Summary of the Mineral- and Energy-Resource Endowment, BLM Roswell Resource Area, East-Central New Mexico

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In this summary of two comprehensive resource reports produced by the U.S. Bureau of Mines and the U.S. Geological Survey for the U.S. Bureau of Land Management, we discuss the mineral- and energy-resource endowment of the 14-million-acre Roswell Resource Area, New Mexico, managed by the Bureau of Land Management. The Bureau and Survey reports result from separate studies that are compilations of published and unpublished data and integrate new findings on the geology, geochemistry, geophysics, mineral, industrial, and energy commodities, and resources for the seven-county area. The reports have been used by the Bureau of Land Management in preparation of the Roswell Resource Area Resource Management Plan, and will have future use in nationwide mineral- and energy-resource inventories and assessments, as reference and training documents, and as public-information tools.

In the Roswell Resource Area, many metals, industrial mineral commodities, and energy resources are being, or have been, produced or prospected. These include metals and high-technology materials, such as copper, gold, silver, thorium, uranium and/or vanadium, rare-earth element minerals, iron, manganese, tungsten, lead, zinc, and molybdenum; industrial mineral resources, including barite, limestone/dolomite, caliche, clay, fluorspar, gypsum, scoria, aggregate, and sand and gravel; and fuels and associated resources, such as oil, gas, tar sand and heavy oil, coal, and gases associated with hydrocarbons. Other commodities that have yet to be identified in economic concentrations include potash, halite, polyhalite, anhydrite, sulfur, feldspar, building stone and decorative rock, brines, various gases associated with oil and gas exploration, and carbon dioxide.

Key words:
Assessment
Guadalupe
Chaves
Lincoln
De Baca
Roosevelt
Curry
Quay

Introduction

In September 1992, the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS) summarized current information, both original and from published sources, on the mines and geology of the Roswell Resource Area, New Mexico. This mineral-resource assessment was used to assist the Bureau of Land Management (BLM) in preparing the required 1992 Resource Management Plan (RMP) for the area. In addition to providing the BLM with synthesized and updated geologic and resource information to be used for land-use decisions, these published reports will be used by all three agencies in future nationwide mineral- and energy-resource inventories and assessments, and will be used as reference documents, in training new employees, and as public-education tools by the BLM.

This article is a summary of the more comprehensive reports provided to the BLM by the USBM (Korzeb and Kness, 1993) and the USGS (Bartsch-Winkler, 1992a, in press). Much of the information in these reports is derived from both original and synthesized data printed in publications of the New Mexico Bureau of Mines and Mineral Resources, the New Mexico Geological Society, and many other publications, which, for the sake of brevity, are not referenced in this summary, but are listed in aforementioned USBM and USGS reports. Two notable publications used extensively are the original work by Kelley (1971) on the Pecos Slope geology and the compiled 1:1,000,000-scale State Highway Geologic Map (New Mexico Geological Society, 1982).

Location and Land Status

The Roswell Resource Area is in east-central New Mexico, within lat 33°–36°N. and long 103°–106°30′W. (fig. 1). In addition to private lands, the largest percentage of land in the resource area, the area includes other State, Federal, and military parcels that are managed, in part, by the BLM. Of the approximately 14 million acres included in the resource area, only about 1.5 million surface acres and 4 million subsurface acres are managed by the BLM. The resource compilations and assessments, however, included all contiguous lands within the boundary of the resource area.

BLM Requirements and Usage of Mineral Information

The USGS and USBM reports provide comprehensive, unbiased, historical, and site-specific information on mineral resources and mineral potential not readily available to the BLM. The National Environmental Policy Act (NEPA) provides for input from agencies with specific expertise (for example, USGS and USBM). The information can be used to identify future land-use plans. The reports are to be used by the BLM in the following ways:

1. Initially, the reports were written to assist the BLM in preparing the required Resource Management Plan (RMP). The reports assess the overall mineral potential of the Roswell Resource Area, as well as the potential for the occurrence of specific mineral types. Because they are comprehensive reports, the BLM is able to apply the information in the preparation and implementation of the RMP.
2. The BLM is responsible for preparing mineral reports on tracts of land under BLM jurisdiction that have been identified for potential disposal, exchange, or withdrawal. Mineral reports are prepared to assess the mineral potential and value of lands identified for possible disposal and to determine if such lands are to be retained in Federal ownership because of their mineral value.
3. The geologic information in these documents is used to make decisions in other activities related to energy and/or mineral resources (for example, land exchange and mineral claim validity).
4. The reports are valuable reference documents for the BLM, both in the information provided and in the references cited. They can be used to train new and seasoned employees by providing geologic and mineral information not previously available in a single report, and will be used to help manage other BLM programs within the Roswell District, including public relations, wildlife, cultural resources, and cave and karst programs.

Methodology

The types of studies conducted by the two agencies, USBM and USGS, differed as a result of variation in the inherent responsibilities of the two agencies, variation in expertise of involved personnel, and dissimilarity in budgetary and time constraints.

Field investigations were conducted by the USBM over a 2-year period. Previously published geologic reports on subsurface geology and mineral deposits and unpublished information from the New Mexico Bureau of Mines and Mineral Resources (Socorro, Mew Mexico) were reviewed. Caliche, clay, coal, gypsum, limestone, rock chip, aggregate, and sand samples were collected. Selected mine workings were mapped and sampled in seven mining districts. Caliche, igneous rock, and limestone aggregate samples were tested using the Los Angeles Abrasion and Sodium Sulfate Soundness test to determine wear and freeze-thaw properties. Clay samples were

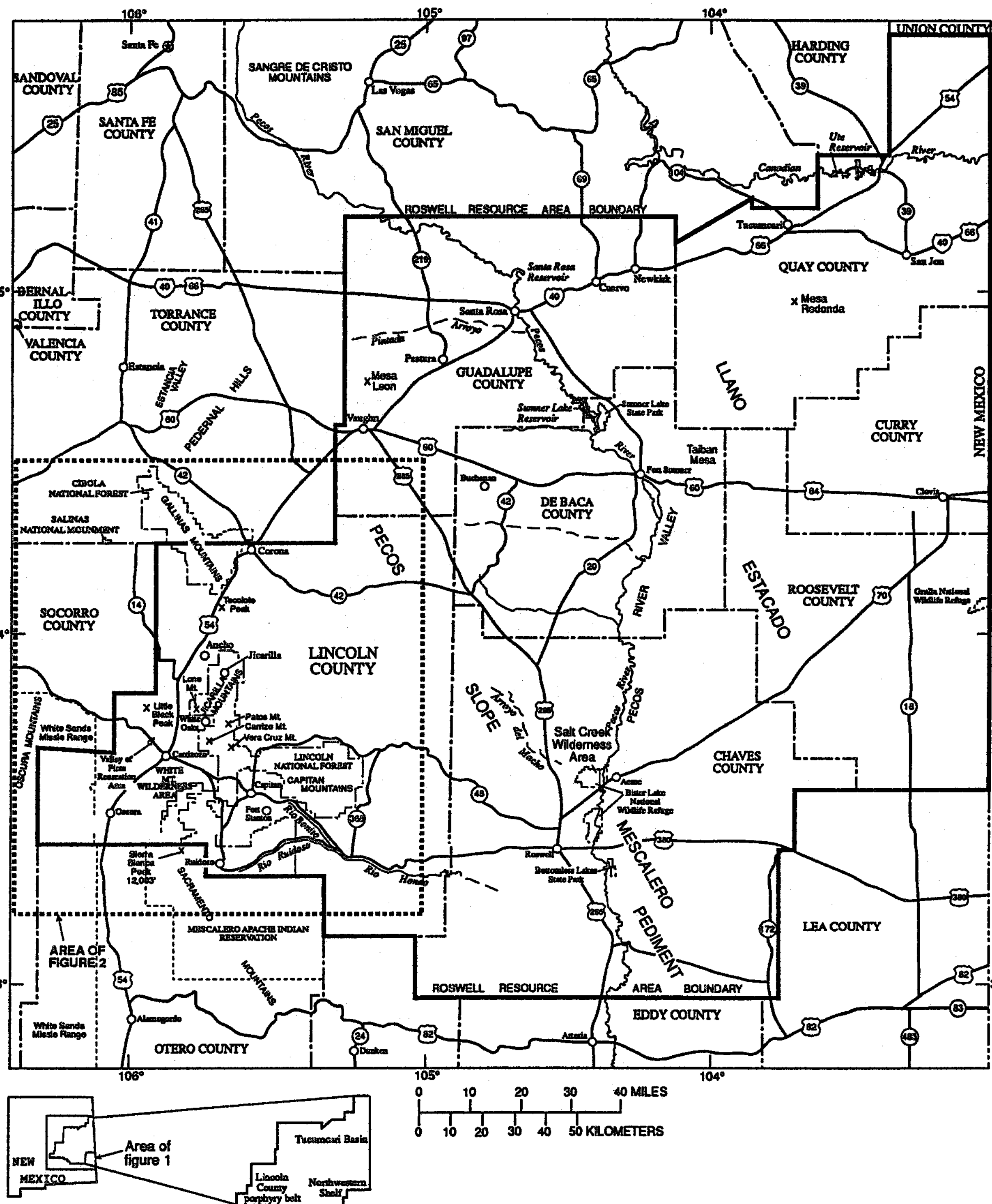


Figure 1. East-central New Mexico, showing location of the Roswell Resource Area; Federal and State parks, refuges, and monuments; counties; and physiographic features mentioned in text. Area of figure 2 is enclosed by a dashed line.

tested for bloating, raw properties, and slow firing properties to determine and evaluate ceramic and lightweight aggregate characteristics. Coal vitrinite measurements were used to determine coal rank. Gypsum was analyzed for free and combined water content to determine its purity. Limestone and sand were analyzed for calcium carbonate, silicon dioxide, and other elements. The rock chip samples were analyzed for gold and 33 other elements.

