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GEOLOGY AND MINERAL RESOURCE POTENTIAL OF SALT FLATS AND SURROUNDING AREA, CIENEGA SCHOOL 71/2' QUADRANGLE, NEW MEXICO AND TEXAS

by

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ABSTRACT

The Salt Flats area of southern Otero County, New Mexico is a U.S. Bureau of Land Management-designated Area of Critical Environmental Concern (ACEC). At the request of the BLM, the U.S. Geological Survey conducted geologic and mineral resource investigations of that part of the Cienega School 71/2' quadrangle in which the Salt Flats ACEC is located. The Cienega School quadrangle is located at the easternmost part of the Basin and Range province of southern New Mexico and is centered on the northern part of the Quaternary-Tertiary Salt Basin graben, which marks this eastern boundary. Permian San Andres and Grayburg Formations exposed in the quadrangle represent the bank-ramp facies of the Capitan reef complex, which underlies the adjacent Guadalupe Mountains on the east. That part of the Salt Basin graben exposed in the quadrangle was the site of a late Pleistocene lake that accumulated an unknown thickness of calcareous, dolomitic, gypsiferous, and salt-bearing lake sediments. Subsequent evaporation of lake waters was followed by the accumulation of alluvial, fluvial, and aeolian sediments across the former lake bed. An immense, stabilized dune field composed mostly of altered, gypsum-rich sediment, covers much of the Salt Flat ACEC. Inset in the stabilized dune field are several ephemeral alkali lakes formed by deflation of interdune areas.

There are no identifiable economic mineral resources in the Salt Flats ACEC. Potential for undiscovered mineral resources is variable. Deposits of lead, zinc, barite, and fluorite in Paleozoic rocks associated with interpreted buried alkalic intrusive bodies appear to have a moderate potential for having formed in and near the Salt Flats ACEC. Potential for economic deposits of uranium and vanadium in the Quaternary deposits of the ACEC is at best moderate. The likely presence of alkalic intrusive bodies in the subsurface of the quadrangle, coupled with intense faulting associated with graben formation and ground water flushing of buried sedimentary rocks, argues against the presence of viable oil and gas reserves.

INTRODUCTION

The Caballo Resource Area is a Bureau of Land Management (BLM) designated region that includes all of Sierra and Otero Counties, south-central New Mexico. Within this resource area of more than 21,000 square miles, nearly one fourth of the land is administered by the BLM. At the request of the BLM, over 7,000 acres in the Caballo Resource Area in southeastern Otero County, New Mexico, were evaluated for potential mineral resources. The BLM-designated study area, called the Salt Flats Area of Critical Environmental Concern (ACEC), is located in the southeast corner of the Cienega School 71/2' quadrangle, New Mexico and Texas. This ACEC is restricted to an area of numerous alkali lakes located directly west of the Brokeoff Mountains, a low lying spur of the adjacent Guadalupe Mountains. The alkali lakes and the Cienega School quadrangle proper are centered on the north-northwest-trending Salt Basin graben, a late Tertiary-Quaternary structural depression (Goetz, 1985). Within the quadrangle, the graben is bounded by rugged, deeply incised hills of the Brokeoff Mountains on the east, and by weakly dissected mesas of the Otero Platform on the west. Elevations in the quadrangle range from 4,740 feet on the east to 3,615 feet in the center of the graben.

This report describes the geology of the Cienega School quadrangle and assesses the mineral resource potential of the Salt Flats ACEC. Resource potential is based on the likelihood that economic deposits of undiscovered metals and nonmetals, industrial rocks and minerals, and energy resources occur in the area.

Previous Investigations

U.S. Bureau of Mines (USBM) geologists conducted an examination of identifiable mineral occurrences in the Salt Flats ACEC in 1992 and 1993 (Korzeb and Kness, 1994). The only potential mineral resource identified in their evaluation was gypsiferous deposits within the alkali lakes and adjacent areas of windblown sand.

Previous investigations by the U.S. Geological Survey in or near this area include a mineral resource evaluation of the adjacent Brokeoff Mountains Wilderness Study Area, part of which is in the northeastern Cienega School quadrangle (Moore and others, 1989). Geologic maps and reports on the Guadalupe Mountains and adjacent Salt Basin graben of Texas, located east and south of the Cienega School quadrangle, were completed by King (1948) and Hayes (1964).

GEOLOGY

Regional Geologic Setting

The Cienega School quadrangle is located in the easternmost part of the Basin and Range province of southern New Mexico (Woodward and others, 1975; Seager and Morgan, 1979; Goetz, 1985). Physiographically, the area could be considered a part of the Rio Grande rift; however, the rift margin is generally drawn west of this area, near the western margin of the Otero and Diablo platforms (Fig. 1). The Salt Basin graben that lies within the quadrangle is thus separate from the main structures of the rift. The Salt Basin graben is, however, the northernmost basin of four elongate, structurally integrated grabens that form a north-trending, narrow rifted zone that joins the Rio Grande rift to the south, near Big Bend National Park (Goetz, 1985; Pearson, 1988). The Guadalupe Mountains of New Mexico and Texas stand as a formidable escarpment east of the graben, rising to elevations near 8,700 feet (2610 m) in Guadalupe Mountains National Park. Rocks west of the escarpment have been downdropped along a series of Tertiary and Quaternary normal faults that define the eastern margin of the Salt Basin graben.

Sedimentary Rocks

The oldest rocks exposed in the area are Permian and represent a shelf-to-basin transition zone related to the formation of the Capitan reef complex; the reef marks the northern boundary of the Permian Delaware Basin of Texas and New Mexico. The western face of the Guadalupe Mountains displays the complete, uninterrupted sequence from shelf to back reef to reef to basin stratal transitions (Fig. 2) and has been the focus of decades-long geologic research of basin margin geology (Pray, 1988). In this scheme of rapid stratal transitions, the Cienega School quadrangle lies on the paleo shelf margin; as such, only the back reef and underlying bank-ramp shelf facies rocks are present.

Permian sedimentary rocks exposed in the Cienega School quadrangle are the San Andres and overlying Grayburg Formations (Plate 1). The San Andres and Grayburg Formations are well exposed along the east margin of the quadrangle; only the San Andres is present on the west. The San Andres and Grayburg Formations in this area are the uppermost formations of the bank-ramp complex of the margin of the Permian shelf edge (Fig. 2). Directly south of the Cienega School quadrangle, the San Andres intertongues with basinal sediments of the Delaware Basin. The overlying Grayburg also cannot be

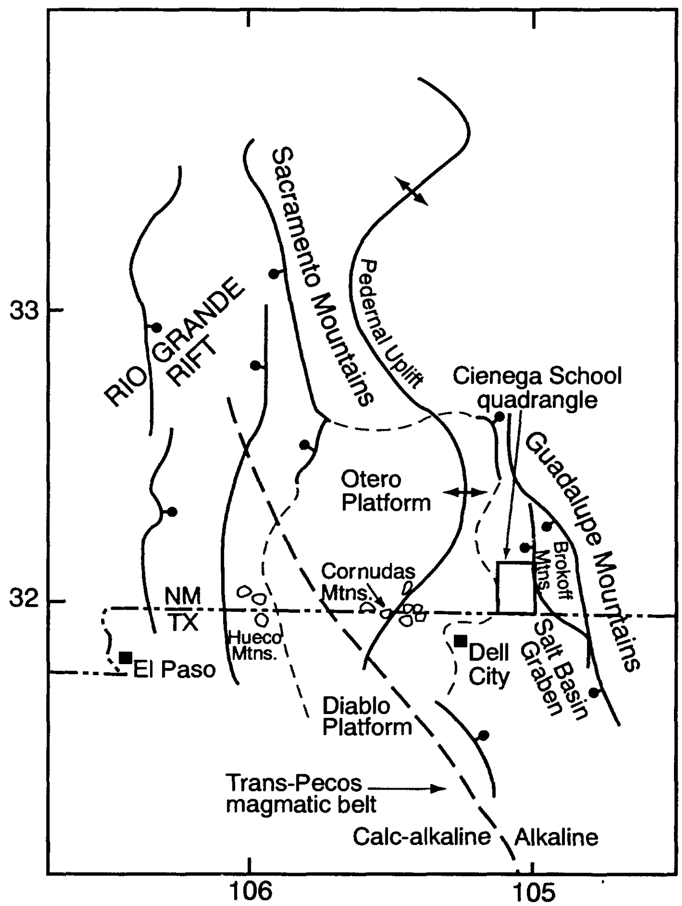

Figure 1: Index map of south-central New Mexico and adjacent Texas (modified from King and Harder, 1985)

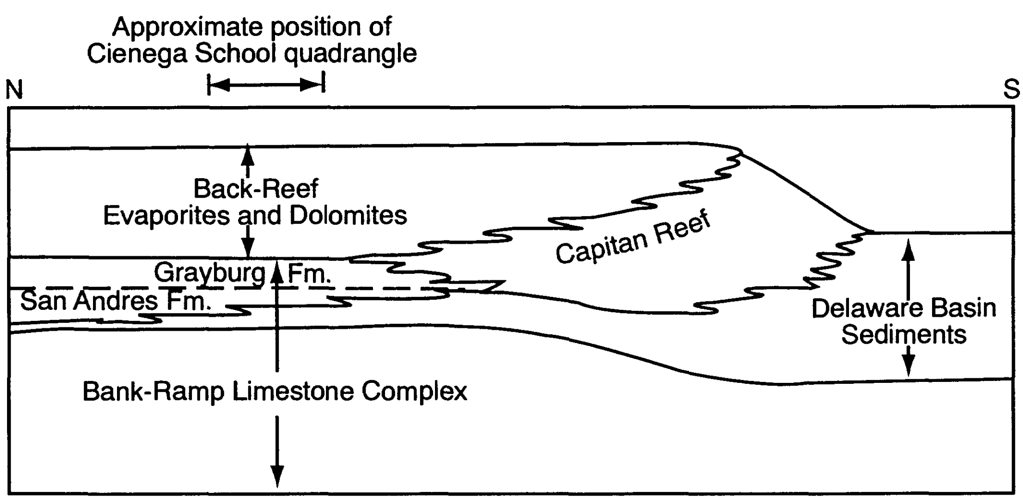

Figure 2: Permian shelf margin stratigraphic complexes, Guadalupe Mountains, showing approximate location of Cienega School quadrangle with respect to the known stratigraphic framework (modified from Pray, 1988)

traced south of the Cienega School quadrangle, as it intertongues with, and is overlain by, the lower part of the main reef complex.

