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MINERALS RECONNAISSANCE OF THE LITTLE BOQUILLAS RANCH AND ADJACENT AREAS, COCHISE COUNTY, ARIZONA

1979

Tenneco Oil Exploration and Production
Minerals Exploration Department

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SUMMARY AND CONCLUSIONS

The mineral reconnaissance of the nearly 113,000 mineral acreas on the Little Boquillas Ranch revealed significant mineral potential, identified mineral resources, and some active mineral production.

ENERGY RESOURCES

Uranium and Thorium

The potential for significant uranium and/or thorium resources on the Little Boquillas Ranch is low. The Whetstone Mountains area offers some potential for "hard rock" uranium in the orthomagmatic class (uranium-enriched pluton) and authegenic class (secondary uranium) within a Precambrian quartz monzonite-alaskite stock. Uranium occurrences are present in the area and some valid uranium claims have been staked by energy companies. The igneous host rock is covered by alluvial debris on the Little Boquillas Ranch, thereby concealing potential uranium mineralization. No orthomagmatic or authigenic "hard rock" uranium deposits are presently mined in the U. S.

Petroleum and Natural Gas

Potential for petroleum and natural gas resources on the Little Boquillas Ranch is considered "good" owing to favorable geological indicators and partly to a lack of drilling data to prove or disprove various theories predicting hydrocarbon accumulations at depth. The ranch lies on the southwestern shelf of the Pedregosa basin and evidence is at least moderately convincing that significant quantities of oil and gas were generated and preserved in Paleozoic and lower Cretaceous sedimentary rocks. Favorable source and reservoir rocks are present and Laramide structural traps may exist at depth. The most serious question is that of preservation after several episodes of deformation, intrusion, and volcanism.

Petroleum geologists are presently projecting the Overthrust Belt through southeastern Arizona and predict oil and gas accumulations similar to those found in Wyoming and Utah. Much exploration interest has been shown by numerous oil companies during 1978-79 and test holes to depths of 20,000+ ft are planned in the region for 1980. Tenneco pursuit of petroleum and natural gas resources on the Little Boquillas Ranch should begin with acquisition of existing 1979 seismic data and subsequent geologic evaluation.

Geothermal Resources

The Little Boquillas Ranch probably contains intermediate geothermal temperatures (80-150°C) in a wet system suitable for non-electrical energy utilization. These temperatures are likely present at depths in excess of 2000+ ft within the San Pedro Valley, provided favorable geologic conditions are present. At least five geothermal anomalies occur on the ranch as defined by the Geothermal Group, Arizona Bureau of Geology and Mineral Technology. A geothermal assessment of the ranch by the Geothermal Group was aborted during 1979 due to curtailiment of DOE funds. Ownership of geothermal resources in Arizona is uncertain and remains untested at present. Pursuit of geothermal resources on the ranch should include taking advantage of available state and federally-funded assessment programs.

Coal

No significant coal resources are known to occur on or adjacent to the Little Boquillas Ranch. Coal potential is nil.

METALLIC MINERALS

Copper

Perhaps the greatest mineral potential on the Little Boquillas Ranch is for copper and associated base and precious metals. The ranch lies within the heart of the southeastern Arizona copper province. Geologic indicators suggest good to excellent potential for a significant porphyry copper deposit in the Charleston area. A hypothetical deposit would likely be deep (2500+ ft) and contain about 100 million tons of copper ore with some molybdenite, silver, and trace gold. Asarco has discovered a deep, low-grade porphyry copper deposit in the Charleston area. Such deposits often occur in clusters. Pursuit of a porphyry copper deposit requires geophysical surveys, geologic mapping, and reconnaissance core hole drilling to depths in excess of 3000 ft.

Base and precious metal potential associated with metasomatic replacement deposits (tactite or skarn) is also considered good to excellent. This potential is present in the Dragoon Mountains area and Charleston-Lewis Springs area. Exploration for such deposits requires geophysical surveys, geologic mapping, and reconnaissance core hole drilling to depths in the range of 1000+ ft.

Silver

Silver potential in epithermal veins in the Charleston area is considered moderate to low. This area is within the Tombstone mining district which is a known silver-producing district. Some potential for a significant silver deposit on the ranch may be present at depth (300+ ft) in zones of suspected vein intersections, however, surface mineralization is generally poor. Some vein production of silver, vanadium, and manganese was reported during the late 1800's and early 1900's. Old workings on ranch property are now caved and dangerous. Angle hole core drilling to depths in excess of 500+ ft would be required to test veins at depth. Trace gold can be expected. Drilling can be designed to test prophyry copper and silver potential in the same hole(s).

Gold

Potential for placer gold is low. Trace gold can be expected associated with base metal deposits and silver-bearing veins.

Tungsten

Tungsten potential in undiscovered metasomatic replacement deposits and placers is low to moderate and does not warrant further consideration at this time.

RECLAIMABLE METALLIC RESOURCES

Mill Tailings

Identified silver and trace gold resources are present in old mill tailings scattered along the east bank of the San Pedro River. Erosion, floodplain deposits, and dense brush are obliterating the 100-year-old cultural deposits. Total identified resources based on tenuous visual estimates at four millsites are 26,000 tons of mill tailings containing 1-4 oz Ag/ton and trace gold. Some reworking of these mill tailings for precious metal recovery occurred during 1905, 1947-48, and 1979. A farmout contract to a small ore reclamation company is likely the best method of obtaining value from the scattered mill tailings.

Slag

Identified silver and trace gold resources are present in old smelter slag at the Gird millsite near Charleston. Total identified resources based on tenuous visual estimates are 30,000+ tons of slag containing 1-5 oz Ag/ton and trace gold. Some metallurgical reworking of the slag for precious metals recovery was reported in 1975. A farmout contract to a small ore reclamation company is likely the best method of obtaining value from the slag resources.

INDUSTRIAL ROCKS AND MINERALS

Clay

Overall clay potential for the Little Boquillas Ranch is fair. Extensive clay-bearing beds are present in the St. David Formation throughout the San Pedro Valley. These clays are generally undesireable for industrial use owing to impurities and poor physical parameters. However, no exploration program has excluded the possibility for commercial-grade clays. The "Knear fire clay" in the Whetstone Mountains area was mined on the ranch in 1900 (?) but proved unsatisfactory as a refractory clay.

Gypsite

Two gypsite deposits have been identified on the Little Boquillas Ranch: 1) Boquillas gypsite deposit, 2) Land gypsite deposit. Both deposits are flat-lying, tabular gypsite beds which occur in Plio-Pleistocene lake beds along the western margin of the San Pedro River. The Boquillas deposit is exposed at the surface and is commonly 1.5-2.0 ft in thickness. Approximately 187,400 tons of strippable gypsite containing 70-80+% gypsum are present in the Boquillas deposit on Tenneco fee land. Three times this tonnage is believed present on adjacent properties. The Land deposit is exposed in badland topography, averages 4 ft in thickness, contains roughly 79% (?) gypsum, and is covered in most places by 20-40 ft of overburden. About 722,000 tons (?) of gypsite are present in the Land deposit on Tenneco fee land. Approximately three times this amount is also believed present on adjacent properties.

Identified gypsite resources on the ranch may be applicable to local agricultural lands as a soil conditioner. An experienced agronomist is needed to determine if local soils would benefit from gypsite application. Exploitation of gypsite resources would be a small operation.

Stone

Identified stone resources for riprap are present in the Charleston-Lewis Springs area along the San Pedro River. The Uncle Sam Porphyry was described by the U. S. Bureau of Reclamation as suitable for riprap and should break out in about equidimensional blocks in the 1-3 ft range. Development of riprap resources is dependent upon demand for channel stabilization of the San Pedro River. Such demand seems remote owing to the environmental concerns expressed by the U. S. Fish and Wildlife Service and the canceled thin-arch concrete dam at Charleston.

Sand and Gravel

Excellent sand and gravel resources are present on the Little Boquillas Ranch. Identified resources are particularly abundant along the San Pedro River and its tributaries. At least six contractors have produced sand and gravel from the ranch on a royalty basis with Tenneco West, Inc. Product is hauled mainly to the nearby town of Sierra Vista where demand is strong. Field observations during 1979 indicate that production is at a high level. Continued exploitation of sand and gravel resources should be more closely monitored to verify actual mined tonnages.

Diatomite

Potential for diatomite resources in the St. David Formation is low and does not warrant exploration efforts.

Fluorspar

Although significant fluorspar resources have been produced from areas adjacent to the Little Boquillas Ranch, potential for fluorspar on Tenneco fee land is low and does not warrant exploration efforts.

Silica

Potential for silica resources in the Whetstone Mountains area of the ranch is fair to poor. Exploration efforts are not warranted.

Zeolites

Potential for commercial zeolite deposits in the St. David Formation is fair to poor. A large portion of the ranch is covered by the formation. The St. David shares lithologic characteristics with commercial zeolite-bearing lacustrine strata near Bowie, approximately 65 miles northeast of the ranch. Exploration for commercial zeolites is difficult, costly, and would be restricted to available surface exposures.

WATER RESOURCES

Much of the Little Boquillas Ranch is alluviated and straddles or flanks the San Pedro River. These alluviated areas contain fluvial and valley-fill deposits which are excellent aquifers with unconfined and confined hydrologic conditions.

A large portion of the ranch has water well potential of 50-2500 gpm with most wells capable of producing 1000 gpm. Wells located in near proximity to the San Pedro River have a greater chance of producing a substantial yield as opposed to those near mountain fronts. Artesian water is locally present. Chemical quality of ground water is suitable for most uses with some local exceptions. Large ground water resources on the ranch are a valuable asset in the arid region. Exploitation of such resources will likely be for growing agricultural demands and for growing population centers.

INTRODUCTION

GOALS AND OBJECTIVES

The Minerals Exploration Department was organized on September 16, 1976 to evaluate the mineral potential of company-owned fee lands, mineral properties and mineral claims. The primary goal of the department is to generate a high-quality geologic data base of Tenneco mineral lands. Subsequent data can be used as the foundation for decision making, proprietary exploration programs, and for future development programs. Mineral reconnaissance of the Little Boquillas Ranch was conducted as part of the overall program. The principal objectives of this study were to identify and document near-surface mineralization with emphasis on energy minerals and easily exploitable industrial minerals. The reconnaissance program included energy resources, industrial minerals, metallic minerals and a cursory assessment of water resources.

PROGRAM DESCRIPTION

The minerals reconnaissance program on the Little Boquillas Ranch and adjacent areas was conducted in a systematic manner consistent with exploration on other Tenneco ranches. Reconnaissance activities were restricted to Tenneco lands on which mineral rights are retained and adjacent lands within longitudes 109° 57' to 110° 30' west and latitudes 31° 20' to 32° 03' north. This area encompasses approximately 1650 sq miles. A flexible plan of operation was designed to guide the reconnaissance program uniformly and is presented in Figure 2-1.

One geologist was assigned to the ranch and was responsible for all field work and raw data compilation. Jeffrey L. Wilson, geological supervisor, assumed initial responsibility for the ranch in September 1976. In January 1978, responsibility was transferred to Roger D. Gill, exploration geologist. Significant contributions to the study were also made by David L. Emmons, senior exploration geologist. Support personnel were provided as required and included temporary help and various contractors. Maps and cross sections were drafted by contract draftsmen, Barbara T. Thomssen and Anne M. Urizar. Company-leased, four-wheel drive vehicles were used for field work. Commercial laboratories and

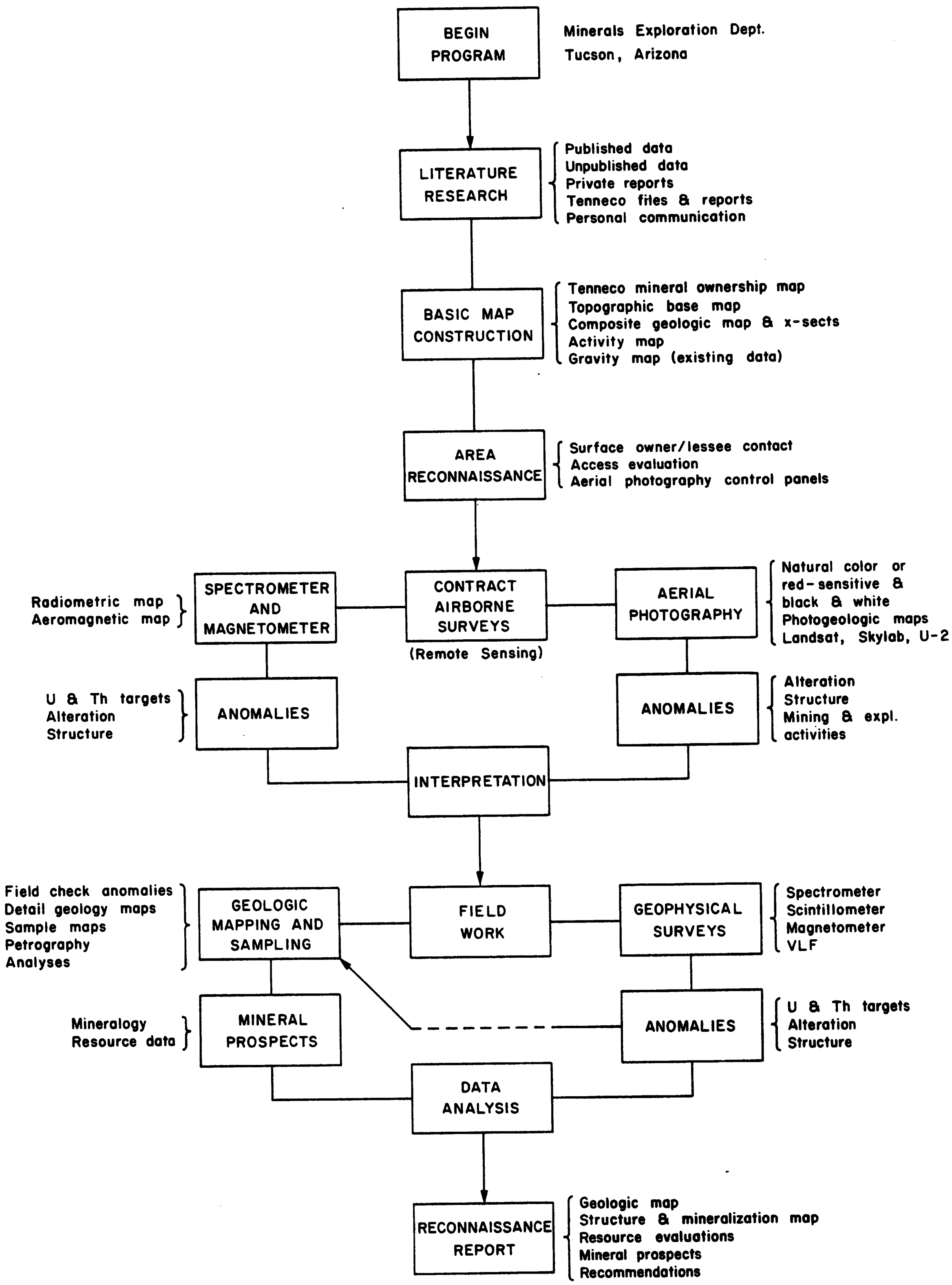


Figure 2-1. Flow chart of mineral reconnaissance program.

some Tenneco (Houston) in-house facilities were used to analyze 425 samples of which 21 were stream-sediment, 46 water, 172 soil, and 186 rock samples. Melvin Jans, vice president of Tenneco West, Inc., made frequent contact with the exploration office and provided relevant data upon request. Dick Rainey, foreman of the Little Boquillas Ranch for the Western Farm Management Company, assisted field work by providing keys to locked gates and informing ranch hands of our presence. It is important to note that the exploration work on the Little Boquillas Ranch was very sporadic from 1976 through 1979 owing to manpower requirements on other properties and projects.

AIRBORNE RADIOMETRIC AND MAGNETIC SURVEY

Introduction

As part of the minerals reconnaissance program of the Little Boquillas Ranch, an airborne radiometric and magnetic survey was flown over the property. The purpose of the survey was to locate areas of anomalous uranium and thorium concentrations and to provide magnetic data relevant to base metal exploration and structural geology. It is important to note that airborne radiometric surveys can detect radiation only from the upper-most 1 ft of the surface.

Survey Specifications

Survey flights were initiated by Geophysical Exploration Corporation (Gx) on December 12 and completed on December 15, 1977. A total of 1441 acceptable line miles were surveyed on N-S flight lines. Line spacing was 0.5 mile with an instrument terrain clearance of 400 ft. Figure 2-2 shows the radiometric survey coverage and Figure 2-3 shows the magnetic survey coverage. Magnetic survey coverage was less than radiometric survey coverage owing to pre-existing aeromagnetic data.

Gx employed a survey package comprised of an EG&G spectral radiation system containing 1025 cubic inches of detector crystal volume, a Varian proton-precession magnetometer, analog and digital recording systems, and a doppler radar navigational system. Spectrometer data were recorded in four channels, 1) uranium

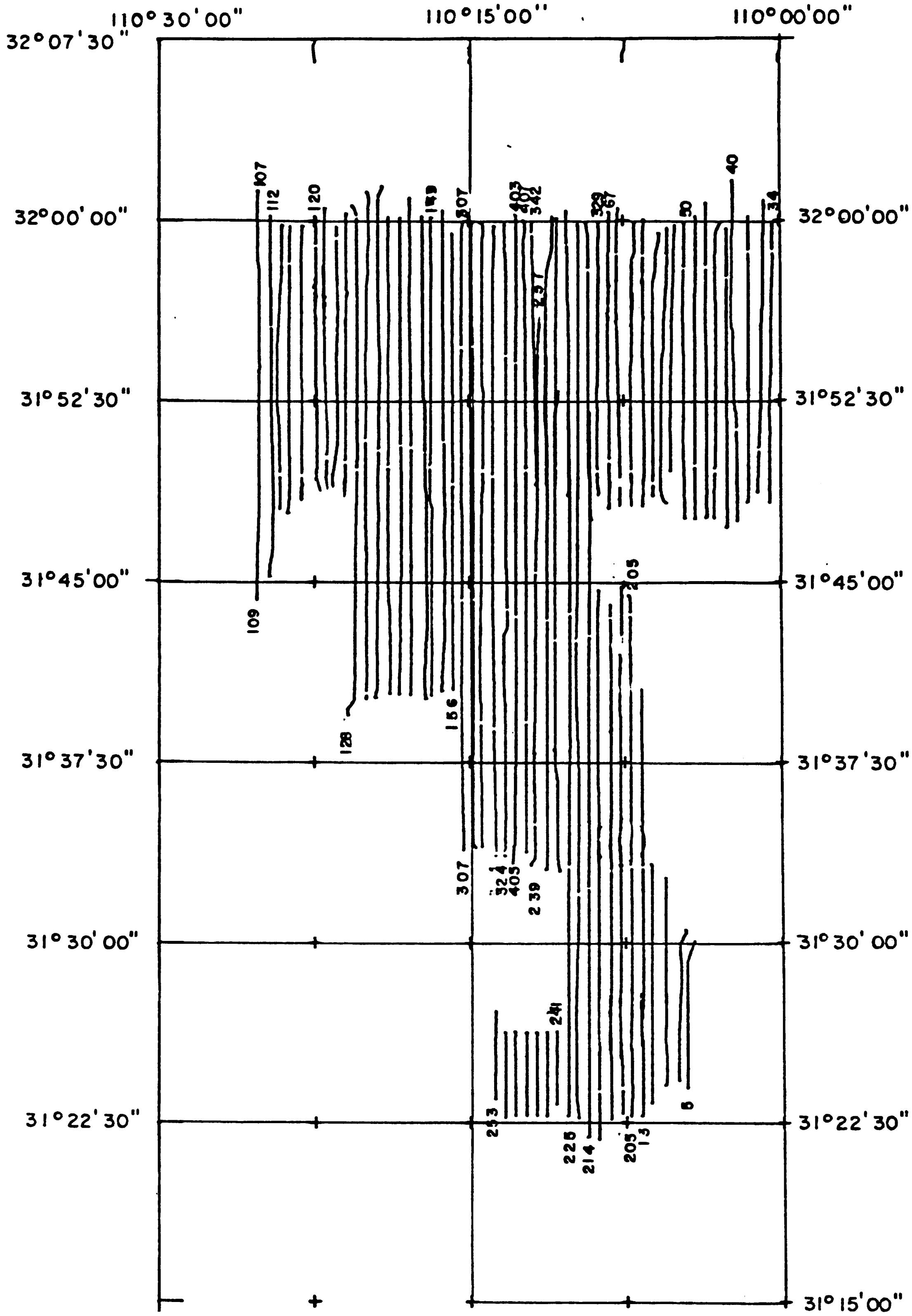


Figure 2-2. Gx airborne radiometric survey.

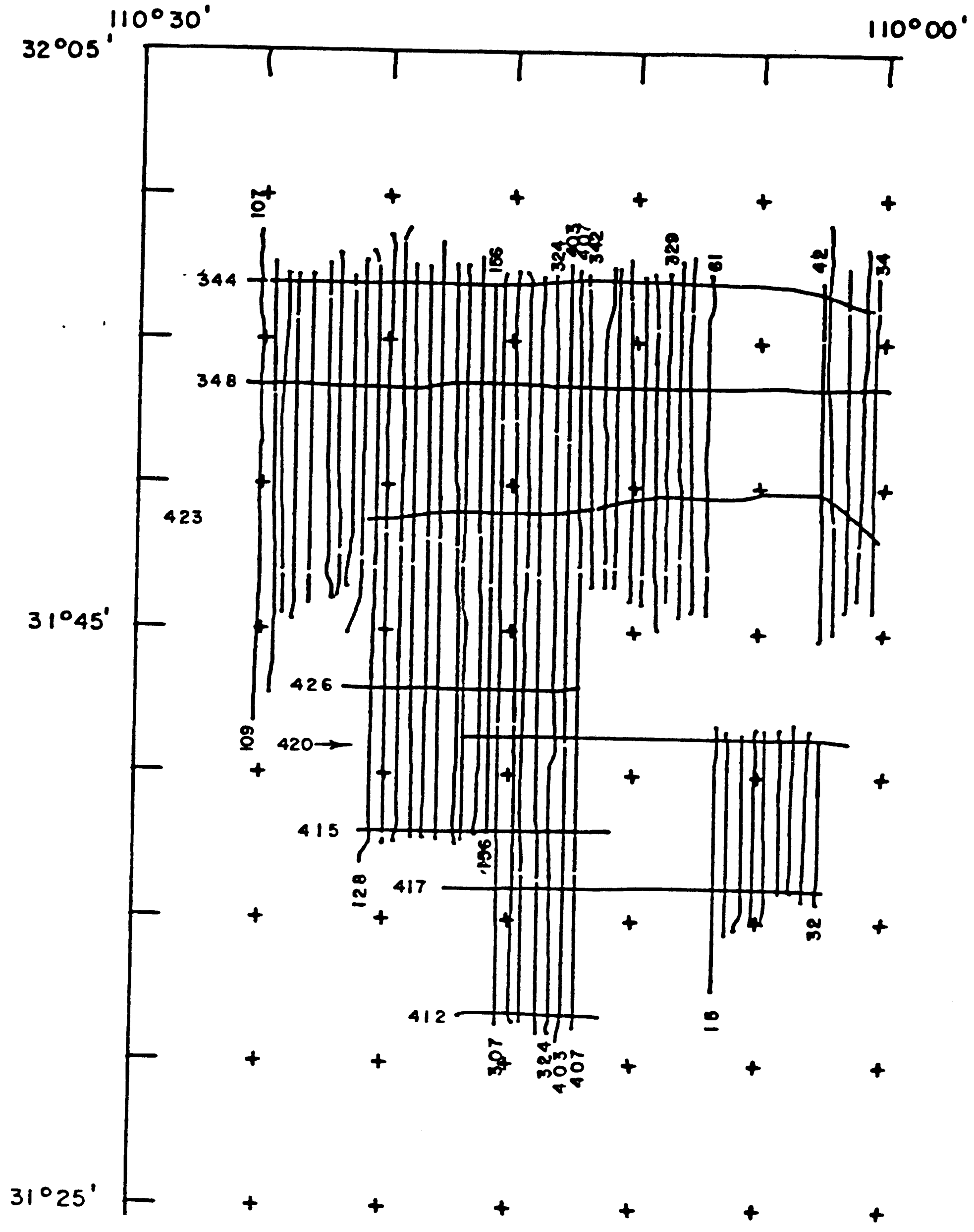


Figure 2-3. Gx aeromagnetic survey.

(^{214}Bi), 2) thorium (^{208}Tl), 3) potassium (^{40}K) and gross count. Diurnal magnetic conditions were monitored during survey flights at the U. S. Geological Survey Magnetic and Seismological Observatory in Tucson. The sensing package was mounted in a 680F AeroCommander, twin-engine, fixed-wing aircraft.

Data

Radiometric data were presented by Gx as gross count and uranium "contour-cut maps" (1:24,000) which were hand-contoured by Tenneco geologists during 1978 and later reduced and compiled at a scale of 1:62,500. Data were contoured to fit the geomorphic trend of the Stronghold Granite pediment, Whetstone pediment and San Pedro River Valley. All radiometric data were normalized by computer to 400 ft terrain clearance. No correction for Compton scattering was made. Aeromagnetic data were prepared by Gx as a contour map at a scale of 1:62,500. Miniplots displaying magnetic profiles, radiometric profiles and terrain clearance supplemented contour maps. A computer-printout listing of all uncorrected and corrected data was also provided. Digital data on magnetic tape, 35mm fisheye tracking film, index maps, fiducial maps, contour-cut maps, aeromagnetic map, and miniplots are stored at Digitcon in Houston, TX.

PROPERTY DESCRIPTION

INTRODUCTION

The Little Boquillas Ranch, Cochise County, AZ is nearly 113,000 acres of large fee land parcels distributed within the San Pedro River valley. The ranch extends for about 48 miles from just north of the small town of Benson southward to within a few miles of the international border with Mexico (Fig. 3-1). Tenneco acquired the Little Boquillas Ranch when it purchased Kern County Land Company in 1967. Kern County Land Company had previously acquired the ranch from the Boquillas Land and Cattle Company in 1959. The Boquillas Land and Cattle Company acquired the grants from the U.S. Government in 1899. At the request of the Minerals Exploration Department, a land status map (Pl. 1) of the ranch was compiled during 1977 in Houston by Robert F. Reed, senior title analyst.

LAND STATUS

The ranch is owned 100% by Tenneco West, Inc. and consists of 112,,745.71 acres (Pl. 1). This includes lands near Sierra Vista, St. David, and Benson which are undergoing commercial, agricultural and residential development. It is policy for Tenneco West, Inc. to retain mineral rights when land parcels are sold.

The nucleus of the actual ranch is two Mexican land grants which straddle the San Pedro River: 1) the San Juan de las Boquillas y Nogales Grant (from which the ranch was named) and 2) the San Rafael del Valle Grant. Tenneco does not retain rights to gold and silver on the Mexican land grants (retained by Federal Government). In addition to various blocks of fee land, the ranch also includes two non-producing patented claims consisting of a total of 41.30 acres and owned 100% by Tenneco Oil Exploration and Production. A land status listing is presented in Table 3-1.

LAND USE

Land use is quite varied on the Little Boquillas Ranch. The majority of ranch land is leased for cattle grazing by the Victorio Land and Cattle Company under

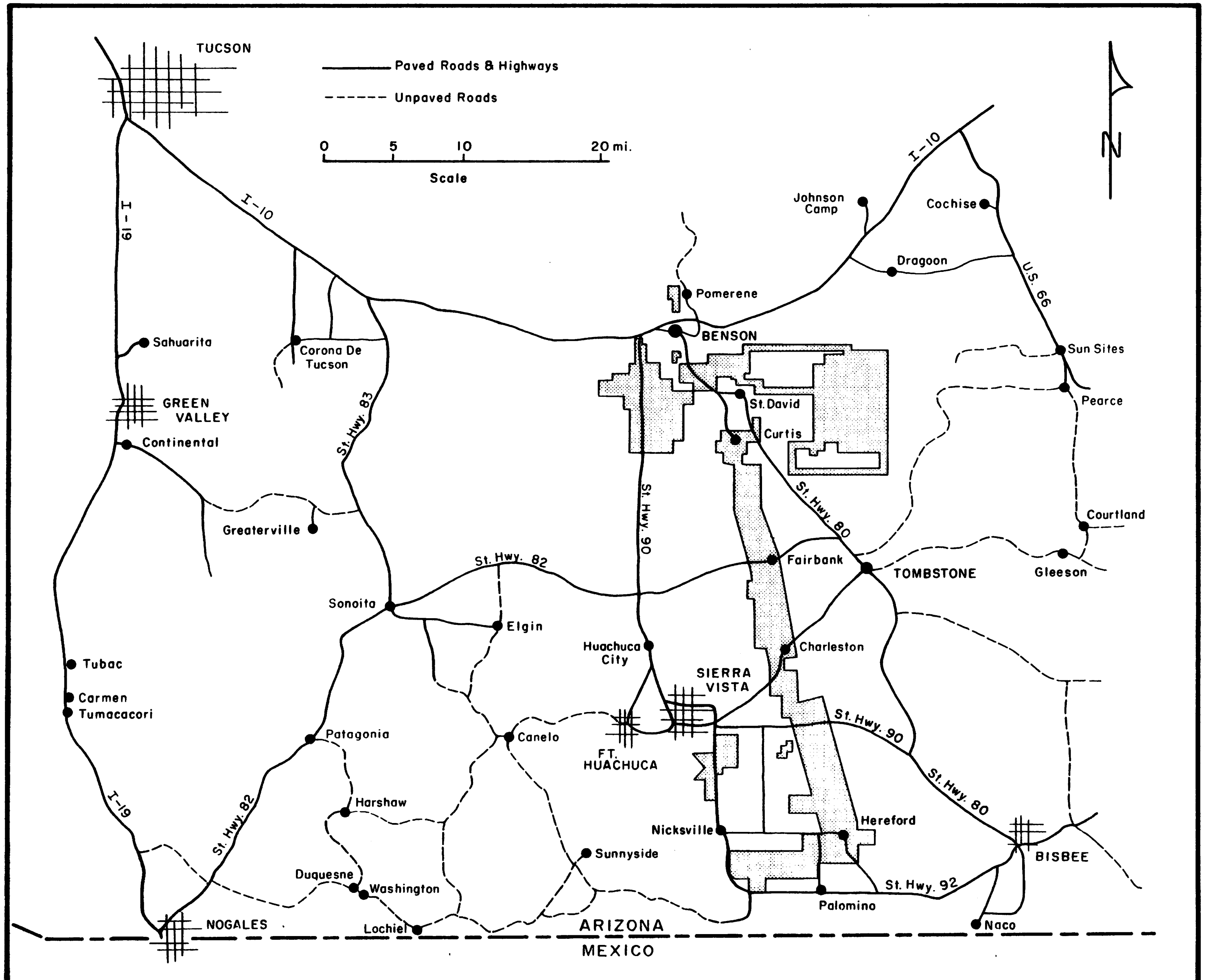


Figure 3-1. Index map.

Table 3-1. Land status of the Little Boquillas Ranch. (Some surface fee land has been sold by Tenneco West since these data were compiled).

Land Classification	Acres	Owner	Other
Fee	106,834.90	TWI	No rights to Au and Ag on grants. No rights to fissionable materials in SW¼, Sec. 20, T.23 S., R.22 E.
Fee, mineral only	2,908.21	TWI	
Fee, surface only	2,956.41	TWI	
TOTAL	112,745.71		
Patented claim, "Dean Richmond"	20.66	TOEP	Patent No. 6386 (1882) claimed on grant for Au & Ag.
Patented claim, "Rad Crow"	20.64	TOEP	Patent No. 44886 (1907)

the supervision of the Western Farm Management Company. On a southern portion of the ranch, Tenneco West has approximately 1000 acres of sugar beets under cultivation and is conducting research concerning the cultivation of jojoba beans. In the Sierra Vista area, Tenneco Realty Development Corp. is actively pursuing residential and commercial development to include the operation of the nine-hole Pueblo del Sol golf course.

CLIMATE

The climate on the Little Boquillas Ranch and adjacent areas is semiarid and characterized by warm summers and mild winters. The average yearly rainfall ranges from about 11 inches in the San Pedro River valley to nearly 25 inches in the mountain areas. Most of the rainfall occurs in July, August and September when moist unstable air invades the area from the Gulf of Mexico. A secondary wet season occurs in the winter when extensive storm systems move into the area from the Pacific Ocean, producing widespread precipitation. The mean maximum temperature in summer months is about 95°F and the mean minimum temperature in winter months is approximately 47°F. At Benson the annual potential evapor-transpiration is three times greater than the annual precipitation.

ACCESSIBILITY

The Little Boquillas Ranch is easily accessible via paved State Highways 90, 82 and 92, U.S. 80 and the Charleston Road (Fig. 3-1). Numerous dirt roads allow good access to various parts of the ranch. Poor access is present chiefly along deeply dissected portions of alluvial surfaces which converge along the axis of the San Pedro River valley.

PHYSIOGRAPHY

The Little Boquillas Ranch is within the upper San Pedro River valley which is a NW-trending linear trough in the Mexican Highland section of the Basin and Range province (Fig. 3-2). The valley is wide with low relief. On the east, the valley is flanked by the Little Dragoon, Dragoon and Mule Mountains and on the west by the Rincon, Whetstone, Mustang and Huachuca Mountains. Valley elevations range from 3400-4800 ft and adjacent ranges are 6000-9466 ft in elevation. The low Tombstone Hills are near the axis of the valley and appear to be an extension of the Mule Mountains trend.

The San Pedro River flows northward with frequent meanders (meander amplitude up to 1 mile) suggestive of a mature geomorphic age, however, rejuvenation is indicated by entrenchment. From the base of bounding mountains, wide pediments (local Whetstone and Tombstone surfaces) and alluviated surfaces slope gently toward the river where they locally form bluffs and scarps. Dissection of these surfaces is moderate to extensive. The San Pedro River has cut a lower flat surface (local Aravaipa surface) and has since entrenched itself 20-50 ft below this lower surface. A map of the physiographic surfaces was presented by Gilluly (1956).

Most of the acreage on the Little Boquillas Ranch consists of moderately- to highly-dissected alluviated surfaces which often inhibit access. Some floodplain topography is present along the San Pedro River as are some low volcanic knobs at Charleston.

VEGETATION AND WILDLIFE

Hawthorne and others (1979, 8 p.) described seven habitat types found on the Little Boquillas Ranch. The principal vegetation is desertscrub which inhabits the lower Sonoran life zone. This zone is prevalent on the northern 75% of the ranch and is characterized by large areas of thorny brush to include white-thorn, allthorn and Mexican crucillo. Creosotebush-tarbush is also present as are various native cacti. At about 4000 ft in elevation, the lower Sonoran life zone is transitional into the upper Sonoran life zone which is characterized by desert grassland and cacti. The upper Sonoran life zone becomes dominant at 4200 ft elevation and is found at the base of mountain fronts and in the Hereford area.

Mammalian species on the ranch consist chiefly of rodents, rabbits, deer, coyotes, foxes, bobcats, javelina, porcupines, racoons and squirrels. Avifauna are numerous and include quail, roadrunners, owls, hawks, dove and migratory waterfowl. The reptilian community is typical of that indigenous to the arid southwest and include various species of snakes and lizards.

During November 27, 1978 through December 8, 1978, the U. S. Fish and Wildlife Service conducted a reconnaissance field survey of a portion of the Little Boquillas Ranch in response to the "Unique and Nationally Significant Wildlife Ecosystems Program". The study was conducted by Mr. Billy J. Hawthorne (wildlife biologist), Mr. James A. Neal (wildlife biologist) and Mr. L. Steve Waide (realty specialist).

The U. S. Fish and Wildlife Service study area was comprised of approximately 49,500 acres of Tenneco land, of which 17,355 acres were on the San Juan de las Boquillas y Nogales Grant and 17,474 acres were on the San Rafael del Valle Grant. An additional 14,600 acres outside of the two land grants completed the study area. This totals approximately 43% of the Little Boquillas Ranch.

The study concluded that the Little Boquillas Ranch along the San Pedro River is an excellent candidate for acquisition as a national wildlife refuge and that action be taken to preserve wildlife values. This conclusion, although not adequately substantiated, is in direct conflict with development of mineral resources on the Little Boquillas Ranch.

PREVIOUS AND CURRENT WORK

INTRODUCTION

Numerous geologists have conducted field work within the general study area. The most significant studies have been conducted by the U. S. Geological Survey and various universities, particularly the University of Arizona. The bibliography in this report lists much of the more relevant geologic literature concerning the Little Boquillas Ranch and adjacent areas.

GEOLOGY

The geologic map of the Little Boquillas Ranch and adjacent areas (Pl. 2) was compiled chiefly from previous studies by the U. S. Geological Survey. Perhaps the most important work is the "General geology of central Cochise County, Arizona" by Gilluly (1956). Gilluly's field work included substantial portions of the Little Boquillas Ranch, particularly in the Tombstone Hills and Dragoon Mountains areas. Subsequent U. S. Geological Survey studies include Cooper (1960, northern extremity of the Dragoon Mountains area), Cooper and Silver (1964, Little Dragoon Mountains area), Hayes and Landis (1964, Mule Mountains area), Creasey (1967, Whetstone Mountains area), Hayes and Raup (1968, Huachuca Mountains area), and Drewes (1979, tectonic map). Two significant university-supported works important to this report are Gray (1965, St. David area) and Newell (1974, Tombstone-Charleston area). Other relevant theses and dissertations are referenced in the bibliography.

ECONOMIC GEOLOGY

The Little Boquillas Ranch is within the southwestern copper province of the United States. Owing to this locality, most geologic work concerning economic geology within the region has been directed towards porphyry copper deposits and associated metals. General works concerning porphyry copper deposits in the southwestern United States include Schmitt (1933, 1959), Mauger, Damon and Giletti (1963), Mabey and Griscom (1963), Schwartz (1966), Schmitt (1966), Titley (1966), Stringham (1966), Brant (1966), Moore, Damon, and Livingston (1966), Guilbert and Sumner (1968), Heidrick and Rehrig (1969), Lowell and

Guilbert (1970), Rose (1970), Carson (1970), Titley (1972), Rehrig and Heidrick (1972), Stillitoe (1973), Lowell (1974), and Greeley (1978).

Numerous workers have also directed studies of mining districts and prospects within the study area. The Little Boquillas Ranch is encompassed by portions of four mining districts: 1) Dragoon (Golden Rule), 2) Middle Pass, 3) Whetstone, and 4) Tombstone (Pl. 3). The ranch is also in near proximity to the Cochise, Hartford (Huachuca) and Warren (Bisbee) mining districts.

The Tombstone mining district is perhaps the most important district in respect to the Little Boquillas Ranch. Many workers have investigated the geology, argentiferous ores and base metals of the district. Among the long list of workers are Church (1882), Goodale (1889), Blake (1902), Church (1903), Ransome (1920), Goodale (1927), Rasor (1937), Butler and Wilson (1937), Rasor (1938), Butler and Wilson (1938), Tenney (1938), Meyer (1939), Butler and Wilson (1942), Devere (1960), Lee (1967), Newell (1974), and Devere (1978).

Geologic studies concerning petroleum and natural gas potential include numerous authors. Relevant works include Stoyanow (1925), Holm (1938), Wengerd (1959, Little Boquillas Ranch), Zeller (1959), Buck (1961), Barwin (1969), Kottlowski (1971), Koester (1972), Koester and Conley (1972), Conley (1975), Grocock (1975), Greenwood, Kottlowski, and Thompson (1977), Crowley (1978), Heylmun (1978), Thompson, Tovar, and Conley (1978), and McCaslin (1979). Test well locations are described by Pierce and Scurlock (1972), Scurlock (1973), and Conley and Stacey (1977). Numerous geologists have published works relevant to the stratigraphy of favorable petroleum formations.

Only three reports have been directed specifically towards the economic geology of the Little Boquillas Ranch. These works include Spellmeyer (1927, 19 p.), Peale (1949, 17 p.), and Wengerd (1959, petroleum potential, 59 p.). Of these, none adequately described the geology and mineral potential of the ranch.

GEOPHYSICS

Published aeromagnetic investigations covering the Little Boquillas Ranch and adjacent areas include those of Dempsey and Fackler (1963), Andreasen (1965), and Sauck and Sumner (1970a and 1970b).

Published gravity maps include those by West and Sumner (1973), Aiken, Schmidt and Sumner (1975) and Sumner (1976). Aiken (1978) reported on gravity and aeromagnetic anomalies of southeastern Arizona.

In 1968, Aero Services Corporation flew aeromagnetic surveys for Tenneco over selected portions of the Little Boquillas Ranch as part of a copper exploration program. During 1974-75, Texas Instruments, Incorporated flew a reconnaissance airborne radiometric and magnetic survey over the Nogales $1^{\circ} \times 2^{\circ}$ quadrangle which includes the Little Boquillas Ranch. This work was conducted as part of a uranium evaluation program under contract for the U. S. Energy Research and Development Administration (now U. S. Dept. of Energy). In 1977, Geophysical Exploration Corporation (Gx) flew a detail, airborne, radiometric and magnetic survey over the ranch for Tenneco Oil Company to delineate areas of potential uranium concentrations (this report).

Induced polarization, resistivity and/or ground magnetic surveys were conducted on selected portions of the ranch by Barringer Research Corporation (1966, no data available), Canadian Aero Mineral Surveys, Limited (1968-1970 for Tenneco), and Texasgulf Western, Incorporated (1979). All of these surveys were in search of base metal deposits (Pl. 3).

Some seismic work has been conducted on the ranch. A seismic refraction survey on a small portion of the ranch near Fairbank was conducted by Spangler (1969) as part of a hydrogeology study. During 1979, Western Geophysical Company conducted in-house vibroseis surveys over portions of the ranch (Pl. 3).

HYDROLOGY

Investigations concerning hydrologic conditions on the Little Boquillas Ranch and adjacent areas include those by Lee (1905, San Pedro Valley), Clarke

(1914, Contention Mine, Tombstone) Bryan, Smith and Waring (1934, San Pedro Valley), Hollyday (1963, mine dewatering, Tombstone area), Brown, Davidson, Kister and Thomsen (1966, Fort Huachuca area), Spangler (1969, Walnut Gulch watershed, Tombstone area), Wallace and Cooper (1970, San Pedro River basin), Roeske and Werrel (1973, San Pedro River valley) and the U. S. Geological Survey (1978, Arizona annual summary). The Water Resources Division of the U. S. Geological Survey is presently (1979) conducting a ground water study of the upper hydrologic basin of the San Pedro River Valley which encompasses the entire Little Boquillas Ranch.

Studies concerning a potential dam site on the San Pedro River at Charleston include those by the U. S. Conservation Service (1936), U. S. Corps of Engineers (1944) and the U. S. Bureau of Reclamation (Gray, 1968).

HISTORY OF EXPLORATION AND MINERAL-RELATED WORK

INTRODUCTION

This historical section is devoted primarily to exploration and mineral-related work conducted specifically on the Little Boquillas Ranch. Data were compiled from Tenneco files, personal communications and relevant publications. Much of the data are sketchy and incomplete. A historical time line is presented in Figure 5-1. Plate 3 shows the location of historical railroads and millsites and past and recent geological surveys.

SONORA EXPLORING AND MINING COMPANY, 1857

The first mineral location on the Little Boquillas Ranch (and also in the general Tombstone mining district) was made in 1857 by Frederick Brunckow on the San Juan de las Boquillas y Nogales Grant near Charleston. At the time of the silver discovery, Brunckow was an engineer for the Sonora Exploring and Mining Company of New York. A subsequent mine ensued but failed, partly due to Brunckow's death and also due to the discovery of high-grade, silver-lead ore in Tombstone during 1878. The mining claim was later relocated as the "Dean Richmond" and patented in 1882. Brunckow's mine workings on the "Manilla" vein are commonly known as the "Bronco" workings or shaft. Peale (1949, p. 5) reported that Brunckow may have mined "some very rich ore", however, only low grade values of silver, gold, lead, zinc and vanadium are present in the old workings.

MILLING OPERATIONS, 1879-1886

The mill town of Charleston was founded in 1879 on the San Juan de las Boquillas y Nogales Grant by the Tombstone Mill and Mining Company. Charleston provided the labor force for various silver mills along the San Pedro River and reached a population of 600-800 inhabitants. The Gird Mill, a ten-stamp, water-driven mill, was the first mill erected on the banks of the San Pedro River to treat Tombstone silver-lead ores and operated from 1879-1884(?). Ore was transported 9 miles from Tombstone at the cost of $3.50 per ton (Devere, 1978, p. 315).

