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GEOLOGY, ENERGY AND MINERAL RESOURCES ASSESSMENT OF THE ARMENDARIS AREA, NEW MEXICO

BY

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GEOLOGY, ENERGY AND MINERAL RESOURCES ASSESSMENT OF THE ARMENDARIS AREA, NEW MEXICO

by

Jan Krason, Antoni Wodzicki and Susan K. Cruver

SUMMARY

The Armendaris "Geological, Energy and Minerals (GEM) Resources Area" (GRA) lies within Socorro and Sierra Counties, central New Mexico, and encompasses three Wilderness Study Areas (WSAs), namely:

NM-020-047A Devil´s Backbone
NM-020-947B Devil´s Backbone
NM-020-055 Jornada del Muerto

The GRA is underlain by Proterozoic granites and metamorphic rocks which are unconformably overlain by a transgressive Early Paleozoic to Pennsylvanian shallow marine clastic and carbonate sequence, and a Late Pennsylvanian and Permian regressive and transgressive sequence of continental and shallow-marine "redbeds" and marine limestones. During the Mesozoic, the area underwent erosion, deposition of Triassic redbeds and mild folding during the Laramide orogeny. From Late Eocene to Early Miocene, it has been subjected to tectonism, intrusion of small epizonal plutons, and voluminous volcanics erupted in part from several cauldrons. From 40 to 30 m.y.B.P. the volcanism was calc-alkaline and mainly of andesitic to quartz latitic composition; from 30 to 20 m.y.B.P. volcanism took on a bimodal character with calc-alkaline to high K calc-alkaline basaltic andesite and high silica rhyolite being the dominant phases. Rio Grande rifting was initiated during Early Miocene and was accompanied by bimodal volcanism and deposition of valley-fill sediments. Igneous and geothermal activity, and deformation continue to the present day.

Geological environments favorable for occurrence of mineral or energy resources include Permian redbeds, Cretaceous coal, Cenozoic hydrothermal systems and valley-fill sediments. The Permian Abo and Yeso Formations are moderately favorable for occurrence of stratabound copper and silver deposits. Extensive, though thin and folded and faulted, coal seams occur in the Cretaceous Mesaverde Group. Hydrothermal manganese and gold veins occur in Tertiary Datil volcanics; and lead-barite-fluorite occur along faults in Precambrian granite and Paleozoic limestones in nearby areas; both of the above are probably related to hydrothermal systems associated with cauldron subsidence. Valley-fill sediments of the Santa Fe Formation are possible hosts for stratabound uranium deposits provided suitable reductants are present at depth. Placer gold could be present in Cenozoic alluvium.

The two Devil´s Backbone WSAs are underlain by Datil volcanics and Quaternary alluvium. They probably have a moderate favorability for hydrothermal gold deposits. It is recommended that a field petrographic and geochemical investigation be carried out in the Devil´s Backbone WSAs in order to assess the favorability for mineral resources more definitively.

The Jornada del Muerto WSA is not favorable for occurrence of mineral or energy resources.

INTRODUCTION

Purpose and Methodology

The need for "Geological, Energy and Minerals (GEM) Resources Assessment" of "Wilderness Study Areas" (WSA) has been recognized for some time by the Bureau of Land Management (BLM). The assessment is now being performed by various contractors for the BLM.

Wilderness Study Areas, widely scattered within the Sonoran Desert and Mexican Highlands and grouped into Region 5 by the BLM, are being studied and assessed by Geoexplorers International, Inc. The present report pertains to three WSAs in central New Mexico which have been grouped together into the Armendaris Geological Energy and Minerals Resources Area (GRA).

The purpose of the present study is to assess the potential for locateable, leaseable and saleable resources within the GRA, and specifically within each of the WSAs. This assessment has been carried out through literature study of the geology, structure and economic geology of the GRA, and a consideration of the regional paleogeographic, plate tectonic and metallogenic setting of the GRA within the southern Cordillera. Thus, the assessment is not only based on data from the GRA itself, but also on metallogenic concepts within the regional paleogeographic and plate tectonic framework.

Location and Access

The Armendaris Geological Resources Area lies in the north-central part of the Tularosa 1:250,000 quadrangle, west-central New Mexico (fig. 1). The Atchison, Topeka and Santa Fe railway line runs through the center of the GRA and highways I-25 and U.S.-380 traverse the central and norhteastern part of the area, respectively. Unimproved dry-weather roads provide reasonable access to the remaining parts of the GRA except in the higher parts of the

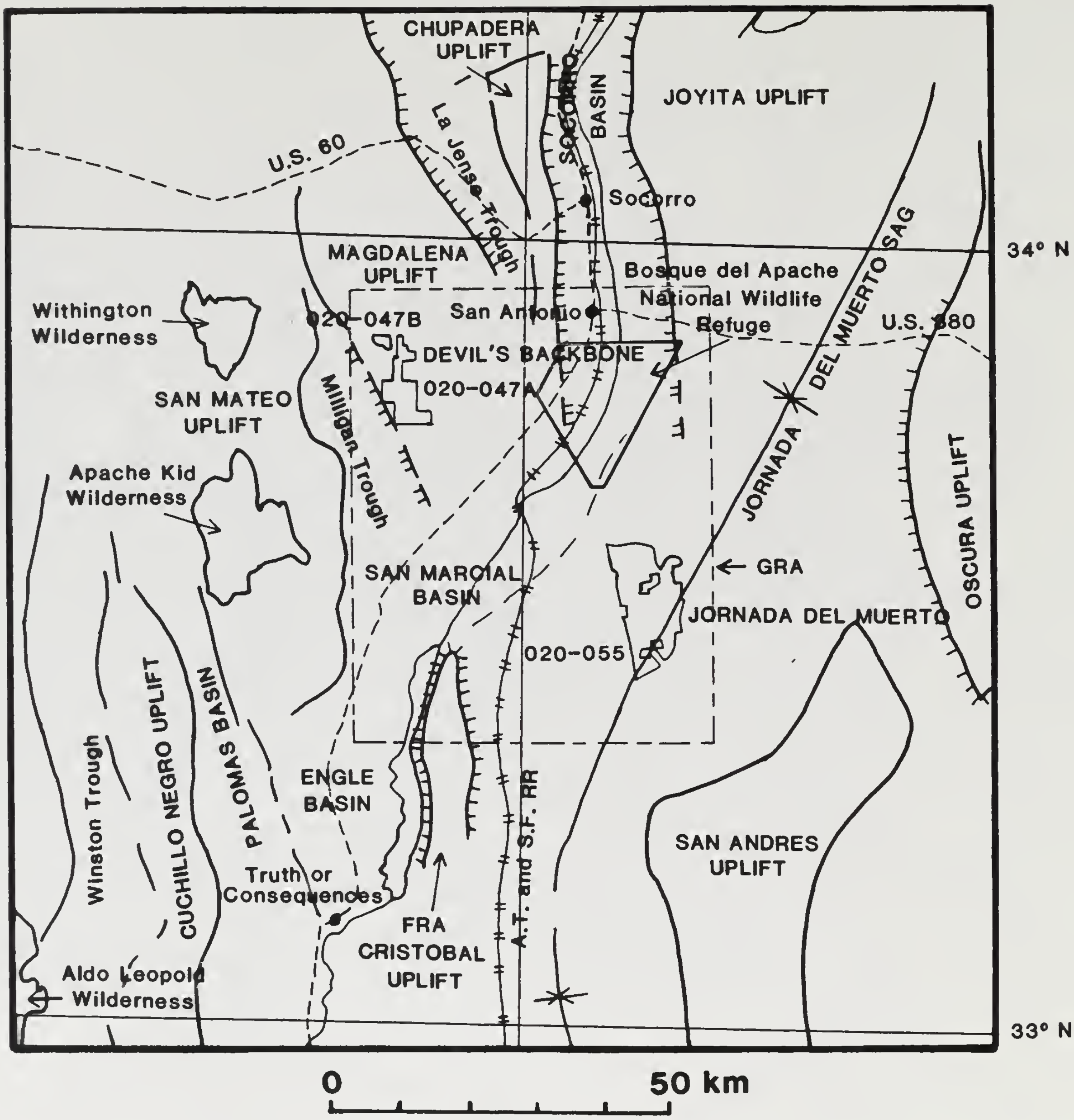


FIGURE 1. PHYSIOGRAPHIC MAP SHOWING THE LOCATION OF THE ARMENDARIS GRA AND THE THREE WSAs. PHYSIOGRAPHY AFTER KELLEY, 1979

Magdalena Mountains and in the steeper parts of the Fra Cristobal Range and the Chupadera Mountains. Two Wilderness Study Areas (WSAs), Devil´s Backbone (020-047A and B), are located in the northwestern part of the GRA and another WSA, Jornada del Muerto (020-055), is located in the southeastern part of the GRA.

All three WSAs are administered by the Socorro BLM District and have been designated in the BLM´s Wilderness Study Areas Decisions (BLM, Nov. 1980 and June 1981) as follows:

NM-020-047A	Devil´s Backbone	8,820 acres	(35.7 km^2)
NM-020-047B	Devil´s Backbone	860 acres	(3.4 km^2)
NM-020-055	Jornada del Muerto	28,919 acres	(117 km^2)
	Total	38,599 acres	(156 km^2)

The WSAs and surrounding areas are shown in figure 1.

PHYSIOGRAPHY

The Armendaris GRA lies within and adjacent to the Rio Grande rift, a pronounced north-trending tectonic and topographic depression. The area is in the Mexican Highland section of the Basin and Range Province as defined by Fenneman (1928). To the north of the area, the Rio Grande rift forms the boundary between the Colorado Plateau to the west and the high plains to the east. Some 100 miles to the south the rift loses its identity as a single physiographic feature and merges into the Basin and Range province of southwestern New Mexico, Mexico, and southern Arizona.

The GRA can be divided into four distinct physiographic terrains (fig. 1): The mountainous areas in the northwest, north-center and south-center, a broad lowland occupying much of the remaining area, the floodplain of Rio Grande bisecting the lowland, and a low hill in the southeast.

The mountainous areas consist of the Magdalena uplift in the northwest, the Chupadera uplift in the north-center and the Fra Cristobal uplift in the south-center. The Magdalena and Chupadera Mountains trend north to NNW and are fault-block mountains. The Magdalena uplift is faulted on the northeast and southwest and the Chupaderqa uplift is faulted on the east. The Fra Cristobal uplift, also a fault-block range, trends north and is faulted on both the east and west sides.

The lowland areas consist of the Milligan trough, the San Marcial basin, the Socorro trough, and the Jornada del Muerto sag (Kelley, 1979). The Milligan and Socorro troughs and San Marcial basin are faulted tectonic depressions filled with poorly consolidated valley-fill deposits and comprise part of the Rio Grande rift. The Jornada del Muerto sag is a NNE-trending tectonic downwarp. It contains pediment surfaces near the highlands, alluvial fan deposits and minor playa lakes and sand dune areas. The Jornada del Muerto sag is adjacent to the San Marcial basin.

The floodplain of the Rio Grande is 1-2 miles wide and is cut into the poorly-consolidated valley-fill sediments of the Rio Grande rift (Denny, 1940). The southern part of the floodplain has been flooded by the Elephant Butte Reservoir.

The broad, low hill in the southeastern part of the GRA consists of Quaternary basalt flows which were erupted from a central crater. One WSA occupies the eastern part of these basaltic flows.

The other two WSAs lie on the boundary between the southernmost extension of the Magdalena uplift and the Milligan gulch trough.

GEOLOGY

The lighology and stratigraphy, structural geology and tectonics, paleontology and geological history of the Armendaris GRA and surrounding central New Mexico are described in this section in order to facilitate the assessment of mineral potential within the area. The regional geologic setting is summarized in figure 2 and the detailed geology of the Armendaris GRA is summarized in figure 3.

Lithostratigraphy - Rock Units

In central New Mexico, Precambrian crystalline basement is unconformably overlain by late Paleozoic to Mesozoic shallow marine and continental sediments, mid-Tertiary arc volcanics, late Tertiary valley-fill sediments within the Rio Grande rift and late Tertiary to Quaternary bimodal volcanics. The area lies close to the eastern limit of Laramide orogeny deformation and has been tectonically active since the Early Miocene.

Precambrian Rocks

The Precambrian rocks of central and south-central New Mexico have been intensely studied by Condie and Budding (1979). They are within an ENE-trending belt that extends from southwest New Mexico to Illinois and contains rocks 1.2-1.65 b.y. old. In central New Mexico it consists mainly of granitic plutons (70%) which intrude metamorphic rocks (30%). The metamorphic grade ranges from lower greenschist to amphibolite facies. In decreasing order of abundance the metamorphic rocks consist of phyllite and quartz-mica schist, quartzite and arkosite, mafic meta-igneous rock, siliceous meta-igneous rock and gneiss. According to Condie and Budding (1979) this sequence of rocks is similar to the association found in modern continental rift systems, but according to Dickinson (1981), the voluminous granites, calc-alkaline metavolcanics and widespread metamorphic belts suggest a convergent environment.

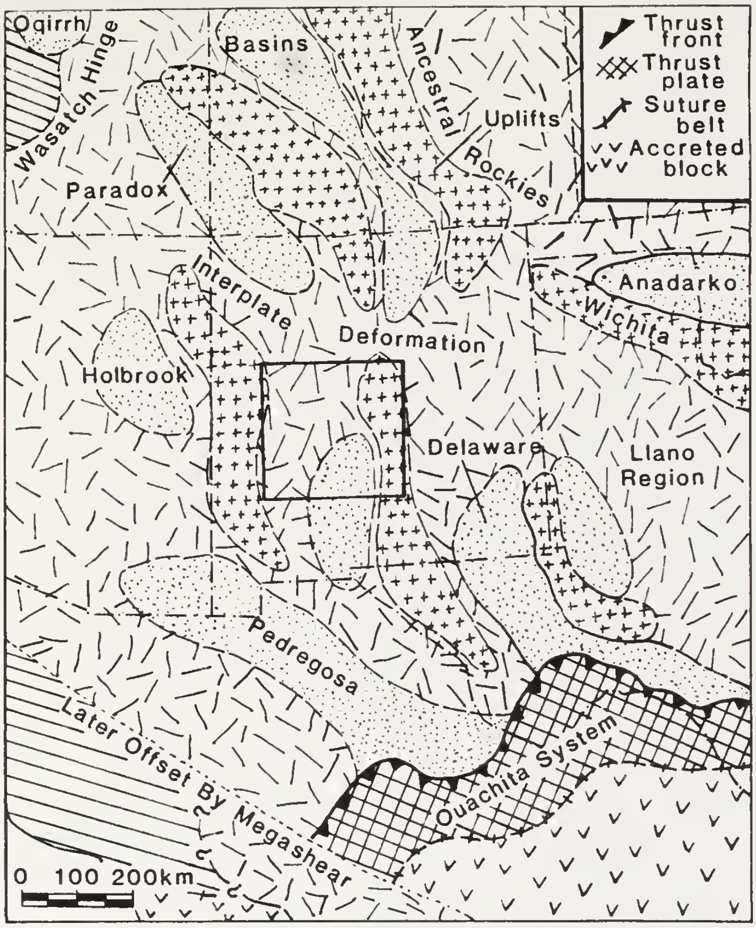
FIGURE 2: Paleotectonic maps of the southern Cordillera, New Mexico and adjoining areas, and map of mineral-deposit assemblage zones of the same area. Square in center of map is approximate location of figure 1.

