Mineral Resources of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, Lincoln County, New Mexico

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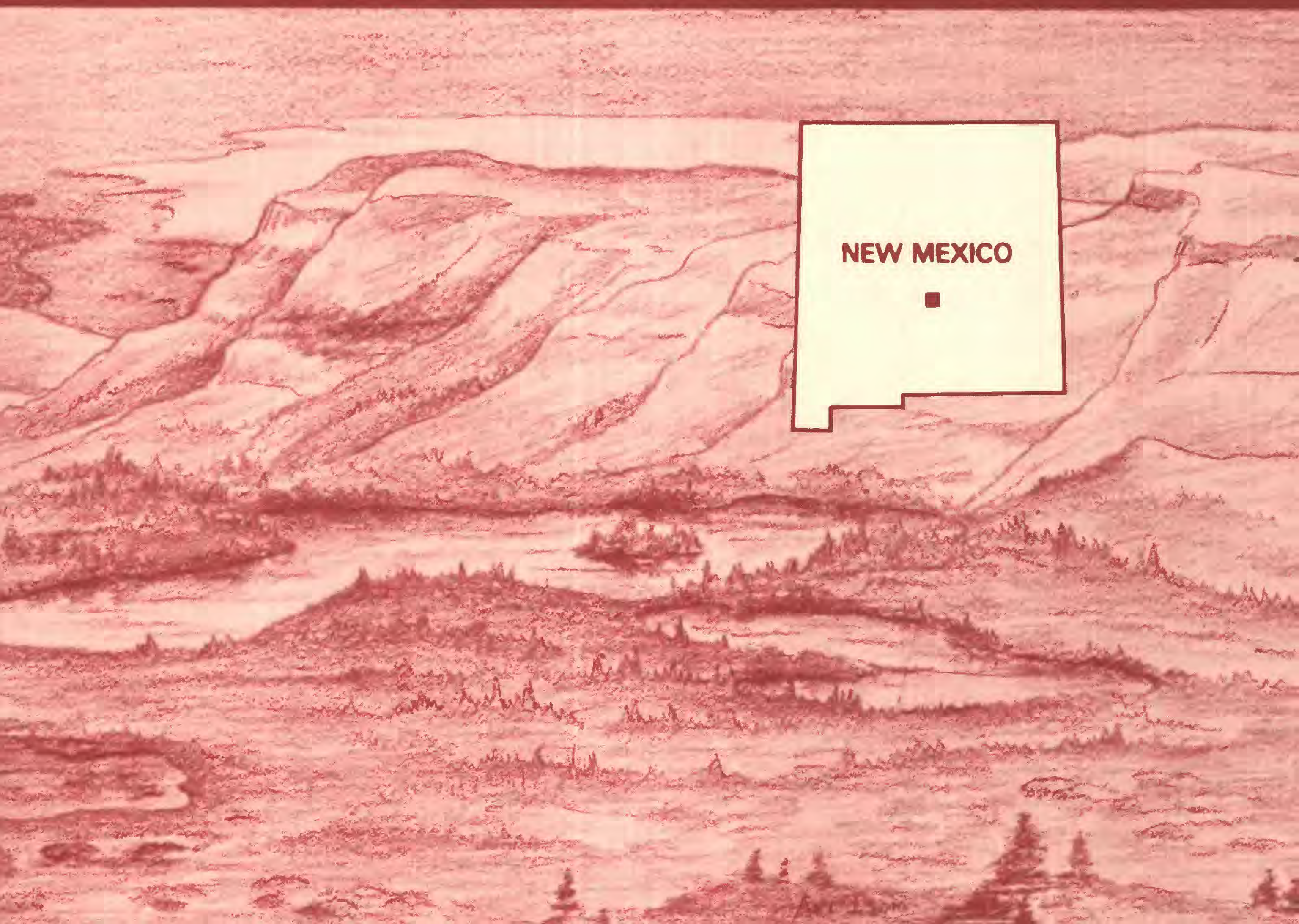

Chapter E

Mineral Resources of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, Lincoln County, New Mexico

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MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
WEST-CENTRAL NEW MEXICO

DEPARTMENT OF THE INTERIOR
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of parts of the Little Black Peak (NM-060-109) and Carrizozo Lava Flow (NM-060-110) Wilderness Study Areas, Lincoln County, New Mexico.

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Mineral Resources of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, Lincoln County, New Mexico

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SUMMARY

Abstract

From 1985 to 1987 the U.S. Bureau of Mines and the U.S. Geological Survey conducted studies to appraise the identified mineral resources (known) and mineral resource potential (undiscovered) of the Little Black Peak (NM-060-109) and Carrizozo Lava Flow (NM-060-110) Wilderness Study Areas, Lincoln County, south-central New Mexico. A combined 24,249 acres were assessed. Both study areas have mainly Quaternary (see geologic time chart in the "Appendix") basalt flows (Carrizozo lava flows) exposed at the surface. The flows overlie an eastward to northward dipping section of Pennsylvanian to Cretaceous age sedimentary rocks. The only identified resource is the lava of the basalt flows which can be used for road metal, construction material, and decorative stone. The basalt is classed as an inferred subeconomic resource, but it is not likely to be developed due to its remote location distant from markets. A low resource potential was assessed for part of the Little Black Peak study area for undiscovered uranium associated with an alkaline Tertiary(?) intrusion. Both study areas were assessed a low resource potential for undiscovered sediment-hosted uranium and copper, oil, gas, coal, and geothermal energy, and moderate mineral resource potential for undiscovered gypsum and salt in Permian evaporites. Two contiguous aeromagnetic anomalies occur beneath the basalt of the study areas. Although the cause of the anomalies is not known, they may be due to one or more concealed Tertiary(?) intrusions; the mineral resource potential associated with the anomalies is unknown.

Manuscript approved for publication, October 7, 1988.

Character and Setting

At the request of the U.S. Bureau of Land Management, the U.S. Bureau of Mines and the U.S. Geological Survey conducted investigations to appraise the identified mineral resources and to assess the mineral resource potential of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas. The study areas cover 24,249 acres in south-central New Mexico in the western part of Lincoln County (figs. 1, 2). In this report, the study areas are called the "wilderness study areas" or the "study areas." The study areas lie approximately 60 mi (miles) southeast of Socorro, 80 mi northwest of Roswell, and 4 mi northwest of the town of Carrizozo. Relief is low in both areas, with a maximum change in elevation of 425 and 565 ft (feet), respectively, in the Little Black Peak and Carrizozo Lava Flow study areas. Both areas are accessible from U.S. Highway 380, which divides the two areas, and from dirt roads which parallel most of the boundaries. The New Mexico Valley of Fires State Park is located along the eastern flanks of the study areas along Highway 380 (fig. 1; pl. 1).

The study areas are underlain by sedimentary rocks of the Pennsylvanian lower part of the Magdalena Group, the Permian Bursum Formation of Magdalena Group, Abo, Yeso, San Andres, and Bernal Formations, the Triassic Santa Rosa and Chinle Formations of Dockum Group, the Cretaceous Dakota Sandstone and Mancos Shale, an intrusive trachyte of probable Tertiary age, and the Quaternary basalt of the Carrizozo lava flow (see geologic time chart in the "Appendix" of this report). The most prominent geological