In, 1880, the Corbin Mill (Corbin Mill and Mining Company), a steam-driven plant of larger capacity, was added and later a smelter was constructed. At least ten other mills were constructed by various companies along the river on the San Juan de las Boquillas y Nogales Grant. Among the more prominant were the Boston and Arizona Mill (Boston and Arizona Smelting and Reduction Company, 1880-1884), Contention Mill (The Western Mining Company, 1879-?), Grand Central Mill (Bunker Hill Mines Company and Grand Central Mining Company, 1880-1886), and Sunset Mill (1880-1884?). Lesser mills included the E. Clifford, Hill, Gray, Masons, Sommers, and Wild. The mill towns of Fairbank and Contention City were also founded on the grant. With the discovery of deep water at Tombstone in July, 1881, however, the river mills were eventually abandoned as new mills were constructed near Tombstone. Today, old mill tailings, slag, and foundations are still present on the Little Boquillas Ranch.

NEW MEXICO AND ARIZONA RAILROAD, 1881-1882

A railroad line was constructed along the Babocomari River to Fairbank and between Benson and Fairbank during 1881-1882 to service the mines.

ARIZONA AND SOUTHEASTERN RAILROAD, EARLY 1880's

A railroad line was constructed between Fairbank and Douglas during the early 1880's to service the mines.

SANTA FE RAILROAD, 1883-1884

A railroad line was constructed between the Southern Pacific Railroad near Benson to Fairbank during 1883-1884 to service the mines.

SPANISH-AMERICAN WAR PERIOD, VEIN PRODUCTION, 1898

At about the time of the Spanish-American War (1898), a local man named H. T. Fisher and a group of men from Pittsburgh, PA developed the Manilla, Honolulu, Josephine and other veins near Charleston. This group did quite a bit of work on the veins within the boundaries of the San Juan de las Boquillas y Nogales Grant (Spellmeyer, 1927). No production data are available.

KNEAR FIRE CLAY PRODUCTION, 1900 (?)

Spellmeyer (1927) reported that black clay was produced from the Little Boquillas Ranch at the base of the Whetstone Mountains. The clay was reportedly used for bricks at the old smelter at Benson and was in demand for lining in copper converters at Douglas smelters. The clay has since been determined unsatisfactory for use as a fire clay.

EL PASO AND SOUTHWESTERN RAILROAD, 1902-1903

A railroad line was constructed between Ft. Huachuca, Lewis Springs and Douglas during 1902-1903 to service the mines.

GRAND CENTRAL TAILINGS TREATED, 1905

During 1905, the Slime Tailings Company attempted to treat the Grand Central Mill tailings for silver and gold recovery (Butler and Wilson, 1938).

RAD CROW CLAIM, 1907

Peale (1944, p. 12) reported the the "Rad Crow" claim was undoubltedly meant to have been the "Red Crow" claim but the misspelling is official. The only sign of mineralization is some iron staining. Peale suggested that the claim was located and patented in 1907 to hold a spring which occurs at the southwest end of the claim. Ironically, this claim is now believed to be in near proximity to Asarco drill holes which have reportedly encountered a deep porphyry copper deposit.

GALLAGHER LODE CLAIMS, 1916-1922

Between 1916 to 1922, the Gallagher brothers located 11 lode claims within the boundaries of the San Juan de las Boquillas y Nogales Grant. Several shafts were dug and some ore (silver, gold, lead, vanadium ?) was shipped. In 1923, the claims were submitted for patent. After a long court battle with the Boquillas Land and Cattle Company, the Arizona State Supreme Court ruled that the claims were invalid. No production data are available.

WORLD WAR I, VEIN PRODUCTION, 1917-1918

During World War I (1917-1918), the interest in alloy metals and the high price of silver stimulated a renewed period of prospecting. Spellmeyer (1927, p. 13) reported that there was some mining for manganese and vanadium on the Dean Richmond claim. No production data are available.

GRAND CENTRAL MILL TAILINGS REWORKED, 1925-1926

From June 1925 to September 1926, approximately 25,000(?) tons of mill tailings from the Grand Central Mill were reworked by the Grand Central Mining Company, headed by Lewis Douglas and Harry Hendrickson. The tailings were trucked to a 150 ton floatation plant at Fairbank for reprocessing.

SPELLMEYER MINERAL RECONNAISSANCE, 1927

The earliest report available concerning the "mineral possibilities" on the Little Boquillas Ranch is by S. A. Spellmeyer (1927). The study was conducted for the Boquillas Land and Cattle Company. Each land parcel was visited by Spellmeyer and further examination was made in promising areas. Spellmeyer summarized that the best potential on the ranch is for oil, lead and fire clay. He further stated that petroleum indications are sufficient to warrant property evaluation by a petroleum geologist.

U. S. SOIL CONSERVATION SERVICE, CHARLESTON DAM SITE STUDY, 1936

The U. S. Corps of Engineers (1944, p. 2) reported that in 1936 the U. S. Soil Conservation Service conducted topographic and geologic mapping of a potential dam and reservoir site on the Little Boquillas Ranch along the San Pedro River at Charleston. No data are available.

U. S. CORPS OF ENGINEERS, CHARLESTON DAM SITE STUDY, 1942

In 1942, the U. S. Corps of Engineers investigated a short, narrow canyon at Charleston as a site for a concrete gravity dam. The study included topographic and geologic mapping, core drilling and limited laboratory testing. Available data are presented in a draft report (U. S. Corps of Engineers, 1944).

GRAND CENTRAL MILL TAILINGS SHIPPED TO DOUGLAS SMELTER, 1947-1948

During 1947-1948, approximately 100,000(?) tons of old mill tailings were trucked from the Grand Central Mill to Fairbank and shipped by rail to the Douglas smelter for use as a silica flux. The tailings were purchased from the Boquillas Land and Cattle Company for $0.15/ton(?) by Anthony Giacoma and sold to Phelps Dodge. Giacoma's payment from Phelps Dodge consisted of the recovered gold and silver values which ran about $4-$5/ton (personal commun., Joseph T. Castles, III, 1979). Peale (1949) also reported shipment of tailings from the Grand Central Mill, however, he indicated that 12,082 tons were sold to the Douglas smelter at the time of his report (Jan., 1949).

PEALE MINERAL RECONNAISSANCE, 1948

During August 22 through October 9, 1948 (19 days), Rodgers Peale, mining geologist, conducted a mineral evaluation of the Little Boquillas Ranch for Kern County Land Company. Peale (1949) reported that no mineralization of "importance" was observed. The most significant contribution by Peale is his geologic sketch maps and cross sections of old mine workings on veins near Charleston, which are now too dangerous to enter.

WENGERD PETROLEUM STUDY, 1959

In 1959, S. A. Wengerd, consulting geologist, conducted a petroleum evaluation of the Little Boquillas Ranch at the request of Kern County Land Company. Approximately 14 days of reconnaissance field work and three days of literature research were involved. The report is divided into two parts. Part one is compiled from original work by R. A. Zeller, Jr. (field work), T. Beard and L. Bogart (photogeologic analysis), and F. E. Kottlowski (Pennsylvanian stratigraphy). Part two is by Wengerd and gives his personal analysis of the petroleum potential. Wengerd (1959, part 2, p. 18-21) reported that the stratigraphy from late Cambrian through early Cretaceous age is favorable for petroleum, however, subsequent volcanism and tectonism may have "destroyed most of the oil and gas potential". He listed six petroleum prospects and recommended that Kern County Land Company consider a "well-rounded exploratory effort by reliable people".

U. S. BUREAU OF RECLAMATION, CHARLESTON DAM SITE STUDY, 1965-66

During late 1965 and 1966, the U. S. Bureau of Reclamation investigated the Charleston dam site and proposed a thin-arch concrete dam. Bureau geologists conducted detail geologic mapping and drilled and trenched abutment rock and borrow sites. Data were reported in a draft feasibility report by Gray (1968).

BARRINGER RESEARCH CORPORATION, I. P. AND RESISTIVITY SURVEY, 1966

No data available.

SPANGLER HYDROGEOLOGY STUDY, 1967-68

During 1967 and 1968, D. P. Spangler, a graduate student at the University of Arizona, conducted a shallow seismic refraction survey of the Walnut Gulch watershed near Tombstone and included about 2 miles of seismic lines on Tenneco property near Fairbank. The goal of the program was to determine subsurface hydrologic and geologic conditions. The study was completed as a master's thesis (1969) and was supported by the U. S. Department of Agriculture. Spangler constructed several shallow geologic cross sections across Tenneco land along the San Pedro River.

AERO SERVICE CORPORATION, AEROMAGNETIC SURVEYS, 1968

In 1968, Aero Service Corporation was contracted by the Minerals Department of Tenneco Oil Company to fly a fixed-wing aeromagnetic survey over portions of the Little Boquillas Ranch. The survey was designed to detect "contact-type pyrometasomatic copper deposits" (skarns or tactites). The contractor was mobilized in June and the project was completed in October 1968. Approximately 4,160 miles (unsubstantiated) of flight lines were flown on 1/8 mile line spacing at 250 ft terrain clearance. A large portion of this mileage was flown over project areas other than the Little Boquillas Ranch. The survey was designed to be followed up by detail, ground-based, geophysical surveys such as induced polarization, resistivity, and magnetics. Promising anomalies were to be drilled.

CANADIAN AERO MINERAL SURVEYS, LTD., LOCAL GROUND-BASED GEOPHYSICAL SURVEYS, 1968-1970

Various areas of the Little Boquillas Ranch were explored using induced polarization (I.P.), resistivity, magnetic and electromagnetic geophysical techniques in response to anomalies defined by the low-level aeromagnetic survey flown during 1968. Canadian Aero Mineral Surveys, Ltd. was the primary contractor for the Minerals Department of Tenneco Oil Company. I.P. and resistivity methods were employed to detect sulfide mineralization. Most of the I.P. surveys led to ambiguous conclusions with water-saturated clays in alluvium suspected as being responsible for anomalies. Some stronger anomalies were recommended for exploration drilling.

TENNECO EXPLORATION DRILLING, 1968-1971

From 1968 through 1971, at least 17 shallow (175-900 ft?) mineral exploration holes were drilled by Tenneco on or adjacent to Little Boquillas Ranch. Lithologic logs and driller's logs are missing for at least 15 of these holes Past correspondence has provided limited information concerning the drill holes. Personal communication with John Beeder (1977), former Tenneco geologist, revealed that some of the drill holes encountered strong indications of base metal mineralization. Follow-up drilling was not performed owing to the termination of Tenneco's Mineral Department base-metal group in 1974.

TEXAS INSTRUMENTS, INCORPORATED, AIRBORNE RADIOMETRIC AND MAGNETIC SURVEY 1974-1975

Texas Instruments, Incorporated (T.I.) was contracted by the U. S. Energy Research and Development Administration during December 1974 to conduct a high-sensitivity, reconnaissance, airborne, gamma-ray spectrometer and magnetometer survey over the Nogales National Topographic Map series $1^{\circ} \times 2^{\circ}$ quadrangle. This quadrangle includes the Little Boquillas Ranch. The goal of the survey was to define those areas showing surface indications of a generally higher uranium content (uraniferous provinces) where detailed exploration for uranium would most likely be successful. A Douglas DC-3 fixed-wing aircraft was employed. Flight lines were flown north-south on 3 mile line spacing at an instrument terrain clearance of 400 ft. Approximately 50 line miles of survey traversed the Little Boquillas Ranch. The T.I. survey correlated well with ground data and outlined gross radiometric provinces. No significant uranium or thorium prospects were detected on the Little Boquillas Ranch from the T.I. survey.

GIRD MILL SLAG MINED, 1975

During 1975, the Utah Valley Mining Company of Provo, UT bought 3,775 tons of slag at $7.50/ton from Tenneco West, Inc. The slag was removed from the Gird Mill area and was reportedly to be used as a fluxing agent. However, on August 15, 1975, a Mr. Russ Phillips of Agri Leasing in Springfield, MO informed Tenneco that a processing plant was being constructed to remove silver, gold and platinum group metals from the slag. No further data are available.

SOUTHWESTERN EXPLORATION ASSOCIATES, AERIAL PHOTOGRAPHY, 1977 (This Report)

During 1977, the newly-formed Minerals Exploration Department of Tenneco Oil Company contracted Southwestern Exploration Associates of Tucson, AZ to conduct high-red sensitivity, 70mm, aerial photography (1:24,000) of the entire Little Boquillas Ranch. High-red sensitivity film (not infra-red) was employed to enhance detection of mineral alternation. All photography was completed and delivered by September, 1977. Photogeologic interpretations and field work were conducted from the photography by Tenneco geologists (this report).

GEOPHYSICAL EXPLORATION CORPORATION, AIRBORNE RADIOMETRIC AND MAGNETIC SURVEY, 1977 (This Report)

In 1977, the Minerals Exploration Department of Tenneco Oil Company contracted Geophysical Exploration Corporation (Gx) of Boulder, CO to conduct a fixed-wing airborne radiometric and magnetic survey over the Little Boquillas Ranch. The purpose of the survey was to locate areas of anomalous uranium and thorium concentrations and to provide magnetic data relevant to base metal exploration and structural geology. Survey flights were initiated on December 12 and completed on December 15, 1977. A total of 1441 line miles (N-S) were surveyed on 0.5 mile line spacing at a terrain clearance of 400 ft. Anomalies were field checked and sampled. No significant uranium prospects were detected.

U. S. FISH AND WILDLIFE SERVICE STUDY, 1978

During November 27 through December 8, 1978 (12 days), the U. S. Fish and Wildlife Service conducted a habitat reconnaissance of 49,500 acres on the Little Boquillas Ranch. The goal of the project was to determine if Tenneco lands which straddle the San Pedro River contain habitats which should be protected under the "Unique and Nationally Significant Wildlife Ecosystems Program". A 1979 memorandum (Hawthorne and others, 1979) concluded that the ranch area is an excellent candidate for acquisition as a national wildlife refuge. Such a conclusion is in direct conflict with development of mineral resources.

TEXASGULF WESTERN, INCORPORATED, I. P. AND RESISTIVITY SURVEYS, 1979

Permission was granted to Texasgulf Western, Incorporated by Tenneco Oil Exploration and Production to conduct induced polarization (I.P.) and resistivity surveys in three areas on the Little Boquillas Ranch along the San Pedro River. The goal of the surveys were to explore aeromagnetic anomalies (lows) suspected of being alteration zones associated with copper deposits. No significant results were encountered.

WESTERN GEOPHYSICAL COMPANY, VIBROSEIS SURVEY, 1979

A permit was granted to Western Geophysical Corporation by Tenneco Oil Exploration and Production to conduct an in-house vibroseis survey across portions of the Little Boquillas Ranch. Approximately 13.4 line miles of data were collected and processed and provided to Tenneco on a confidential basis.

EOCENE RESEARCH MILL TAILINGS REPROCESSING, 1979

Eocene Research, a small Las Vegas-based ore reclamation firm, signed an agreement with Tenneco during 1979 which allowed Eocene Research to remove and reprocess old mill tailings on the Little Boquillas Ranch for silver and gold. The contract awarded Tenneco $5,000/qtr plus a 7% royalty on recovered precious metals. Approximately 500 tons of tailings were removed from the Grand Central Mill, however, operations ceased in November 1979 owing to leach recovery problems and internal problems within Eocene Research.

GEOLOGY

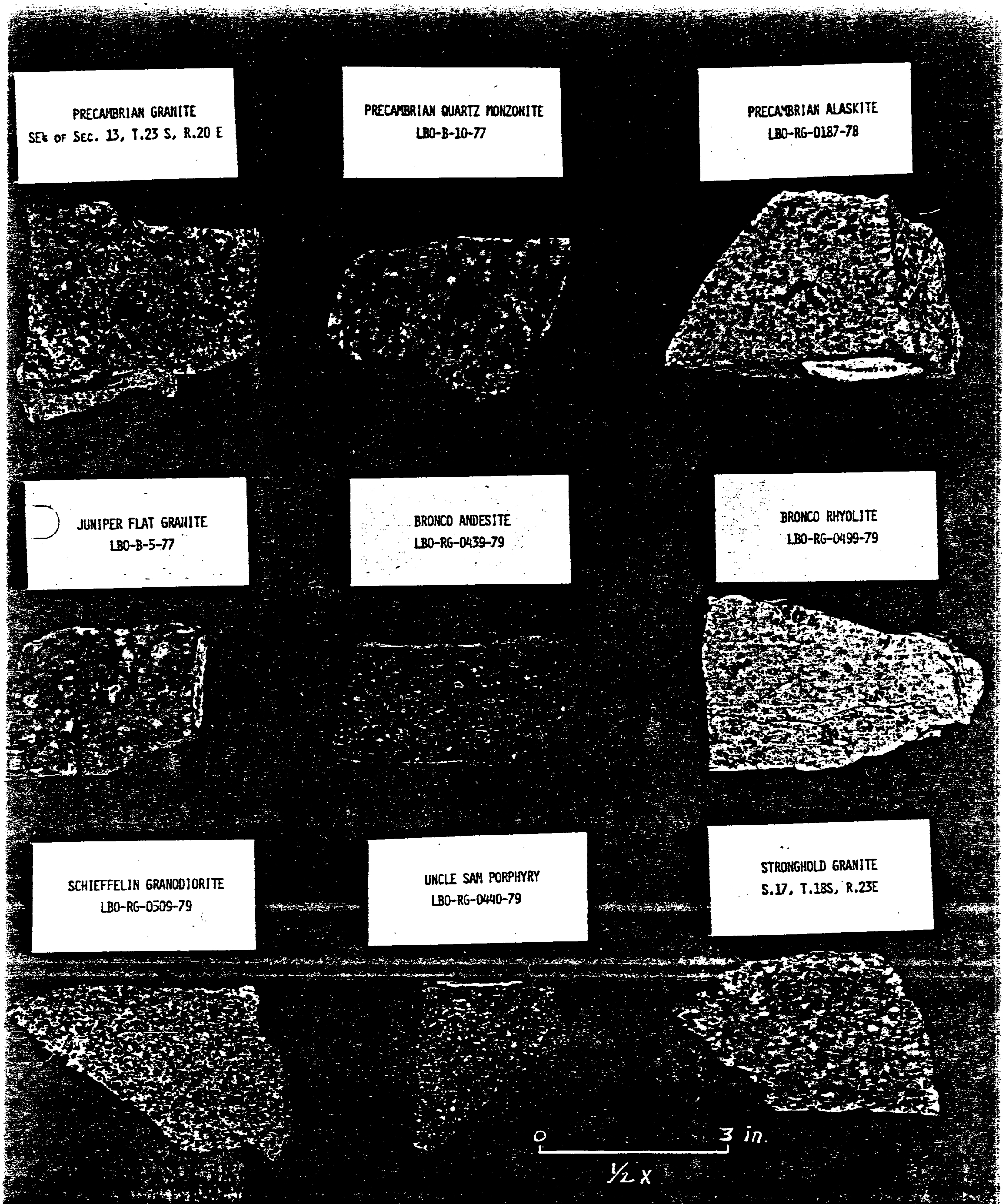
INTRODUCTION

The geology of the Little Boquillas Ranch is diverse and complex. Numerous geologists have studied portions of the ranch and adjacent areas, particularly the bounding mountain ranges (see "Previous and Current Work"). It is the goal of this section to briefly summarize the general geology of the Little Boquillas Ranch and to avoid extensive descriptions which are beyond the scope of this section. Much of the geology is summarized and condensed in accompanying plates which depict surface geology, subsurface geology, stratigraphy, and structural elements. Many aspects of the subsurface geology remain unknown due to limited drill hole and seismic data.

The geology of the Little Boquillas Ranch and adjacent areas is presented at a scale of 1:62,500 in Plate 2a with corresponding geologic cross sections in Plates 2b and 2c. Plate 4 is a composite stratigraphic column of the sedimentary rock units on the ranch and adjacent areas. These sedimentary units are correlated across the study area in the fence diagram of Plate 5. Plate 6 summarizes the igneous rock units. Photogeologic interpretations at a scale of 1:24,000 were made of three areas from red-sensitive 70mm aerial photography. These areas include the Dragoon area (Pl. 7), Whetstone area (Pl. 8), and the San Juan de las Boquillas y Nogales Grant area (Pl. 9). A geologic map and cross sections of the Charleston area (Pls. 10a and 10b) were constructed at a scale of 1:6000.

STRATIGRAPHY

The following is a brief description of the major stratigraphic units on and adjacent to the Little Boquillas Ranch. Plates 4, 5, and 6 depict stratigraphic relationships. Many of these units are present only in subcrop on the Little Boquillas Ranch. The reader is referred to the abundant geologic literature for more detail descriptions. A picture of major igneous rock units is presented in Photograph 6-1.



Photograph 6-1. Major igneous rock units on the Little Boquillas Ranch and adjacent area.

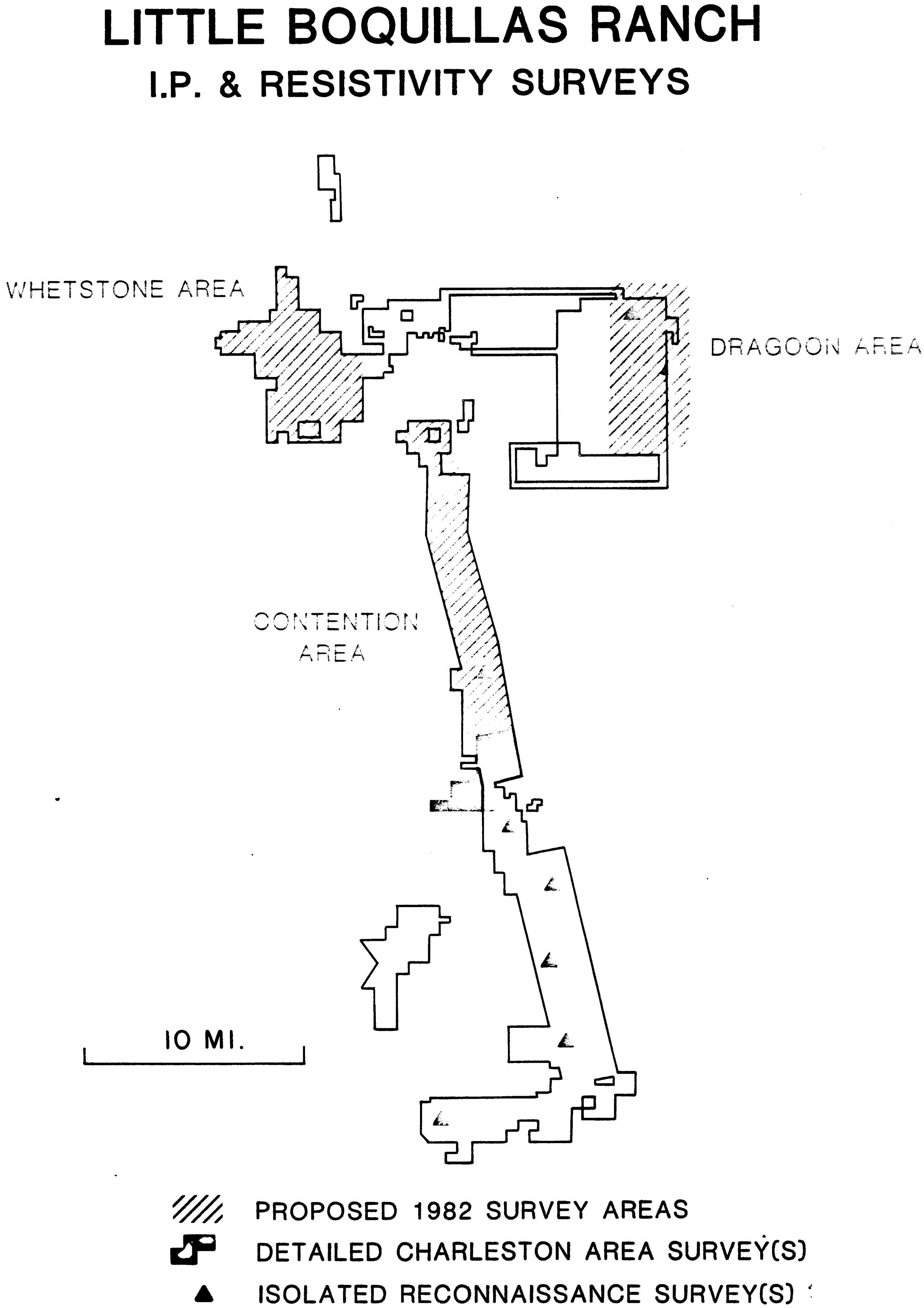
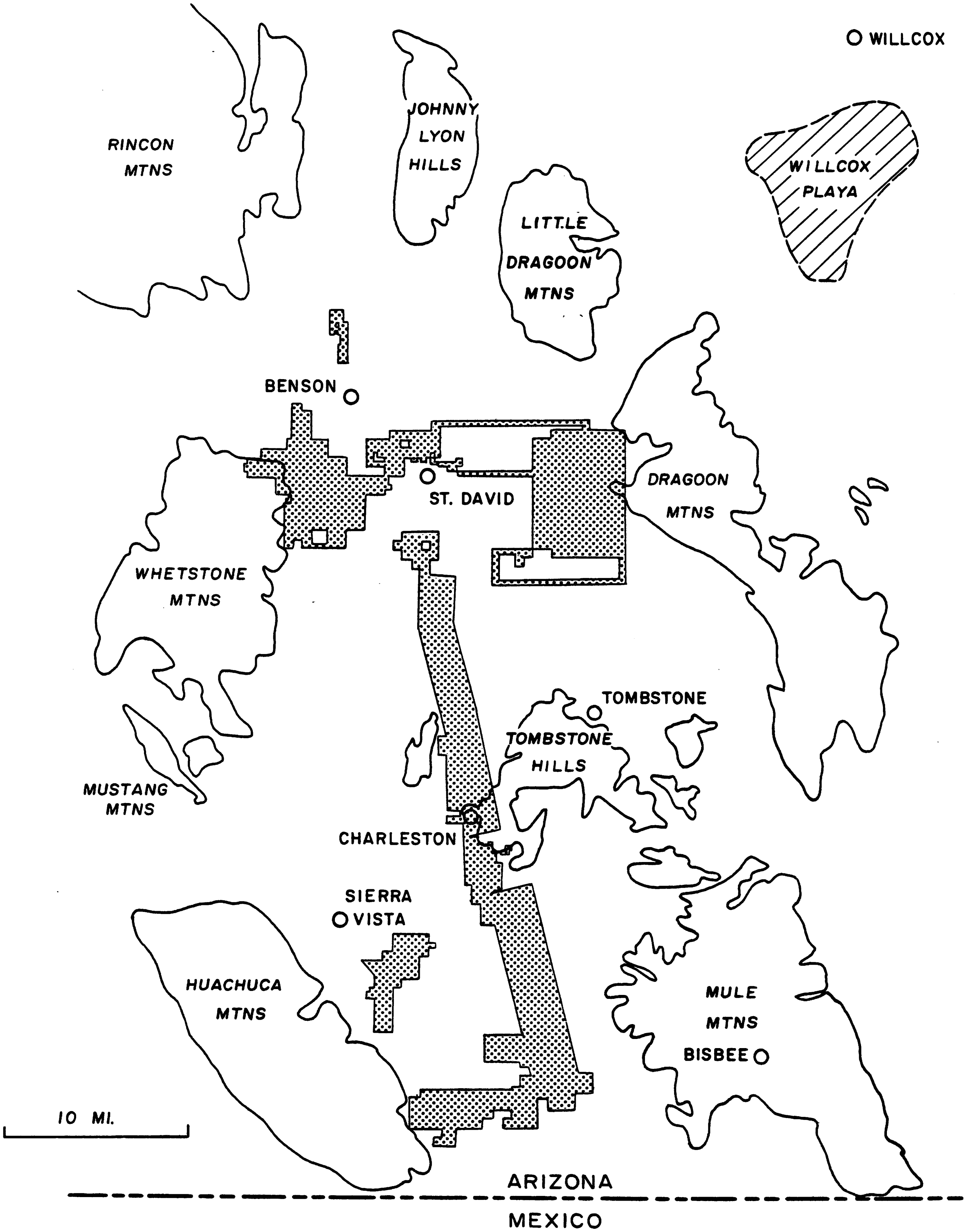


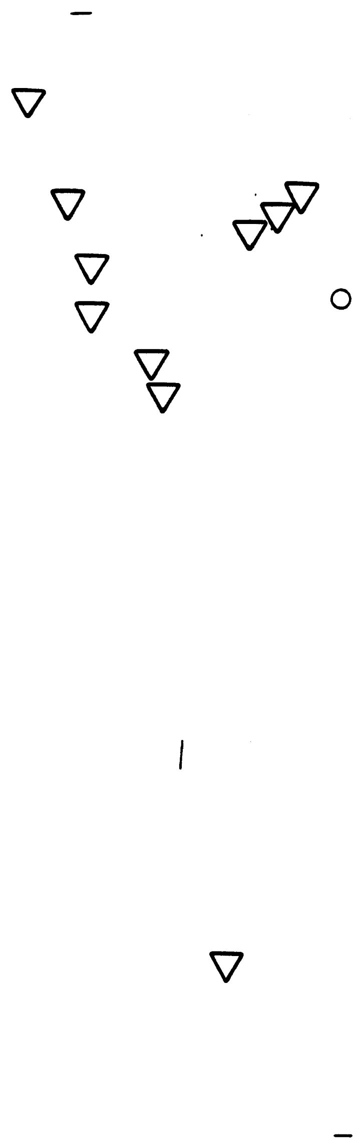
FIGURE 3. Completed and proposed I.P. and resistivity surveys.

MINES AND PROSPECTS, HUACHUCA MOUNTAINS
IN THE VICINITY OF NICKSVILLE,
COCHISE CO., AZ

Mine or Prospect	Location T.R.	Sec.	Mineral Products	Mineralogy	Host Rock(s)	Geology	Type of Operation and Production	References
Reef Mine (Tungsten Reef Exposed Reef, Sitric Primos Chemical Co., Tungsten Reef Mines Co., Exposed Reef Tungsten Co.)	23S 20E SW E cent.	14 15	W, Au, Ag, Pb, Cu, Zn,	Scheelite, oxidized base metal sulphides	Cambrian Abrigo Limestone	Irregular and sporadic bunches and disseminations of scheelite with some gold and silver values and weak, oxidized base metal sulfides along fractures and at joint intersections in a quartz blanket at the base of the Cambrian Abrigo Limestone.	Open cut and adit workings. Minor gold-silver production in early 1900's. Total of several thousand tons of tungsten ore and concentrates produced in 1916-1918, 1934-1942, and 1955-1956.	Webber, 1950, p. 122-156 Wilson, 1941, p. 48-49 Dale, et al, 1960, p. 26-32 ABM file data
Morgan Mine (nugget)	24S 20E SE¼	1	Au, Ag, W	Gold, silver, scheelite	quartz veins in Jurassic (164-167 my) qtz monzonite intrusive and placers	Veins and associated placer Veins are in the Huachuca Qtz. Monzonite pluton. Pluton 7 x 1 mi, NW trending areal extent.	Pits and shaft workings. Gold-silver ore produce from mine and placers in early 1900's and 1939.	ABM file data
Baumkirchner Mine(s) (Crocket Moon, M Lode, International, Golconda, Golden Crown groups; Ariz. Imperial Mines Extension Co., Inter. Gold and Rave Metals Co.)	23S 21E Cen 24S 21E	30 5	Pb, Zn, Cu Au, Ag	Base metal carbonates and sulphides	- Qtz veins in p6 granite - exotic blocks of Pz ls in Triassic-Jurassic volcanics	- Large qtz vein along thrust fault in Precambrian granite. - Spotty and sparse base metal carbonate and sulphide ore in small erratic replacement in exotic blocks.	Many shaft and tunnel workings, only minor test lots of ore, 1925-1937.	Mines handbook, 1926 Mines Register, 1937 ABM file data
Lucky Bell Mine (Lucky Bell Mng. Co.)	24S 21E NW¼ NE¼	5 6	Cu, Pb, Ag, Au	Partially oxidized base metal sulphides	exotic blocks of Pz ls in Triassic-Jurassic volcanics	Small, irregular replacement masses in exotic blocks of blocks.	Shaft and tunnel workings. 15 tons ore produced from 1934-1935.	ABM file data
Zaleski Mine	24S 21E NW¼	7	Au, W	Gold, scheelite	Qtz veins in Jurassic qtz monzonite	Sparse and spotty gold values and high grade pockets of scheelite in qtz veins.	Shaft, adit, and surface workings. Few tons of gold ore produced in the early 1900's and some tons of tungsten ore in later years.	Wilson, 1941, p. 49 Dale, et al, 1960, p. 40

LITTLE BOQUILLAS RANCH





Precambrian Rocks

Pinal Schist

Ransome (1903) applied the name "Pinal Schist" to the crystalline schist of the Pinal Mountains south of Globe, AZ. The name has come into general use in southeastern Arizona to include the ranch area. At the type locality, the formation is described as laminated, gray, sericitic schist with interbedded quartzose "grits". The schist is of marine sedimentary origin with a little amphibolite-schist representing metamorphosed volcanic rocks.

In most areas, the Pinal Schist forms relatively subdued topography and weathers to dark brown or greenish brown. Within the study area, the Pinal Schist ranges in composition from muscovite-quartz schist to chlorite-muscovite-quartz schist and chlorite-albite-quartz schist.

Granite

A NW-trending pluton of Precambrian granite is present in the Huachuca Mountains. The intrusive rock is yellowish to pinkish gray, coarse grained, and prophyritic. Rock texture is holocrystaline with hypidiomorphic phenocrysts of plagioclase, orthoclase, quartz, and muscovite.

Quartz Monzonite

A W-NW-trending pluton of Precambrian quartz monzonite is present in the Whetstone Mountains. The intrusive rock is pinkish gray and coarse grained. Rock texture is holocrystalline with allotriomorphic plagioclase, orthoclase, quartz, and muscovite. Most specimens show propylitic alteration with feldspars weakly sericitized, biotite altering to chlorite, and minor epidote. Subordinate mafic dikes of similar age are sparingly present.

Alaskite

Light-cream colored, medium-grained, Precambrian alaskite intrudes the Precambrian quartz monzonite in the Whetstone Mountains. Rock texture is holocrystalline with hypidiomrophic to allotriomorphic plagioclase, orthoclase, quartz, and muscovite. In general, the alaskite displays weak weathering.

Other

Numerous "other" Precambrian igneous rock occurrences are locally present within the study area and range in composition from aplite to basalt.

Paleozoic Rocks

Bolsa Quartzite

The Bolsa Quartzite is Cambrian in age and ranges 200-600 ft in thickness within the study area. It is more resistant to erosion than any other formation within the region. Weathered surfaces are rusty brown and fresh surfaces are dark brown, red to tan, and commonly show distinctive banding. Gilluly (1956) described the Bolsa as consisting of quartzite conglomerate which grades upward without sharp discontinuity into gritty quartzite. Pebbles of conglomerate are chiefly milky white quartz in the Mule Mountains, Tombstone Hills, and Dragoon Mountains, but in the Whetstone Mountains rose quartz is conspicuous. The pebbles are mostly very well rounded, but some are subangular and most are less than 10 cm in diameter. The matrix is generally pebbly grit. The Bolsa Quartzite represents offshore bar or beach deposits (Hayes, 1978, p. 168) of a sea transgressing over a smoothly worn plain carved upon Precambrian rocks.

Abrigo Limestone

The Abrigo Limestone is Cambrian in age and ranges 400-900 ft in thickness within the study area. It generally forms subdued topography. The contact between the Abrigo and underlying Bolsa is transitional, thereby making the division entirely artificial at many localities. The Abrigo Limestone is divided into three members. The lower member is characterized by silty shale and sandstone which are usually greenish on fresh surfaces and weather dark borwn. The middle member consists almost entirely of thin-bedded limestone and silty limestone which are locally dolomitized. The limestone is bluish gray and locally mottled with yellow. The upper member consists of sandy limestone which grades upward into standstone or quartzite which is light brownish gray on weathered surfaces. The formation represents in intertidal to subtidal shallow marine shelf environment (Hayes, 1978, p. 168, 170).

Martin Limestone

The Martin Limestone is Devonian in age and ranges 200-600 ft in thickness within the study area. It is the least resistant Paleozoic formation and is generally poorly exposed. The Martin unconformably overlies the Abrigo Limestone and is more lithologically variable than any other Paleozoic formation in the area. Alternating beds of clastic and carbonate strata are distinctive features along with fossiliferous (coral) zones. Shale with subordinate sandstone dominates the formation in the Tombstone area. The depositional history of the Martin is complex and includes tidal-flat, lagoonal and carbonate-platform marine environments and associated fluvial environments (Schumacher, 1978, p. 179).

Escabrosa Limestone

The Escabrosa Limestone is Mississippian in age and ranges 500-800 ft in thickness within the study area. The formation is white to light-gray, coarse-grained limestone commonly composed of crinoid stem fragments. The basal section unconformably overlies the Martin Limestone and contains corals and crinoid fragments. Higher in the Escabrosa other fossils, especially brachiopods, are relatively abundant. Neither sandstone nor shale have been found in the formation, but chert bands and nodular chert are common in upper zones. The Escabrosa may be dolomitic in the massive lower part. Marine fossils and a general lack of sand and shale suggest a shallow-marine, clear-water, carbonate-platform depositional environment. Two massive reefs have been identified in the Mule Mountsin.

Black Prince Limestone

The Black Prince Limestone is considered late Mississippian and early Pennsylvanian in age by Cooper and Silver (1964) and Creasey (1967). Ross (1978) considered the Black Prince as Pennsylvanian in age. The formation ranges 0-180 ft in thickness within the study area and unconformably overlies the Escabrosa with conspicuous shale, siltstone, and conglomerate. The basal shale is 10-30 ft in thickness and is commonly maroon or red with green mottling. The overlying fossiliferous limestone is in 1-4 ft beds and is gray with bright mottles of yellow, pink, and green. The basal shale portion of the Black Prince marks an important regional unconformity and may represent residual deposits from the erosion of the underlying Escabrosa Limestone (Gilluly, 1956, p. 35).

All limestone in the Black Prince appears to have been deposited in shallow-marine waters (Ross, 1978, p. 195).

Horquilla Limestone

The Horquilla Limestone is Pennsylvanian in age and ranges 600-1600 ft in thickness within the study area. The formation unconformably overlies the Escabrosa and is much less resistant than the Escabrosa. Limestone beds range 2-5 ft in thickness and are separated by thin interbeds of shaly limestone and shale. Carbonate units are rather pure, weather bluish gray, and are composed mostly of fossil-shell detritus. The lower part of the Horquilla contains oolitic beds and lentils composed of crinoidal debris. Black chert nodules predominate above the lower oolitic beds and decrease upward. In the Tombstone Hills, several small reefs averaging 40 ft in thickness and 200 ft in length are present in the middle or upper part of the formation (Wengerd, 1959). These reefs are massive, show little stratification, and are composed of recrystallized limestone comprised of fossil-shell detritus. Similar reefs have been identified in the Mule Mountains. Ross (1978, p. 193, 196, 197) interpreted the format within the Horquilla as transgressive-regressive marine sequences composed of shallow-shelf, open-shelf, carbonate-bank, bay, and lagoonal depositional environments.

Earp Formation

The Earp Formation is Pennsylvanian-Permian in age and ranges 400-1100 ft in thickness within the study area. Contact with the underlying Horquilla Limestone is not well defined. The base of the Earp is the position where thin shaly limestone and reddish shale become dominant over the more massive limestone characteristic of the underlying Horquilla (Ross, 1978, p. 194). The Earp contains many shale beds, calcareous sandstone and marl, and a few thin, conspicuous beds of tan- to orange-weathering dolomite. About half of the formation is limestone. The various rock types alternate with one another in units ranging from 1 ft to a few tens of feet in thickness. Ross (1978, p. 198) interpreted the Earp as representing many different shallow-marine depositional environments (i.e., carbonate banks, tidal flats, sand bars, etc.) and associated fluvial deposits.

Colina Limestone

The Colina Limestone is Permian in age and ranges 200-1000 ft in thickness within the study area. The formation consists of regularly-spaced, medium-bedded, clastic limestone interbedded with shaly limestone and shale beds. Basal contact with the Earp Formation is unclear and arbitrary, occuring where carbonate beds become predominant over clastic beds of the Earp. The most characteristic lithologic feature of the Colina is the dominance of dense limestone that is very dark gray and almost black on fresh surface. A feature valuable in discriminating the Colina Limestone from other limestone formations is the great abundance of gastropods, particularly the very large gastopod Omphalotrochus which has not been noted in any other carbonate formation within the area. The Colina represents a major Permian marine transgression with shallow water conditions. Subtidal, intertidal and lagoonal environments are interpreted (Butler, 1971).

Epitaph Dolomite

The Epitaph Dolomite is Permian in age and ranges 100-900 ft in thickness within the study area. The base of the Epitaph is arbitrarily set at the base of the first massive dolomite above the upper zone of partially dolomitized limestone in the Colina. Several hundred feet of dolomite forms the lowest portion of the formation. This dolomite ranges from medium to light gray and weathers from light to very dark gray. One of the most characteristic features of the dolomite is the presence of knots of silica. The upper portion of the Epitaph contains considerable reddish shale, thin-bedded limestone, and thin sandy layers. The lower dolomite portion of the formation is resistant and forms topographic highs and ledges while the upper portion is much less resistant and more subject to erosion. In the southern Whetstone Mountains, a middle portion of the Epitaph contains 250 ft of massive, medium-gray gypsum. The depositional environment of the Epitaph is interpreted as continued marine transgression with shallow-water conditions and frequent accumulation of dense brines. Intertidal and subtidal conditions within a shelf lagoon predominated (Butler, 1971). The upper part of the Epitaph contains reefs up to 200 ft in thickness within the Mustang Mountains (Wengerd, 1959).

Scherrer Formation

The Scherrer Formation is Permian in age and ranges 150-700 ft in thickness within the study area. It consists primarily of quartz sandstone and is one of the best marker units within the Paleozoic stratigraphic section. The formation is characterized by three members. Red siltstone, minor dolomite, and a thick (200 ft) sequence of pinkish-white, crossbedded, quarzitic sandstone comprises the lower member. The middle member is a vuggy, thickly-bedded, buff to gray dolomite. Approximately 100 ft of crossbedded, pinkish-white sandstone dominates the upper member. Much of the sandstone within the Scherrer is interpreted as being deposited in a marine near-shore, intertidal, littoral environment with ineffective dispersement of sand parallel to the shoreline. Dolomite in the middle member may represent a low-energy, carbonate-forming environment within the intertidal system (Butler, 1971, p. 79).

Concha Limestone

The Concha Limestone is Permian in age, ranges 100-600 ft in thickness within the study area, and has not been identified in the Dragoon Mountains, Mule Mountains, or Tombstone Hills. The resistant, cliff-forming formation consists of gray, clastic limestone which is exceptionally rich in chert nodules, particularly in its lower parts. In the Mustang Mountains, the upper beds thicken and become massive to form prominent reefs in excess of 200 ft in thickness. Deposition of the Concha is interpreted as occurring during a period of slow subsidence as indicated by deeper-water shelf fauna. Detritus-free sediments reflect deposition below effective wave base (after Butler, 1971, p. 82).

Rainvalley Formation

The Rainvalley Formation is Permian in age and found only in the Mustang and Whetstone Mountain where it is approximately 400 ft in thickness. It is distinguished from the underlying Concha Limestone by its thin-bedded, varicolored limestone and dolomite with sandstone. Marine deposition of the Rainvalley is interpreted as a slight shoaling of the Permian sea (Butler, 1971, p. 85).

Mesozoic Rocks

Bisbee Group

The Bisbee Group is Cretaceous in age and is composed of the Glance Conglomerate, Morita Formation, Mural Limestone, and the Cintura Formation. Locally, these formations are in excess of 7000+ ft in total thickness. Where undifferentiated, some authors have mapped these units as the "Bisbee Formation". The group is comprised largely of clastic sediments deposited in a subaerial environment believed to be part of a large delta complex on the margin of a cretaceous sea and of marine deposits reflecting estuarine environments. Some reefs are conspicuous.

Glance Conglomerate

The Glance Conglomerate is Cretaceous in age and may attain thousands of feet in thickness within the study area. The formation rests unconformably on Paleozoic and Precambrian rocks and varies rapidly in thickness owing to the irregularities along the depositional surface. Conglomerate composition reflects underlying formations and clasts range from pebble to cobble size. Hayes and Drewes (1978, p. 204) and Bilodeau (1978, p. 209) reported that the conglomerates locally represent alluvial fan deposits.

Morita Formation

The Morita Formation is Cretaceous in age and ranges 700-4000+ ft in thickness within the study area. It is recognized only in the Mule and Huachuca Mountains. Contact between the Morita and underlying Glance Conglomerate is gradational within a thin transitional zone which grades upward into finer clastic rocks of the Morita Formation. The Morita is comprised of an alternating series of sandstone, mudstone, and shale. Mudstone and shale are generally brown or maroon and sandstone is gray. Some petrified logs and fresh-water fauna are present. Towards the top of the Morita are sporadic, oyster-bearing, limestone beds 5-8 ft in thickness. The Morita is interpreted as being deposited under estaurine conditions that fluctuated between marine, brackish, and fresh-water environments. Water conditions were generally shallow and probably dominated by a fresh-water environment. (After Gilluly, 1956, p. 73).