A. Paleotectonic map, mid-Carboniferous to mid-Triassic (325-225 m.y.B.P.), featuring basins and uplifts of the Pennsylvanian and Early Permian. Dotted areas = basins; plusses (+) = uplifts.

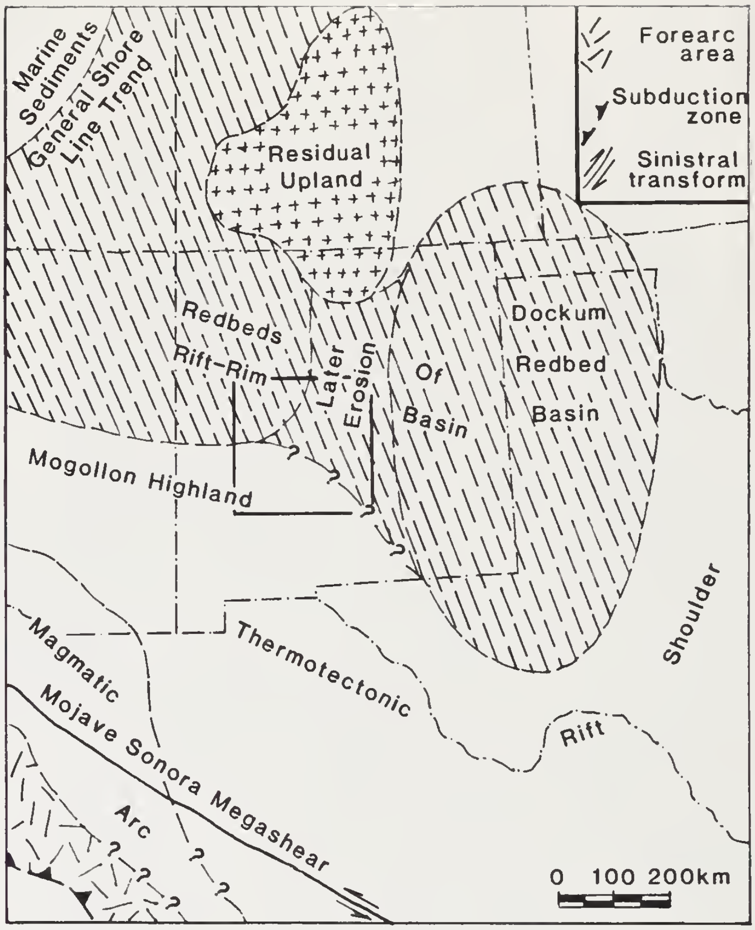
B. Paleotectonic map, mid-Triassic to mid-Late Jurassic (225-150 m.y.B.P.), showing redbed basins (dashed pattern) and thermo-tectonic rift shoulder. Rifted continental margin is immediately southeast of the area.

C. Paleotectonic map, latest Cretaceous to Recent time (75-0 m.y.B.P.), showing extent of Tertiary Laramide deformation and later Tertiary to present Rio Grande rift.

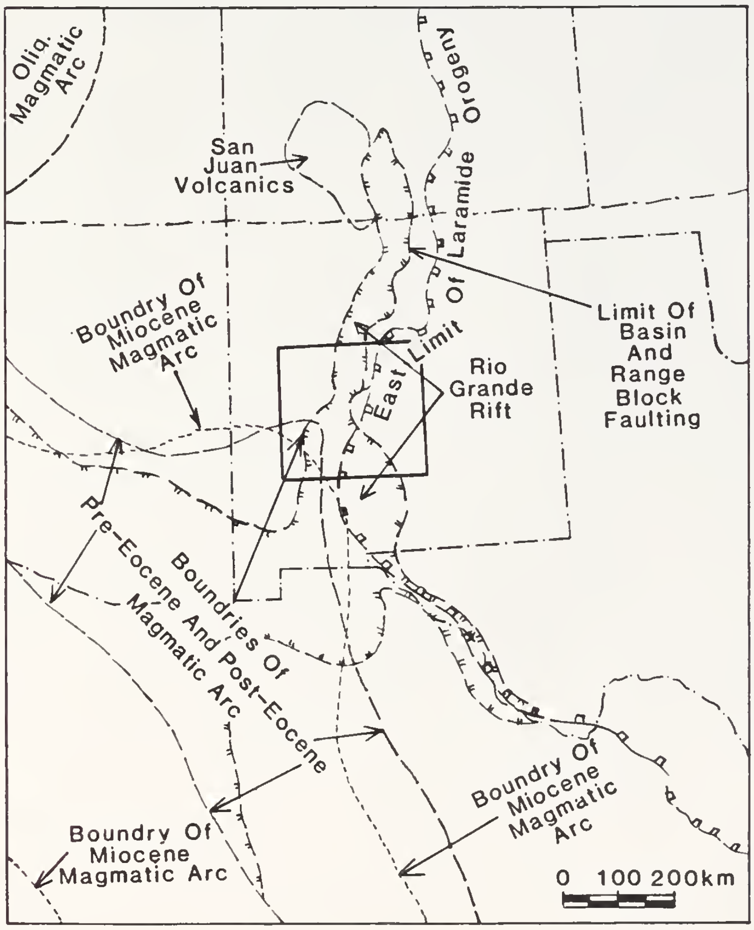
D. Mineral deposit assemblage zones. Light face dotted pattern = fluorite zone; bold face dotted pattern = molybdenum zone; v = copper-molybdenum zone. A, B, and C after Dickinson, 1981; D after Clark et al., 1982.


Oqirrh
Wasatch Hinge
Basins
Ancestral Rockies
Uplifts
Thrust front
Thrust plate
Suture belt
Accreted block
Paradox
Interplate Deformation
Anadarko
Wichita
Holbrook
Delaware
Llano Region
Pedregosa
Ouachita System
Later Offset By Megashear
0 100 200km

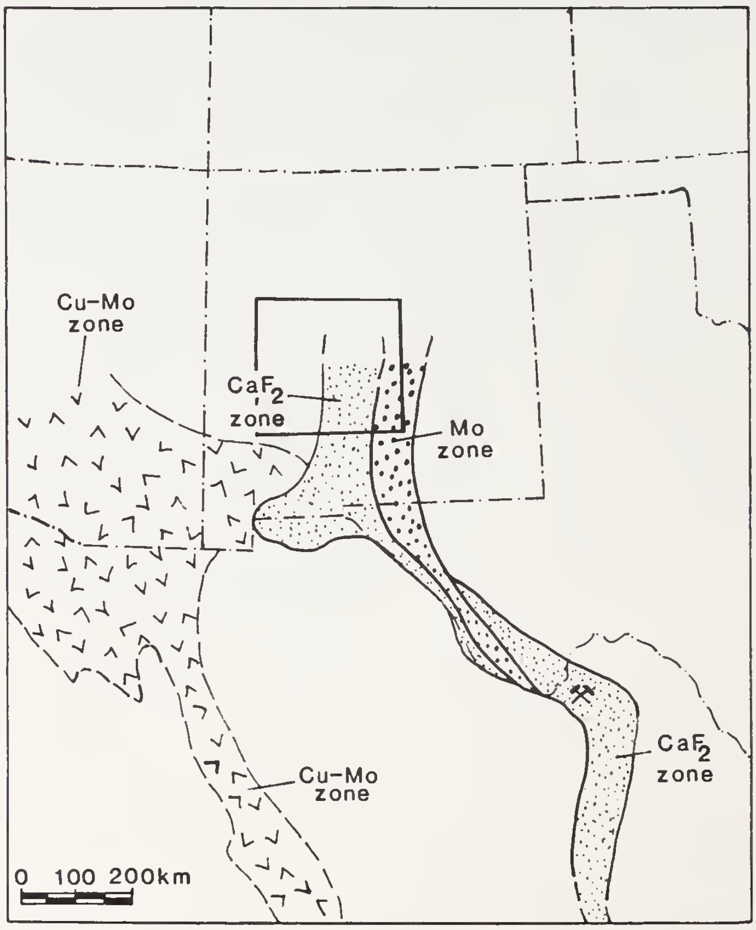
2a.


Marine Sediments
General Shore Line Trend
Residual Upland
Forearc area
Subduction zone
Sinistral transform
Redbeds
Rift-Rim
Later Erosion
Of Basin
Dockum Redbed Basin
Mogollon Highland
Thermotectonic
Rift
Shoulder
Magmatic Arc
Mojave Sonora Megashear
0 100 200km

2b.


Oliq. Magmatic Arc
San Juan Volcanics
Laramide Orogeny
East Limit Of
Limit Of Basin And Range Block Faulting
Boundry Of Miocene Magmatic Arc
Rio Grande Rift
Pre-Eocene
Boundries Of Pre-Eocene And Post-Eocene Magmatic Arc
Boundry Of Miocene Magmatic Arc
Boundry Of Miocene Magmatic Arc
0 100 200km

2c.


Cu-Mo zone
CaF2 zone
Mo zone
Cu-Mo zone
CaF2 zone
0 100 200km

2d.

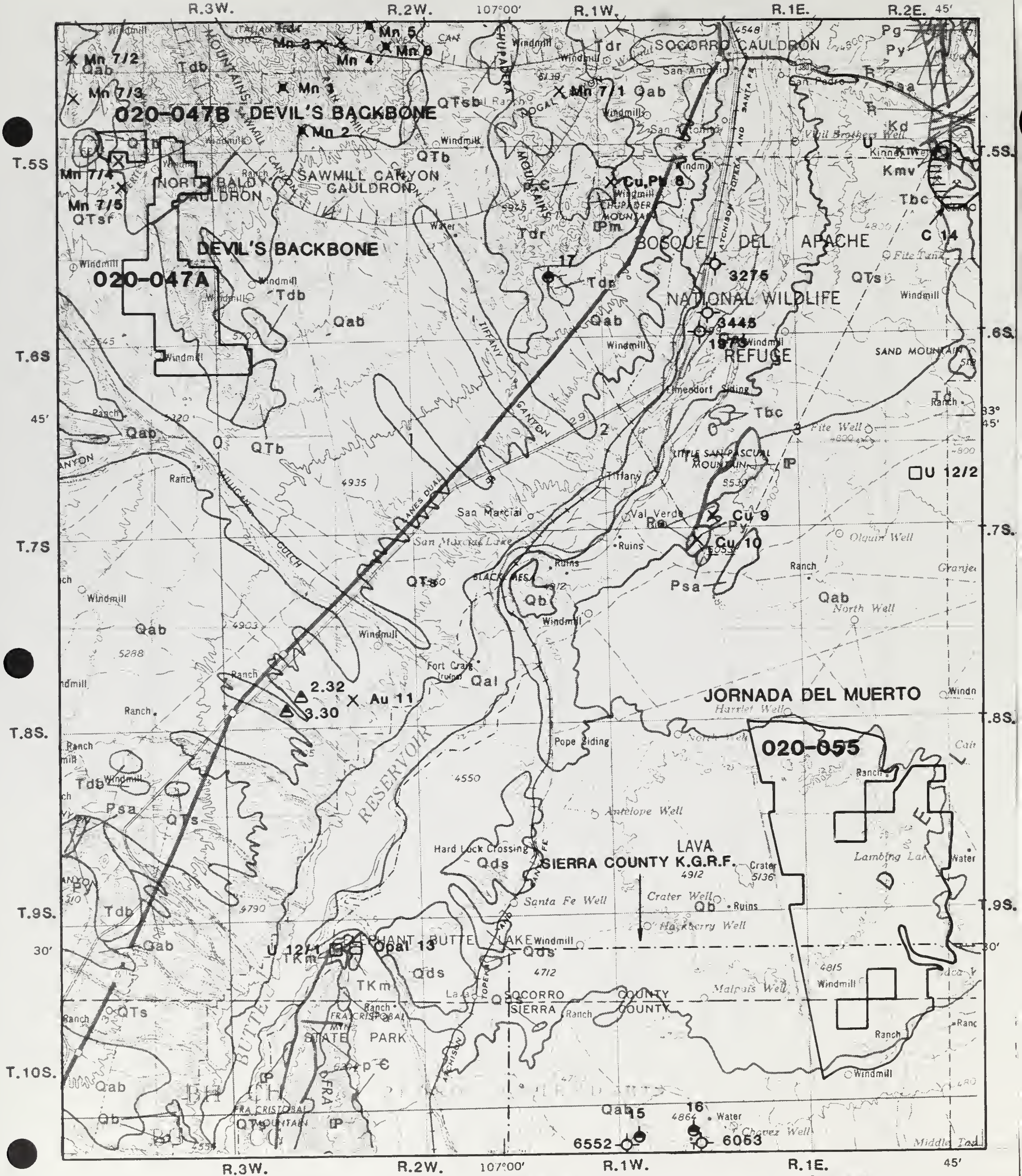


FIG. 3. GEOLOGIC, ENERGY AND MINERAL RESOURCES MAP OF THE ARMENDARIS AREA, NEW MEXICO

Scale
1 : 250,000
LEGEND: see enclosed

Figure 4. **LEGEND**

FOR

GEOLOGIC, ENERGY AND MINERAL RESOURCES MAPS

Scale of all maps is 1:250,000 or as otherwise indicated.