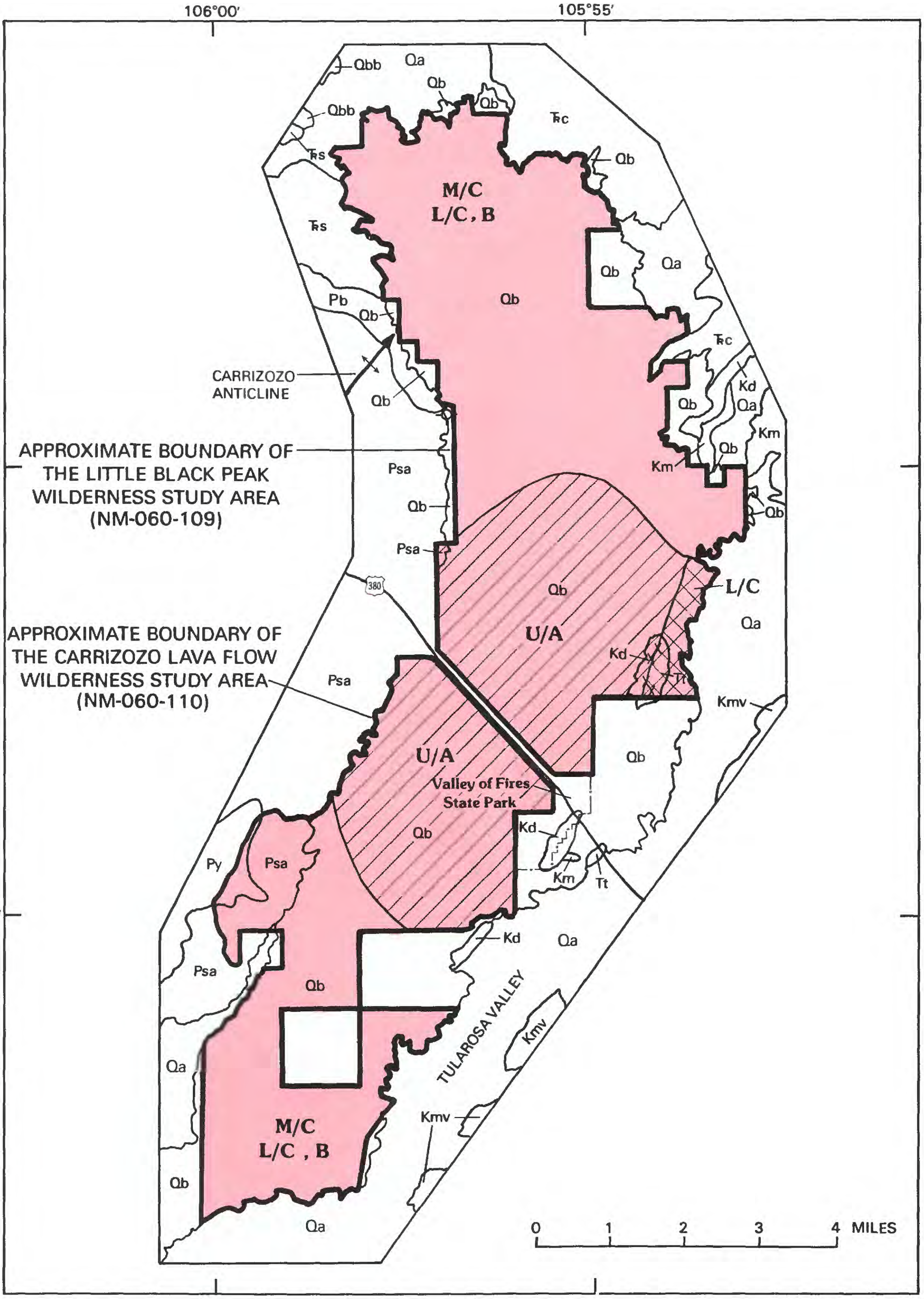

Figure 1 (above and facing page). Summary map showing mineral resource potential and generalized geology of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, Lincoln County, New Mexico (geology modified from Smith, 1964; Weber, 1964).

EXPLANATION OF IDENTIFIED RESOURCES AND MINERAL RESOURCE POTENTIAL

The Carrizozo lava flows (Qc) are an inferred subeconomic resource of lava in both study areas

Symbol	Explanation
M/C	**Geologic terrane having moderate mineral resource potential for the nonmetallic commodities, gypsum and salt, at certainty level C**—Applies to all of both study areas
L/C,B	**Geologic terrane having low mineral resource potential for oil and gas, at certainty level C, and for coal and geothermal sources, at certainty level B**—Applies to all of both study areas
L/C	**Geologic terrane having low mineral resource potential for uranium associated with Tertiary(?) trachyte, at certainty level C**—Applies to southeastern part of Little Black Peak Wilderness Study Area
L/B	**Geologic terrane having low mineral resource potential for sediment-hosted copper and uranium, at certainty level B**—Applies to all of both study areas
U/A	**Geologic terrane having unknown mineral resource potential associated with aeromagnetic anomalies, at certainty level A**—Applies to southern part of the Little Black Peak Wilderness Study Area and northern part of the Carrizozo Lava Flow Wilderness Study Area

Levels of certainty

Level	Description
A	**Available information is not adequate for determination of the level of mineral resource potential**
B	**Available information suggests the level of mineral resource potential**
C	**Available information gives a good indication of the level of mineral resource potential**

DESCRIPTION OF MAP UNITS

Symbol	Unit
Qa	**Alluvium (Quaternary)**
Qb	**Carrizozo lava flows (Quaternary)**
Qbb	**Broken Back lava flow (Quaternary)**
Tt	**Trachyte (Tertiary?)**
Kmv	**Mesaverde Group (Cretaceous)**
Km	**Mancos Shale (Cretaceous)**
Kd	**Dakota Sandstone (Cretaceous)**
TRc	**Chinle Formation (Triassic)**
TRs	**Santa Rosa Formation (Triassic)**
Pb	**Bernal Formation (Permian)**
Psa	**San Andres Formation (Permian)**
Py	**Yeso Formation (Permian)**
———	Contact
(line symbol)	**Anticline, Showing direction of plunge**
X	**Prospect**
(symbol)	**Drill hole**

and physiographic feature of both study areas is the Carrizozo lava flows. The Little Black Peak study area has mostly basalt exposed at the surface with only local outcroppings of the San Andres and Santa Rosa Formations, Dakota Sandstone, and the trachyte. The Carrizozo Lava Flow study area also has chiefly basalt at the surface but also contains significant outcroppings of the Yeso and San Andres Formations in the southwestern part.

Resources

The only identified resource in either study area is inferred subeconomic resources of the Carrizozo lava flow, the rock of which can be used for road metal, construction material, or decorative stone. No mines are known to be present in either study area and prospects are present at only one locality in the Little Black Peak study area. The prospects consist of uranium exploration trenches dug along the contact zone between the Dakota Sandstone and trachyte where these units are exposed in a kipuka (outcrop island) within the basalt of the Carrizozo flows. The mineral resource potential for undiscovered uranium associated with the trachyte is assessed as low with a certainty level of C.

Two aeromagnetic anomalies beneath the northern part of the Carrizozo Lava Flow area and the southern part of the Little Black Peak area may indicate the existence of either Quaternary basaltic intrusions beneath and of the same age as the Carrizozo flows, or one or more intrusions of Tertiary(?) age. Elsewhere in the Carrizozo region, Tertiary intrusive rocks are associated with iron, gold, silver, zinc, copper, fluorspar, molybdenum, and rare-earth elements. There are no other data upon which to evaluate the rocks causing the magnetic anomalies, and the associated mineral resource potential can only be assessed as unknown with certainty level A.

The Pennsylvanian to Cretaceous sedimentary formations that underlie both study areas are known to host redbed copper and sandstone uranium deposits elsewhere in New Mexico. Although these rocks represent a permissive environment such deposits are not known in the Carrizozo region, and the mineral resource potential for undiscovered sediment-hosted copper and uranium is low with a certainty level of B. The Permian Yeso and San Andres Formations underlying both study areas contain evaporites, and both areas are assessed as having a moderate mineral resource potential for undiscovered gypsum and salt with a certainty level of C.

On the basis of the results of previous test drilling in the region, the energy resource potential for oil and gas in both study areas is low with a certainty level of C. The most favorable stratigraphic units for hosting oil and gas are the Yeso and San Andres Formations and the Dakota Sandstone. Although the Sierra Blanca coal field lies immediately east of the study area, the Mesaverde Formation which hosts the coal is not present beneath the study areas and the resource potential for coal in the sedimentary rocks known to occur beneath the study areas is assessed as low with a certainty level of B. On the basis of the lack of hot springs and a low heat flow for the Carrizozo area, the resource potential for geothermal energy resources is low in both study areas with a certainty level of B.

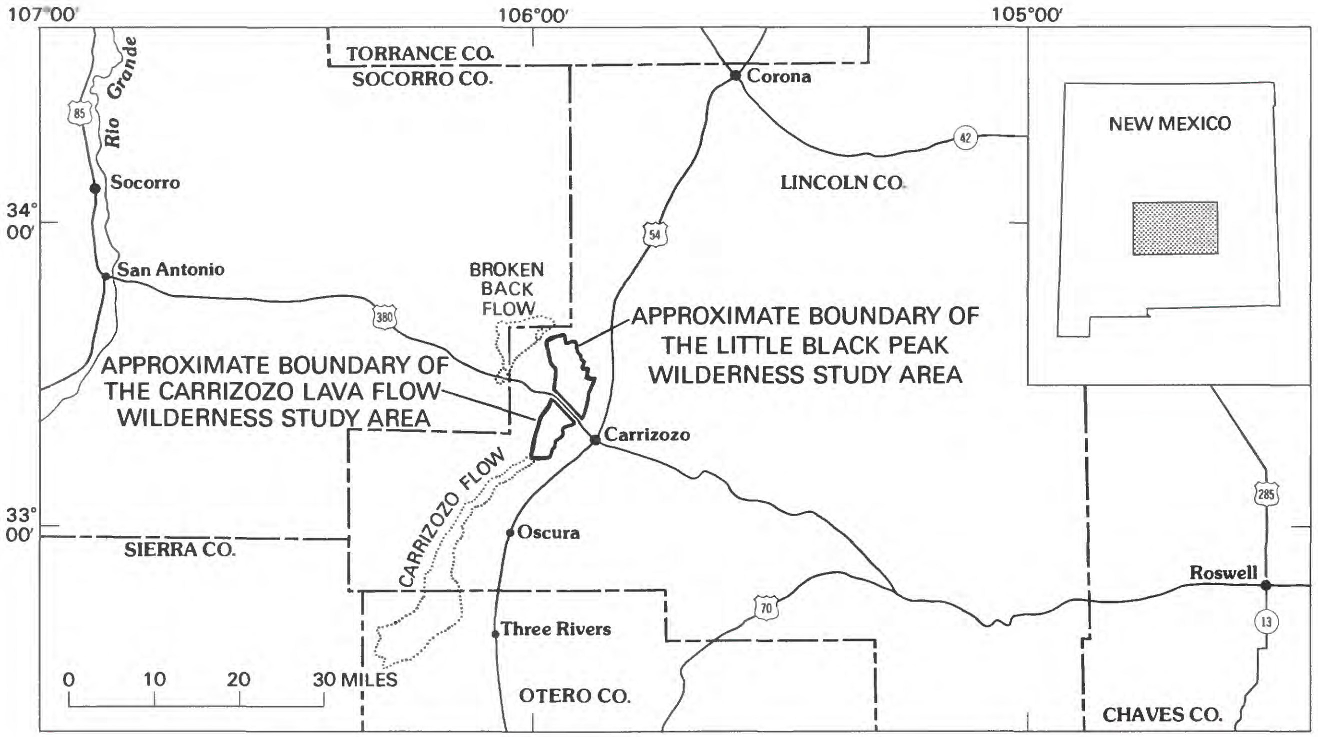

Figure 2. Index map showing the location of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, Lincoln County, New Mexico.