Mural Limestone

The Mural Limestone is Cretaceous in age and ranges 500-700 ft in thickness within the study area. Contact between the Mural and underlying Morita is conformable and locally marked by interfingering relationships. The Mural is readily distinguishable into three members: 1) lower member - thin-bedded limestone interbedded with shale and sandstone, 2) middle member - massive limestone with practically no clastic material, and 3) upper member - thin beds of shale, sandstone, and limestone. Patch reefs, composed mainly of corals and stramatolites, are present in the limestone facies of the Mural and may be up to 80 ft in thickness and 1 mile in length (Scott, 1979). The Mural was deposited during a transgressional period with deposition of shallow-marine, near-shore, clastic facies and patch reefs which occuppied a carbonate shelf or ramp (after Scott, 1979).

Cintura Formation

The Cintura Formation is Cretaceous in age and ranges 600-1800 ft in thickness within the study area. It has been recognized in the Huachuca, Little Dragoon, and Mule Mountains. Contact between the Cintura and underlying Mural Limestone is gradational and the base of the Cintura is generally marked by the first thick sandstone in the transitional zone from limestone to clastic rocks. The formation consists chiefly of a series of alternating maroon and green mudstone, buff to gray sandstone, and sporadic, thin, oyster-bearing, limestone beds. The main portion of the Cintura seems identical lithologically with the Morita Formation. Deposition was probably under shallow-water, estuarine conditions that fluctuated between marine, brackish and fresh-water environments.

Fort Crittenden Formation

The Fort Crittenden Formation is Cretaceous in age and ranges 0-1500 ft in thickness within the study area. It is recognized only in the Huachuca Mountains and rests unconformably on the Bisbee Group. The base of the Fort Crittenden is dominated by conglomerate which is overlain by interbedded, pale-red to brown siltstone, light-brown feldspathic sandstone, and conglomerate. The presence of fresh-water mollusks in shale and sandstone and terrestrial vertebrates found at localities outside of the study area suggest that the formation was deposited in a subaerial valley cut on Bisbee Group rocks and older rocks after an orogenic episode (Hayes and Drewes, 1978, p. 206).

Huachuca Volcanics

The Huachuca Volcanics (informal name) are Triassic and/or Jurassic in age and consist of weathered rhyodacitic (?) tuffs and lavas several thousands of feet in total thickness. The formation occurs in the Huachuca Mountains and contains exotic blocks of Paleozoic sedimentary rocks.

Mustang Volcanics

The Mustang Volcanics (informal name) are Triassic and/or Jurassic in age and occur in the Mustang Mountains where they attain a total thickness of 1100+ ft. The formation is divisible into two members. Conglomerate, silstone, mudstone, and rhyolitic and latitic flows occur in the lower member as do sparse exotic blocks of Paleozoic sedimentary rocks. The upper member contains rhyolitic flows and welded tuff.

Cochise Peak Quartz Monzonite

The Cochise Peak Quartz Monzonite is Triassic-Jurassic in age and occurs in the Dragoon Mountains where it is intensely faulted. The unit is generally light greenish gray and weathers to dark grayish brown. In thin section, Gilluly (1956) described the quartz monzonite as greatly altered. Conspicuous flesh-colored crystals of microcline up to 4 cm in length are generally present. Most specimens are cataclastic or crystalloblastic-cataclastic. Originally the rock was probably a biotite-quartz monzonite. Most contacts are faults and thus give little insight to original intrusive relations.

Canelo Hills Volcanics

The Canelo Hills Volcanics are Jurassic in age, rest unconformably on Paleozoic formations, and occur chiefly in the Canelo Hills area where they range 1000-6000 ft in total thickness. The formation is divided into three members: 1) lower member - interbedded volcanic and sedimentary rocks, 2) middle member- rhyolitic lavas, and 3) upper member - welded tuff. All units are not everywhere present. Age date on lower member: 177 ± 8 m.y. Age dates on upper member: 147 ± 6 m.y.; 149 ± 11 m.y.; 169 ± 6 m.y.; 173 ± 7 m.y.

Rhyolite Porphyry

Rhyolite Porphyry of Jurassic age is present in the Canelo Hills area and has intruded the Canelo Hills Volcanics. The unit is a pale-red, aphanitic, rhyolite porhyry with conspicuous quartz and feldspar phenocrysts.

Juniper Flat Granite

The Juniper Flat Granite is Jurassic in age and occurs in the Mule Mountains where it is associated with a porphyry copper deposit at Bisbee. The formation forms a NW-trending stock which is resistant to erosion, forming topographic highs. In general the granite has a typical granitic texture with a distinct porphyritic phase. The coarse-grained variety is composed of quartz, orthoclase, plagioclase, and biotite. The finer-grained porphyritic rock consists of orthoclase and quartz with minor plagioclase and biotite. Age dates: 163 m.y.; 171.7 ± 7 m.y.; 182 ± 7 m.y.; 184 ± 8 m.y.; 186 m.y.

Huachuca Quartz Monzonite

The Huachuca Quartz Monzonite is Jurassic in age and consists of medium- to coarse-grained, equigranular rock with roughly equal portions of pink orthoclase, white plagioclase, and gray quartz. Most bounding contacts are faults, but locally the plutonic rock has definite intrusive relations with Permian carbonate rocks. Age dates: 164 ± 6 m.y.; 167 ± 6 m.y.

Bronco Volcanics

The Bronco Volcanics are Cretaceous in age and present mainly in the Tombstone-Charleston area. The formation consists of a lower andesite member and an upper rhyolite member which are separated by an irregular and uneven flow surface. Together the extrusive rocks total 2000+ ft (?) in total thickness. The lower andesite member is greenish gray to moderate red and consists of fine-grained plagioclase and hornblende phenocrysts in an aphanitic groundmass. The upper rhyolite member is composed of tuffaceous beds and pale-orange to light-gray rhyolite flows. Typically, the rhyolite is composed of fine- to very-fine-grained quartz phenocrysts in a micro-crystalline groundmass.

Schieffelin Granodiorite

The Schieffelin Granodiorite is Cretaceous in age and present mainly in the Tombstone-Charleston area. The pluton is clearly instrusive into all older rocks and cross-cuts cleanly without disturbing structural trends in adjacent rocks. The formation is light-gray to grayish-pink, medium-grained, holocrystalline rock with hypidiomorphic-granular texture and poorly defined lineations. Emplacement of the Schieffelin is thought to be directly related to mineralization in the Tombstone mining district. Age dates: 72.2 m.y.; 76 ± 3 m.y.

Uncle Sam Porphyry

The name "Uncle Sam Porphyry" is actually a misnomer because the formation is technically a pale-yellowish brown to light-brown tuff described as a lithic, crystal, vitric quartz latite by Newell (1974, p.50). It is thought to be the eruptive volcanic equivalent of the Schieffelin Granodiorite and occurs chiefly in the Tombstone-Charleston area. Intrusive breccia bodies containing fragments of Bronco Volcanics, Bisbee Group, Eitaph Dolomite, Colina Limestone, Pinal Schist and Schieffelin Granodiorite exist within the Uncle Sam Porphyry. Contact relations between the Uncle Sam and other lithologies are extremely varied with cross-cutting and flow relationships. Age dates: 71.9 ± 2.7 m.y.; 73.5 ± 2.8 m.y.

Other

Within the study area there are numerous, small, Cretaceous intrusive complexes of granite, granodiorite, rhyodacite, and andesite. Conspicuous hornblende andesite dikes are present in the Tombstone-Charleston area. These dike rocks are younger than the Schieffelin Granodiorite and the Uncle Sam Porphyry.

Mesozoic-Cenozoic Rocks

Rose Tree Ranch Formation

The Rose Tree Ranch Formation (informal name) is considered Creaceous and/or Tertiary in age, rests unconformably on the Mustang Volcanics, and is present only in the Mustang Mountains where it is 200+ ft in thickness. The formation consists of pale-red to brown siltstone interbedded with light-brown feldspathic sandstone and conglomerate containing clasts of sedimentary and volcanic rocks. Origin of the Rose Tree Ranch Formation is uncertain. No paleontological or geological data are available to determine precise age. The formation seems to be a terrestrial accumulation of volcanic rocks with associated erosional debris.

Jones Mesa Volcanics

The Jones Mesa Volcanics (informal name) are considered Cretaceous and/or Tertiary in age, rest unconformably on the Fort Crittenden Formation, and are present only in the Huachuca Mountains where it attains a thickness greater than 2000 ft. The formation consists of red and green, cross-laminated sandstone, volcanic conglomerate, pale-pink biotite-rich tuff, and deeply-weathered greenish-gray andesitic flow rocks.

Sugarloaf Quartz Latite

The Sugarloaf Quartz Latite is considered Cretaceous and/or Tertiary in age and may be up to 1500 ft in thickness. The formation consists of two members. Light-gray to pinkish-gray quartz latite with local phenocrysts of biotite, quartz, and feldspar comprises the lower member. The upper member is mainly andesite. Nearly all contacts with other formations are faults. Age date on lower member: 74.5± 2.9 m.y. Age date on upper member: 33.9 ± 2.6 m.y.

Cenozoic Rocks

S O Volcanics

The S O Volcanics are thought to be Paleogene (Eocene-Oligocene) in age and occur approximately 4 miles east of the Tombstone Hills where they attain a total thickness of several thousand feet. The stratified formation consists of three members: 1) lower tuff member - quartz latite tuffs, breccias, and minor obsidian flows with tuffaceous interbeds of conglomerate, sandstone, and mudstone, 2) middle member - hornblende andesite flows, and 3) upper tuff member - quartz latite tuff. These volcanic strata are highly variable laterally and vertically. Age dates: 47 ± 2 m.y.; 48 ± 2 m.y.

Texas Canyon Quartz Monzonite

The Texas Canyon Quartz Monzonite is Oligocene in age and occurs as a pluton in the Little Dragoon Mountains where it is associated with base metal mineralization. Rock texture is porphyritic with phenocrysts of microcline/orthoclase in a medium-grained groundmass of quartz, feldspar, and biotite; primary accessory minerals include magnetite, apatite, and some zircon. Emplacement of the quartz monzonite sotck caused widespread contact metamorphism in enclosing strata. Age dates: 31.0 m.y.; 48.5 m.y.; 49.5 m.y.; 50.9 m.y.; 51.7 m.y.; 53 ± 3 m.y.; 55.4 m.y.; 70.4 m.y.

Stronghold Granite

The Stronghold Granite is Oligocene in age and is the youngest major intrusion within the study area. The pluton occupies the northern portion of the Dragoon Mountains and is conspicuous by prominent NE-SW- and NW-SE-trending joints which form many narrow and steep-walled canyons throughout the complex. Most of the contacts between the Stronhold and enclosing strata are clean cut and distinct with no distortion, suggesting a very permissive rather than forceful emplacement. Contact metamosphic effects with countryrocks are very pronounced and extend well into the host rocks. Three facies have been recognized with the Stronhold Granite: 1) main facies - light-gray to light-pink, medium- to coarse-grained, hypidiomorphic-granular granite with crystals of microcline, plagioclase, quartz, and minor biotite, 2) border facies - porphyritic granite with composition essentially the same as the main facies, and 3) aplitic facies - fine-grained and hypidiomorphic- to allotriomorphic-textured aplite. Age dates: 22 ± 3.1 m.y.; 24.1 ± 2 m.y.; 27 ± 2 m.y.

Pearce Volcanics

The Pearce Volcanics are Miocene to Pliocene in age and are at least several thousand feet in total thickness. The formation is comprised of a lower andesite member and an upper rhyolite member. Andesite flows, subordinate flow breccias, and a few, thin, water-laid tuffs comprise the lower member. The upper member contains thick, massive flows of rhyolite, flow breccias, agglomerate, and tuff with the fragmental rocks seemingly dominant.

Other

Within the study area there are numerous local occurrences of Tertiary intrusive rocks which vary in composition from alaskite to diorite. Occurrences of Tertiary extrusive rocks are also present and range in composition from rhyolite to basalt. Perhaps the most significant of these "other" igneous rocks is the olivine basalt which occurs in outcrops northeast of Tombstone and is revealed in Tenneco mineral test holes on the southern postion of the Little Boquillas Ranch (Pl. 11, Appendix E). This basalt reflects magmatism associated with Basin and Range Disturbance.

Gila Conglomerate - Pantano Formation

The term "Gila Conglomerate" is considered somewhat ambiguous owing to its general application to most older (oligocene-Pleistocene) valley-fill deposits which occupy structural basins south and southeast of the Mogollon Rim in Arizona. Younger alluvial/fluvial deposits and geologically-distinct deposits are generally not included in the Gila. The Gila Conglomerate may locally attain a total thickness of several thousand feet and rests unconformably on older rocks. The Pantano Formation (Miocene) is included as a valley-fill type deposit and consists of conglomerate, sandstone, mudstone and local adnesite flows in the Huachuca Mountains area where it attains a total thickness of up to 15,000 ft. Local unconformities separate groups of beds and reflect continued uplift and tectonic unrest coincident with deposition. (After Brown and others, 1966)

St. David Formation

The St. David Formation is Plio-Pleistocene in age and ranges 0-1000+ ft in thickness within the study area. It is expressed in badland topography. The formation consists of alternating beds of light-colored siltstone, claystone, mudstone, sandstone, fresh-water limestone, and water-laid pyroclastic units which rest unconformably on older rocks. Vertebrate fossils are present. Deposition of the St. David Formation occurred in a large, slow-moving, through-flowing stream system which spread fine-grained sediments on an aggrading floodplain and, at times, in large lakes, ponds, and marshes (Gray, 1965, p. xi). Age dates: 2.7± 0.4 m.y.; 3.1 ± 0.7 m.y.

Surficial Deposits

Surficial debris is divided into "older alluvium" and "alluvium". Older alluvium includes pediment gravels and old, dissected alluvial fans and may locally include undifferentiated portions of the Gila Conglomerate and equivalent formations. Alluvium consists of active alluvial, colluvial, and fluvial deposits which occur mainly in braided streams and major tributaries. These deposits range from a few feet to several tens of feet in thickness.

STRUCTURAL ELEMENTS

Introduction

The structural framework of the Little Boquillas Ranch and adjacent areas has been dominated by multiple, contrasting, and superimposed episodes of deformation. Drewes (1979) best described the structural setting of the region:

> "The structural features of southeastern Arizona are many in kind and age, for the region is located in one of the most active parts on the Earth's crust. The extensive record of tectonic activity . . . . . . means that the supracrustal rocks were structurally anisotropic from a very early time. Subsequent responses to repeated deformational stresses reflect not only the orientation of the new stresses but the effect of the older planes of weakness. Some rocks have been folded several times, and many segments of faults have been reactivated - - in places repeatedly, diversely, and even with opposite direction of movement."

The complex structural setting has resulted in a poliferation of geologic literature concerned with dynamic structural interpretations, many of which are conflicting. Owing to this situation, this report presents only a simplistic synopsis of the structural framework of the ranch with due respect to various hypotheses.

A structure and mineralization map is presented in Plate 11. This map is a compilation of major structural features observed at the surface and/or interpreted from remote sensing and available geophysical data. Much of the map is strictly interpretive and therefore subject to individual discretion concerning specific features. The purpose of the map is to aid in the exploration and discovery of economic mineralization on or near the Little Boquillas Ranch.

Prevalent Structural Trends

Surface topography and geology express a dominant northwest structural trend on the Little Boquillas Ranch and adjacent areas to include mountain blocks, folds, faults, and dikes (Pl. 11). The ranch lies within the northwest-trending San

Pedro Valley which is a structural basin bounded by normal faults. Bordering mountain ranges are essentially horsts and the valley is a graben complex characteristic of Basin and Range terrain. Northwest-trending folds and faults are common within Mesozoic and Paleozoic rocks throughout the study area. Gravity and magnetic geophysical features and Landsat lineaments also display prevalent northwest structural trends.

A subordinate northeast structural trend, nearly normal to the major northwest fabric, is present throughout the study area and is pronounced within the Schieffelin igneous complex between Charleston and Tombstone (Pl. 11). This northeast trend probably represents reactivated Precambrian basement structure. The northwest and northeast structural elements are apparent in the directional rose histograms of Lepley (1978) in the explanation of Plate 11 and in various site-specific fracture rose diagrams (Pl. 11).

Lesser dominant structural trends include east-west-trending faults and folds. A major east-west-trending fault is believed to extend across the San Pedro Valley near Lewis Springs (Pl. 11). Some prevalent east-west folds are in the Tombstone area.

Laramide thrust faults are abundant in bounding mountain blocks, particularly in the Huachuca, Whetstone, and Dragoon Mountains. These thrust faults define numerous imbricated thrust sheets. Similar thrust sheets are probably present in the subsurface below the San Pedro Valley floor.

A myriad of geologic structures exist within the 1650 sq. miles of the study area, however, discussion of each feature would be excessively lengthly and beyond the reconnaissance scope of this study. For more information, the reader is referred to the various figures and plates in this report and the abundant geologic literature as listed in "References and Selected Bibliography."

Precambrian Structural Influence

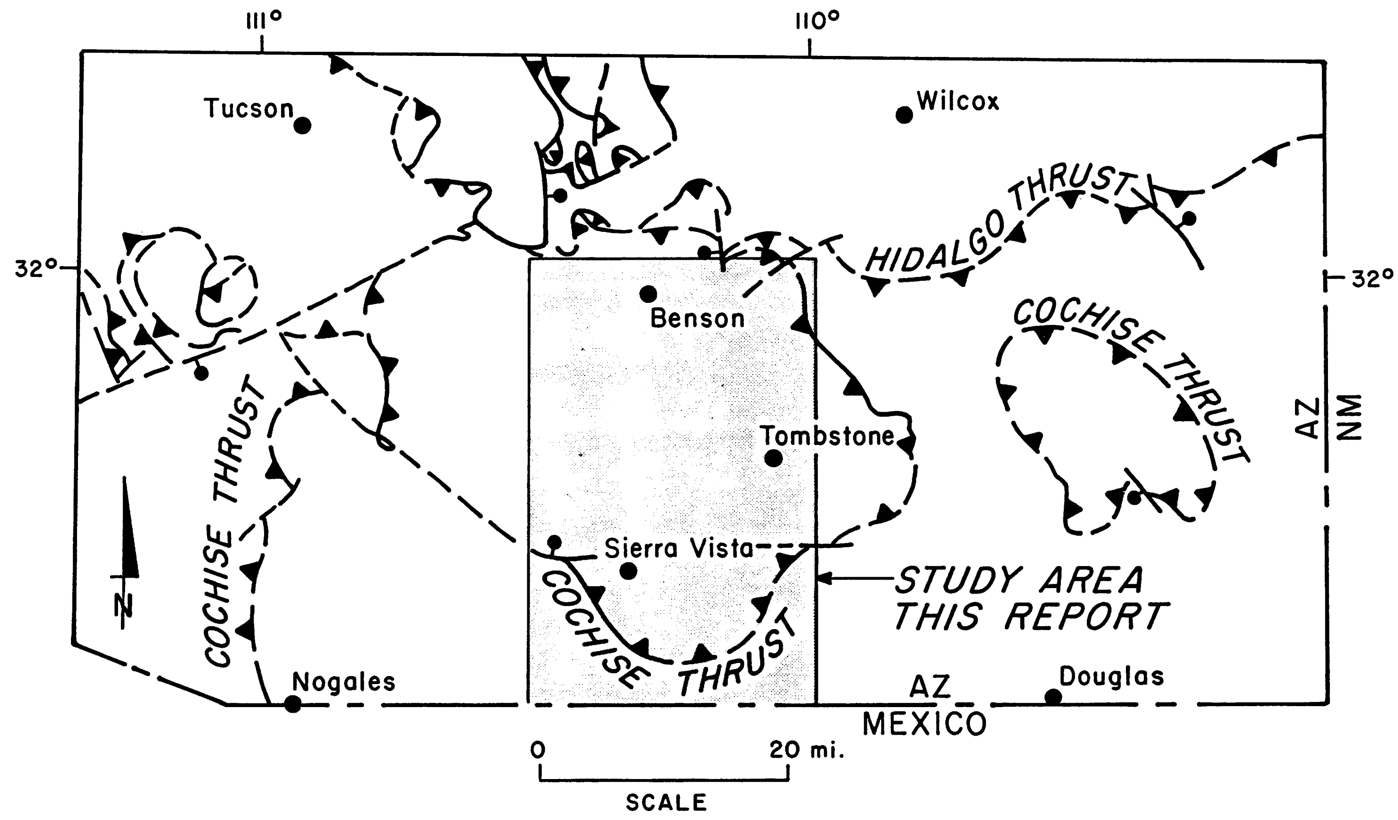
The Little Boquillas Ranch lies well within the intersection of three orogenic belts 1) the northeast-trending Precambrian belt, 2) the northwest-trending

Wasatch-Jerome belt, and 3) the northwest-trending Texas lineament (Pl. 11, explanation). All of these structural zones are thought to have originated during Precambrian time. These Precambrian structural fabrics are believed to be retained in the basement rocks (Pinal Schist and granitic bodies) within the study area and have been fundamental to subsequent deformation. Components of Nevadan, Laramide, and Basin and Range deformational forces have reactivated some Precambrian planes of weakness causing preferred deep-seated structural elements to be expressed in younger rocks at the surface. Therefore, some of the structural features which are readily related to younger orogenic events actually have substantial influence from underlying basement structure. This may be particularly true with northeast- and east-west-trending structures within the study area.

Laramide Thrust Faulting

Perhaps one of the most significant structural uncertainties within the study area is the questionable extent and magnitude of Laramide thrust faulting. Drewes (1979) suggested that two major Laramide thrust faults, the Hidalgo thrust and the Cochise trust, were thrust in a northeastward to eastward direction towards the continental interior in response to Laramide compressive forces. These compressive forces were likely generated by northeast motion and subduction of the Pacific plate into a trench along the western margin of the North American plate during Laramide time (inset, Fig. 7-5).

Figure 6-1 shows the major Laramide thrust faults in southeastern Arizona and depicts much of the study area as within a "mega klippe". Hypothetical cross sections by Drewes (1979) across portions of the Little Boquillas Ranch are presented in Figure 6-2. These cross sections reveal some features which conflict with local geological interpretations, however, the presence of low-angle thrust faults at depth is supported by available seismic data. Dislocation of the allochthonous sheets has been interpreted to range 20-100 miles. Subsequent Basin and Range faulting and igneous activity have severely distorted and obscurred the thrust system. As a result, few geologists can agree on the mechanics, direction, and magnitude of Laramide thrusting in the area. Some geologists suggest that the regional thrusting in southeastern Arizona is part


111°
110°
32°
32°
Tucson
Wilcox
Benson
Tombstone
Sierra Vista
Nogales
Douglas
HIDALGO THRUST
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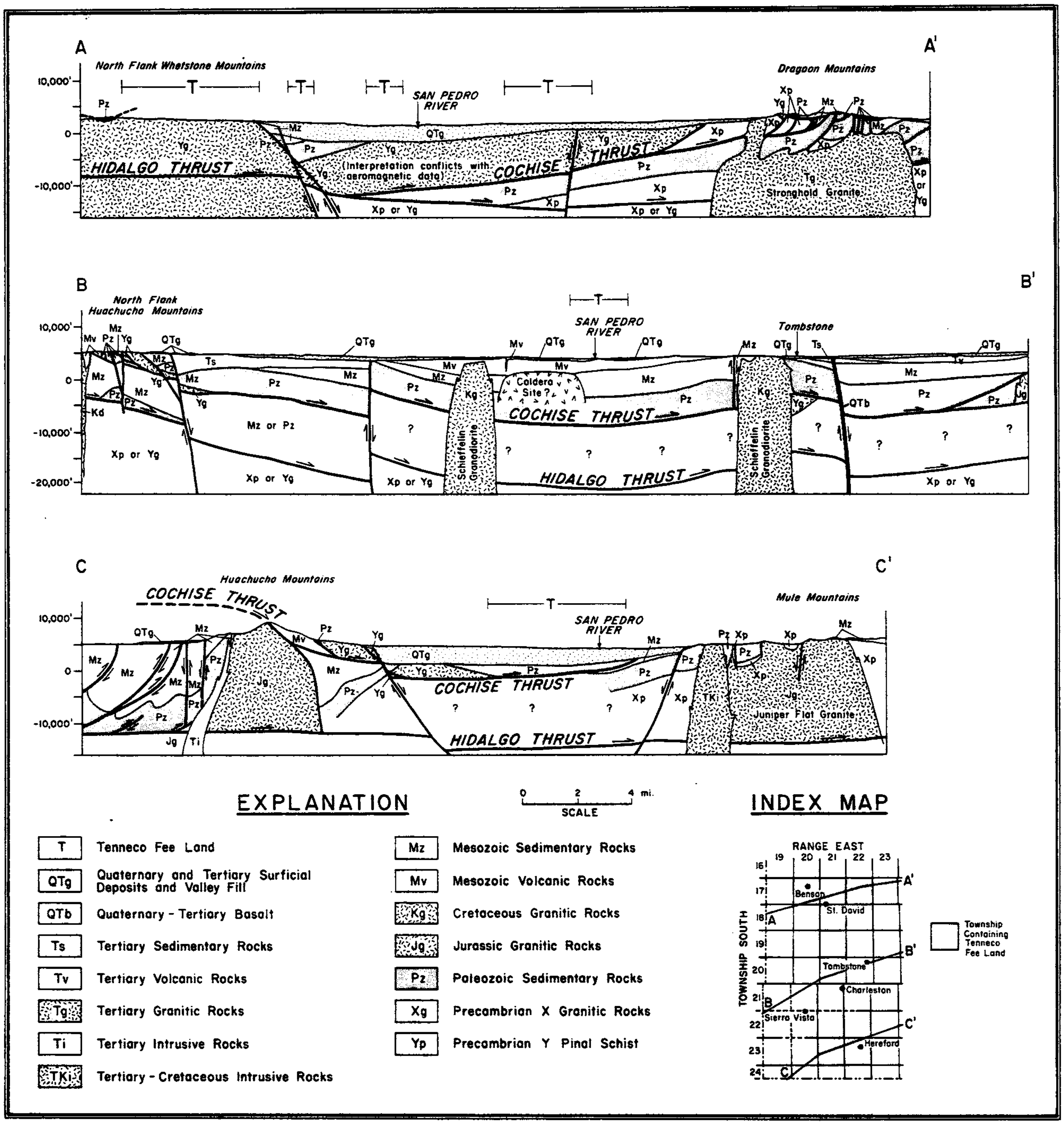


Figure 6-2. Hypothetical cross sections across portions of the Little Boquillas Ranch (modified after Drewes, 1979).

of the Overthrust belt which extends southward through Montana, Idaho, Colorado, Utah, and Nevada. This thrusting is now a focal point for petroleum exploration in southeastern Arizona (see "Petroleum and Natural Gas Resources", this report).

Basin and Range Structure

Basin and Range structure on the Little Boquillas Ranch is a Cenozoic phenomena and consists of N-NW-trending, fault-bounded mountains and the intermontane San Pedro Valley. This structure is attributed to block faulting whereby mountain ranges are created by vertical movements along major normal faults. The concept of block faulting can imply simple structure, however, the system is actually highly complex and not confined to the sides of mountains but is distributed throughout mountain areas and in the valley subsurface.

Stewart (1978, p. 16-18) presented two general models for Basin and Range structure. One relates the structure to a system of structural blocks rotated along curving, downward-flattening normal faults, sometimes called "listric" faults. The second model (horst and graben model) relates the structure to a system of relatively downthrown blocks (grabens) that form valleys, and relatively upthrown blocks (horst) that form mountains. Basin and Range structure on the Little Boquillas Ranch may involve both models. Seismic data may eventually reveal the structural style.

Major normal faults on the Little Boquillas Ranch and adjacent areas are concealed by pediment gravels, colluvium, and alluvium. Most pre-Cenozoic structures, such as thrust faults, have been affected to some degree by Basin and Range structure (Fig. 6-2). Holocene Basin and Range fault traces are conspicuously absent on the ranch.

General Structural Evolution

The Little Boquillas Ranch has been subjected to numerous deformational episodes extending back into older Precambrian time. The Precambrian was dominated by the folding, faulting, and plutonism of the Mazatzal Revolution followed by epeirogeny during Paleozoic time. During Triassic-Jurassic time, the Nevadan orogeny ensued with associated plutonism and volcanism. The Laramide orogeny during late Cretaceous to early Tertiary time has probably had the most profound structural effect on the Little Boquillas Ranch with prevalent eastward thrusting and emplacement of granitic plutons and associated precious and base metal mineralization. The Laramide orogeny was followed by the Basin and Range disturbance in mid-Tertiary time which has extended into the present. This episode of tectonism is characterized by N-NW-trending block faulting and attendant volcanism. Table 6-1 summarizes many of the major structural elements imposed upon the Little Boquillas Ranch by the forementioned tectonic events. The reader is referred to Plates 2 and 11 for specific structural features.

Table 6-1. General structural elements relevant to the Little Boquillas Ranch and adjacent areas.

Time	Orogenic Activity	Plate Tectonic Setting	Structures	Igneous Activity	Remarks
Precambrian	Mazatzal orogeny	- N. Am. plate part of Lurasia which diverged from Gondwanaland.	- NW-SE compressional forces - NE-trending folds; some N-S-, NW- & E-W-trending folds. - E-W- & N-S-trending faults - Some thrusting to N & NE	- Granitic plutons emplaced - Younger Precambrian intrusions	- Structure of Precambrian rocks are fundamental to subsequent structural development of region. - Texas Lineament, Wasatch-Jerome orogenic belt, & Precambrian orogenic belt origin
Cambrian-Penn.	Epeirogeny	- Lurasia convergence towards Gondwanaland.	- Uplift-Ord.-Sil.-no deposition - SE-trending Pedregosa marine basin developed - Penn.-Per. - Mild tilting, arching, & sagging		- Established structural trends prevailed - Notably deficient of severe deformational tectonism - Oil generation (Dev.-Permian)
Permian	Regional uplift	- Lurasia collides with Gondwanaland to form Pangea	- SE-trending Pedregosa marine basin continued - Mild tilting, arching, & sagging		- Same as above
Triassic-Jurassic	Nevadan orogeny	- Pangea breakup into Lurasia & Gondwanaland	- NE-SW compressional forces - Uplift & erosion - NW-trending folds - Exotic blocks	- Granitic plutons emplaced - Rhyolitic & andesitic volcanism	- Some copper mineralization (Bisbee)
L. Cretaceous-E. Tertiary	Laramide orogeny	- Subduction of Pacific plate in N motion under N. Am. plate; increased plate motion & shallow Benioff zone during Laramide	- NE-SW compressional forces - E-W & N-S faults parallel to Precambrian faults - Major thrusting to NE & E - Basement-cored uplifts - NW-trending folds; some N-S-, E-W-, & NE-trending folds	- Granitic to monzonitic plutons emplaced - Rhyolitic & andesitic volcanism	- Major porphyry copper mineralization - Structural style & intensity inhomogenous - Two theories on origin of basement-cored uplifts: 1) thrust faulting 2) vertical tectonic forces - Oil generation (Cretaceous)
M. Tertiary-Present	Basin & Range disturbance	- Cessation of subduction of Pacific plate along N. Am. plate; change to NW motion of Pacific plate along San Andreas fault	- E-W extensional forces - NW- & N-trending normal faults - NW- & N-trending horsts & grabens - Periodic uplift	- Basaltic & rhyolitic volcanism	- Several theories on origin: 1) relaxation of Laramide compressive forces 2) extensional tectonics related to transform faults and cessation of subduction 3) collapse over regional dome 4) withdrawal of vertical support due to extensive Tertiary and Quaternary volcanism

GEOLOGIC HISTORY

The following narration is a brief geologic history of the Little Boquillas Ranch and adjacent areas. The goal of this section is to present a gross overview of the more important geologic events and to avoid documentation of numerous and complex transgressive-regressive depositional and tectonic episodes which vary locally. Table 6-2 is a general summary.

Precambrian Time

The oldest rock unit within the study area is the Pinal Schist which is thought to be approximately 1700 m.y. in age. This formation is interpreted as a thick accumulation of marine sediments (turbidites ?) and associated volcanic rocks which were deposited in a major eugeosynclinal basin. These deposits were later altered to schist by major orogenic deformation, plutonism, and metamorphism during the Mazatzal Revolution between 1400-1450 m.y. A prominant, NE-trending, structural fabric was developed. Emplacement of Precambrian granitic rocks in the Whetstone, Huachuca, and Dragoon Mountains probably occurred during this orogenic episode. An extended period of erosion followed and resulted in a low- to moderate-relief surface upon which Paleozoic rocks were to be deposited.

Paleozoic Time

Paleozoic time was dominated by fluctuating marine deposition and epeirogeny. The marine-transgressive Bolsa Quartzite was deposited during Cambrian time on the smoothly-worn Precambrian surface and represents deposition either in an offshore bar or beach environment. The Abrigo Limestone (Cambrian) overlies the Bolsa and is interpreted as a shelf area of an encroaching epeiric sea which served as a deposition site for mainly carbonate and some clastic material.

The marine shelf area was uplifted during Ordovician and/or Silurian time resulting in no rock record for these periods. Absence of appreciable erosion of Cambrian rocks suggests that the area was near sea level at the end of the Silurian period.

Table 6-2

GENERAL GEOLOGIC HISTORY OF THE LITTLE BOQUILLAS RANCH AND ADJACENT AREAS

(Modified from Aiken and Sumner, 1974, p. 4)

ERA	Period	EPOCH	Age: Millions of Years		
CENOZOIC	Quat.	Recent	.01	Alluvial sediments	Uplift & erosion
		Pleistocene	2	Locally, 1,000+ ft of alluvial, fluvial, and lacustrine sediments. Basaltic volcanics.	Uplift & erosion Volcanism
	Tertiary	Pliocene	5	Conglomerate	
		Miocene	23	Unconformity	Basin & Range Disturbance: uplift, faulting, magmatism, erosion
		Oligocene	40	Igneous rocks. Several hundred ft of non-marine sediments, principally siltstone & sandstone.	
		Eocene	53		Laramide Orogeny: uplift, folding & faulting, granitic intrusions, volcanism, widespread mineralization
		Paleocene	65	Unconformity	
MESOZOIC	Cretaceous		141	About 7,500 ft of marine & non-marine sediments, chiefly sandstone, shale & conglomerate. Unconformity	
	Jurassic		195	Igneous rocks	Nevadan Orogeny: granitic intrusions, volcanic activity, mineralization, uplift & erosion
	Triassic		230	Igneous rocks; various sedimentary rocks Unconformity	
PALEOZOIC	Permian		280	Up to 2,700 ft of marine sediments, principally carbonates with some clastics & gypsum	General Uplift
	Pennsylvanian		320	Up to 2,000 ft of marine sediments, principally carbonates & shales Unconformity	
	Mississippian		345	Up to 1,000 ft of marine sediments, principally carbonates Unconformity	
	Devonian		395	Up to 400 ft of marine sediments, principally carbonates Unconformity	
	Silurian		435	Not known in Arizona	General Emergence
	Ordovician		500	Absent Unconformity	
	Cambrian		600	Up to 1,300 ft of marine sediments, principally carbonates, quartzite, sandstone and shale Unconformity	
PRECAMBRIAN			2000+	Several thousand feet of metamorphosed sediments and volcanics	Mazatzal Revolution: granitic intrusions, folding, uplift & erosion Earlier disturbances

During Devonian and Mississippian time, shelf areas were again submerged by an epeiric sea and became the depositional site for marine carbonate and clastic material. Sea level fluctuation is evident by alternating clastic and carbonate facies of the Martin Limestone (Devonian). In contrast, the overlying Escabrosa Limestone (Mississippian) lacks significant clastic content, indicating a carbonate platform.

Late Mississippian-Pennsylvanian time marked an important regional unconformity in which the marine shelf was exposed and resubmerged. This disconformity is indicated by the basal shale portion of the Black Prince Limestone which is thought to represent residual deposits from erosion of the underlying Escabrosa Limestone.

Pennsylvanian through Permian time was dominated by continued deposition of marine carbonates and fine-grained sediments on a marine shelf subjected to fluctuating water levels and local uplifts. The study area occuppied the southwestern shelf of a subsiding, NW-trending, depositional trough known as the "Pedregosa Basin" (Fig. 7-3). Shallow-marine shelf limestone was common along the margin of the trough and was deposited at nearly the same rate of subsidence. Water conditions were mainly shallow and various, short-lived, transgressive-regressive episodes ensued. Marine facies vary locally and include tidal-flat, lagoonal, intertidal (littoral), subtidal, restricted-shelf, open-shelf, carbonate-platform, and reef depositional environments. Some deeper-water facies are evident in the Horquilla Limestone (Pennsylvanian) and Concha Limestone (Permian). General uplift marked the end of significant marine deposition during Paleozoic time.

Mesozoic Time

Triassic-Jurassic time was dominated by the Nevadan orogeny. This time span was marked by granitic intrusions, volcanic activity, mineralization, uplift, and erosion. Volcanic activity was mainly silicic and included local deposition of many thousands of feet of rhyolite, latite, tuff, and associated volcanoclastic rocks. Local emplacement of the Juniper Flat Granite (Mule Mountains) and the Huachuca Quartz Monzonite (Huachuca Mountains) occurred during Jurassic time. Economic base metal mineralization is associated with the Juniper Flat Granite.

A thick sequence of sedimentary rocks was deposited during Cretaceous time, mainly as subaerial conglomerate in part of a large delta complex on the margin of a Cretaceous epeiric sea, and as transgressive-regressive, shallow-marine deposits. Some Cretaceous patch reefs are evident. Dominant marine facies suggest shallow-water, estuarine, and carbonate-shelf, depositional environments. Rocks comprising this Cretaceous suite are included within the Bisbee Group.

Cretaceous and older rocks were severly deformed by the Laramide orogeny which began in late Cretaceous and extended into early Tertiary time. Orogenic activity was dominated by granitic intrusions, volcanism, mineralization, uplift, folding and thrust faulting induced by regional compressive forces. Andesite and rhyolite of the Bronco Volcanics was extruded in the Charleston-Lewis Springs area, followed by emplacement of the Schieffelin Granodiorite and its eruptive volcanic equivalent, the Uncle Sam Porphyry. Much of Arizona's copper mineralization is associated with Laramide plutonic/ volcanic activity.

Cenozoic Time

Early and medial Tertiary time was marked by a lenghty episode of erosion and sedimentation stimulated by the Basin and Range disturbance. East-west extensional tectonics caused block faulting and subsequent horst and graben terrian. Erosion of mountain blocks and detrital in-filling of structural basins ensued. The Gila Conglomerate and Pantano Formation represent thick valley-fill accumulations with some intercalated volcanic flows. These rock suites attest to structural unrest which extended into Quaternary time. Block faulting was also accompanied by local deposition of several thousand feet of volcanic rocks and some major plutonism. Andesite, latite, rhyolite, tuff, agglomerate, flow breccia, and associated volcanoclastic rocks were deposited locally as evident in the S O Volcanics and Pearce Volcanics. Major plutonism is represented by emplacement of the Texas Canyon Quartz Monzonite (Little Dragoon Mountains) and the Stronhold Granite (Dragoon Mountains). Economic base metal mineralization is associated with the Texas Canyon Quartz Monzonite.

Northwest-trending, intermontane valleys became local depocenters during Plio-Pleistocene time for lacustrine/fluvial accumulations such as the St. David Formation. Some basaltic flows also invaded valley areas. Subsequent regional uplift has caused dissection of lacustrine/fluvial deposits, Holocene alluvial fans, and valley fill. Stream down-cutting and terrace development is also evident.

ENERGY RESOURCES

URANIUM AND THORIUM RESOURCES

Introduction

Potential uranium and thorium resources on and adjacent to the Little Boquillas Ranch consist of submarginal orthomagmatic, authigenic, and placer concentrations as modeled after Mickle and Mathews (1978). Some radioactive slag is also present. All are considered of low potential and of no present mineral value for fissionable materials.

Definitions

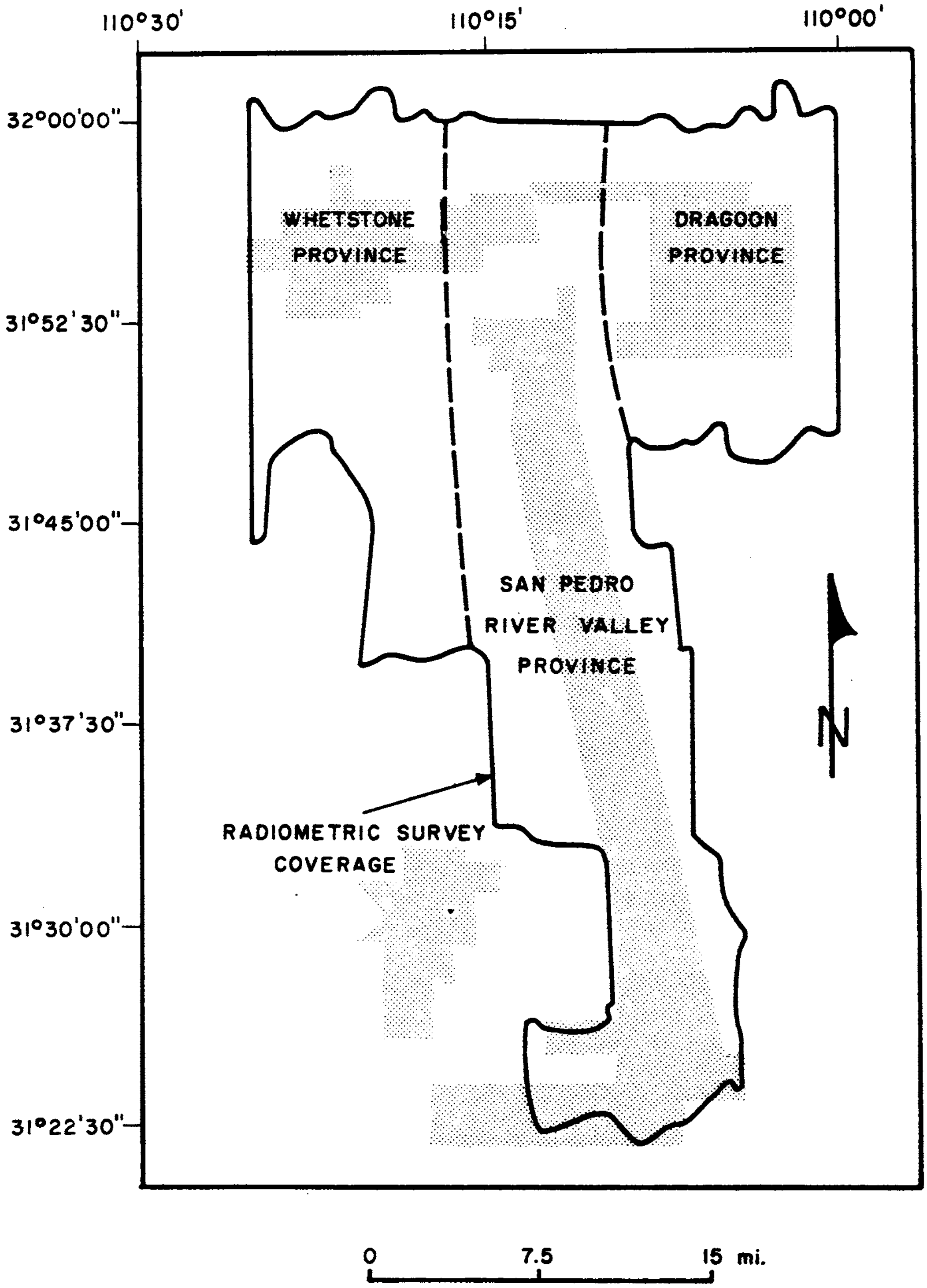
Orthomagmatic deposits: Concentrations of uranium and/or thorium which occur in plutons or stocks and develop by liquidus crystallization of uranium and uranium-bearing minerals in late stage magmatic differentiates. Plutons containing uranium and/or thorium in the orthomagmatic class are typically alaskite, quartz monzonite and granite. A small percentage of mafic intrusive phases is characteristic. Most plutons and hypabyssal intrusives containing orthomagmatic deposits are steeply-dipping stocks and dikes. Such deposits may provide a source of low-grade uranium and/or thorium in the future.

Authigenic deposits: Postmagmatic, secondary concentrations of uranium formed by leaching and redeposition of uranium in shears and fractures zones within the parent pluton. Redistribution and enrichment of authigenic uranium occurs in the near-surface environment and may be related to groundwater. Thorium is essentially insoluble and not subject to redistribution. Authigenic uranium occurrences are generally small and low grade owing to the mobility of uranium in the near-surface environment and the low probability of retaining remobilized uranium within the parent pluton.