The San Andres Formation consists of olive gray to tan, generally fine-grained, thin- to medium-bedded dolomite, and dolomitic limestone. Gray to brown chert nodules and stringers are common. On the east, in the Brokeoff Mountains, thin beds of gypsum are locally associated with limestone (Moore and others, 1989).

The Grayburg Formation conformably overlies the San Andres and is preserved only on the east. In the adjacent Brokeoff Mountains, Moore and others (1989, p. E5) describe the Grayburg as a mostly grayish-orange and light- to medium-gray, fine-grained, medium-bedded dolomite and dolomitic limestone containing some interbeds of dolomitic sandstone.

The remaining sedimentary rocks in the Cienega School quadrangle are Quaternary alluvial, fluvial, aeolian, and lacustrine deposits of the Salt Basin graben (Plate 1). Total thickness of the basin fill has been estimated to be between 1,650 and 2,300 feet (500 and 700 m) (Friedman, 1966; Gates and others, 1980). In late Pleistocene time, a fresh water lake occupied much of the Salt Basin graben (King, 1948); the northernmost reaches of this lake, informally referred to as Lake King (Miller, 1981), extended into the Cienega School quadrangle. Alluvial fans, shed from the adjacent Brokeoff Mountains, were active while the lake occupied this part of the Salt Basin graben. As the lake decreased in size, in response to evaporation and decreased recharge, alluvial and fluvial deposits were shed onto the lake floor as it became subaerially exposed.

Lake sediments are exposed locally in the central part of the graben in the quadrangle and consist of two types: layered sedimentary deposits and gypsiferous evaporite deposits. Limited exposures of layered, locally laminated lake deposits are restricted to areas adjacent to contemporary, ephemeral alkali lakes, where they are overlain by younger aeolian deposits. The lake deposits consist of laminated to thinly layered gypsiferous, saline, dolomitic and calcareous rocks (Fig. 3). South of the quadrangle, these lacustrine deposits have been examined in shallow, subsurface cores up to 9 feet (3 m) in length (Hussain and others, 1988). The cores exposed laminated, varve-like, light and dark colored layers or couplets. Hussain and others (1988, p. 180) recognized three couplet types: a) gypsum and algal laminae; b) gypsum and organic matter-rich dolomicrite; and c) dolomite and organic-rich dolomicrite. X-ray fluorescence analysis of lake sediments in the Cienega School quadrangle revealed beds with similar compositional layering (Plate 1).

Gypsiferous evaporite deposits can be traced from north to south in the central and western parts of the quadrangle. The deposits are not well exposed in this area; to the south, near Dell City, Texas, a pit excavated in these deposits exposed about 6 feet (1.8 m) of cream-colored, loosely compacted gypsum-rich basin fill capped by a well developed gypcrete duricrust (Love and Hawley, 1993). The thickness of these evaporite deposits is not known.

Resting above laminated, layered lake sediments is an immense, stabilized dune field that extends from the southern part of the Cienega School quadrangle, southward at least 10 miles (16 km). The dunes are restricted to the eastern, leeward side of the former lake basin and consist of transverse dunes, barchanoid ridges, and large and small parabolic dunes (Plate 1). Like the evaporite lake deposits, the gypsiferous dune forms are lithified and capped by a hard, gypcrete duricrust that ranges in thickness from 4 to 16 inches (10 to 40 cm) (Fig. 4).

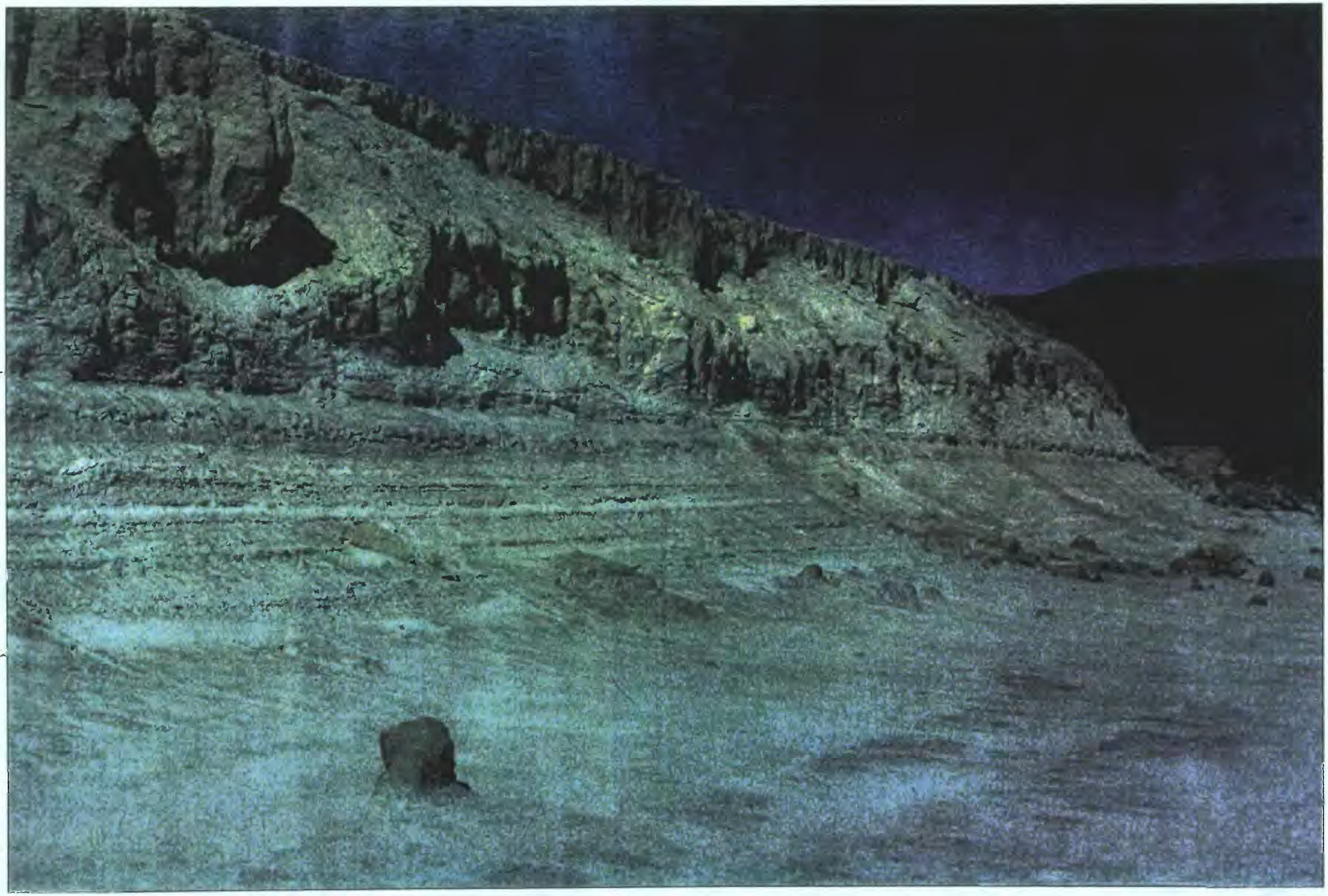

Figure 3: Margin of alkali lake deflation basin. Cliff is about 15 ft (5 m) high. Lower part exposes late Pleistocene laminated to thinly layered gypsiferous, dolomitic to calcareous lake sediments; upper part is lithified, altered aeolian sand. Contact between lake sediments and aeolian sand is planar, abrupt, and commonly marked by large crystals of selenite. Note uppermost, cliff-forming duricrust capping the stabilized aeolian deposit

Figure 4: Cross section through rounded crest of large parabolic dune Relief on the dune is about 6 ft (2m). Note thick gypsiferous duricrust capping dune form

Present day "lakes" within the graben are deflation basins formed by wind erosion of the Pleistocene lake beds (Fig. 3). The extremely flat nature of the lake bottoms is a reflection of the local water table; at the water table, gypsum of the Pleistocene sediments periodically remains sufficiently wet and cohesive to resist wind erosion. Consequently, the planer surface of the water table determines the depth of wind erosion, which defines the bottom of the "lakes." Gypsum scoured from at or above the water table presently accumulates in small, patchy dune fields and sheet sand deposits along the leeward sides of the "lakes" and on the older, stabilized dune forms (Plate 1).