INTRODUCTION

The Little Black Peak (NM–060–109) and Carrizozo Lava Flow (NM–060–110) Wilderness Study Areas are located in south-central New Mexico in Lincoln County about 60 mi (miles) southeast of Socorro and 80 mi northwest of Roswell (fig. 2). The town of Carrizozo lies 4 mi to the southeast along U.S. Highway 380. The two study areas are contiguous and are separated only by U.S. Highway 380 (fig. 1). A resource assessment study of a combined area of 24,249 acres was requested by the U.S. Bureau of Land Management (BLM). In this report each studied area is called the "wilderness study area" or simply the "study area." Both areas are accessible from Highway 380 and from dirt roads which parallel most of the boundaries. The New Mexico Valley of Fires State Park (Weber, 1979) borders parts of both study areas along their eastern margins and is accessible from Highway 380 (fig. 1; pl. 1). Environmental, geomorphological, and cultural aspects of study areas are presented by the U.S. Bureau of Land Management (1985).

The dominant feature of both areas is a large lava flow, called the Carrizozo lava flow or Carrizozo Malpais (Allen, 1951). The surface of the Little Black Peak study area is completely covered by the flow except for kipukas; whereas, the Carrizozo Lava Flow study area also has some surface area consisting of older sedimentary rock in the western part (fig. 1). Both study areas have low relief. Elevations range from about 5,250 ft on the eastern side of the Little Black Peak study area to a maximum elevation of 5,676 ft at the summit of Little Black Peak. Elevations in the Carrizozo Lava Flow study area range from approximately 5,000 ft to a maximum of 5,565 ft in the southwestern hills. Both study areas lack established drainage, except for a few eastward-draining intermittent streams in the southwestern part of the Carrizozo Lava Flow study area. These intermittent streams, as well as most intermittent streams near the border of the Carrizozo lava flow, drain towards and end at the margin of the flow. This has resulted in a zone of flat meadow lands and a number of small playas (dry lake beds formed by episodic ponding) along the margin of the flow.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). Identified resources are classified according to the system of the USBM and USGS (1980), which is shown in the "Appendix" of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) shown in the "Appendix." Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

Investigation of the Little Black Peak and Carrizozo Lava Flow study areas by the USBM consisted of a literature search and field work. Prior to the field investigation, various sources of minerals information, including published and unpublished literature and Bureau files, were reviewed regarding the geology and mineral resources of the region. Records at the BLM State Office in Santa Fe, N. Mex., and at the BLM district office in Roswell, N. Mex., were searched for mining claim, and oil, gas, and geothermal lease information pertinent to the study areas. Local residents, BLM personnel, and personnel from the New Mexico Bureau of Mines and Mineral Resources in Socorro, N. Mex., were interviewed regarding minerals information in the region.

Field investigation, consisting of a search for mines, prospects, and mineralized areas, and examining and sampling lava, uranium prospects, and outcrops, was conducted in April 1985. Seventeen chip samples were taken, including 7 lava samples, 8 samples of uranium-bearing sandstone exposed in prospect trenches, 1 sample from a gypsum outcrop, and 1 sample from a dolomitic limestone outcrop.

All 17 samples were analyzed for gold and silver by fire assay. Ten of the samples were analyzed by fluorimetry for uranium. Whole rock analyses were performed on a sample of gypsum and a sample of dolomitic limestone. Sixteen samples were analyzed by semiquantitative optical emission spectrography for 40 elements. Analyses of all samples were performed by the U.S. Bureau of Mines, Reno Research Center, Reno, Nev. (Zelten, 1986). Additional sample information is available from the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colorado.

Investigations by the U.S. Geological Survey

In 1986 and 1987, D.B. Stoeser of the USGS conducted field investigations to assess the potential for undiscovered mineral resources of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas. These investigations included a field check of previous geological mapping, the collection of 14 rock and 10 stream-sediment samples, and an examination of mineralized areas. All samples were analyzed by spectrographic and X-ray fluorescence methods in the USGS laboratories, Denver, Colo. Interpretation of available aeromagnetic and gravity data was by M.K. Senterfit.

The study areas lie within the Little Black Peak and Carrizozo 15-minute quadrangles which have been mapped by Smith (1964), Smith and Budding (1964), and Weber (1964). Their work, along with the regional geologic map of Dane and Bachman (1958), was used extensively in preparing the geologic map (pl. 1) for the present report. In addition, high-resolution, high-altitude infrared photography (scale 1:58,000) was used to compile plate 1. In addition to the present report, mineral and energy assessments that include the study areas are contained in unpublished reports by Krason and others (1982) and the U.S. Bureau of Land Management (1985).

APPRAISAL OF IDENTIFIED RESOURCES

By Jeanne E. Zelten U.S. Bureau of Mines

Mining and Mineral-Exploration History

The study areas are not included in any mining district and, as of November 1985, there were no mining claims in or within 1 mi of the boundaries. Precious and base metals, fluorite, uranium, gypsum-rich evaporites, coal, and vermiculite deposits occur in mining districts within 10 mi northeast to southeast of the study areas. The deposits occur in formations which are projected to underlie the lava, but there is no surface evidence of similar deposits beneath the lava. Most of the production from mining districts in this part of New Mexico was during World War II, and virtually no production has occurred since.

Claims were staked for uranium during the mid-1950's across a large kipuka (Hawaiian term for an island of older rocks and surficial material surrounded by lava) in the southeastern part of the Little Black Peak study area in secs. 9 and 16, T. 7 S., R. 10 E. (pl. 1). Prospect trenches were bulldozed in limonite-stained Cretaceous Dakota Sandstone and Tertiary(?) trachyte along the summit of the kipuka, but no uranium was mined. The claims were abandoned in February 1985.

Small amounts of lava, extracted from near the edges of the flow, have been used locally for road metal

(Smith, 1964), decorative stone, landscaping, and building material. From 1964 through 1972, lava was removed from outside the Carrizozo Lava Flow study area (SW¼ sec. 31, T. 7 S., R. 10 E.) and sold to the Stone Center in St. Louis, Mo. Limited sales also were made over the years to local individuals (Custer, 1975).

As of April 1985, oil and gas leases and lease applications covered about 15 percent of the study areas (fig. 3). As of April 1982, seven exploration holes (fig. 4) had been drilled to depths ranging from 1,250 to 8,050 ft, within 3 mi of the boundaries (Krason and others, 1982); three of these wells, Bryce Dugger No. 1 Federal, Gallagher, and Helen (fig. 4), had a show of oil in the Permian San Andres Formation (Havenor, 1964). Additional exploration is necessary to determine if oil and gas are present under the areas.

Appraisal of Sites Examined

Vesicular, basaltic lava underlies most of both study areas. Uranium occurs at the Dakota Sandstone-trachyte contact in the Little Black Peak study area. Gypsum and limestone crop out west of the lava and dip easterly beneath it.

The abundant lava from the study areas has local use for road metal, landscaping, and building material and represents an inferred subeconomic resource. Scoria, present in small cinder cones in the northern part of the Little Black Peak study area, could be used for construction purposes, specifically road metal and aggregate, and also as decorative stone. Much of the surface in the interior of the study areas is covered by pahoehoe (ropy) lava, with ropes averaging from 1 to 3 in. (inches) in diameter, but sometimes as much as 6 in. This lava has value for decorative use.

Because of the extremely rugged lava surface, mining in the interior of the flows would be difficult and costly (Clippinger, 1946). No major population centers are nearby, so the cost of transporting a high-bulk, low-unit-value commodity, such as construction material, would be prohibitive (Osburn, 1979). Large, easily accessible quantities of scoria, suitable for construction, are available elsewhere in New Mexico and are adequate to supply current needs. Decorative stone has a higher unit value than construction material, and although extraction of lava for decorative stone is labor intensive and suitable rock is widely scattered, a low-volume operation might be profitable, as it was from 1964 to 1972 when shipments were made to St. Louis. Seven lava samples were taken and analyzed; no unusual concentrations of elements were present (Zelten, 1986).

