained mostly normal background values for the elements shown in Table 7, and no anomalous patterns are discernable . Au and Ag were not determined.

Chemical modeling of the waters

To gain understanding of processes such as speciation of elements, redox conditions, and identification of minerals that may control the mobility, attenuation, and concentrations of elements in the waters, chemical modeling of the well waters was carried out using PHREEQC (Parkhurst, 1995). The modeling program assumes mineral-solution equilibrium. For some chemical reactions with slow kinetics, this may not be the case. The dominant cations in the well waters are simple cations of Ca^{2+}, Na^{+}, Mg^{2+} and K^{+} or sulfate complexes $CaSO_4^0$ and $MgSO_4^0$. The dominate anions are SO_4^{2-}, HCO_3^-, Cl^-, and F^-. Other dominant species include Fe^{2+}, $FeSO_4^0$, Mn^{2+}, $MnSO_4^0$, Zn^{2+}, $ZnSO_4^0$, Cu^{+}, and Cu^{2+}.

Saturation indexes were calculated for a suite of minerals to determine if concentrations of trace metals in water were controlled by mineral phases. The saturation index is a convenient means of expressing saturation states of minerals (Barnes and Clark, 1969 where:
$SI=\log_{10} IAP/K_T$.
In the expression, SI is the saturation index, IAP is the ion activity product, and K_T is the equilibrium constant of the dissolution reaction at the temperature in question. We considered mineral phases supersaturated at $SI>0$, saturated or near saturation at $SI= -0.3$ to 0, and under saturated at $SI<0.3$

The results (Table 8) indicate that calcite and chalcedony are near or supersaturated with

Table 5. Average concentation in ppb of stream waters from Turekian (1969) compared to TR01

Element	Turekian (1969)	TR01
La	0.2	34
Ce	0.06	60
Pr	0.03	9.7
Nd	0.2	23
Tb	0.008	4.3
Yb	0.05	3.2
Lu	0.008	4.2