Igneous Rocks

There are no known exposures of igneous rocks in the Cienega School quadrangle. A small plug of syenite underlies Round Mountain and the Wilcox Hills about 3.5 miles (6 km) south of the quadrangle near Dell City, Texas. Intrusions of syenite, common in this part of New Mexico, are part of a major northwest-trending belt of calcalkaline to alkalic igneous activity of mid-Tertiary age (Fig. 1). Major syenitic intrusions related to the belt of alkalic rocks are exposed in the Cornudas Mountains (Nutt and others, 1997) 16 miles (45 km) west of the Cienega School quadrangle.

Structural Geology

Faults

The Salt Basin graben, which underlies the central part of the Cienega School quadrangle, formed in Tertiary and Quaternary time (King, 1948; Goetz, 1985). To the south, in Texas, clearly defined faults separate the graben from the Guadalupe Mountains on the east and the Diablo platform on the west. In southernmost New Mexico the Guadalupe Mountains are separated from the main trace of the graben by the partly down-dropped and strongly faulted Brokeoff Mountains. In the Cienega School quadrangle, bounded on the east by the Brokeoff Mountains and on the west by the Otero platform, no graben-bounding faults are exposed (Plate 1). The broadly anticlinal nature of the Brokeoff-Guadalupe Mountains may control the position of the range margin; the west limb of the anticline dips gently to moderately beneath the Quaternary sediments that fill the graben. Permian rocks that underlie the Otero platform on the west are cut by faults of small displacement, none of which can be traced into Quaternary deposits of the graben. Although the eastern escarpment of the platform may be structurally controlled, as inferred by Black (1975) and Goetz (1985), it is possible that the break in slope is an erosional feature as well.

Major faults that cut the rocks of the Otero platform trend north-northwest and are associated with a second set of faults of smaller displacement and trace that trend west-northwest (Plate 1). Slickensides, where preserved on surfaces of north-northwest-trending normal faults, indicate a component of strike-slip displacement. In contrast to the through-going normal faults, the smaller, west-northwest-trending faults commonly show oblique reverse displacements. A well exposed west-trending fault of small displacement, mapped at the southern end of the platform, dips 45 degrees northeast; slickenlines plunge 5 degrees to the northwest. The observed displacements and overall map pattern of the smaller west-northwest-trending faults of the Otero platform suggest that they represent secondary structures kinematically related to through-going north-northwest-trending faults. The west-northwesterly orientation of the smaller faults, coupled with evidence of reverse and strike slip displacement, indicate that they are contractional structures necessarily associated with an overall right-slip component on the major faults. These observations appear to support the interpretation of Goetz (1985) that the Salt Basin graben formed in response to right-transtensional displacement on north-northwest-trending normal faults.

Folds

Gentle undulations of sedimentary rocks of the Otero platform are common, subtle, and not mappable. Gentle warping of the strata adjacent to some faults has occured, and where mappable, are defined as small folds subparallel to the trace of the adjacent fault.

The Brokeoff Mountains in the northeast part of the quadrangle are the west limb of a large north-northwest-trending anticline that underlies the range. The trace of the fold axis is located near the range crest, east of the quadrangle boundary.

GEOPHYSICS

Aeromagnetic and Gravity Anomaly Maps

Aeromagnetic and gravity anomaly maps (Figs. 5 and 6) were compiled for southern Otero County, New Mexico and northern Hudspeth County, Texas, from reconnaissance data that are available in the public domain. The aeromagnetic data were obtained courtesy of the Geophysics Department, University of Texas-El Paso, and are compilations of data collected under the National Uranium Resources Evaluation (NURE) program of the Department of Energy (Geometrics, Inc., 1983; Carson Helicopters, Inc., 1981). The NURE data were collected along east-west flight lines spaced 6 mi (about 10 km) apart for the Carlsbad 1:250,000 quadrangle (northeast of Lat. 32° N and Long. 106° W) and 3 mi (about 5 km) apart for the Van Horn 1:250,000 scale quadrangle (southeast of Lat 32° N and Long. 106° W). Flight altitudes were 400 ft (about 120 m) above terrain. Data reduction and merging of the NURE surveys are described by Keller and others, 1983. The broad flight line spaced data are adequate for regional geologic studies and of some value for mineral resource assessment studies, such as predicting buried igneous intrusive rocks in the vicinity of the Salt Flats ACEC located within the Cienega School Quadrangle (Figs. 5 and 6).

The gravity data were obtained from the National Imagery and Mapping Agency (NIMA) and are distributed by the National Oceanic and Atmospheric Administration (NOAA) at the National Geophysical Data (NGDC) Center, Boulder, Colorado. During field work in September 1996, 6 new gravity stations were read in the vicinity of the Cienega Quadrangle in order to better constrain the gravity interpretations. The reference base used was DOD 479-1 located at the Kidd Observatory, University of Texas at El Paso. The gravity data were reduced using standard USGS procedures (Bankey and Kleinkopf, 1988).

Geophysical Patterns

The total-intensity aeromagnetic map (Fig. 5) shows north- to northwest trending patterns roughly parallel to known structures of Laramide and Basin and Range tectonism (Goetz, 1985). Prominent aeromagnetic anomalies are assumed to reflect Precambrian crystalline basement lithologies as well as younger igneous intrusive rock that may occur at basment level, within the sedimentary section, or exposed at the surface. For example, an aeromagnetic high is associated with igneous intrusions in the Cornudas Mountains. A string

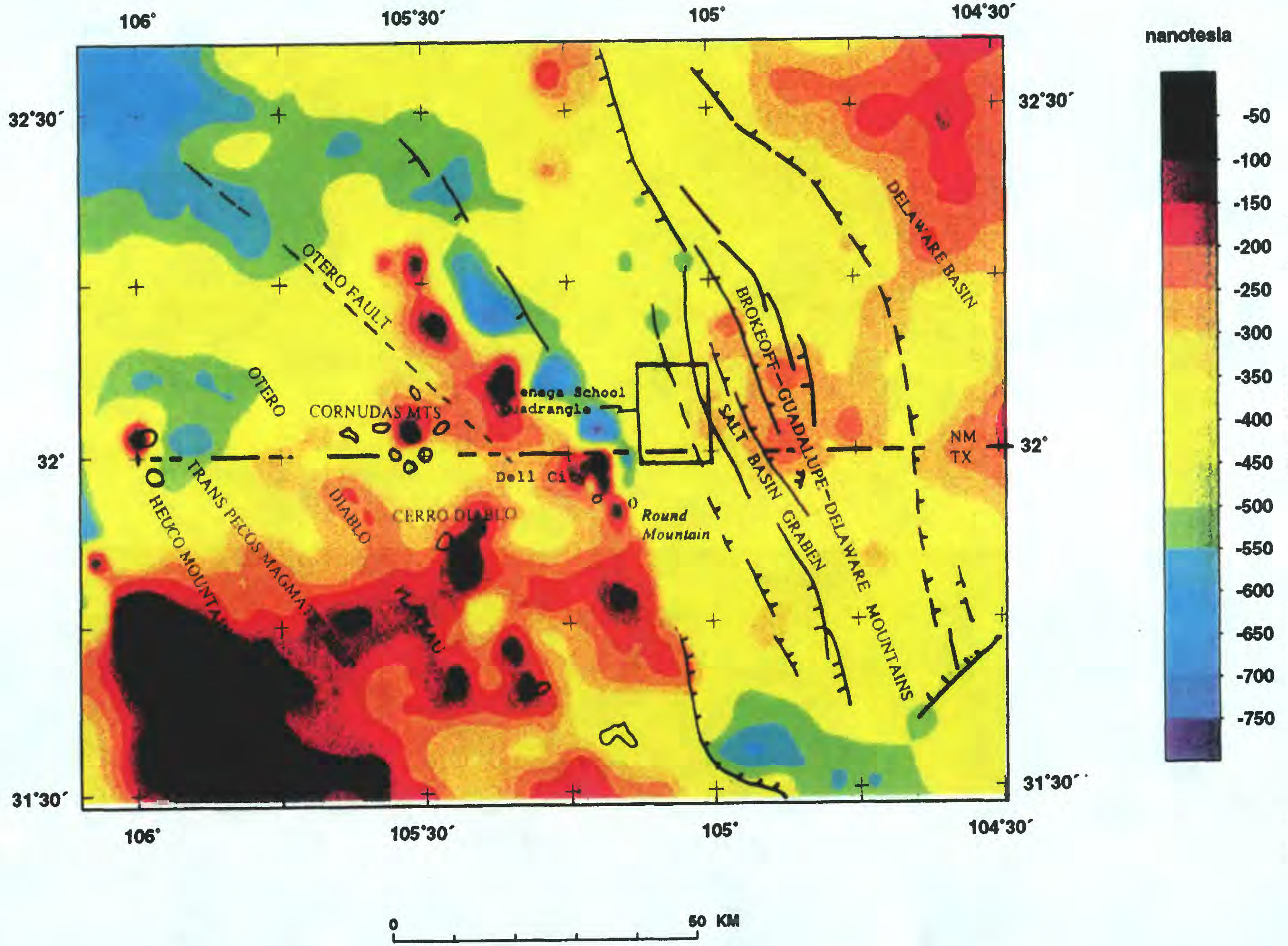

Figure 5: Total-intensity aeromagnetic anomaly map, southern Otero County, New Mexico and northern Hudspeth County, Texas. Contour interval 50 nanotesla. For survey specifications, see Keller and others, 1983.