A contact between the Dakota Sandstone and trachyte crops out in a kipuka near the southeastern edge of the Little Black Peak study area. A uranium occurrence along the contact was explored by bulldozer trenches (fig. 1), but there is no evidence of any production. Total-count scintillometer readings taken along the length of the kipuka ranged from 20 to 1,500 cps (counts per second); background for the area averaged 40 cps. Chip samples from the sandstone and trachyte exposed in the trenches contained from 0.98 to 106 ppm (parts per million) uranium and averaged 44 ppm. No uranium minerals were identified in or near the workings. Uranium deposits mined in New Mexico in 1986 averaged at least 0.3 percent (3,000 ppm) U_3O_8 (George Grandbouche, Department of Energy, Grand Junction, CO, oral commun., 1986), or about 2,550 ppm uranium. Analyses of samples from the workings did not exceed 106 ppm uranium. The uranium occurrence in the kipuka is small and low-grade; no uranium resource can be identified at this location. (See Zelten, 1986).

Gypsum in the Yeso and San Andres Formations crops out west of the Carrizozo lava flows. Alternating gypsum and limestone beds, each no more than about 20–30 ft thick, occur in the San Andres near Crockett's Cave (Jagnow, 1973), about ½ mi west of the Carrizozo Lava Flow study area (pl. 1). Gypsum in the San Andres, exposed in a sinkhole near the southwestern boundary of the Little Black Peak study area, is at least 10 ft thick and dips about 20° southeast beneath the lava. Examination and analysis of the gypsum showed it to contain many impurities, which would limit its commercial value.

Minable gypsum beds are usually flat lying to moderately dipping, massive, with little to no overburden, and low in impurities. Gypsum occurs at or near the surface in beds up to 100 ft thick in New Mexico and is easily mined at localities closer to major population centers (Elston, 1967). Because of limited markets and the high cost of shipping a high-bulk, low-unit-value commodity, gypsum mines and plants are near markets (Logsdon, 1982). Large amounts of overburden would have to be removed to surface mine the gypsum in the study areas. If gypsum is present beneath the lava, it would not be economical to mine in the foreseeable future because of impurities, distance from markets, and expensive mining methods.

A sample of dolomitic limestone was taken from a sinkhole that exposes Yeso Formation just outside the western boundary of the Carrizozo Lava Flow study area. The limestone exposed at this location is intermixed with thin layers of dolomite and gypsum, and contains other impurities. Whole-rock analysis of the limestone showed it to be of poor quality and not commercially valuable for chemical use (Zelten, 1986).

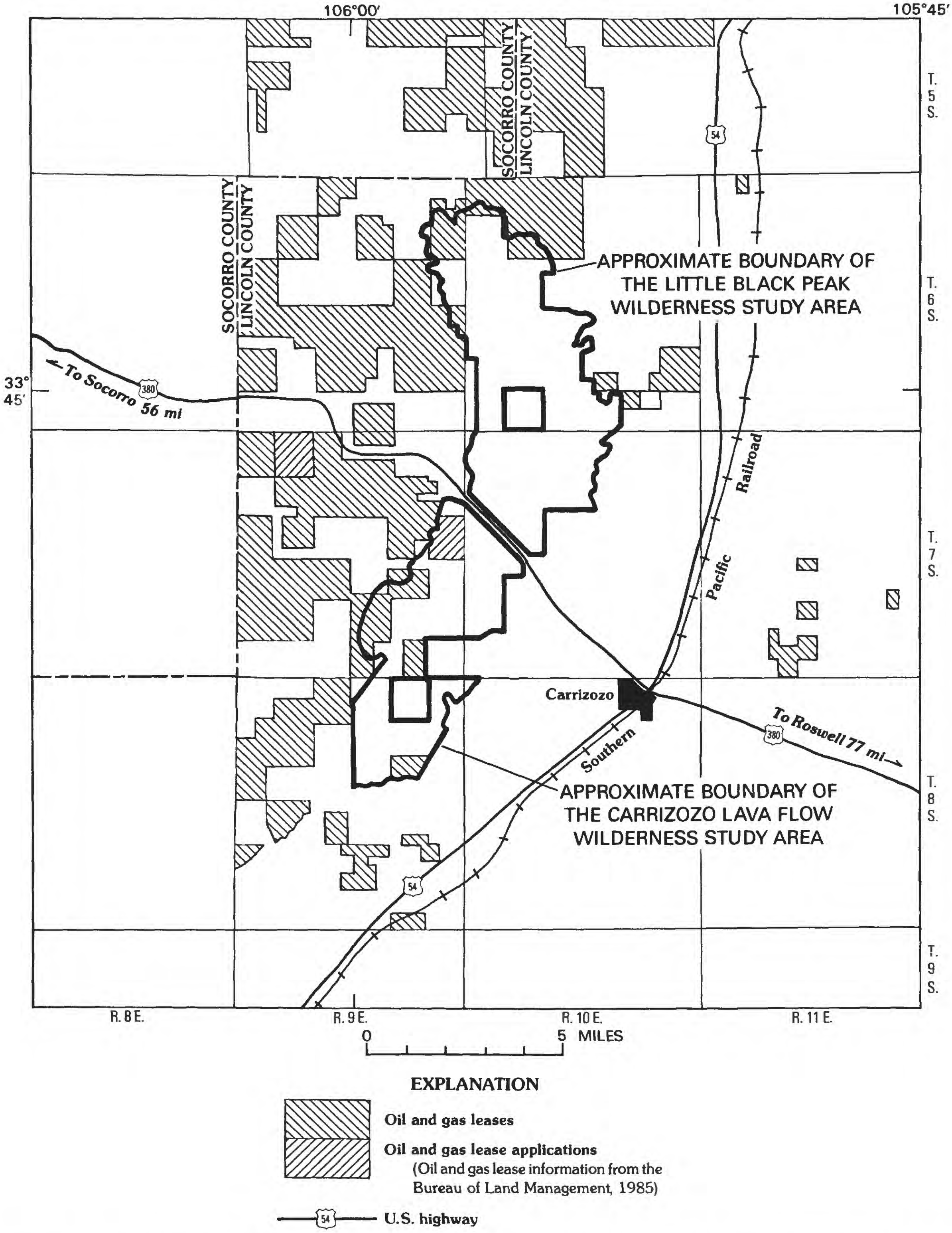

Figure 3. Map showing oil and gas leases and lease applications in and near the Little Black Peak and Carrizozo Lava Flow study areas, Lincoln County, New Mexico.

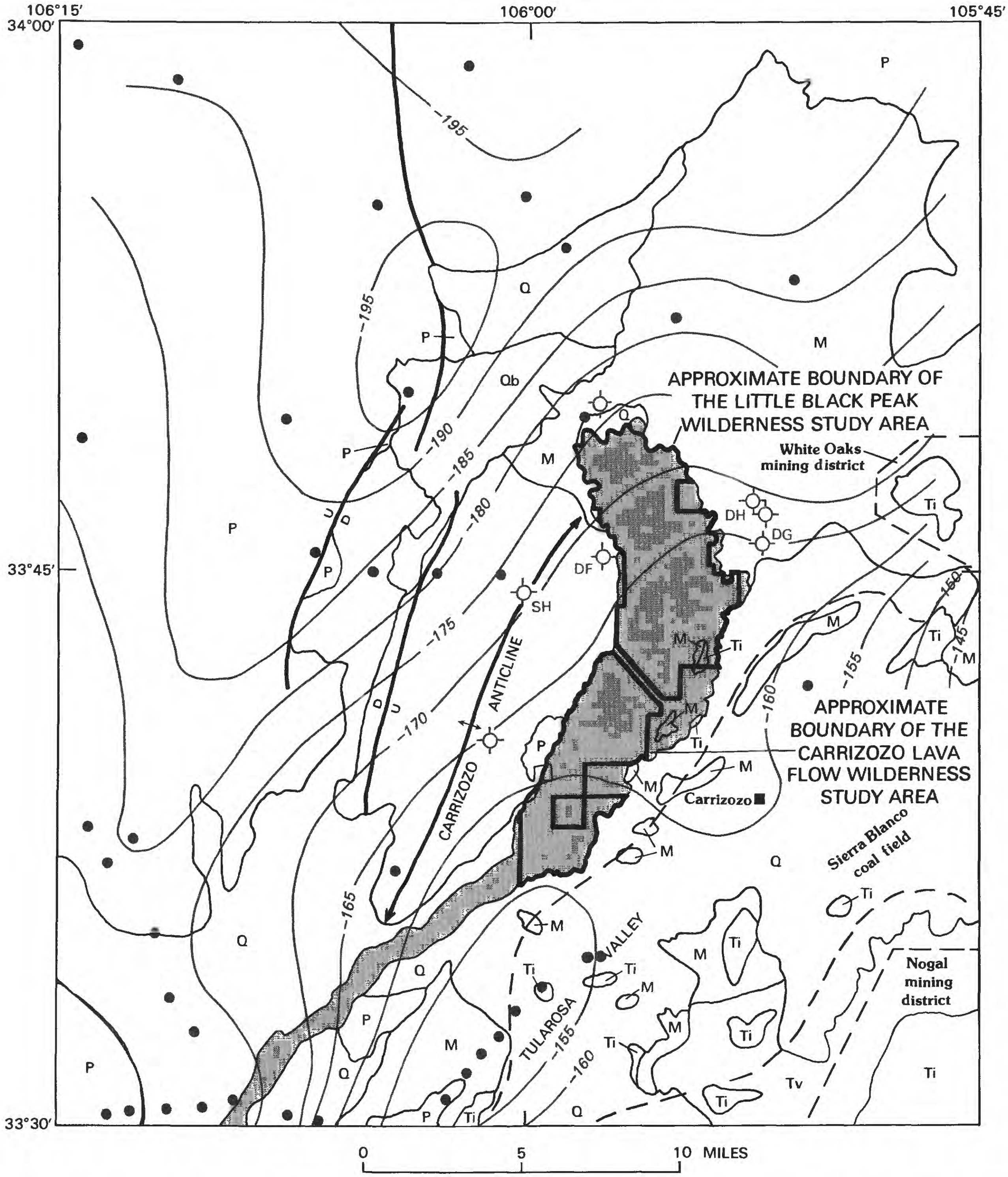

Figure 4 (above and facing page). Generalized geologic and complete Bouguer gravity anomaly map of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas and vicinity, Lincoln County, New Mexico (from Healy and others, 1978). Contour interval, 5 milligals. Abbreviations: oil and gas test wells: DF—Dugger No. 1 Federal, DG—Dugger No. 1 Gallagher, DH—Dugger No. 1 Helen, and SH—Standard of Texas No. 1 Heart.