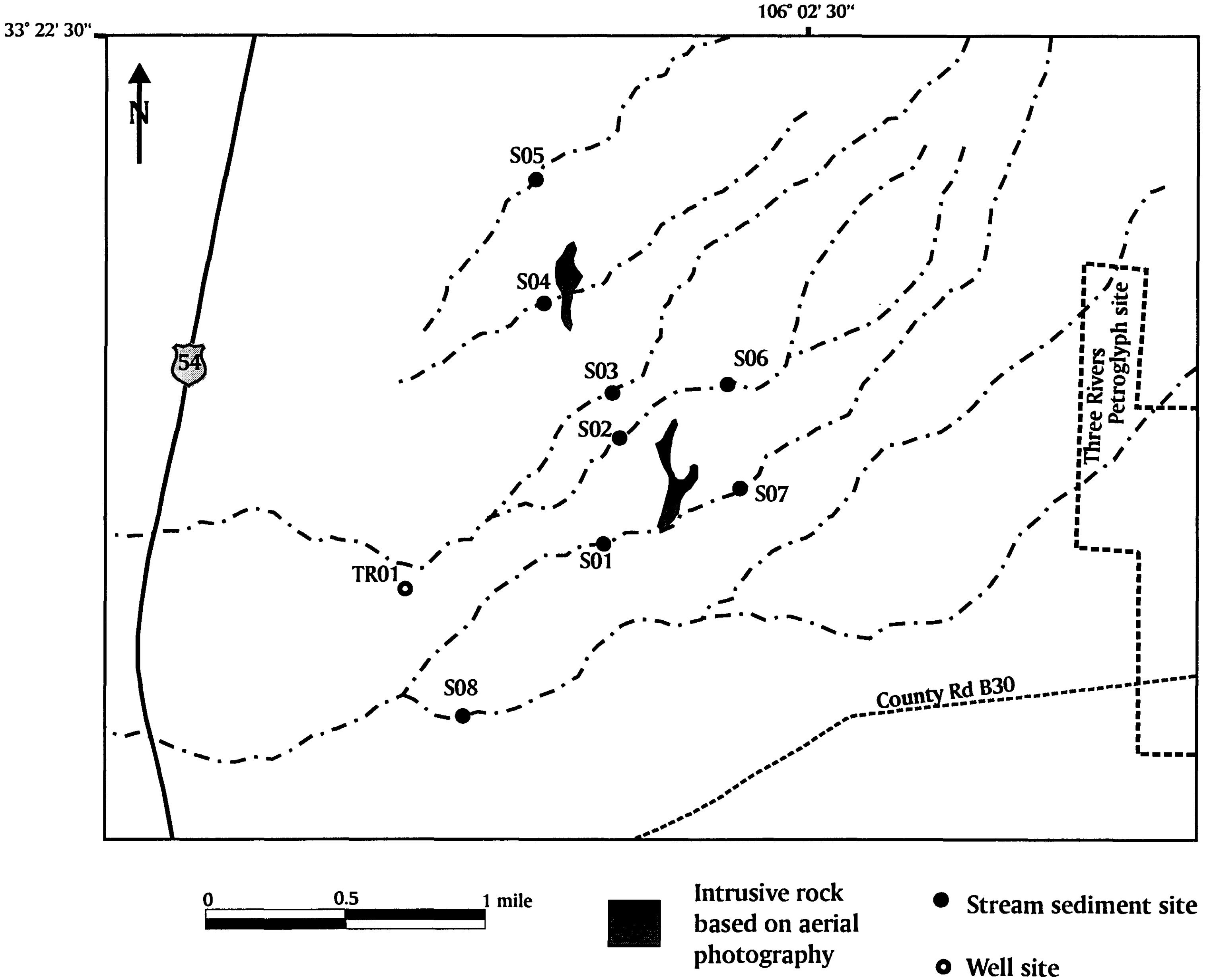

Figure 6. Map showing locations of steam sediment sample, Three Rivers area, New Mexico

Table 6. Chemical analyses of stream sediments collected in the Three Rivers area. Metals in ppm.

Site	Cu	Pb	Zn	Co	Cr	Ni	Au	Sb	As	Cd	Ce	Nd	Sm	U
S01	<1	22	88	10	49	19	0.4	0.4	2	3.8	62	26	3.3	2.8
S02	<1	33	51	7	30	6	0.007	0.4	2.1	2.8	55	24	2.9	2.9
S03	2	9	35	4	15	5	<.002	0.3	1.4	1.8	47	19	2.5	2
S04	<1	43	131	13	53	19	0.012	0.6	2.8	6.6	78	28	4.3	2.4
S05	5	9	35	4	12	7	0.009	0.4	1.9	1.2	46	19	3.2	1.7
S06	1	13	82	6	22	11	0.005	0.5	2.5	3.1	36	13	2.8	2.6
S07	<1	15	83	9	41	9	0.006	0.4	2.3	3.4	48	18	3.5	2.6
S08	<1	8	84	8	34	6	<.002	0.4	1.6	3.9	42	16	2.9	2.3