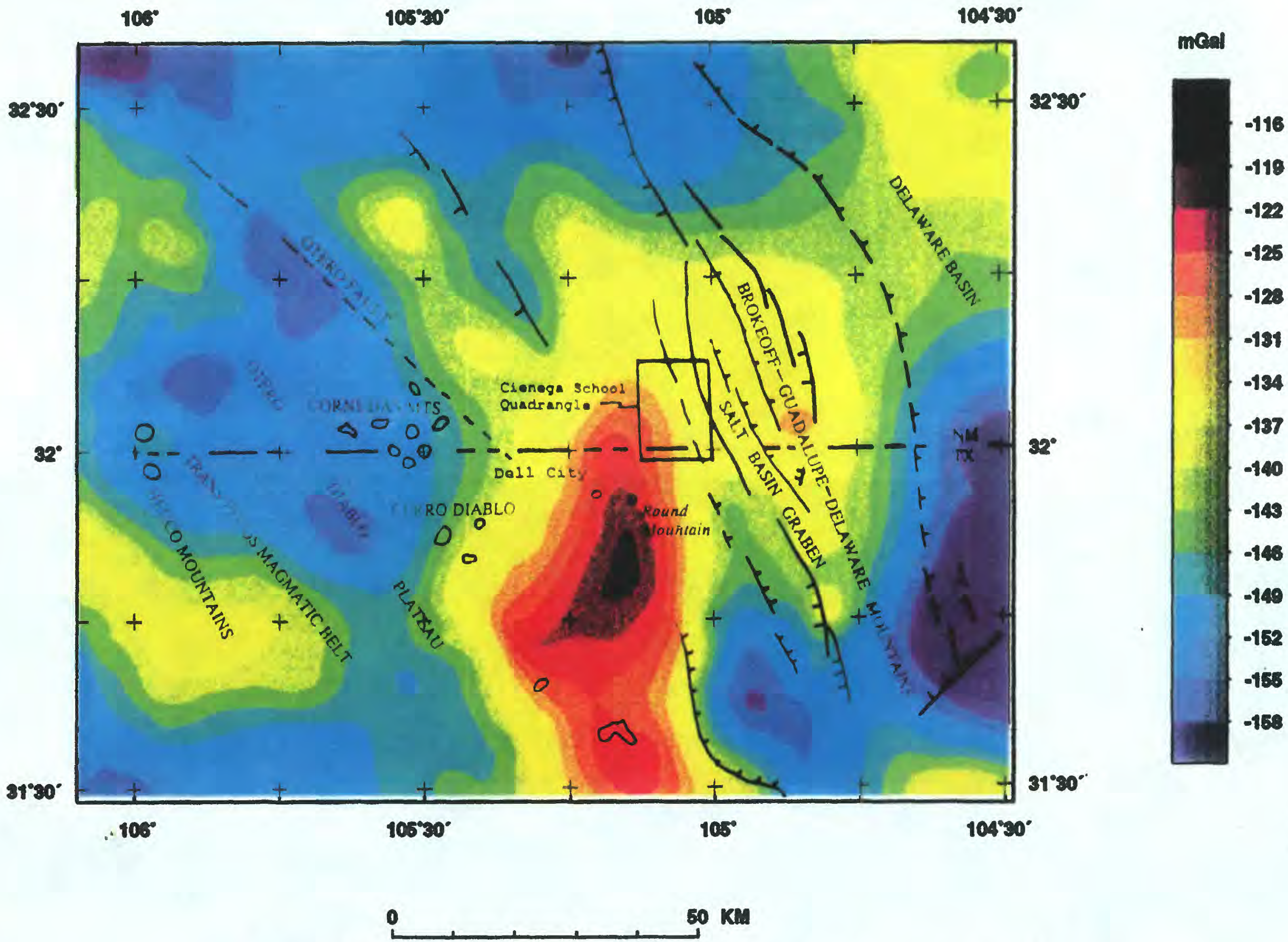

Figure 6: Bouguer gravity anomaly map, southern Otero County, New Mexico and northern Hudspeth County, Texas. Contour interval 3 milligals.

of northwest trending positive and negative anomalies (probably typical dipolar pairs) that cross the New Mexico state line about 18 mi (30 km) east of the Cornudas Mountains is interpreted to reflect near-surface intrusions of syenite composition, as suggested by the syenite at Round Mountain (V.T. McLemore, oral commun., 1996), which outcrops along the anomaly trend east of Dell City. The location of the igneous intrusions may have been controlled by a northwest trending fracture zone in the crystalline basement.

The Bouguer gravity anomaly map (fig. 6) displays similar north to northwest anomaly trends. Several positive aeromagnetic highs are observed to coincide with the gravity gradient zone along the flank of the broad gravity high roughly centered at Round Mountain, including a narrow extension of this high to the northwest of Round Mountain. This gradient zone may reflect a contact between different basement lithologies and indicate a zone of crustal weakness that accomodated placement of igneous intrusions. The northwest trending gravity high is interpreted to reflect dense rocks in the Precambrian basement complex. An alternative interpretation is that the gravity high reflects a northwest-trending string of postulated syenite intrusions injected into less dense sedimentary rocks. However, the syenite intrusions of the Cornudas Mountains do not exhibit gravity highs, but rather correlate with low gravity (Fig 6). The Otero fault, described by Goetz (1985) as a Paleozoic transform fault, may extend southeast into Texas on the basis of lineations in the aeromagnetic anomalies. The Otero-Diablo Plateau is expressed in the gravity data as a broad gravity low. In the southwestern part of region, mostly covered by sedimentary rocks, areas of high gravity and aeromagnetic intensity probably reflect buried igneous intrusions and metamorphic rocks (Keller and others, 1983).

Cienega School quadrangle

Residual aeromagnetic and gravity anomaly maps (figs. 7 and 8) exhibit anomalies that suggest geologic complexities beneath the surficial evaporate sediments of the Cienega School quadrangle (Plate 1). The quadrangle is located on the northeast flank of a broad gravity high and on the west edge of an elongated gravity low associated with the Salt Basin Graben (Veldhuis and Keller, 1980 and Moore and others, 1989) located west of Brokeoff Mountains (Fig. 6).

The residual aeromagnetic anomaly map (Fig. 7) was calculated by removing a sloping plane surface from the total-intensity magnetic anomaly field. The aeromagnetic flight line control for the map area consists of four east-west profiles and a single north-south tie line (Fig. 7). The distribution of control is adequate only to detect the major aeromagnetic features larger than 5 to 10 km in diameter. In the central part of the map, three residual lows lie along a north-northwest trend that parallels the trend of a gravity axis that connects two gravity lows (Figs. 7 and 8). Magnetic anomalies are present that may indicate local buried igneous intrusive rocks. One case is the dipolar pair of positive and negative anomalies that straddle the New Mexico-Texas state boundary. The source of the dipolar pair is most likely a buried igneous intrusion estimated to occur some 3,000 ft (about 900 m) below the surface based on measurement of the steepest gradient, a method developed by Vacquier, Steenland, Henderson, and Zietz (1951). In the southwest part of the map (Fig. 7), Round Mountain, composed of syenite (V.T. McLemore, oral commun., 1996), is located on the flank of a large amplitude aeromagnetic high (fig. 6 and 7) that probably represents a much larger syenite intrusion in the sub-surface.