EXPLANATION

Q	Alluvium (Quaternary)
(shaded)	Carrizozo lava flows (Quaternary)
Qb	Broken Back lava flow (Quaternary)
Ti	Felsic intrusive rocks (Tertiary)
Tv	Volcanic rocks (Tertiary)
M	Sedimentary rocks (Mesozoic)
P	Sedimentary rocks (Permian)
———	Contact
———	Fault—U on upthrown side and D on downthrown side
—+→	Anticline—Showing direction of plunge
— -165 —	Gravity contour line, in milligals
●	Gravity station
-◇-	Drill hole
— — — —	Mining and coal district boundary

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Douglas B. Stoeser and Michael K. Senterfit
U.S. Geological Survey

Geology

The Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas and adjoining region are underlain by sedimentary rocks of Pennsylvanian, Permian, Triassic, and Cretaceous age; by trachyte of probable Tertiary age; and by Quaternary age basaltic volcanic rock, stream alluvium, alluvial fan terrace deposits, and playa deposits (pl. 1). The Quaternary units were deposited in the northernmost part of the Tularosa Basin, the easternmost basin of the Highland section of the Basin and Range physiographic province in New Mexico (Weber, 1964; New Mexico Geological Society, 1982).

The pre-Tertiary sedimentary rocks beneath the Carrizozo Lava Flow study area lie on the eastern flank of the north-northeast trending Carrizozo anticline (figs. 1, 4, 5) (Kelly and Thompson, 1964); these sedimentary rocks have a simple monoclinal dip of generally less than 20° southeast. The nose of the Carrizozo anticline plunges north-northeast beneath the northern part of the Little Black Peak study area (fig. 1), and thus the strike of layered rocks immediately west of and beneath the Little Black Peak study area changes from north-northeast to northwest as these beds wrap around the nose of the fold (pl. 1). The Standard of Texas No. 1 Heard Well (fig. 4) was drilled on the axis of the anticline adjacent to Highway 85, approximately 3 mi west of the study areas and penetrated 7,740 ft of Permian and Pennsylvanian sedimentary rocks before bottoming in crystalline basement rocks (R.W. Foster in Griswold, 1959; figure 20 of King and Harder, 1985). It is also thought that the stratigraphic section of these rocks beneath the anticline have been tectonically thickened due to mobilization of evaporites within the Permian section and that these units thin away from the core of the anticline (Kelley and Thompson, 1964; Weber, 1964).

Rock units exposed within the Little Black Peak study area are the Permian San Andres Formation, the Triassic Santa Rosa Formation, the Cretaceous Dakota Sandstone, a Tertiary(?) trachyte intrusive mass, and the Quaternary Carrizozo lava flows (also referred to as the Little Black Peak lava flow by Smith, 1964). In addition, the following sedimentary rock units occur adjacent to and beneath the study area (pl. 1): the Permian Bernal Formation, Triassic Chinle Formation, and Cretaceous Mancos Shale (Smith, 1964). The distribution of the Bernal Formation and Triassic units beneath the Carrizozo lava flows is not known, but it appears that they wedge out against the Dakota Sandstone going southwards and may or may not extend as far south as the Carrizozo study area.

Rock units exposed within the Carrizozo Lava Flow study area include the Permian Yeso and San Andres Formations and the Quaternary Carrizozo lava flows (Weber, 1964). The Cretaceous Dakota Sandstone, Mancos Shale, and Mesaverde Group crop out near the eastern margin of the study area (pl. 1), but only the Dakota Sandstone and Mancos Shale appear to underlie the southeasternmost part of the study area.

Although not exposed within the study areas, the Pennsylvanian Magdalena Group, and the Permian Bursum (of the Magdalena Group) and Abo Formations are interpreted to underlie both study areas (fig. 5) (Kelley and Thompson, 1964). In the study region, the lower Magdalena Group is approximately 1,300–1,700 ft thick and consists of limestone, shale, and minor conglomerate, the Bursum Formation is less than 250 ft thick and consists of shale interbedded with sandstone and conglomerate, and the Abo Formation is approximately 1,250–1,500 ft thick and consists of reddish-brown mudstone, claystone, and arkosic conglomerate (R.W. Foster in Griswold, 1959; Foster, 1978; King and Harder, 1985).

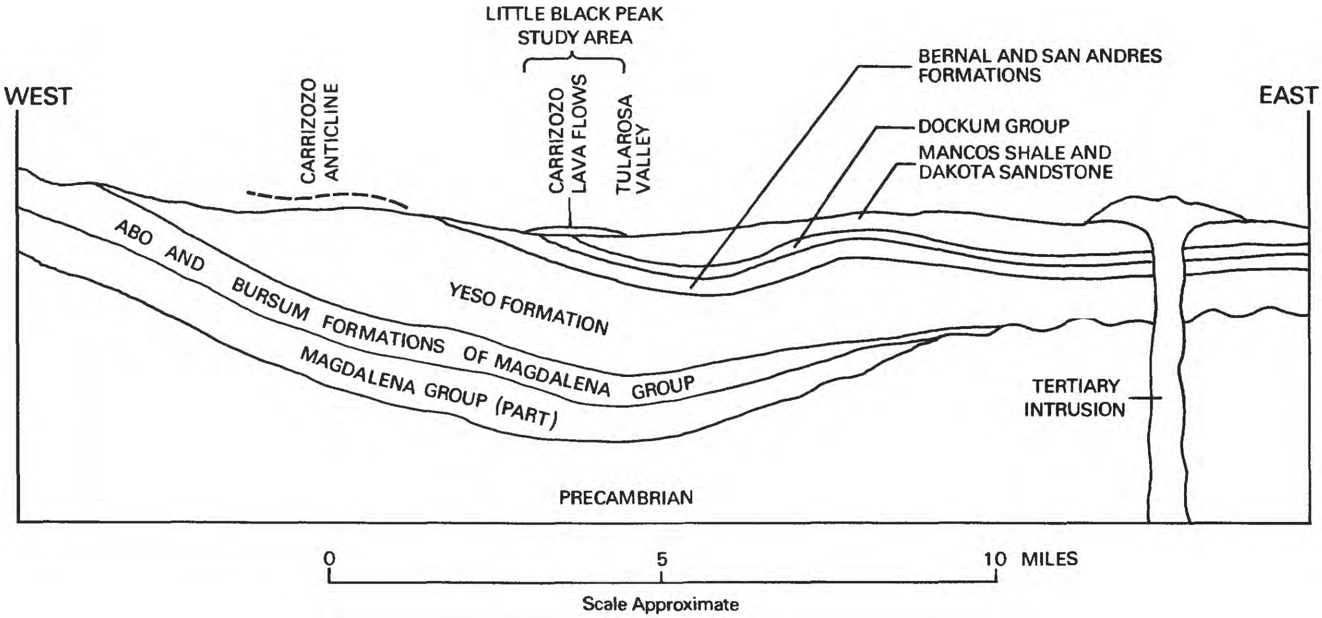

Figure 5. Diagrammatic east-west structure section through the Little Black Peak region (modified from Kelley and Thompson, 1964).

The Permian Yeso Formation underlies both study areas and consists of interbedded limestone, dolomite, salt, gypsum, sandstone, and mudstone, including redbed sandstone and shale, and minor anhydrite (R.W. Foster in Griswold, 1959; King and Harder, 1985). In the study region, the Yeso is approximately 3,500–4,300 ft thick (Foster, 1978; King and Harder, 1985). The upper part of the Yeso Formation is exposed in the west-central part of the Carrizozo Lava Flow study area and consists of tan to brown interbedded limestone, sandstone, siltstone, and gypsum (Weber, 1964). In addition to these lithologies, evaporitic salt beds in the lower part of the Yeso Formation are reported for the Standard of Texas No. 1 Heard well, including one 900-ft section consisting mainly of salt (R.W. Foster, reported in Griswold, 1959; Milner, 1978; King and Harder, 1985). Because of the presence of soluble rock types within the section, sinkholes (collapsed solution caves) have developed within the Yeso, and several of these are shown on plate 1.