Placer deposits: Alluvial and fluvial concentrations of uranium- and/or thorium-bearing accessory minerals such as zircon, monazite, and apatite. These deposits are commonly richest along the margins of crystalline mountain complexes where streams debouch from side canyons. Although there are some domestic placers which contain significant amounts of radioactive minerals, most placers are of no apparent value for fissionable materials.

Radiometric Provinces

Three major radiometic provinces have been defined on the Little Boquillas Ranch as a result of the airborne radiometric survey flown for Tenneco by Gx


110°30'
110°15'
110°00'
32°00'00"
31°52'30"
31°45'00"
31°37'30"
31°30'00"
31°22'30"
WHETSTONE PROVINCE
DRAGOON PROVINCE
SAN PEDRO RIVER VALLEY PROVINCE
RADIOMETRIC SURVEY COVERAGE
N
0
7.5
15 mi.

during late 1977. These provinces are the 1) Dragoon province, 2) Whetstone province, and 3) San Pedro River valley province (Fig. 7-1). Each province is delineated by a characteristic radiometric background as measured within the Gx uranium (^{214}Bi) spectrometer channel in gamma-ray counts per second (cps). The gross count channel also reflects these provinces. Characteristic radiometric backgrounds are caused by the dominant rock type or rock suite (i.e., granitic terrain) within each province.

Radiometric Data

Radiometric data are presented in various maps and tables. Contour maps of uranium (^{214}Bi) and gross count spectrometer data are presented in Plates 12 and 13 respectively. Table 7-1 lists the approximate range of radiation per given formation on the Little Boquillas Ranch. Gx uranium (^{214}Bi) anomalies and relevant data are listed in Appendix B. Fifty uranium (^{214}Bi) anomalies have correlating gross count anomalies (Pls. 12 & 13) which are annotated by the same anomaly number(s).

Field work was concentrated on 63 significant uranium (^{214}Bi) anomalies, many of which are on the Little Boquillas Ranch. Work consisted of traverses and spot surveys with a Geometrics model GR-310 hand-held, gamma-ray spectrometer and geochemical sampling. Ten exploration trenches were dug by backhoe on selected anomalies in alluvial debris on Tenneco property. Thirty-one minor gross count anomalies are listed in Appendix B and do not correlate with uranium (^{214}Bi) anomalies. These anomalies were not field checked.

Fluorimetric and X-ray fluorescent (XRF) analytical techniques were used to detect uranium. The minimum detection limit of uranium by fluorimetric analysis is 2 ppm for rock, soil and stream sediment samples, and 2 ppb for water samples. The minimum XRF detection limit for uranium is 20 ppm, however, XRF uranium analyses are tenuous at this level. Thorium was detected solely by XRF analysis with a minimum detection limit of 20 ppm. Sample locations are shown on Plate 12 and subsequent analytical data are presented in Appendix B.

Table 7-1. Airborne radiation ranges by formation

MAP SYM.	FORMATION	URANIUM(^{214}Bi) cps	CROSS cps x 1,000
QTsd	St. David Formation	3-8;c/o 7-8 WP; c/o 5-6 SPRV	20-30 SP & SPRV
Qtg	Gila Conglomerate	5-7; 5-6 WP; 6-7 SPRV	20-30
Tap	Andesite Porphyry	5-6 SPRV	10-30 (E) SPRV
Tup	Uncle Sam Porphyry	7-8 SPRV	20-30 SPRV
Tsg	Stronghold Granite	12-26; c/o 12-13 DP	70-120; c/o 70-80 DP
TKsc	Schieffelin Granodiorite	5-7 SPRV	20-30- SPRV
TKba/TKbl	Bronco Volcanics	- - -	20-30 SPRV
TKg	Granitic Gneiss	5 (E) DP	30 (E) DP
Kgd	Granodiorite	- - -	- - -
Kb	Bisbee Formation	4-8; c/o 7-8 SP; 4-5 SPRV	10-40; c/o 30 SP, c/o 10-20 SPRV
Pe	Epitaph Dolomite	- - -	- - -
Pc	Colina Limestone	7 SPRV	- - -
PPe	Earp Formation	3 (E) DP	20 (E) DP
Ph	Horquilla Limestone	3-5; 3 WP; 3-5 DP	20-30; 20 WP; 20-30 DA
PMb	Black Prince Limestone	2-3 (E) WP	10-20 (E) WP
Me	Escabrosa Limestone	2-3 (E) WP	10-20 (E) WP
Dm	Martin Limestone	3 (E) WP	20 (E) WP
Ca	Abrigo Limestone	4-5 (E) WP: 5 (E) DP	20-30 WP: 20-30 (E) DP
Cb	Bolsa Quartzite	5-6 (E) WP: 5 (E) DP	20-30 WP: 20-30 (E) DP
pCal	Alaskite	6-8 WP	20-30 WP
pCm	Quartz Monaonite	9-15, c/o 9 WP	30-40 WP
pCp	Pinal Schist	6-13.5 WP	30-60; 30-40 WP; 40-60 DP

(E) = Estimate c/o = Contact outline DP = Dragoon Province

WP = Whetstone Province SPRV = San Pedro River Valley Province

Whetstone Province

The Whetstone radiometric province is dominated by a Precambrian quartz monzonite-alaskite stock in the Whetstone Mountains. The radiometric background in the Gx uranium (^{214}Bi) channel is approximately 30-40 cps and ranges from 20 cps to nearly 60 cps. Radiometric anomalies are present within the quartz monzonite-alaskite stock and in alluvial debris at its flanks (Pl. 12). A total of 110 samples, principally from anomalous areas, were collected and analyzed to include 60 rock, 21 soil, 10 stream-sediment, and 19 water samples.

Orthomagmatic and Authegenic Deposits

Numerous hardrock uranium prospects and claims are located in the Precambrian quartz monzonite-alaskite stock of the Whetstone Mountains, primarily in the Coronado National Forest west and south of the Little Boquillas Ranch (Pl. 11). Aeromagnetic data (Pl. 14) indicate that the stock complex extends in the subsurface onto Tenneco fee land in T.18 S., R.20 E. A list of uranium prospects is presented in Table 7-2. Table 7-3 lists reported uranium minerals.

Rocky Mountain Energy Corporation (RMEC), Kerr McGee Resources Corporation (KMRC) and other companies have conducted uranium exploration in the Whetstone Mountains during the 1970's. RMEC has claimed Tenneco lands where mineral rights are retained by the Federal Government (W½, Sec. 1, T.18 S., R.19 E.). At least 17 mineral exploration holes (10 RMEC), presumably drilled for uranium, are within the stock complex. These holes range 20-310 ft in depth. All RMEC holes are in quartz monzonite. Drill cuttings from six exploration drill holes were analyzed and found to contain from less than 2 ppm uranium to 85 ppm uranium (fluorimetric). Various drill hole data are presented in Table 7-4.

Gx anomalies within the quartz monzonite-alaskite complex are attributed to orthomagmatic and authigenic zones enriched with uranium and/or thorium within quartz monzonite, alaskite, shears, fractures and altered mafic dikes. Assays reveal that uranium is the principal radioactive element as opposed to thorium.

Table 7-2. Reported uranium prospects in the Whetstone Mountains. (After U.S. Atomic Energy Comm. and U.S. Geologic Survey, 1970, and miscellaneous sources)

Prospect or Claim(s)	Location	Equivalent % U_3O_8	Chemical % U_3O_8	Remarks
Lost Apache Girl	Sec. ?, T.18S., R.19E.	-	-	Vein 3 ft in thickness within porphyritic granite.
Windmill Group (Now RMEC Shoe claims)	Sec. 10, T.18S., R.19E. (Dolphin well area)	0.57	0.72	Sheared orthoclase-rich phase of granite. Radioactivity associated with limonitic gouge near surface and black gouge below 3 ft in depth. Uranium minerals appear to be uraninite, uranophane and autunite. (Drilled by RMEC during 1973)
Neglea Claim	Sec. 2, T.18S., R.19E.	0.02	-	Altered basic dike which is 8-10 ft in thickness within granite.
Lucky Seven #1	Sec. ?, T.18S., R.19E.	-	-	Vertical vein 4-5 ft in thickness within porphyritic granite.
First Chance	Sec. 9(?), T.18S., R.19E.	0.13 0.16	-	Shear zone in porphyritic granite. No distinct uranium minerals present. (Drill holes present)
East Peak #1	Sec. ?, T.18S., R.19E.	-	-	Weathered porphyritic granite. Specularite and zircon.
Chadwick Mine	Sec. 25 & 26, T.18S., R.19E.	0.009	-	Torbernite found in granite wallrock of a 6 inch quartz vein. (Tungsten prospect
Little David Claims	Sec. 10, T.18S., R.19E.	0.052 0.019 0.008	(select) (select) (dump)	Quartz vein in granite and fractures.

Table 7-3. Reported uranium minerals in the Whetstone Mountains.

Mineral Name	Chemical Group	Formula	Percent Uranium
Uraninite	Oxide	UO_2	46.5 - 88.2
Uranophane (Secondary uranium mineral)	Silicate	$Ca(UO_2)_2(SiO_3)_2(OH)_2.5H_2O$	60.0
Zircon	Silicate	$ZrSiO_4$	0 - 2.7
Autunite	Phosphate	$Ca(UO_2)_2(PO_2)_2.10\text{-}12H_2O$	48.3 - 50.1
Torbernite (Secondary uranium mineral)	Phosphate	$Cu(UO_2)_2(PO_4)_2.12H_2O$	47.1
Metatorbernite (Secondary uranium mineral)	Phosphate	$Cu(UO_2)_2(PO_4)_2.4\text{-}8H_2O$	50.8 - 55.0
Wulfenite	Molybdate	$Pb(Mo,U)O_4$	9.65
Tyuyamunite	Vanadate	$Ca(UO_2)_2(VO_4)_2.5\text{-}8H_2O$	49.4 - 54.1

Table 7-4. Uranium exploration drill hole data, Whetstone Mountains.

N.D. = No detection   N.S. = No sample

DRILL HOLE	TOTAL DEPTH (FT)	COMPANY	YEAR DRILLED	LOCATION (Sec., T., R.)	SURFACE GEOLOGY	URANIUM FLUORIMETRIC	URANIUM XRF
79-16-73	180	RMEC	1973	10-18S-19E	qtz monz.	85 ppm, cuttings 240 ppb, water, Dolphin well	N.D.
79-28-73	250	RMEC	1973	10-18S-19E	qtz monz.	N.S.	N.S.
79-29-73	250	RMEC	1973	11-18S-19E	qtz monz.	N.S.	N.S.
79-39-75	220	RMEC	1975	3-18S-19E	qtz monz.	8 ppm, cuttings	N.D.
79-42-75	222	RMEC	1975	3-18S-19E	qtz monz.	3 ppm, cuttings	N.D.
79-44-75	85	RMEC	1975	2-18S-19E	qtz monz.	2 ppm, cuttings	N.D.
79-48-75	310	RMEC	1975	1-18S-19E	qtz monz.	<2 ppm, cuttings	30 ppm
No number	20	RMEC	-	3-18S-19E	qtz monz.	N.S.	N.S.
No number	200	RMEC	-	9-18S-19E	qtz monz.	N.S.	N.S.
No number	100	RMEC	-	10-18S-19E	qtz monz.	N.S.	N.S.
WMCH-50	-	-	-	4-18S-19E	qtz monz.	N.S.	N.S.
WMCH-51	-	-	-	4-18S-19E	qtz monz.	<2 ppb, water	-
No number	-	-	-	25-18S-19E	alluvium	N.S.	N.S.
No number	-	-	-	25-18S-19E	alluvium	<2 ppm, cuttings	N.D.
No number	-	-	-	25-18S-19E	alaskite	<2 ppm, surf. rx	24 ppm, surf.
No number	-	-	-	26-18S-19E	alaskite	110 ppb, water	-
No number	-	-	-	34-18S-19E	granodiorite	<2 ppm, surf. rx	N.D.

Rock and soil samples collected on or near Tenneco property at anomaly Gx-47 (Pl. 12) reveal conflicting assays of 30-35 ppm uranium (XRF) and 2-8 ppm uranium (fluorimetric). XRF uranium data are considered tenuous owing to a minimum detection level of 20 ppm uranium. Mafic dikes and quartz veins within the area of anomaly Gx-47 are uranium barren. One water sample from Naegle well (Sec. 2, T.18 S., R.19 E.) near anomaly Gx-47 revealed 14 ppb uranium (fluorimetric) which is moderately anomalous over a ground-water background of 2-4 ppb uranium. Anomalously high concentrations of uranium in ground water were detected in other areas to include the Dolphin well (240 ppb uranium, Sec. 10, T.18 S., R.19 E.), and Bathtub Springs (55 ppb uranium, Sec. 16, T.18 S., R.19 E., Gx-51).

Data suggest that the anomalous radioactivity detected at anomaly Gx-47 is from a slightly uranium-enriched portion of the quartz monzonite-alaskite stock. Anomalous uranium in ground water reflects leaching of uraniferous zones within the stock with subsequent uranium enrichment of local ground water and perhaps along shears and fractures.

The only locality at which uranium mineralization was actually observed was at anomaly Gx-56 which is the Chadwick Mine (tungsten prospect) in the SW¼, Sec. 25, T.18 S., R.19 E. Here, torbernite and autunite (authigenic uranium minerals) are present along fractures in Precambrian alaskite. Manganese and iron oxides are also present. The prospect diggings follow a 6 inch wide quartz vein, however, uranium mineralization does not seem associated with the vein. An assay of the uraniferous material revealed a surprisingly low concentration of 13 ppm uranium (fluorimetric). Numerous other prospect diggings are in the area.

Conspicuous uranium radiation within the Whetstone stock was noted in an altered mafic dike at an exploration adit in Sec. 26, T.18 S., R.19 E. This locality was not detected by the Gx airborne radiometric survey. Analyses indicate that the altered dike contains 370 ppm uranium (fluorimetric) and 670 ppm (XRF). A water sample from within the adit contained 8,000 ppb uranium (fluorimetric), indicating the high solubility of the uranium at this location. The dike is 4-5 ft in thickness, hundreds of feet in length, and dips 30-35° to the north. Host rock is alaskite which contains 10 ppm uranium (fluorimetric).

Studies concerning uranium in the quartz monzonite-alaskite stock by the U. S. Geological Survey for the U. S. Atomic Energy Commission were conducted during 1950-1957 (U. S. Atomic Energy Comm., 1970). These investigations indicate that uranium mineralization is concentrated in veins, shears, altered dikes and weathered granite (Table 7-2).

Placer Deposits

Several radiometric anomalies occur in alluvial debris at the base of the Whetstone Mountains (Gx-41 through Gx-46, Gx-57; Pl. 12). These anomalies were verified by ground spectrometer traverses and soil sampling. Anomaly Gx-57 is a cultural anomaly consisting of an old garbage dump. Four exploration trenches (T-7 through T-10, Pl. 12) were dug to test anomalies Gx-45 and Gx-46 (Pl. 12). Trenches ranged 5-11 ft in depth and did not encounter bedrock. The four trenches had similar soil profiles consisting of a thin upper humic zone underlain by reddish-brown alluvial debris consisting mainly of granitic material from the Whetstone Mountains. Samples were collected at various depths in each trench. XRF and fluorimetric analyses revealed no significant uranium or thorium.

Available data suggest that Gx uranium (^{214}Bi) anomalies in alluvial debris reflect minor placer deposits of uranium- and/or thorium-bearing accessory minerals from the Precambrian quartz monzonite-alaskite stock in the Whetstone Mountains. Such accumulations are common along the flanks of mountain blocks comprised of plutonic rocks. The placer concentrations are considered of no apparent mineral value for fissionable materials.

Slag

An abandoned line of the Southern Pacific Railroad is present in the Whetstone province. All rails and ties have been removed, however, roadbed slag still remains and is slightly radioactive. Slag material contains 30-65 ppm uranium (fluorimetric) and is of no apparent value for uranium.

Dragoon Province

The Dragoon radiometric province is dominated by the Stronghold Granite (22-27 m.y.) and granite-rich alluvial debris. The radiometric background in the

Gx uranium (^{214}Bi) channel is approximately 70-80 cps with a range of 60-120 cps (Pl. 12). Four strong radioactive anomalies were identified within the Dragoon province (Gx-1 through Gx-4). Two of these strong anomalies are on Tenneco fee land in alluvial debris and two are in the Stronghold Granite (Dragoon Mountains) east of the ranch in the Coronado National Forest (Pls. 12 & 13). A total of 102 samples, primarily from anomalous areas, were collected and analyzed to include 33 rock, 53 soil, 3 stream sediment, and 13 water samples.

Orthomagmatic Deposits

The Gx spectrometer miniplot in the thorium (^{208}Tl) channel indicates thorium concentrations in the Stronghold Granite. Geochemical analyses from anomalous areas verified thorium enrichment with lesser amounts of uranium. Thorium- and uranium-bearing minerals are probably zircon, apatite, monazite(?) and other accessory minerals. Thorium concentrations within the Stronghold granite range 20-240 ppm (XRF) and uranium values range 2-20 ppm (fluorimetric).

Gilluly (1956, p. 106) described three different facies within the Stronghold Granite: 1) main (granite) facies, 2) porphyritic border facies, and 3) aplitic facies. Accessory minerals of the main facies include magnetite, notably large zircon crystals, and less abundant rutile, sphene, fluorite, tourmaline and apatite. The porphyritic facies has essentially the same accessory minerals which are less abundant in the aplitic facies. XRF analyses of samples collected from the Stronghold Granite include detection of columbium, zirconium, yittrium, cerium and lanthanum which indicate the presence of common radioactive accessory minerals. Accessory minerals which contribute the most to the thorium content of bulk rock are zircon, sphene, apatite and monazite. Zircon ($ZrSiO_2$) can contain up to 13.1% thorium and 2.7% thorium. A histogram of zirconium analyses within the Dragoon radiometric province is presented in Figure 7-2.

The aforementioned data indicate that the Gx anomalies within the Stronghold Granite are orthomagmatic concentrations of chiefly thorium-bearing accessory minerals with a lesser uranium content. These thorium concentrations contributed substantial radiation into the Gx unstripped uranium (^{214}Bi) spectrometer channel

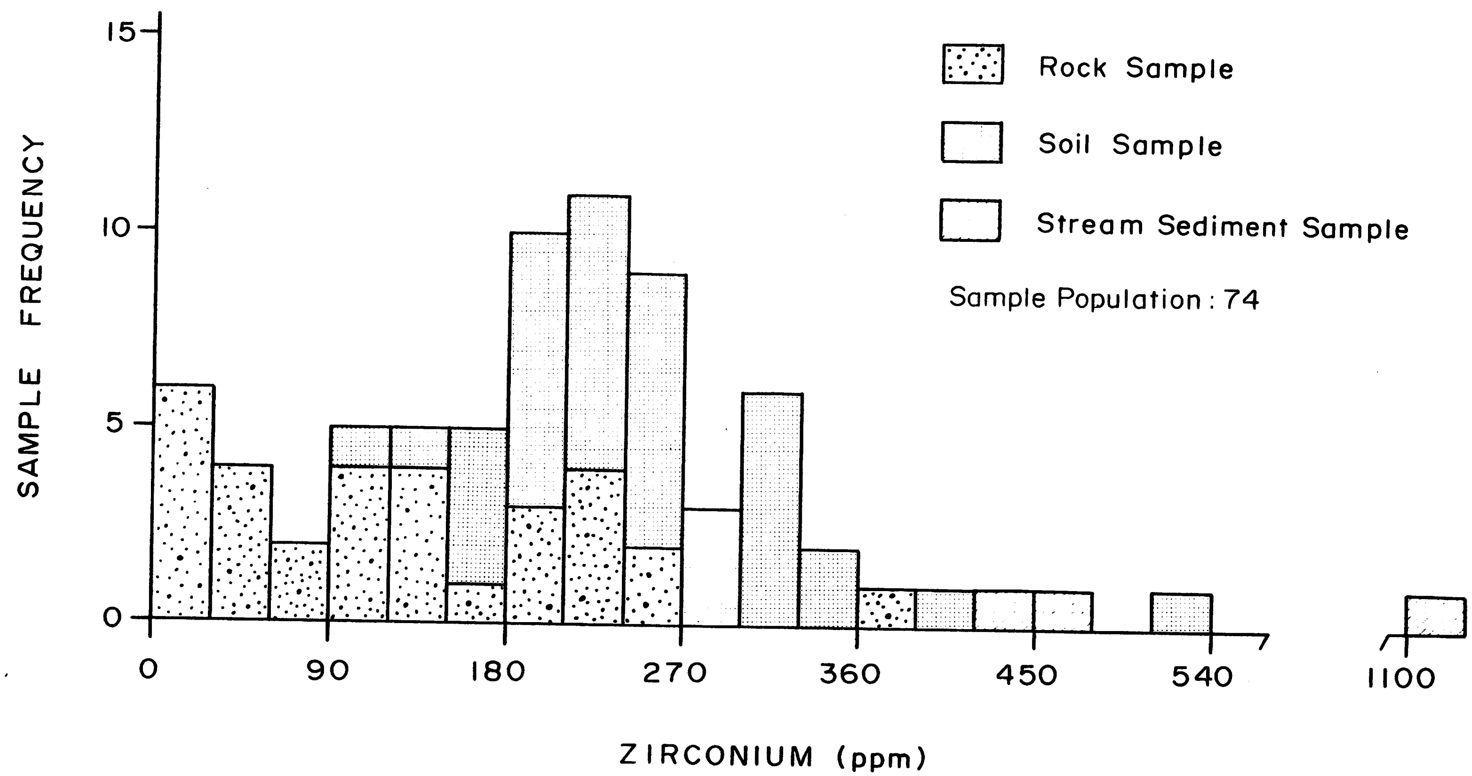


Figure 7-2. Zirconium histogram, Dragoon radiometric province.

via Compton scatter. Thorium resources in the Stronghold Granite are considered of no apparent mineral value.

Placer Deposits

Two radiometric anomalies, Gx-1 and Gx-2, are on Tenneco property approximately 1-1.5 miles west from the base of the Dragoon Mountains (Pl. 12). Both anomalies are in alluvial debris derived from the Stronghold Granite. These anomalies were verified by ground spectrometer traverses and by geochemical sampling. Fluorimetric analyses of surface samples revealed 2-4 ppm uranium. Four exploration trenches ranging 6-11 ft in depth were dug on anomaly Gx-1 and two trenches ranging 6.5-8 ft in depth were dug on Gx-2. The six trenches had similar soil profiles consisting of an upper humic zone approximately 1 ft in thickness underlain by clay-rich material and granitic debris. Bedrock was not encountered. Caliche horizons are present at various depths. Systematic sampling and XRF analyses of trench material at various depths revealed that thorium-bearing minerals are prevalent. Trench material contained 0-110 ppm thorium.

Available data suggest that the radiometric anomalies observed in granitic outwash within the Dragoon province are in response to slight to moderate placer deposits of primarily thorium-bearing accessory minerals with lesser uranium content. The source of these minerals is the Stronghold Granite. Mickle and Mathews (1978, p. 3) reported that radioactivity in such placers is typically from thorium-bearing minerals such as monazite, zircon, thorite and euxenite. Thorium-bearing minerals are generally more resistant than uranium-bearing minerals to weathering and destruction during transport and redeposition. A notably greater concentration of zirconium in soil samples and stream sediments, as shown in Figure 7-2, attests to zones of preferential zircon deposition. These local placers are similar to those at the flanks of the Precambrian quartz monzonite-alaskite stock in the Whetstone province and are of no apparent mineral value for fissionable materials.

San Pedro River Valley Province

The San Pedro River valley (SPRV) province is dominated by Holocene alluvial and fluvial deposits, and lacustrine lake beds of the St. David Formation

(Plio-Pleistocene). Some post-Jurassic volcanic and intrusive rocks and Paleozoic formations are exposed in the Charleston-Fairbank area. The province is characterized by a low radiometric background of 20-30 cps in the Gx uranium (^{214}Bi) channel and a range of 20-60 cps. Slightly anomalous areas are 40-60 cps.

Gx anomalies within the SPRV province are primarily associated with cultural features. These features consist of new housing developments (Gx-70, Gx-74, Gx-75, Gx-76), garbage, landfill, and sewage disposal sites (Gx-34, Gx-35), and agricultural lands, pastures, and tanks (Gx-66, Gx-37). Field investigations revealed that slag roadbed material is somewhat radioactive along active and abandoned lines of the Southern Pacific Railroad. Assays revealed 30-65 ppm U_3O_8 (fluorimetric) in railroad slag and slag at the abandoned Gird millsite. Slag was not delineated as anomalous by the Gx airborne radiometric survey. Some radiometric anomalies within the province are probably from slight placer accumulations of thorium- and uranium-bearing accessory minerals transported from bounding mountain ranges. Sandy zones within the St. David Formation offer favorable zones for uranium mineralization via groundwater percolation from bounding granitic blocks, however, no significant radioactive anomalies were detected in the organic-poor formation.

A total of 25 samples were collected in the SPRV province and analyzed. These included three rock, nine soil, eight stream sediment, and five water samples. All samples were submitted for fluorimetric uranium analysis. Only three samples contained detectable uranium values (2, 3, 15 ppm uranium). Water samples ranged from 2-4 ppb uranium. No uranium occurrences were encountered in the SPRV province.

Uranium and Thorium Potential

The potential for discovering significant uranium or thorium resources on the Little Boquillas Ranch is low. The Dragoon and SPRV radiometric provinces have minimum potential for fissionable materials. The Whetstone radiometric province offers the best potential for uranium resources on Tenneco fee land, however, this potential is also considered low. Potential uranium resources in the Whetstone province are in the orthomagnetic class (uranium-enriched pluton) and authigenic class (secondary uranium accumulation) within a Precambrian quartz monzonite-alaskite pluton. The plutonic host rock is mostly covered by alluvial debris on Tenneco fee land, limiting exploration to radon gas surveys and drilling. Placer concentrations of uranium- and/or thorium-bearing minerals in all three provinces are considered of no apparent mineral value for fissionable materials.

No orthomagmatic uranium deposits are presently being mined in the United States. Such deposits are considered submarginal. With improved market conditions and improved mining and metallurgical technology, orthomagmatic uranium occurrences may become a source of low-grade uranium ore in the future. Leaching processes applied to large volumes of uraniferous plutonic rocks may eventually be developed and allow recovery of large quantities of orthomagmatic uranium (Mickle and Mathews, 1978).

Authigenic uranium is sparingly present in the Whetstone Mountains, however, no authigenic uranium was observed on Tenneco property. Such deposits are generally considered to be small and submarginal to paramarginal. The outlook for discovering a significant authigenic uranium deposit on Tenneco property is poor.

PETROLEUM AND NATURAL GAS RESOURCES

Introduction

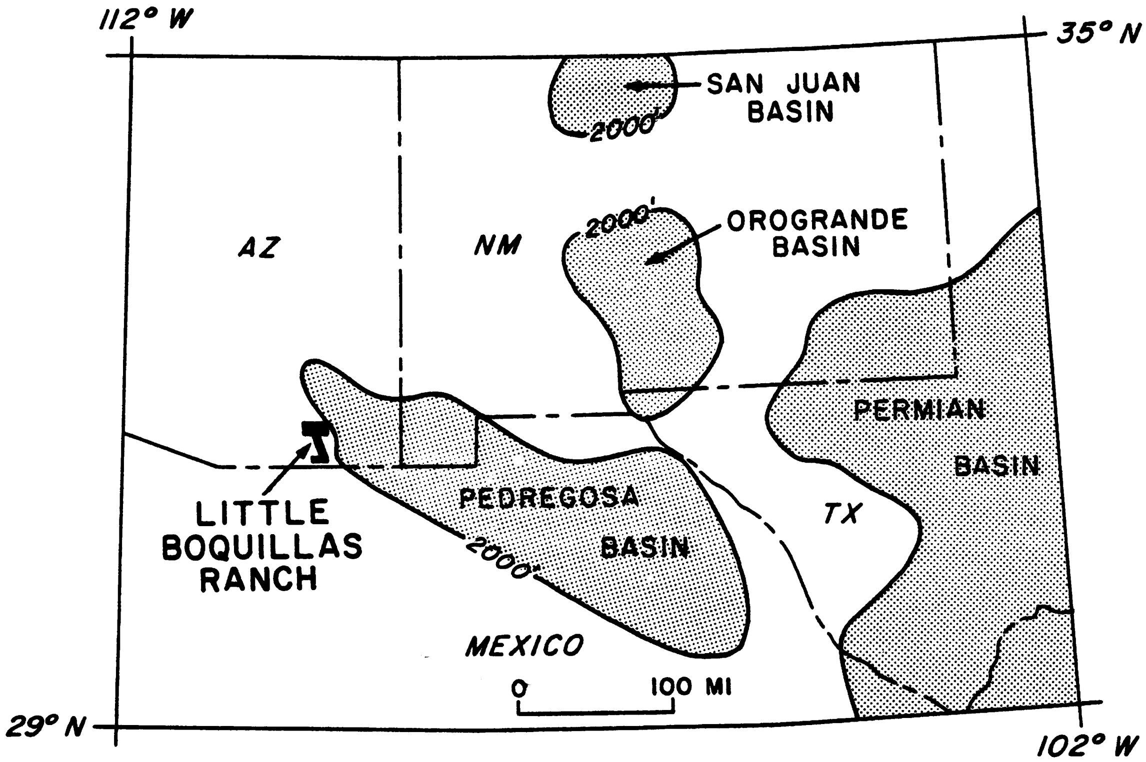
The purpose of this section is to summarize the general petroleum and natural gas potential of the Little Boquillas Ranch and to document old and new data. A detailed petroleum investigation is beyond the scope of this report and would require significant time and manpower.

Arizona is not a significant oil-producing state, mostly because of its adverse Basin and Range tectonic setting and Laramide through mid-Tertiary igneous activity. There are only 34 operating oil wells which produce about 3000 bpd on a Navajo Indian reservation in the northeastern portion of the state. However, with oil production firmly established in the Basin and Range province at two fields in Nevada, explorationists are now considering possibilities for oil and gas throughout Arizona. The Little Boquillas Ranch lies within southeastern Arizona which has essentially no petroleum production. However, exploration activity has now focused in on the ranch area owing to favorable source rocks, reservoir rocks and structures within the Pedregosa basin.

Pedregosa Basin

General Description

The Little Boquillas Ranch lies on the southwestern shelf of the northwest-trending Pedregosa basin (Fig. 7-3) which is defined in southeastern Arizona to contain Pennsylvanian strata of the Black Prince Limestone, Horquilla Limestone, and lower Earp Formation. Kottlowski (1960) considered the Pennsylvanian rocks as favorable for oil and gas accumulations and constructed isopach and lithofacies maps which encompass the Little Boquillas Ranch (Fig. 7-4). Ross (1978) has summarized the Pennsylvanian depositional framework in southeastern Arizona to include the ranch area. Current authors have loosely expanded the term "Pedregosa basin" to include the thick sequence of Paleozoic, Mesozoic, and Tertiary sedimentary rocks present in southeastern Arizona, southwestern New Mexico, and northern Mexico. The basin is more than 250+ miles long and 100+


112° W
35° N
SAN JUAN
BASIN
2000'
AZ
NM
2000'
OROGRANDE
BASIN
PERMIAN
BASIN
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29° N
102° W

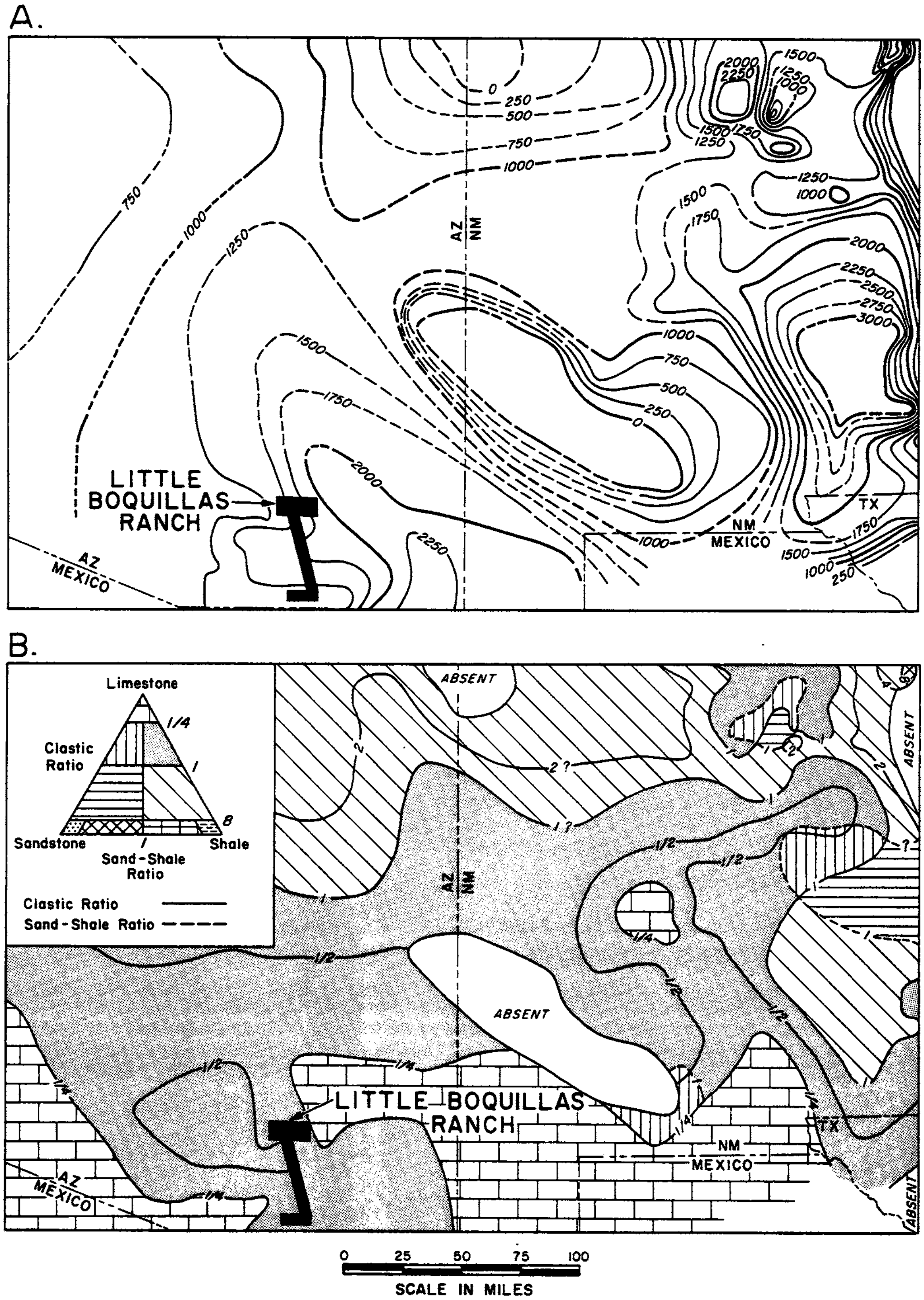


Figure 7-4. Isospach (A) and lithofacies (B) maps of Pennsylvanian rocks, Little Boquillas Ranch and vicinity (after Kottlowski, 1960).

miles wide and contains in excess of 25,000 ft of sedimentary rocks in its deeper parts.

Numerous petroleum geologists have reported that the Pedregosa basin may contain significant quantities of oil and gas (Kottlowski, 1959, 1960; Wengerd, 1962; Greenwood, 1969; Greenwood, Kottlowski, and Thompson, 1977; Heylmun, 1978; Thompson, Tovar, and Conley, 1978; McCaslin, 1979). This belief is based on Paleozoic stratigraphic similarities of the Pedregosa basin to the highly-productive Permian basin of western Texas and southeastern New Mexico (Fig. 7-3). In addition, significant quantities of oil and gas may be present in the Mesozoic rocks within the basin. An excellent summary of the petroleum potential and stratigraphy of the Pedregosa basin is presented by Greenwood, Kottlowski, and Thompson (1977).

In contrast to the Permian basin, the Pedregosa basin lies within the structurally complex Basin and Range province and has been subjected to intense tectonism and igneous activity from Laramide time onward. In spite of the local igneous activity and tectonism, large quantities of petroleum were probably generated and collected prior to Laramide time and should be preserved in the Pedregosa basin (Greenwood, Kottlowski, and Thompson, 1977).

Source and Reservoir Rocks

Petroleum was probably generated in the dark mudstones and limestones of the Pedregosa basin, collected in carbonate and/or clastic reservoirs and stratigraphic or structural traps, and preserved at least up to the time of the Laramide orogeny. Table 7-5 lists the general source and reservoir rock qualities of formations within the Pedregosa basin which are on or adjacent to the Little Boquillas Ranch. Important source rocks include Mississippian to Permian basin carbonates and shale and Cretaceous limestone. Significant reservoir rocks include Pennsylvanian to Permian shelf and reef carbonates and sandstone, and Cretaceous shelf limestone and sandstone.

The Pennsylvanian Horquilla Limestone is among the most important reservoir rocks on the Little Boquillas Ranch. Most oil well shows in areas adjacent

Table 7-5. Source and reservoir rock qualities of formations on the Little Boquillas Ranch and adjacent areas (modified after Thompson, Tovar, and Conley, 1978, p. 333).

AGE	FORMATION	MAIN ROCK TYPE	GENERAL DEPOSITIONAL ENVIRONMENT	PRELIMINARY EVALUATION: SOURCE QUALITY	PRELIMINARY EVALUATION: RESOURCE QUALITY
QUATERNARY	Alluvial Deposits	Sand and Gravel	non-marine	very poor	fair
QUAT. — TERTIARY	St. David / Gila	Lake Beds / Conglomerate			poor
TERT. — CRETACEOUS	Ft. Crittendon	sandstone			
CRETACEOUS	Bisbee Group: Cintura	sandstone	shallow marine/non-mar.		fair to. good
	Bisbee Group: Mural Ls.	limestone	shallow marine	fair	fair
	Bisbee Group: Morita	red mudstone	non-marine	very poor	very poor
	Bisbee Group: Glance	conglomerate			
PERMIAN	Rainvalley	limestone, dolomite	shallow marine	fair (limestone) to poor	fair to good (dolomite)
	Concha Ls.				
	Scherrer	sandstone		very poor	poor
	Epitaph Dolomite	dolomite		poor	fair
	Colina Ls.	limestone		fair	very poor
	Earp	red mudstone, limestone	non-mar./shallow marine	very poor to fair	poor to fair
PENNSYLVANIAN	Earp	limestone dolomite mudstone / limestone, sandstone	shallow to deep marine / shallow marine	fair to good (deep marine mudstone, limestone)	fair to good (shallow marine dolomite
	Horquilla Ls.	limestone dolomite mudstone / limestone	shallow to deep marine / shallow marine		
	Horquilla Ls. / Black Prince Ls.	limestone, sandstone	shallow marine	fair	poor
MISSISSIPPIAN	Escabrosa Ls.	limestone, chert		fair	poor
DEVONIAN	Martin Ls.	dolomite / dol., chert		poor	good (dolomite) to poor
CAMBRIAN	Abrigo Ls.	limestone, dolomite		fair to poor	fair
	Bolsa Qtz.	sandstone	shallow marine/non-mar.	poor	poor
PRECAMBRIAN	———	igneous and metamorphic rocks	———	———	———

to the ranch are in the Horquilla Limestone. Ross (1978) has compiled reconstructed cross sections of the Horquilla in the vicinity of the ranch. Plate 5 indicates that the Horquilla probably exists under large portions of the ranch and may range from 600-1200 ft in thickness. Permian and lower Cretaceous strata also offer fair to good reservoir quality and are present in subcrop. Wengerd (1959) reported that Humble Oil and Refining Company drilled a well in southwestern New Mexico and encountered a strong but subeconomic show of gas in the gypsiferous part of the Epitaph Dolomite (Permian). Favorable Cretaceous strata are known to exist in the Sonoita basin approximately 18 miles east of the Little Boquillas Ranch and are presently receiving some exploration attention from various oil companies.

Petroleum Preservation

Paleozoic and Cretaceous strata within the Pedregosa basin probably contained significant quantities of oil and gas by latest Cretaceous time. These accumulations have been subjected to Laramide and Basin and Range tectonic and igneous activity with both positive and negative effects.

The locally intense faulting and folding of the Laramide orogeny probably had more positive effects than negative effects on oil preservation. Oil and gas undergoing migration was likely trapped in extensive Laramide fold and/or fault systems, although, some existing petroleum reservoirs were surely breeched and lost.

In contrast to the Laramide orogeny, the widespread Basin and Range disturbance may have produced more negative effects on petroleum accumulations than positive ones. Basin and Range faulting created a horst and graben structural framework which involved the total sedimentary section and underlying basement. Horst structures likely promote erosion of traps and seals, escape of petroleum to the surface, and flushing in the subsurface by meteoric waters. Grabens, however, are probably relatively free from such effects although tilted blocks may promote hydrocarbon escape.

Igneous effects on petroleum accumulations in the Pedregosa basin are considered adverse for oil preservation in the vicinity immediately around granodiorite to quartz monzonite stocks intruded during Laramide time. Large cauldrons or calderas are also considered detrimental to oil preservation owing to associated deep-seated plutons. Volcanic and hypabyssal processes have less influence on petroleum reservoirs and outflow lavas and pyroclastics are considered to have minimal effect. Some heat is required in the generation and maturation of petroleum, and moderate igneous activity within the Pedregosa basin may have provided some positive effects. (Preceding paragraphs modified from Thompson, 1976).

The effects of Laramide and Basin and Range faulting and igneous activity on possible petroleum accumulations on the Little Boquillas Ranch remain unknown. Perhaps one of the most detrimental thermal effects may be from the Laramide Schieffelin igneous complex centered near Charleston. The plutonic phase (granodiorite) of the igneous complex has probably exerted a negative thermal effect on local Paleozoic and Cretaceous strata, however, its range of thermal influence and detriment is uncertain. The eruptive phase of the complex has had a much lesser if not minimal thermal influence. Also of concern are the deep-seated St. David pluton east of St. David and the exposed Stronghold Granite pluton in the Dragoon Mountains which may have produced some adverse thermal effects with respect to petroleum preservation.

Overthrust Belt

The Overthrust belt (Fig. 7-5) is an imbricated system of thrust plates which was thrust in a general west-to-east direction against the continental interior during Laramide time. Anticlinal structures, truncations, and other traps lying beneath the thrust plates are responsible for prolific oil and gas production in Wyoming, Utah, and elsewhere along the belt. Many geologists now project the Overthrust belt into Arizona (Fig. 7-5) where the system is complicated by igneous intrusions, volcanism, and block faulting, conditions which characterize the Basin and Range province.