Limited field investigations of less than one month were conducted by the USGS. All available previously published geologic reports and maps on surface and sub-

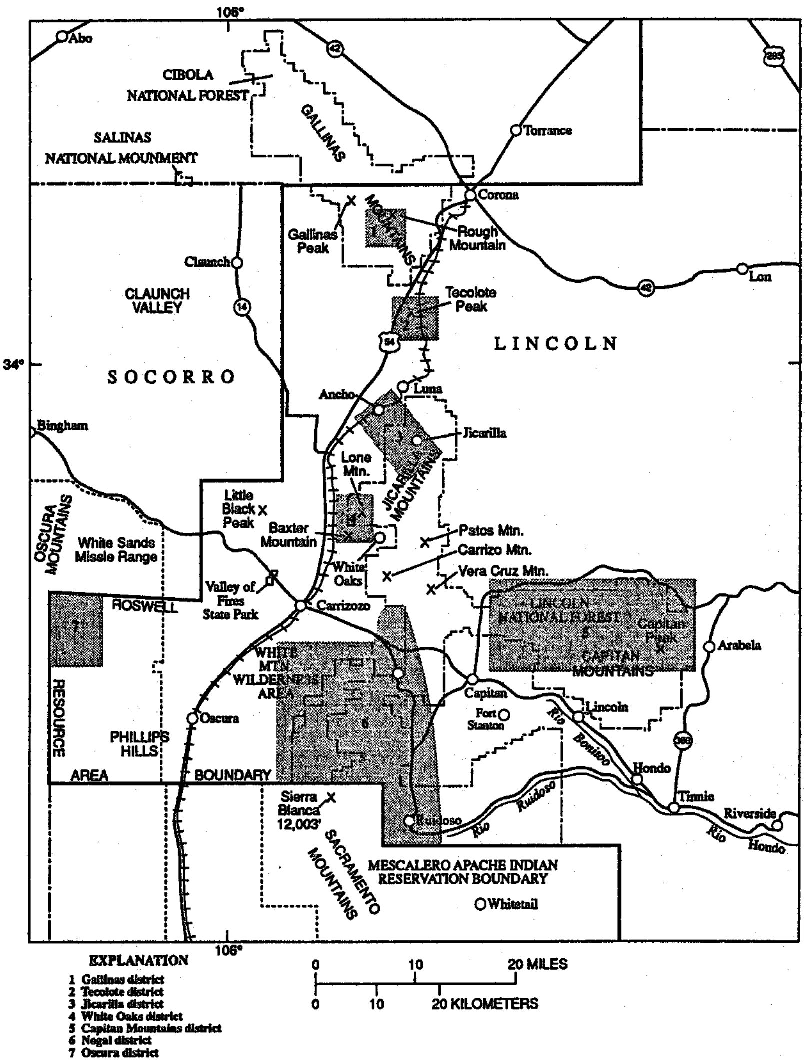
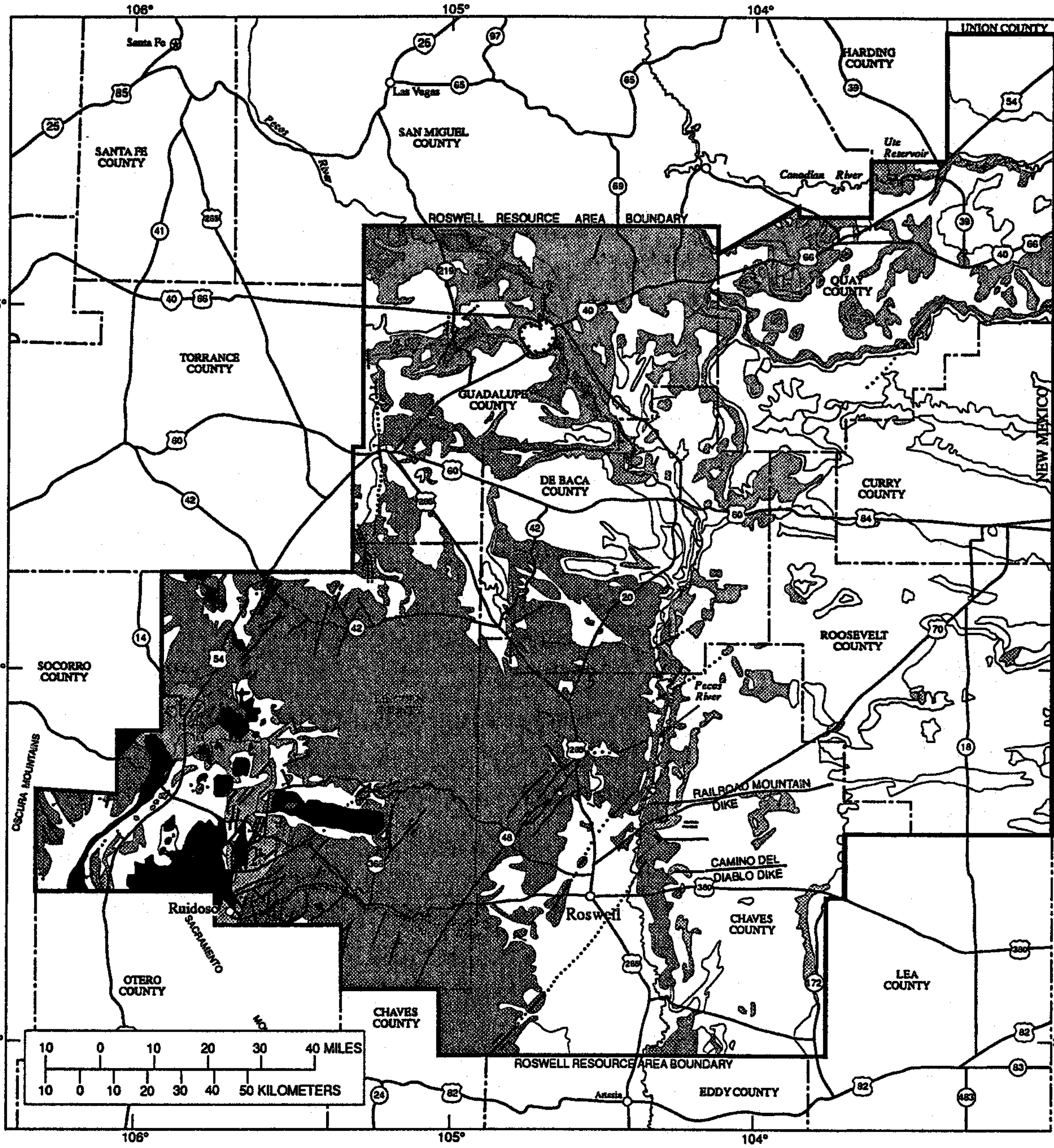


Figure 2. Mining districts of the Lincoln County porphyry belt, Roswell Resource Area.

surface geology and mineral occurrences were summarized, and unpublished information from sources including the Anaconda Collection (University of Wyoming, Laramie, Wyoming), New Mexico Bureau of Mines and Mineral Resources (Socorro and Albuquerque, New Mexico), and the Bureau of Land Management (Roswell, New Mexico) were reviewed. Data from the National Uranium Resource Evaluation (NURE) surveys were used in both geochemical and geophysical studies. Aeromagnetic data are from the Composite Residual Total Intensity Aeromagnetic Map of New Mexico (Cordell, 1983); gravity data were provided by the University of Texas at El Paso. Mineral deposit tracts were outlined and mineral deposit types identified (where possible) for predicting the amounts of various commodities using computer simulation techniques. Syntheses of oil and gas resources data in the study area and previously published regional assessments were undertaken to delineate oil and gas plays in the Roswell Resource Area.

Geologic and Tectonic Setting

The Resource Area includes three major geologic terranes: (1) the Lincoln County porphyry belt that includes the western half of Lincoln County and contains most of the known and potential metallic mineral deposits (figs. 1, 2); (2) the Northwestern Shelf of the Permian Basin in the central and southeastern part of the study area, the area most important to oil and gas, and to industrial mineral exploration and production; and (3) the Tucumcari Basin, in the northern part of the study area, that may contain small undiscovered petroleum reserves. Exposed formations in the study area are mostly marine limestone, dolomite, and evaporite of late Paleozoic (Permian) age, and terrestrial and marine clastic rocks of Mesozoic and Quaternary age that lie above warped and faulted granitic and metamorphic Precambrian basement rocks and overlie lower to upper Paleozoic sedimentary marine rocks in the subsurface (figs. 3, 4). Exposed Paleozoic and younger sedimentary rocks contain signifi-



cant quantities of identified and potential industrial commodities, especially gypsum. In Laramide (Late Cretaceous and Tertiary) time, surface and subsurface Mesozoic and older sedimentary units were intruded by alkaline laccoliths and stocks, and overlain by volcanic rocks (the Sierra Blanca Igneous Complex and related intrusive rocks and veins in the Lincoln County porphyry belt), resulting in uplift and tilting of the Paleozoic and Mesozoic clastic and carbonate sequences to the east-southeast toward the Northwestern Shelf of the Permian Basin. These tilted units are deformed by small-scale faults and folds that have been reactivated at various times in the geologic past. Tilting and repeated deformation contributed to dissolution of the evaporite-bearing Paleozoic shelf rocks and development of karst terrane. Post-Tertiary deposits include Tertiary and Quaternary alluvium, gravel, and basalt.

Geochemical Investigations

Results of analyses on nearly 6,000 NURE samples were used in this study. Because the samples were collected and analyzed by two contract laboratories (at Los Alamos, New Mexico, and Oak Ridge, Tennessee), the results were difficult to compare and interpret (Erdman and others, 1992). Patterns were identified for ore-related elements on a broad regional basis; the data identified lo-

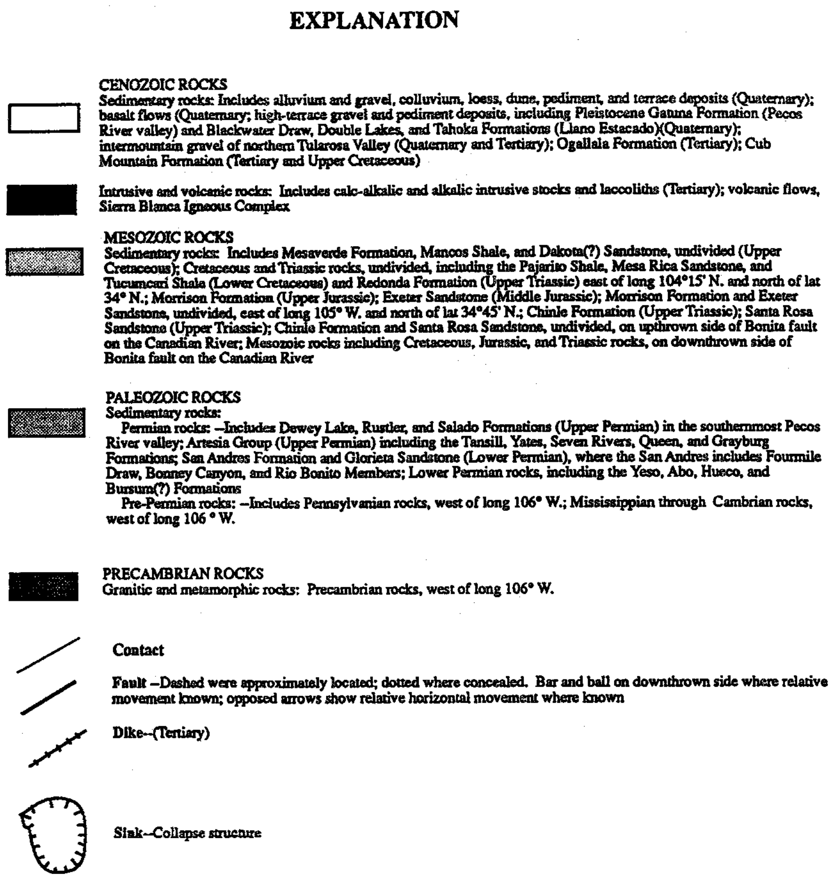


Figure 3. Generalized geologic map of the Roswell Resource Area (modified from New Mexico Geological Society, 1982).