The Permian San Andres Formation, which overlies the Yeso Formation, also underlies both study areas and consists of interbedded dolomite, dolomitic limestone and gypsum with minor cherty zones and sandstone beds (Weber, 1964; Foster, 1978). In the study region the San Andres Formation is approximately 600–850 ft thick (Smith, 1964; Weber, 1964; Foster, 1978). Extensive collapse due to solution of the gypsum and carbonate beds has caused structural complexity within the unit (Weber, 1964) as indicated by highly variable dips to more than 60° and local minor folds (pl. 1). In addition, solution of these rocks has led to the formation of sinkholes, several of which are shown on plate 1. One sinkhole occurs within the central part of the Carrizozo lava flows in the northern part of the Carrizozo Lava Flow Wilderness Study Area (sec. 24, T. 7 S., R. 9 E.). Here, collapse within the San Andres occurred after the Carrizozo flow was erupted and, as a result, the upper part of the 160 ft deep sinkhole includes the basalt (pl. 1).

Although not exposed within the Little Black Peak study area, the Permian Bernal Formation underlies the northwestern part of the study area. It consists of red to brown thin-bedded siltstone, claystone, shale, and fine-grained sandstone, and in the study area ranges in thickness from approximately 20 to 200 ft (Smith, 1964). As noted previously, it may extend beneath the Carrizozo Lava Flow study area, but this is not known.

Triassic sedimentary rocks of the Dockum Group underlie the Carrizozo region (Smith, 1964). The Dockum Group is subdivided into the Santa Rosa Formation at the base and the overlying Chinle Formation. The Santa Rosa Formation underlies much of the Little Black Peak study area and may extend as far south as the northeastern part of the Carrizozo Lava Flow study area. It consists of red, reddish-brown, and buff-colored, coarse- to medium-grained, crossbedded sandstone and pebble conglomerate, with minor interbeds of siltstone and claystone. In the Little Black Peak area, it is approximately 150–200 ft thick. The Chinle Formation underlies the northeastern and eastern part of the Little Black Peak study area. It consists of purplish-red to brown thin-bedded siltstone, mudstone, claystone, sandstone, and lenses of limestone-pebble conglomerate and is approximately 200–400 ft thick.

The Cretaceous Dakota Sandstone underlies the eastern part of both study areas and is approximately 150–200 ft thick (Smith, 1964; Weber, 1964). The formation is composed of sandstone and shale. The lower part of the formation is composed of massive buff to brown sandstone characterized by crossbedding and ripple-mark features. Shaly partings and thin siltstone interbedded with sandstone occur in the middle part of the unit, and the upper part consists of interbedded sandstone and shale. The Dakota Sandstone exposed in the kipukas of the Little Black Peak study area and in the Valley of Fires State Park (pl. 1) consists of crossbedded cream to mottled brown or red carbonate-cemented sandstone, which suggests that the exposed sandstone belongs to the lower part of the formation.

The Mancos Shale is not exposed in either study area, but underlies the southeastern part of the Little Black Peak study area and the southeasternmost part of the Carrizozo study area. The Mancos Shale consists of gray to black calcareous pyritic shales, shaly to sandy limestone, and thin-bedded sandstones (Smith, 1964; Weber, 1964). The Mancos Shale is approximately 600–700 ft thick, but only the lower part of the formation underlies the study areas.

Tan-colored trachyte (flow-banded, feldspar-rich intrusive igneous rock) occurs in the large kipuka within the Little Black Peak study area and along Highway 380 at the eastern margin of the Carrizozo flow (fig. 1; pl. 1). At the kipuka locality the trachyte intrudes Dakota Sandstone; whereas, along Highway 380 it intrudes the Mancos Shale (Weber, 1964). It is not known whether the trachytes exposed at the two locations are part of the same intrusive body, but samples of the trachyte from both localities are virtually identical. The trachyte is weakly altered, porous, fine-grained, and contains greater than 95 percent feldspar. Minor minerals include aegerine-augite pyroxene, opaque minerals, late pale brown mica, and calcite. This unit was interpreted by Weber (1964) to be a sill in the Dakota Sandstone, but this is not apparent in outcrop since the trachyte cannot be shown to be overlain by Dakota Sandstone, nor can the dip of the contact with the sandstone be determined. The sill interpretation is supported by the fact that flow banding and a well-developed parting within the trachyte are parallel to the 13–16° east dip of the sandstone. The trachyte is undated but is interpreted to belong to a widespread series of middle Tertiary alkaline intrusive rocks that crop out to the east and southeast of the study areas (fig. 4) (Smith, 1964; Weber, 1964, Thompson, 1972; Moore and others, 1986).

As noted previously, a number of uranium exploration trenches were bulldozed within the large kipuka in the Little Black Peak study area (collectively referred to as the "Harkey prospect" in McLemore, 1983). Most of these trenches are across the Dakota Sandstone-trachyte contact, but one is within the trachyte (pl. 1). Anomalous amounts of uranium are also reported at the trachyte-Mancos Shale contact along Highway 380 (secs. 21, 28, 29, T. 7 S., R. 10 E.) (Berry and others, 1982). Traverses made with a scintillometer across the kipuka showed that radioactivity is elevated above background levels up to 150 ft from and on both sides of the contact. Radioactivity is only strongly concentrated within a few feet of the contact, where levels up to 12 times background were observed. Although O.E. Collins (1956 data, presented in McLemore, 1983) indicated that the host rock for the radioactivity was limonite-stained, buff-colored sandstone, our field examination showed that the most radioactive rock was limonite-stained fine-grained trachyte from within a foot of the contact with the sedimentary rocks. It was not clear in the field, whether the anomalously radioactive trachyte is from the chill zone of the intrusion or from minor offshoots of the trachyte into the sandstone at the contact. In addition, at most places examined, a caliche (calcium carbonate) zone up to 4 or 5 in. thick was found adjacent to the anomalously radioactive trachyte at the contact. It is not known whether the uranium occurs as a uranium mineral or is dispersed in other minerals within the rock.

The most widespread lithologic units within both study areas are the late Quaternary Carrizozo basalt lava flows. The flows are 44 mi long, range in width from ½ to 5 mi, and are up to 160 ft thick (Allen, 1951; Weber, 1964). Because of their black color and great length, the Carrizozo flows are one of the most remarkable features seen on the composite color Landsat satellite image of New Mexico (see Highway geological map, New Mexico Geological Society, 1982). Although generally referred to as one flow, the Carrizozo actually consists of two basalt flows (Renault, 1970), of which only the upper flow is exposed in the study areas (except in the sinkhole in the northern part of the Carrizozo study area). The flows appear to have erupted from a vent at Little Black Peak and flowed southwards down the Tularosa Valley (pl. 1). Little Black Peak consists of a small, well-preserved cinder cone and several other older subdued craters that sit at the summit of a broad shield of basaltic spatter and flow basalt. The Carrizozo basalt flows have not been dated, but on the basis of a lack of erosion and the preservation of fine surface features of the flows and of the Little Black Peak cinder cone, Weber (1964) estimated an age of 1,000–1,500 years before present. In addition to the Carrizozo flows, older Quaternary flow rocks of the Broken Back basalt flow (Smith, 1964) are present near the northwestern margin of the Little Black Peak Study Area (figs. 1, 2; pl. 1). Detailed studies of these basalts and their chemistry are presented in Renault (1970) and Faris (1980).

Table 1. Concentrations of selected trace elements in trachyte samples from in and near the Little Black Peak Wilderness Study Area, Lincoln County, New Mexico

[Concentrations in parts per million (ppm). All elements analyzed by X-ray fluorescence by Betsi Esposito, USGS; <, less than; number in parentheses, lower limit of detection. The following elements were analyzed for but not detected (detection limits in ppm in parentheses): Bi (2), Cd (10), Sb (6), Sn (6), U (8)]

Sample No.	Cu (20)	Zn (26)	Pb (5)	As (1)	Rb (3)	Sr (3)	Ba (5)	Zr (2)	Mo (1)	Th (6)	Ga (6)	Y (2)	Nb (2)	La (4)	Ce (4)	Nd (7)
Interior																
D003	39	97	40	15	259	78	<5	792	6	36	23	51	204	140	191	54
D015	34	123	41	15	236	77	12	1237	6	49	31	55	203	138	184	48
D017	<20	102	33	15	207	51	47	388	3	43	26	43	225	150	190	47
Chill zone																
D012	27	117	40	16	166	117	89	904	18	32	29	55	171	133	184	51
D016	30	93	42	14	115	524	265	2258	13	26	26	56	61	61	96	36
D018	23	122	38	15	107	215	198	1241	19	44	25	49	196	132	174	47

SAMPLE DESCRIPTIONS

Sample D003 was taken from the Mancos Shale-trachyte contact in a road cut on U.S. Highway 380, all other samples were taken from the Dakota Sandstone-trachyte contact the kipuka in the Little Black Peak Wilderness Study Area.

Geochemistry

Because of the lack of established drainage within the Carrizozo basalt field, no stream-sediment samples could be taken, nor were rock samples of the flow taken because of lack of evidence for mineralization of the basalt. Ten reconnaissance stream-sediment samples were taken along the western margin of the flow to check for possible mineralization of the sedimentary rock units which dip eastward toward and underlie the basalt. The samples were analyzed for 31 elements by six-step optical emission semiquantitative spectrography (Grimes and Marranzino, 1968). These analyses revealed no anomalous element concentrations nor has any mineralization been reported within 5 mi of the western border of the study areas (Griswold, 1959; Smith, 1964; Weber, 1964; Krason and others, 1982).