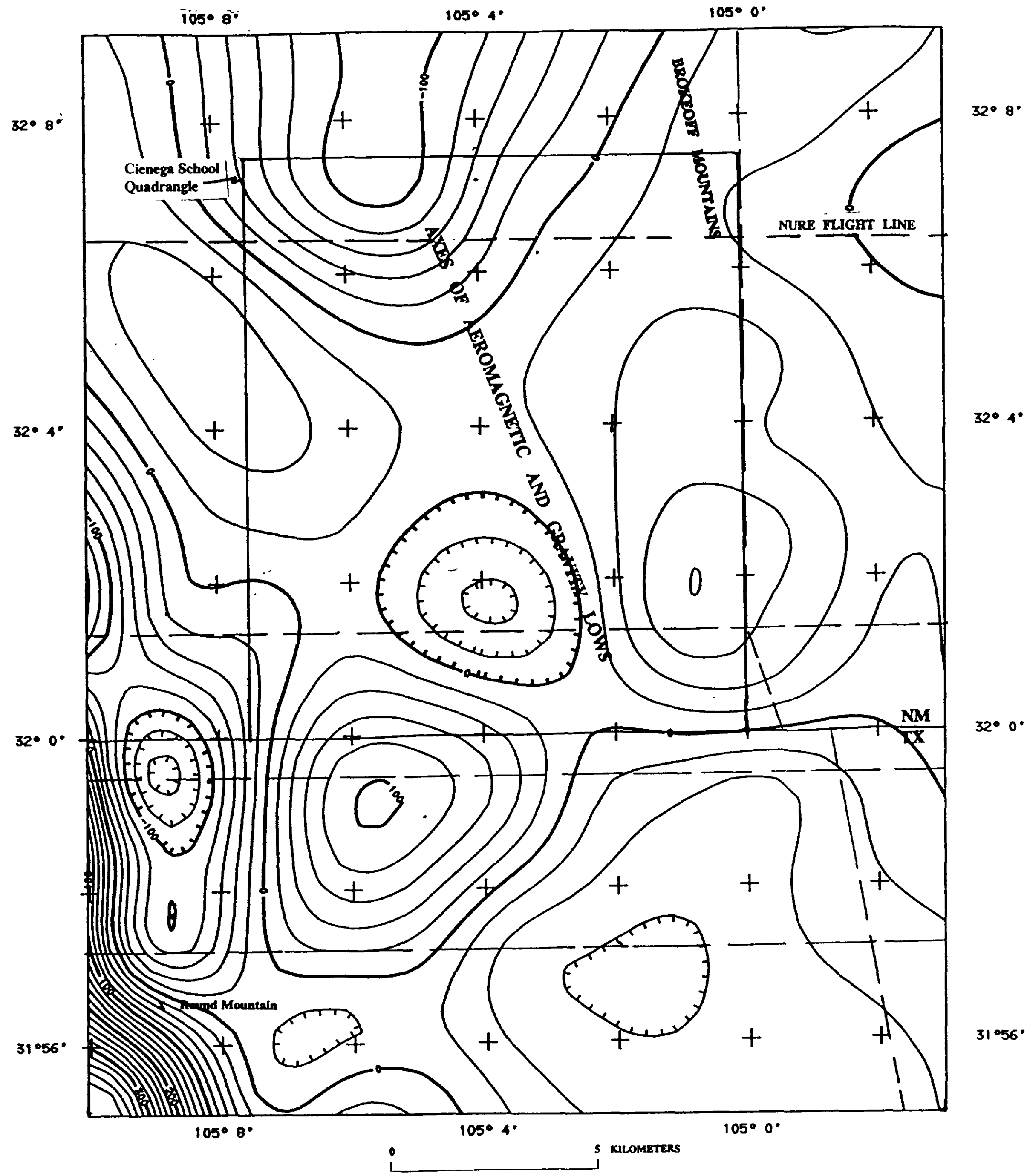

Figure 7: Residual aeromagnetic anomaly map of the Alkali Flats study area, southeastern Otero County, New Mexico and northeastern Hudspeth County, Texas. Contour interval 20 nanotesla. Aeromagnetic flight lines shown by dashed lines.

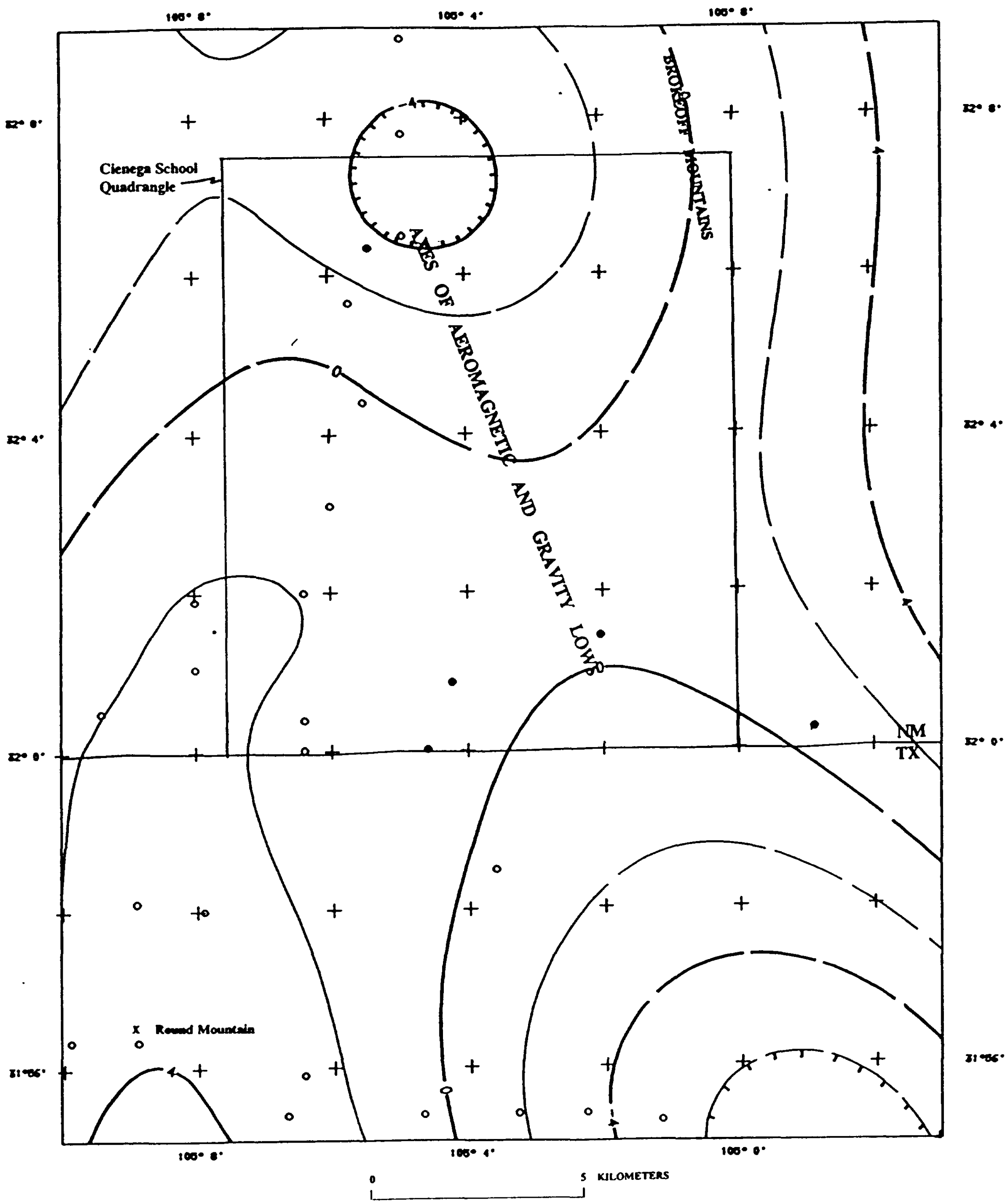

Figure 8: Residual gravity anomaly map of the Alkali Flats study area, southeastern Otero County, New Mexico and northeastern Hudspeth County, Texas. Contour interval 2 milligals. Gravity control shown by small open circles; newly collected control by solid circles. Contours dashed in areas of poor or no control.

The residual gravity anomaly map (fig. 8) shows anomalies calculated by removing a sloping plane surface from the complete Bouguer gravity anomaly field. The gravity control consists of 28 stations for the map area (Fig. 7). The distribution of stations is adequate to define gravity features having diameters of 5 to 10 km in the southwestern part of Cienega Quadrangle, but, control is inadequate to define anything but 20-50 km features to the northeast. The north-northwest axis connecting two gravity lows and the nearly coincident aeromagnetic lows are interpreted to reflect the approximate locations of the thickest sections of alluvial sediment and older underlying sedimentary rocks in this part of Alkali Flats (Figs. 7 and 8).

MINERAL RESOURCES

Appraisal of Identified Resources

U.S. Bureau of Mines conducted field investigations of surficial deposits of the Salt Flats ACEC in the Cienega School quadrangle (Korzeb and Kness, 1994, p. 10-12). The USBM recognized gypsiferous deposits in the ACEC. Chemical analyses of deposits from the ephemeral alkali lake bottoms revealed that the gypsum-rich sediments were too impure and salt-rich to be of any economic value. No other deposits of economic value were recognized within the area.

Assessment of Potential for Undiscovered Resources

[The definitions of mineral resource potential used in the following section, that is low, medium, and high, follow the rating system proposed by Guidarzi (1984).]

Nepheline syenite

Nepheline syenite of substantial economic value (for the manufacture of amber glass) occurs at Wind Mountain approximately 28 miles (45 km) west of the Salt Flats ACEC (Korzeb and Kness, 1994). Wind Mountain is one of many intrusions of an alkalic igneous province, which includes the Salt Flats ACEC. Round Mountain, approximately 3.5 miles (6 km) south of the alkali lakes, is the nearest of these alkalic intrusions to the Salt Flats ACEC. Although other alkalic intrusions might be present beneath the Salt Flats ACEC, magnetic anomaly data suggest that they are at least 3,000 feet (900 m) beneath the surface. In order to be of economic value, the iron-bearing minerals in any nepheline syenite that might be present must be amenable to easy removal by, for example, magnetic separation. This mineralogical requirement is not commonly found in such alkalic rocks and precludes most nepheline syenites from economic consideration. Because of the unlikely presence of near surface intrusions of nepheline syenite beneath the Salt Flats area and the uncertainty in the mineralogical character (and hence economic viability) of any intrusions that might be present, the resource potential for nepheline syenite in the Salt Flats ACEC is considered low.

`Mississippi Valley-type (MVT) deposits

The name Mississippi Valley-type deposit was derived from descriptions of lead-zinc-barite deposits in the upper Mississippi Valley, USA (Heyl and others, 1959). Although fluorite was not mined in the Upper Mississippi Valley district, it is an ore mineral in many other MVT districts. There are 4 essential requirements for forming an MVT ore deposit: a source of energy (heat) to drive the flow of mineralizing fluids, a fluid capable of transporting elements to the sites of mineralization, a source of elements to be concentrated into the deposit, and a trap or site where concentrating mechanisms operate to form ore-grade enrichments. Although the nature of each of these requirements is controversial, considering the likelihood that each requirement was satisfied is a logical means of producing a defendable resource assessment.

An important and possible source of energy for genesis of ore deposits beneath the Salt Flat ACEC is igneous activity at the time of mineralization. In some geologically similar areas containing discovered MVT ore bodies, as in the Illinois-Kentucky district, an alkalic intrusion concomitant with mineralization provided the source of heat. As Fehn and others (1978) pointed out, intrusions highly enriched in uranium and thorium (such as alkalic intrusions) generate substantial internal heat--enough that a large pluton may be 150°C hotter than rocks of normal radioactivity at a given depth. Fehn and others (1978) proposed that faulting of such hot rocks generated fracture permeability, which initiated thermal convection and transported heat to the overlying rocks. The alkalic intrusions of the Cornudas Mountains to the west of the Salt Basin graben (Fig. 1) are enriched in uranium and thorium (McLemore and Guilinger, 1993). Similar rocks occur to the east of the graben (Hayes, 1964), and one such intrusion (Round Mountain) lies about 3.5 miles (6 km) south of the ACEC (Barnes, 1975). Aeromagnetic studies (this report) suggest possible buried alkalic intrusions beneath and adjacent to the Salt Basin graben. Both the heat from the initial emplacement of these intrusions and from a faulting-induced episodic release of pent-up radiogenic heat during formation of the graben could have provided the energy needed for mineralization. The requirement for an energy source to drive ore-forming fluids beneath the ACEC appears to be satisfied.