From 8,000± ft to 12,000± ft of Paleozoic and Mesozoic strata are believed present in the general ranch area. Additional Mesozoic and Paleozoic strata in allochthonous thrust sheet(s) may hypothetically increase the total

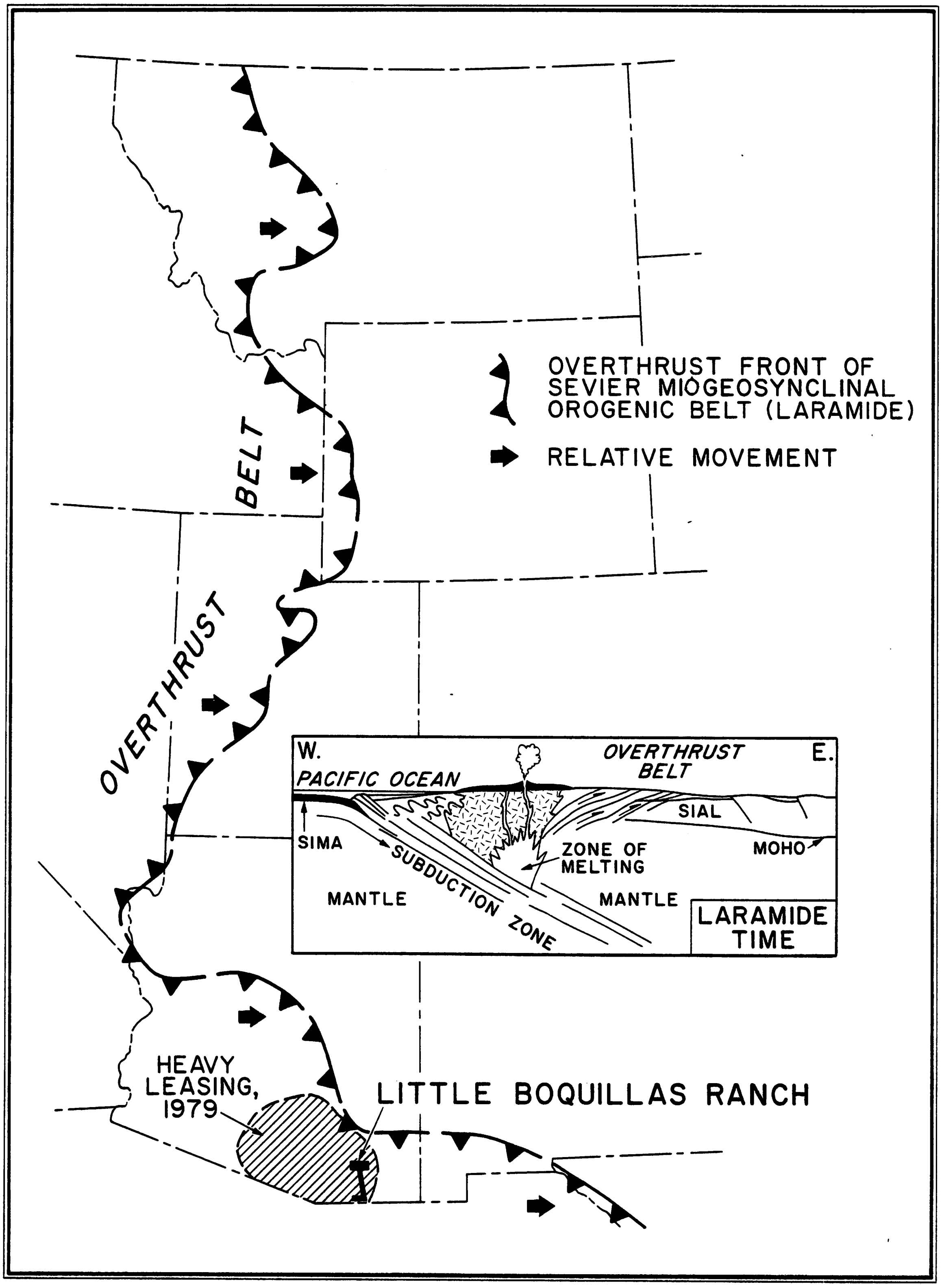


Figure 7-5. Overthrust belt and area of heavy leasing in southern Arizona.

stratigraphic sequence up to 20,000± ft in thickness. Major structural traps related to thrusting may also exist. Some geologists predict that favorable Paleozoic strata may even occur beneath thrust sheets of granitic rocks as exemplified in Figure 6-2.

Various oil companies are presently pursuing the Overthrust theory, although, substantial skepticism has been expressed. Anschutz Corporation, Denver, CO is leading exploration efforts in southeastern Arizona and reportedly leased 5 to 6 million acres during 1977-79. At least 17 other petroleum companies are actively seeking leases in the region to include Arco, Texaco, Gulf, Phillips Petroleum, May Petroleum, Westland Oil, Northern Michigan Exploration, Kansas Nebraska Natural Gas, Peoples Gas Company of Chicago, and Juniper Petroleum. Amoco is exploring local areas but is not pursuing the Overthrust concept. A total of approximately 10 million acres has been tied up in petroleum leases as of 1979 (Fig. 7-5). Mexico's national oil company, Pemex, is also reportedly active in the vicinity south of the border. To test the Overthrust theory, Anschutz and its followers are conducting approximately 5,000 line miles of seismic surveys in southeastern Arizona and southwestern New Mexico. Geophysical contractors include Pacific West Exploration Company, Western Geophysical Company, and Dawson Geophysical Company. Subsequent exploration drilling is planned to test strata at 12,000 ft to 30,000 ft.

To date, Western Geophysical Company has conducted approximately 13.4 miles of vibroseis survey (in-house) across the Little Boquillas Ranch (Pl. 3) and subsequent data were made available to Tenneco on a confidential basis. Other lines are apparently available for purchase. Pacific West and Dawson (both under contract to Anschutz) have requested seismic survey permits to cross the ranch (Pl. 3), however, their requests were denied owing to a reluctance to make resulting data available to Tenneco.

Petroleum Test Wells

The best summary of petroleum test wells in the vicinity of the Little Boquillas Ranch was compiled by Thompson, Tovar R., and Conley (1978). The reader is referred to their article for a detailed discussion of petroleum test holes in the region. A general map of test holes in southeastern Arizona is presented in Figure 7-6. Eleven test holes are within the study area of this report and are shown on Plates 3, 5, and 11 and summarized in Table 7-6. The deepest petroleum test hole in near proximity to the Little Boquillas Ranch is 5,500 ft in total depth. Oil and gas shows in local wells are reported to occur chiefly in the Horquilla Limestone. There are no oil and gas test holes on Tenneco fee land.

Petroleum Indicators

Paraffin Balls

The earliest indication of oil in the vicinity of the Little Boquillas Ranch was made by Spellmeyer during his 1927 mineral reconnaissance of the ranch. In reference to Cretaceous strata observed near the ranch, Spellmeyer (1927, p. 8) stated:

> "In these Cretaceous limestones are found occasionally, balls of paraffin. Vug holes were filled with bituminous matter and as the rock eroded away the volatile parts were evaporated leaving the paraffin base."

Spellmeyer further stated that the northern and southern portions of the ranch were probably the best oil territories. No effort was made during the present study to try and find paraffin balls as described by Spellmeyer. However, Spellmeyer was probably referring to the shallow-marine Mural Limestone of the Cretaceous Bisbee Group which exists in subcrop on ranch properties.

Reefs

During 1959, Wengerd conducted a study of the petroleum potential of the Little Boquillas Ranch for Kern County Land Company in which he reported that reefs of potential reservoir quality exist in the Cretaceous Mural Limestone, Permian Concha Limestone and Epitaph Dolomite, Pennsylvanian Horquilla Limestone, and Mississippian Escabrosa Limestone. Two massive reefs were noted in the Escabroa on the west side of the Mule Mountains. Several Horquilla reefs averaging 40 ft in thickness were observed in the Tombstone Hills and similar reefs were noted on

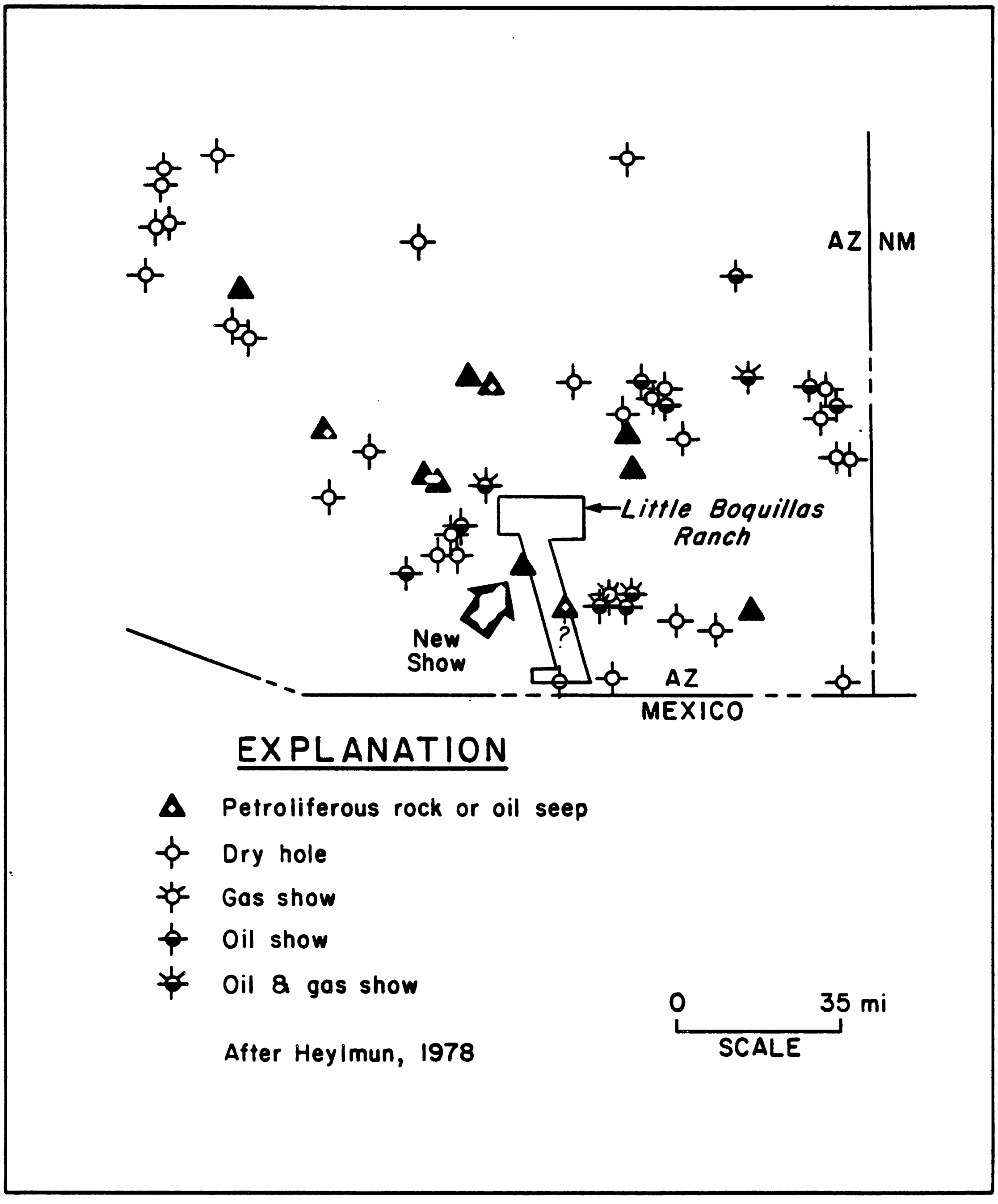

AZ
NM
Little Boquillas Ranch
New Show
?
AZ
MEXICO
EXPLANATION
Petroliferous rock or oil seep
Dry hole
Gas show
Oil show
Oil & gas show
0
35 mi
SCALE
After Heylmun, 1978

Table 7-6. Petroleum test wells in the vicinity of the Little Boquillas Ranch, AZ (see Plate 5 for location).

Drill Hole Number	Location S	T	R	Drilled By	Drilled For	Year Drilled	Depth Total	Depth Target	Type of Show	Stratigraphic Units Surface	Stratigraphic Units Depth
CENTURY PETR 1 COLGLAZIER	17	17S	19E	ND	ND	1931	1560'	ND	Oil & Gas	Alluvium	120' Bisbee Group
CIENEGA BASIN 1 STATE	33	18S	18E	ND	ND	1952	2760'	ND	Dry	Alluvium	Bisbee Group
TED JONES 1 JUANITA STATE	34	18S	18E	ND	ND	1954	2656'	ND	Oil & Gas ?	Alluvium	Bisbee Group
MOUNTAIN STATES EXPL 1 STATE	29	19S	18E	ND	ND	1962	1050'	ND	Dry	ND	Bisbee Group (lost hole)
MOUNTAIN STATES EXPL 1-A STATE	29	19S	18E	ND	ND	1964	4410'	ND	Dry	ND	Bisbee Group
FRASER OIL NO. 1 STATE	19	21S	23E	ND	ND	1960 1968	1899' 1903'	ND	Oil & Gas 1409'-1449'	Alluvium	50' Colina Ls. 410' Earp Fm. 1230' Horquilla Ls
R. B. MONCRIEF 1 STATE	17	21S	23E	ND	ND	1963	2446'	ND	Gas 1600'-1640' 1840'-1884'	Colina Ls.	592' Earp Fm. 1216' Horquilla Ls. 2440' Escabrosa Ls. (lost hole)
R.B.MONCRIEF 1 DAVIS-CLARK	5	21S	24E	ND	ND	1963	3525'	ND	Oil & Gas 1950'-1970'	Alluvium	300' Morita Fm. 1135' Horquilla Ls. 2480' Escabrosa Ls. 3026' Martin Ls. 3335' Abrigo Ls.
SOUTHWEST OIL 1 DAVIS-CLARK	5	21S	24E	ND	ND	1967	3570'	ND	Oil & Gas 2570'-2590'	Alluvium	200' Morita Fm. 1150' Earp Fm. 1575' Horquilla Ls. 2670' Escabrosa Ls. 3290' Martin Ls.
THOMPSON-MANLEY 2 STATE	2	24S	21E	ND	Sterling Oil Co	ND	5500'	ND	Dry	Alluvium	Ordovician Test?
ARI-TEX 1 GOINS	4	24S	23E	ND	ND	1945	1005'	ND	Dry	Alluvium	Permian? @ bottom of hole

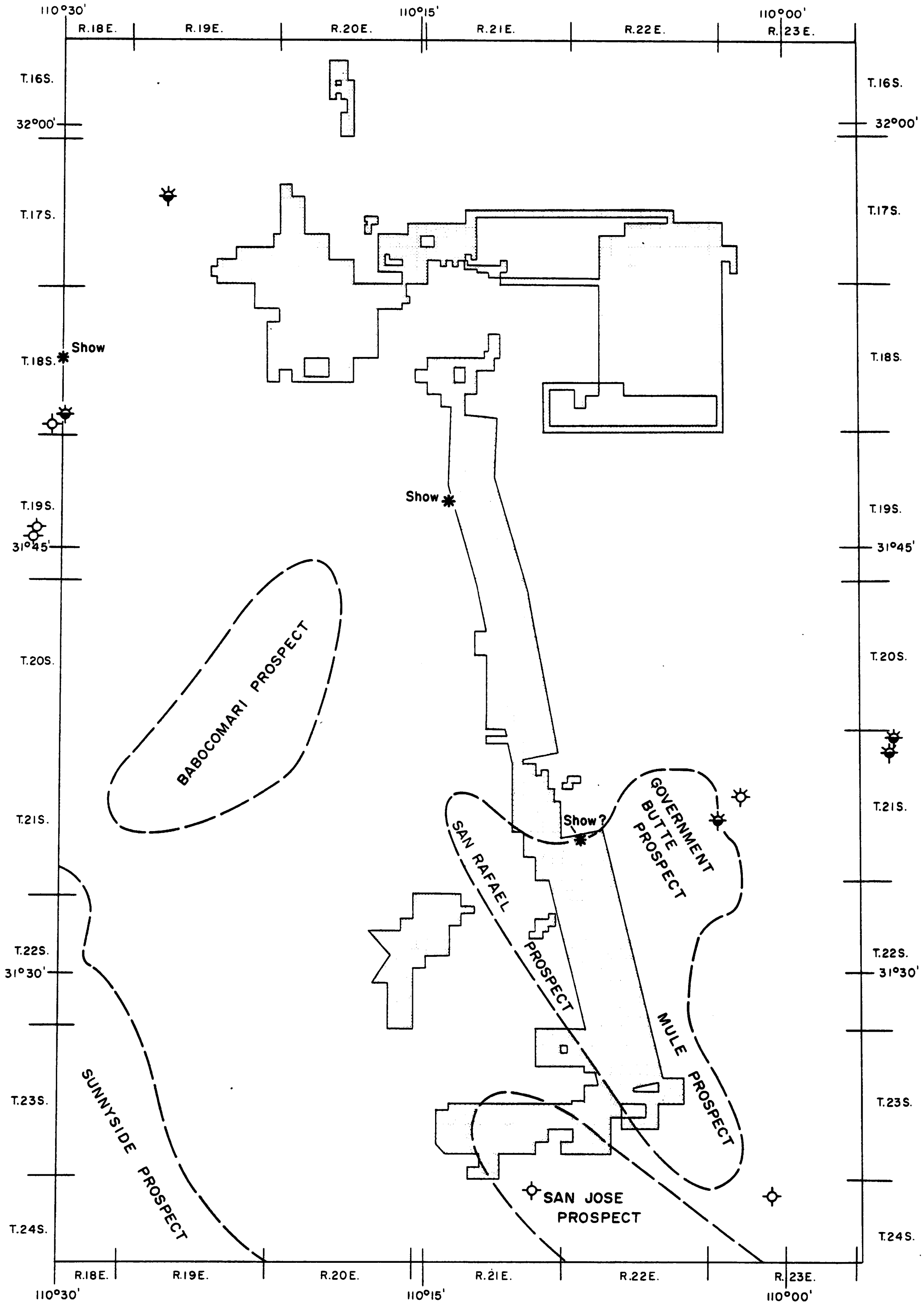
the western and southwestern flanks of the Mule Mountains. Ross (1978) compiled reconstructed cross sections of the lower Horquilla and indicated carbonate banks hundreds of feet in thickness in the vicinity of the Little Boquillas Ranch. Epitaph reefs and bioherms were reported by Wengerd (1959) on the southern flank of the Whetstone Mountains. Massive Concha reefs 200+ ft in thickness were identified in the Mustang Mountains and their rich and diversified faunal assemblage has been described by Bryant (1951). Wengerd (1959) indicated that the local Cretaceous Mural Limestone represents a series of reefs which were restricted to a narrow stratigraphic interval. Scott (1979) described the Mural as comprised of patch reefs up to 80 ft (25 m) in thickness and up to 1 mile (1.5 km) in length.

All of the forementioned reefs are potentially present in the subsurface on the Little Boquillas Ranch and may offer fair to good reservoir quality (Table 7-5). Most of the shows of oil and/or gas in test holes near the Little Boquillas Ranch have been in the Horquilla Limestone. Wengerd (1959) suggested six general oil prospects in the San Pedro River valley as shown in Figure 7-7. These prospects were generated by Wengerd chiefly from guesswork with buried reefs as targets.

Boquillas Surface Oil Shows

Figure 7-8 shows three localities in Secs. 17 and 18, T.19 S., R.21 E. at which petroliferous material was observed during this study. The three localities are in near proximity to the Little Boquillas Ranch. All of the oil occurrences are within the Plio-Pliestocene St. David Formation which is comprised chiefly of lacustrine deposits overlain by "outwash" gravels. Geochemical data indicate that the oil shows are biodegraded crude oil. These data are summarized in Table 7-7 and Figure 7-9. Some questions arise concerning the validity of the oil shows owing to a nearby dismantled railroad which may have spilled crude oil in route to the Douglas smelter to the south. However, the oil shows are most likely a natural phenomena.

Locality No. 1: A 3-4 inch unconsolidated, petroliferous sand bed is present at Locality No. 1 and is underlain by clay and overlain by sand and gravel (Fig. 7-8,



110°30'
110°15'
110°00'
R.18E.
R.19E.
R.20E.
R.21E.
R.22E.
R.23E.
T.16S.
T.17S.
T.18S.
T.19S.
T.20S.
T.21S.
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T.23S.
T.24S.
32°00'
31°45'
31°30'
Show
Show
Show?
BABOCOMARI PROSPECT
GOVERNMENT BUTTE PROSPECT
SAN RAFAEL PROSPECT
MULE PROSPECT
SUNNYSIDE PROSPECT
SAN JOSE PROSPECT

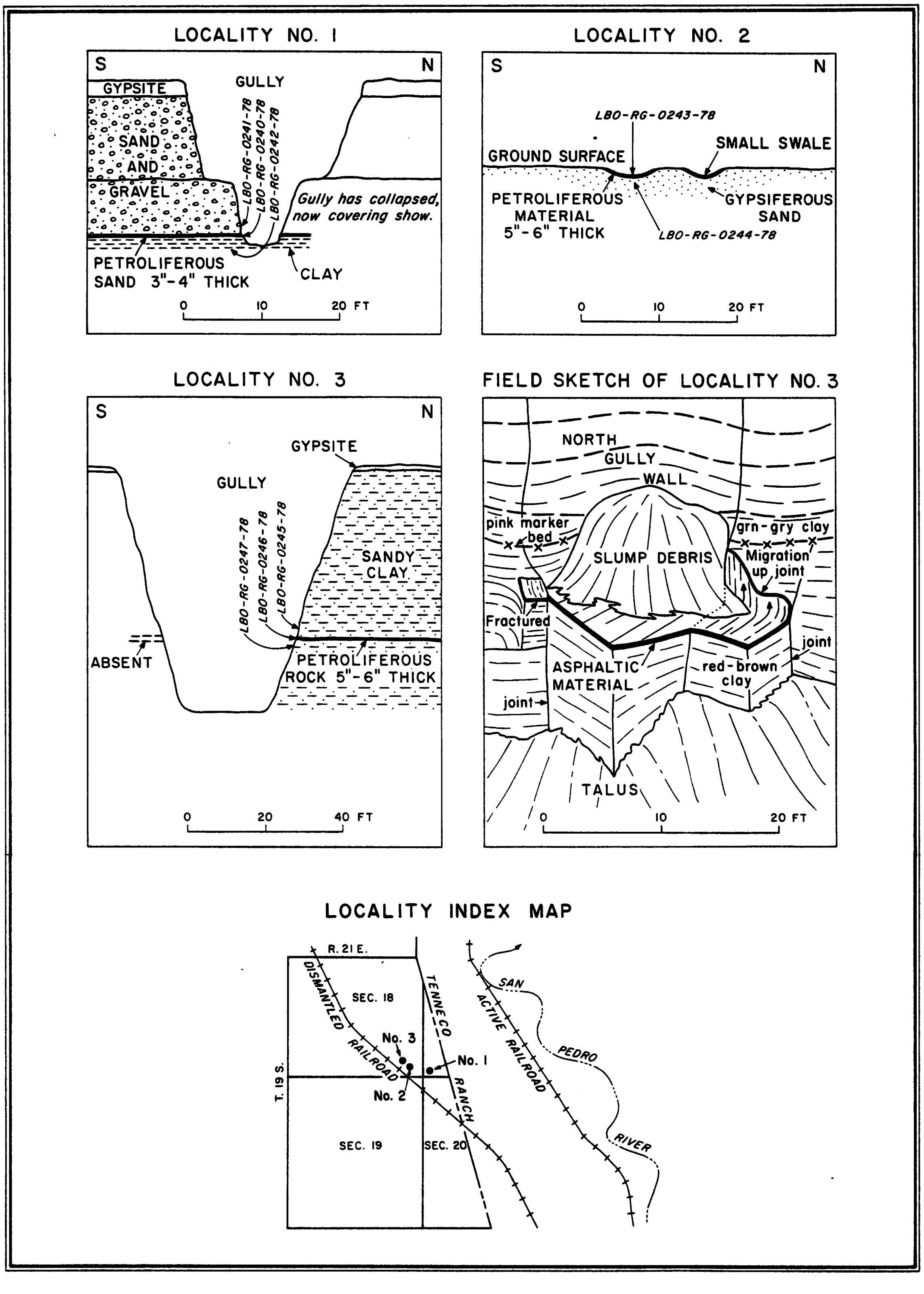


Figure 7-8. Boquillas surface oil shows.

Table 7-7. Geochemical data on the Boquillas surface oil shows.

SAMPLE NO.	LOCALITY (T.19S.,R.21E.);	GAS CHROMATOGRAPH	EXTRACTABLE HYDROCARBONS(ppm) *	SAPROPELIC (OILY KEROGEN)	VITRINITE REFLECTANCE(R_o)	MATURATION LEVEL	PROBABLE HYDROCARBON	REMARKS
LBO-RG-0240-78	Gully, SW¼ Sec. 17 Locality No. 1	Yes	5000 +	Some detected	0.556	Transitional	Gas & minor oil	Absence of n-paraffin (alkane) indicates crude oil is biodegraded. C_{25} peak suggests 1) origin from coaly material, or from 2) lagoonal type saline environment. No in situ spore/pollen.
LBO-RG-0241-78	Gully, SW¼ Sec. 17 Locality No. 1	No	430	Some detected	- - -	- - -	- - -	No in situ spore/pollen.
LBO-RG-0242-78	Gully, SW¼ Sec. 17 Locality No. 1	No	280	Some detected	- - -	- - -	- - -	No in situ spore/pollen.
LBO-RG-0243-78	Surface near RR, SW¼, Sec. 17 Locality No. 2	Yes	5000 +	Some detected	0.480	Immature	Gas	Severely biodegraded and weathered asphaltic crude oil. Normal n-paraffin portion of crude removed by microbial action. Sterance r region (C_{25}-C_{30}) indicates substantial contribution from land-derived organic material. Carbon distribution pattern is somewhat similar to sample LBO-RG-0240-78. No in situ spore/pollen.
LBO-RG-0244-78	Surface near RR, SW¼, Sec. 17 Locality No. 2	No	5000 +	Some detected	0.750	Mature	Gas & Oil	No in situ spore/pollen.
LBO-RG-0245-78	Gully, SE¼ Sec. 18 Locality No. 3	No	5000 +	- - -	- - -	- - -	- - -	No in situ spore/pollen.
LBO-RG-0246-78	Gully, SE¼ Sec. 18 Locality No. 3	Yes	5000 +	Some detected	0.636	Transitional	Gas & minor Oil	Absence of n-paraffin (alkane) indicates oil is biodegraded. Origin is possibly from terrestrial environment. No in situ spore/pollen.
LBO-RG-0247-78	Gully, SE¼, Sec. 18 Locality No. 3	No	880	Some detected	- - -	- - -	- - -	No in situ spore/pollen.

* Maximum detection limit of analytical instrument is 5000 ppm

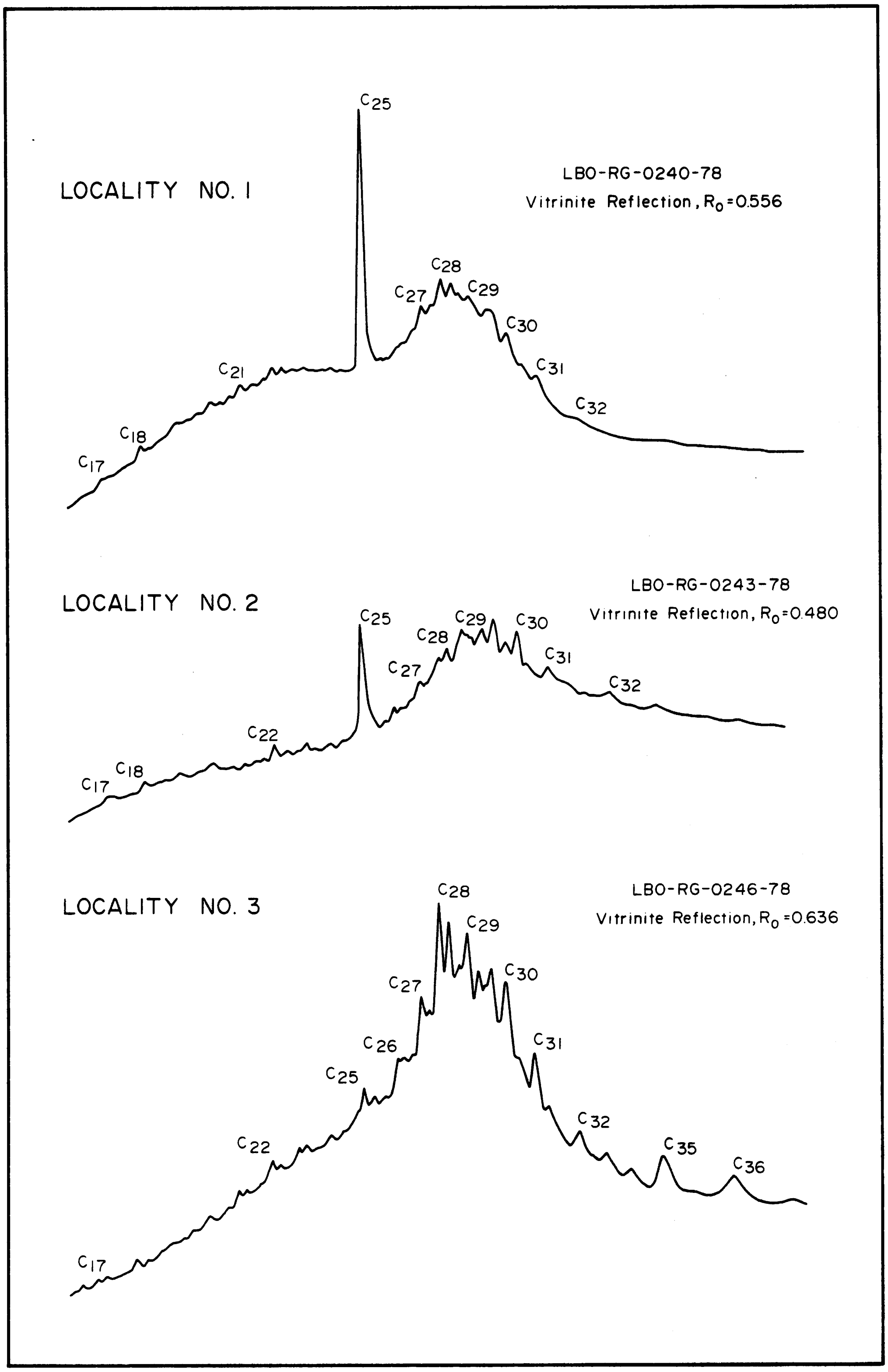


Figure 7-9. Gas chromatographs of extracts from Boquillas surface oil shows.

Photo 7-1). The thin, nearly flat-lying, concordant, oil-bearing sand is within a coarse facies of the St. David Formation and was exposed intermittently for 58 ft along the base of the south wall in a deeply-dissected gully. Slumping has since concealed all exposures of the oil sand. The sand is coarse grained, poorly sorted, and stained dark with a kerosene-like petroliferous substance which would not ignite when exposed to flame.

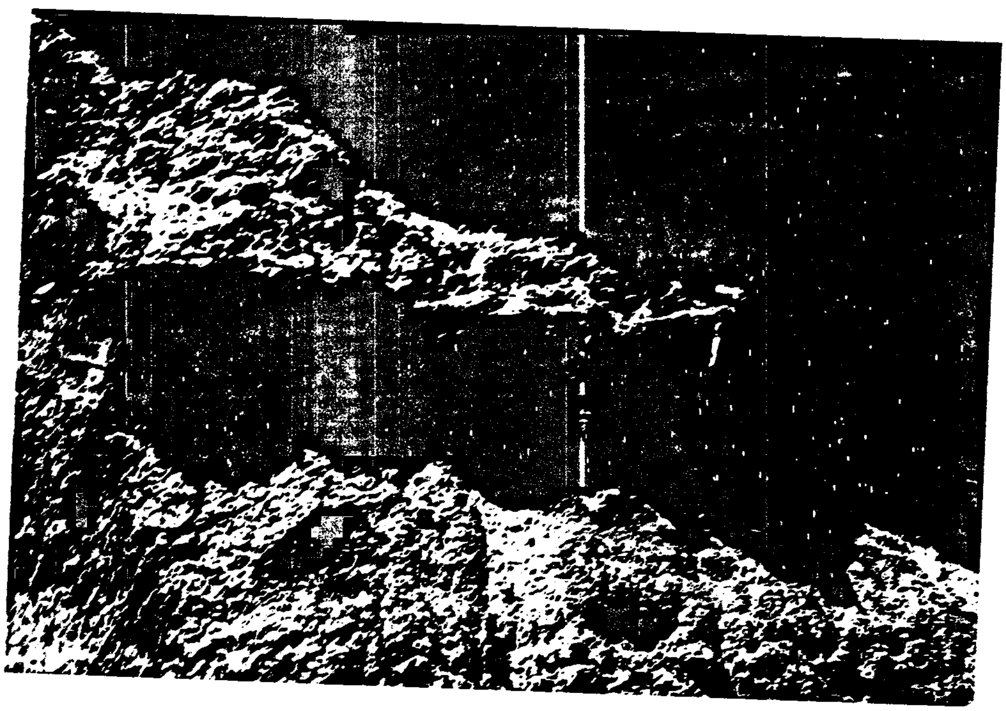
Locality No. 2: Black asphaltic material is exposed at Locality No. 2 in shallow surface swales (Fig. 7-8, Photo 7-2). Petroliferous material is up to 5-6 inches in thickness and is apparently confined to the troughs and margins of the surface swales which drain eastward from the abandoned Santa Fe Railroad bed. The asphaltic occurence extends 250-300 ft down drainage to the east of the railroad bed and gives an impression of being the result of an old crude-oil spill which emanated from the railroad. No petroliferous material was observed west of the railroad bed.

Locality No. 3: A nearly flat-lying, black, asphaltic seam averaging 5-6 inches in thickness and more than 20 ft in length is present in the north wall of a deeply-dissected gully at Locality No. 3 (Fig. 7-8, Photo 7-3). The seam is about 15-20 ft above the gully floor and is concordant and apparently bedded within lacustrine clay of the St. David Formation. The seam was partially exhumed by shovel and was observed to extend into the gully wall, thereby dispelling the idea that the seam may be an asphaltic accumulation which had accreted to the steep wall during entrenching of the gully. No continuation of the seam is present on the south wall of the drainage. The petroliferous material is locally fractured by desiccation joints and is expressed in a vertical plane where it has partially migrated up a desiccation joint (Fig. 7-8). Associated with the seam within the joint is a "pistachio green", botryoidal, resinous substance (hardness 6.5) which locally coats the asphaltic material. No vertical source or "root" for the seam was observed below the exposure. Field observations suggest that the asphaltic seam is syngenetic with the lacustrine host rock and not the result of an oil spill.

Geochemical data indicate that all three oil shows are severely biodegraded crude oil with a strong contribution from land-derived materials. The crude oil

Photograph 7-1. Boquillas surface oil show, locality No. 1.

Photograph 7-2. Boquillas surface oil show, locality No. 2.



Photograph 7-3. Boquillas surface oil show, locality No. 3.

likely originated from coaly material or from a lagoonal-type environment. No in situ spore or pollen could be isolated for age determinations. All three petroliferous localities contain 5000+ ppm soluble hydrocarbons (max. instrument detection limit) and enclosing sediments also contain significant amounts of soluble hydrocarbons. Some oily kerogen was detected. Vitrinite reflection values range from 0.480 to 0.750 and indicate maturity levels ranging from immature to mature and probable oil and gas.

The three oil shows are most likely a natural phenomena, although, some doubt still remains owing to the possibility of an oil spill along the railroad. Locality No. 2 is suggestive of a spill, however, Locality No. 3 strongly favors a geological oil occurrence. Heylmun (1978, p. 176) reported that some water wells drilled during the 1880's at St. David, approximately 9 miles north of the Boquillas oil shows, were ruined by oil. Mr. Tom C. Hargis, a local valley resident, stated that some local water wells have been ruined because of oil contamination (personal commun. with R. Gill, 1978). Many of these water wells were drilled in the St. David Formation. These data support a natural oil occurrence.

One hypothesis explaining the origin of surface and near-surface oil shows in the St. David Formation is that oil was and is migrating upward from breeched Paleozoic and Mesozoic accumulations and seeping directly into the St. David lake beds and/or to the surface. This has probably been occurring since at least Pliocene time. Cretaceous and Permian strata of potential reservoir quality crop out in the area and other favorable formations are present in sub-crop near the three surface oil shows (Pl. 9). Faults are probably the best avenues of oil migration in the area. Oil at the surface may have periodically seeped into the Plio-Pliestocene St. David lake where floating oil masses would eventually biodegrade and sink to the lake bottom and become preserved as scattered, irregularly-shaped, asphaltic layers within the lacustrine muds. Such deposits would be subject to remobilization. Recent seeps would be confined to local drainages near their source or may invade near-surface permeable zones. Erosion has since exposed some asphaltic layers and mobilized oily sands. Water wells have apparently encountered such zones.

From the above synopsis, Locality No. 1 likely represents mobilized petroliferous fluids which are occupying a permeable sand. The source of the hydrocarbons may be from remobilized petroliferous material in the St. David Formation or directly from underlying Paleozoic and Mesozoic strata. Locality No. 2 may be a partially-exhumed recent seep confined to existing drainage or remobilized asphaltic material from within the St. David Formation. Locality No. 3 is probably a syngenetic asphaltic deposit enclosed within lacustrine muds and has been partially remobilized as indicated by migration up a desiccation joint.

Lewis Springs Surface Oil Shows

Unconfirmed surface oil shows on the Little Boquillas Ranch near the Lewis Springs railroad depot (T.21 S., R.22 E.) were reported by Mrs. Mary Baker, a local valley resident (personal commun. with R. Gill, 1979). Mrs. Baker has lived at the depot for the past 15 years and stated that approximately 5 years ago (1974) oil began to appear in the local springs. Since then, oil(?) has periodically seeped up at several springs and has killed surrounding vegetation. The springs occur sporadically at an elevation of 4050 ft and extend 4000 ft southeast along a slope between Lewis Springs and Banning (abandoned railroad siding). Water samples were collected at the Lewis Springs depot (LBO-RG-0501-79) and at Banning (LBO-RG-0502-79), however, no soluble hydrocarbon content was detected. Sampling may have occurred at a time when oil was not seeping to the surface. If oil is actually present at periodic intervals, it is probably the result of seepage from underlying Paleozoic and/or Mesozoic strata.

Seismic Data

Confidential vibroseis seismic data (one line, approx. 13.4 mi) were provided to Tenneco Oil by Western Geophysical Company (1979) and indicate favorable subsurface geology. These data are not included or discussed in this report.

Petroleum and Natural Gas Potential

The general petroleum and natural gas potential on the Little Boquillas Ranch is classified as "good" owing to favorable geological indicators and partly to a lack of drilling data to prove or disprove various theories predicting hydrocarbon accumulations at depth. These theories can only be tested by seismic investigations and follow-up drilling of prime targets.

Evidence is at least moderately convincing that significant quantities of oil and gas were generated and preserved in Paleozoic and lower Cretaceous sedimentary rocks in the Pedregosa basin. Oil and gas shows have been reported near the Little Boquillas Ranch. The most serious question is that of preservation after several episodes of deformation, intrusion, and volcanism. The ranch has undergone multiple episodes of intense tectonism, plutonism, and volcanism, especially in the vicinity of Charleston. However, favorable source rocks, reservoir rocks, and perhaps stratigraphic and structural traps are present at depth at various localities. Mississippian, Pennsylvanian, Permian, and Cretaceous reefs offer attractive reservoir targets. Structures induced by Laramide tectonism may also offer favorable prospects.

No site-specific petroleum prospects are delineated in this report owing to the mineral-related and reconnaissance nature of this study. Pursuit of such prospects requires acquisition of existing seismic data and a concentrated exploration effort by petroleum geologists.

GEOTHERMAL RESOURCES

Introduction

Geothermal resources are defined in this report as useful heat energy which can be extracted from the earth via naturally occurring ground water, artificially injected ground water, steam, or steam-water combination. There are two major types of geothermal systems: 1) vapor-dominated or "dry steam system", and 2) hot water or "wet systems". Artificial wet systems can be established by injecting water into hot dry rock.

Wet systems can be divided into three temperature ranges:

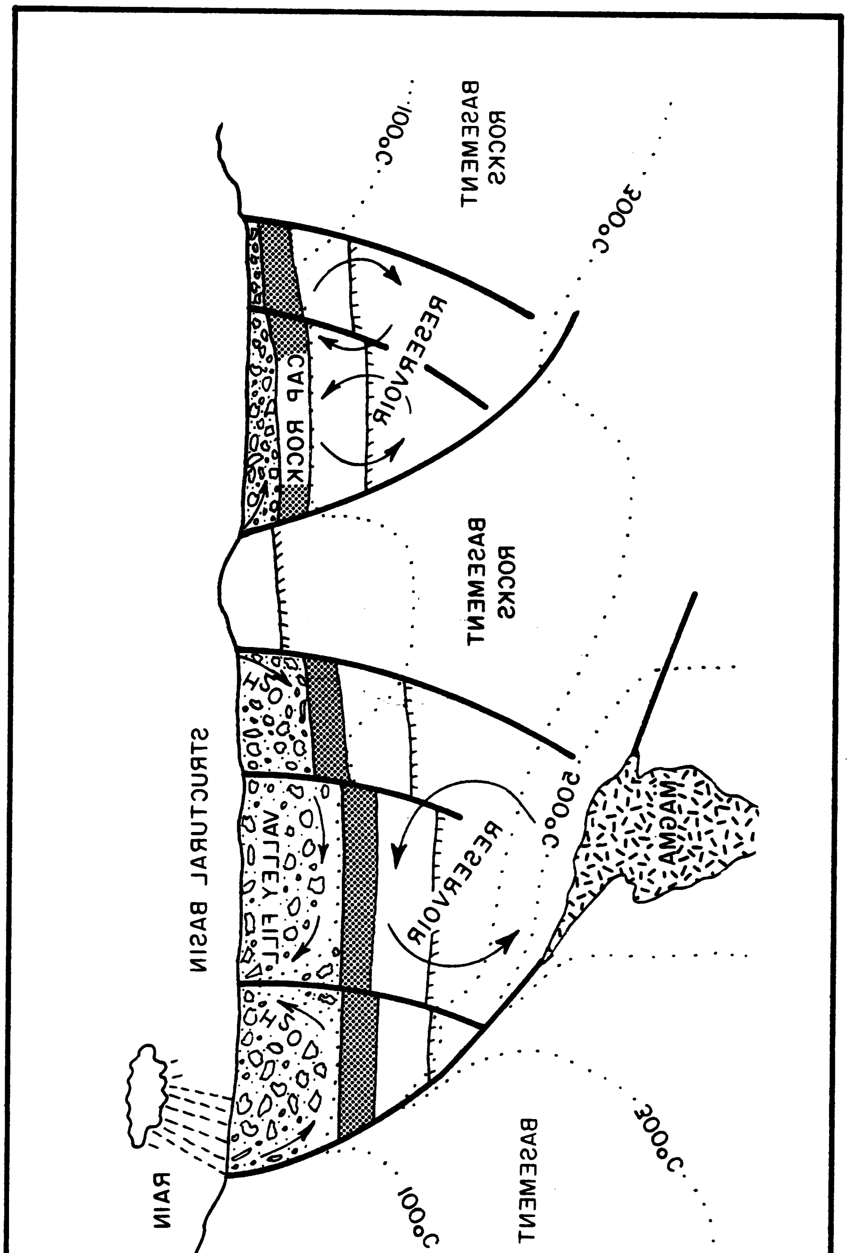
1. 150°C or greater - high temperature
2. 90-150°C - intermediate temperature
3. 20-90°C - low temperature

Potential geothermal systems on the Little Boquillas Ranch are probably wet (personal commun., Hahman, 1979) and of intermediate temperature.

Heat can seldomly be extracted economically from water below 50°C. Geothermal energy can not be extracted from hot water unless it is at least 5°C greater than the ambient air temperature. The annual ambient air temperature (1941-70) in the Little Boquillas Ranch area is 17.1°C (Benson) to 17.6°C (Tombstone).

Geothermal systems require four geologic conditions: 1) heat source, 2) reservoir rock, 3) cap rock (impermeable zone), and 4) water or steam. A model is presented in Figure 7-10. There are no producing geothermal systems in Arizona and projected application is speculative.

Ownership of geothermal resources in Arizona is uncertain and untested at present. California has ruled that geothermal energy systems belong to the mineral rights owner, however, geothermal legislation in other states involves water rights and surface rights. Tenneco West, Inc. retains fee ownership of mineral rights, water rights and surface rights on the Little Boquillas Ranch.