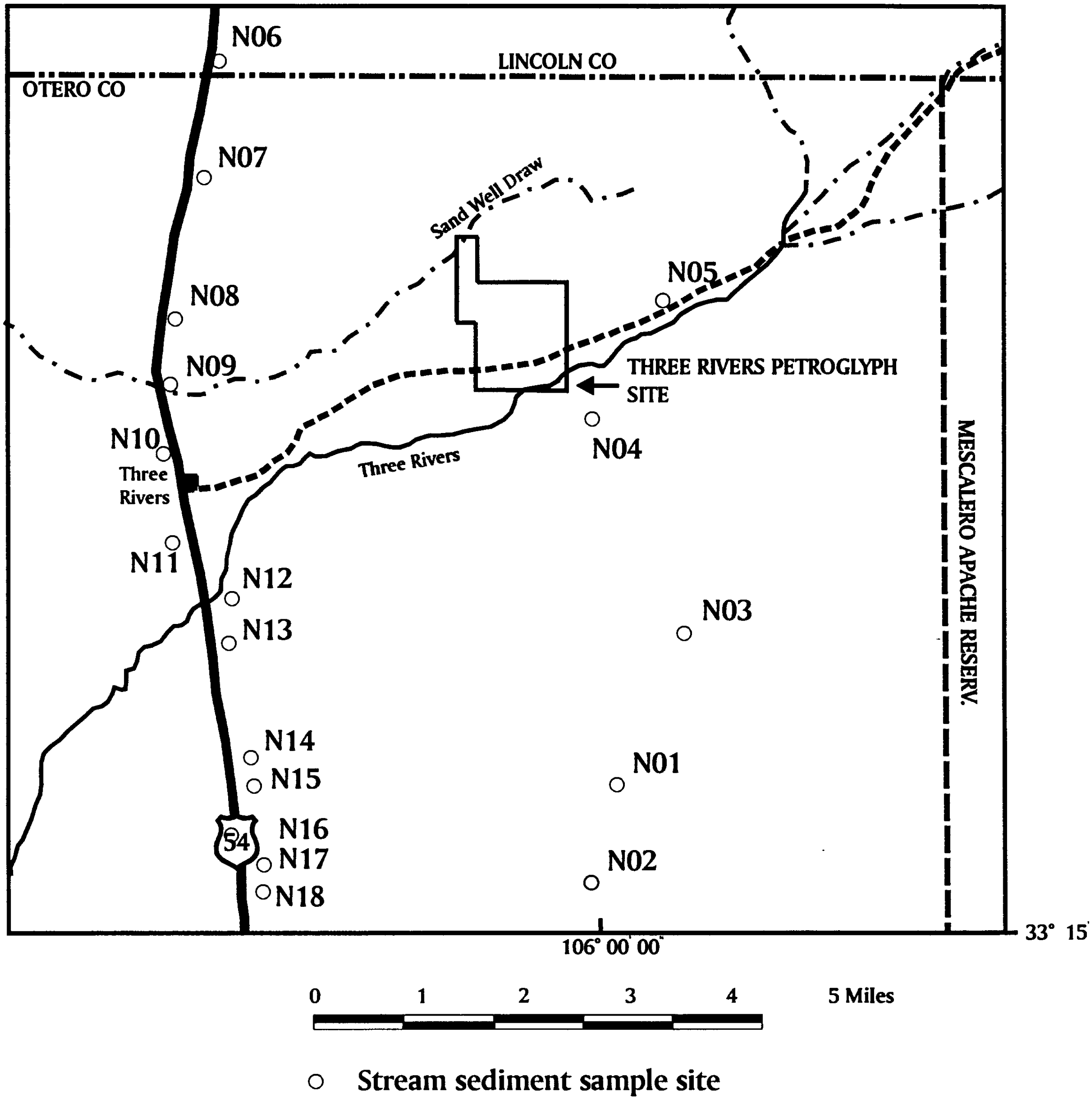

Figure 7. Map showing showing locations of stream sediments sites sampled by the NURE program in the Three Rivers study area, New Mexico

Table 7. Chemical analyses of stream sediments collected during the Nure program in the Three Rivers area, New Mexico. All values in ppm.

SITE NO.	LAT	LONG	AL	B	BA	BE	CA	CE	CO	CR
N01	33.2722	105.9922	61	15	329	3	49900	89	15	53
N02	33.2561	105.9961	41	10	408	1	77400	47	8	30
N03	33.2972	105.9781	53	15	662	1	17700	61	8	24
N04	33.3331	105.9961	44	10	598	1	20900	47	6	22
N05	33.3494	105.9864	56	13	656	1	20000	57	10	22
N06	33.3919	106.0706	37	16	478	1	15400	38	4	17
N07	33.3731	106.0753	38	14	511	1	12500	36	<4	14
N08	33.3494	106.0811	37	12	467	1	17400	44	6	21
N09	33.3381	106.0828	45	13	614	1	17800	38	<4	15
N10	33.3272	106.0806	43	15	515	1	19100	38	5	18
N11	33.3131	106.0764	62	10	720	1	28100	57	10	19
N12	33.3031	106.0681	50	12	632	1	35400	51	8	19
N13	33.2956	106.0681	46	10	572	1	20900	56	12	30
N14	33.2764	106.0644	40	17	584	1	26300	40	5	22
N15	33.2722	106.0639	40	-10	526	1	59200	43	5	19
N16	33.2642	106.0625	57	20	563	1	48700	48	8	28
N17	33.2589	106.0614	49	15	537	1	60200	45	6	23
N18	33.2544	106.0611	49	26	501	1	70000	36	7	25