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cally anomalous areas that may relate to underlying structures serving as conduits for metal-rich fluids. A potentially significant hazard to human health was recognized in certain groundwater samples with reported high levels of uranium.

Geophysical Investigations

Aeromagnetic and gravity data provide important information on geophysically identified basement rocks and faults that may affect regional mineral and petroleum exploration. Geophysical results indicate the presence of dense and/or basement rocks that have been inferred to be a subsurface extension of the exposed intrusive rocks of the Lincoln County porphyry belt. This subsurface extension of intrusive rock underlies exposed Permian carbonate rock like those that host mineral deposits in the porphyry belt (Kulik, 1992) (figs. 3, 4) and suggests possible sites of undiscovered mineral occurrences in these rocks or those adjacent to them. Additionally, geophysical data show that northeast-trending faults east of the porphyry belt (fig. 4) probably have a greater subsurface extent than is indicated by surface exposures, and that the faults may form additional structural and stratigraphic traps in Permian and pre-Permian rocks of the Northwestern Shelf that are significant in hydrocarbon exploration.

Reprocessed aerial gamma-ray data were interpreted from the NURE data set (Duval, 1992). Results show that the most radioactive rock units, mostly located in the western part of the study area, are Cenozoic volcanic rocks and alkalic intrusions, Mesozoic and Cenozoic sedimentary rocks rich in volcanic constituents, and Cenozoic gravel deposits.

Occurrence and Production

Metallic Minerals

Gold, copper, silver, lead, zinc, and rare-earth elements occur in seven mining districts in Lincoln County, including the Capitan Mountains, Gallinas (Red Cloud), Jicarilla, Nogal, Oscura, Tecolote, and White Oaks districts (fig. 2). Only a small number of grade and tonnage estimates are available for resources in deposits within

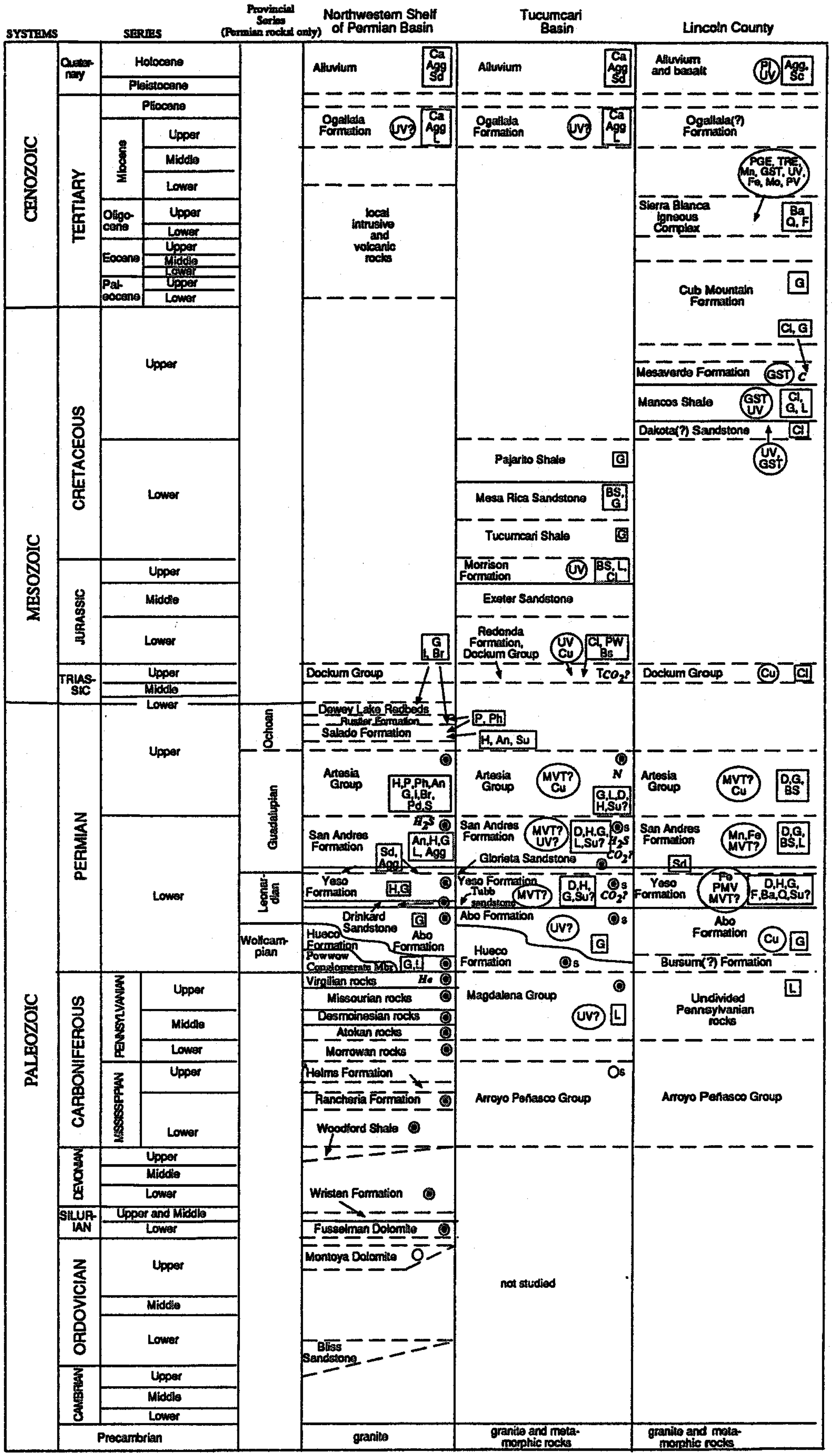
SYSTEMS
SERIES
Provincial Series (Permian rocks only)
Northwestern Shelf of Permian Basin
Tucumcari Basin
Lincoln County
CENOZOIC
MESOZOIC
PALEOZOIC
Quaternary
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper
Middle
Lower
Upper and Middle
Precambrian
Ochoan
Guadalupian
Leonardian
Wolfcampian
Alluvium
Ogallala Formation
local intrusive and volcanic rocks
Dockum Group
Dewey Lake Redbeds
Rustler Formation
Salado Formation
Artesia Group
San Andres Formation
Yeso Formation
Drinkard Sandstone
Abo Formation
Hueco Formation
Powwow Conglomerate Mbr
Virgilian rocks
Missourian rocks
Desmoinesian rocks
Atokan rocks
Morrowan rocks
Helms Formation
Rancheria Formation
Woodford Shale
Wristen Formation
Fusselman Dolomite
Montoya Dolomite
Bliss Sandstone
granite
Pajarito Shale
Mesa Rica Sandstone
Tucumcari Shale
Morrison Formation
Exeter Sandstone
Redonda Formation, Dockum Group
Glorieta Sandstone
Tubb sandstone
Magdalena Group
Arroyo Peñasco Group
not studied
granite and metamorphic rocks
Alluvium and basalt
Ogallala(?) Formation
Sierra Blanca Igneous Complex
Cub Mountain Formation
Mesaverde Formation
Mancos Shale
Dakota(?) Sandstone
Bursum(?) Formation
Undivided Pennsylvanian rocks
Ca Agg Sd
Ca Agg L
UV?
PI UV
Agg, Sc
PGE, TRE, Mn, GST, UV, Fe, Mo, PV
Ba Q, F
G
Cl, G
GST
C
GST UV
Cl, G, L
Cl
UV, GST
BS, G
UV
BS, L, Cl
G L, Br
UV Cu
Cl, PW Bs
TCO_2?
Cu
P, Ph
H, An, Su
H,P,Ph,An G,I,Br, Pd,S
MVT? Cu
N
G,L,D, H,Su?
D,G, BS
H_2S
An,H,G L, Agg
Sd, Agg
MVT? UV?
D,H,G, L,Su?
H_2S CO_2?
Mn,Fe MVT?
D,G, BS,L
Sd
H,G
D,H, G,Su?
CO_2?
Fe PMV MVT?
D,H,G, F,Ba,Q,Su?
G,I
He
L

Table 1. Total reported past production, Roswell Resource Area, New Mexico (Korzeb and Kness, 1993; Sutphin and Bartsch-Winkler, 1992).

Commodity	Production
Copper	7,092 st
Gold	194,000 oz
Silver	161,476 oz
Lead	909 st
Zinc	9 st
Iron ore	270,000–320,000 st
Tungsten	34 st
Manganese	small
Rare-earth concentrates	73 st
Caliche	2,694,243 cu yd (1978–91)
Fire clay	Unknown
Gypsum	Unknown
Limestone, dolomite (aggregate)	Unknown
Fluorspar concentrates	1,608 st
Tar sand	153,000 st
Coal	625,000 st
Uranium (U_3O_8)	91 lbs
Vanadium (V_2O_5)	84 lbs

st = short tons; oz = ounces; cu yd = cubic yard; lbs = pounds. Unknown means records are not available.

Table 2. Reported identified mineral resources, listed by commodity, for mines and deposits in the Roswell Resource Area, New Mexico (Sutphin and Bartsch-Winkler, 1992).

Commodity	Identified resources (short tons, st)
Gold	33.9
Copper	7,494
Iron	2,975,400
Fluorspar	50,692
Molybdenum	20,938
Rare-earth oxides	281
Clay	117,914
Thorium oxide	134
Gypsum	5,565,100,000
Coal	1,763,200,000

the Roswell Resource Area (table 1). Most of the commodities are found in deposits linked genetically to igneous rocks, where they occur as mineralized breccias and fractures, fissure veins, skarns, disseminated and replacement deposits, and associated placers. More than an estimated $600 million worth of resources of gold, copper, iron, fluorspar, molybdenum, rare-earth oxides, and thorium have been identified (table 2).