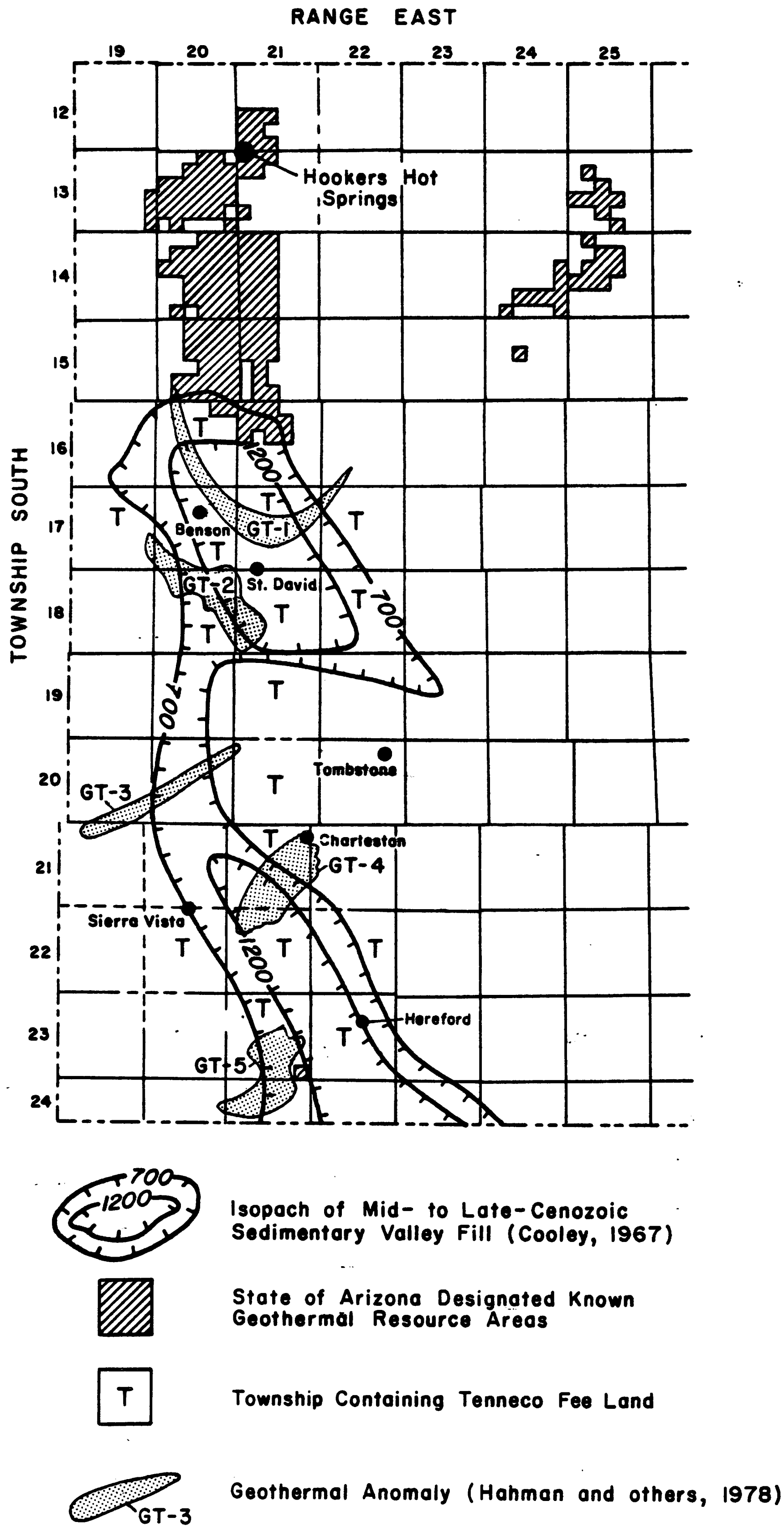

RAIN
STRUCTURAL BASIN
VALLEY FILL
H_2O
CAP ROCK
RESERVOIR
RESERVOIR
BASEMENT ROCKS
BASEMENT ROCKS
BASEMENT ROCKS
MAGMA
100°C
300°C
500°C
300°C
100°C

Geothermal Setting

The Little Boquillas Ranch is in the Basin and Range province which is characterized by north-trending mountain ranges (horsts) and intermontane valleys (grabens) containing Cenozoic sedimentary fill. Most of the thermal waters produced in the Basin and Range are from wells penetrating Tertiary, Quaternary and Recent sedimentary fill in structural basins. The mean water temperature for the Basin and Range in Arizona is 26.2°C. Any well or spring having a water temperature greater than 30°C is considered anomalous. The normal geothermal gradient for the province is 30°C/km. Anomalous gradients are considered 50-75°C/km. Approximately 87% of the geothermal anomalies in the Basin and Range province in Arizona are within 2000 ft of the land surface (Giardina and Conley, 1978, p. 12). Arizona lineaments trending N 40-60°E are related to high temperature gradients as are those trending N 40-45°W. Intersections of NW- and NE-trending lineaments are also considered favorable geothermal areas. (From Hahman, 1978 and personal commun., 1979) Blackwell (1978, p. 181, 198, 199) indicated that the region containing the Little Boquillas Ranch has a general terrestrial heat flow of 1.55-1.99 HFU (heat flow units), a range of 1.4 to 2.4 HFU, and an average of 1.8 HFU.

Mid- to late-Cenozoic valley fill on the Little Boquillas Ranch in the San Pedro River valley is relatively shallow as indicated by Figure 7-11. Ground water conditions in valley fill are excellent and are under both confined and unconfined conditions. Artesian wells are reported in valley fill deposits at Benson, St. David and Hereford, indicating reservoir and cap rock conditions. Gray (1965, p. 54) suggested that actual hot springs may have existed during the deposition of the St. David Formation (Plio-Pleistocene lacustrine valley fill) as indicated by gypsiferous zones.

Five anomalous ground water temperature gradients from 55-164+°C/km are present on or near the Little Boquillas Ranch. Jones (personal commun., 1979) stated that old houses in the St. David area have been warmed for years by thermal waters from wells. Jack Vraham, a local resident at Keller Ranch southwest of Tombstone, stated that steam was encountered in the Fraser No. 1 State oil test hole in Sec. 19, T.21 S., R.23 E. (personal commun., 1979). This is an anomalous situation owing to the shallow depth (1903 ft) of the test hole.


RANGE EAST
19
20
21
22
23
24
25
TOWNSHIP SOUTH
12
13
14
15
16
17
18
19
20
21
22
23
24
Hookers Hot Springs
Benson
St. David
GT-1
GT-2
GT-3
GT-4
GT-5
Tombstone
Charleston
Sierra Vista
Hereford
700
1200
T
Isopach of Mid- to Late-Cenozoic Sedimentary Valley Fill (Cooley, 1967)
State of Arizona Designated Known Geothermal Resource Areas
Township Containing Tenneco Fee Land
Geothermal Anomaly (Hahman and others, 1978)

The nearest significant hot springs to the Little Boquillas Ranch is Hooker Hot Springs which is about 27 miles north of Benson and has produced water at 54.4°C. The State Land Department has designated state lands north of the Little Boquillas Ranch as "Known Geothermal Resources Areas" (KGRA) based solely on their proximity to Hookers Hot Springs (Fig. 7-11).

Hahman (1978, p. 2) suggested five explanations for geothermal systems in the Basin and Range:

1. Deep circulation of meteoric water through intense, complex fracture systems.

2. Igneous rock intrusions along fractures or zones of weakness not exposed at the surface.

3. A combination of numbers 1 and 2.

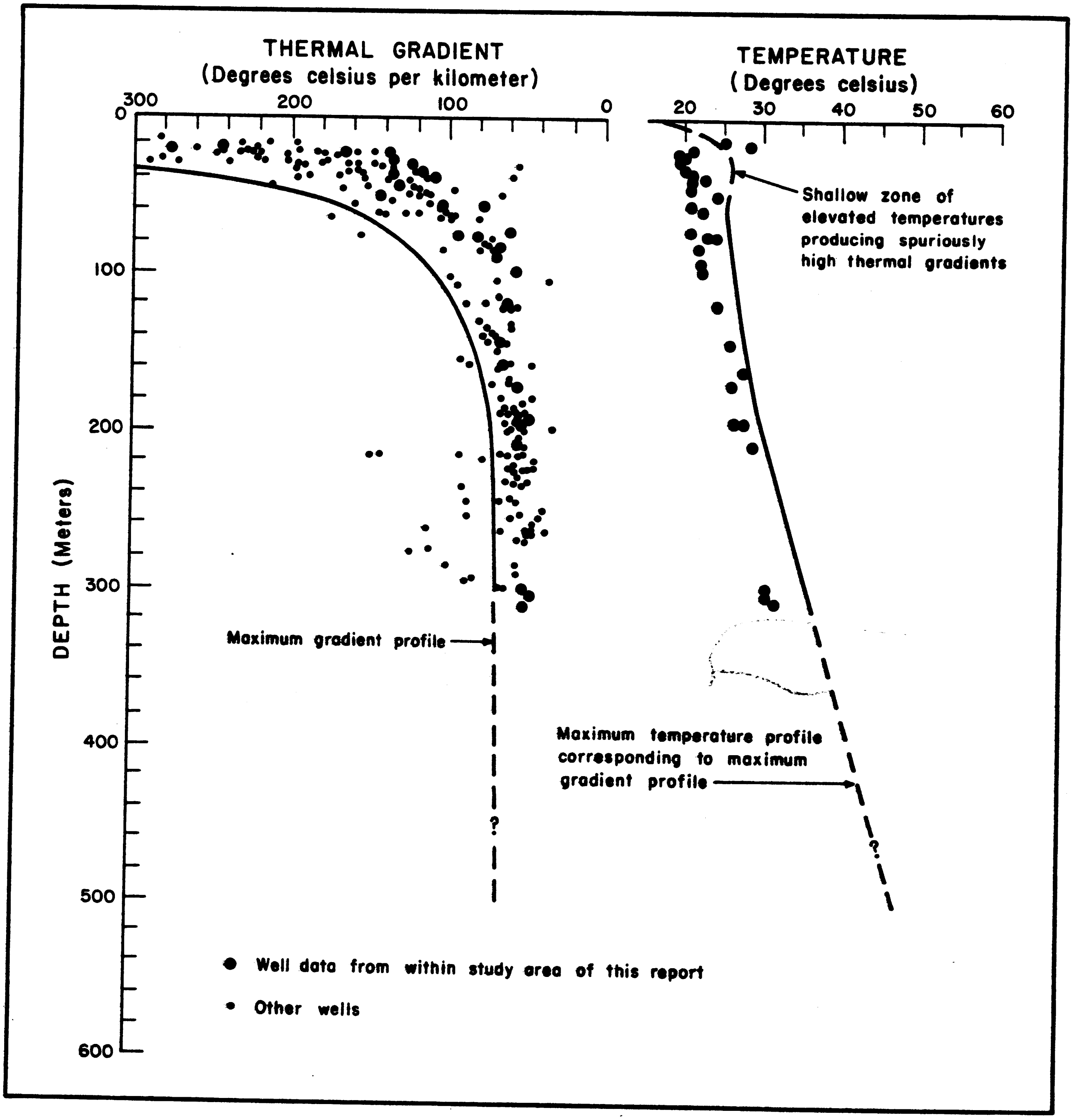
4. Heat generated by radiogenic decay of radioactive elements in igneous rocks.

5. Exothermic reaction resulting from the hydration of anyhdrite in the evaporative sequence of sediments that occur in some intermontane basins (Gerlach and others, 1975).

A possible explanation for anomalous ground water temperature gradients in the San Pedro River valley is that ground water moves vertically from deeply-heated crustal rock along faults and then moves horizontally into relatively shallow valley fill deposits (Giardina and Conley, 1978, p. 15). Hahman (personal commun., 1979) believes that thermal gradients along faults are sufficient to heat ground waters and cause anomalous geothermal gradients. Such gradients are potentially adequate for non-electrical energy applications. Maximum gradient and temperature profiles for Cochise County are presented in Figure 7-12.

Geothermal Anomalies

Five anomalous ground water temperature gradients from 55°C/km to 164+°C/km are present on or near the Little Boquillas Ranch (Fig. 7-11). These anomalies were compiled from water well data by Hahman, Stone and Witcher (1978). A brief narrative concerning each anomaly is presented below.



THERMAL GRADIENT
(Degrees celsius per kilometer)
300
200
100
0
TEMPERATURE
(Degrees celsius)
20
30
40
50
60
DEPTH (Meters)
0
100
200
300
400
500
600
Shallow zone of elevated temperatures producing spuriously high thermal gradients
Maximum gradient profile
Maximum temperature profile corresponding to maximum gradient profile
?
Well data from within study area of this report
Other wells

GT-1: The crescent-shaped geothermal anomaly (GT-1) with its apex in the St. David area (Fig. 7-11) may be due to the St. David pluton which is well-defined by aeromagnetic data to be 6700-7000 ft below the land surface in T.17, 18 S., R.21, 22 E. (Pls. 11 and 15). If the St. David pluton is Precambrian and rich in uranium (similar to the exposed quartz monzonite pluton in the Whetstone Mountains), then it may produce significant heat by radioactive decay and warm local ground water. It is unlikely that the St. David pluton is a cooling magma chamber owing to excellent magnetic definition which would not be expected at high temperatures (magnetic materials lose their magnetic properties at the Curie Point, 575^{o}C). It is also possible that the St. David pluton contributes minimal heat and is similar in age and composition to neighboring Cretaceous-Tertiary granitic plutons. If this is the case, the heat source for GT-1 is probably from faults which cut deeply-heated crustal rocks, perhaps related to the Sonoita and Huachuca lineaments.

GT-2: In T.18 S., R.20, 21 E. is a geothermal anomaly (GT-2) which is near the intersection of the Sonoita and Huachuca lineaments (Pl. 11) and also over a shallow, buried intrusive body (as defined by aeromagnetics) which may be related to the Precambrian, uranium-rich pluton exposed in the Whetstone Mountains. Radioactive decay may be a local heat source, however, ground water may also be heated along buried faults such as the one which trends E-W and bounds the northern margin of the Precambrian Whetstone pluton.

GT-3: Little speculation can be made at present concerning the elongate, NE-trending geothermal anomaly (GT-3) in T.20 S., R.19, 20 E. Aeromagnetic data in this area are limited. Buried faults may account for high thermal gradients in this alluviated area.

GT-4: The geothermal anomaly (GT-4) in T.21 S., R.21, 22 E. is likely related to the intersection of the Huachuca, Tombstone and Tucson lineaments. The area is the site of intense Cretaceous plutonism and volcanism and may contain rocks from younger igneous activity at depth. Portions of exposed outcrops have been altered by hydrothermal solutions and circulating meteoric waters. Owing to a concentration of fracturing and faulting in the area, the igneous terrain may prove favorable for the percolation of geothermal fluids along faults which intercept deeply-heated crustal rocks. The presence of an adequate cap rock for a geothermal system is uncertain.

GT-5: South of Hereford in T.23, 24 S., R. 22, 23 E. is a geothermal anomaly (GT-5) which is in near proximity to two suspected, buried volcanic necks as indicated by aeromagnetic data (Pls. 11 and 15). The anomaly also falls on the Huachuca lineament. Tenneco drilled one aeromagnetic anomaly in 1968 and encountered olivine basalt at 798 ft. Two other drill holes encountered basalt north of the suspected necks (Pls. 11 and 15). The basalt may be Quaternary in age and was possibly extruded from the suspected volcanic necks or vents as a surface flow (now buried) in the San Pedro trough. This rather young volcanism may account for the anomalous ground water temperature gradient and indicate that actual geothermal resources are present at depth.

Geothermal Resource Potential

Mr. W. R. Hahman, Sr., director of the Geothermal Group, Arizona Bureau of Geology and Mineral Technology, Tucson, AZ, stated that the geothermal potential of the Little Boquillas Ranch is "highly favorable" (personal commun., 1979). Upon request, Mr. Hahman and Mr. N. O. Jones, geologist, rated the ranch on a geothermal application scale presented in Figure 7-13. Assuming that adequate geologic conditions are present, a minimum temperature of $80^{\circ}C$ in a wet system is likely present at a depth of 2000 ft. Should the San Pedro structural basin extend to a depth of 10,000 ft, temperatures from $150-200^{\circ}C$ may be present.

On an overall basis, the Little Boquillas Ranch probably has intermediate geothermal temperatures in a wet system suitable for non-electrical energy utilization. Adverse salinity may be present in the Benson and St. David areas. Those portions of areally large anomalies exhibiting thermal gradients equal to or greater than $60^{\circ}C/km$ may be closest to the fault zones emitting thermal water. Localities containing such sites offer some degree of selectivity for initial geological, geophysical, and geochemical exploratory programs designed to evauate the geothermal energy potential (Giardina and Conley, 1978, p. 15).

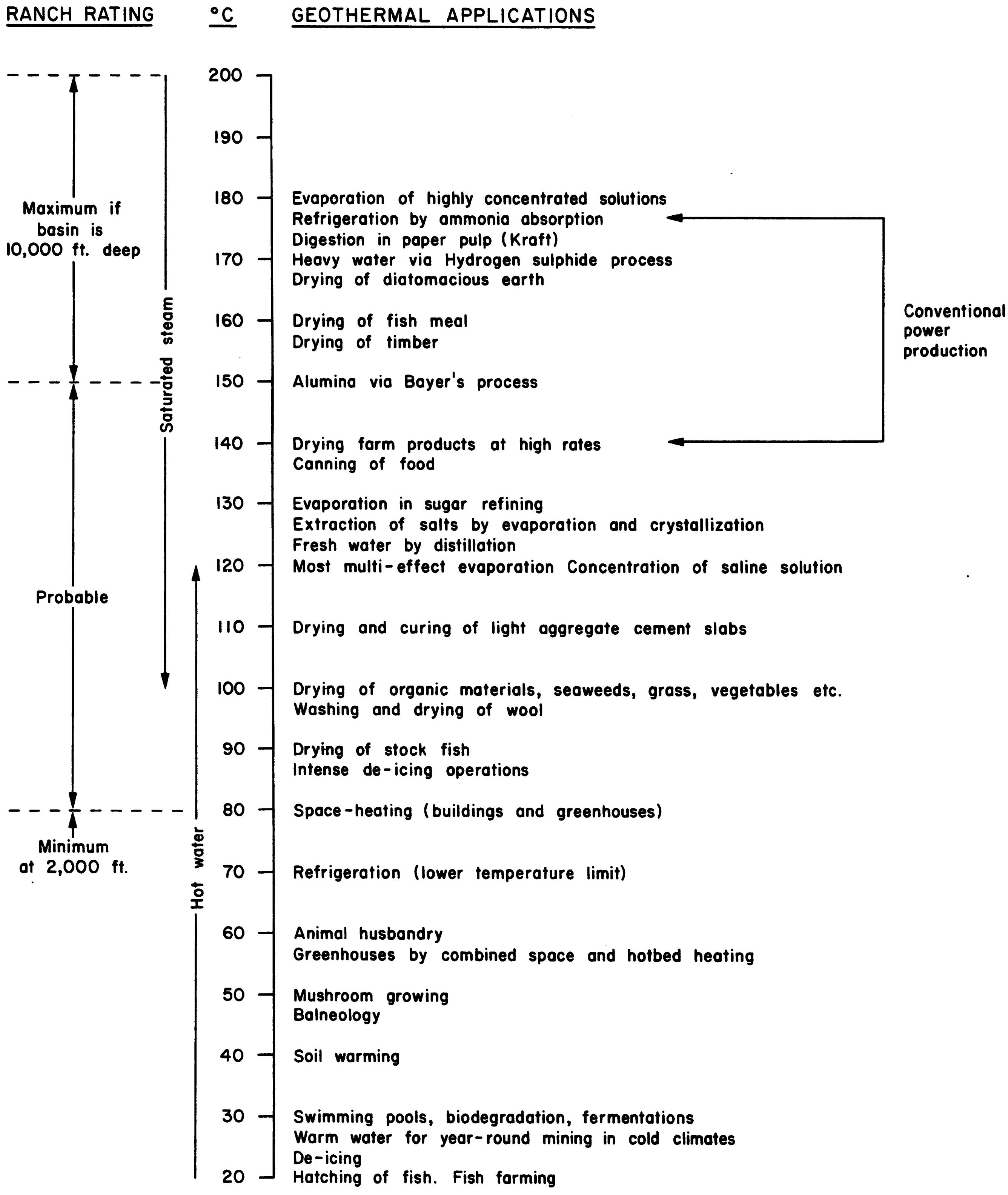


Figure 7-13. Geothermal potential rating of the Little Boquillas Ranch.

COAL RESOURCES

No significant coal resources are known to be on the Little Boquillas Ranch and adjacent area. Although much of Arizona was once covered by thick sequences of Cretaceous sedimentary rocks which may have contained coal, subsequent erosion has removed these strata leaving only isolated rock remnants that may contain coal potential.

Lower Cretaceous carbonaceous material has been reported in the western Whetstone Mountains, approximately 7-10 miles west of the Little Boquillas Ranch. Schrader (1915) was informed by local ranchers that a 40 ft deep shaft was sunk on a low-grade coal occurrence in the Whetstone Mountains area, but that there was no perceptible improvement of grade with depth. Another report relates that 4 inches of coal of "good grade" was found but that exploration work was unsuccessful in developing thicker coal deposits. Creasey (1967) has measured and described more than 7,000 ft of Cretaceous strata in the Whetstone Mountains, however, he did not encounter recognizable coal or lignite. These data support poor coal potential on the Little Boquillas Ranch.

METALLIC MINERALS

BASE AND PRECIOUS METAL RESOURCES

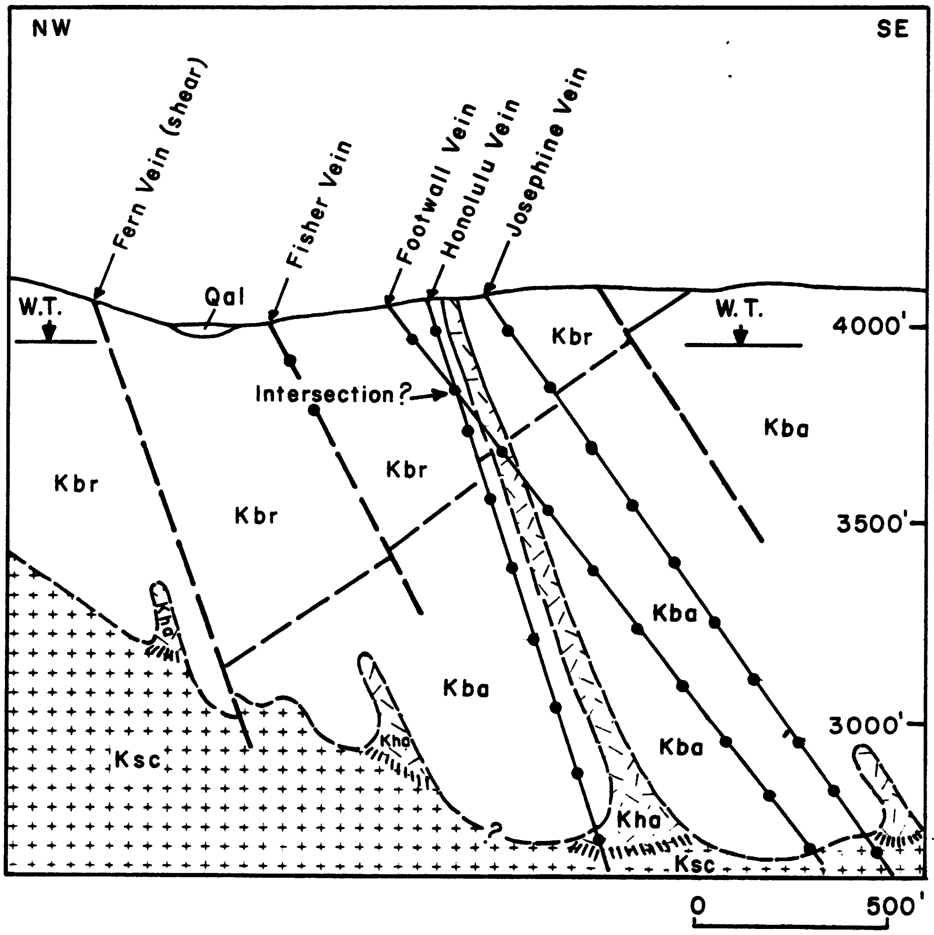
Introduction

The southeastern Arizona copper province is one of the great metallogenic regions on earth (Keith, 1979, p. 1). Metal production from this region consists chiefly of copper, molybdenum, lead, zinc, silver, and gold. The Little Boquillas Ranch lies well within the copper province and within the intersection of three major orogenic belts, 1) northeast-trending Precambrian belt, 2) northwest-trending Wasatch-Jerome belt, and 3) the northwest-trending Texas lineament (Fig. 8-1). A majority of the great domestic copper deposits occur along the Wasatch-Jerome orogenic belt and most of the total copper production in the U.S. comes from within the intersection of the three orogenic belts. Arizona produced 62% of the U.S. domestic copper production during 1978. Ten of the 15 leading copper producing mines in the U.S. are in Arizona. There are at least 14 major copper deposits within a 60 mile radius of the Little Boquillas Ranch (Table 8-1). Of these, five are porphyry copper deposits, eight are metasomatic replacement deposits, and one is a vein deposit. The ranch is in or adjacent to seven mining districts (Pl. 3). A summary of base and precious metal production from these districts from 1879 to 1970 is presented in Table 8-2.

In this report, base metal resources are confined chiefly to copper, lead, zinc, manganese, and molybdenum. Precious metals are principally silver and gold. Tungsten is considered an "other metal". On the Little Boquillas Ranch, identified and undiscovered base and precious metal resources are present or potentially present in porphyry copper deposits, metasomatic replacement deposits, vein deposits, and possibly in placer deposits. Some base and precious metal resources are present in old mill tailings and slag but are discussed under "Reclaimable Metallic Resources" in this report.

Definitions

Porphyry copper deposit: A copper deposit in which the copper-bearing minerals occur as disseminated grains and/or in veinlets



Qal – Alluvium

Kha – Hornblende Andesite

Kbr – Bronco Rhyolite

Kba – Bronco Andesite

Ksc – Schieffelin Granodiorite

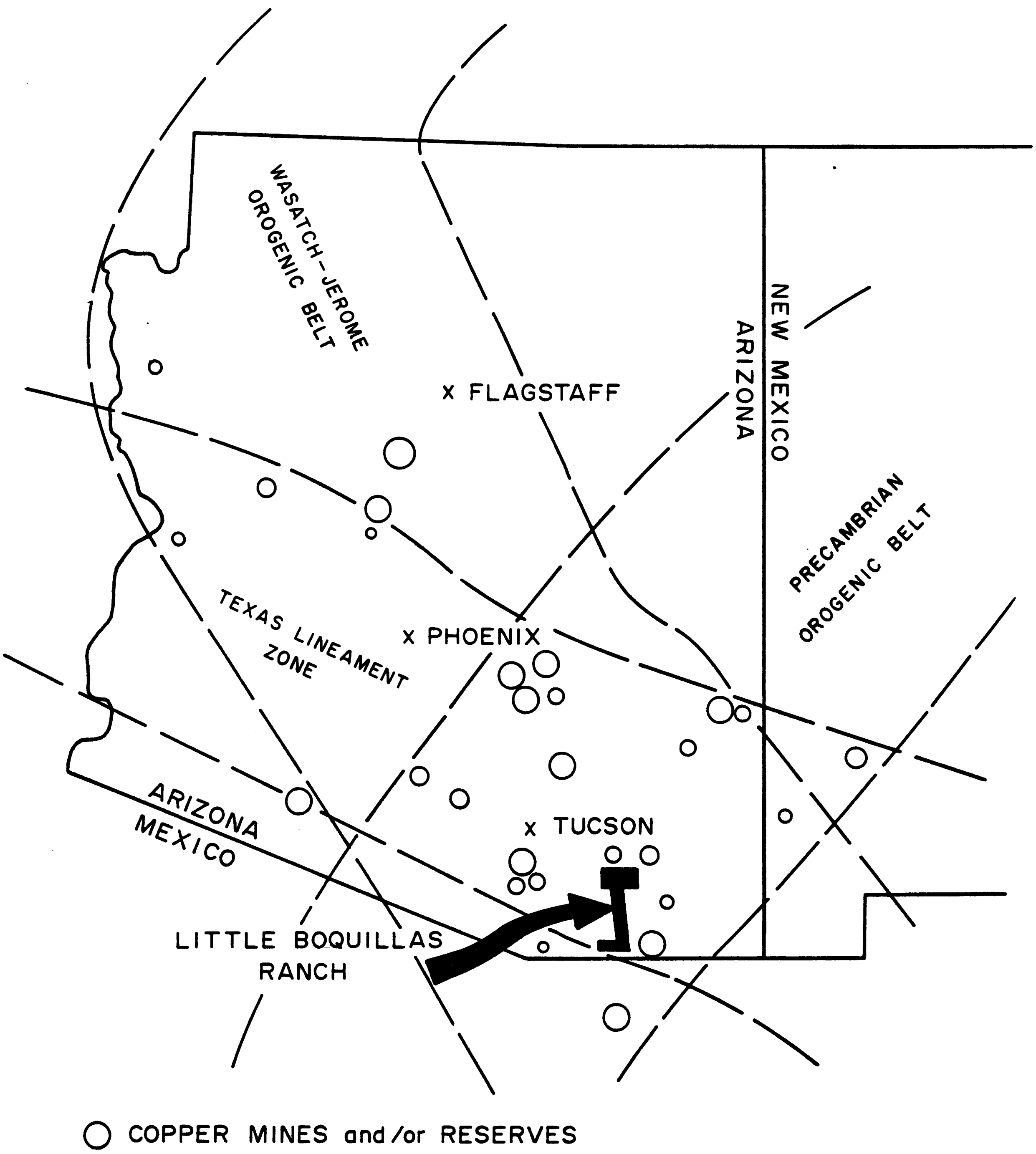

WASATCH-JEROME OROGENIC BELT
NEW MEXICO
ARIZONA
x FLAGSTAFF
PRECAMBRIAN OROGENIC BELT
TEXAS LINEAMENT ZONE
x PHOENIX
ARIZONA
MEXICO
x TUCSON
LITTLE BOQUILLAS RANCH
COPPER MINES and/or RESERVES

Table 8-1. Major copper deposits within a 60 mile radius of the Little Boquillas Ranch.

Deposit Name	Major Mineral Type	Tonnage (millions)	Avg. Cu Content (%)	Deposit Type
1. Aztec (Mame)	Oxide	2	1.00	Metasomatic replacement
2. Bisbee - north	Sulfide & oxide mixed	20	0.80	Quartz vein
3. Cananea	Sulfide & oxide	1700	0.70	Porphyry copper and metasomatic replacement
4. CF & I	Oxide	20 (?)	0.50 (?)	Metasomatic replacement
5. Copper Queen	Sulfide & oxide mixed	?	4.3	Porphyry copper
6. Dragoon	Sulfide & oxide mixed	500	0.50	Metasomatic replacement
7. Helvetia	Sulfide & oxide	320 20	0.64 0.55	Porphyry copper
8. I-10	Sulfide & oxide mixed	100	0.52	Metasomatic replacement
9. Johnson Camp	Oxide & Sulfide + oxide	9.9 10.0	0.50 0.60	Metasomatic replacement
10. Lavender (Bisbee)	Sulfide	380	0.68	Porphyry copper
11. Peach Elgin	Sulfide & oxide mixed	23	0.75	Metasomatic replacement
12. Red Mountain	Sulfide	100 (?)	0.71	Porphyry copper
13. Strong & Harris	Sulfide + oxide	60	0.60	Metasomatic replacement
14. Turquoise	Oxide	10	0.50	Metasomatic replacement

Table 8-2. Production summary of base and precious metals from mining districts in the vicinity of the Little Boquillas Ranch, 1879-1970 (after Keith, 1973).

Mining District	Short Tons Ore (1,000's)	Pounds Copper (1,000's)	Pounds Lead (1,000's)	Pounds Zinc (1,000's)	Ounces Gold	Ounces Silver (100's)	Total Value (1,000's)
1. Cochise (Johnson	1,640	74,775	605	93,650	229	734	32,180
2. Dragoon (Golden Rule)	19	18	356	249	9,741	72	340
3. Hartford (Huachuca)	9	74	588	375	393	25	140
4. Middle Pass (S. Dragoon)	76	2,011	274	9,251	337	147	1,725
5. Tombstone	1,500	3,018	45,000	1,179	240,000	30,000	38,800
6. Warren (Bisbee)	150,991	7,693,257	309,756	378,450	2,630,572	100,312	1,834,365
7. Whetstone	2	37	-	-	8	620	15

throughout a large volume of rock. The term implies a large, low-grade, disseminated copper deposit which may occur in granodiorite, quartz monzonite, schist, silicated limestone, and volcanic rocks, but is always associated with quartz-bearing igneous rocks. A porphyry copper deposit generally contains associated base and precious metals important to economic development.

Metasomatic replacement deposit: A mineral deposit formed by interstitial pore liquids and gases within a rock body. These fluids and gases replace the host rock by depositing new minerals of partly or wholly different chemical composition. Replacement deposits generally occur in areas of contact metamorphism, however, they may also occur somewhat distant from the contact zone. Rock within the contact zone is referred to as "tactite" or "skarn". In most places, tactites form distinctive, sharply-bounded bodies whose shape and distribution are controlled by many factors but mainly by the contact with an intrusive body which usually forms one wall, by favorable composition of the invaded strata, and by structural relations of the strata to the contact. Metasomatic replacement deposits may contain base and precious metals as well as non-metallic ore minerals.

Vein deposit: An epigenetic mineral filling of a fracture or fault in a host rock, in tabular or sheetlike form, often with associated replacement of the host rock. Veins may contain deposits of base and precious metals as well as non-metallic ore minerals.

Placer deposits: A surficial mineral deposit formed by mechanical concentration of mineral particles from weathered debris. Placers generally contain dense metallic minerals such as free gold and scheelite (tungsten mineral).

Porphyry Copper Deposits

Introduction

Perhaps the greatest mineral potential on or adjacent to the Little Boquillas Ranch is that of a porphyry copper deposit. A prime area of such potential on the ranch is within the Tombstone mining district along the flanks of the San Pedro River near the abandoned mill town of Charleston (Pl. 3). The district was actively mined in the late 1800's and has produced silver, lead, zinc, copper, and minor gold, manganese, and vanadium from vein and replacement deposits. Other areas on Tenneco fee land outside of the Tombstone mining district have also been identified as favorable for porphyry copper deposits.

Models showing the alteration and mineralization zoning of typical porphyry copper deposits have been adapted from Lowell and Guilbert (1970), Stillitoe (1973), and Hollister, Potter, and Barker (1974), and are presented in Figure 8-2. These models will be referred to periodically during the discussion of porphyry copper deposits on the Little Boquillas Ranch. The reader is referred to the literature for a complete discussion on the origin and characteristics of porphyry copper deposits.

Tombstone Mining District and Adjacent Areas

General Geology

The Tombstone mining district is located on a Laramide plutonic and volcanic center which is informally referred to in this report as the "Schieffelin igneous complex" (Fig. 8-3). The district geology consists chiefly of Paleozoic marine carbonates, Mesozoic marine and non-marine deposits, and Mesozoic volcanic rocks which are intruded by the Schieffelin Granodiorite and its tuffaceous eruptive equivalent, the Uncle Sam "porphyry" (misnomer), both of Laramide age. The Uncle Sam "porphyry" and the Schieffelin Granodiorite comprise the Schieffelin igneous complex and exhibit compositional, textural, timing, and spacial characteristics typical of good porphyry copper host rocks. Cross sections B-B', C-C', and D-D' in Plate 2a, cross sections B-B' and C-C' in Plate 9, and cross sections A-A' and B-B' in Plate 10a reveal the stratigraphic and structural relationships between rock units.

The Charleston area is considered a volcanic vent area for the eruptive phase of the Schieffelin igneous complex and contains Laramide outcrops of Uncle Sam "porphyry" and Schieffelin Granodiorite. Also present are Cretaceous outcrops of Bronco Volcanics (andesite and rhyolite) (Pl. 2). Detailed descriptions of these rock units are presented in Appendix C. Outcrops of Uncle Sam intrusive breccia within the general vicinity (Fig. 8-3) suggest that Laramide eruptive activity continued following partial solidification of the magma. Stillitoe (1973) includes intrusive breccias as an important part of his porphyry copper model (Fig. 8-2). Some "old timers" refer to such intrusive breccias as "mill rock" because you can genrally see a copper mill from the breccia outcrop.

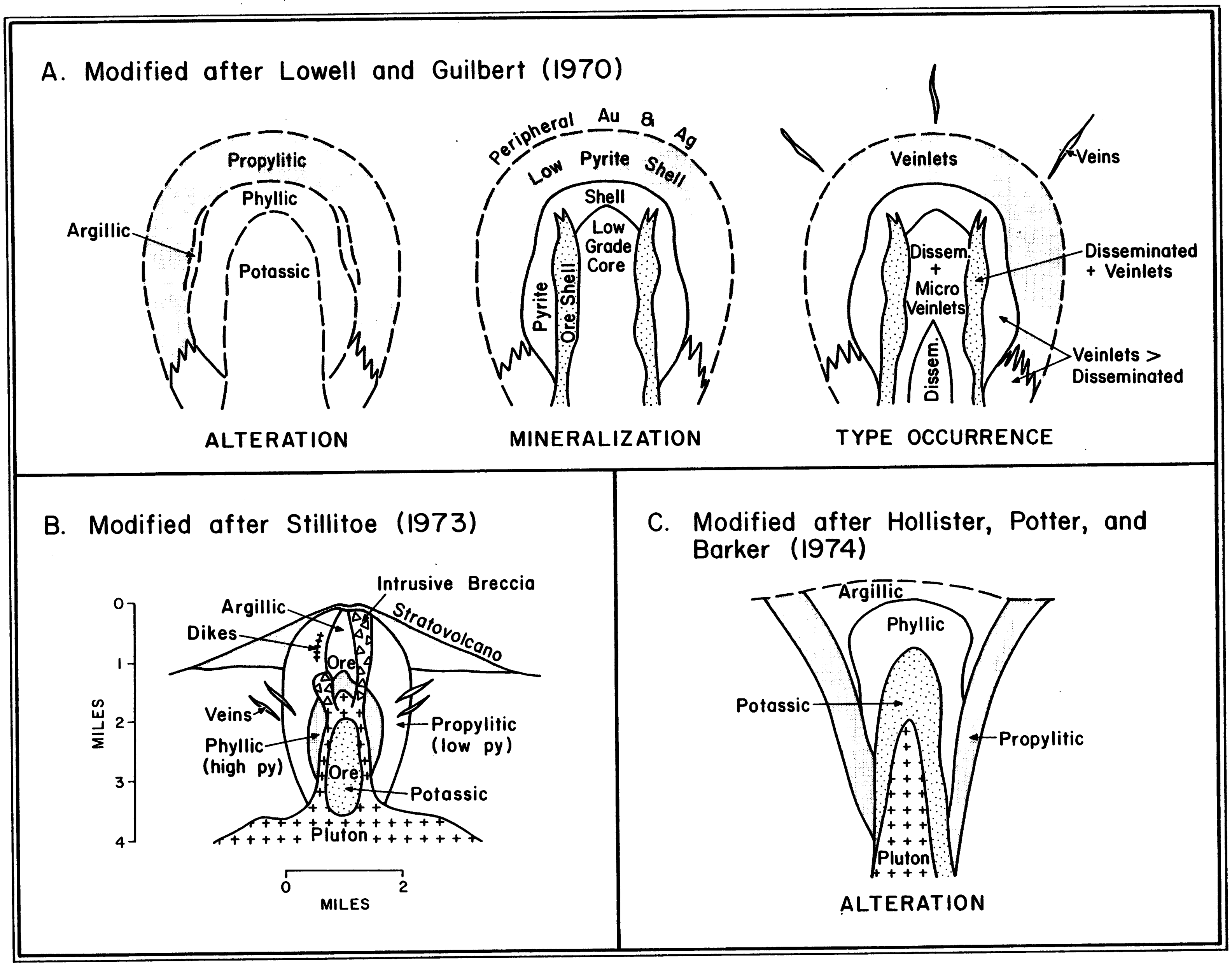


Figure 8-2. Models showing alteration and mineralization zoning of typical porphyry copper deposits.

The volcanic center in the Charleston area lies at the intersection of the Tucson, Huachuca, and Tombstone Landsat lineaments (Pl. 11). The probability of discovering porphyry copper deposits is believed higher along or adjacent to regional lineaments and their intersections. The Ray and San Manuel porphyry copper deposits (Laramide) are associated with the Huachuca lineament and the Bisbee porphyry copper deposit (Jurassic) is associated with the Tucson lineament. Fracture attitudes and fracture intersections measured near Charleston (rose diagrams, Pl. 11) indicate that the NE-trending Tombstone lineament and the N-NW-trending Huachuca lineament are the most prevalent. Fracture intersections near Charleston offer favorable avenues for porphyry copper mineralization at depth. A strong NE-trending fabric of alteration, fractures, dikes, and veins suggests that the Tombstone lineament is a controlling structural element (Fig. 8-3). This structural element may reflect a prominent direction of basement weakness associated with the NE-trending Precambrian orogenic belt and may have been subject to periodic reopening and subsequent mineralization, particularly during Laramide time.

Alteration and Mineralization

Introduction

Past base and precious metal production from the Tombstone mining district has been predominantly from vein and metasomatic replacement deposits associated with faults, folds, dikes, and sedimentary rocks on the eastern flank of the Schieffelin igneous complex near the town of Tombstone. No porphyry copper deposits are expressed at the surface.

Age of Mineralization

Available age dates and geology indicate that mineralization is related to the Laramide emplacement of the Schieffelin Granodiorite (72.2 m.y.; 76 ± 3 m.y.) and the Uncle Sam "porphyry" (71.9 ± 2.4 m.y.; 73.5 ± 2.8 m.y.) and subsequent alteration. Newell (1974) stated that silver mineralization at Tombstone is 72 m.y. in age and base metal mineralization at Charleston is 74.5 ± 3 m.y. in age; both are essentially indistinguishable. Fifteen of the sixteen known porphyry copper deposits in southern Arizona are between 55-75 m.y. in age. Thus, the timing of base metal mineralization on the Little Boquillas Ranch near Charleston is in the Laramide time realm of major porphyry copper deposits.

Charleston Alteration Zone

An elongate, northeast-trending, alteration zone extends 10 miles southwestward from Uncle Sam Hill across the Little Boquillas Ranch at Charleston onto the Ft. Huachuca Military Reservation (Fig. 8-3; Pl. 10). The "Charleston alteration zone" was initially identified in this study from color aerial photography and verified by ground observations and petrographic analyses. Propylitic, phyllic, argillic and silicic alteration have been identified at the surface within the gross alteration zone. Potassic alteration has been identified in core from a local drill hole. Such alteration zones are typically associated with porphyry copper deposits (Fig. 8-2).

Propylitic Alteration

Propylitic alteration is generally the weakest alteration type at major Arizona porphyry copper deposits, commonly forming a transitional fringe or halo between unaltered country rock and the more intensely altered zones (Fig. 8-2). Some large deposits have a propylitic halo which extends outward in radius for more than 1 mile. Minerals diagnostic of this zone are epidote, chlorite, calcite, and sericite with minor quartz and clay. In the Charleston area, some rocks exhibit relatively intense propylitic alteration, whereas other rocks are propylitically altered only along local structures such as shears, faults, and fractures. Quartz, epidote, and chlorite are dominant. Biotite is generally replaced along foliation by chlorite and calcite. Plagioclase is "cloudy" and generally contains fine grains of epidote, sericite, and calcite. Albite and veinlet orthoclase with minor calcite are sparingly present. Pyrite is the principal sulfide mineral. Some local drill holes contain 1-3% pyrite.

Argillic Alteration

Argillic alteration is characterized by alteration of feldspars to clay minerals (kaolinite, montmorillonite). In the Charleston area, moderate argillic alteration is locally concentrated along shears and fractures and was reported in drill hole T-71-2 (Pl. 11).

Phyllic Alteration

There are two principal zones of phyllic alteration in the general Charleston area. One zone is on the Little Boquillas Ranch in SW¼, Sec. 2, T.21 S., R.21 E. (Pl. 10) and the second zone is east of the ranch in Secs. 25 and 36, T.20 S., R.21 E. and Secs. 29 and 30, T.20 S., R.22 E. (area of Asarco copper exploration). Phyllic alteration is typically characterized by a quartz-sericite-pyrite mineral assemblage. Principal sulfides are generally pyrite and chalcopyrite occurring as disseminated grains. The most distinctive phyllic alteration in the Charleston area is complete sericitization of silicate minerals except for quartz. Plagioclase and orthoclase are both pervasively replaced by a "felted mat" of fine-grained sericite with abundant fine-grained granular quartz. Vestiges of plagioclase cleavage, zoning, and twin planes are retained. Primary quartz is unaltered but generally overgrown with secondary quartz. Oxidation has caused limonite psuedomorphs after pyrite at both phyllic alteration localities.

Potassic Alteration

Potassic alteration is the most important alteration type associated with a porphyry copper system. It represents the innermost alteration zone (Fig. 8-2) and is characterized by replacement of primary minerals by secondary biotite (brown), orthoclase, quartz, and sericite. Principal sulfides are chalcopyrite, pyrite, and lesser amounts of molybdenite. Contact between the potassic and phyllic zones is typically gradational over several hundred feet. Although potassic alteration has not been observed at the surface in the Charleston area, subsurface potassic alteration has been identified in core from Asarco drill hole CHS-1 (Appendix D). Weak potassic alteration begins at about 1467 ft below the surface and becomes progressively more distinct to a TD depth of 3968 ft. Data suggest that the potassic alteration is comprised of two phases; 1) an enclosing, outer, biotite (brown) envelope and 2) an inner orthoclase zone. A hypothetical interpretation depicting the potassic alteration zone is presented in Plate 2b, cross section D-D'. Core from the potassic zone in CHS-1 (Appendix D) contains pyrite (0.5-10%), chalcopyrite (0.3-0.7%), and trace molybdenite. Unfortunately, the exact location of CHS-1 is unknown. The hole location is believed to be nearby in the vicinity of Asarco copper exploration, beginning approximately 1 mile east of Tenneco fee land (Fig. 8-3).

Silicification

Silicification is present throughout the Charleston area and is primarily associated with faults and/or veins. Northeast-trending veins in the Charleston area locally contain low concentrations of precious and base metals. Such veins may represent a halo related to a porphyry copper deposit at depth as depicted in the models in Figure 8-2.