LITHOSTRATIGRAPHY

After C.H. Dane and G.O. Bachman, 1965

QUATERNARY	HOLOCENE	Qal	Alluvium
		Qab	Alluvium, bolson deposits and other surficial deposits
		Qds	Dune sand
	PLEISTOCENE	Qb	Basalt, including Jornada olivine basalt
TERTIARY	PLIOCENE	QTb	Olivine tholeiite, basaltic andesite, alkali olivine basalt, rhyolite
	MIOCENE	QTs	Santa Fe Group – conglomerate, sandstone, mudstone, playa deposits and tuffs QTsb – basalt flows
	OLIGOCENE	Td / Tdr / Tdb	Datil Formation – Td: Datil volcanic rocks Tdr: welded and crystal rhyolite tuffs, flows and breccias Tdb: pumiceons tuff and breccia
	EOCENE	Tbc	Baca Formation – conglomerate, sandstone and clay
	PALEOCENE	Ta	Andesite and other volcanic rocks, exact age uncertain
		TKm	McRae Formation – shale, sandstone, conglomerate, agglomerate, graywacke, andesite

CRETACEOUS	UPPER	Kmv	Mesaverde Group – conglomerate, sandstone, shale, siltstone, coal
		Km	Mancos Formation – shale, coal, sandstone, limestone
	LOWER	Kd	Dakota Sandstone – includes glauconitic shale
TRIASSIC		TR	Dockum Formation – red siltstone, shale, conglomerate, sandstone
PERMIAN	LEONARD	Psa	San Andres Limestone – includes some sandstone and gypsum lenses
		Pg	Glorieta Sandstone – quartz sandstone
		Py	Yeso Formation – sandstone, gypsum, limestone, siltstone, shale (light red)
	WOLFCAMP	Pa	Abo Sandstone – includes limestone pebble conglomerates, limestone, shale, siltstone (dark red)
PENNSYLVANIAN		IP	Pennsylvanian undivided – includes Sandia Formation (sandstone, coal, shale, limestone) and Madera Formation (limestone, sandstone, siltstone, shale)
		IPm	Madera Limestone – includes sandstone, siltstone, shale
PRECAMBRIAN		p€	Gneiss, schist, amphibolite, siliceons, meta-igneous rocks, quartzite, arkose

SPECIAL SYMBOLS

OF STRUCTURAL FEATURES

After U.S. Geological Survey

Contact – Dashed where approximately located; short dashed where inferred; dotted where concealed

45

Contact – Showing dip; well exposed at triangle

Fault – Dashed where approximately located; short dashed where inferred; dotted where concealed

20

Fault, showing dip – Ball and bar on downthrown side

Normal fault – Hachured on downthrown side

Fault – Showing relative horizontal movement

Thrust fault – Sawteeth on upper plate

Anticline – Showing direction of plunge; dashed where approximately located; dotted where concealed

Asymmetric anticline – Short arrow indicates steeper limb

Overturned anticline – Showing direction of dip of limbs

Syncline – Showing direction of plunge; dashed where approximately located; dotted where concealed

Asymmetric syncline – Short arrow indicates steeper limb

Overturned syncline – Showing direction of dip of limbs

Monocline – Showing direction of plunge of axis

20 Minor anticline – Showing plunge of axis

60 Minor syncline – Showing plunge of axis

Strike and dip of beds – Ball indicates top of beds known from sedimentary structures

70 Inclined   Horizontal

Vertical   40 Overturned

Strike and dip of foliation

20 Inclined   Vertical   Horizontal

Strike and dip of cleavage

15 Inclined   Vertical   Horizontal

Bearing and plunge of lineation

15 Inclined   Vertical   Horizontal

Strike and dip of joints

40 Inclined   Vertical   Horizontal

Note: planar symbols (strike and dip of beds, foliation or schistosity, and cleavage) may be combined with linear symbols to record data observed at same locality by superimposed symbols at point of observation. Coexisting planar symbols are shown intersecting at point of observation.

SPECIAL SYMBOLS

FOR ENERGY AND MINERAL RESOURCES

KNOWN DEPOSITS AND OCCURRENCES

- -O Oil field
- -G Gas field
- -Os Oil shale
- -C Coal deposit
- -C Coal occurrence
- -Mineral orebody - as specified with symbol
- -Mineral deposit - as specified with symbol
- -Mineral occurrence - as specified with symbol
- -Mineral district (Fig.= inserted map)

EXPLORATION AND/OR MINING ACTIVITY

MINERALS AND COAL

- Mineral deposit, mine or prospect with recorded prod.
- Prospect or mine with no recorded production
- Accessible adit, or tunnel
- Inaccessible adit, or tunnel
- Vertical shaft
- Inclined shaft
- Active open pit, or quarry
- Inactive open pit, or quarry
- Active gravel or clay (cl) pit
- Inactive gravel or clay (cl) pit
- Exploration hole with data available
- Exploration hole without data
- Mining district (Fig.= inserted map)

PETROLEUM

- Oil well
- Oil and gas well
- Gas well
- Show of gas
- Show of oil
- Show of oil and gas
- Shut-in well
- CO_2- or He-helium- rich well
- Dry well - abandoned

GROUND WATER

- Water well of special importance
- Water well of high yield
- Flowing water well
- Brine
- Mineral water
- Thermal water
- Radioactive water
- Thermal point

ENERGY RESOURCES

O	Oil	C	Coal	U	Uranium
G	Gas	Cb	Lignite (brown coal)	Th	Thorium
Os	Oil shale	Cp	Peat	Gt	Geothermal
Ot	Tar sands				

MINERAL RESOURCES

METALS

- Al Aluminum
- Sb Antimony
- As Arsenic
- Be Beryllium
- Bi Bismuth
- Cd Cadmium
- Cr Chromium
- Cs Cesium
- Co Cobalt
- Cu Copper
- Ga Gallium
- Ge Germanium
- Au Gold
- Fe Iron
- Pb Lead
- Li Lithium
- Mn Manganese
- Hg Mercury
- Mo Molybdenum
- Ni Nickel
- Nb Niobium or Columbium
- Pt Platinum group
- RE Rare earth
- Re Rhenium
- Sc Scandium
- Ag Silver
- Te Tellurium
- Tl Thallium
- Sn Tin
- Ti Titanium
- W Tungsten
- V Vanadium
- Zn Zinc
- Zr Zirconium and Hf Hafnium

NONMETALS - INDUSTRIAL MINERALS

- ab Abrasives
- al Alum
- as Asbestos
- Ba Barite
- be Bentonite
- ca Calcite
- cl Clay

Construction materials :

- cs Crushed stone
- la Lightweight aggregates, includ.:
  - pm Pumice and volcanic cinders
  - pe Perlite
  - ec Expanded clay, shale, slate
  - vm Vermiculite
- sg Sand and gravel
- cr Cement raw materials
- bs Building stones
- ll Lime

- di Diatomite

Nonmarine and marine evaporites and brines

- pt Potash
- na Salt - mainly halite
- gy Gypsum and anhydrite
- nc Sodium carbonate or sulfate
- bn Boron minerals
- ni Nitrates
- Sr Strontium
- Br Bromine
- cc Calcium chloride
- mg Magnesium compounds

- fs Feldspar
- F Fluorite (fluorspar)
- gs Gem stones
- ge Graphite
- He Helium
- kl Kaolin
- ky Kyanite and related minerals
- ls Limestone
- lm Lithium minerals

- mg Magnesian refractories
- mi Mica
- ph Phosphate
- pi Pigment and fillers
- qz Quartz crystals
- si Silica sand
- S Sulfur
- tc Talc
- ze Zeolites
- hm Humate

SPECIAL GEOLOGICAL FEATURES

POINT OF SPECIAL GEOLOGIC INTEREST

m	Mineral occurrence	s	Structural, bedding, foliation, etc.,	u	Radioactive spring
f	Fossil locality	b	Brecciation, shear zone, etc.,	g	Thermal spring
v	Volcanic phenomenon	y	High yield spring	a	Extensive rock alteration
t	Stratigraphic sequence	p	Spring with mineral water	r	Lithologic type locality

FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE FOR MINERAL RESOURCES

FAVORABILITY:

1A - Undefined

1 - Not favorable - combine with either B, C, or D

2 - Low
3 - Moderate
4 - High
} combine with either A, B, C, or D

LEVEL OF CONFIDENCE:

A - Insufficient data

B - Indirect evidence

C - Direct evidence

D - Abundant direct and indirect evidence

In the Armendaris GRA, small exposures of Precambrian rocks are found near the southern end of the Chupadera Mountains and along the margins of the Fra Cristobal range (fig. 3). In the Chupadera Mountains the rocks consist of gneiss, schist and minor amphibolite interlayered with siliceous meta-igneous rocks, quartzite and arkosite (Condie and Budding, 1979). In the Fra Cristobal range the rocks consist of quartz monzonite and comprise part of the Fra Cristobal pluton (Condie and Budding, 1979).

Undifferentiated Cambrian to Silurian

Ordovician to Silurian sediments crop out over a small area on the west side of the Fra Cristobal in the south-central part of the GRA (fig. 3). They may be a thin wedge of the Ordovician Bliss sandstone and El Paso dolomite which crop out to the west and southwest in the Oscura and San Andres Mountains (Bachman, 1968; Bachman and Harbour, 1970). The rocks rest unconformably on Precambrian basement.

Mississippian

Mississippian sediments are found in the northern Magdalena Mountains (Titley, 1961) and, according to Bachman and Stotlemeyer (1967), in tiny exposures in the Chupadera Mountains of this GRA (fig. 3). According to Armstrong (1958), the Caloso and Kelly Formations comprise the Mississippian of central New Mexico. The Caloso is about 30 feet thick and consists of a basal arkosic sandstone overlain by a dark algal limestone. This agrees with the description of Mississippian rocks of Bachman and Stotelmeyer (1967) in the Chupadera Mountains. The Kelly Formation is not exposed in the Armendaris GRA but could underlie the northwest part of it. It is up to 70 feet thick (up to 125 feet, according to Titley, 1961) and consists of light tan to gray, medium-grained limestone (Kottlowski, 1960; Armstrong, 1958). In the

Magdalena mining district it is the host rock for the replacement Pb-Zn-Ag deposits (Titley, 1961). It disconformably overlies the Caloso Formation or Precambrian crystalline basement.

Pennsylvanian

Pennsylvanian sediments crop out in a small area in the Chupadera Mountains in the north-central part of the GRA and in the eastern Fra Cristobal Range in the south-central part of the GRA (fig. 3), but probably underlie much of the area. Kottlowski (1960) has studied Pennsylvanian sections of central New Mexico where it is divided into the Sandia and Madera Formations of the Magdalena Group.

The Sandia Formation consists of pebbly to fine-grained arkosic sandstone, coal laminae, black and green shales and dark arenaceous limestones. Calcareous rocks contain abundant brachiopods. The formation ranges in thickness from 100-700 feet and rests unconformably on older paleozoic strata or on Precambrian basement.

The Madera Formation is between 1400 and 1850 feet thick. It is divided into three members: The Gray Mesa member which is 800-900 feet thick and consists of a gray cherty limestone with fusulinids and brachiopods; the Astrado member which is 750 feet thick and consists of siltstone and arkosic sandstone; and the Red Tanks member which is 200-300 feet thick and consists of red buff sandstone, conglomerate, siltstone, shale, limestone and arkosic sandstone (Kottlowski, 1960). The Madera Formation rests conformably on the Sandia Formation.

Permian

Permian sediments crop out over small areas in the Fra Cristobal Range and along the eastern margin of the Rio Grande rift (fig. 3). The Permian rocks of central New Mexico have been studied by Kottlowski et al. (1956) and Kottlowski (1963), and have been divided into the Bursum, Abo, Yeso, Glorieta and San Andres Formations, all of which, except the Bursum, crop out in the Armendaris GRA.

The Abo Formation consists of a basal limestone pebble conglomerate and silty limestone, dark red arkosic sandstone and reddish shale and siltstone. In the Oscura Mountains to the east, Bachman (1968) reports the presence of granite, quartzite and rhyolite clasts in the conglomerate. The Abo is mainly terrestrial and is 300-750 feet thick. It rests unconformably on earlier Paleozoic sediments.

The Yeso Formation is mainly shallow marine-lagoonal and consists of orange to light red sandstones, evaporitic gypsum-bearing beds up to 150 feet thick, orange to light gray sandstone, arenaceous to argillaceous limestone, siltstone and shale. The Yeso is 750 feet thick at the type section to the northeast of Socorro, but is reported to be 1500 feet thick in the San Andres Mountains to the southeast (Bachman and Harbour, 1970) and 900 feet thick near the Rio Grande (Bachman and Stotelmeyer, 1967). It grades into the underlying Abo Formation from which it is distinguished mainly by a change in color from dark to light red. The boundary also represents a change from dominantly terrestrial conditions in the Abo to mainly lagoonal conditions in the Yeso.

The Glorieta sandstone is present on the east side of the Rio Grande. It is a well-sorted, light gray quartzose sandstone which occurs as lenses up to 200 feet thick near the boundary between the Yeso Formation and the overlying San Andres Formation and is probably part of the latter.

The San Andres Formation consists of gray, medium-bedded to massive fossiliferous limestone containing cephalopods and brachiopods. Locally, the basal part is interbedded with gypsum and lenses of sandstone. It is about 600 feet thick and grades into the underlying Yeso Formation.

The Permian sediments were deposited in a basin into which sediments were fed from the Pedernal uplift to the east and southwest and from the Burro-Zuni uplift to the west and northwest (fig. 2; Dickinson, 1981).

Triassic

The Triassic Dockum Formation crops out in the northeast part of the Armendaris GRA. The Dockum Formation consists of pale reddish calcareous siltstone and shale with local lenses of conglomerate and sandstone (Kottlowski, 1963). It varies in thickness from 50-100 feet, rests unconformably on the San Andres Formation, and is terrestrial. Hilpert (1969) suggests it is similar to the Shinarump member of the Chinle Formation, which in northwestern New Mexico is host to important stratabound uranium deposits. Sediments of the Dockum Formation were derived from the Mogollan Highlands to the south (fig. 2; Dickinson, 1981).

Cretaceous

Cretaceous sediments of the Dakota, Mancos, Mesaverde and McRae Formations crop out in the southwest and northeast parts of the GRA and are described by Kottlowski et al. (1956) and Kottlowski (1963).