Gold placers containing minor amounts of silver and possibly rare platinum-group elements occur in several of the area's districts. The Jicarilla district, possibly the largest identified low-grade placer resource in the State, reportedly contains nearly 18 short tons of gold. The White Oaks district, the major gold producer in the study area, produced gold and tungsten from vein deposits. In 1949, iron resources of the Capitan skarn deposit were estimated to be about 3 million short tons (st) of iron ore. Iron ore was also produced from the Tecolote district. The Nogal Peak porphyry molybdenum deposit is estimated to contain about 19,000 st of molybdenum, but it has also produced copper, gold, lead, silver, and zinc. The Gallinas (Red Cloud) district produced copper, fluorite, iron ore, lead, rare-earth elements, and silver. Copper and zinc were produced from the Oscura district.

Gold. Gold was probably the first metallic commodity to be commercially mined in the Roswell Resource Area and has the highest production value of metallic deposits. Total gold production from lodes and placers in the study area is about 194,000 oz. Search for the source of placer gold resulted in discovery of the lode gold deposits. The gold occurs in lode Tertiary veins and associated alkalic intrusive rocks, in Upper Cretaceous Mesaverde Formation shale near these rocks, and in placers derived from them. Veins commonly occur where alkaline igneous rocks have intruded through disrupted Precambrian basement into Paleozoic or Mesozoic sedimentary or volcanic rocks. At White Oaks, a breccia pipe that hosts gold shows evidence of at least four episodes of alteration, with gold mineralization associated with the youngest episode. A total of 152,373 oz of gold was produced from White Oaks lodes, mostly between 1879 and

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Figure 4. Correlation chart showing stratigraphic relations of rock units in the three provinces and commodities occurring or having potential to occur in the Roswell Resource Area. DEPOSITS AND PROSPECTS (Queried where potential for occurrence exists)

Metallic Minerals: Cu = Sediment-hosted copper; Fe = Iron skarn; GST = Gold-silver tellurium veins; Mn = Replacement manganese; Mo = Porphyry molybdenum-low fluorine; MVT = Mississippi-Valley-type lead-zinc; PGE = Platinum-group elements; PMV = Polymetallic veins; Pl = Placer gold, titanium; TRE = Thorium-rare-earth veins; UV = Uranium and vanadium (mostly sandstone-hosted).

Industrial and other Minerals: Agg = Aggregate; Ba = Barite; Br = Bromine (brine); BS = Building or decorative stone; Ca = Caliche; Cl = Clay; D = Dolomite; F = Fluorspar; G = Gypsum; I = Iodone (brine); L = Limestone; Pd = "Pecos diamonds;" PW = Petrified wood; Q = Quartz crystals; S = Salt; An = Anhydrite; H = Halite; PH = Polyhalite; P = Potash; Sc = Scoria; Sd = Sand and gravel; Su = Sulfur.

Oil and Gas: O Gas; ◉ Oil and gas; T Tar sand, heavy oil; s = show.

Associated Gases and Coal: A = associated gas (type not specified); N = Nitrogen; He = Helium; CO_2 = Carbon dioxide (Bravo Dome); H_2S = Hydrogen sulfide; C = Coal.

1930. A subeconomic inferred gold resource was identified on BLM land on the northeast edge of the patented mining claims in the White Oaks district. This inferred resource consists of 5,000 st of material with a grade of 381.7 ppb (0.01 oz/st) gold. This resource is too small and too low in grade to be mined at the present time.

Copper. Copper was produced from the Pastura mining district north of Pastura along Pintada Arroyo in Guadalupe County (fig. 1) from the Pintada and Stauber mines; the mines have produced both from underground and open-pit operations. In the Pastura district, 6,879 st of copper, 23 st of lead, 8,466 oz of silver, and 2 oz of gold were produced from the Upper Triassic Santa Rosa Sandstone of the Dockum Group (fig. 4). Ore at the Pintada mine, ranging from 1.7 percent to 5.6 percent copper, consisted of patches, streaks, and disseminated chalcocite in fine-grained, well-cemented sandstone of the Upper Permian Artesia Group. The Oscura district, now within the White Sands Missile Range in western Lincoln County, produced an estimated 21.1 st of copper and 124 oz of silver from 234 st of ore.

Silver. Silver has been produced as a by-product of base-metal mining in intrusive, volcanic, and intruded sedimentary rocks. The Gallinas (Red Cloud) district produced about 23,723 oz of silver between 1909 and 1955; Nogal district produced about 20,000 oz between 1868 and 1942. Silver has also been produced from copper ore of the Pastura and Oscura districts.

Base Metals (Copper, Lead, Zinc). Numerous small veins, some in iron skarn deposits, were worked from 1904 to 1955 in the Gallinas (Red Cloud) district for copper, lead, zinc, and silver. The district produced about 193 st of copper, 863 st of lead, and about 8.7 st of zinc.

Iron. Of the counties in the study area, only Lincoln County has iron deposits and historical iron ore production. The iron ore occurs as pyrometasomatic replacements (skarns) in Lower Permian carbonate rocks of the Yeso and San Andres Formations (fig. 4). There are approximately 24 known deposits in the Capitan Mountains, Tecolote, Gallinas (Red Cloud), Jicarilla, and White Oaks districts. Total production for the study area is 270,000 to 320,000 st of iron ore.

Tungsten. Tungsten was produced intermittently from 1915 to 1952 in the White Oaks district; a reported 60 st of tungsten concentrate containing 56.8 percent tungsten trioxide was produced. Tungsten was not recognized as being of economic importance in the early days of mining, and much of the later production came from waste dumps.

Manganese. Manganese was mined from a replacement manganese deposit in the northeastern Capitan Mountains at some time between 1959 (when the deposit was described as a promising prospect) and 1983. At least one short ton of concentrate containing 54 percent manganese was shipped. Crude estimates from abandoned workings and measurements of the mined trench indicate that as much as several thousand tons of manganese ore may have been produced.

Rare-Earth Element Minerals. Numerous small bastnaesite-bearing deposits occur in the eastern Gallinas Mountains in polymetallic veins and mineralized breccias in Yeso Formation sandstone adjacent to or near alkalic intrusive rocks. Many of the rare-earth element minerals occur in faults and breccia pipes where fluorite is the principal ore mineral. As much as 60 st of bastnaesite concentrate was extracted from 1920 to 1955. The Gallinas (Red Cloud) district is estimated to contain about 28,000 st of material with 1.4 percent bastnaesite. Thorium rare-earth element mineral veins are known to occur in the Capitan Mountains.

Industrial Minerals

Caliche, clay, decorative rock, aggregate, gypsum, and limestone resources were identified in the Roswell Resource Area. All of these commodities were produced in the past; caliche is currently being mined (fig. 4, tables 1, 2). Only a limited economic analysis of the identified resources is possible, however, because of a lack of detailed production and geologic information.

Caliche. Caliche production reflects hydrocarbon exploration activity in the resource area because this commodity is used in road construction and for slope stability on drill pads. Caliche, a near-surface calcium carbonate deposit that forms by leaching (weathering) of calcium carbonate at the surface and redeposition beneath the surface, is found in surficial Tertiary and Quaternary deposits, principally in the eastern part of the study area (fig. 3). Caliche is sold, mostly to the oil industry, by the BLM. It is mined on an as-needed basis from open pits generally within 2 mi of roads or drill pads. Indurated caprock caliche can be used as a subbase for road construction and for making bituminous asphalt. Production increased from 40,073 cu yd in 1974 to a high of 592,492 cu yd in 1985. In 1987, production dropped to 5,500 cu yd, reflecting a decrease in drilling activity that followed a drop in oil prices. Caliche sales peaked again in 1989 to 500,000 cu yd and then steadily dropped to 55,000 cu yd in 1991. Oil exploration activities are currently down, resulting in a lower demand for caliche.

Clay. Fire clay deposits occur in Lincoln County 2 mi east of Ancho in clay, clay shale, and sandy clay beds of the Upper Cretaceous Dakota(?) Formation. Fire clay was mined by both underground and surface methods from 1902 until 1922. Clay was processed at the Ancho brick plant where structural tile, face brick, and firebrick were produced. An inferred 107,000-st clay resource is identified 2 mi northeast of Ancho. The clay is suitable for making structural clay products, such as building brick, but demand for structural clay products and fire clay has decreased 23 percent from 1989 to 1990. In 1990, the value of common clay ranged from $5 to $36 per ton, and fire clay ranged from $25 to $77 per st, depending on the end product. Specific uses for the clay must be determined before a value can be placed on the clay in the resource area.

Decorative Rock. Decorative rock was mined from the Railroad Mountain diorite dike located 20 mi northeast of Roswell (fig. 3). A basaltic lava flow of approximately 1 mi^3 located 2 mi west of Carrizozo is a resource for decorative rock and a potential source of aggregate used in road construction. Decorative rock in the resource area was mined and sold on an as-needed basis, mostly for local use. There is no present market for this material.

Aggregate. In addition to unconsolidated surficial sources of aggregate, crushed carbonate rocks are used as aggregate for road construction and similar purposes. Aggregate is quarried and crushed when needed. There is currently no steady market for aggregate, and there are no operating aggregate quarries.

Gypsum. In 1902, a gypsum-crushing and calcining plant with a daily capacity of 100 st produced cement plaster, dental plaster, plaster of Paris, and stucco from Lower and Upper Permian evaporite deposits at Ancho, New Mexico (Lincoln County) (fig. 1). Operations ceased prior to 1925. Gypsum was also mined at Acme, New Mexico (Chaves County) (fig. 1), from before 1915 until after 1925, where gypsum beds are as thick as 75 ft. Exact production dates are unknown, and production records are not available. Inferred, high-purity gypsum resources are present in Lower and Upper Permian rocks east of Roswell, New Mexico, extending southward from Acme to Bottomless Lake State Park (fig. 1). Approximately 5.05 billion st of gypsum are estimated to occur in these rocks along the Pecos River east of Roswell, but the value of the gypsum resource is difficult to determine without knowing the percentage of the inferred resource that can be recovered. Crude, unprocessed gypsum averages $6.61 per ton (free-on-board at mine site, 1987–1991); thus, the in-place value for the identified resource along the Pecos River east of Roswell could be as much as $33 billion, if all of the inferred gypsum were recovered. Gypsum is not currently being mined in the resource area, but there may be demand for this resource in the future. A decrease in construction activity in the last two years has resulted in a lower demand for gypsum products (used primarily in the manufacture of wallboard).

Carbonate Rock. Limestone production from the Roswell Resource Area is not recorded, but limestone was produced for use as aggregate on an as-needed basis by the New Mexico Highway Department (see previous discussion). Carbonate rock resources that can be used in lime manufacturing and crushed for aggregate are found in the gently dipping Lower Permian San Andres Formation. Inferred carbonate rock resources consisting of dolomitic limestone, high-magnesium dolomite, and high-purity dolomite are found in Lincoln County and the western half of Chaves County, but resources of ultra-high-calcium and high-calcium limestone are small.