Fluid inclusion data show that MVT mineralizing fluids were highly saline basinal brines (White, 1958). A high chloride ion content is critical to complexing and transporting metals (Barnes, 1979). Although the original basinal brines of the formations of the Salt Basin graben were flushed with fresh water in the Pleistocene (King and Harder, 1985), at the time of mineralization, saline brines were likely to have been present in the pore space. Because salt in a convection system is simply recycled, circulation of these brines in a convection system (instead of flushing through the ore zone and out of the basin) requires no more salt to form an MVT deposit than was initially present in the formation water.

In many MVT districts, lead in the ores is radiogenic (derived from the decay of uranium and thorium), and the distinctive ratios of lead isotopes have been used to identify the local basement rocks as the source of lead. Sawkins (1989) observed that all major lead ore deposits are younger than about 2 billion years and their formation was preceded by major episodes of anorogenic felsic magmatism. He suggested that this felsic magmatism enriched the crust in lead at the expense of the mantle and generated potential source rocks for subsequent lead mineralization. Both the regional basement and the younger alkalic intrusions (which may be enriched in lead) are possible sources of lead as well as other metals for MVT mineralization in the Salt Basin graben.

Organic matter is inevitably associated with MVT deposits (Spirakis, 1986) and the interaction of a hot mineralizing solution with concentrations of organic matter in the host rocks has been used to explain why all of the minerals (including sulfides, disulfides, sulfates, carbonates, fluorite and silica) in the paragenesis of these deposits precipitated at the same sites (Spirakis and Heyl, 1993). In some districts, such as the Upper Mississippi Valley district, indigenous organic matter was disseminated within specific limestones, which became the hosts for mineralization. In others, such as the

Illinois-Kentucky district, oil migrated to the sites of mineralization and was trapped to provide the conditions for mineralization. The dark color of some of the limestones in the Salt Basin graben (Permian Bone Springs and Cutoff Limestones) suggests that these formations may have been sufficiently organic rich to precipitate MVT ores. Alternatively, the organic-rich Devonian Percha Shale appears to have been an adequate source rock for oil generation in the basin. Black (1975) suggested that oil may have migrated into the Salt Basin from the Delaware Basin and become trapped beneath a seal formed by the Permian formations and possibly in reefs in the Abo Formation; he noted oil and gas shows in a well 2.5 miles (4 km) north of the ACEC. According to King and Harder (1985), Quaternary flushing by fresh water has probably destroyed oil pools in the Salt Basin graben. However, because MVT deposits would have formed before water flushing and considering that MVT districts are typically flushed with fresh water, it is unlikely that ground water conditions would diminish the potential for MVT deposits in the Salt Basin graben.

Fluorine may be an indicator of MVT mineralization both because fluorite is part of the MVT assemblage of minerals and because fluorine in magmas complexes uranium and concentrates uranium in the residual melts. This concentration aids in producing high heat-production granites to act as heat sources for MVT mineralization. Shawe (1976) identified a fluorine-rich province extending into the Salt Basin graben, and Hill (1993) described a few minor occurrences of fluorite a few tens of kilometers east of the graben. Although Hill (1993) considers the small deposits around the Delaware basin (just east and south of the ACEC) to be MVT deposits, none of these deposits contains more that a few minerals of the MVT assemblage and many of the minerals (azurite, malachite, smithsonite, hemimorphite, chrysocolla) and elements noted in these deposits (U, V, W, Mo, Bi) are not associated with MVT deposits.

Despite the lack of known MVT mineralization in the vicinity, this analysis suggests that there is a moderate potential for MVT deposits in the Salt Basin graben, including the Salt Flats ACEC.

Red bed copper deposits

The Devils's Den copper prospect lies approximately 4.3 miles (7 km) northeast of the ACEC, and the Calumet-Tejas mine lies approximately 4.3 miles (7 km) southeast of the ACEC. These two sites are the closest known metallic deposits to the ACEC. Descriptions in Hill (1993) indicate that at both sites the most obvious minerals are copper oxides (malachite and azurite) and iron disulfides (pyrite and/or marcasite), which have been largely oxidized. Mineral deposits occur in nearly vertical fractures in silicified carbonate rocks. Along with copper, some silver was produced from the Calumet-Tejas mine. Scintillometer readings at the Calumet-Tejas mine indicate a localized enrichment in uranium of 5 times background at one of the mine openings. This is consistent with the slight enrichment of uranium (20 ppm) reported by Hill (1993). Her analyses also showed enrichments in Ag, As, Bi, Cd, Co, Cu, Mo, Pb, Sc, V, W, and Zn. With the exception of tungsten, these are the same elements enriched in redbed copper deposits (Lindsey and others, 1995). All of these elements (including tungsten as WS_2) precipitate directly by reduction or as sulfides that are the byproduct of sulfate reduction. According to genetic models for redbed copper deposits (such as Lindsey and others, 1995), reduction is the precipitation mechanism involved in the formation of these deposits. The deposits at Devil's Den and the Calumet-Tejas mine are probably variants of redbed copper deposits. In the genesis of these deposits, it appears likely that an oxidizing mineralizing solution, produced by reactions with red (oxidized) sandstones, was forced upward along fractures until it encountered organic matter in the host limestone. Reduction then precipitated the ores. Lindsey and Clark (1995) described several deposits similar to those east of the ACEC in Pennsylvanian and Permian rocks throughout the west-central USA. The deposits are all small and are sparsely distributed. In addition, the volume of oxidized sandstone (potential source rock) in the area of the ACEC is low. All this suggests that there is only a low potential for finding even a small redbed copper deposit in the Salt Flat ACEC.

Native sulfur deposits

Two types of native sulfur deposits occur in the Guadalupe Mountains or Delaware basin just east of the Salt Basin graben. One of these is the relatively small (100-ton) type of deposit in limestone caves, such as Lechuguilla cave. These apparently formed where hydrogen sulfide-bearing water from oil basins mixed with oxygenated ground water. The oxidation of hydrogen sulfide produced sulfuric acid and dissolved limestones to form caves; however, if the supply of hydrogen sulfide exceeded that of oxygen, some of the hydrogen sulfide was only oxidized to native sulfur, thus forming the native sulfur deposits (Spirakis and Cunningham, 1992). The abundance of caves exposed in outcrops around Carlsbad Caverns suggests that a great amount of hydrogen sulfide migrated into the eastern Guadalupe Mountains. In contrast, outcrops on the east side of the Otero platform (west side of the ACEC) and in the Brokeoff Mountains (east side of the ACEC), do not present evidence for cave-forming processes. Consequently, native sulfur deposits formed as a byproduct of cave formation are unlikely to be found in or adjacent to the ACEC.

The second type of native sulfur deposit is exemplified by the huge (multi-million ton) Culberson deposit in the Rustler Springs sulfur district about 25 miles (40 km) east of the Salt Basin graben. These deposits formed by the bacterially catalized reduction of sulfate by organic matter--a genesis similar to native sulfur deposits in salt domes (Feely and Kulp, 1957). Sulfate was provided by bedded gypsum or anyhdrite deposits and organic matter by oil or gas, which migrated into the host sulfate beds. According to Hentz (1990), this type of sulfur deposit is often associated with grabens, possibly because faults of the graben enhance permeability and allow oil or gas to migrate to the sulfate-bearing formations. Traces of native sulfur have been found near the surface in the salt flats (Kreitler and Sharp, 1990). Although traces of sulfur at the surface led to the discovery of the Culberson deposit, traces of sulfur in the salt flats may simply have formed from the interaction of gypsum and organic matter in the modern alkali lakes of the area. Nevertheless, the presence of Permain anhydrites as potential sources of sulfate and of the Percha Shale as a potential source of oil for native sulfur formation, suggest a high probability that this type of native sulfur deposit formed in the Salt Basin graben. Unfortunately, native sulfur deposits are easily destroyed (oxidized to sulfate) by oxygen-bearing ground water, which is the reason these deposits are recently formed in arid environments such as west Texas or are protected by a thick cover of impermeable shale as in Poland. According to King (1948) and from the results of this study (Plate 1), the Salt Basin graben was the site of a Pleistocene lake more than 70 feet deep. Water from such a lake is likely to have destroyed any sulfur deposits that may have formed. Consequently, the potential for finding commercial sulfur deposits in the Salt Basin graben, and specifically in the Salt Flats ACEC, is low.