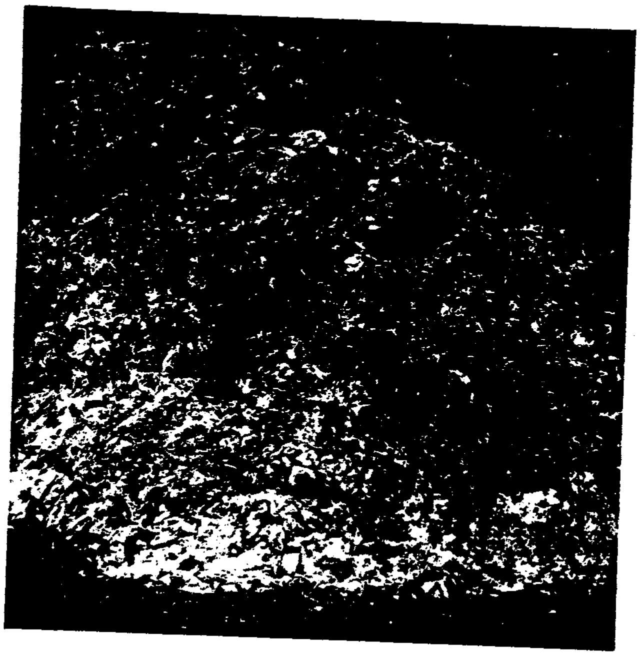
Origin

The origin of a porphyry copper deposit in the Charleston area and outlying areas is directly related to the emplacement of the Schieffelin igneous complex or coeval plutonic activity. Upward migration of magma was promoted by deep crustal fracture at the intersection of at least three lineaments and/or orogenic belts.

The Bronco Volcanics are the oldest igneous rocks near Charleston and may have vented to the surface as a Cretaceous predecessor of the Schieffelin igneous complex. Initial volcanism was mainly andesite flows, followed by tuffaceous rhyolite flows. These volcanic episodes were probably differentiates from the same magma chamber.

Following deposition of the Bronco Volcanics, the Schieffelin pluton was emplaced. This was a major igneous event which has been dated at 72 to 76 m.y. Aeromagnetic data suggest that the Schieffelin pluton has an approximate radius of 6 miles in outcrop and subcrop.

The Uncle Sam "porphyry" is thought to be a volcanic and/or subvolcanic differentiate of the Schieffelin Granodiorite. The Uncle Sam exhibits both flow and hypabyssal textures and is more siliceous and less mafic than the Schieffelin Granodiorite. Intrusive breccia phases within the Uncle Sam indicate release of volatiles during eruptive activity (Photo 8-1). Numerous dikes of varying compositions were emplaced after the Uncle Sam. The most characteristic are hornblende andesite dikes which trend northeasterly along the regional Precambrian orogenic belt trend.



Photograph 8-1. Uncle Sam intrusive breccia.

Mineralization and alteration were introduced coincident or shortly after emplacement of the Schieffelin igneous complex. Silver and base metal mineralization are dated at 72 m.y. and 74.5 ± 3 m.y. respectively. Mineralization and alteration probably resulted from heated meteoric and juvenile waters and metal-rich volatiles in a convective cell generated by the ascending Schieffelin pluton. Precious and base metal concentrations were subsequently deposited along fractures, shears, faults, and as stockwork mineralization. Erosion has removed upper portions of a porphyry system, exposing parts of the upper phyllic zone (Fig. 8-2). Metal-bearing minerals expected in a porphyry copper deposit include chalcopyrite, gold minerals, molybdenite, sphalerite, covellite, chalcocite, azunite, malachite, native copper, enargite, bornite, and tetrahedrite. Gangue minerals include pyrite, quartz, calcite, magnetite, pyrrhotite, limonite, and hematite.

Conflicting ideas concerning the primary origin of metallogeny in the southwestern U.S. are widespread. Stillitoe (1972) suggested that porphyry copper deposits are confined to orogenic belts characterized by calc-alkaline magmatism (Circum-Pacific belt). He further stated that such magmatism is generated by subduction of oceanic crust under continental crust. Metals are subsequently extracted from oceanic material and released during partial melting to ascend as components of calc-alkaline magmas. Keith (1978) lends supporting evidence to a plate tectonic origin for porphyry copper deposits and proposed a subduction model with ascending copper-bearing magma occurring in southeastern Arizona 50 to 70 m.y. ago. On the other hand, Lowell (1974) suggested that subducted oceanic crust is an unlikely source for metals in southwestern U.S. porphyry deposits and that many aspects of timing and distribution do not fit current plat tectonic models. Lowell further stated that the lower crust or upper mantle is a more logical source of metals which may be incorporated in magmas migrating upwards along zones of weakness.

Geophysical Exploration

From 1966 to 1970, periodic airborne magnetic surveys, ground magnetic surveys, and induced polarization surveys (I.P.) were conducted by Tenneco's past base metal group over portions of the Little Boquillas Ranch and adjacent areas. These surveys were aimed chiefly at locating sulfide mineralization associated with porphyry copper and metasomatic replacement deposits. Plate 3 depicts many of the survey areas. Limited follow-up drilling was conducted in areas of magnetic "highs", however, inadequate attention was directed towards magnetic "lows". Evaluation of aeromagnetic anomalies was never completed owing to dissolution of the exploration group in 1974.

In this report, available aeromagnetic data are compiled with newly acquired data and are presented in Plate 15. These data form the aeromagnetic base from which anomalies have been interpreted. Table 8-3 summarizes thirteen aeromagnetic anomalies which may contain porphyry copper or metasomatic replacement deposit potential. These anomalies are also presented as prospects in Plate 16.

Titley and Hicks (1966) postulated that Laramide porphyry copper deposits are not expected to be marked by positive magnetic anomalies and are more likely to occur in areas of magnetic "lows". Laramide host rocks (i.e. quartz monzonite) are generally weakly magnetic (500×10^{-6} gauss or less) and are frequently in a setting of more magnetic rocks. Magnetic "lows" are also associated with intense hydrothermal alteration within an intrusive complex where primary magnetite has been replaced by sulfide minerals. Such replacement is common in the upper portions of porphyry copper deposits. Highly-magnetic "skarns" or "tactites" may also form at the periphery of porphyry copper deposits, thereby rendering a magnetic "high" halo about a magnetic "low" within the porphyry interior.

The Laramide Schieffelin Granodiorite, an excellent base metal host rock on the Little Boquillas Ranch, has a magnetic susceptibility of $1500\text{-}3000 \times 10^{-6}$ gauss which is non-typical of Laramide intrusives according to Titley and Hicks (1966). This may be due to multiple chemical phases within the Schieffelin pluton or from an original magma rich in iron assimulated from basement rock.

I.P. surveys have been conducted in the Charleston area and along the western flank of the Dragoon Mountains (Pl. 3). These surveys have been in search for sulfide mineralization associated with both porphyry copper and metasomatic

Table 8-3. Aeromagnetic anomalies that may represent porphyry copper and/or metasomatic replacement deposits.

AEROMAGNETIC ANOMALY NUMBER & PROSPECT NAME	LOCATION Section(s)	Township(s)	Range(s)	MINERALIZATION POTENTIAL Porphyry-Type	Metasomatic Replacement-Type
1 2/ Fort Huachuca	9 & 10	21S	21E	Excellent	Fair
2 2/ Charleston	1 6	21S 21S	22E 21E	Excellent	Good
3 3/ Government Draw	18 & 19	21S	22E	Good to Excellent	Excellent
4 1/ Contention	16 & 17	19S	21E	Good to Excellent	Excellent
5 1/ Lewis Springs	29 & 30	21S	22E	Fair to Good	Poor to Fair
6 3/ Four Breccia	13 & 24 18 & 19	20S 20S	21E 22E	Good	Good
7 2/ Babocomari	4,5,8,9,16 17,20 & 21	20S	21E	Good	Good
8 3/ Walnut Gulch	31 & 32 5 & 6	19S 20S	22E 22E	Fair to Good	Fair
9 3/ Graveyard Gulch	16,17,28 & 29	21S	21E	Fair to Good	Poor to Fair
10 2/ San Juan	13,14,15,22, 23 & 24	18S	20E	Fair	Poor
11 2/ Land	8,17 & 20	18S	21E	Fair to Good	Fair
12 3/ Haberstock	28,29,32 & 33	18S	23E	Fair	Fair
13 2/ Dragoon	24,25,26,35,36 1,2,12,13 7,17,18,20,21	17S 18S 18S	22E 22E 23E	Poor	Excellent

1/ On Tenneco Fee Land   2/ Partially on Tenneco Fee Land   3/ Off Tenneco Fee Land replacement deposits. Most I.P. surveys to date have led to ambiguous conclusions with water-saturated clays in alluvial debris suspected as being responsible for some anomalies.

Future geophysical exploration should consist of ground magnetic and I.P. surveys over areas of suspected base metal mineralization. Such surveys should be used to refine geophysical control on larger targets which have been delineated by aeromagnetic surveys and geologic mapping.

Past Exploration Drilling

During 1971, eight shallow, vertical, copper exploration holes were drilled by Tenneco's past base metal group within or adjacent to the Schieffelin igneous complex, chiefly in the general Charleston area (Fig. 8-3 and Pl. 11). All Tenneco drill logs and/or reports are missing. Personal communication with Mr. John Beeder (1977), former Tenneco geologist, revealed some geologic data (Appendix E) as annotated at drill sites on Plate 11. In most cases, drilling was terminated due to caving or excessive ground water. Maximum hole depth is believed to be in the vicinity of 800 ft. Drill hole depths were not sufficient to test the area. Pyrite mineralization (1-3%) was prevalent in many of the drill holes, perhaps indicating a low pyrite shell encompassing a porphyry copper system at depth as suggested by the models in Figure 8-2. Past Tenneco exploration drilling concentrated on or near aeromagnetic "highs" which may represent magnetite enrichment at the flanks of a porphyry copper system. Aeromagnetic "lows", possibly representing zones of hydrothermal alteration, were not drilled. Mr. Beeder seemed convinced that a porphyry copper system exists at at depth within the general Charleston area.

Asarco has drilled at least 11 copper exploration holes within a 2 sq. mile area, approximately 2-2.5 miles northeast of Charleston (Pl. 11). Drilling was perhaps in response to seven copper targets delineated by Newell (1974) (Pl 3). Some whole and split drill core is stored at the abandoned Charleston Lead mine, however, much of this core is scattered in piles (Photo 8-2). Core observation made from drill hole CHS-1 (Appendix D) indicate a porphyry copper system at depth. An abstract of CHS-1 is presented as follows:

Photograph 8-2. Drill core stored at Charleston lead mine.

Drill Hole CHS-1: Asarco; location - T.20 S., R.21 E., SW¼ of twnshp, Sec. unknown; hole vertical(?); TD 3968 ft(?); collar elev.(?); 0-300 ft Uncle Sam, intense oxidation; 84-2480 ft Uncle Sam, phyllic alteration w/sericite, pyrite, qtz, pyrite veinlets, trace chalcopyrite; 2480-2826 ft no core; 2826-2860 ft Uncle Sam, potassic alteration w/biotite-rich zone, disseminated pyrite, sparse chalcopyrite along fractures, qtz stockwork; 2860-3200 ft textural transition zone from porphyritic Uncle Sam to equigranular Schieffelin Granodiorite; 3200-3220 ft Schieffelin Granodiorite, granular texture, potassic alteration w/orthoclase, biotite, disseminated pyrite, sparse chalcopyrite, trace molybdenite, overall chalcopyrite to pyrite ratio increase; 3220-3968 ft Schieffelin Granodiorite, equigranular, potassic alteration overprinted by weak propylitic alteration suggesting that hydrothermal convection cell collapsed rapidly; chalcopyrite to pyrite ratio increase, magnetite to sulfide ratio increase, primary magnetite augmented by secondary magnetite; TD 3968 ft(?) - No supergene enrichment observed in hole; pyrite range 0-10%; chalcopyrite range 0-0.7%; trace molybdenite.

Porphyry Copper Deposit Potential

The Little Boquillas Ranch offers good to excellent potential for a porphyry copper deposit(s) and associated base and precious metals. This potential is expressed by many favorable indicators to include locality, host rock, geologic timing, structural geology, alteration, mineralization, geophysical data, and sparse drill data. The Charleston area and out-lying areas associated with the Schieffelin igneous complex offer the best exploration potential.

A hypothetical porphyry copper deposit in the Charleston area will likely be deep (2500+ ft), well below the local water table. A supergene enrichment blanket may or may not be expected. Erosion has probably stripped overburden down to the upper phyllic zone of the porphyry copper system. Alteration at depth will probably be moderately to well zoned. Sulfide ore will likely predominate. Some molybdenite, silver, and trace gold can be expected with copper ore.

Past shallow exploration drilling (800 ft) by Tenneco did not adequately test the Charleston area for porphyry copper deposits. Limited exploration drilling to depths of 3000+ ft is necessary to delineate specific target zones. Asarco drill holes (up to 400+ ft?) on nearby lands east of Tenneco property (Fig. 8-3) have encountered a deep, low grade porphyry copper system of unknown size. Such systems commonly occur in clusters and may extend onto the Little Boquillas Ranch in the Charleston area.

Metasomatic Replacement Deposits

Introduction

Table 8-3 lists anomalies interpreted from aeromagnetic data and geology of which some are thought to be favorable for metasomatic replacement deposits. These anomalies are presented as prospects in Plate 16. Several metasomatic replacement prospects are briefly described in this section.

Metasomatic replacement deposits are characteristic of the Dragoon, Middle Pass, and Tombstone mining districts which locally include portions of the Little Boquillas Ranch. The majority of such deposits have been described as mantoes and chimneys in Paleozoic and/or Mesozoic carbonate host rocks. Production from metasomatic replacement deposits has consisted mainly of base metals in the Dragoon and Middle Pass mining districts and base and precious (mainly silver) metals in the Tombstone mining district.

Dragoon Prospect

The Dragoon prospect (Pl. 16, prospect no. 13) represents a projected curvilinear intrusive contact between the Tertiary Stronghold Granite and bordering Mesozoic and Paleozoic strata along the western flank of the Dragoon Mountains. This concealed igneous contact is below alluvial debris and is described as a "tactite zone" in Plate 11. Actual tactite may include buried roof pendants and thrust sheets as exposed in the Dragoon Mountains. The Little Boquillas Ranch includes approximately 5 miles of the projected "tactite zone".

Tactite is exposed at two localities along the Dragoon prospect; 1) in the S½, Sec. 24, T.17 S., R.22 E. where the Bisbee Formation (Cretaceous) is locally altered to tactite with sparse pyrite and magnetite (sample LBO-RG-0053-78) and 2) in Sec. 21, T.18 S., R.23 E. where Devonian Martin Limestone(?) is altered to tactite with minor malachite and azurite along fractures (sample LBO-RG-0042-78). At least three mineral test holes (DDH-1, T-3, and T-4) were drilled by Tenneco's past minerals department in the early 1970's to explore these tactite occurrences. Only sparse data concerning these holes are available and drill logs are missing. Some tactite was reportedly encountered. The middle and lower members of the Abrigo Limestone (Cambrian) offer excellent host rock for metasomatic replacement deposits and were probably prime drilling targets in the past.

The Stronghold Granite is the youngest (22-27 m.y.; post Laramide) major intrusion within the study area and is conspicuous among other intrusive rocks by its pronounced metamorphic effects on adjacent strata. Minor metasomatic replacement deposits associated with roof pendants are scattered throughout the exposed pluton (Pl. 10). Cooper and Silver (1964) noted that the Stronghold Granite resembles the nearby Texas Canyon Quartz Monzonite (31-70 m.y.; probably Laramide - 53 m.y.) and may be part of the same large intrusive complex. The Texas Canyon Quartz Monzonite is responsible for the economic skarn mineralization of the middle and lower members of the Abrigo Limestone at Johnson Camp and vicinity (Pl. 11) north of the Dragoon prospect. Similar mineralization may be present along the "tactite zone" of the Dragoon prospect on the Little Boquillas Ranch.

Government Draw Prospect

The Government Draw prospect (Pl. 16, prospect no. 3) represents an igneous contact area between the Laramide Schieffelin Granodiorite and the Bisbee Formation (Cretaceous) in Secs. 17, 18, 20, T. 21 S., R.22 E. and partially extends onto the Little Boquillas Ranch. Tactite is exposed in local outcrops. Paleozoic rocks are suspected to be within several hundred feet of the surface and may offer favorable host conditions for metasomatic replacement deposits.

Contact alteration between the Schieffelin Granodiorite and local country rock is well developed and metamorphic conditions have been described by Newell (1974) as those of the pyroxene-hornfels facies (low pressure: 1-2 km; moderate temperature: 600-700°C). Rasor (1937) reported that intrusion of the Schieffelin resulted in a "simple heat effect" on adjacent rocks with little or no addition of iron or other elements. Such conditions do not support metasomatic replacement deposits of economic minerals. However, Newell (1974) outlines the particular area as his "Government Draw-San Pedro intersection" exploration target based on anomalous mesquite biogeochemical molydenum values.

Contention Prospect

The Contention prospect (Pl. 16, prospect no. 4) is totally on the Little Boquillas Ranch in projected Sec. 16, T.19 S., R.21 E. This prospect is delineated by a aeromagnetic "high" and associated "low" (Pl. 15).

Tenneco's past minerals department drilled a single mineral test hole (C-1, Pl. 11) on the Contention prospect during the early 1970's(?), however, only sparse data are available and drill logs are missing. Paleozoic limestone was reportedly encountered beneath the Plio-Pleistocene St. David lake beds at 800 ft below the surface. The carbonate rock was described as gray with flat shears and cubes of pyrite of which many were replaced by limonite. These carbonate strata may be favorable host rocks for metasomatic replacement deposits provided the aeromagnetic signature represents a local Tertiary intrusive body which has induced mineralization.

Origin

Potential metasomatic replacement deposits on the Little Boquillas Ranch are the result of interstitial pore liquids and gases replacing the host rock with new minerals. The deposits generally occur in areas of contact metamorphism associated with plutonic rocks. Such deposits may also occur at the flanks of porphyry copper systems.

Tactite zones within the region exhibit conversion of clean limestone and dolomite to marble. Clean limestone near faults may alter to garnet tactite. Impure dolomite alters to forsterite, diopside, tremolite, wollastonite, and actinolite. Impure limestone converts to garnet, diopside, epidote, wollastonite, and idocrase. Shale alters to biotite hornfels.

Primary metallic mineralization may occur simultaneously with contact metamorphism or follow thereafter, filling fractures, faults, and void spaces and replacing mineral species. Secondary oxidation of such deposits is often stratigraphically controlled by host rock permeability and dip direction causing discrete zones of oxide mineralization and argillaceous mineral products. Metal-bearing minerals associated with skarn deposits include chalcopyrite, chalcocite, sphalerite, malachite, chrysocolla, azurite, smithsonite, hemimorphite, covellite, cuprite, tenorite, native copper, bornite, galena, scheelite, tetrahedrite, wolfranite, and aurichalcite. Gangue minerals may include pyrite, pyrrhotite, limonite, hematite, calcite, gypsum, and quartz. The Johnson Camp skarn deposit is an excellent example of an economic metasomatic replacement deposit in near proximity to the Little Boquillas Ranch.

Metasomatic Replacement Deposit Potential

The Little Boquillas Ranch offers good to excellent potential for metasomatic replacement deposits similar to those at Johnson Camp and at Tombstone (Pl. 11). This potential is expressed by a favorable geologic setting to include important late Mesozoic-Tertiary plutonism with attending metamorphism of adjacent strata. Excellent carbonate host rocks are present within the study area near plutonic intrusive bodies. Also, favorable porphyry copper potential for the ranch indicates favorable potential for metasomatic replacement deposits owing to their common occurrence at the flanks of a mineralized porphyry system.

The Stronghold prospect is promising for metasomatic replacement deposits, although some reservation is expressed concerning its post-Laramide age in regards to significant mineralization in the region. The Government Draw, Contention, and other prospects (Pl. 16) also offer favorable exploration sites. Good to excellent host rocks consist of the lower and middle members of the Abrigo Formation (Cambrian), the Horquilla Limestone (Penn.-Miss.), and other Paleozoic and Mesozoic carbonate strata within the region.

Exploration for metasomatic replacement deposits on the Little Boquillas Ranch should include detail geologic mapping where possible followed by site-specific geophysical surveys and subsequent drilling where warranted.

Vein Deposits

Introduction

Significant veins on the Little Boquillas Ranch are seemingly restricted to the Charleston area within the Tombstone mining district (Pl. 10). Silver is the most widely and uniformly distributed metal in the district, however, lead, manganese, and antimony are also somewhat ubiquitous. Silver is present in nearly all types of ore and is not confined to any single mineral assemblage. Some ores have practically all their value in silver. (After Butler, Wilson, and Rasor, 1938)

Structure and Mineralization

Base and precious metal deposits within the Tombstone mining district have been classified into four distinct structural groups by Butler, Wilson and Rasor (1938) to include the following categories with addendum:

1. Deposits associated with N-S-trending fissures
2. Deposits associated with faults
3. Deposits associated with anticlines and "rolls"
4. Deposits associated with NE-trending fissures
5. Addendum: A fifth type is here added to include porphyry copper deposits associated with well-developed fractures and shears

At least twelve hydrothermal veins or mineralized faults of the fourth category occur on the Little Boquillas Ranch in the Charleston area (Pl. 10) and include the following:

1. Footwall Vein
2. Honolulu Vein
3. Josephine Vein
4. Let 'er Go Gallagher Vein
5. Manganese Vein
6. Manila Vein
7. Rattler Vein
8. A Vein
9. B Vein
10. C Vein
11. Fern Vein
12. Fisher Vein

The NE-trending veins are narrow, ranging 0.25-4.6 ft in thickness, subparallel, dip steeply to moderately to the southeast, and occur within the NE-trending Charleston alteration zone (Pl. 11). Surface exposures are poor and discontinuous. Host rocks are rhyolite and andesite members of the Bronco Volcanics (Cretaceous).

Veins in the Charleston area are considered epithermal in origin, containing low-temperature mineral assemblages of pimarily quartz, chalcedony, manganese oxides, iron oxides, calcite, pyrite, sericite, clays, adularia, rutile, vanadinite, wulfenite, malachite, chrysocolla, azurite, galena, anglesite, cerrusite, and uncommon barite. Common vein characteristics are open-space fillings, vugs, stockworks, pervasive alteration, and brecciated zones. Some exotic mineral species are undoubtedly present but are not readily identifiable in hand specimen. A list of silver-bearing minerals identified within the general district is presented in Table 8-4. The reader is referred to Butler, Wilson, and Rasor (1938) for a more comprehensive discussion concerning mineralogy.

Many of the veins on the Little Boquillas Ranch have been mined or explored to varying degrees during the late 1800's and early 1900's. Workings consist primarily of shafts down to 430 ft in depth, various underground working levels, stopes, tunnels, exploration cuts, trenches, and pits (Photo 8-3). Because the workings are 70-100 years old and are caved and very dangerous, the only detail data are from previous work by Peale (1949) and Spellmeyer (1927). A summary of old data with additional observations is presented in Table 8-5. Plan and cross-sectional drawings from Peale (1948) are reproduced in Figures 8-4, 8-5 and 8-6 and geochemical data for sample locations are listed in Appendix F.

Origin

The epithermal vein deposits are considered products of hydrothermal solutions during late Laramide time, controlled by faults and shears and forming at shallow depths and low temperatures. Such deposition normally takes place within 3,000 ft of the surface in the temperature range of 50-200°C. The hydrothermal solutions were likely related to the intrusive emplacement of the underlying Schieffelin Granodiorite pluton. Subsequently, the solutions permeated faults, and fractures thought to have developed along a pre-existing NE-trending, Precambrian orogenic belt. Ore deposits at Tombstone (8 miles away) are mesothermal (175-3-0°C + moderate pressure) and are believed to be related similarly to the emplacement of the Schieffelin Granodiorite and its various phases.

Table 8-4. Reported silver-bearing minerals in the Tombstone mining district.

Mineral	Chemical Composition
Native Silver	Ag
Argentite	Ag_2S
Galena	$Pb(Ag)S$
Proustite	$3Ag_2S\ As_2S_3$
Stromeyerite	$Ag_2S\ Cu_2S$
Tetrahedrite (Freibergite)	$(Cu,Fe,Zn,Ag)_{12}Sb_4S_{13}$
Hessite	Ag_2Te
Cerargyrite	$AgCl$
Embolite	$Ag(Br,Cl)$
Bromyrite	$AgBr$
Argentiferous black calcite; silver is disseminated in Mn oxides (i.e. todorokite).	$CaCO_3$ + Ag & Mn oxides

Photograph 8-3. Exposed stope, Manila vein.

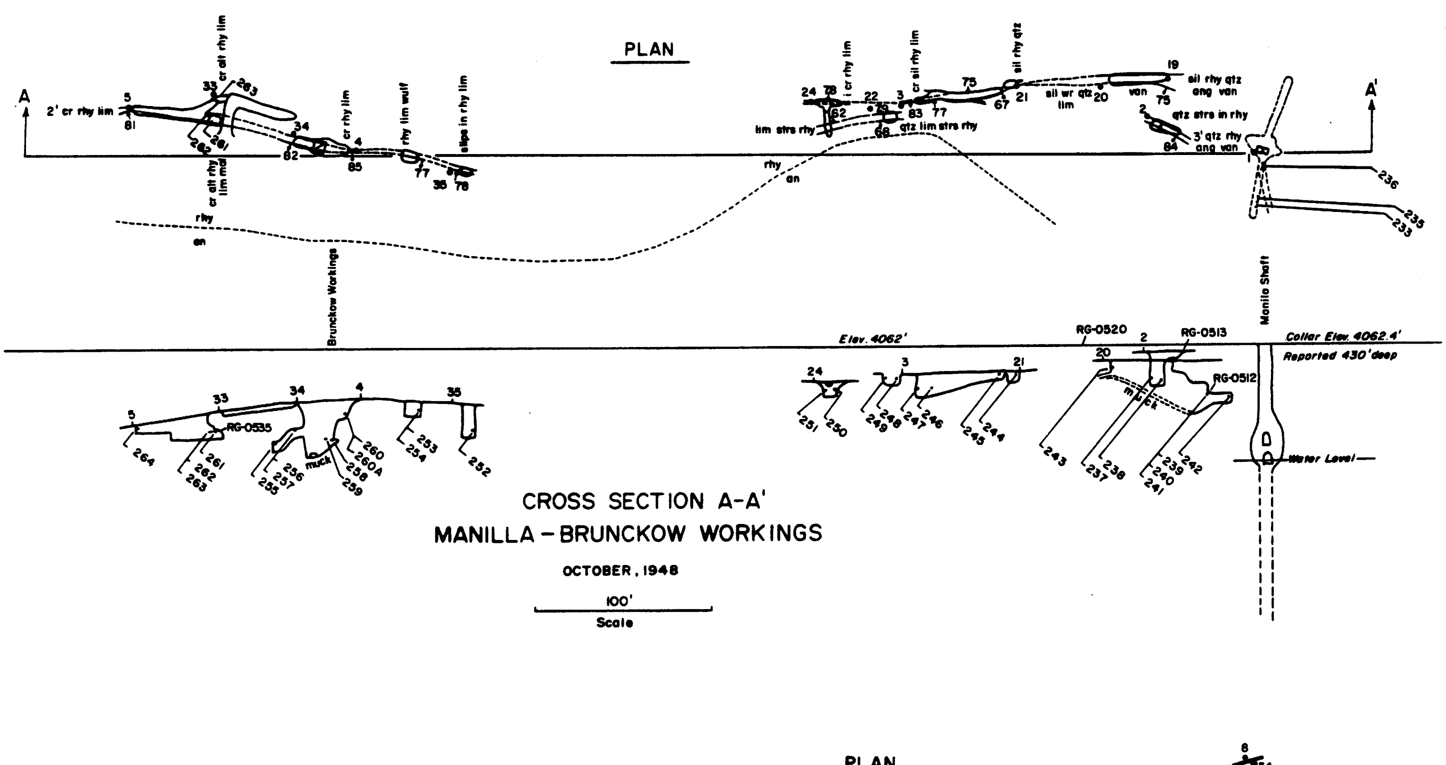
Table 8-5. Summary of veins in the Charleston area on Little Boquillas Ranch. Data are primarily from Spellmeyer (1927) and Peale (1949) with supplemental data gathered during this study.

VEIN	EXPOSED LENGTH	INFERRED LENGTH	WIDTH	STRIKE	DIP	HOST ROCK & STRUCTURE	REPORTED VEIN COMPOSITION	GRADE [1]	PAST DEVELOPMENT	REMARKS
1. Manila	270'	800'	0.8-3.5'	N45-65°E	73-85°SE	Bronco Rhyolite & Andesite, silicification, felsic dike & fault	Quartz, Mn oxides, iron oxides, siderite, breccia, various copper minerals, sericite, wulfenite, altered wall rock, malachite, chrysocolla	Ag 0.66 oz avg 2-12 oz high grade Au 0.03 oz avg Pb 2.62 % avg V_2O_5 0.26 % avg	Manila Shaft - 430' Manila #2 Shaft - 20' Bronco Shaft - 400'(?) Bronco Cut - 15' Cuts, pits, trenches Two groups of workings	Manila Shaft flooded at 70'. Workings caved and in poor condition. Northeastward from Bronco Shaft, vein contains conspicuous vanadinite with no visible copper mineralization. Southwestward of Bronco Shaft, vein contains conspicuous copper mineralization and wulfenite and no obvious vanadinite.
2. Footwall	350'	1550'	0.7-2.3'	N55°E	51-56°SE	Bronco Rhyolite, argillic alteration(?), fault & dike(?)	Quartz, sheared rhyolite, clays, sericite, iron oxides (minor), Mn oxides (minor)	Ag 0.19-2.25 oz range Au Tr-0.02 oz range Pb 0.1-7.6% range V_2O_5 ID	Inclined shaft-70' at 51°, Inclined shaft - 30.2' at 57°, surface stopes, pits, Two groups of workings	70' shaft flooded. Workings caved and in poor condition.
3. Honolulu	560'	1500'	0.25-1.2'	N53°E	70-82°SE	Bronco Rhyolite, argillic alteration(?), mafic dike & shearing	Quartz, massicot, cerargyrite, breccia, altered feldspar, malachite, Mn oxides (minor), iron oxides	Ag 1.83(?) oz avg Au Tr-0.035 oz range Pb 0.45-4.4 % range V_2O_5 ID	Shaft - 44', Shaft - depth(?) at 40°, tunnel, pits	Workings caved and in poor condition.
4. Josephine	650'	750'	1-2'	N60°E	67-82°SE	Bronco Rhyolite, argillic alteration(?), mafic dike & shearing	Quartz, galena, cerargyrite, anglesite, Mn oxides, iron oxides, sheared rhyolite	Ag 0.48 oz avg 2-24 oz high grade Au Tr-0.01 range Pb 1.6 % avg 0.3-6.8 % range V_2O_5 ID	Josephine Shaft - 74.5', Josephine #2 Shaft - 40+', pits, cuts	Workings caved and in poor condition.
5. Rattler	1600'	1700'	0.5-1.6' avg 1.1'	N45°E	67-80°SE	Bronco Andesite, propylitic alteration, fault	Quartz, galena, Mn oxides, iron oxides	Ag 0.67 oz avg 1-2 oz high grade Au 0.02 oz avg Pb Tr-6.2 % range V_2O_5 ID	Silver Hill Shaft - 85', pits	Workings caved and in poor condition.
6. Let'er Go Gallagher	?	1500'	1-8' avg 4.6'	-	-	Bronco Rhyolite, phyllic alteration, felsic dike & shearing	Silicified rhyolite, quartz, chrysocolla, iron oxides	Ag 0.15 oz avg Au Tr-0.02 oz range Pb 0.3 % avg V_2O_5 0.03-0.32 % range	Shaft - 23', tunnel, pits, cuts	Workings caved and in poor condition. Some vanadium produced in past.
7. Manganese	250'	1250'	1-3'	N45-50°E	60-85°SE	Uncle Sam Quartz Latite Tuff & Bronco Rhyolite, propylitic alteration, mafic dike & shearing	Quartz, black calcite, Mn oxides, siderite, sheared rhyolite	Ag 0.27 oz avg Au Tr-0.02 oz range Pb ID V_2O_5 ID Mn 1-24 % range	Shaft - 75', Shaft - 95', pits	Workings caved and in poor condition.
8. A Vein	-	340'	2.5-5'	N53°E	77°SE	Bronco Rhyolite, propylitic alteration, shear	Sheared rhyolite, quartz stringers, Mn oxides	Ag 0.04-0.12 oz range Au Tr Pb 0.55 % avg V_2O_5 0.03 %	Shaft - 23', pits, trenches	Workings caved and in poor condition.
9. B Vein	70'	-	0.2-1'	N35°E(?)	65°SE	Uncle Sam Quartz Latite Tuff, propylitic alteration, rhyolite dike & shearing	Quartz, Mn oxides	Ag 0.15-0.73 oz range Au Tr-0.01 oz range Pb 1.16 % avg V_2O_5 0.09 % range 0.04-0.13% range	Shaft - 16', pits	Workings caved and in poor condition.
10. Fern Vein (shear)	230'	660'	-	N70°E	73-75°SE	Bronco Rhyolite, propylitic alteration, fault	Shear zone, Mn Oxides, iron oxides, barite	Ag 0.48 oz avg Tr-1.0 oz range Au Tr-0.05 oz range Pb ID V_2O_5 0.36 % avg	Fern Shaft - 35+', pits	Flooded at 35'. Workings caved and in poor condition. Mineralization weak.
11. Fisher Vein	-	200'	-	-	-	Bronco Rhyolite, silification, felsic dike & shearing	Quartz (?)	Ag 0.03 oz Au ID Pb ID V_2O_5 ID	Fisher Shaft - 45', pits	Workings caved and in poor condition.

[1] Average grade was estimated from available data. High-grade assays were disregarded where not representative. Grade ranges are stated where only limited data are available.

oz = troy ounces/ton

ID = Insufficient Data
Tr = Trace

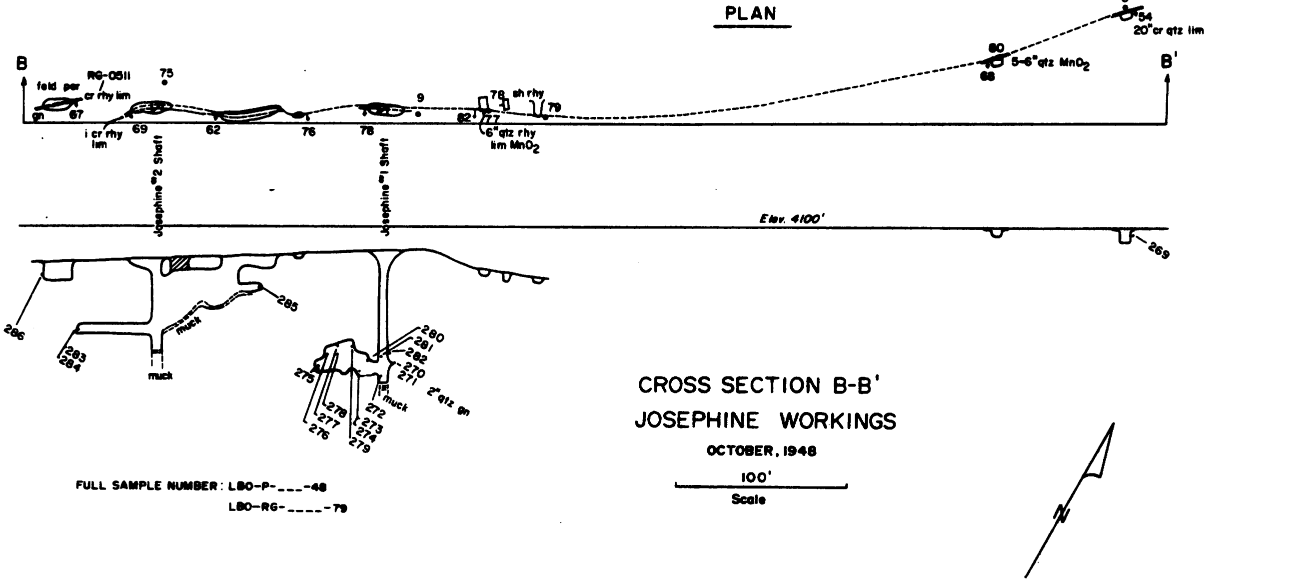


CROSS SECTION A-A'

MANILLA - BRUNCKOW WORKINGS

OCTOBER, 1948

100'
Scale



CROSS SECTION B-B'

JOSEPHINE WORKINGS

OCTOBER, 1948

100'
Scale

FULL SAMPLE NUMBER: LBO-P-___-48

LBO-RG-_____-79

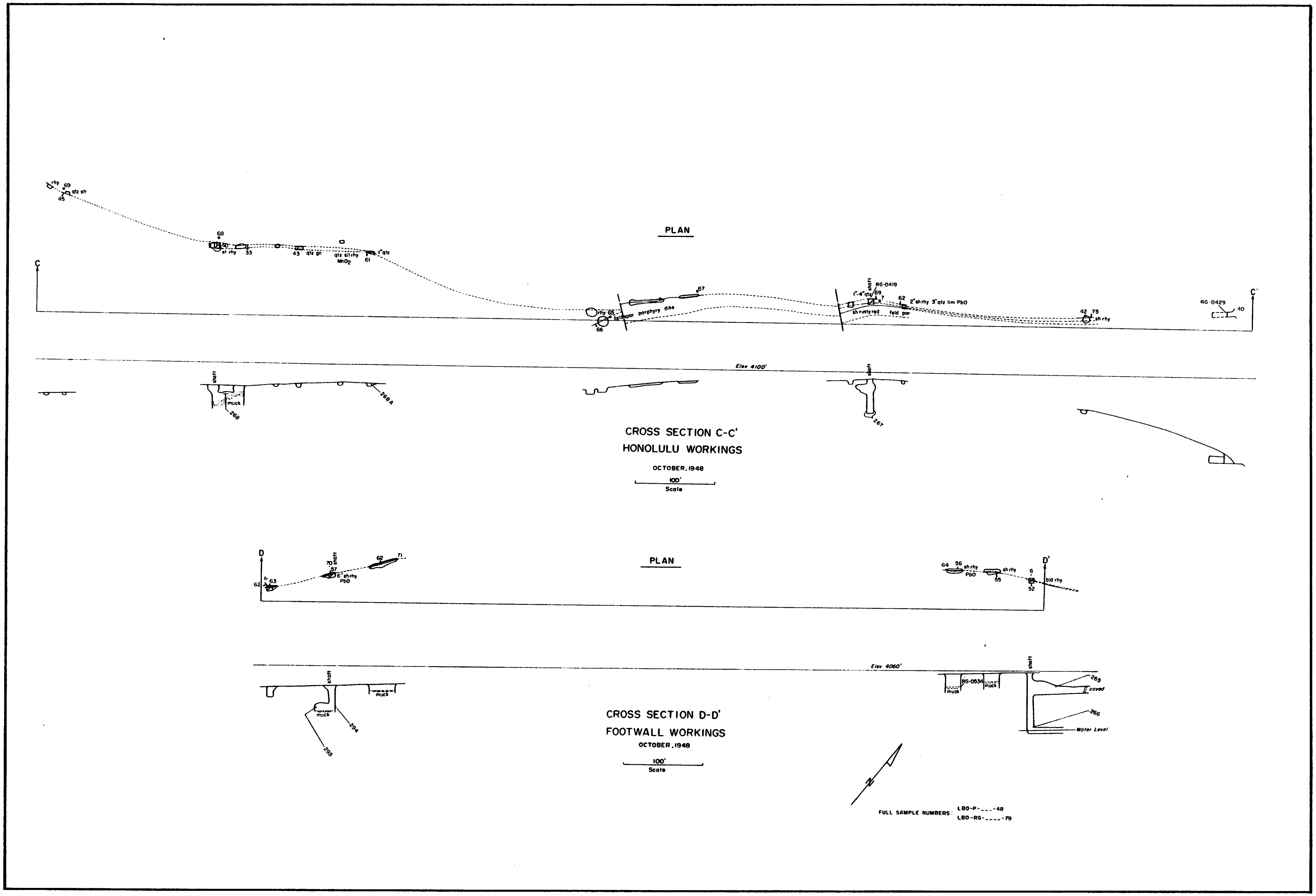
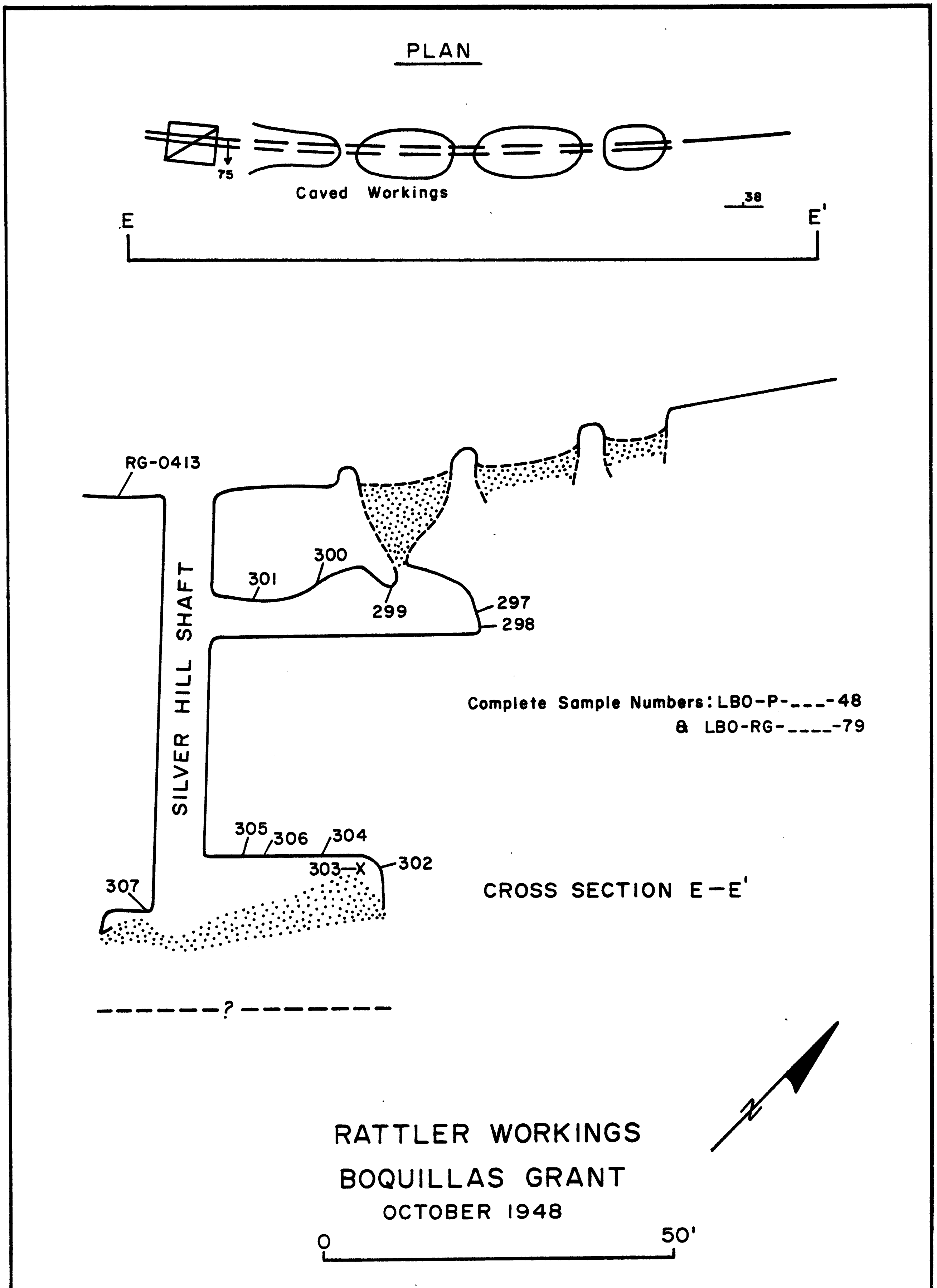


Figure 8-5. Plan view, cross section, and sample locations of the Honolulu and Footwall veins (modified after Peale, 1948).



PLAN
75
Caved Workings
38
E
E'
RG-0413
SILVER HILL SHAFT
300
301
299
297
298
Complete Sample Numbers: LBO-P-___-48
& LBO-RG-____-79
305
306
304
303—X
302
307
CROSS SECTION E—E'
?
RATTLER WORKINGS
BOQUILLAS GRANT
OCTOBER 1948
0
50'

Vein Deposit Potential

Identified base and precious metal resources associated with veins on the Little Boquillas Ranch in the Charleston area are presently considered to be of minor value. This judgement is based on available surface data and on data from underground workings. Average silver values are very low, generally less than 1 oz/ton, and base metal values are insufficient considering the low tonnages associated with narrow veins. Some scattered high-grade zones may be present. Overall vein potential for silver is considered low to moderate.