Fluorspar. Fluorspar occurs in three areas of Lincoln County: the Gallinas (Red Cloud) district (mined from 17 deposits), the Julia Ann prospect on Lone Mountain (no reported production), and the Capitan Mountains (fig. 1). Fluorspar was probably produced from gangue in earlier mined lead and copper ores near intrusive and volcanic rocks and veins. Fluorspar occurs in disseminations, brecciated zones, and along contacts and faults in intruded sedimentary rocks of the Lower Permian Yeso Formation. Grade and quality of the fluorspar are irregular and variable. Fluorspar production in Lincoln County totaled 1,608 st as of 1966 (table 1).

Energy and Associated Resources Production

Petroleum. Twenty oil and 12 gas fields have a cumulative production, through 1988, each exceeding one million barrels of oil equivalency (Ball and others, 1992) (figs. 4, 5, tables 3, 4). Total liquids recovered from these fields are 225 million barrels; total gas amounts to 830 billion cu ft. Nearly all production has occurred in Chaves and Roosevelt Counties.

Caprock field (fig. 5), discovered in 1940, has produced 33 percent of the oil in the resource area; fields discovered in the 1950's have produced 24 percent of the oil. The 1960's were the decade of discovery for most of

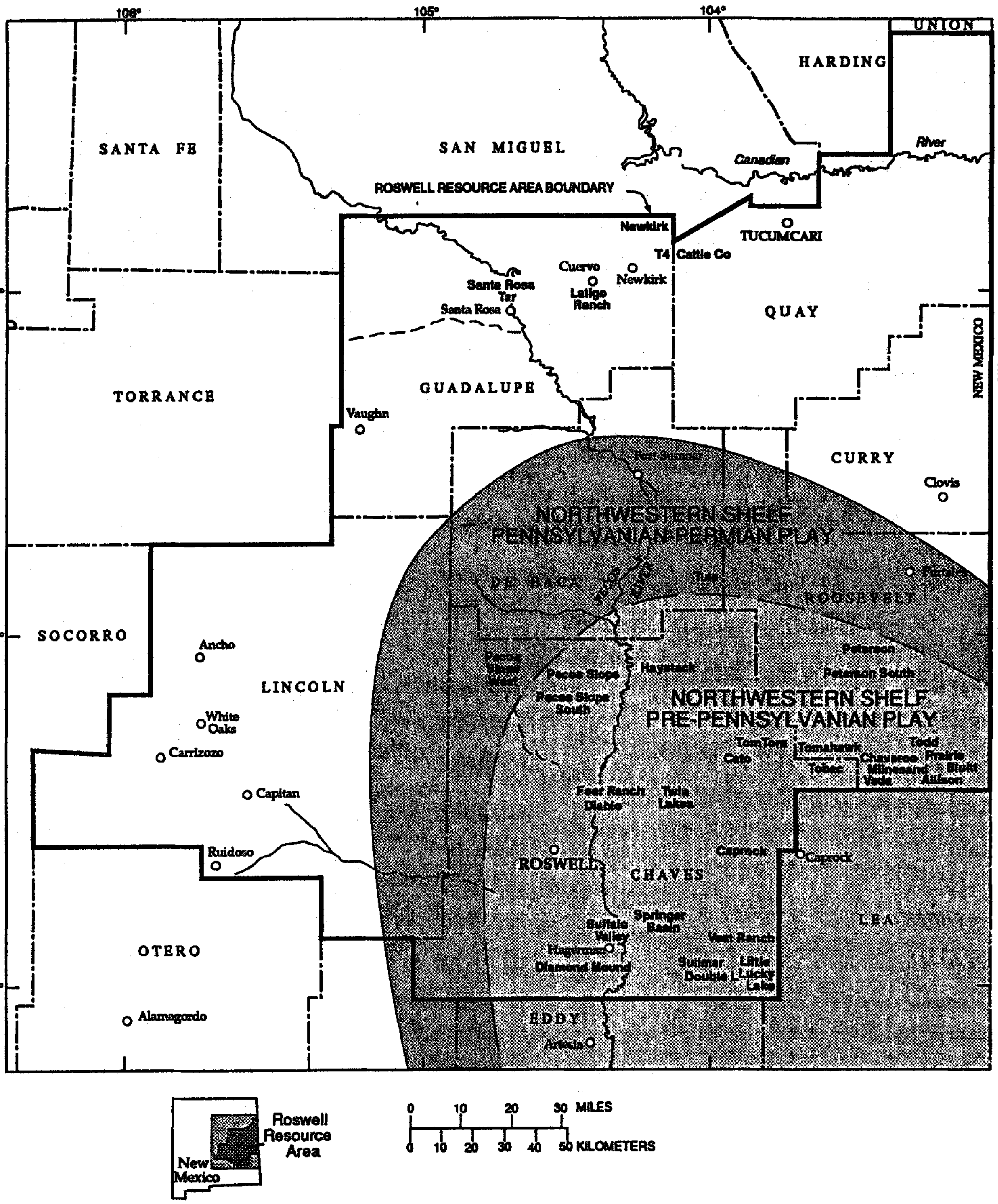

Figure 5. Approximate location of oil and gas fields and hydrocarbon plays in the Roswell Resource Area and vicinity. Northwestern Shelf Pennsylvanian-Permian play boundary = solid line; Northwestern Shelf pre-Pennsylvanian play boundary = dashed line.

the oil produced, with a total of 88.6 million barrels produced, constituting 39 percent of the total for the area. Only 3 percent of the oil produced was from fields found in the 1970's, and 1 percent was from fields discovered in the 1980's. The history of oil production indicates that exploration activity in the area is in a mature state, a characteristic typical of the Permian Basin province.

Pecos Slope gas fields (fig. 5), discovered between 1977 and 1980, have produced 317 billion cu ft of gas (38 percent of the area's total). Fields having produced 33 percent of the area's total were discovered in the 1950's. Sixteen percent of the area's gas was discovered during the 1960's, 39 percent during the 1970's, and 12 percent during the 1980's.

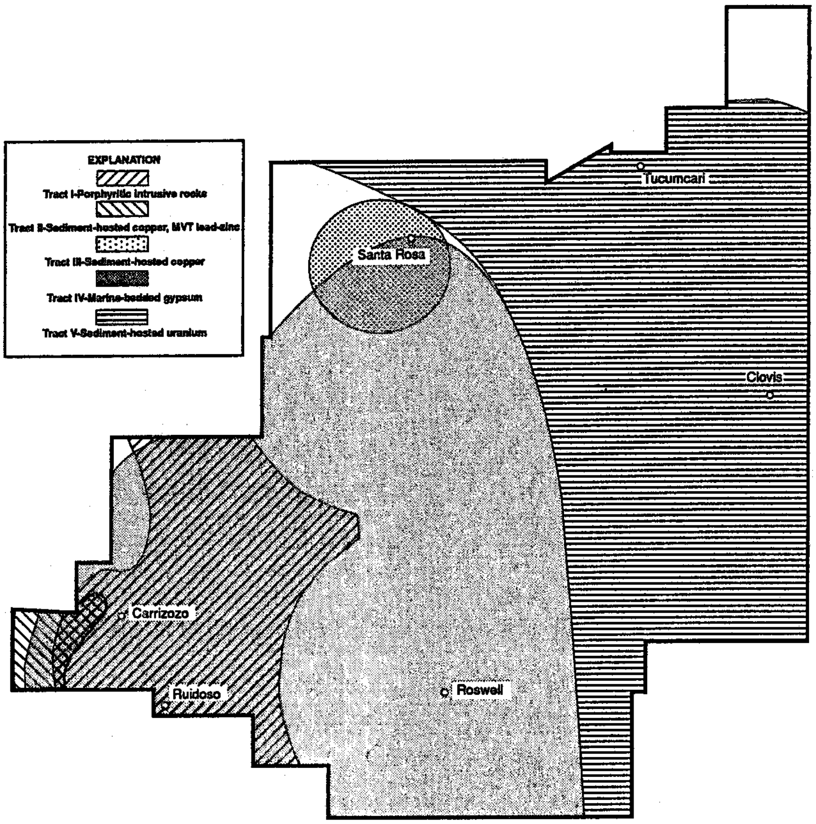

Figure 6. Mineral resource tracts, Roswell Resource Area.

Tar Sand and Heavy Oil. Tar sand for use in bituminous pavement was produced from the Dockum Group north of Santa Rosa in Guadalupe County (fig. 5). The deposits are partly covered by the Santa Rosa Reservoir (fig. 1) and can no longer be recovered. Heavy oil was recovered in the 1980's from the Santa Rosa Sandstone tar sands on an experimental basis at the Newkirk (O'Connell Ranch) field several kilometers north of Newkirk (fig. 5).

Coal. Coal was produced in the Sierra Blanca coal field (Lincoln County) from the Upper Cretaceous Mesaverde Formation that encircles the northern end of the Sacramento Mountains west of Capitan, New Mexico (fig. 5); it extends southward along the east and west flanks of the range. Coal mining in 13 mines took place from 1880 through World War II. Production totaled 625,000 st, but ceased because of difficulty in mining related to faulting, steepness and lenticularity of beds, and igneous intrusion. An inferred coal reserve of approximately 1.6 billion st of low-sulfur and medium- to high-ash content, with a rank of high-volatile-C bituminous rank occurs in the Sierra Blanca coal field, but there is no demand for the coal resource in the study area. Today the coal is uneconomical to mine because of structural complications, including faulting and lenticularity of bedding. In addition, the coal would require cleaning to reduce the high ash content, further increasing the production cost.

Uranium and Vanadium. A uranium boom occurred in eastern New Mexico in the early 1950's. Uranium was produced in the resource area from three prospects located in Quay County. From these prospects, a total of 30 st of uranium ore was produced yielding 90 lbs of uranium oxide (Finch and others, 1992). In Chaves, De Baca, Guadalupe, and Quay Counties, 21 uranium occurrences are documented. A small amount (82 lbs) of vanadium pentoxide was produced near San Jon, Quay County, New Mexico (fig. 1), as a by-product of uranium production; in Lincoln County, 2 lbs of vanadium pentoxide was produced from a uraniferous hydrothermal magnetite vein (Breit, 1992). Because all uranium mines in New Mexico are idle because of lack of demand, it is unlikely that these uranium and vanadium deposits will be developed in the near future.

Potential for Undiscovered Mineral Resources

The USGS delineated tracts favorable for the occurrence of various types of undiscovered mineral deposits and, where feasible, estimated the probable number of undiscovered deposits of each type within numbered tracts (fig. 6, tables 5, 6) (Sutphin, 1992). These estimates are

Table 3. Geological, engineering, and production parameters of oil fields exceeding cumulative production of 1 million barrels of oil equivalency through 1988 in the Roswell Resource Area (Ball and others, 1992).