Table 7 (cont.)

CU	FE	K	LA	LI	MG	MN	NA	NB	NI
26	52400	13900	33	24	9900	560	8600	19	32
15	29500	9800	17	19	7000	458	9600	12	12
15	31600	13400	25	18	5200	412	13000	14	11
14	25000	11400	23	14	5600	417	11700	15	12
24	34500	11100	28	14	8800	555	12400	16	13
7	19500	9800	21	11	4700	326	10300	16	6
6	16200	10200	19	11	4300	289	11400	13	5
8	27200	9000	23	11	5400	446	9100	18	7
7	17600	11800	22	13	4400	299	12200	13	4
11	22300	9800	22	13	6000	371	10100	16	6
17	35000	11100	29	14	10800	629	12700	17	8
16	29500	10100	25	13	8400	492	11200	18	11
19	51600	9000	28	13	6500	526	9200	17	11
18	24300	8800	20	13	5400	386	8900	12	26
14	19000	8400	21	14	5300	345	7800	13	8
26	26200	9600	25	18	11600	524	9000	14	12
19	22800	9400	23	19	10900	449	8800	12	10
1025	22700	9100	19	22	11100	597	6900	10	13

Table 7 (cont.)

P	PB	SC	SR	TH	TI	V	Y	ZN	ZR
933	9	9	242	6	6830	123	29	102	127
671	5	5	471	<2	5049	87	18	57	88
717	5	5	295	5	3791	102	10	56	50
680	5	5	335	2	3414	77	10	45	66
1143	7	7	394	5	3948	106	11	65	65
381	4	4	214	<2	2903	62	10	30	51
372	4	4	222	<2	2443	48	9	25	55
372	5	5	211	<2	3758	88	10	37	57
446	4	4	273	<2	2527	51	10	28	69
437	5	5	248	3	2891	72	10	31	48
1040	8	8	452	2	4041	119	12	46	74
742	7	7	376	<2	3581	98	11	38	57
780	6	6	229	3	4053	154	12	49	50
450	4	4	258	8	2688	79	9	36	43
470	4	4	302	10	2321	61	10	35	47
730	6	6	320	7	2579	78	11	43	47
646	5	5	356	6	2431	68	11	38	47
602	5	5	427	2	2125	58	12	430	46

Table 8. Calculated Eh values, saturated indexes for selected minerals and PCO2 values of well waters in the Three Rivers area, New Mexico

Site No.	Eh mv	Calcite SI	Chalcedony SI	Dolomite SI	Fluorite SI	Gypsum SI	CO2 atm
TR01	0.158	0.16	0.23	-0.19	-1.64	-0.33	-2
TR02	0.138	-0.03	0.29	-0.37	-0.83	-0.57	-2.19
TR04	0.106	0.75	0.23	0.90	-1.01	-0.46	-2.27
TR05	0.078	0.79	0.29	0.82	-1.75	-0.13	-2.57
TR06	0.150	0.07	0.66	-0.18	-0.95	-0.76	-2.28
TR07	-0.011	0.86	0.42	1.31	-0.72	-0.56	-3.04
TR08	0.156	0.05	0.65	-0.14	-1.23	-0.69	-2.18
TR26	0.149	0.33	0.22	0.38	-0.75	0.00	-2.13
TR27	0.161	0.48	0.17	0.83	-0.71	0.00	-2.05
TR28	0.004	1.07	0.17	1.88	-0.66	-0.01	-3.27