Fourteen rock-chip samples were taken from the interior and chill zone of the trachyte. Six of these samples were selected for trace element analysis (1 from the Mancos Shale-trachyte contact on U.S. Highway 380, 2 from the kipuka trachyte interior, and 3 from the contact with the Dakota Sandstone within the exploration trenches chosen by locating rock with the highest readings on the scintillometer). These samples were analyzed with an air-path Kevex X-ray fluorescence unit, which used radionuclide sources to irradiate the powdered samples. The results are presented in table 1. The trace element concentrations are typical of alkali-element-rich syenitic and trachytic quartz-poor igneous rocks (Gerasimovsky, 1974), and none of the concentrations are considered to be significantly anomalous. The high content of zirconium (table 1), in particular, indicates that the trachyte has an alkaline composition (Watson, 1979). The lower amounts of rubidium and higher contents of strontium, barium, and niobium in the chill zone samples suggests some chemical zonation in the trachyte. No detectable uranium was found in the samples; however, a slight concentration of molybdenum in the chill zones samples was observed. O.E. Collins (1956 data presented in McLemore, 1983) reported 0.009–0.028 percent uranium and 0.03–0.07 percent vanadium in radioactive samples from the kipuka, and Berry and others (1982) reported 207 ppm uranium from a sample from the Highway 380 locality.

Geophysics

The complete Bouguer gravity map of Healey and others (1978), along with their first- and third-order residual maps, display large gravity lows that reflect the great thickness of sedimentary fill in the Tularosa Basin (fig. 4). A regional gradient that extends from the southeast to the northeast over the Carrizozo region (fig. 4), reflects the transition from a basement high with Tertiary intrusions and volcanics on the eastern flank of the Tularosa Basin to the central part of the basin. Steep gravity gradients to the west of the study areas may reflect the presence of major normal faults along the western flank of the basin (fig. 4; Kelley and Thompson, 1964; Woodward and others, 1975). In the vicinity of the study areas, the gravity anomaly may not be fully defined owing to a lack of gravity stations.

A magnetic high located in the northern part of the Little Black Peak study area (anomaly A, fig. 6) occurs over the area containing Little Black Peak and presumably reflects the underlying intrusive vent. Two other similar highs beneath the Carrizozo flow in the southern part of the Little Black Peak and in the northern part of the Carrizozo Lava Flow study areas (anomalies B and C, fig. 6) suggest additional vents for the Carrizozo lava flows, other than the one at Little Black Peak, or may indicate one or more concealed shallow older intrusive masses beneath the flow. The trachyte intrusions, shown on plate 1, have no magnetic expression in figure 6. The lack of any magnetic high associated with the trachyte is in line with the very low magnetic susceptibility readings for two typical samples of the trachyte (averaging 200 emu, electromagnetic units).

On the basis of a series of 1:1,000,000 scale color composite maps developed from aerial gamma-ray survey data of the U.S. Department of Energy, J.S. Duval (USGS, written commun., 1986) reported that the rocks of the Little Black Peak Wilderness Study Area have an overall low radioactivity with concentrations of 1.0–1.8 percent potassium, 1.5–2.0 ppm equivalent uranium, and 1–6 ppm equivalent thorium. Similarly, the rocks of the Carrizozo Lava Flow Wilderness Study Area have overall low radioactivity with concentrations of 1.0–1.8 percent potassium, 1.6–2.5 ppm equivalent uranium, and 1–7 ppm equivalent thorium. There are no radiometric anomalies within or near the study areas.

Mineral and Energy Resource Potential

Uranium Associated with Alkaline Rocks

There are no known occurrences of metallic minerals in or near the Little Black Peak or Carrizozo Lava Flow study areas. Metallic and non-metallic mineral deposits associated with alkaline Tertiary intrusive rocks have been mined east and southeast of the study areas (Griswold, 1959; Kranson and others, 1982). The closest mining districts associated with these intrusives are the White Oaks district, 5 mi east of the Little Black Peak study area, and the Nogal mining district, 10 mi southeast of the Carrizozo Lava Flow study area (fig. 4). These districts have produced iron, gold, silver, zinc, copper, fluorspar, molybdenum, and rare-earth elements (Griswold, 1959). The trachyte of the Little Black Peak study area is interpreted to be related to these Tertiary intrusives, and, although the trachyte intrusion has uranium mineralization associated with it, there are no other mineral occurrences or geochemical anomalies. The uranium is concentrated in very minor amounts immediately along the contact of the trachyte with its host sedimentary rocks. A low resource potential for uranium in the contact zone is assigned with a certainty level of C.

Resources Associated with Magnetic Highs

The cause of the aeromagnetic highs beneath the southern part of the Little Black Peak study area and the northern part of the Carrizozo Lava Flow study area (fig. 6) is unknown. Two possible interpretations are that they result from one or more Tertiary intrusive masses or are basaltic intrusive rocks related to the Carrizozo lava flows. If the anomalies are due to Tertiary intrusions buried beneath the Carrizozo lava flows, then there would be some likelihood for the occurrence of metals and non-metals known to be associated with such intrusions. In particular, Tertiary intrusions elsewhere in the Carrizozo region are associated with replacement iron deposits that consist chiefly of magnetite, which could be the cause of one or more of the anomalies (Griswold, 1959). If the source of the anomalies is due to basaltic intrusive rocks associated with the Carrizozo flows, then the probability for any type of associated mineral deposits would be extremely low. However, detailed geophysical studies and (or) drilling will be needed to determine the cause of the aeromagnetic high. Therefore, the resource potential is unknown, with certainty level A, for metals and nonmetals in areas of the magnetic anomalies.

Sediment-hosted Uranium and Copper

Terrestrial, lagoonal, and shallow-marine clastic sedimentary rocks, including redbed clastic and evaporite sedimentary rocks, occur throughout much of the Pennsylvanian to Cretaceous age stratigraphic units beneath both study areas. This type of sedimentary rock assemblege is known to host stratiform base metal and uranium deposits elsewhere in the Western United States (Gustafson and Williams, 1981; Nash and others, 1981). Stratiform copper and uranium deposits are known to occur in these units elsewhere in New Mexico, particularly in northwestern New Mexico (Woodward and others, 1974; North and McLemore, 1986; McLemore and Chenoweth, in press). These deposits can also contain anomalous concentrations of silver, lead, zinc, and vanadium (North and McLemore, 1986). Within 50 mi of the study areas five minor sediment-hosted copper and uranium deposits, for which there is no known production, occur within the Abo and Yeso Formations. The closest of these occurrences is sediment-hosted copper in the Abo Formation of the Esty (or Oscuro) district 24 mi west of Carrizozo (McLemore and Chenoweth, in press). The occurrence of these types of deposits within such rocks depends on a number of factors including adequate permeability, a reducing