Field name	County	Reservoir	Discovery date	Depth to top (ft)	Trap type[a]	Net pay thickness (ft)	Porosity (%)
Caprock	Chaves	Queen Formation sandstone	1940	2,971	Strat	10	21
Allison	Roosevelt	Virgilian limestone Cisco Group	1954	9,490	Comb	11	7
Chaveroo	Roosevelt	San Andres Formation dolomite	1965	4,184	Comb	40	6
Cato	Chaves	San Andres Formation dolomite	1966	3,496	Comb	33	8
Milnesand	Roosevelt	San Andres Formation dolomite	1958	4,534	Strat	40	8
Tobac	Chaves	Virgilian limestone Cisco Group	1964	9,058	Comb	10	7
Vada	Roosevelt	Virgilian limestone Cisco Group	1966	9,792	Strat	10	8
Todd	Roosevelt	San Andres Formation dolomite	1963	4,202	Comb	40	4
Twin Lakes	Chaves	San Andres Formation dolomite	1950	4,266	Comb	—	7
Peterson South	Roosevelt	Silurian dolomite Virgilian limestone	1978	7,808	Comb	10	8
Prairie	Roosevelt	Virgilian limestone	1960	9,651	Comb	24	6
Bluitt	Roosevelt	San Andres Formation dolomite	1951	4,500	Comb	30	8
Double L	Chaves	Queen Formation sandstone	1969	1,920	Strat	6	22
Tom Tom	Chaves	San Andres Formation dolomite	1967	3,914	Comb	20	7
Peterson	Roosevelt	Virgilian limestone	1971	7,542	Comb	—	—
Tomahawk	Chaves	San Andres Formation dolomite	1967	3,914	Comb	22	7
Sulimar	Chaves	Queen Formation sandstone	1968	2,028	Strat	6	20
Milnesand	Roosevelt	Virgilian limestone	1956	9,125	Comb	—	3.6
Diablo	Chaves	San Andres Formation dolomite	1962	2,060	—	—	—
Bluitt	Roosevelt	Silurian-Devonian	1987	8,845	—	—	—

— None reported.

[a] Strat, stratigraphic; comb, structural/stratigraphic.

[b] Permeability in millidarcies.

[c] Natural gas liquids.

[d] Sour, high sulfur content; sweet, low sulfur content; T°, bottom hole temperature in degrees Fahrenheit; GOR, gas to oil ratio in cubic ft/barrel.

used in the MARK-3 mineral-resource Monte Carlo simulation program (tracts I–IV; Drew and others, 1986) and in the Deposit-Size-Frequency (DSF) statistical method for uranium (tract V; Finch and McCammon, 1987). The amount of material in the undiscovered deposits in five tracts within the Roswell Resource Area was calculated for the 90-, 50- (median), and 10-percent probability levels (Sutphin, 1992; Finch and others, 1992). The undiscovered mineral resource estimates are incorporated into the overall BLM land-use plan.

Tract Delineation Criteria and Estimated Quantities of Assessed Mineral Commodities

Grades and tonnages of the same type of mineral deposits and occurrences in the Roswell Resource Area were compared to mineral deposit models. Estimates were made

Table 3. Extended.

Field name	kmd[b]	API gravity	Drive	Initial pressure (psi)	Oil and NGL[c] cumulative production (MMBOE)	Gas (BCF)	Miscellaneous[d]
Caprock	250H 150V	38	Solution gas	900	74	—	S = 1.07% $>N_2$, T° = 154f
Allison	200	48	Water	—	26	51	Sweet[e]
Chaveroo	0.7	26	Solution gas	1,340	26.2	31.4	Sour,[f] GOR = 810, T° = 110f
Cato	1.0	26	Solution gas, water	1,116	17.4	30	Sour, T° = 100f
Milnesand	1.0	29	Solution gas, water	1,100	14.5	14.7	Sour, T° = 90F f
Tobac	100	44	Solution gas, water	3,083	10.1	12.4	Sweet
Vada	150	47	Solution gas, water	2,800	9.4	26.6	Sweet, T° = 145f
Todd	—	24	Solution gas	1,339	4.0	19.2	Sour, T° = 102f
Twin Lakes	—	24	Solution gas	700	4.8	5.4	Sour, T° = 100f
Peterson South	20	46	Solution gas	2,634	4.3	15.3	Sweet, T° = 152f
Prairie	90	49	Water	3,159	4.0	6.9	Sweet, T° = 186f
Bluitt	5	27	Solution gas	1,515	4.0	14.7	Sour, T° = 105f
Double L	40	35	Gas cap, solution gas	743	3.9	5.8	$>N_2$ (55%), T° = 84f
Tom Tom	2	25	Solution gas	1,192	3.2	2.0	Sour, T° = 100f
Peterson	—	35	—	—	1.6	5.7	—
Tomahawk	—	26	Solution gas	1,302	2.2	1.9	Sour, T° = 102f
Sulimar	150	35	Solution gas	—	2.3	0.8	$>N_2$ (55%)
Milnesand	1.4	44	Solution gas	—	1.0	1.7	Sweet
Diablo	—	30	—	—	1.0	—	—
Bluitt	—	—	—	—	1.0	—	—

of the numbers of deposits of the types known or expected to occur in the Roswell Resource Area and having grade and tonnage models (table 5). When combined with estimates of the numbers of deposits that may be located in an area, statistical methods can be applied to grade and tonnage models to obtain estimates of the area's undiscovered mineral resources.

The technique used in estimating the undiscovered mineral resources is based upon the three-step type of assessment described by Singer and Ovenshine (1979). The steps are (1) using known geological, geochemical, and geophysical characteristics to delineate tracts that may contain specific deposit types; (2) estimating the probabilities that a certain number of undiscovered deposits exist in these tracts; and (3) estimating the amount of a given commodity contained in the undiscovered

Table 4. Geologic, engineering, and production parameters of gas fields exceeding cumulative production of 1 million barrels of oil equivalency (6BCF = 1 MMBOE) through 1988 in the Roswell Resource Area, New Mexico (Ball and others, 1992).

Field name	County	Reservoir	Discovery date	Depth to top (ft)	Trap type[a]	Net pay thickness (ft)	Porosity (%)
Pecos Slope	Chaves	Abo, Formation sandstone	1977	4,406	Strat	30	13
Buffalo Valley	Chaves	Atokan sandstone	1959	8,181	Strat	22	12
Bluitt (Wolfcamp)	Roosevelt	Wolfcampian limestone	1959	8,022	Strat	36	13
Foor Ranch	Chaves	Silurian Fusselman Dolomite	1981	6,154	Struct, drive	10	13
Pecos Slope West	Chaves	Abo Formation sandstone	1980	2,923	Strat	20	14
Pecos Slope South	Chaves	Abo Formation sandstone	1979		Strat		14
Little Lucky Lake	Chaves	Silurian & Devonian dolomite	1958	11,050	Comb	84	6
Diamond Mound	Chaves	Atokan-Morrowan sandstone	—	—	—	—	—
Tule	Roosevelt	Pennsylvanian limestone	1986	6,759	Comb	10	—
Springer Basin	Chaves	Atokan-Morrowan sandstone	1979	8,050	Strat	8	13
Haystack	Chaves	Virgilian limestone (Cisco Group)	1970	5,832	Comb	11	7
Vest Ranch	Chaves	Queen Formation sandstone	1971	5,999	—	2	—

— None reported.

[a] Strat, stratigraphic; comb, structural/stratigraphic; struct, structural.

[b] Permeability in millidarcies.

[c] Natural gas liquids.

[d] Sour, high sulfur content; sweet, low sulfur content; T°, bottom hole temperature in degrees Fahrenheit.

deposits by means of comparison with the grades and tonnages of known deposits of a similar type. Steps (1) and (2) are conducted by a team of USGS specialists; step (3) uses computer simulation. The USGS assessment team that delineated the mineral-resource tracts and estimated the probabilities of undiscovered deposits in the tracts consisted of specialists in economic geology, geochemistry, geophysics, and mineral-resource assessment who had studied information on the study area and who had briefly visited and sampled many of the locations in that area. The team, guided by R.B. McCammon and D.M. Sutphin, included T.J. Armbrustmacher, S. Bartsch-Winkler, G.N. Breit, J.S. Duval, J.A. Erdman, W.I. Finch, D.M. Kulik, J.K. Otton, C.S. Spirakis, and R.R. Tidball; not every member participated in the assessment of each tract. W.A. Scott executed the computer simulations.

Tracts favorable for the occurrence of undiscovered mineral resources in the Roswell Resource Area were delineated from interpretation of the geology, geochemistry, and geophysics of the area. Geology was used initially to select areas (or tracts) of favorable rock types and to interpret the structure of the surface and subsurface. Geochemical data revealed areas of anomalous values for metals in deposits, such as silver or copper, or for pathfinder elements, such as barium. Maps of geochemical data were used to reduce or expand the areas initially based on the geology, and for detecting targets in areas that might have been overlooked initially. Geophysical maps were used to outline the distribution of rock types in the subsurface. Remote sensing and aeroradioactivity surveys enabled detection of additional anomalies on the surface. The geology, geochemistry, and geophysics of the study area were compared to the geologic environments and characteristics of deposit types until the assessment team agreed upon a consensus on tract borders. A consensus on the types of deposits per-

Table 4. Extended.

Field name	kmd[b]	API gravity	Drive	Initial pressure (psi)	Oil and NGL[c] cumulative production (MMBOE)	Gas (BCF)	Miscellaneous[d]
Pecos Slope	0.03–0.05	54	Solution gas	1,125	4.0	261	Tight gas
Buffalo Valley	High	61.5	Solution gas	3,282	0.9	132	T° = 135f
Bluitt (Wolfcamp)	80	50	Solution gas	—	0.5	36	—
Foor Ranch	—	—	Water	2,377	0.1	36	T° = 120f
Pecos Slope West	0.3	—	Solution gas	—	0.5	30	—
Pecos Slope South	0.3	—	Solution gas	—	0.5	25.5	—
Little Lucky Lake	55	—	—	—	2.1	13.2	—
Diamond Mound	—	—	—	—	0.4	23.3	—
Tule	—	62	—	—	0.1	9.0	—
Springer Basin	—	62.5	Solution gas	3,000	0	7.89	T° = 145f
Haystack	13	56.5	Solution gas, water	2,421	0.1	6.3	T° = 112f
Vest Ranch	—	—	—	—	0.3	4.1	—

missible in the tract and the number of those deposits at the 90-, 50-, and 10-percent probability levels was also reached.