respect to the waters, indicating that these mineral phases play a major role in controlling the concentrations of Ca^{2+}, HCO_3^-, and SiO_2 in the waters. Waters at sites TR05, 26,27, and 28 are saturated or near saturation with respect to gypsum, suggesting that these waters are in contact with and readily dissolve the gypsum. All the waters are saturated or supersaturated with respect to dolomite, indicating that the waters are in contact with dolomite. All the waters are undersaturated with respect to fluorite.

The oxidation potential (Eh) of the well waters were calculated using PHREEQE, assuming equilibrium of the waters with respect to ferrihydrite. The Eh values ranged from the 0.172 to -0.011 volts (Table 8). The most reducing conditions are Golondrina well, TR07 and Crosby spring, TR28.

Processes controlling water geochemistry

The source of the water in the study area is precipitation which falls within the immediate area and the Godfrey Hills and Black Mountain to the west. The chemical composition of the water is derived from the minerals in which the water comes into contact. Therefore the composition of the bedrocks is a major factor in the type of natural waters generated within the study area. In addition, wind-bourn dust picked up within the study area or from outside the study area can be deposited as eolian material within the study area. Waters, coming into contact with this material, can pick up additional constituents. The most dominant processes controlling ground water chemistry within the study area are the dissolution of gypsum and the interaction of water with carbonate rocks.

Waters in contact with limestone and dolomitic limestone will have increased concentrations in Ca^{2+}, Mg^{2+}, and HCO_3^-. The presents of the HCO_3^- ion imparts an acid buffering capacity on the waters proportional to the concentration of H^+. The bicarbonate ion will consume H^+ ions and raise the pH (reaction 1).

Buffering of the H^+ by bicarbonate ion: $H^+ + HCO_3^- \rightarrow H_2CO_3$ [1]

The pH of water in equilibrium with calcite at 25°C and $PCO_2 = 10^{-2.40}$, which is the calculated average PCO_2 of the waters using PHREEQEC, will be buffered by the calcite to a pH value of approximately 7.7 (see Drever, 1982, p.46-49 for details on the calculations). If these waters come into contact with acid waters from processes such as oxidizing sulfides or acid rain, the waters have a natural buffering capacity for neutralizing the introduced acid.

The dissolution of gypsum is responsible for the high concentrations of Ca^{2+} and SO_4^{2-} of most of the waters within the study area. Gypsum occurs within several formations within the Permian sedimentary rocks. In addition, gypsum which dissolves easily, has done so in the past and reprecipitated when runoff containing high concentrations of Ca^{2+} and SO_4^{2-} evaporated or formed temporary shallow lakes which dried up. This material then can be easily picked up by the wind and redistributed where it is again available for dissolution. So the gypsum is ubiquitous in both the surface and subsurface within the study area.

The presence and dissolution of gypsum is probably causing the process of dedolomitization in the subsurface. This process, described by Black and others (1983), begins with gypsum dissolutions and the release of Ca^{2+} ions to the water. With the increase in Ca^{2+}, calcium carbonate precipitates, decreasing the carbonate ions. The decrease in carbonate ions from the waters causes undersaturation and dissolution with respect to dolomite. The net effect of this process is the increase of Ca^{2+}, Mg^{2+}, and SO_4^{2-}, a decrease in pH, and a slight decrease in bicarbonate concentration (see Miller, 1997 for details).

Other processes within the study area include: 1) dissolution of halite; 2) the precipitation of halite in the surface because of capillary action and evaporation; 3) oxidation of organic material in the aquifer causing a reduction in oxidation potential. The elevated chloride contents of the ground waters is probably due to dissolution of halite present in rocks such as the Mancos shale. Halite is often present during deposition of shales because of the high content Cl^- in sea water. Because of the presence of gypsum and halite, ground waters in contact with the Permian shales will be high in Ca^{2+}, Na^{2+}, and SO_4^{2-}.