The Dakota Formation consists mainly of gray-brown quartz sandstone with interbedded gray to green, locally glauconitic shale near the base, fluvial channel deposits including conglomerate lenses, crossbedded sandstone and carbonaceous shale. The presence of glauconite suggests that the upper part of the Dakota is marine. Near Socorro, the Dakota is about 20 feet thick and rests unconformably on the Dockum Formation.

The Mancos Formation consists of gray carbonaceous shale with local coal lenses, minor fine, locally calcareous and gypsiferous, sandstone and limestone. It is marine and contains abundant plant fossils, cephalopods, pelecypods, ostrea and brachiopods. It is up to 295 feet thick and conformably overlies the Dakota.

The Mesaverde Formations consists of olive-brown basal conglomerate overlain by marine sandstone and sandy, calcareous shale and siltstone, which in turn are overlain by non-marine mudstones, shales and coal. The formation is about 900 feet thick and it conformably overlies the Mancos.

The McRae Formation crops out at the northern end of the Fra Cristobal Range (fig. 3). To the south it has been divided into the lower Jose Creek member and upper Hall Lake member. The lower member is 400 feet thick and consists of brown to green shale, tan to brown sandstones and conglomerate lenses and agglomerates with andesitic cobbles. The upper member is up to 2900 feet thick and consists of conglomerate with basement-derived and andesitic clasts, volcanic greywackes and tuffaceous sandstones and siltstones. A fossil triceratops has been found in the lower part of the Hall Creek member. The andesitic volcanics within the McRae were derived from a volcanic center near Elephant Butte dam. The McRae Formation unconformably overlies the Mesaverde.

Early Tertiary

The Baca Formation of probable Eocene age crops out near the Rio Grande in the north-central and northeast part of the GRA (fig. 3). According to Hilpert (1969), it consists of conglomerate, red and white sandstone and red clay. The conglomerate contains pebbles to boulders to Precambrian and Paleozoic provenance. Near Carthage, in the northeast part of the GRA, it is about 1000 feet thick. It rests unconformably on a bevelled surface formed on the underlying Paleozoic and Mesozoic sedimentary rocks.

Volcanic flows and tuffs of latite to basalt composition crop out over a small area in the north-central part of the GRA (fig. 3). They underlie the Santa Fe Formation (Bachman and Stotelmeyer, 1967) and may be Paleocene to Eocene in age (Dane and Bachman, 1965).

Mid-Tertiary

Late Eocene to Early Miocene volcanic rocks of the Datil Formation crop out over much of the Magdalena and Chupadera Mountains, and the two northwestern WSAs lie largely within them (fig. 3). Smaller outcroppings of Datil volcanic rocks are located in the east-central and southwest parts of the GRA. The volcanism lasted between 40 and about 20 m.y. ago (Burchfiel, 1979) and peaked about 30 m.y. ago (Lipman, 1981). According to Elston and Bornhorst (1979), between 40 and 32 m.y. ago the volcanism was related to subduction of the Farallon plate and consisted of calc-alkaline andesite, quartz latite and rhyolite; activity became more felsic with time. These rocks may possibly be correlated with the calc-alkaline and potassic calc-alkaline rocks described by Clark et al. (1982) to the south of the Socorro area. In the central New Mexico area voluminous quartz latitic ash flow deposits, tuff breccias and flows were erupted from cauldrons (Elston, 1978) into which later epizonal monzonite and quartz monzonite plutons were intruded. During this time the North Baldy cauldron (fig. 3) was active (Elston, 1978).

Between 32 and 20 m.y. ago the Pacific plate collided with the American plate, the San Andres fault was initiated, subduction slowed and back arc, bimodal, calc-alkaline, basaltic andesite and high-silica rhyolite volcanism developed (Elston and Bornhorst, 1979). These rocks may possibly be correlated with potassic calc-alkaline and alkaline volcanics described by Clark et al. (1982) to the south of the Socorro area. In central New Mexico voluminous high silica rhyolitic ash flow deposits, tuff breccias and flows were erupted from cauldrons (Elston, 1978), into which later epizonal plutons were intruded. During this time the Nogal Canyon, Mt. Withington, Sawmill Canyon, Socorro and Hop Canyon cauldrons were active (Elston, 1978).

Volcanic rocks close to the cauldron have been extensively hydrothermally altered and strongly enriched in potassium (Chapin et al., 1978). This was probably caused by ancient geothermal systems and may be associated with hydrothermal ore deposits.

The Devil´s Backbone WSAs lie close to the margin of the North Baldy, Hop Canyon and Withington cauldrons, and are largely within tuffs and breccias of the Datil Formation.

Late Tertiary

During the Miocene and Pliocene, valley-fill sediments of the Popotosa and Santa Fe Formations were deposited along the Rio Grande rift, a major tectonic depression which extends into Colorado in the north and to the south merges into the Basin and Range Province. Coeval volcanism is associated with the rifting. The Popotosa and Santa Fe Formations have been described from the Albuquerque basin and Socorro trough by Denny (1940) and Kelley (1977).

In the Armendaris GRA, the Popotosa Formation is not exposed but the Santa Fe crops out in the Socorro trough, the San Marcial basin and the Milligan trough (fig. 3). At the southern end of the Albuquerque basin and in the Socorro trough, the Santa Fe Formation is at least 2000 feet thick. It consists of conglomerate, pinkish, light olive and white sandstone, gray and brown mudstone and, in the Socorro trough, playa deposits. The conglomerates contain boulders, cobbles and pebbles of granite, quartzite, schist and volcanics. The Santa Fe is locally tuffaceous. It rests unconformably on Precambrian basement, the Popotosa Formation and Datil volcanics. The southwestern part of the northwestern WSAs probably overlies the Santa Fe Formation.

Volcanism associated with the Rio Grande rift commenced 21 m.y. ago and coincided with the growth of the San Andres transform and intra-plate block faulting in the Basin and Range Province (Elston and Bornhorst, 1979). According to Balbridge (1979), the volcanics consist of olivine tholeiite, basaltic andesite, alkali olivine basalt and lesser rhyolite. Similar volcanics locally rest on Datil volcanics in the north-central and northwest parts of the GRA, and may be interbedded with the Santa Fe.

Quaternary

Quaternary deposits include basalt and unconsolidated sediment. The basalt is present as flows in the southwestern and south-central part of the GRA (fig. 3) and represents a continuation of the Rio Grande rift-related volcanism. According to Kottlowski et al. (1956), it is an olivine-rich basalt which is between 50 and 100 feet thick. Sediments include older terrace gravel deposits, present-day floodplain gravels of the Rio Grande and dune sands. The Jornada del Muerto WSA covers the eastern part of the basalt flows.

Igneous activity is continuing to the present day. Recent work involving seismic refraction (Olsen et al., 1979), seismic reflection (Brown et al., 1979), and microearthquake studies (Sanford et al., 1979) have shown that a magma sill underlies the Albuquerque basin to the north of Socorro at a depth of 19-20 km and that several smaller magma chambers are present near Socorro at a depth of about 5 km.

Structural Geology and Tectonics

The area lies within the North American craton which, during the Proterozoic, had undergone two periods of deformation and granite intrusion (Condie and Budding, 1979). The area remained tectonically quiet until the Pennsylvanian-Permian, at which time, possibly due to the Ouachita orogeny in the south, the region underwent warping (fig. 2A) (Dickinson, 1981).

During the Laramide, minor folding and thrusting took place (see fig. 2C) but this was not associated with any igneous activity in central New Mexico. During the Oligocene the dip of the Farallon plate beneath North America decreased to about 15° (Coney and Reynolds, 1977) and voluminous calc-alkaline volcanics were erupted from several cauldrons in central New Mexico (Elston, 1978; Elston and Bornhorst, 1979). These were undoubtedly associated with collapse structures and normal faults. The Nogal Canyon, Mt. Withington, Hop Canyon, North Baldy, Sawmill Canyon and Socorro cauldrons were formed in the western and northern parts of the GRA. The two Devil´s Backbone WSAs lie partly within the boundaries of the North Baldy and Hop Canyon cauldrons (fig. 3).

From early Miocene to the present has been a time of intense tectonic activity along, and close to, the Rio Grande rift (fig. 2C). The activity has been dominated by normal faulting and bimodal volcanism within, and along the flanks of, the Rio Grande rift. Brown et al. (1979) have found evidence of faults with displacements of up to 4 km within the rift and Reilinger et al. (1979) have shown from repeated leveling measurements that parts of the Albuquerque basin are being uplifted at a rate of 0.5 cm per year. The crustal thickness beneath the Rio Grande rift has been found to be 35 km, compared to 45 km and 55 km beneath the Colorado Plateau and Great Plains respectively (Keller et al., 1979). The thinning of the crust, the bimodal volcanism and the normal faulting are probably related to cessation of subduction and the growth of the San Andres fault since the Miocene.

In the Armendaris GRA, normal faulting is probably present along the margins of the San Marcial basin just as it is further to the north in the

Socorro GRA. Other normal faults may be present near the Santa Fe Formation, as has been shown to be the case by Brown et al. (1979) farther to the north in the Albuquerque basin. Northwest- to northeast-trending faults are present in the Fra Cristobal Range, Magdalena Mountains and Chupadera Mountains. At least some of these faults post-date mid-Tertiary intrusives and may be related to the Rio Grande rift. The Jornada del Muerto sag strikes northeast across the GRA and may also be related to the rifting episode. No important deformation has taken place since the outpouring of the Quaternary basalt in the southeast part of the GRA, which includes the Jornada del Muerto WSA.

Geological History

The geological history of the area is long and complex and only a brief synopsis is presented here. Excellent summaries of the main geological events that affected the Cordillera of New Mexico are given by Hilpert (1969), Burchfiel (1979) and Dickinson (1981). More detailed accounts are given by Condie and Budding (1979) for the Precambrian, Bachman (1968) for the Paleozoic, Kottlowski et al. (1956) and Kottlowski (1963) for the Paleozoic and Mesozoic, and Elston and Bornhorst (1979) for the mid-Tertiary to Quaternary.

The area lies within a 1.2-1.65 b.y. ENE-trending belt within the North American craton, which is distinct from a 1.65-1.9 b.y. belt to the northwest. It contains metasedimentary and both mafic and felsic meta-igneous rocks that have been folded twice, metamorphosed and intruded by granites.

The post-Precambrian geologic history can be summarized as follows:

1. Sometime prior to the mid-Paleozoic, the area was uplifted and eroded to a peneplain.
2. Transgression took place during the Mississippian and Pennsylvanian. At this time the shallow marine clastic and carbonate

sequence represented by the Caloso, Kelly, Sandia and lower Madera Formations was deposited.

3. During the Late Pennsylvanian and Early Permian, the Ouachita orogeny to the south caused in the Pedernal and Burro-Zuni uplifts and a gradual regression in the central New Mexico area (fig. 2A). The uplifts were the main sediment sources during the Late Pennsylvanian and Permian. During the regression, shallow marine limestone and red clastics of the upper Madera and Bursum Formations were deposited. The culmination of this regressive sequence is the Abo Formation which is a continental redbed sequence.
4. A marine transgression followed with deposition of shallow marine-lagoonal Yeso Formation which contains evaporites and redbeds, and the mainly carbonate San Andres Formation.
5. During the Triassic, the area was uplifted, bevelled and the continental redbed Dockum Formation was deposited (fig. 2B).
6. The area remained uplifted during the Jurassic and no sedimentation took place. During the Cretaceous, shallow marine sedimentation was followed by deposition of coal-bearing terrestrial beds of the Mesaverde Formation.
7. The Laramide orogeny barely affected central New Mexico and resulted in minor thrusting and folding (fig. 2C). This was followed by a prolonged erosion and bevelling of the surface.
8. From the latest Eocene to the present day followed a period of volcanism and tectonism which can be divided into three phases:

a. The first phase lasted from 40 to 30 m.y. During this time, the dip of the Benioff zone beneath the American plate decreased to less than 15° and calc-alkaline, mainly andesitic and quartz latitic volcanism took place. Voluminous quartz latitic ash flow deposits were erupted from cauldrons and small epizonal monzonite to quartz monzonite plutons were intruded.

b. The second phase lasted from 30 to 20 m.y. At this time the Pacific plate collided with North America, the San Andreas fault was initiated and a modified back arc stage of volcanism took place as a result of the still active Farallon plate beneath the southern Cordillera. Volcanism took on a bimodal character with calc-alkaline to high potassium calc-alkaline, basaltic andesite and high silica rhyolite being the dominant phases erupted. Extensive ash flow deposits of high silica rhyolite were erupted from cauldrons and epizonal plutons of quartz monzonite and granite were intruded.

c. From 20 m.y. to the present, intraplate normal faulting and bimodal volcanism has taken place and is probably associated with cessation of subduction and the growth of the San Andreas transform. During this time, the Rio Grande rift developed (fig. 2C) and was filled with valley-fill sediments.

9. Igneous activity and deformation have continued to the present day as evidenced by the presence of magma chambers beneath the Socorro area.

ENERGY AND MINERAL RESOURCES

The following are descriptions of known mineral deposits, prospects, occurrences, mineralized areas, thermal wells and other energy resources in the GRA. Locations of the deposits are shown in figure 3. The following information was derived largely from U.S. Geological Survey (1981a; the CRIB File), Haigler and Sutherland (1965), New Mexico Bureau of Mines and Mineral Resources (1965), U.S. Geological Survey (1981b), and other references quoted in the main body of this report. It represents a summary of knowledge available to the writers regarding individual mines and occurrences.

Known Mineral Deposits, Mines or Prospects with Recorded Production

1. Buena Vista Group
   Location: Center of Sec. 2, T5S, R3W New Mexico Meridian, 33°54´15"N, 107°7´21"W
   Commodity: Mn
   Ore Materials: Pyrolusite, wad.
   Description of Deposit: Shear zone. Small deposit consists of 5 unpatented claims, strikes N10°-20°W.
   Geology: Mineralization occurs in fractures and along brecciated shear zones in Tertiary rhyolite of the Datil Formation. Mineralization is Tertiary in age and gangue minerals are calcite, quartz and limonite.
   Production: About 33 tons of Mn-concentrates.