The computer program used to transform estimates of the number of undiscovered deposits into estimates of contained commodities in those deposits is known in the U.S. Geological Survey as MARK-3 (Drew and others, 1986; Root and Scott, 1988; Root and others, 1992). The program requires estimates of the number of undiscovered deposits of a given type within an area. The number of deposits is stated in terms of likelihood of occurrence, resulting in a probability distribution. Computer simulations are performed by selecting simulated deposits from this probability distribution, for each simulated deposit, selecting a grade and tonnage according to probability distributions of the grades and tonnages of known deposits of the given type. Grade and tonnage models used in this report, with a few exceptions, were taken from Cox and Singer (1986), Orris and Bliss (1991), and Bliss (1992). The alkaline-associated gold-silver-tellurium (Au-Ag-Te) veins deposit model (Bliss and others, 1992) was developed for this study, whereas models for epigenetic vein barite (Orris, 1992a) and marine bedded gypsum (Orris, 1992b) are preliminary. For the Roswell Resource Area, new estimates of the undiscovered uranium endowment in Dockum Group rocks were made using the DSF method (Finch and McCammon, 1987). This method was used because no grade and tonnage models are available for use with the MARK-3 mineral-resource simulator.

Tract I includes areas where geophysical evidence suggests shallow Tertiary intrusive bodies; it includes several mining districts and encompasses the most significant identified metal resources in the study area. The assessment team recognized that a large percentage of the exposed intrusions in the Lincoln County porphyry belt

Table 5. Estimated numbers of undiscovered deposits at different probabilities. Estimate for tracts I–IV for use in three-step style of assessment and MARK-3 simulation; the estimates for tract V for use in the Deposit-Size-Frequency (DSF) assessment of uranium, Roswell Resource Area, New Mexico (after Sutphin, 1992; Finch and others, 1992).

Model (commodity)	Probability percentile No. undiscovered deposits		
MARK-3 assessment			
	90	50	10
Tract I—Deposits associated with porphyritic intrusive rocks			
Th-REE vein (ThO_2, REO)	0	1	1
Iron skarn (Fe)	2	4	5
Replacement Mn (Mn, Cu, Fe, P_2O_5)	0	1	1
Porphyry Mo, low F (Mo)	0	1	2
Alkaline-associated Au-Ag-Te (Au)	2	4	8
Polymetallic veins (Au, Ag, Cu, Pb, Zn)	1	2	4
Epigenetic barite veins (barite)	1	1	2
Placer Au-PGE (Au, Ag)	1	2	4
Tract II—Sediment-hosted copper and Mississippi Valley Type lead-zinc			
Sediment-hosted Cu (Cu, Ag, Co)	0	1	2
Mississippi-Valley-Type Pb-Zn (Ag, Pb, Zn)	0	0	1
Tract III—Sediment-hosted copper			
Sediment-hosted Cu (Cu, Ag, Co)	0	0	1
Tract IV—Marine-bedded gypsum			
Bedded gypsum (gypsum)	2	3	4
DSF assessment			
Tract V—Sediment-hosted uranium			
Ogallala Formation (U_3O_8)	2	3	7
Dockum Group (U_3O_8)	23	47	78

Table 6. Estimates of premining tonnages of undiscovered commodities resulting from the MARK-3 Monte Carlo simulation and the Deposit-Size-Frequency (DSF) assessment techniques, Roswell Resource Area, New Mexico (after Sutphin, 1992; Finch and others, 1992).

Commodity	Resource estimate probability range (short tons) .90	.50 (Median)	.10
MARK-3 assessment:			
Tract I—Deposits associated with porphyritic intrusive rocks on the surface and in the subsurface			
Gold	23	290	1,664
Silver	34	260	1,124
Iron	3,438,240	51,353,200	525,654,000
Thoria	0	188	8,794
Rare-earth oxides	0	0	860
Molybdenum	0	54,990	553,204
Manganese	0	852	161,994
Copper	0	8.32	333
Lead	58	4,441	53,006
Zinc	0	1,355	39,672
Barite	521	139,954	1,895,440
Tract II—Sediment-hosted Cu, Mississippi-Valley-Type Pb-Zn			
Silver	0	0	722,912
Zinc	0	0	4,198,620
Cobalt	0	0	90,364
Tract III—Sediment-hosted Cu			
Silver	0	0	0
Copper	0	0	1,366,480
Cobalt	0	0	0
Tract IV—Marine-bedded gypsum			
Gypsum	1.26×10^8	1.95×10^9	2.59×10^{10}
DSF assessment:			
Tract V—Sediment-hosted uranium			
Ogallala Formation	833	1,271	1,771
Dockum Group	0.30	0.61	0.90

had associated mineral deposits with a substantial production history, and that unexposed intrusions had a good chance of having associated mineral deposits. The assessment team predicted a 90 percent probability that the tract contains two or more undiscovered iron skarn and alkaline associated gold-silver-tellurium vein deposits and one or more undiscovered polymetallic vein, epigenetic barite vein, and placer gold-platinum-group-element deposits. There is a 50 percent probability that one or more thorium-rare-earth vein, replacement manganese, and porphyry-molybdenum low-fluorine deposits occur in the tract, and a 10 percent probability that one or more undiscovered fluorite-bastnaesite deposits occurs. The predicted median premining tonnages of commodities contained in undiscovered mineral deposits of selected types (table 6) in tract I are 290 short tons (st) gold, 260 st silver, 52 million st iron, 188 st thorite (ThO_2), 55,000 st molybdenum, 852 st manganese, about 9 st copper, 4,441 st lead, 1,355 st zinc, and 139,954 st barite.

Tract II delineates an area permissible for sediment-hosted copper and southeast Missouri lead-zinc deposits in western Lincoln County, based on geological and geochemical data. The tract includes outcrops and inferred subsurface continuations of Permian and Pennsylvanian sedimentary rocks that are permissible for redbed-type, sediment-hosted copper deposits because they are permeable continental margin sandstone deposits and they host mineralization of this type in the Oscura district within the tract. Evidence for undiscovered southeast Missouri lead-zinc deposits is based on the extension of Pennsylvanian limestone and geologic structures into the tract from deposits outside of the study area. There is a 50 percent probability of at least one sediment-hosted copper deposit and a 10 percent probability of at least one southeast-Missouri lead-zinc deposit in tract II, with median predicted resources of 268,888 st of copper in undiscovered deposits in the tract, and a 10 percent probability of 4,331 st silver, 9 million st copper, 722,912 st lead, 4.4 million st zinc, and 90,364 st cobalt in the undiscovered deposits.

Tract III encloses an area 30 mi in diameter centered on the Stauber mine in Guadalupe County. The tract includes continuations of the sedimentary formations that contain sediment-hosted copper deposits at the Pintada and Stauber mines and that contain copper and uranium minerals in measured sections in Santa Rosa. Geochemical anomalies and karst topography in the tract favor formation of deposits of this type. The circular outline of the tract is the maximum radius from the Stauber mine that the team would predict the probability of an undiscovered sediment-hosted copper deposit. The tract has a 10 percent probability for one sediment-hosted copper deposit, and a 50 percent probability of no remaining undiscovered copper deposits. There is a 10 percent probability of 1.37 million st of undiscovered copper.

The boundary of tract IV connects 12 known gypsum occurrences and includes the area between the occurrences. We predicted that the tract has a 90 percent probability of containing two or more undiscovered marine-bedded gypsum deposits. The median amount of gypsum contained in those undiscovered deposits is estimated to be 1.95 billion st.

Tract V, partly underlain by the Dockum Group, has the potential for undiscovered sandstone-hosted uranium deposits totalling less than one ton and extremely small potential for large uranium deposits (Finch and others, 1992). Vanadium in sandstone-hosted deposits is less than 5 st (Breit, 1992). Part of tract V, underlain by deposits of the Ogallala Formation, is a likely source of undiscovered uranium in surficial deposits, with an estimated mean endowment of 1,287 st (Finch and others, 1992).

Nonquantitatively Assessed Mineral Commodities

Several commodities present in the Roswell Resource Area were assessed qualitatively, rather than quantitatively using statistical procedures, because of the lack of production data, grade and tonnage models for the specific commodity, and/or adequate subsurface or other information. These commodities include evaporites (except gypsum), brine deposits, sulfur, aggregate, sand and gravel, caliche, dike rock and scoria, limestone and dolomite, building stone, clay and adobe brick, and gemstones and collectible specimens (Bartsch-Winkler, 1992b). The various settings for each of the deposit types in the study area were described, and the potential for future deposits was discussed, using the terminology "high," "moderate," and "low" (Goudarzi, 1984).

Evaporites. Evaporite deposits are widespread beneath Guadalupe, De Baca, Chaves, Quay, Curry, and Roosevelt Counties, and include gypsum, halite, and potash salts. Evaporites are known to be as much as 130 ft thick in western Quay County, 80 ft thick in northern Roosevelt County, and 60 ft thick in southeast Roosevelt County. Potash-bearing units to the south in the world-class Carlsbad potash district near Carlsbad, New Mexico, 30 mi south of Artesia (fig. 1), extend northward into the Northwestern Shelf (fig. 4). Potassium minerals are present in 12 soluble potash horizons in southeastern Chaves County. Thickness and extent of the potash-bearing horizons are not known because of the lack of subsurface information, but an estimate of the volume of K_2O that is currently economic in grade is approximately the equivalent of 2 billion st (Williams-Stroud, 1992a). Halite-bearing formations are present in the subsurface of the Northwestern Shelf in Guadalupe, Quay, Curry, De Baca, Chaves, and Roosevelt Counties and beneath the eastern half of Lincoln County (fig. 4). Known halite beds of variable thickness and unknown grade occur beneath approximately 13,000 sq mi of the study area, and thus have a high potential for occurrence.

Brine Deposits. Iodine and bromine brines occur south of the study area, where iodine occurs at concentrations of less than 1 ppm, and bromine occurs in brines at concentrations of 26–78 ppm—concentrations near or below the typical concentration necessary for production. Although there is little evidence, only low subeconomic concentrations of iodine and bromine in brines are expected to occur in the southeastern part of the study area, having a low potential for the occurrence of undiscovered brine deposits (Williams-Stroud, 1992a) (fig. 4).

Sulfur. The largest U.S. production of sulfur by the Frasch process is in the Rustler Springs district, Culberson County, West Texas, southwest of the study area. Many occurrences of native sulfur associated with anhydrite have been reported and/or noted in drill cuttings and cores in the Roswell Resource Area (Spirakis, 1992) (fig. 4). Except for sulfur recovered as a by-product of oil and gas production, no sulfur has been produced in the study area, but exploration is continuing, especially near Santa Rosa and in an area stretching from just east of the city of Roswell to the southern boundary of the study area. In the study area, the region of high potential for native sulfur deposits may be outlined by superimposing the areas of high potential for oil, gas, or tar sand and areas underlain by anhydrite deposits. Much of the Roswell Resource Area is underlain by anhydrite deposits, and migrated organic matter (oil, gas, and tar sand) is present in rock near Artesia and Santa Rosa. In these two areas, large deposits of sulfur may be found. An area of moderate potential for sulfur surrounds the region of high potential and may contain deposits derived from migrated hydrogen sulfide. It is not clear, however, what the extent of migration might be before oxidizing conditions are encountered; therefore, the outer limit of moderate potential is not well defined. Sulfur may also be produced as a by-product of oil and gas processing near Artesia, or from refining of sulfide minerals.