Chemistry of waters in contact with the igneous alkalic rocks will be much different from waters in contact with the Permian sedimentary rocks. These waters will evolve to Ca^{2+} - HCO_3^- waters of low ionic strength with pH values of neutral to slightly alkaline. They will not be as well buffered as the waters in contact with carbonate rocks. No waters within the study area are derived solely from areas of igneous rocks. The small amount of precipitation which falls on the alkalic igneous rocks and the subsurface water which comes into contact with the igneous rocks will evolve toward low-ionic strength waters, but then will mix with waters derived from the Permian sedimentary rocks.

As shown earlier, water at 25°C and $PCO_2 = 10^{-2.40}$ in contact with carbonate minerals, which are abundant in the bedrocks of the study area, should be buffered to a pH value of approximately 7.7. The average pH values of the waters is 7.52, which is slightly lower than buffering by calcite, indicating that other processes may be responsible for the lower pH. In the Cornudus Mountains to the south, pH was significantly lower then that predicted by buffer by calcite only (Miller, 1997). In the Cornudus Mountains area, much of the lower pH values were attributed to the oxidation of sporatic petroleum and organic material present within the sedimentary rocks. This does not appear to be the case in the Three Rivers area. The process which is probably responsible for the slightly lower pH values is dedolomitization which lowers pH. Another process which could also lowering pH is that some of the sulfate, which is abundant in the ground waters, may be reduced to HS^- or H_2S by the reducing environment. The process will generate acid which will lower the pH of the waters. The reducing environment and acid pH values will also cause the release of iron and manganese to the ground waters.

Environmental geochemistry of the Three Rivers study area

Natural and anthropogenic-related sources can contribute heavy metals and acid to the environment. The purpose of this section is to determine environmental problems that may presently exist or potentially exist if mining occurs within the study area in the future. The study area is sparsely populated, no industry is present, and no mining has taken place. Therefore, environmental concerns must be considered in the context of geology and in particular, the composition of the rocks. Any present geochemical environmental problems are the result of natural processes that occur when the rocks of the study area are subjected to chemical and mechanical weathering. The oxidation of pyrite will have the greatest effect of releasing acid and heavy metals to the natural waters of an area. Pyrite appears to be absent in the surface rocks of the Three Rivers area, and the subsurface rocks are not known to contain significant amounts of pyrite. In addition, the rocks present in the study area, namely limestones, sandstones, and alkalic igneous rocks, generally contain normal low concentrations of trace elements such as Zn, Cu, Pb, Cd, and Hg. Shales, particularly black shales, can have anomalous concentrations of metals, but this does not appear to be the case for shales in the study area. Other trace elements in the rocks, such as As, are also apparently low. Consequently there are minimal heavy metals and acid released from the rocks to the waters during normal weathering.

Two lithologies present in the surface and/or subsurface of the Three River area are effective for mitigation any acid drainage that may presently or in the future be generated: 1) limestones and dolomites and 2) caliche that is abundant and often cements Quaternary alluvium. Tertiary lacustrine beds containing calcite may also occur. The carbonate minerals react with the waters, buffer the H^+, and raise the pH. Heavy metals such as Cu and Zn, if present, will hydrolyze and precipitate at the higher pH values.

The other major rock group in the study area are the alkaline intrusive rocks. These rocks have less buffering capacity than the carbonate rocks, mainly form minerals such as plagioclase. But the ubiquitous occurrence of calcite in the surficial material will provide buffering capacity to neutralize any acid generated in the surface environment.

Climate plays a significant role in geochemical processes. Water is necessary for chemical weathering to occur. The climate of the study area is semi-arid. Because of the low annual precipitation, chemical weathering at the surface probably takes place in pulses when water is present following runoff from storms. Within the zone of ground water, water is in contact with the rocks and chemical processes are taking place.