2. Burris Claims
   Location: 33°3´05"N, 107°6´51"W, SE-1/4 Sec. 11 and SW-1/4 Sec. 12, T5S, R3W, New Mexico Meridian
   Commodity: Mn
   Ore Materials: Pyrolusite, wad.
   Description of Deposit: Shear zone deposit. Small ore body strikes N50°-70°W.
   Geology: Mineralization is controlled by fault-fractures present in Tertiary rhyolite of the Datil Formation. Mineralization occurred in the Tertiary.
   Production: A few tens of tons of hand-sorted 20% Mn ore was produced.

5. Lucky Ridge Prospect
   Location: 33°56´01"N, 107°4´32"W, W-1/2 Sec. 29, T4S, R2W New Mexico Meridian
   Commodity: Mn
   Ore Materials: Pyrolusite, wad.
   Description of Deposit: Deposit is a small, irregularly shaped ore body in a shear zone striking N20°-30°W.

Geology: Mineralization is along faults and fractures in Tertiary rhyolites of the Datil Formation. Three parallel fracture zones are present. Mineralization occurred in the Tertiary. Calcite is present as gangue.

Production: Production in 1958 was about 50 tons of concentrates containing 43% Mn.

6. Bianchi Claims

Location: 33°55´23"N, 107°03´52"W, NE-1/4 Sec. 32, T4S, R2W New Mexico Meridian

Commodity: Mn

Ore Materials: Pyrolusite, wad, psilomelane.

Description of Deposit: Small deposit in shear zone.

Geology: Fault-fracture structurally controlled deposit in Tertiary rhyolite of the Datil Formation. Mineralization occurred in the Tertiary. Gangue minerals are quartz and calcite.

Production: At least a few hundred tons of ore mined in the 1950s.

14. Carthage Coal Field

Location: 33°51´57"N, 106°43´55"W, Secs. 13, 14, 15, 16, 17, 20, 21, 22, 23, T5S, R2E, New Mexico Meridian

Commodity: Coal

Ore Materials: Bituminous coal.

Description of Deposit: Two coal seams are 4 to 7 feet thick each. The field is ten square miles in area.

Geology: Coal seams occur in the terrestrial part of the Cretaceous Mesaverde Formation.

Production: Yes; total unknown.

Known Prospects, Mineralized Areas and Energy Resources with No Recorded Production

3. Section 36 Deposit

Location: 33°55´39"N, 107°5´58"W, NE-1/4 Sec. 36, T4S, R3W

Commodity: Mn

Ore Materials: Psilomelane, pyrolusite.

Description of Deposit: Small, irregular ore bodies in a N35°-40°W trending brecciated shear zone.

Geology: Structurally controlled; mineralization along faults and fractures in rhyolites of the Tertiary Datil Formation. Gangue materials are iron oxide, rhyolite fragments, calcite and quartz.

Production: None.

4. Red Bluff Group

Location: 33°55´24"N, 107°5´32"W, NW-1/4 Sec. 31, T4S, R2W New Mexico Meridian

Commodity: Mn

Ore Materials: Pyrolusite, wad, psilomelane.

Description of Deposit: Three unpatented claims of irregular shape in a N20° trending shear zone in Tertiary rhyolites

of the Datil Formation. Calcite, quartz and limonite are present in gangue.
Production: Undetermined.

7. Unnamed Manganese Locations
Location: 7/1: 33°54′13"N, 106°58′7"W (SW-1/4 Sec. 5, T5S, R1W);
7/2: 33°54′58"N, 107°14′22"W (SE-1/4 Sec. 34, T4S, R4W);
7/3: 33°53′52"N, 107°14′22"W (SE-1/4 Sec. 3, T5S, R5W);
7/4: 33°52′15"N, 107°12′54"W (SW-1/4 Sec. 13, T5S, R4W);
7/5: 33°51′28"N, 107°12′50"W (SW-1/4 Sec. 24, T5S, R4W)
Commodity: Mn
Geology: Probably are mineralized shear zones in Tertiary rhyolites of the Datil Formation.
Production: Unknown.

8. Unnamed Copper and Lead Deposit
Location: 33°51′31"N, 106°56′27"W, E-1/2 Sec. 21, T5S, R1W
Commodities: Cu, Pb
Ore Materials: Azurite, malachite.
Description of Deposit: Mineralized fault zone.
Geology: Mineralization occurs along a fracture zone in Precambrian schist.
Production: Unknown.

9. Unnamed Copper Deposit
Location: 33°42′15"N, 106°52′57"W, SW-1/4 Sec. 18, T7S New Mexico Meridian
Commodity: Cu
Ore Materials: Azurite and malachite.
Description of Deposit: Two small redbed copper deposits in N60°E striking beds.
Geology: Redbed copper deposit in the Permian Abo Formation.
Production: Unknown.

10. Unnamed Copper Deposit
Location: 33°41′32"N, 106°53′27"W, SE-1/4 Sec. 24, T7S, R1W New Mexico Meridian
Commodity: Cu
Ore Materials: Unknown.
Description of Deposit: Mineralization in fault gouge.
Geology: Mineralization along fault in the Permian Yeso Formation.
Production: Unknown.

12. Unnamed Uranium Occurrences
Location: 33°30′0"N, 107°5′55"W, NE-1/4 Sec. 25, T9S, R3W
33°43′12"N, 106°46′15"W, NE-1/4 Sec. 7, T7S, R2E
New Mexico Meridian
Commodity: U
Geology: Unknown. Locations are from USGS Map I-1327, no other information is available.
Production: Unknown.

13. Unnamed Opal Location
    Location: 34°0´00"N, 107°5´0"W, W-1/2 Sec. 29
    T9S, R2W, New Mexico Meridian (T & R location is approximate--area is unsurveyed
    Commodity: Opal
    Ore Materials: Opalized petrified wood present in unknown rock unit.

15. Tucson Spring
    Location: 33°24´25"N, 106°56´00"W, Sec. 27, T10S, R1"
    New Mexico Meridian
    Thermal spring; water temperature = 24°C

16. Victoria L.C. Co. #L
    Location: 33°24´40"N, 106°53´45"W
    Sec. 25, T10S, R1W, New Mexico Meridian
    Thermal well; water temperature is 34°C, thermal gradient is 50°/km

17. Unnamed Thermal Spring
    Location: 33°48´55"N, 106°58´35"W
    W-1/2 Sec., T6S, R1W
    Thermal well; water temperature 21°C

Mining Claims, Leases and Material Sites

For this study, the BLM office in Santa Fe, New Mexico has provided us a microfiche with up-to-date (April 1982) records of all valid patented and unpatented records and leases. We checked them very thoroughly and found no claims or leases within any of the WSAs grouped in the Armendaris GRA.

Mineral Deposits Types

Geological environments to be considered as potentially favorable for the occurrence of mineral or energy resources include: Precambrian metamorphic rocks, Paleozoic sedimentary rocks, specifically Permian redbeds, Cretaceous coal measures, fossil hydrothermal systems associated with Oligocene to Quaternary volcanism, late Tertiary valley-fill sediments, Quaternary alluvium, and active geothermal systems.

Precambrian Metamorphic Rocks

Felsic metavolcanic rocks are associated with massive sulfide deposits in Arizona (Anderson and Guilbert, 1979) from a 1.6-1.9 b.y. old belt which extends into northern New Mexico. The Proterozoic of central New Mexico also contains felsic metavolcanics but is distinctly younger (Condie and Budding, 1979) and there are no known massive sulfide deposits within it.

Paleozoic Sedimentary Rocks

Oil and gas have long been produced from the Paleozoic rocks of southeastern New Mexico, with most of the oil production coming from Permian rocks. In the GRA, potential source rocks are black marine shales of the Sandia and Mancos Formations, and the potential reservoir rocks are sandstones in the upper Madera, Abo and Yeso Formation and the Glorieta sandstone. Oil and gas are, however, unlikely to have remained trapped in significant quantities because of faulting associated with Oligocene volcanism and with Miocene to Quaternary volcanism and rifting along the Rio Grande.

Five dry wells have been drilled within the GRA (fig. 3; U.S. Geological Survey, 1981; Arnold and Hill, 1981).

Permian Redbeds

Redbed copper deposits, often containing silver, are found in Permian and Triassic rocks and are widely distributed throughout central and north-central New Mexico (LaPoint, 1974a). In the Armendaris GRA, two minor occurrences are found in the Yeso and Abo Formations in the west-central part of the GRA. Outside the GRA redbed-type copper mineralization is found in the Estey district, Oscura Mountains (Bachman, 1968) and in the Scholle district to the northeast of Socorro (LaPoint, 1974b). In the Estey district, uneconomic concentrations of malachite, azurite and lesser hematite, pyrite, bornite, chalcocite, covellite, chalcopyrite and melaconite are found mainly in arkosic channel deposits within the Bursum and Abo Formations. The copper-rich zones are 1-3 feet thick and copper minerals cover fractures, fill voids, coat detrital grains and are most abundant replacing and surrounding plant debris. In the Schollė district chalcocite replaces wood in reddish-brown sandstone and organic-rich shales below fluvial channels in the Abo Formation. In the Nacimiento region of north-central New Mexico, chalcocite, covellite, bornite, chalcopyrite and pyrite are associated with carbonaceous materials such as fossil log jams in arkosic sandstone paleochannels. The deposits occur in the Abo Formation and the Agua Zarca member of the Chinle Formation.

The redbed copper deposits of New Mexico were first studied in Lindgren et al. (1910) who favored an origin in involving hydrothermal fluids rising along faults and spreading out along permeable aquifers. More recent workers, such as LaPoint (1974a, 1974b) and Woodward et al. (1974), favor deposition from circulating groundwater in response to a local lowering of Eh. The ultimate source of the copper is considered to be Precambrian copper deposits and/or copper-enriched lithologies.

The Yeso Formation also contains abundant gypsum-rich evaporites. Fifteen miles northeast of Socorro, Weber and Kottlowski (1959) report 100-150 feet of gypsum within the Canas member. Such evaporitic sequences suggest the possibility of "sabkha"-type copper deposits being present within this formation.

Cretaceous Coal Measures

The Carthage coal deposit of the northwestern part of the GRA occurs in the terrestrial part of the Mesaverde Formation. A four to seven foot thick coal seam extends over ten square miles. This formation could underlie other parts of the GRA.

Oligocene to Quaternary Hydrothermal Deposits

The hydrothermal deposits have been described in a previous section. Hydrothermal manganese deposits are found in the northern part of the GRA. In addition, silver and gold associated with base metals, barite, fluorite, galena deposits and uranium-vanadium deposits, although not found in the GRA, do occur in the Socorro GRA to the north and in areas to the east.

Manganese deposits of the Luis Lopez district all occur along breccia zones in rhyolites of the Datil Formation and have been described by Miesch (1956), Jicha (1956) and Hewett and Fleischer (1960). The principle manganese minerals are psilomelane, pyrolusite, wad, coronadite $(Pb(Mn,Cu,Zn)_8O_{16})$, cryptomelane $(K(Mn,Zn)_8O_{16})$ and hollandite $(Ba,Mn)_8O_{16})$. Gangue minerals are calcite, anhydrite, gypsum, quartz, barite and minor fluorite. Ore produced from the district during the early 1950s typically contained Mn (50%), Cu (0.02-0.08%), Pb (0.1-4.3%), Zn (0.1-0.55%), Ba (10-13%), and, locally, up to 0.24% U_3O_8. Jicha (1956) concluded that the ores were hypogene rather than supergene in origin because: The presence of ore does not depend on topography, the ore often increases in thickness and grade with depth, blind ore bodies occur, the ore is structurally controlled, the ore contains anhydrite and unusual concentrations of base metals and tungsten, and there is a district-wide zonation of lead with the lead content increasing in a northeasterly direction. On the basis of regional studies of manganese deposits, Hewett and Fleischer (1960) concluded that the deposits were formed from hydrothermal fluids associated with late stages of volcanic activity. Similar manganese deposits lie along a N-S zone extending from Durango, Mexico to Socorro, New Mexico. In the Socorro GRA to the north, hydrothermal gold-silver deposits are present, also containing barite, fluorite, vanadinite and manganese oxides, and anomalous concentrations of copper, zinc and molybdenum. They are similar to the manganese deposits in that they occur along faults in volcanics and carry significant manganese, barite, fluorite and base metals.

Deposits of barite, fluorite, galena and sphalerite and of uranium and vanadium do not occur in the GRA but are found to the north in the Socorro GRA.

It is possible that the above types of hydrothermal deposits are associated with Tertiary volcanic activity. Elston (1978) has suggested that some major hydrothermal deposits are associated, in both space and time, with the Oligocene cauldrons. Kesler (1977) has suggested that manto fluorite deposits lie on a north- to northeast-trending belt from northern Coahuila, Mexico, through central New Mexico and are associated with alkaline volcanics and normal faulting. Damon et al. (1981) and Clark et al. (1982) also show a northeast- to north-trending belt of fluorite mineralization that goes through Socorro and the Hansonburg mining district, and a molybdenum belt which runs slightly east of the GRA and includes the Cave Creek, Nogal Peak, Questa, Urad, Henderson and Climax deposits. These belts are considered to be related to high-K calc-alkaline to alkaline volcanism of Oligocene age represented by the Datil volcanics in the GRA. They were erupted at a time when the Farallon plate was dipping at a shallow angle beneath North America.

Late Tertiary Valley-Fill Sediments

Valley-fill sediments of the Santa Fe Formation and possibly the Popotosa Formation underlie the Rio Grande valley. They probably represent a potentially favorable environment for stratabound uranium deposits. According to Hilpert (1969) the favorability for occurrence of uranium deposits in the Popotosa and Santa Fe Formations is poor at the surface and good at depth.

In order to form a uranium deposit by the agency of circulating groundwater, it is necessary to have adequate source rocks, permeable sediments and a suitable reductant. Both formations contain clasts of rhyolitic Datil volcanics and coeval rhyolitic ash. Both are probably suitable sources of uranium and Miesch (1956) reports that Datil rhyolites contain between 10 and 15 ppm eU. Both formations contain abundant sandstones and gravels (Denny, 1940) and are undoubtedly sufficiently permeable. It is not certain, however, whether adequate reductants are present within the formations to cause precipitation of uranium. Suitable reductants would be organic matter within the sediments or reducing geothermal fluids. The latter would appear as possible reductants in light of present-day and past geothermal activity in the Rio Grande rift and surroundings (Chapin et al., 1978).

Quaternary Alluvium

Quaternary alluvium represents a possible site where placer gold might be concentrated. In the Armendaris GRA, a gold occurrence of probable placer origin is present in the central part of the GRA. The gold is probably derived from hydrothermal veins in the San Mateo Mountains located to the west of the GRA.