Aggregate. Aggregate supply is plentiful in the eastern part of the study area in pediments, terraces, and valley alluvium of the Llano Estacado, Mescalero Pediment, Pecos and Canadian Rivers, and parts of the Pecos Slope, resulting in a high potential for this commodity (fig. 1). Although the deposits are abundant, their location is not amenable to quarrying and use. Because of variation in occurrence and quality, more work is needed to assess aggregate deposits quantitatively. Aggregates for use in road construction include sand and gravel from rivers, creeks, and the Ogallala Formation, and caliche, basalt, igneous dikes, and sandstone and limestone bedrock deposits. Concrete-quality aggregate occurs only in terrace deposits of the Canadian and Pecos Rivers. Pecos River terrace gravel is most plentiful in De Baca and Guadalupe Counties, but the highest quality, low-clay gravel is in De Baca County where the beds are as much as 60 ft thick. Fair-to-good quality aggregate from pediment deposits occurs near Santa Rosa and Vaughn (figs. 1, 4). The potential for undiscovered resources of aggregate is high, but the extent and quality of aggregate resources is extremely variable.

Sand. In the study area, sand deposits are abundant. Quaternary sand dune deposits cover large tracts from the vicinity of Clovis southwest to the Mescalero pediment (fig. 1). Sand and gravel occurs along the Pecos and Canadian River valleys and their tributary systems, as well as in Tertiary and Quaternary deposits on the Llano Estacado. In addition to that extracted from Holocene deposits, sand is produced from the friable Glorieta Sandstone (fig. 4). The potential for the occurrence of undiscovered resources of sand in the Roswell Resource Area is high, but the deposits are of unknown composition and extent.

Caliche. Caliche deposits in the Roswell Resource Area form one of the most abundant caliche resources in New Mexico. The most extensive deposits of caliche occur in Curry and Roosevelt Counties, and, except for areas covered by eolian deposits, both counties have large supplies of caliche for aggregate. Deposits are as thick as 32–49 ft on the Llano Estacado in the eastern part of the study area, where the highest quality caliche is well indurated and averages 3–6 ft thick. Caliche is plentiful on the Buchanan Mesa surface and outliers near Buchanan, Taiban Mesa, the aggraded surface southeast of Vaughn, the aggraded surface west of Santa Rosa, the mesa south of Cuervo, the Mescalero pediment, and lower erosional surfaces near the Canadian River and other drainages. The best source of caliche aggregate occurs in the older caliche deposits, but quality is variable depending on amount of carbonate content, amount of sand cover, elevation of the caliche deposit, type of bedrock on which the caliche forms, the weather zone in which the caliche is formed, and other factors. Locally, caliche on the Llano Estacado may be equivalent in quality to high-calcium limestone, but deposits are localized and discontinuous. As in the case of aggregate, because of variation in quality and thickness, more data are needed to assess caliche deposits quantitatively. Nonetheless, the potential for undiscovered caliche resources is high.

Dike Rock and Scoria. Railroad Mountain dike, Camino del Diablo dike, and other well-indurated dikes in the study area (fig. 3) are locally abundant. Scoria, a lightweight aggregate, is found in lava of the Little Black Peak and Carrizozo flows, which provide significant resources of scoria in western Lincoln County. Thus, the potential for undiscovered dike rock and scoria resources in the Roswell Resource Area is high.

Limestone and Dolomite. Limestone and dolomite are plentiful on the western Pecos Slope in Permian units at or near the surface; the potential for undiscovered deposits of these commodities in the study area is high. Typically, limestone composition (which determines use) varies laterally and vertically, so it cannot be assessed quantitatively without more detailed studies. High-calcium limestone comprises some of the Ogallala caliche deposits on the Llano Estacado, extensive deposits in Pennsylvanian and Permian rocks of the Sacramento and Oscura Mountains, probably localized deposits on the Pecos Slope in southwestern Chaves County along Rio Peñasco near Dunken (south of the study area in Otero County) (fig. 1), and in Jurassic limestone near the Quay-Guadalupe county line east of Santa Rosa. Low-purity dolomite deposits are abundant in the San Andres and Yeso Formations and the Artesia Group, especially on the Pecos Slope (fig. 4).

Bedded Barite. Bedded barite deposits associated with sulfur deposits occur in the subsurface outside the Roswell Resource Area. Although the geologic setting seems favorable for the formation of large quantities of bedded barite, and geochemical data support the nearly ubiquitous presence of barite, no barite has been produced and no occurrences are known, in part because of the lack of subsurface information. There is only moderate potential for the occurrence of undiscovered bedded barite deposits in the Roswell Resource Area.

Clay. Thin beds of clay and clay-rich zones occur in various formations at or near the surface in the study area. Rare beds of bentonite as thick as 1 ft occur in the Upper Jurassic Morrison Formation. In Quay and Guadalupe Counties, thin beds of montmorillonite (smectite) occur in Triassic rocks; other clay types occur in the Upper Cretaceous Mancos Shale and Mesaverde Formation. Although clay mining is not currently feasible, the existence of numerous localized clays of variable thickness and composition provide moderate potential for additional undiscovered small deposits.

Adobe. Adobe has been used for several centuries for building construction in this region. Although the study area contains resources of adobe materials (sand, silt, and clay deposits) in lower to upper Tertiary deposits, including the Ogallala Formation of the eastern Roswell Resource Area, and in the Quaternary floodplain arroyo, terrace, and dune deposits in areas adjacent to the Pecos River, it contains no adobe-brick manufacturing facilities. Adobe bricks would have to be shipped to construction areas, generally near the larger towns. The Roswell Resource Area has high potential for undiscovered adobe-materials resources.

Collectible Specimens. Various gemstones and collectible specimens occur in the Roswell Resource Area, but none are of commercial importance. They may be locally abundant (like the "Pecos diamonds") or rare (jet, turquoise, quartz crystals), but their collection may be prohibited because of land status.

Energy and Associated Resources

The Permian Basin, one of the largest oil- and gas-producing basins in the United States, extends from West Texas into southeastern New Mexico. Oil and gas discovered in this basin (in 4,400 oil pools and 900 gas pools) totals more than 90 billion bbl of oil-in-place and 106 trillion cu ft of gas-in-place (Dolton and others, 1979; Ward and others, 1986). Part of the Northwestern Shelf of the Permian Basin is included within the Roswell Resource Area boundary. The oil and gas assessments presented herein were derived from the national assessment of 1988 (U.S. Geological Survey and Minerals Management Service, 1988; Mast and others, 1989) and are based on hydrocarbon play analysis. The following discussion of petroleum resources is from Ball and others (1992).

A hydrocarbon play is a group of actual or potential oil and gas accumulations that share certain geologic attributes. Some of the geologic attributes included in the hydrocarbon play analysis in this report are regional structural setting, reservoir type and configuration, sealing mechanisms, reservoir age, characteristics of the hydrocarbon source rocks, timing of hydrocarbon maturation and migration, and fluid types associated with the reservoir.

Two hydrocarbon plays that extend into the Roswell Resource Area have undiscovered, recoverable, conventional accumulations of oil and gas estimated to exceed 1 million barrels or equivalent (MMBOE) in size: the Northwestern Shelf Pennsylvanian-Permian Play and the Northwestern Shelf pre-Pennsylvanian play (fig. 5). Additionally, four other plays in two provinces (parts of the Permian and Palo Duro Basins that occur within the Roswell Resource Area) have expected oil and gas accumulations of less than 1 MMBOE. The Tucumcari Basin play, although not quantitatively assessed herein, could prove to be of future importance.

Uplift in the Lincoln County porphyry belt influenced the entire Roswell Resource Area, effecting erosion and deposition of strata that are potential hydrocarbon hosts, and created stratigraphic and structural traps. Folding associated with faults in eastern Lincoln County, and fault-bounded horst blocks in Tucumcari Basin, may prove to be important in forming structural traps.

The Northwestern Shelf Pennsylvanian and Permian play is a combination of stratigraphic, stratigraphic and structural, and structural traps, in a predominantly carbonate sequence that is as thick as 15,000 ft (fig. 5). This oil play, which covers the whole of the Northwestern Shelf of West Texas and New Mexico south of the Tucumcari Basin and east of the Lincoln County porphyry belt, contained more than 12 billion barrels of conventionally recoverable oil-in-place. Future oil potential is estimated as relatively good for the discovery of many additional conventionally recoverable small fields and possibly one or more medium-size fields.

The Northwestern Shelf pre-Pennsylvanian play for conventionally recoverable oil and associated gas, in a combination of structural and stratigraphic, structural, and, to a lesser extent, stratigraphic traps, is in a predominantly carbonate sequence less than 5,000 ft thick (fig. 5). This play, which encompasses the northern part of the Texas Eastern Shelf and northern part of the Texas Midland Basin outside the study area, and a large part of the Northwestern Shelf within the study area, contained more than 103 million barrels of oil, with an average size of gas fields of 9.7 billion cu ft. The future oil and gas potential of the play is probably fair to good, and limited to small fields.

For the entire study area, estimates indicate undiscovered, conventionally recoverable oil and gas resources of about 55–140 million barrels of oil (with a mean of 87 million barrels), 260–555 billion cubic ft of gas (with a mean of 375 billion cu ft) and 6–13 million barrels of natural gas liquids (with a mean of 8 million barrels) (tables 3, 4). Petroleum resources in the Tucumcari Basin in the northern part of the Roswell Resource Area are considered too speculative to assess quantitatively.

Associated and Nonhydrocarbon Gases

Nitrogen gas is produced along with oil and/or gas from Permian rocks east of Roswell and Hagerman (Bartsch-Winkler and Ball, 1992). Hydrogen sulfide, hydrogen, and helium gases have been detected in oil and gas wells encountering Upper Pennsylvanian and Permian rocks. Carbon dioxide gas is produced north of the study area from the Bueyeros, Bravo Dome, and Des Moines fields in Union and Harding Counties, and from the Estancia Field in northern Torrance County. Moderate potential exists for carbon dioxide gas in traps updip from Tertiary intrusions north and east of the porphyry belt in southwestern Lincoln County. All of these gas resources are considered too speculative to assess quantitatively.

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