Tabular-type uranium-vanadium deposits

The genesis of tabular-type uranium-vanadium deposits, such as in the Grants uranium region of New Mexico or the Henry Mountains of Utah, is believed to be dependent on the presence of large alkaline lakes (Turner-Peterson, 1985; Turner and others, 1993; Sanford, 1995). Much of the controversy on the genesis of these deposits involves the emplacement and importance of organic matter. In most of the deposits in the Grants uranium region, tabular layers of humic organic matter are coextensive with the tabular uranium-vanadium deposits (Granger, 1968)--a spatial relationship which clearly indicates a genetic relationship, most likely by reduction of uranium and vanadium from oxidizing, alkaline ground waters (Hostetler and Garrels, 1962). However, some of the tabular deposits in the Grants region and all in the Henry Mountains district lack humic organic matter. For these, a series of inorganic reactions occurring at and dependent on an interface between solutions of contrasting chemistries has been proposed to explain the genesis of the deposits (Northrop and Goldhaber, 1990; Wanty and others, 1990). Because, among other problems, the proposed inorganic reactions required that the interface was maintained for 160 million years in rocks that were 130 million years old (Spirakis, 1991), and because of the many similarities between the organic-rich and organic-poor tabular deposits, Hansley and Spirakis (1992) concluded that humic organic matter was essential in forming all of these deposits and that organic-rich deposits were converted to clay-rich organic-poor deposits by reactions definitive of more advanced stages of diagenesis. That is, the organic-rich and organic-poor deposits differ only in the intensity of the diagenesis they have experienced, and therefore, determining if the conditions were right to emplace humic organic matter is important to evaluating the potential for this type of deposit. Turner and others (1993) concluded that humic organic matter was squeezed out of lake sediments by compaction during burial and forced downward into the underlying sandstones; however, Sanford (1994) pointed out that the volume of water from compaction of the lake sediments, even if saturated with humic acid, could not provide sufficient humic matter. He also pointed out that lakes are typically points of ground water discharge, which would not permit the downward migration of humic acids, and he argued (as had others before) that the tabular shape of the deposits indicated precipitation at a solution interface. As a compromise that draws from both models, Spirakis (1996) suggests that during flooding of a lake, the height of water in the lake causes the lake to become a temporary point of ground water recharge. This recharging alkaline lake water has a sufficiently high pH to solubilize humic acids and transport them downward to a drought-depressed water table or to an interface with a more saline solution. At the interface, humate precipitates in tabular layers. This model might apply to the precipitation of layers of organic matter in the alkali lakes of the Salt Basin graben.

Whether or not the Pleistocene lake in the Salt Basin graben was alkaline and had a sufficiently high pH to solubilize humic acids is not known. However, the Pleistocene lake evolved into the modern alkaline, high pH lakes (King, 1948). Kreitler and Sharp (1990) observed that horizontally bedded organic layers are common in the sediments of the alkali lakes. Although the present day alkali lakes are points of ground water discharge, during flooding, they are points of recharge (Kreitler and Sharp, 1990). This flood-stage recharge may have precipitated the organic layers by the process described above and thereby provided the reducing conditions required for the precipitation of tabular-type uranium-vanadium deposits.

Another critical requirement in forming tabular-type uranium-vanadium deposits is a source of uranium and/or vanadium. The ideal source rock is rhyolitic volcanic ash (which is highly enriched in uranium) of the same age and in close proximity to the alkaline lake sediments. (Ash is a component of the Morrison Formation, which hosts the classic tabular uranium-vanadium deposits in the Grants and Henry Mountains regions.) Because elements are easily and quickly leached from rhyolitic ash, it is likely that the ash in west Texas and adjacent parts of New Mexico, which is much older than the Pleistocene or modern lakes, was not a viable source of uranium or vanadium when the lakes formed. Other highly differentiated igneous rocks, including the syenites of the Cornudas Mountains, are enriched in uranium, and elsewhere such rocks have been shown to be suitable sources of uranium for young surficial uranium deposits, as in beat bogs. Even though the most liable uranium may have been leached from the syenites before the lakes formed, even today the syenites are still enriched in uranium, and ground water from the west recharges into the Salt Basin graben (Kreitler and others, 1990), which suggests that the syenites are possible (but less than ideal) sources of uranium for tabular-type deposits in the alkaline lakes. Therefore, there is a low to moderate potential for tabular-type uranium-vanadium deposits in the alkaline lakes of Salt Basin graben.

Evaporite minerals

A substantial amount of salt was mined from a 2 centimeter thick, renewable salt crust from Zimpleman Salt Lake in the Salt Basin graben about 18.5 miles (30 km) south of the Salt Flats ACEC (Boyd and Kreitler, 1986). This deposit is no longer economical and only traces of halite are reported in the alkali lakes of the Salt Flats area. Gypsum formed in the alkali lakes contains too much chlorine to be of commercial value (Korzeb and Kness, 1994). No other valuable evaporite minerals, as occur in some saline lakes, are reported in these lakes. The waters of the Salt Basin graben evolve into Na-Mg-SO_4-Cl brines (Boyd and Kreitler, 1986), which are not of economic interest. Therefore it is unlikely that evaporite minerals or brines will ever be mined from the Salt Flats ACEC.

Oil and gas deposits

In the mineral resource assessment of the Brokeoff Mountains, part of which is included in the Cienega School quadrangle, Moore and others (1989) concluded that the study area has a low potential for oil and gas resources. The low potential for the Brokeoffs is largely due to the structural development of the Salt Basin graben that involved extensive faulting, tilting, and probable destruction of any possible petroleum traps that may have once been present (Moore and others, 1989, p. E10). That conclusion applies directly to all rocks in the Cienega School quadrangle. Analysis of petroleum potential in the Salt Basin graben by King and Harder (1985) was not positive; of the wells drilled in the area, most drill stem tests indicated fresh water flushing of favorable reservoir rocks. In addition, heat related to the possible presence of intrusive rocks beneath the surface of the quadrangle could have destroyed any oil and gas accumulations and further diminishes the potential for oil and gas reserves in and adjacent to the Salt Flats ACEC.

Caves

The popularity of Carlsbad Caverns demonstrates that caves are an economic (if not mineable) resource, and caves are abundant throughout the Guadalupe Mountains. While caves may exist in the limestones beneath the Salt Basin graben, the high water table, especially in the alkali lakes, guarantees that any caves in the area would be flooded and hence are of no economic value. The absence of observable caves in the outcrops of the Otero platform and the Brokeoff Mountains suggests that the parts of the ACEC above the watertable are also unlikely to contain caves of economic value.

References Cited

Bankey, V.L., and Kleinkopf, M.D., 1988, Bouguer gravity anomaly map and four derivative maps of Idaho: U.S. Geological Survey Geophysical Investigations Map, GP-978, 3 sheets, scale 1:1,000,000.

Barnes, H.L., 1979, Solubilities of ore metals, *in* Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: New York, John Wiley, p. 404-460.

Barnes, V.E., 1975, Geologic atlas of Texas, Van Horn-El Paso Sheet: Bureau of Economic Geology, Austin, scale 1:250,000.

Black, B.A., 1975, Geology and oil and gas potential of the northeast Otero platform area, New Mexico, *in* Seager, W.R., Clemmons, R.E., and Callender, J.F., eds., New Mexico Geological Society Guidebook, 26th Field Conference, Las Cruces County, p. 323-333.

Boyd, F.M., and Kreitler, C.W., 1986, Hydrology of a gypsum playa, northern Salt Basin: Texas Bureau of Economic Geology, Report of Investigations 158, 37 p.

Carson Helicopters, Inc., 1981, Residual total-intensity magnetic profiles and contour maps, Van Horn quadrangle, Texas: National Uranium Resource Evaluation Project, U.S. Department of Energy, Grand Junction office, Open-File Report GJM-17, scale 1:250,000.

Feely, H.W., and Kulp, J.L., 1957, Origin of Gulf coast salt-dome sulfur deposits: American Association of Petroleum Geologists Bulletin, v. 41, p. 1802-1853.

Fehn, U., Cathles, L.M., and Holland, H.D., 1978, Hydrothermal convection and uranium deposits in abnormally radioactive plutons: Economic Geology, v. 73, p. 1556-1566.

Friedman, G.M., 1966, Occurrence and origin of Quaternary dolomite of Salt Flat, west Texas: Journal of Sedimentary Petrology, v. 36, p. 263-267.

Gates, J.S., White, D.E., Stanley, W.D., and Ackermann, H.D., 1980, Availability of fresh and slightly saline ground water in the basins of westernmost Texas: Texas Department of Water Resources, Report No. 256, 103 p.

Geometrics, Inc., 1983, Residual total-intensity magnetic profiles and contour maps, Carlsbad quadrangle, New Mexico: National Uranium Resource Evaluation Project, U.S. Department of Energy, Grand Junction office, Open-File Report GJM-394, scale 1:250,000.

Goetz, L.K., 1985, Salt Basin graben: A basin and range right-lateral transtensional fault zone—Some speculations, *in* Dickerson, P.W. and Muehlberger, W.R., eds., Structure and tectonics of Trans-Pecos Texas: West Texas Geological Society Publication 85-81, p. 165-168.

Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84-787, p. 7-8.

Granger, H.C., 1968, Localization and control of uranium deposits in the southern San Juan basin mineral belt, New Mexico--An hypothesis: U.S. Geological Survey Professional Paper 600 B, p. B60-B70.

Hansley, P.L., and Spirakis, C.S., 1992, Organic matter diagenesis as the key to a unifying theory for the genesis of tabular uranium-vanadium deposits in the Morrison Formation, Colorado Plateau: Economic Geology, v. 87, p. 352-365.

Hayes, P.T., 1964, Geology of the Guadalupe Mountains, New Mexico: U.S. Geological Survey Professional Paper 446, 69 p.

Heyl, A.V., Jr., Agnew, A.F., Lyons, E.J., and Behre, C.H., Jr., 1959, The geology of the upper Mississippi Valley zinc-lead district: U.S. Geological Survey Professional Paper 309, 310 p.