Active Geothermal Systems

Evidence for the presence of some geothermal activity in central New Mexico is found in the form of widespread, though generally low temperature, hot springs. Factors that are favorable for the existence of substantial active geothermal systems include: The presence of a high temperature heat source, such as an underlying magma chamber, the presence of aquifers which allow large volumes of water to circulate through the hot rocks, and the presence of cap rocks which will prevent the escape of at least some of the geothermal energy to the surface.

The Armendaris GRA contains an extensive Quaternary basalt flow and the Milligan trough and San Marcial basin of the Rio Grande rift. West of the Rio Grande, the heat flow is greater than 2.5 hfu and three thermal springs (24°, 34° and 21°) are located in the area. There are no known magma chambers underlying the area but several magma chambers, at depths of 4-5 km, have been identified in the Socorro area to the north (Chapin et al., 1978). Sedimentary rocks of high primary permeability underly the Milligan trough and the San Marcial basin and high secondary permeability may be associated with the various cauldrons located within the GRA (Chapin et al., 1978) and with faulting related to the formation of the Rio Grande rift. The Popotosa Formation, which may be present in the Milligan trough and the San Marcial basin, contains claystone which could act as in impermeable cap.

The western parts of the two Devil's Backbone WSAs overlie the margin of the Milligan trough and are within the area where heat flow is greater than 2.5 hfu, but no warm springs are near its boundaries.

The Jornado del Muerto WSA lies in an area of heat flow less than 2.5 hfu. The southern boundary is within four miles of a warm spring and the southern half of the WSA lies within a Known Geothermal Resource Field (KGRF) as defined by the State of New Mexico. The entire WSA is located on a recent basalt flow.

Mineral Economics

The following is a discussion of the economics of mineral and energy production in the Armendaris GRA.

Manganese was produced from deposits within and adjoining the GRA only when artificial price supports were in effect during government stockpiling. It is likely that these small manganese deposits will never again be economic without artificial supports.

Hydrothermal gold deposits to the west of the GRA enjoyed only small production previous to 1930. There are no known hydrothermal gold deposits in the GRA and only one placer deposit.

Small, structurally controlled deposits of uranium occurring along faults in the Paleozoic sediments north of the area record little past production. There is potential for stratabound roll-front uranium deposits in the Santa Fe Formation, which either crops out or underlies much of the GRA. At this time it is unlikely that deposits would be economic, but conditions may again become favorable for uranium exploration and production.

Barite-fluorite-lead-zinc deposits and redbed copper deposits in and around the GRA are all very small and unlikely to be economic in the near future.

Several things make coal mining in the Carthage Field a difficult and uneconomic venture. The deposits are fairly small in area and the coal seams are thin. Intense folding and faulting makes the beds difficult to follow and increases the cost and difficulty of mining. All strippable resources have already been mined.

Oil and gas exploration in the past has yielded only dry wells. Although Paleozoic strata in southeastern New Mexico provide both source and reservoir rocks, it seems likely that any oil and gas that may have originally been present in the rocks is now gone due to faulting associated with the Rio Grande rifting.

Impure gypsum-bearing sediments comprise 12% of the Yeso Formation (Weber and Kottlowski, 1959). The Yeso crops out over a very small area in the northeast corner of the GRA. Gypsum of higher purity and easy access is common in central New Mexico in playa lakes and in dunes, thus the deposits within the Yeso are unlikely to be of economic value.

The Sierra County Known Geothermal Field (KGRF), located in the southeastern part of the GRA and including part of the southern WSA, contains only two thermal springs (24° and 34°C) and has heat flow of less than 2.5 hfu. It does not seem likely that this field could become a power producer and its distance from population centers make it unlikely as a heating source. The other isolated thermal spring in the area has even cooler temperatures (21°C) and also does not seem likely to become a producer of heat and power.

Basalt and rhyolite, sand and gravel, and limestone (especially the San Andres Formation) are present in the GRA and are unlikely to be useful in local building industry. Bentonite, formed from diagenesis of tuffaceous beds, is found locally in the Santa Fe Formation and could be suitable for use in drilling mud (New Mexico Bureau of Mines and Mineral Resources, 1965).

LAND CLASSIFICATION FOR GEM RESOURCES POTENTIAL

The area covered by the GRA and the WSAs are classified with respect to their resources potential and level of confidence according to the schemes provided by the Bureau of Land Management (attachment 9, dated 3/24/82). The data on which this classification is based is presented in a preceding part of this report. The potential resources are divided into locateable, leaseable and saleable categories.

Locateable Resources

Potential locateable resources include metallic minerals, uranium and thorium, and non-metallic minerals.

Metallic Minerals

Potentially favorable environments for the occurrence of metallic minerals within the Armendaris GRA include: Stratabound copper ± silver in Permian redbeds; structurally controlled hydrothermal deposits of manganese (with minor Cu, Pb, Zn, W, Ba and U), gold (with minor Ag, Cu and Pb) and lead ± zinc (with barite and fluorite), all probably associated with Oligocene volcanic cauldrons; and placer gold deposits.

1. Stratabound copper ± silver deposits. Only two minor occurrences with no history of production are present within the GRA, but occurrences and mines are widespread in central and north-central New Mexico (LaPoint, 1974a). Geologically, Permian redbeds are moderately favorable for the occurrence of this type of deposit, and the GRA is assigned a moderate favorability (3) at a confidence level of B.

   There are no outcroppings of Permian sediments in the WSAs and they are considered unfavorable for the occurrence of redbed copper.

2. Hydrothermal manganese deposits. In the GRA and just to the north of the GRA, mines produced several thousand tons of manganese ore with various byproducts during the 1950s, at a time of government stockpiling. The mines are unlikely to be reopened under present circumstances, but could become producers if foreign supplies of manganese were cut off. The GRA lies within a zone extending from Durango, Mexico, to Socorro in which similar volcanic-hosted manganese deposits occur (Hewett and Fleischer, 1960). The volcanic rocks in the northwestern part of the GRA are favorable for the occurrence of hydrothermal

manganese deposits. This area coincides with several cauldrons with which the hydrothermal deposits may be associated. The GRA is assigned a high favorability (4) at a confidence level of D.

The Devil´s Backbone WSAs contain Datil volcanics and are close to three cauldron margins. One manganese occurrence is within a mile of a WSA boundary but there has been no production. The area was intensely prospected during the 1940s and 1950s, therefore the Devil´s Backbone WSAs are assigned a low favorability (2) at a confidence level of C (fig. 5). The southern WSA is located many tens of miles away from any manganese occurrences or outcroppings of Datil volcanics and is considered unfavorable.

3. Hydrothermal gold deposits. There has been minor production of gold with some silver, copper and lead from mines in the San Mateo Mountains to the west of the GRA. The mineralization is associated with Oligocene cauldrons, several of which are present in the northwestern part of the GRA. The GRA lies close to a mid-Tertiary molybdenum porphyry belt extending from west Texas to Colorado (Damon et al., 1981; Clark et al., 1982), but there are no known disseminated deposits in this area. However, such deposits could underlie some of the cauldrons in the GRA. The GRA is assigned a moderate favorability (3) at a confidence level of C.

The Devil´s Backbone WSAs contain Datil volcanics and are close to cauldron edges. The WSAs do not contain any

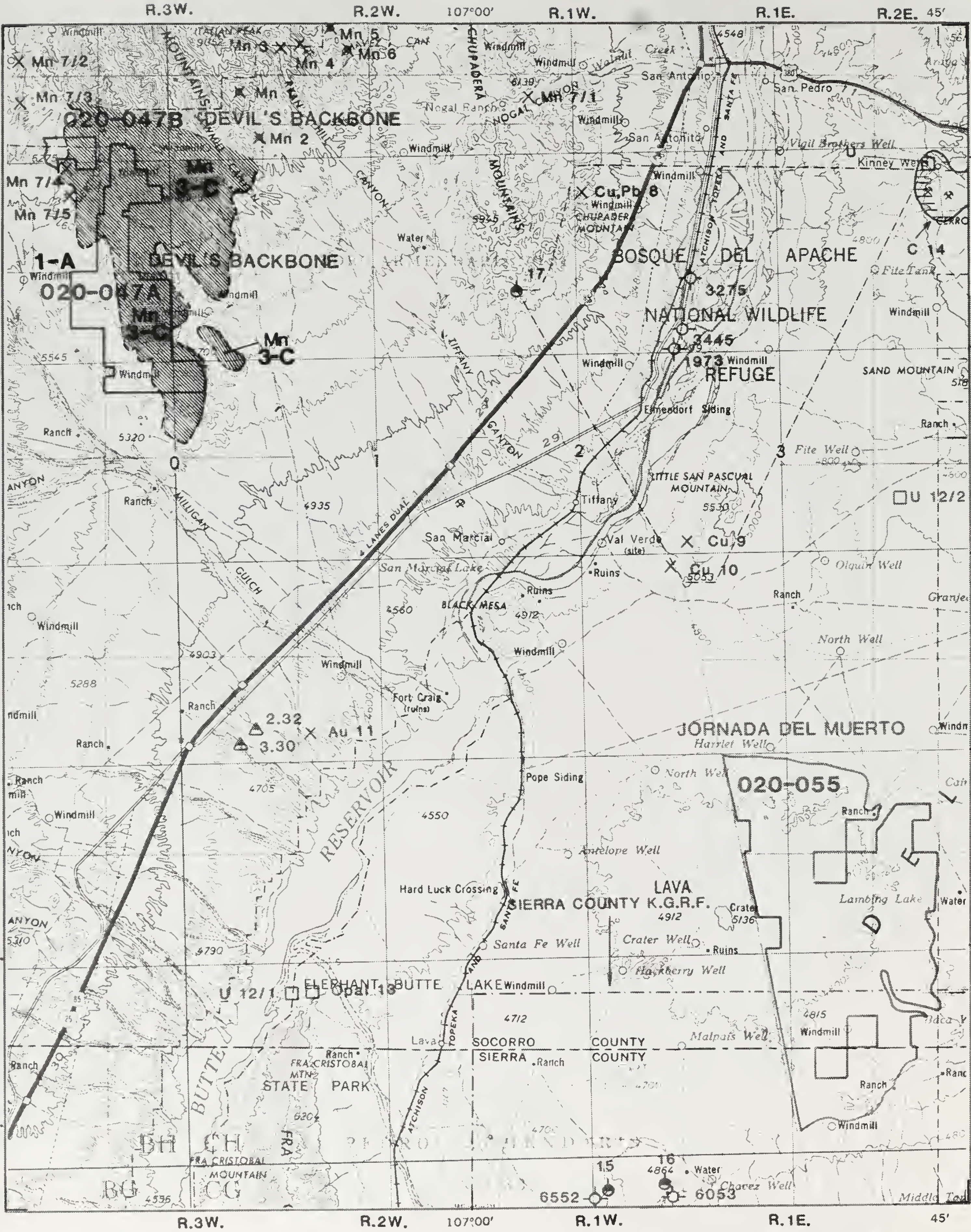


FIG. 5 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR HYDROTHERMAL MANGANESE RESOURCES OF THE ARMANDARIS AREA, NEW MEXICO.

known gold occurrences and are assigned a low favorability (2) at a confidence level of B (fig. 6). The Jornada del Muerto WSA, located far from cauldrons and outcroppings of Datil volcanic rocks, is considered unfavorable for this type of deposit.

4. Hydrothermal lead ± zinc deposits. No occurrences are known in the GRA, but there are occurrences and mines immediately to the southeast of the GRA in the San Andres Mountains and to the east in the Hansonburg mining district. These deposits occur along faults in the Precambrian basement and in Paleozoic limestones and are invariably associated with barite and fluorite. The GRA lies within a zone extending from Coahuila to New Mexico (Kesler, 1977) in which similar deposits occur in association with alkaline volcanism. The GRA is assigned a moderate favorability (3) at a confidence level of C.

   None of the three WSAs contain outcroppings of Precambrian or Paleozoic sediments and are considered unfavorable for this type of deposit.

5. Placer gold. A smaller placer gold deposit is located near Elephant Butte Reservoir and appears to be within the Santa Fe Formation. Hydrothermal gold occurs in the San Mateo Mountains to the west and placer gold may have accumulated elsewhere in Tertiary valley-fill sediments and in Quaternary alluvium in the Milligan trough and the San Marcial basin. The GRA and the Devil's Backbone WSAs are assigned a low favorability (2) at a confidence level of B. The Jornada del Muerto WSA is considered unfavorable (1) at a confidence level of D.