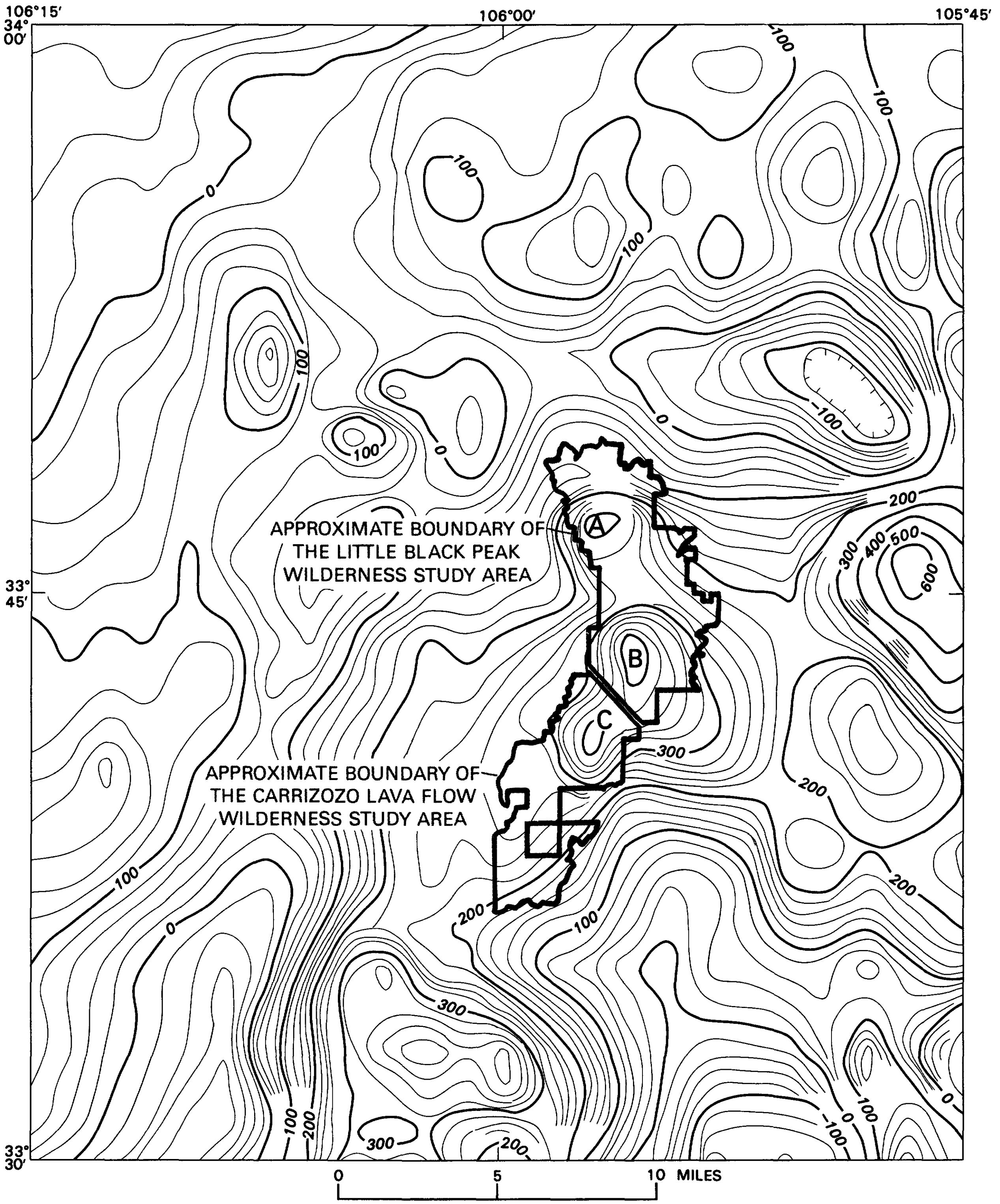

Figure 6. Aeromagnetic contour map of the Little Black Peak and Carrizozo Lava Flow Wilderness Study Areas, New Mexico, and vicinity (from Cordell, 1983). Contour interval, 20 gammas. Anomalies labeled A, B, and C are discussed in the text.

environment containing organic material and sulfur-bearing material, and a source region from which to mobilize the copper and uranium (Cox, 1986; Turner-Peterson and Hodges, 1986). There is no available evidence to indicate the presence of such deposits in the Pennsylvanian to Cretaceous sedimentary rocks beneath the study areas; however, compared to deposits in similar rocks elsewhere in New Mexico, the Pennsylvanian to Cretaceous section beneath the study areas is permissive for the occurrence of sediment-hosted copper and uranium deposits. Given the lack of detailed knowledge of the stratigraphic section beneath the study areas, lack of evidence for such mineralization, and lack of deposits in central New Mexico of these types with known past production, we assign a low resource potential with a level of certainty of B for the occurrence of sediment-hosted copper and uranium deposits beneath all of both study areas.

Gypsum

In the Carrizozo area, gypsum occurs as interbeds throughout the Yeso and San Andres Formations (Smith, 1964; Weber, 1964; Milner, 1978; King and Harder, 1985). In addition, as reported previously, gypsum beds are exposed within the Yeso and San Andres Formations in the southwestern part of the Carrizozo Lava Flow study area (Weber, 1964). Because both formations appear to underlie all of both study areas, both areas are assessed as having a moderate resource potential for gypsum with a confidence level of C.

Salt

As logged by R.W. Foster (in Griswold, 1959) and by King and Harder (1985), the Yeso Formation in the Standard of Texas No. 1 Heard well, approximately 3 mi west of the Little Black Peak Wilderness Study Area (fig. 4), contains a 900 ft section of salt (halite), interbedded with shale, sandstone, and anhydrite. The lateral extent of this salt section is unknown but could extend beneath the study areas (Kelly and Thompson, 1964) (fig. 5). Cuttings from the Heard well were also examined for potash, but the results were negative (Weber, 1964). Milner (1978) also reported that the upper Yeso and lower San Andres contain numerous evaporite beds in western Lincoln County, although no detailed information is presented for the immediate vicinity of the study areas. On this basis, both study areas have a moderate resource potential for salt at a certainly level of C.

Oil and Gas

Prior to 1983, seven oil and gas exploration holes were drilled within 3 mi of the study areas (fig. 4; Foster, 1978; Krason and others, 1982). Three of these holes had slight shows of hydrocarbons, and the others were dry. At least 22 other test holes drilled elsewhere in Lincoln County prior to 1978 were dry (Havenor, 1964; Foster, 1978). In addition, another nine deep tests were completed to basement during 1984 and 1985 (Broadhead, 1985, 1986) in central and eastern Lincoln County to test the Yeso Formation and underlying Abo Formation. All nine wells were without hydrocarbon or gas shows. In the vicinity of the study areas, the Abo, Yeso, and San Andres Formations and the Dakota Sandstone are considered to have the highest oil and gas potential (Havenor, 1964; Foster, 1978; King and Harder, 1985). In particular, the San Andres is considered to have the best potential based on porosity and petroliferous odor (Havenor, 1964). Negative factors for the occurrence of petroleum resources are the destructive thermal effects of the Tertiary and Quaternary magmatism within the study areas and the surface exposure of the favorable host units which would allow for the incursion of meteoric (ground) waters and the flushing of hydrocarbons (Foster, 1978; Milner, 1978; Ryder, 1983; King and Harder, 1985). Although the oil and gas resources of the region cannot be considered to be fully explored, available data are sufficient to indicate that the mineral resource potential for oil and gas in both study areas is low with a certainty level of C.

Coal

Low-grade coal is present within sedimentary rocks of the Upper Cretaceous Mesaverde Group in the Sierra Blanca coal field east of both study areas (fig. 4) (Griswold, 1959; Arkell, 1983); however, the Mesaverde Group does not underlie either study area. Smith (1964) reported that "locally, thin coal seams are found in the shaly central portion" of the Dakota Sandstone in the eastern part of the Sierra Blanca coal field east of the Little Black Peak study area. Coal is not reported from any of the other sedimentary rock units that underlie the study areas. On this basis, the resource potential for coal is assessed as low in both study areas with a certainty of B.

Geothermal Energy

Although the Carrizozo lava flows are very recent, no hot spring activity has been reported in either study area, and Krason and others (1982) report low heat flow for the region (1.44 heat flow units). The study areas are assigned a low resource potential for geothermal energy sources with a certainty level of B.

Recommendations for Further Work

The mineral potential for metals and nonmetals is unknown in areas of magnetic highs. Further work is needed to determine the source of the magnetic anomalies and to better define mineralization associated with that source. Such work should be based on initial, more detailed geophysical studies.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is unlikely. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

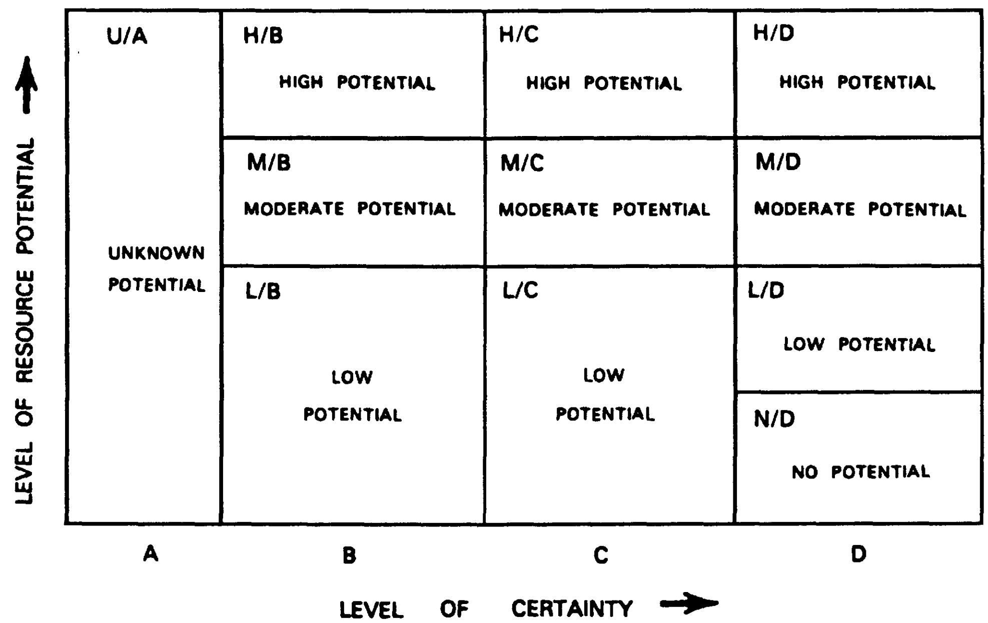
MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

Levels of Certainty



A. Available information is not adequate for determination of the level of mineral resource potential.
B. Available information suggests the level of mineral resource potential.
C. Available information gives a good indication of the level of mineral resource potential.
D. Available information clearly defines the level of mineral resource potential.

Abstracted with minor modifications from:

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, 1972, Mineral resource estimates and public policy: American Scientist, v.60, p.32-40, and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p.5.

GEOLOGIC TIME CHART

Terms and boundary ages used in this report

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~ 240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~ 570[1]
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				3800?
pre-Archean[2]					4550

[1] Rocks older than 570 m.y. also called Precambrian, a time term without specific rank.

[2] Informal time term without specific rank.

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