Hentz, T.F., 1990, Native sulfur deposits in the western Delaware Basin, Trans-Pecos Texas--Origin, distribution and exploration strategy, *in* Kyle, J.R., ed., Industrial mineral resources of the Delaware Basin, Texas and New Mexico: Society of Economic Geologists Guidebook Series, v. 8, p. 115-140.
Hill, C.A., 1993, Sulfide/barite/fluorite mineral deposits, Guadalupe Mountains, New Mexico and west Texas: New Mexico Geology, v. 15, no. 3, p. 56-59.
Hostetler, P.B., and Garrels, R.M., 1962, Transportation and precipitation of uranium and vanadium at low temperatures, with special reference to sandstone type uranium deposits: Economic Geology, v. 7, p. 137-157.
Hussain, Mahbub, Warren, J.K., and Rohr, D.M., 1988, Depositional environments and facies in a Quaternary continental sabkha, west Texas, *in* Reid, S.T., Bass, R.O., and Welch, Pat, eds., Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society Publication 88-84, p. 177-185.
Keller, G.R., Veldhuis, J.H., and Powers, D.W., 1983, An analysis of gravity and magnetic anomalies in the Diablo Plateau area: Permian Basin Section, Society of Economic Geologists and Mineralogists, Field conference guidebook, Geology of the Sierra Diablo and southern Hueco Mountains, West Texas, p.152-165.
King, P.B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geological Survey Professional Paper 215, 183 p.
King, W.E., and Harder, V.M., 1985, Oil and gas potential of the Tularosa Basin-Otero platform-Salt Basin graben area, New Mexico and Texas: New Mexico Bureau of Mines and Mineral Resources Circular 198, 6 p.
Korzeb, S.L., and Kness, R.F., 1994, Mineral resources in areas of critical environmental concern in the Caballo resource area, Otero County, New Mexico: U.S. Bureau of Mines, Land Management Assessment Open-File Report 20-94, 73 p.
Kreitler, C.W., Mullican, W.F. III, and Nativ, R., 1990, Hydrology of the Diablo Plateau, Trans-Pecos Texas, *in* Kreitler, C.W., and Sharp, J.M., Jr., eds., Guidebook 25, Hydrology of Trans-Pecos Texas: Texas Bureau of Economic Geology, p. 49-58.
Kreitler, C.W., and Sharp. J.M., Jr., 1990, Guidebook 25, Hydrology of Trans-Pecos Texas: Texas Bureau of Economic Geology, p. 49-58.
Lindsey, D.A., and Clark, R.F., 1995, Copper and uranium in Pennsylvanian and Permian sedimentary rocks, Northern Sangre de Cristo Range, Colorado: U.S. Geological Survey Bulletin 2116, 23 p.
Lindsey, D.A., Woodruff, L.G., Cannon, W.F., Cox, D.P., and Heran, W.D., 1995, Sediment-hosted copper deposits, *in* Du Bray, E.A., ed., Preliminary compilation of descriptive geoenvironmental mineral deposit models: U.S. Geological Survey Open-File Report 95-831, p. 214-224.
Love, D.W., and Hawley, J.W., 1993, Supplemental Road Log 2 from Junction of NM-137 and Sitting Bull Falls Road to Salt Flat graben, *in* Love, D.W. , Hawley, J.W., Kues, B.S., Adams, J.W., Austin, G.S., and Barker, J.M., eds., Carlsbad region, New Mexico and west Texas: New Mexico Geological Society Field Conference Guidebook no. 44, p. 99-108.
McLemore, V.T., and Guilinger, J.R., 1993, Geology and mineral resources of the Cornudas Mountains, Otero County, New Mexico and Hudspeth County, Texas, *in* Love, D.W., Hawley, J.W., Kues, B.S., Adams, J.W., Austin, G.S., and Barker, J.M., eds., Carlsbad region, New Mexico and west Texas: New Mexico Geological Society Field Conference Guidebook no. 44, p. 145-153.
Miller, R.R., 1981, Coevolution of deserts and pupfishes in the American southwest, *in* Naiman, R.J., and Soltz, D.L., eds., Fishes in North American deserts: New York, John Wiley and Sons, p. 39-94.

Moore, S.L., Kleinkopf, M.D., Nowlan, G.A., and Corbetta, P.A., 1989, Mineral resources of the Brokeoff Mountains wilderness study area, Otero County, New Mexico: U.S. Geological Survey Bulletin 1735, 13 p.

Northrop, H.R., and Goldhaber, M.B., 1990, Genesis of tabular-type vanadium-uranium deposits of the Henry basin, Utah: Economic Geology, v. 85, p. 215-269.

Nutt, C.J., O'Neill, J.M., McLemore, V.T., Kleinkopf, M.D., Klein, D.P., and Miller, W.R., 1997, Geology and mineral resources of the Cornudas Mountains, New Mexico: U.S. Geological Survey Open-File Report 97- , p.

Pearson, B.T., 1988, A three-hundred-mile fault zone: the Trans-Pecos rift, *in* Reid, S.T., Bass, R.O., and Welch, Pat, eds., Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society Publication 88-84, p. 171-176.

Pray, L.C., 1988, The western escarpment of the Guadalupe Mountains, Texas and day two of the field seminar, *in* Reid, S.T., Bass, R.O., and Welch, Pat, eds., Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society Publication 88-84, p. 23-31.

Sanford, R.F., 1994, A quantitative model of ground-water flow during formation of sandstone uranium deposits: Economic Geology, v. 89, p. 341-360.

Sanford, R.F., 1995, Mineralization, diagenesis, isotope geochemistry, and hydrochemistry of tabular sandstone uranium deposits: U.S. Geological Survey Open-File Report 95-531, 63 p.

Sawkins, F.J., 1989, Anorogenic felsic magmatism, rift sedimentation, and giant Proterozoic Pb-Zn deposits: Geology, v. 17, p. 657-660.

Seager, W.R., and Morgan, Paul, 1979, Rio Grande rift in southern New Mexico, west Texas, and northern Chihuahua, *in* Reicker, R.E., ed., Rio Grande Rift: tectonics and magmatism: American Geophysical Union, p. 87-106.

Shawe, D.R., 1976, Geology and resources of fluorine in the United States: U.S. Geological Survey Professional Paper 933, 99 p.

Spirakis, C.S., 1986, Occurrence of organic carbon in Mississippi Valley deposits and an evaluation of processes involving organic carbon in the genesis of these deposits, *in* Dean, W.A., ed., Organics in ore deposits: Proceedings of the Denver Regional Exploration Geologists Society, p. 85-95.

______, 1991, Genesis of tabular vanadium-uranium deposits of the Henry basin--A discussion: Economic Geology, v. 86, p. 1350-1353.

______, 1996, The roles of organic matter in the formation of uranium deposits in sedimentary rocks: Ore Geology Reviews, v. 11, p. 53-69.

Spirakis, C.S., and Cunningham, K.I., 1992, Genesis of sulfur deposits in Lechuguilla Cave, Carlsbad National Park, New Mexico, *in* Wessel, G., and Wimberly, B., eds., Native sulfur--Developments in geology and exploration: American Institute of Mining, Metallurgical and Petroleum Engineering Press, p. 139-145.

Spirakis, C.S., and Heyl, A.V., 1993, Organic matter (bitumen and other forms) as the key to the localisation of Mississippi Valley-type ores, *in* Parnell, J., Kucha, H., and Landais, P., eds., Bitumens in ore deposits: Society of Geology Applied to Mineral Deposits, Springer-Verlag, Special Publication 9, p. 381-389.

Turner, C.E., Fishman, N.S., Hatcher, P.G., and Spiker, E.C., 1993, Nature and role of organic matter in sandstone uranium deposits, Grants uranium region, New Mexico, USA, *in* Parnell, J., Kucha, H., and Landais, P., eds., Bitumens in ore deposits: Society of Geology Applied to Mineral Deposits, Springer-Verlag, Special Publication 9, p. 239-275.

Turner-Peterson, C.E., 1985, Lacustrine-humate model for primary uranium deposits, Grants uranium region, New Mexico. American Association of Petroleum Geologists Bulletin, v. 69, p. 1999-2020.

Vacquier, V., Steenland, N.C., Henderson, R.G., and Zietz, I., 1951, Interpretation of aeromagnetic maps: Geol. Soc. America Mem. 47, 151 p.

Veldhuis, J.H., and Keller, G.R., 1980, An integrated geological and geophysical study of the Salt Basin graben, west Texas, *in* Dickerson, P.W., Hoffer, J.M., and Callender, J.F., eds., Trans-Pecos region: New Mexico Geological Society Guidebook 31, p. 141-150.

Wanty, R.B., Goldhaber, M.B., and Northrop, H.R., 1990, Geochemistry of vanadium in an epigenetic, sandstone-hosted vanadium-uranium deposit, Henry basin, Utah: Economic Geology, v. 85, p. 270-284.

White, D.E., 1958, Liquid of inclusions in sulfides from Tri-state (Missouri-Kansas-Oklahoma) is probably connate in origin: Geological Society of America Bulletin, v. 69, p. 1600-1601.

Woodward, L.A., Callender, J.F., Gries, J., Seager, W.R., Chapin, C.E., Zilinski, R.E., and Schaffer, W.L., 1975, Tectonic map of the Rio Grande region, Colorado-New Mexico border to Presidio, Texas, *in* Seager, W.R., Clemons, R.E., and Callender, J.F., eds., Las Cruces Country, New Mexico: New Mexico Geological Society Field Conference Guidebook No. 26, p. 239.