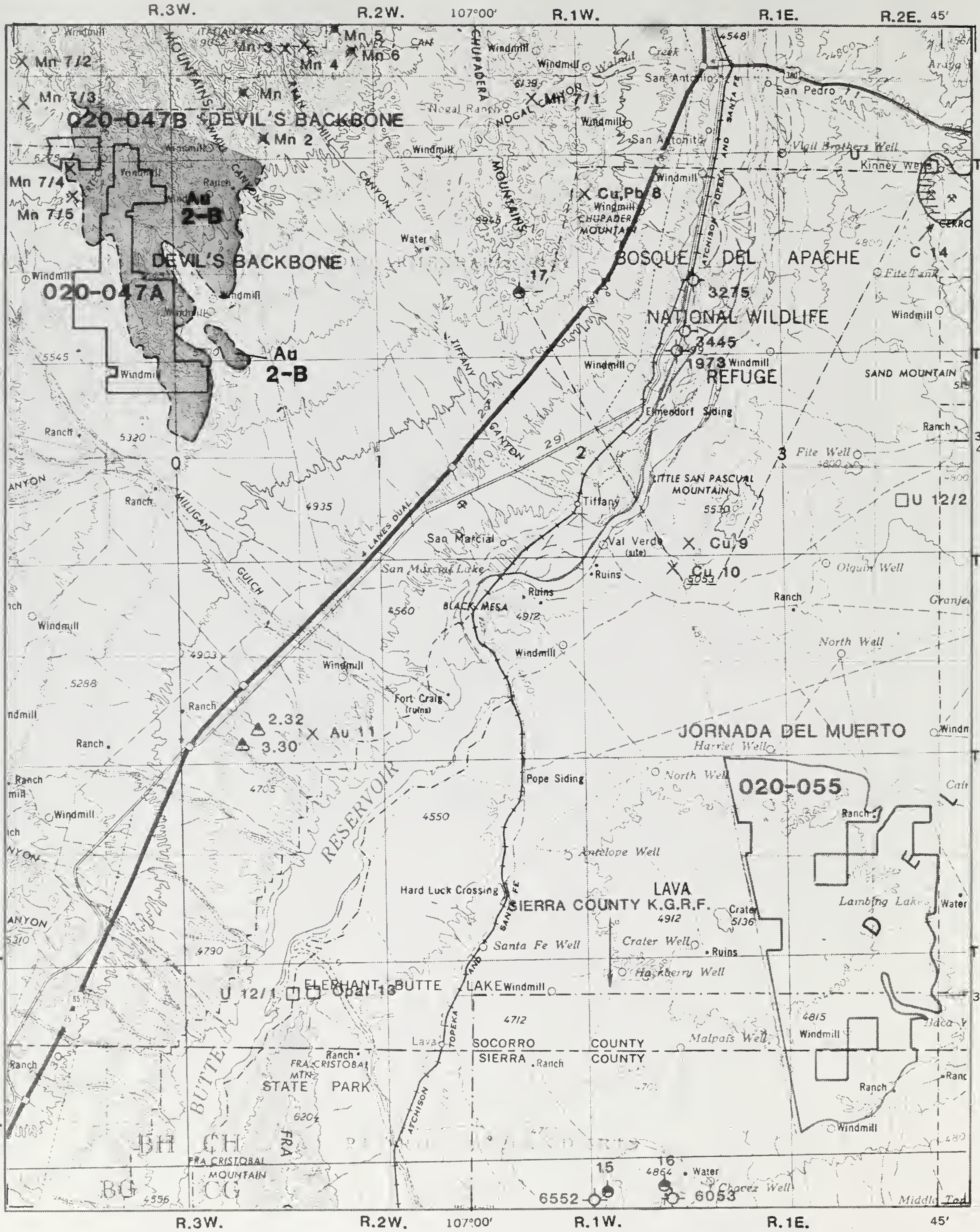


FIG.6 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR HYDROTHERMAL GOLD RESOURCES OF THE ARMENDARIS AREA, NEW MEXICO.

Uranium and Thorium

A potentially favorable environment for uranium in the Armendaris GRA is stratabound uranium in the later Tertiary valley-fill sediments. There are no known favorable environments for thorium.

No known uranium occurrences of this type are known in the GRA. However, the Santa Fe Formation could be host for roll-front type stratabound uranium deposits because it contains uranium-rich volcanic source rocks, permeable horizons, and may contain reactants such as organic matter or reducing geothermal fluids. Therefore, the GRA is assigned a moderate favorability (3) at a confidence level of B.

The Devil´s Backbone WSAs may be partly underlain by the Santa Fe Formation but it is likely to be very thick, and are assigned a low favorability (2) at a confidence level of D. The Jornada del Muerto WSA, largely underlain by basalt, is not considered favorable (1) for this kind of deposit at a confidence level of D.

Nonmetallic Minerals

Potentially favorable environments for the occurrence of nonmetallic minerals within the Armendaris GRA include: Hydrothermal barite-fluorite (with lead ± zinc) deposits possibly related to alkaline volcanism; opal in Quaternary gravels; and hydrothermal kaolin deposits resulting from the alteration of Tertiary rhyolitic rocks, as occurs in the Socorro Peak to the north.

1. Hydrothermal barite-fluorite deposits. No occurrences are known in the GRA, but there are numerous occurrences and mines immediately to the southeast of the GRA in the San Andres Mountains and to the east in the Hansonburg mining district.

These deposits occur along faults in the Precambrian basement and in the Paleozoic limestones and are generally associated with galena. The GRA lies within a belt extending from Coahuila to New Mexico (Kesler, 1977) in which similar deposits are found and are associated with alkaline volcanism. The GRA is assigned a moderate favorability (3) at a confidence level of C.

The Jornada del Muerto WSA is blanketed by Quaternary basalt and is not considered favorable (1) at a confidence level of D. The Devil´s Backbone WSAs lie far from the deposits of the San Andres Mountains and are also considered unfavorable (1) at a confidence level of D.

2. Opal. Opalized wood is reported to occur in the southern part of the GRA. Nothing is known about this occurrence except its location. Somewhat arbitrarily, the GRA is assigned a moderate favorability (3) at a confidence level of A.

   The Jornada del Muerto WSA is blanketed by Quaternary basalts and is not favorable (1) at a confidence level of D. The two Devil´s Backbone WSAs, possibly underlain by the Santa Fe Formation alluvium and blanketed by a more recent alluvium is arbitrarily assigned a low favorability (2) at a confidence level of A.

3. Kaolin. At Socorro Peak to the north of the GRA, rhyolite has been hydrothermally altered to kaolin. Hydrothermal alteration of the Datil volcanics within the GRA and northern WSAs could have caused kaolinization.

   The GRA is assigned a low favorability (2) at a confidence level of B, as are the Devil´s Backbone WSAs (fig. 8). The

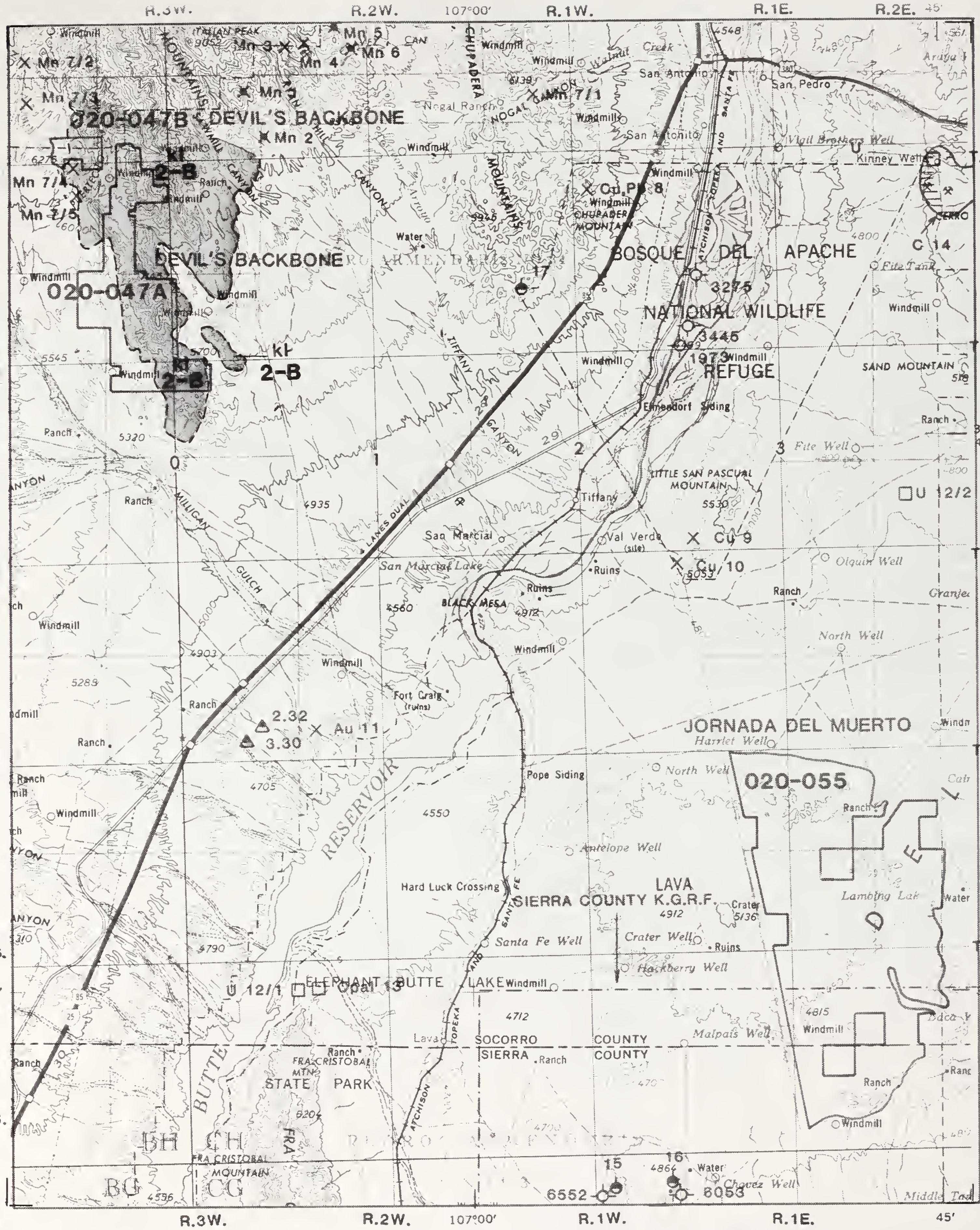


FIG.8 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR HYDROTHERMAL KAOLIN RESOURCES OF THE ARMENDARIS AREA, NEW MEXICO.

Jornada del Muerto WSA is not considered favorable (1) for this type of deposit at a confidence level of D.

Leaseable Resources

Potential leaseable resources include oil and gas, geothermal, gypsum and coal.

Oil and Gas

Five oil exploration wells were drilled within the GRA and all were dry. Paleozoic formations underlying the area include adequate source and reservoir rocks, but faulting associated with cauldron formation and Rio Grande rifting probably preclude entrapment of oil and gas in significant quantities. The GRA and Jornada del Muerto WSA are assigned a low favorability (2) at a confidence level of C (fig. 7).

Geothermal

In the Armendaris GRA the presence of three warm springs and, in the west, heat flow greater than 2.5 hfu suggests that a somewhat anomalous heat source underlies the area. There is no evidence, however, of underlying magma chambers as in the Socorro KGRA to the north. Adequate reservoir and cap rocks may be present in the Milligan trough and the San Marcial basin. The southeastern part of the GRA has been designated as a KGRF by the State of New Mexico. The GRA is assigned a low favorability (2) at a confidence level of B, as is the Jornada del Muerto WSA. The two Devil´s Backbone WSAs are considered unfavorable.

Gypsum

Gypsum-rich sediments occur in the Torres Member of the Yeso Formation, which crops out only in the northeastern corner of the GRA. Any deposits

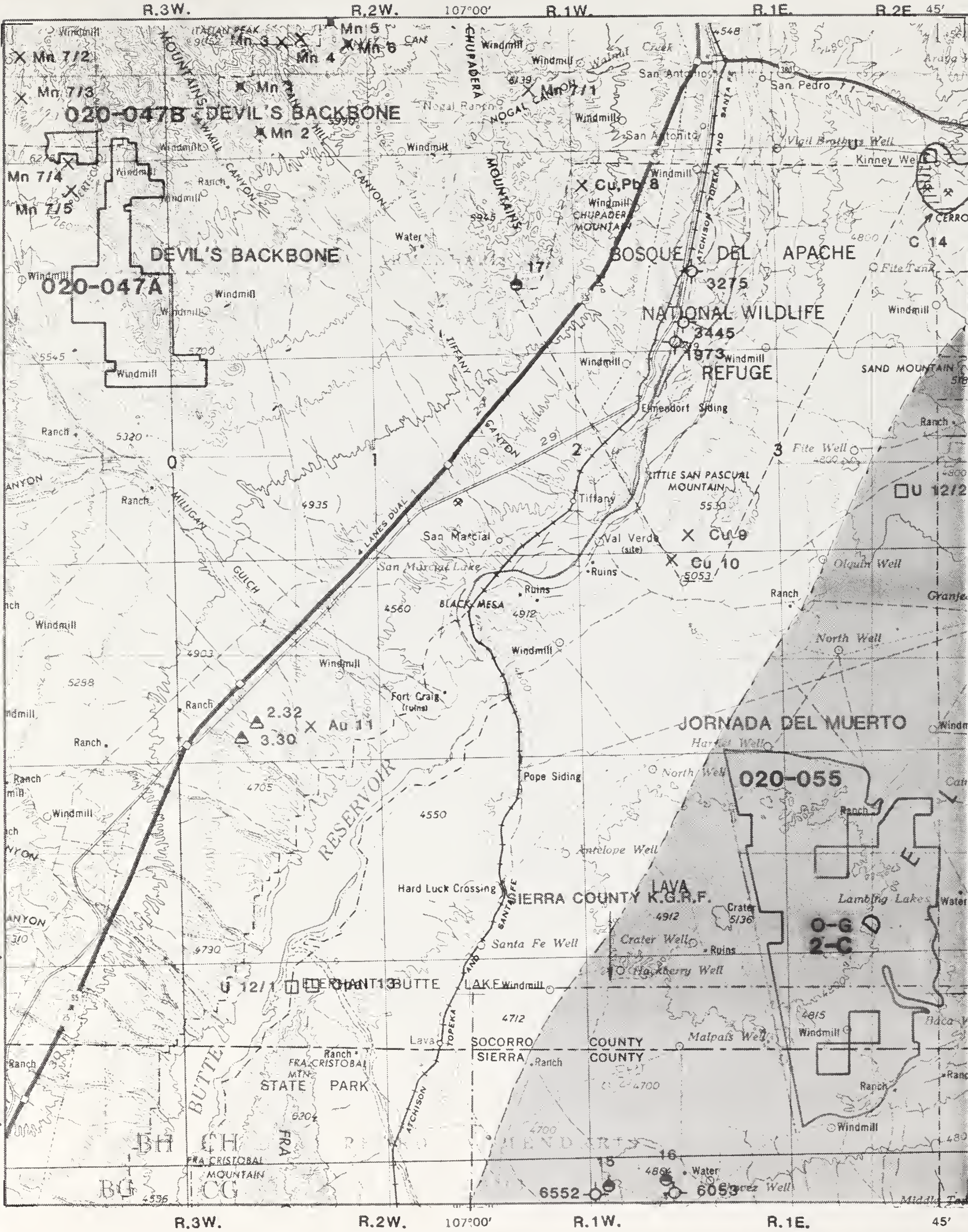


FIG.7 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR OIL AND GAS RESOURCES OF THE ARMENDARIS AREA, NEW MEXICO.

present are unlikely to be economic because of the availability of purer deposits in playa lakes and dune sands in other parts of central New Mexico. The GRA is assigned a low favorability (2) at a confidence level of C. Permian rocks do not crop out in any of the WSAs which are classified as unfavorable.