Peale (1949, p. 8) suggested the possibility that the Josephine and Honolulu veins may intersect at a depth of about 300 ft. However, dip values indicate that the Honolulu and Footwall veins have a greater probability of intersecting at depth (Fig. 8-7). Such an intersection may provide the right conditions for an orebody. The hypothetical intersection would probably occur within rhyolite or andesite of the Bronco Volcanics. Angle core drilling would be required to test the hypothesis of intersecting veins.

The Charleston Lead mine (inactive) is in the NW¼, Sec. 36, T.20 S., R.21 E., approximately 2,000 ft east of the San Juan de las Boquillas y Nogales Grant. At the mine, an andesite porphyry dike has been locally altered to sericite (phyllic alteration) and cut by an E-W-trending, mineralized fault. This fault extends westward onto the Little Boquillas Ranch. Peale (1949, p. 10) reported some exploration for the Charleston "extension" onto the ranch, however, no significant mineralization was encountered. During 1969, an induced polarization and resistivity survey was conducted within the grant across the suspected westerly extension of the Charleston mine fault. No anomalous response was encountered.

The greatest significance of the veins in the Charleston area is that they may represent a halo related to a porphyry copper deposit at depth. Such veins fit the copper porphyry models suggested by Lowell and Guilbert (1970) and Stillitoe (1973) (Fig. 8-2). Asarco has drilled a deep copper porphyry system in the area immediately east of the Charleston Lead mine.

Placer Deposits

The only known placer operations near the Little Boquillas Ranch have been in the Huachuca Mountains prior to 1940. These operations focused on placer gold in Ash Canyon (Pl. 3). Spellmeyer (1927) reported that Ash Canyon has produced placer gold and that one nugget of over $300 in value was found. Peale (1949) sampled drainages on the Little Boquillas Ranch in Garden, Ramsey, Hunter, Stump, and Ash Canyons by carefully panning stream sediments (Pl. 18). No gold or tungsten was found. Peale also panned several streams on Tenneco fee land near McGrew Springs on the eastern flank of the Whetstone Mountains (Pl. 18). Results were negative.

Coalescing alluvial fans debouching from Miller, Hunter, Stump, and Ash Canyons are present on the Little Boquillas Ranch in T.23 S., R.21 E. A few stream-sediment and soil samples collected in this area (Pl. 18) were analyzed during 1979 for gold and silver. Results were negative.

Potential for gold and tungsten placers on the Little Boquillas Ranch seems low at this time. Further sampling may not be warranted owing to the marginal production from local placer deposits over the past 80 years. Some renewed placer operations (small) have been reported during 1979 owing to rising gold prices.

<u>Other Metals</u>

Tungsten

Introduction

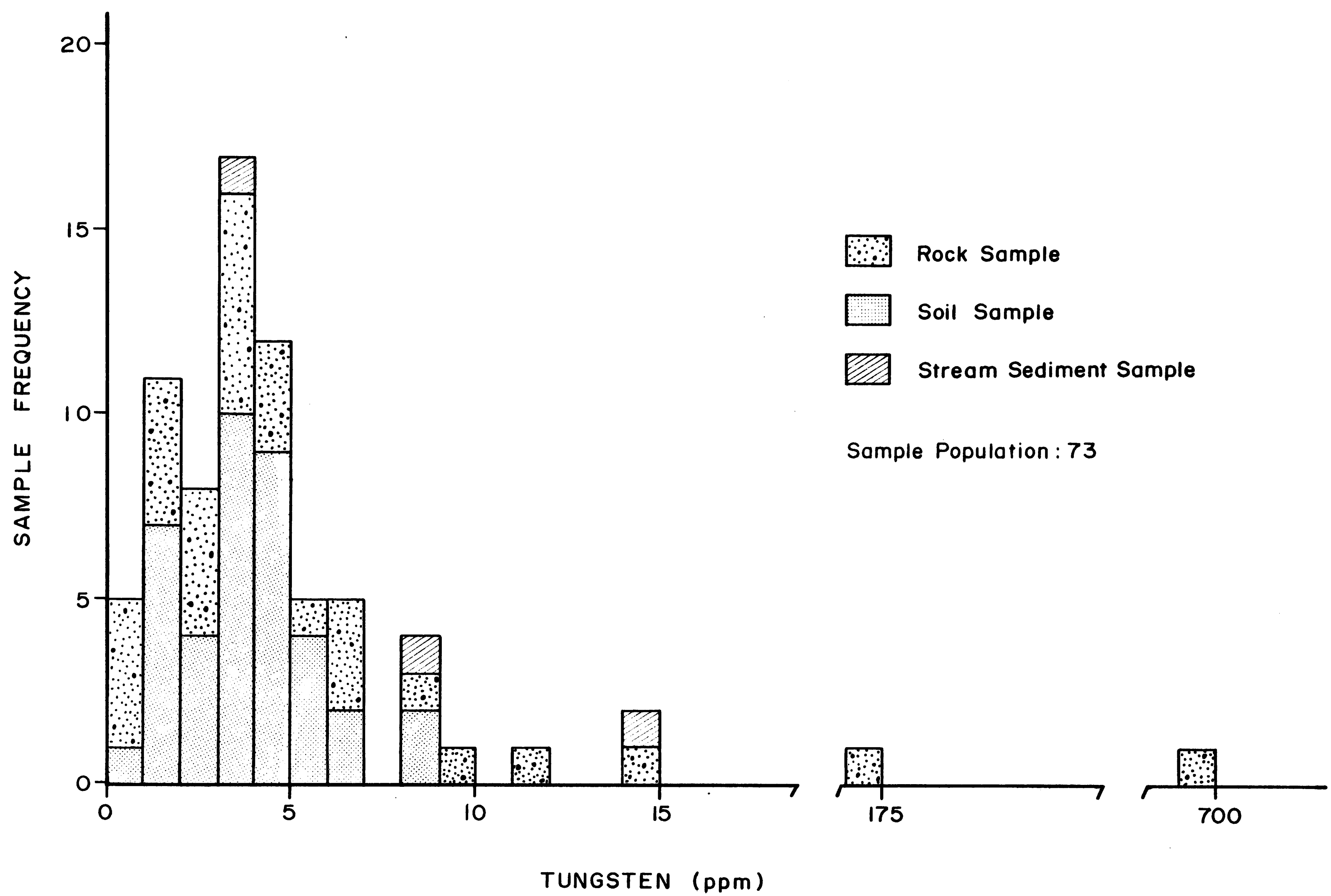
The Little Boquillas Ranch is located within a tungsten province described by Hobbs and Tooker (1979) as containing the following types of tungsten deposits: 1) quartz veins in granite and adjoining sedimentary rocks; commonly associated with gold and base metal sulfides, 2) tactite; contact-metamorphic skarn zones adjoining granitic plutonic rocks, 3) disseminations in sedimentary rocks, including volcanogenic and metamorphosed types, and 4) porphyry disseminations.

Dragoon Area

Seventy-three geochemical samples were analyzed for tungsten in the Dragoon area. Of these, 39 were soil, 31 rock, and 3 stream-sediment samples. Soil samples range from 2-9 ppm W, rock 2-700 ppm W, and stream sediment 4-15 ppm W. The average abundance of tungsten in granite and shale is 2 ppm W and in limestone 0.5 ppm W (Levinson, 1974). A histogram of the Dragoon area tungsten values shows that 74% of the rock values are greater than 2 ppm W (Fig. 8-8). Two anomalous tungsten values (700 and 175 ppm W) infer some tungsten potential in the Dragoon area. Sample LBO-RG-0042-78 represents the 700 ppm W value and was collected in Sec. 21, T.18 S., R.23 E., 2.5 miles east of Tenneco property. The sample was collected from a prospect pit along the Martin Limestone and Stronghold Granite contact. Along the intrusive contact a tactite zone is inferred to be 20-40 ft wide. Sample LBO-RG-0077-78 (175 ppm W) was collected on Tenneco fee land in Sec. 24, T.17 S., R.22 E. from an 8 ft wide tactite zone.

Peale (1949) panned gravels from both Stronghold and Slavin creeks and the concentrate was inspected for scheelite with an ultra-violet lamp. No gold was found and only a trace of scheelite was detected in Slavin creek.

There is approximately 5 miles of buried intrusive contact on Tenneco fee land in the Dragoon area (Pl. 11). The anomalous to weakly anomalous tungsten values and close proximity of operating mines (metasomatic replacement type) suggest



SAMPLE FREQUENCY
20
15
10
5
0
0
5
10
15
175
700
TUNGSTEN (ppm)
Rock Sample
Soil Sample
Stream Sediment Sample
Sample Population : 73

that the Dragoon area is favorable for tungsten mineralization as well as for base metals.

Whetstone Area

In the Whetstone mining district there are three abandoned tungsten prospects within 1-2 miles of the Little Boquillas Ranch. They are the Chadwick, Evening Star and James "mines". Mineralization has been primarily wolframite and minor scheelite in irregular quartz veins within Precambrian alaskite near the alaskite-Pinal Schist contact. Prospect work was conducted between 1937 and 1944, but only a few tons of tungsten were mined (Keith, 1974). F. L. Hess (1908) reported that the Euclid Mining Company attempted to mine wolframite from the two prospects which are now called the Chadwick and James mines. No production data are available.

Warren, Hobbs and Elliott (1973) reported that tungsten-bearing quartz veins account for more than 75% of the known world reserves. They also report that most tungsten-bearing veins are associated spatially and probably genetically with plutonic rocks of granitic composition and usually occur near their contacts; either within border zones of the plutons or, more generally, in the adjacent intruded terrain. Most tungsten veins are mineralogically simple and consist of quartz with scheelite and/or one of the wolframite series and minor accounts of other minerals.

The above description of tungsten-bearing vein deposits by Warren, Hobbs and Elliott (1973) is very similar to the geology observed at the three prospects in the Whetstone area. This same geologic environment is projected onto the Little Boquillas Ranch beneath surficial debris.

Peale (1949) panned several washes near McGrew Springs in the Whetstone Mountains area to test for gold and tungsten, all tests were negative.

During 1978, 82 geochemical samples were collected in the Whetstone area, and of these, only two, LBO-RG-0120-78 and LBO-RG-0167-78, had tungsten values (Pl. 18 and Appendix F).

Tungsten Potential

Tungsten potential on the Little Boquillas ranch is presently considered as low to moderate. The best potential on the ranch is in buried tactite in the Dragoon area and in buried quartz veins in the Whetstone area. No significant tungsten has been produced within the study area except as by-product tungsten associated with base metals in tactite.

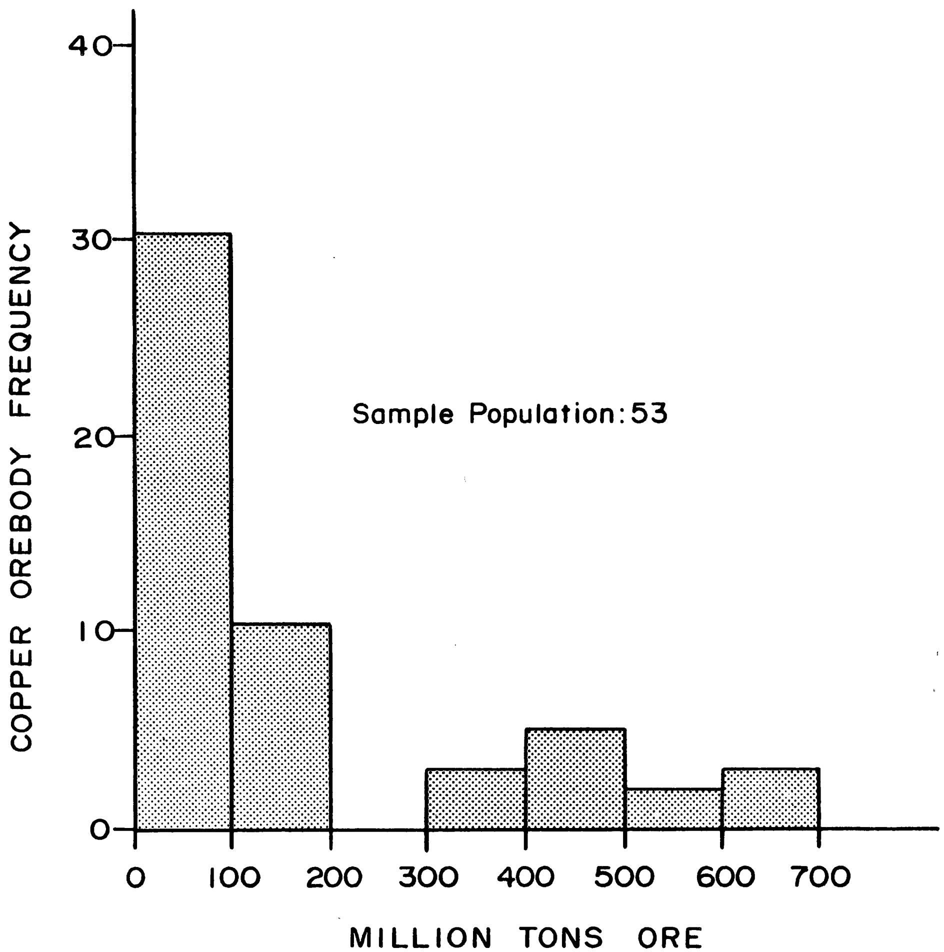
Overall Potential for Metallic Resources

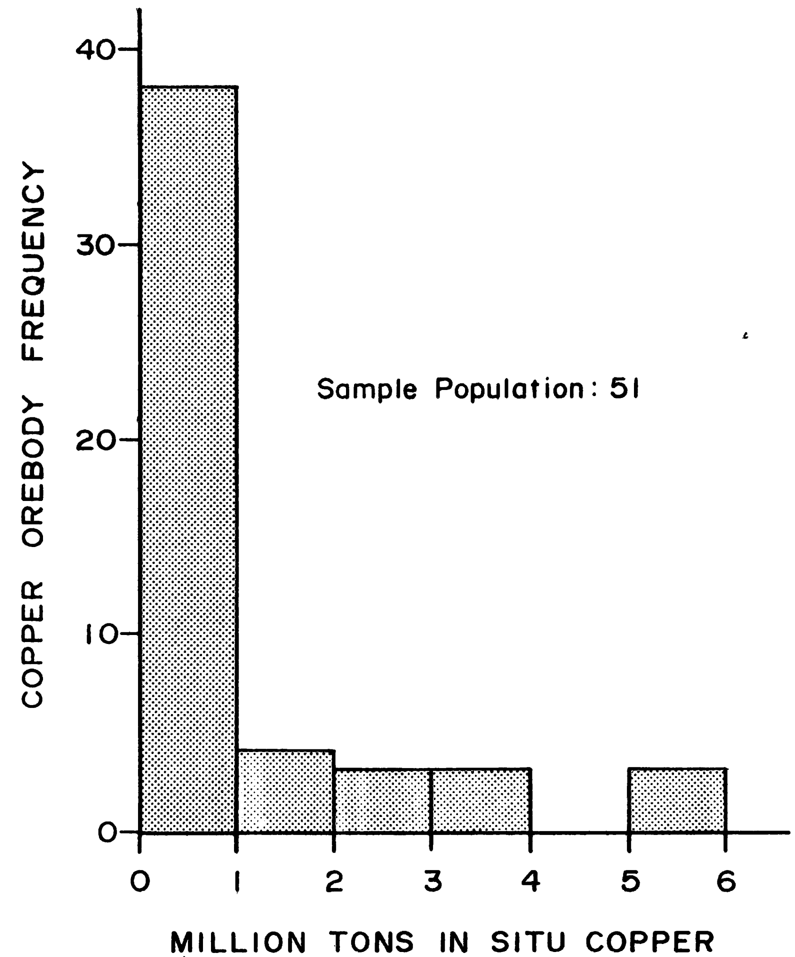
The Little Boquillas Ranch lies within the southeastern copper province of Arizona and has good to excellent potential for base metal deposits comprised chiefly of copper and associated metals. This potential exists primarily in porphyry copper and/or metasomatic replacement deposits.

Histograms of Arizona copper deposits (Fig. 8-9) suggest that a copper deposit(s) of less than 200 million tons ore containing less than one million tons of in situ copper may be expected on the Little Boquillas Ranch. It is reasonable to assume that a 100 million ton copper orebody may be present near Charleston or at other localities on the ranch. Such a copper deposit should contain quantities of associated base and precious metals. Owing to a narrow profit margin associated with copper as an individual commodity, byproducts such as molybdic oxide, lead, zinc, silver, and gold are necessary to have a viable economic deposit at this time (1979).

Potential for precious metals and tungsten in veins and placer deposits is speculative at present. Some silver potential may be present in veins at depth on the Little Boquillas Ranch near Charleston.

Pursuit of metallic resources requires continued geologic mapping and sampling, site-specific geophysical surveys and drilling where warranted.


COPPER OREBODY FREQUENCY
0
10
20
30
40
Sample Population: 53
0
100
200
300
400
500
600
700
MILLION TONS ORE


COPPER OREBODY FREQUENCY
0
10
20
30
40
Sample Population: 51
0
1
2
3
4
5
6
MILLION TONS IN SITU COPPER

RECLAIMABLE METALLIC RESOURCES

MILL TAILINGS

Introduction

At least twelve abandoned silver mills are on the banks of the San Pedro River on the San Juan de las Boquillas y Nogales Grant (Pl. 9). These include the following mills:

1. Boston and Arizona
2. E. Clifford
3. Contention
4. Corbin
5. Gird
6. Grand Central
7. Gray
8. Hill
9. Masons
10. Sommers
11. Sunset
12. Wild

Old mill tailings which exist at some of these millsites are considered to contain identified silver, gold, and lead resources as indicated by analytical data. Summary data concerning the mill tailings are presented in Table 9-1. The reader is referred to the "History" section of this report for a historical review concerning the old mills.

Boston and Arizona Mill

Sketch maps of the Boston and Arizona Mill tailings after Bernardi (1977) and Peale (1949) have been modified and a composite is presented in Figure 9-1. Tailings occur in front of the mill foundation and extend laterally for as much as 500 ft. Photograph 9-1 shows the mill tailings. Tailings thickness varies from a few inches to as much as 5 ft. The tailings are generally a reddish

Table 9-1. Summary of identified precious and base metal resources in mill tailings on the Little Boquillas Ranch

Mill Name	Estimated Grade[1]	Estimated Tonnage	Contained Metal[1]	Remarks
Boston and Arizona	Ag - 4.14 oz/ton	10,000 (?)	Ag - 41,400 oz Au - 200 oz Pb - 213 tons	4,500 tons estimated by Peale (1949) east of railroad tracks. Additional tonnage probably west of tracks. Alluvium and brush hinder visual estimate.
E. Clifford	No data	No data	No data	Mill ruins and tailings could not be located in field during this study.
Contention	Ag - 1.07 oz/ton Au - 0.038 oz/ton Pb - (?)	Unknown	Unknown	Peale (1949) reported tailings washed away by floods prior to 1916. However, some red tailings exposed in small drainages and covered by alluvial deposits. Dense brush present.
Corbin	Ag - 3.41 oz/ton Au - 0.063 oz/ton	0	0	Peale (1949) reported a pile of mill tailings (1044 tons) which he sampled. The pile is no longer present. No mill tailings are visible.
Gird	No data	0	0	No mill tailings are visible. Slag is present. Some mill tailings may be present under slag.
Grand Central	Ag - 2.88 oz/ton Au - 0.043 oz/ton Pb - 1.36% (?)	13,000 (?)	Ag - 37,400 oz Au - 559 oz Pb - 177 tons	Some reworking of mill tailings during 1924-26 and 1948-49.
Gray	No data	0	0	No mill tailings are visible.
Hill	No data	0	0	No mill tailings are visible.
Masons	No data	0	0	No mill tailings are visible.
Sommers	No data	0	0	No mill tailings are visible.
Sunset	Ag - 2.36 oz/ton Au - 0.052 oz/ton Pb - 1.36%	3,000 +	Ag - 7,080 oz Au - 156 oz Pb - 41 tons	Mill tailings locally covered by alluvium and brush. Discontinuous due to erosion.
Wild	Ag - 1.13 oz/ton Au - 0.026 oz/ton Pb - (?)	300	Ag - 339 oz Au - nil Pb - (?)	Thin 3-4" layer of red tailings under alluvial debris and dense brush.

[1] Precious metals measured in troy ounces; 12 troy ounces = 1 pound; 1 troy ounce = 480 grains.

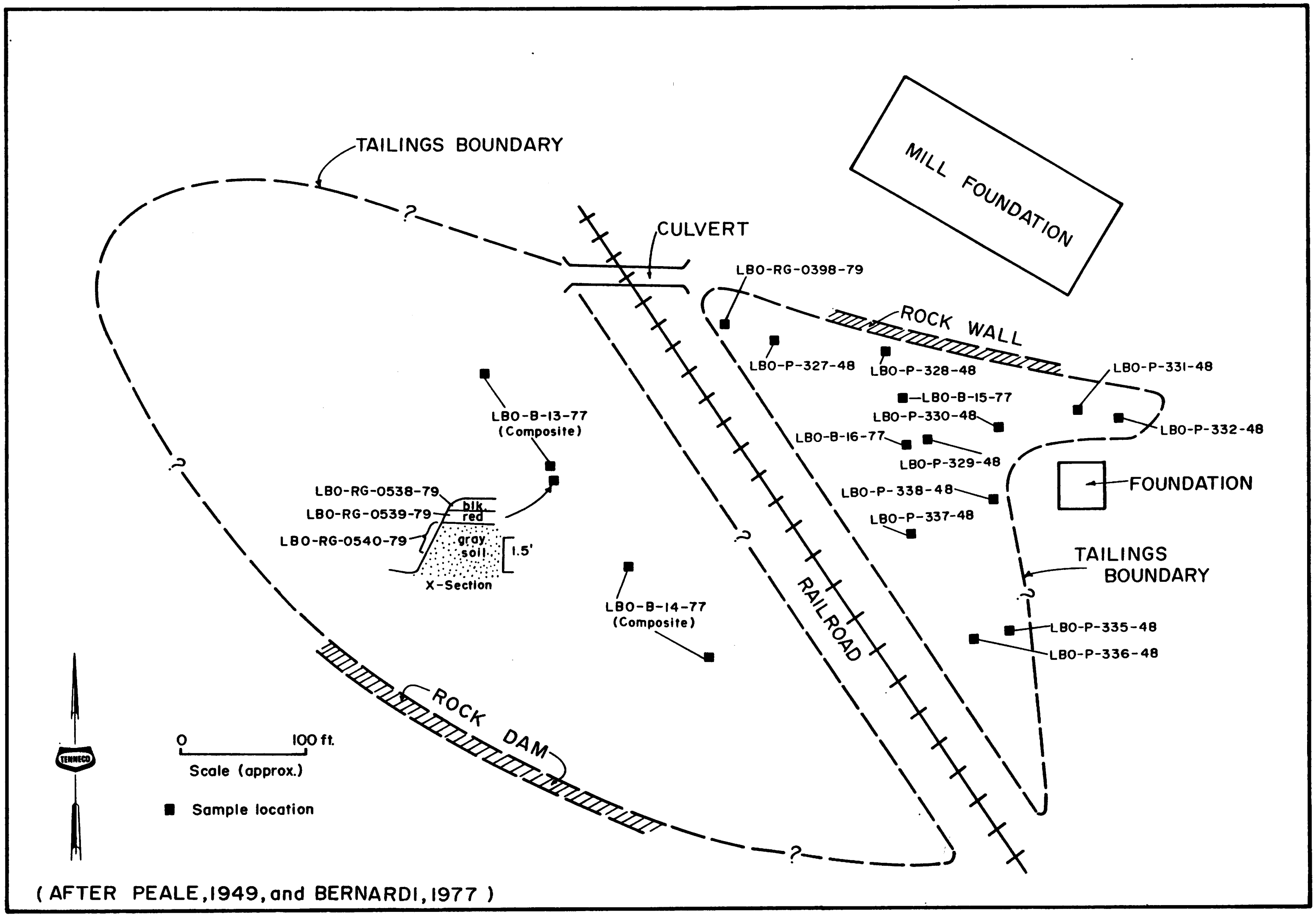


Figure 9-1. Sketch map of the Boston and Arizona millsite.

Photograph 9-1. Boston and Arizona mill tailings.

color with horizons of gray-brown to black. Alluvium and dense vegetation locally cover the tailings, making the limits of the deposit hard to discern.

Assays indicate that the tailings contain about 4.14 oz Ag/ton, 0.02 oz Au/ton and 2.13% Pb. Assays from ten samples collected by Peale (1949) are consistent with five analyses obtained by Tenneco. One 4 inch layer of black sand collected from 2 ft below the surface was assayed to contain 14.95 oz Ag/ton. Multiple high-grade horizons may be present. Peale (1949) reported approximately 4,500 tons of tailings east of the railroad tracks. Additional tonnage is probably present west of the tracks. Trenching is necessary to obtain reliable tonnage figures. Total identified resources are likely 10,000 tons of mill tailings.

E. Clifford Mill

No remnants of the E. Clifford Mill could be located during this study.

Contention Mill

Peale (1949) reported that a large tailings pile was once present, however, flooding prior to 1916 washed the tailings away but that mill foundations and debris are still present. A field check during 1979 revealed that mill tailings are present, but are discontinous and covered by alluvial deposits.

Corbin Mill

Peale (1949) reported that little effort was made to impound tailings at the Corbin Mill. He further reported that one pile (1,044 tons) of mill tailings was present at the Corbin or Gird Mill. Assay data from this pile indicate 3.41 oz Ag/ton, 0.063 oz Au/ton and 3.80% Pb. This tailings pile is no longer present. No mill tailings are now visible from visual inspection. Mill foundations and debris are present (Photo. 9-2).

Gird Mill

Mill foundations and debris are present at the Gird Mill, however, no mill tailings are visible. Peale (1949) reported that little effort was made to impound

Photograph 9-2. Corbin millsite.

tailings and much was allowed to run off with slag from the smelter. Most of the Gird Mill site is now covered with slag piles. Some mill tailings may be present beneath slag material.

Grand Central Mill

A sketch map of the Grand Central Mill, modified from Bernardi (1977), is presented in Figure 9-2. Red mill tailings are present in a semi-circular configuration in front of the mill foundation. Owing to the reddish color (light brown, 5 YR 6/4 to 5 YR 5/6) of the tailings, the Grand Central Mill stands out strikingly on red-sensitive aerial photography. The old mill ruins are shown in Photo 9-3.

The mill site contains the remnants of two tailings ponds and possibly three. Some reworking of tailings was reported in 1925-26 and 1948-49 (see "History" section, this report). The main pond wall ranges 1-4 ft in height and contains the best surface show of tailings. A discontinous veneer of tailings, perhaps averaging 1 ft in thickness and reaching up to 3 ft in thickness, may still be present in the pond areas. Dark floodplain deposits locally cover some tailings. Tailings are also present in a brushy area west of the breached portion of the main dam (Fig. 9-2).

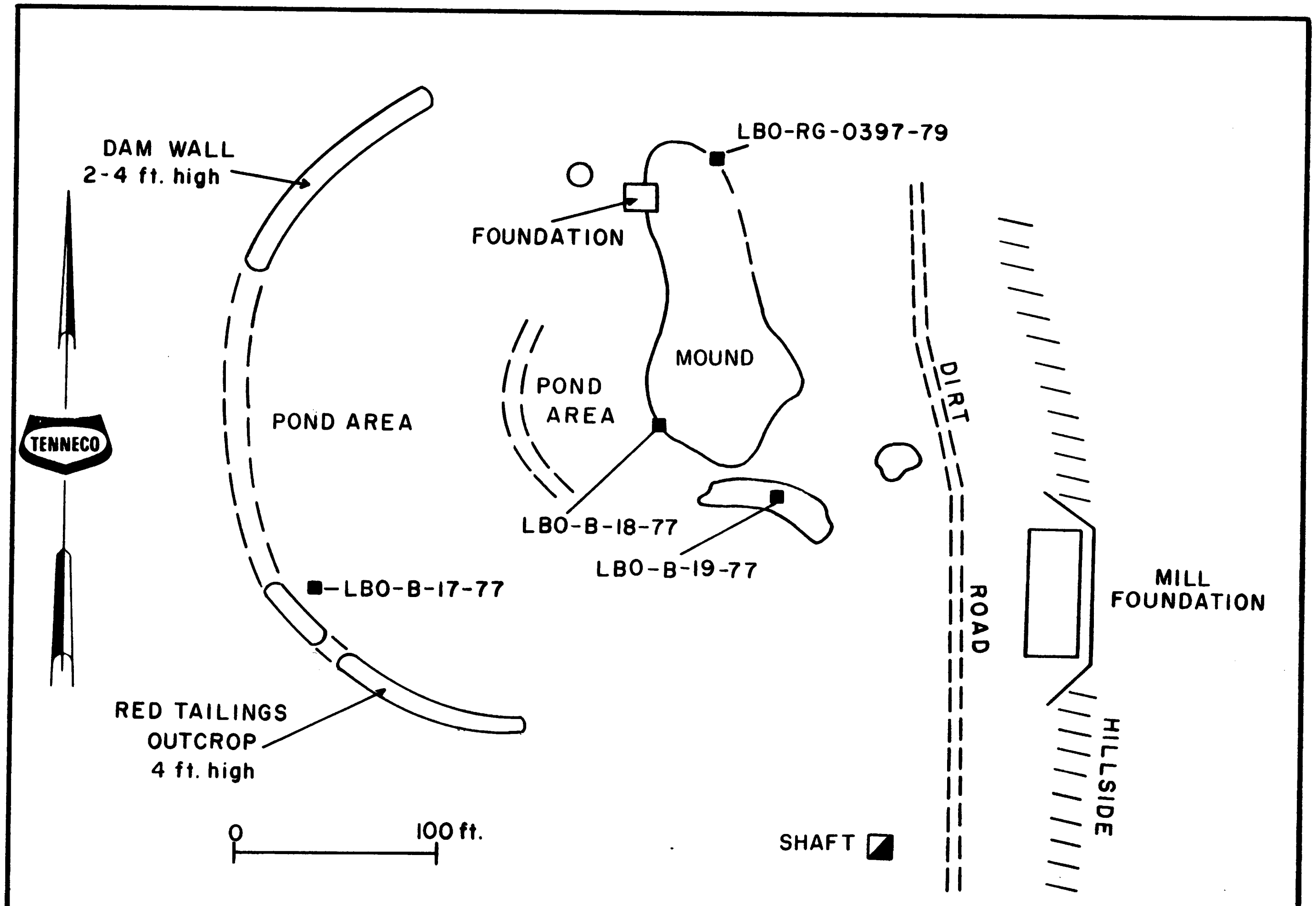
Total identified resources are perhaps 13,000(?) tons of mill tailings, however, this is a very rough estimate. A reliable tonnage estimate would require trenching. Assay data indicate that the tailings contain 2.88 oz Ag/ton, 0.043 oz Au/ton, and 1.36%(?) Pb.

Gray Mill

No mill tailings were observed at the Gray Mill. Foundations and debris are present.

Hill Mill

No mill tailings were observed at the Hill Mill. Foundations and debris are present.



Modified after Bernardi (1977)

Photograph 9-3. Grand Central millsite.

Masons Mill

No mill tailings were observed at Masons Mill. Foundations and debris are present.

Sommers Mill

No mill tailings were observed at Sommers Mill. Foundations and debris are present.

Sunset Mill

A sketch map of the Sunset Mill is presented in Figure 9-3. Red mill tailings are exposed as a discontinuous tabular layer 0-2 ft in thickness within the impoundment area behind an earthen dam (Photo. 9-4). Tailings are also present in front of the dam and extend to the San Pedro River in a thin layer which ranges 0-3 inches in thickness. Dense brush, alluvial cover and erosion hinder visual tonnage estimates. Total identified resources are thought to be 3,000+ tons of mill tailings containing 2.36 oz Ag/ton, 0.052 oz Au/ton, and 1.36% Pb. A reliable tonnage estimate requires trenching.

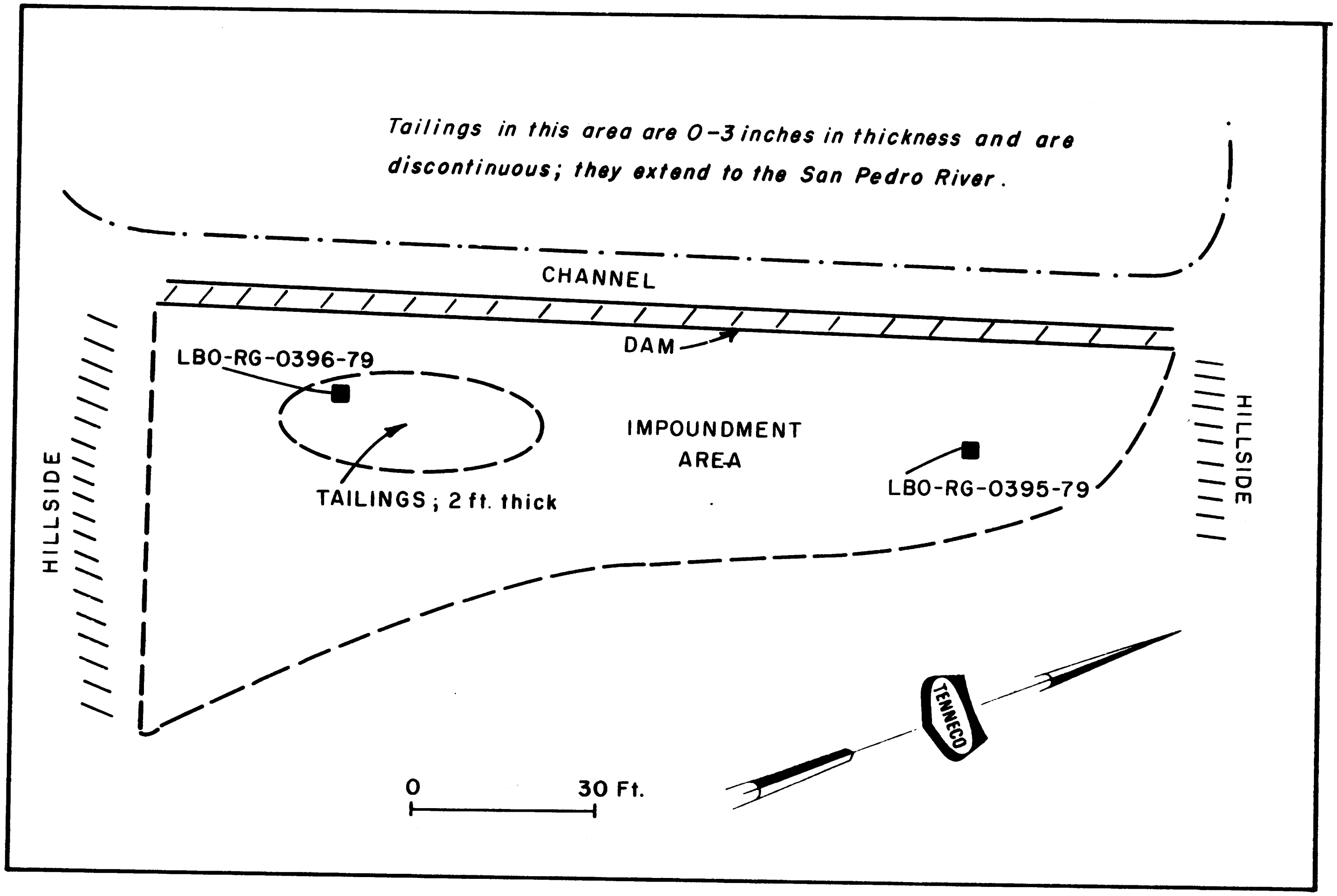
Wild Mill

The Wild millsite contains a thin horizon of red mill tailings 3-4 inches in thickness. Floodplain deposits 0.5-2 ft in thickness locally cover the tailings. Mill tailings are exposed in a small wash along the abandoned New Nexico and Arizona Railroad. The lateral extent of the tailings can not be adquately determined owing to overburden and dense brush.

Isolated exposures suggest that 300+ tons of identified tailings resources are present in an area 150 ft x 150 ft. A reliable tonnage estimate requires trenching. A single tailings sample indicates 1.13 oz Ag/ton and 0.026 oz Au/ton.

Mill Tailings Potential

Total identified mill tailings resources on the Little Boquillas Ranch are presently beileved to be in excess of 26,000 tons and contain 1-4+ oz Ag/ton,


Tailings in this area are 0-3 inches in thickness and are discontinuous; they extend to the San Pedro River.
CHANNEL
DAM
LBO-RG-0396-79
TAILINGS; 2 ft. thick
IMPOUNDMENT AREA
LBO-RG-0395-79
HILLSIDE
HILLSIDE
0
30 Ft.
TENNECO

Photograph 9-4. Sunset mill tailings.

0.02-0.06+ oz Au/ton, and 1+%Pb. Some thin high-grade horizons on the order of 14+ oz Ag/ton may be expected. Local precious-metal enrichment is suspected with increasing depth within tailings owing to natural leaching over the past 100 years. Floodplain deposits immediately below the tailings may also be somewhat enriched with precious metals. No cyanide was detected in mill tailings. Firm tonnage and grade estimates require data from exploration trenching. Exploration trenching could reveal tailings in quantities which may double the present tonnage estimate.

Precious metals can be leached from mill tailings. Eocene Research, a small Las Vegas-based ore reclamation firm, attempted to reprocess mill tailings from the Grand Central Mill for silver and gold under contract with Tenneco Oil Company during 1979. The contract agreement awarded Tenneco $5,000/qtr plus a 7% royalty on recovered metal values. However, Eocene Research curtailed operations that same year after encountering recovery problems due to mill tailings contamination by floodplain deposits. About 500 tons of mill tailings were removed from the Grand Central Mill. Other ore reclamation companies may become interested in old mill tailings once leachable mine dumps in the region become scarce. During January, 1979, however, some concern was expressed by the Arizona Corporation Commission in regards to possible fraudulent promotion of a silver-leaching process at depleted mines near Tombstone.

SLAG RESOURCES

Introduction

Slag is a substance formed in the top layer of the multilayer melt during smelting and refining of metallic ores. In smelting, slag contains the gangue minerals and the flux; in most refining operations, slag contains oxidized impurities.

Slag on the Little Boquillas Ranch is primarily from base and precious metal smelters which processed ore from local mines during the late 1800's and early 1900's. Slag resources are present at the Gird Mill as waste and as railroad bed material along abandoned railroad lines which traverse the ranch (Pl. 3). Table 9-2 summarizes identified slag resources on the Little Boquillas Ranch.

Gird Mill Slag

The Gird Mill was the first silver mill erected on the banks of the San Pedro River at Charleston to treat Tombstone silver-lead ore and operated from 1879-1884(?). During this period, a smelter was constructed nearby and subsequent slag is present in an area 400 ft x 600 ft at the millsite (Photo. 9-5). The slag ranges in color from black (N1) to dark gray (N3) and occurs as a dense, hard, brittle, obsidian-like, glassy material with conchoidal fracture to a dull or slightly-irridescent, vesicular, metallic material with abundant flow structures. Some light green (5 G 7/4) to moderate green (5 G 5/6) copper mineralization is sporadically present in the slag. The slag is chiefly pebble- to cobble-size.

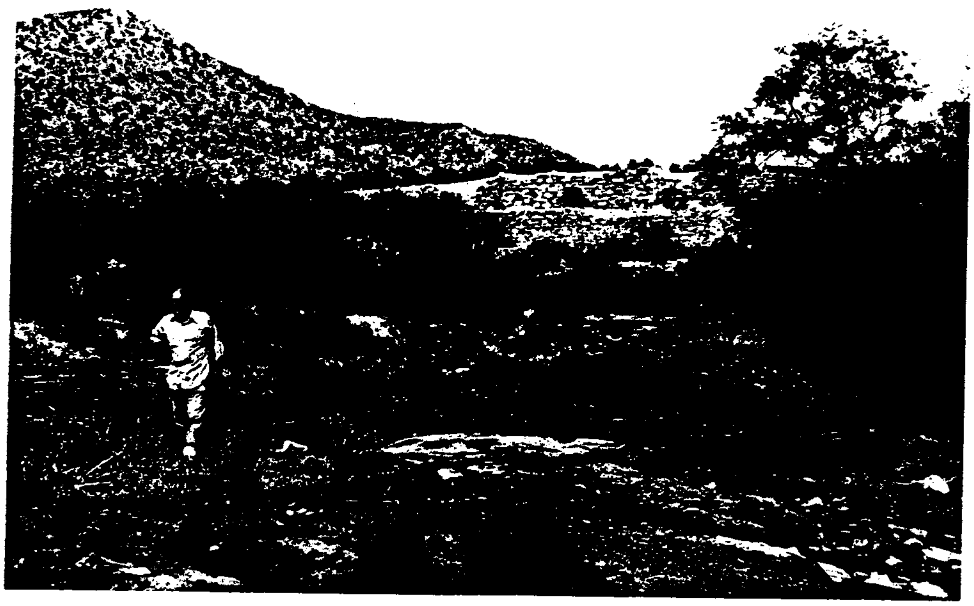
During 1975, the Utah Valley Mining Company of Provo, UT bought 3,775 tons of the slag at $7.50/ton from Tenneco West, Inc. to be used as a fluxing agent. Tenneco was later informed that an attempt to extract precious metals from the slag was in progress. Mining of the slag left an irregular distribution of remaining material, chiefly in sporadic piles and thin layers.

Identified slag resources at the Gird Mill are roughly estimated to be about 30,000+ tons. Limited assay data suggest that the slag contains about 1-5

Table 9-2. Identified slag resources on the Little Boquillas Ranch.

Location	Year(s) Constructed	Miles of Abandoned Railroad Bed on Ranch	Miles of Abandoned Railroad on Ranch w/Slag	Visual Tonnage Estimate	Sample No. [1/]	(%) Cu	(%) Pb	(%) Zn	(oz/T) Ag	(oz/T) Au
Gird Mill	1879	N/A	N/A	30,000+	-0531-	0.81	2.54	2.61	5.40	0.001
					-0532-	0.25	2.94	2.97	1.54	0.009
El Paso & South-western Railroad	1902-03	3.4	0.8	3,000	-0536-	0.40	0.11	0.55	0.22	0.005
Santa Fe Railroad	1883-84	8.0	8.0	29,000	-0533-	0.51	0.17	0.54	0.20	0.003
New Mexico & Arizona Railroad	1881-83	10.3	0.6	600+	-0541-	0.32	0.06	0.60	0.08	ND
Arizona & South-eastern Railroad	Early 1980's(?)	1.6	0	0						
	Totals:	23.3	9.4	62,600+						

1/ Full sample number LBO-RG-____-79



Photograph 9-5. Gird millsite and slag.

oz Ag/ton and considerable copper, lead, and zinc values (Table 9-2). Only trace amounts of platinum group metals were detected.

Railroad Slag

Railroad bed material comprised chiefly of black slag is prevalent along approximately 9.4 miles of the 23.3 miles of abandoned railroad lines on the Little Boquillas Ranch. Assay data indicate that this slag contains much lower total base and precious metals than the Gird Mill slag (Table 9-2), indicating a greater efficiency of smelting and refining at the slag source.

The railroad slag is primarily dull to slightly-irridescent, brownish black (5 YR 2/1) to blackish red (5 R 2/2), dense, hard, vesicular, metallic material with abundant flow structures. Light green (5 G 7/4) to moderate green (5 G 5/6) copper mineralization is sporadically present as is pyrite. Variegated inclusions and gangue mineralization are also present. Some areas contain dark yellowish orange (10 YR 6/6) to dark reddish brown (10 R 3/4) oxidized material. The slag is chiefly pebble to cobble size with occasional boulder-size material.

Identified slag resources along the abandoned railroad lines are estimated to be approximately 32,600+ tons. Assay data indicate that the railroad slag contains low values of base and precious metals.

Radioactivity

Slag along railroad beds (abandoned and active) and at the Gird Mill was found to be slightly radioactive. This was first noticed when a field geologist traversed a railroad bed with a scintillometer. Subsequent fluorimetric analyses revealed that the various slag materials on the ranch contain 30-65 ppm uranium. These values are presently insignificant.

Slag Potential

Total identified slag resources on the Little Boquillas Ranch are believed to be in excess of 62,000 tons. Although the slag may be considered as an aggregate or road base resource, it should not be compared with contemporary iron-blast-furnace slag or steel slag which has numerous grades and many industrial applications.

Assay data indicate that only the Gird Mill slag (30,000+ tons) contains sufficient base and precious metals to be considered for extractive metallurgy. Interest in extracting precious and/or base metals from the Gird Mill slag was expressed during 1979 by Delthe Resources Corporation of North Quincy, MA., Minerals Investment Company of Salt Lake City, UT, and P.C. Development of Scottsdale, AZ.