The geochemical environmental consequences of future mining depend on the type of mine that would be developed. If a REE, base metal, or precious metal deposit containing pyrite was developed, acid and metal release would occur, but the large amounts of carbonate minerals in the surrounding rocks and surfical material would quickly buffer the acid and metals. So the effect on the surface would be minimal.

In summary, the main geochemical environmental concern presently in the study area is: (1) the presence of slightly saline water due to the abundant gypsum and sometimes halite; (2) the neutral to slightly acid ground waters due to dedolomitization or reduction of sulfate; and (3) the moderately elevated concentrations of nitrate, possibly due to leaching of cattle wastes in the vicinity of well sites. These problems, except for the nitrate, are due to natural processes that have operated for at least 1000's of years. Possible future mining would probably have no significant impact on the chemistry of the surface or ground waters.

Mineral resource potential of the Three Rivers Petroglyph Site

In order to not disturb the protected prehistoric site, no solid samples were collected from the Petroglyph Site. Samples for mineral resource evaluation were collected from the BLM land surrounding the site and are discussed later. Exposed rocks within the Petroglyph Site show no evidence of hydrothermal alteration or mineralization. The trachybasalt sills and small plugs appear to lack any associated alteration or mineralized zones; the only alteration associated with their implacement is the structural dilation of the intruded rocks and the baking of those rocks near the intrusive contacts. Based on observation of surface outcrops only, no evidence was seen to indicate potential for mineral resources at the Three Rivers Petroglyph Site.

Mineral resource potential of the Three Rivers study area

The high concentrations of rare earth elements La, Ce, Pr, Nd, Tb, Yb, and Lu in the alkaline waters indicate that the REE-bearing minerals are soluble in water. Most REE-bearing minerals are refractory, such as monozite, xenotime, or cerite, and are generally insoluble in waters, except under extreme acid conditions. The most likely mineral that is the source for the REE metals in the alkaline waters in the Three Rivers area is bastnasite, a REE-bearing fluorcarbonate. Bastnasite is an important ore mineral in REE deposits such as Mountain Pass, California. Bastnasite occurs along with copper and fluorite in the Gallinas Mountains, about 40 miles to the north of Three Rivers. The deposits, which are small in size, are associated with a trachyte laccolith, and consist of low-temperature epithermal veins and breccia fillings in the Yeso Formation (Perhac, 1970).

The results of the stream sediment survey during the NURE program in the Three Rivers area indicate two anomalous sites but no discernable pattern. Au and Ag were not determined. A detailed stream sediment survey in 1996 indicates that gold mineralization as well as REE mineralization may be present. Highly anomalous concentrations of gold occur at site S01 as well as weakly anomalous concentrations of Au, Pb, and Zn at other sites (Fig. 6 and Table 5).

The belt of alkalic intrusive rocks (Kelly and Thompson, 1964) that occurs to the north and east of the study area is associated with mineralization, particularly gold deposits as discussed earlier.

REE metals and precious metal deposits occur to the north of the Three Rivers area as intrusive breccia-pipe deposits and epithermal veins at Nogal and White Oaks districts in Lincoln county (McLemore, 1991). If REE and Au mineralization is present in the Three Rivers area, it is likely that the age and occurrence is similar to these districts to the north.

The anomalous concentrations of REE metals in the water samples and the anomalous concentration of Au in stream sediments is permissive evidence for moderate potential for REE and gold mineralization in the Three Rivers area. The bedrock in the study area is mostly covered with coalesced alluvial fans. Only a few small outcrops of intrusive rock are present. The intrusive rocks are mainly lamprophyric sills and dikes striking approximately north-south. The intrusive rocks are associated in age with the Sierra Blanca igneous complex. Based only on cursory look, the intrusive rocks show no obvious signs of hydrothermal alteration at the surface. Well site TR01 is probably less than 200 feet deep and contains water which is anomalous in REE. This suggests that the mineralization is probably in the shallow subsurface.

It should be noted that this anomaly is based on scant evidence and further studies, particularly subsurface drilling, are needed in order to confirm or deny the presence of subsurface mineralization.

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