Coal

A four to seven foot coal seam extends under several square miles in the Carthage field. Readily strippable coal has been removed and the coal beds are folded and faulted increasing the difficulty of underground extraction. The GRA is assigned a moderate favorability (3) at a confidence level of C. Coal seams do not crop out in the three WSAs, which are assigned to an unfavorable class (1) at a confidence level of D.

Saleable Resources

Potential saleable resources within the GRA include basalt and rhyolite for crushed rock, sand and gravel, limestone and bentonite.

Crushed Rock

Quaternary basalt and Oligocene rhyolite are found in the GRA and could be crushed for use in local construction industry. However, the absence of important population centers in the GRA makes it less likely that the materials would be utilized. The GRA is assigned a low favorability (2) at a confidence level of C. The WSAs are partly underlain by Datil volcanics or basalt and are also assigned a low favorability (2) at a confidence level of C (fig. 9).

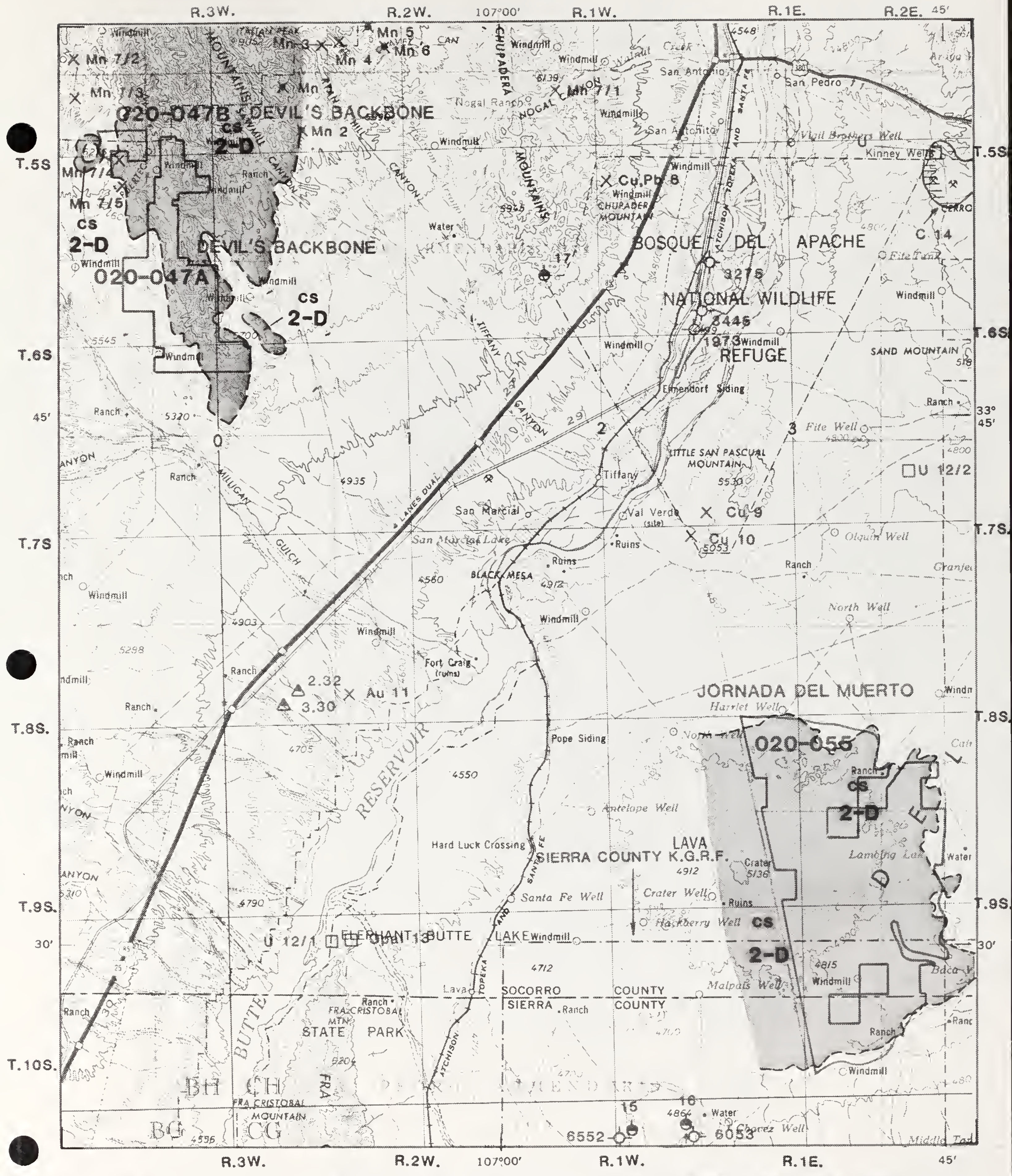


FIG.9 FAVORABILITY POTENTIAL AND LEVEL OF CONFIDENCE MAP FOR CRUSHED ROCK RESOURCES OF THE ARMENDARIS AREA, NEW MEXICO.

Sand and Gravel

Sand and gravel occur in the Santa Fe Formation and in Quaternary alluvium along the Rio Grande and could be useful in local construction industry. The absence of important population centers in the GRA, however, makes it less likely that the material would be utilized. The GRA is assigned a low favorability (2) at a confidence level of C. The Devil's Backbone WSA's are partly underlain by alluvium but they are distant from population centers and are considered unfavorable (1) at a confidence level of D. The Jornada del Muerto WSA is largely underlain by basalt and is assigned to an unfavorable class (1) at a confidence level of D.

Limestone

The San Andres limestone crops out only in the northeast corner of the GRA but it is widespread to the north of the GRA. It is probably of sufficient purity for use as agricultural lime or in manufacture of cement. The GRA is assigned a low favorability (2) at a confidence level of D. The WSAs contain no limestone outcrops and are assigned to an unfavorable class (1) at a confidence level of D.

Bentonite

Bentonite is reported as beds in the Santa Fe Formation and might be used in drilling mud if a local market for it exists. The GRA is assigned a low favorability (2) at a confidence level of B. The WSAs do not contain outcrops of the Santa Fe Formation and are considered unfavorable (1) at a confidence level of D.

RECOMMENDATIONS FOR ADDITIONAL WORK

The recommendations presented in this section pertain to the three WSAs within the Armendaris GRA. They describe proposed work that would allow a more specific definition of mineral potential for the various mineral deposit types for which the geologic environment appears favorable.

The Devil´s Backbone WSAs

The WSAs overlie tuffaceous Datil volcanics and Quaternary alluvium. The Datil volcanics could host structurally controlled hydrothermal deposits of precious metals and base metals, possibly associated with nearby cauldrons, and placer gold deposits could be located in the alluvium.

Hydrothermal Deposits

In order to assess the potential for hydrothermal deposits in the Datil volcanics it is recommended that:

1. The volcanics be field checked for evidence of intense and extensive hydrothermal alteration and evidence for the presence of low grade, possibly disseminated gold/silver mineralization. Such occurrences could have been missed during earlier prospecting.
2. Selected samples should be studied petrographically to check the nature of hydrothermal alteration and to select possible samples for assay.

Placer Gold Deposits

Hydrothermal gold deposits are found in the Chupadera Mountains to the north and in the San Mateo Mountains to the west of the WSAs. The alluvium should be field checked for any evidence suggesting placer operations.

The Jornada del Muerto WSA

This WSA lies entirely over Quaternary basalt and no additional work is recommended.

REFERENCES

Anderson, P., and Guilbert, J.M., 1979, The Precambrian massive sulfide deposits of Arizona -- a distinct metallogenic epoch and province, in Drew, J.D., ed., Papers on mineral deposits of western North America: Nevada Bureau of Mines and Geology Report 33, p. 39-48.

Armstrong, A.K., 1958, The Mississippian of west-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 5, 49 p.

Arnold, E.C., and Hill, G.M., 1981, New Mexico's energy resources '80: New Mexico Bureau of Mines and Mineral Resources Circular 181, 59 p.

Bachman, G.O., 1968, Geology of the Mockingbird Gap quadrangle, Lincoln and Socorro Counties, New Mesico: U.S. Geological Survey Professional Paper 594-J, 43 p.

Bachman, G.O., and Harbour, R.L., 1970, Geologic map of the northern part of the San Andres Mountains, central New Mexico: U.S. Geological Survey Miscellaneous Investigation Series Map I-600, scale 1:500,000.

Bachman, G.O., and Stotelmeyer, R.B., 1967, Mineral appraisal of the Bosque del Apache National Wildlife Refuge, Socorro County, New Mexico: U.S. Geological Survey Bulletin 1260-B, 9 p.

Balbridge, W.S., 1979, Petrology and petrogenesis of Plio-Pleistocene basaltic rocks from the central Rio Grande rift, New Mexico, and their relation to rift structures, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 323-353.

Brown, L.D., Krumhansl, P.A., Chapin, C.E., Sanford, A.R., Cook, F.A., Kaufman, S., Oliver, J.E., and Schilt, F.S., 1979, COCORP seismic reflection studies of the Rio Grande rift, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 169-184.

Burchfiel, B.C., 1979, Geological history of the central western United States, in Ridge, J.D., ed., Papers on mineral deposits in western North America, IAGOD Symposium, v. 2: Nevada Bureau of Mines and Geology Report 33, p. 1-12.

Chapin, C.E., Elston, W.E., and James, H.L., eds., 1978 Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico, 1978: New Mexico Geological Society Special Publication 7, 149 p.

Clark, K.F., Foster, C.T., and Damon, P.E., 1982, Cenozoic mineral deposits and subduction related magmatic arcs in Mexico: Geological Society of American Bulletin, v. 93, p. 533-544.

Coney, P.J., and Reynolds, S.J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403-406.

Condie, K.C., and Budding, A.J., 1979, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 35, 58 p.

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1981, Age trends of igneous activity in relation to metallogenesis in the southern Cordillera, in Dickinson, R.W., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Tucson, Arizona Geological Society Digest, v. 14, p. 137-154.

Dane, C.H., and Bachman, G.O., 1965, Geologic map of New Mexico: U.S. Geological Survey, scale 1:500,000.

Denny, C.S., 1940, Tertiary geology of the San Acacia area, New Mexico: Journal of Geology, v. 48, p. 73-106.

Dickinson, W.R., 1981, Plate tectonic evolution of the southern Cordillera, in Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 113-135.

Elston, W.E., 1978, Mid-Tertiary cauldrons and their relationship to mineral resources, southwestern New Mexico: A brief review: New Mexico Geological Society Special Publication 7, p. 107-113.

Elston, W.E., and Bornhorst, T.J., 1979, The Rio Grande rift in context of regional post-40 m.y. volcanic and tectonic events, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 416-438.

Fenneman, N.M., 1928, Physiographic divisions of the United States: Annals of the Association of American Geographers, v. 28, p. 261-353.

Haigler, L.B., and Sutherland, H.L., 1965, Reported occurrences of selected minerals in New Mexico: U.S. Geological Survey Mineral Investigations Resource Map MR-45, scale 1:500,000.

Hewett, D.F., and Fleischer, M., 1960, Deposits of manganese oxides: Economic Geology, v. 55, p. 1-55.

Hilpert, L.S., 1969, Uranium resources of northwestern New Mexico: U.S. Geological Survey Professional Paper 603, 166 p.

Jicha, H.L., Jr., 1956, Manganese deposits of the Luis Lopez district, Socorro County, New Mexico, in Reyna, J.G., ed., Symposium sobre yacimientos de manganeso [Symposium on deposits of manganese]: 20th International Geological Congress, v. 3, p. 213-253.

Keller, G.R., Braile, L.W., and Schule, J.W., 1979, Regional crustal structure of the Rio Grande rift from surface wave dispersion measurements, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 115-126.

Kelley, V.C., 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 33, 59 p.

___________, 1979, Tectonics, middle Rio Grande rift, New Mexico, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 57-70.

Kesler, S.E., 1977, Geochemistry of manto fluorite deposits, northern Coahuila, Mexico: Economic Geology, v. 72, p. 204-218.

Kottlowski, F.E., 1960, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources Bulletin 66, 187 p.

___________, 1963, Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 79, 100 p.

Kottlowski, F.E., Flower, R.H., Thompson, M.L., and Foster, R.W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 1, 132 p.

LaPoint, D.J., 1974a, Possible source areas for sandstone copper deposits in northern New Mexico: New Mexico Geological Society, 25th Field Conference, p. 305-308.

___________, 1974b, Genesis of sandstone-type copper deposits at the Scholle district, central New Mexico (abst.): Geological Society of America, Abstracts with Programs, v. 6, p. 451-452.

Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Lipman, P.W., 1981, Volcano-tectonic setting of Tertiary ore deposits, southern Rocky Mountains, in Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, p. 199-214.

Miesch, A.T., 1956, Geology of the Luis Lopez manganese district, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 38, 29 p.

New Mexico Bureau of Mines and Mineral Resources, U.S. Geological Survey, State Engineer of New Mexico, New Mexico Oil Conservation Commission, and U.S. Bureau of Mines, 1965, Mineral and water resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 87, 437 p.

Olsen, K.H., Keller, G.R., and Stewart, J.N., 1979, Crustal structure along the Rio Grande rift from seismic refraction profiles, in Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 115-126.

Reilinger, R.E., Brown, L.D., Oliver, J.E., and York, J.E., 1979, Recent vertical crustal movements from leveling observations in the vicinity of the Rio Grande rift, _in_ Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 223-236.

Sanford, A.R., Olsen, K.H., and Gaksha, L.H., 1979, Seismicity of the Rio Grande rift, _in_ Riecker, R.E., ed., Rio Grande rift: Tectonics and magmatism: American Geophysical Union, p. 223-236.

Titley, S.R., 1961, Genesis and control of the Linchburg ore body, Socorro County, New Mexico: Economic Geology, v. 56, p. 695-722.

U.S. Geological Survey, 1981a, CRIB Mineral Resources File 12, Records 414, 419, 446, 460, 465, p. 745-749, 759-761, 823-825, 853-854.

U.S. Geological Survey, 1981b, Energy resources of New Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1327, scale 1:500,000.

Weber, R.H., and Kottlowski, F.E., 1959, Gypsum resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 6, 68 p.

Woodward, L.A., Kaufman, W.H., and Schumacher, D.L., 1974, Sandstone copper deposits of the Nacimiento region, New Mexico: New Mexico Geological Society Guidebook, 25th Field Conference, p. 295-299.