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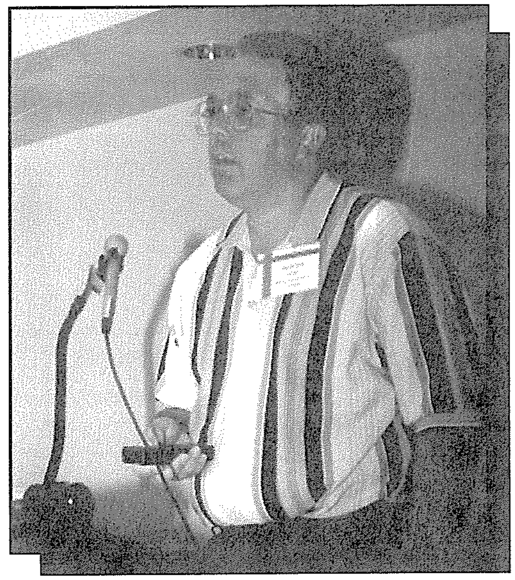

AN OVERVIEW OF THE GEOLOGY OF NORTHEASTERN NEW MEXICO

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INTRODUCTION

Northeastern New Mexico has been less studied geologically than other areas of New Mexico because of its scarcity of economically important resources and its paucity of complex geological structures. However, this relatively flat-lying terrane of Mesozoic and Cenozoic strata has received increased attention during the last 15 years, principally through the work of students and staff from the New Mexico Museum of Natural History and Science and the University of New Mexico (e.g., Lucas and Zidek 1985; Lucas and Hunt 1987, 1989a). The purpose of this paper is give a brief overview of our current state of knowledge of the geology of northeastern New Mexico including Union, Harding, Quay counties and the eastern portions of Guadalupe, San Miguel, Mora and Colfax counties (Figure 1). I have deliberately tried to cite references that are easily available to non-geologists and many are from the excellent guidebooks of the New Mexico Geological Society.

HISTORY OF STUDY

Six major expeditions that produced geological information, traversed northeastern New Mexico prior to 1860 (Kues 1985a, Figure 1). The French geologist Jules Marcou traveled with the 1853 Whipple Expedition and controversies that resulted from his work caused a series of geologists to visit the Quay County area for another 40 years (Kues 1985b). Geologic work in this area has been sporadic in the twentieth century, with increasing interest in the sedimentary geology and paleontology during the last 15 years.

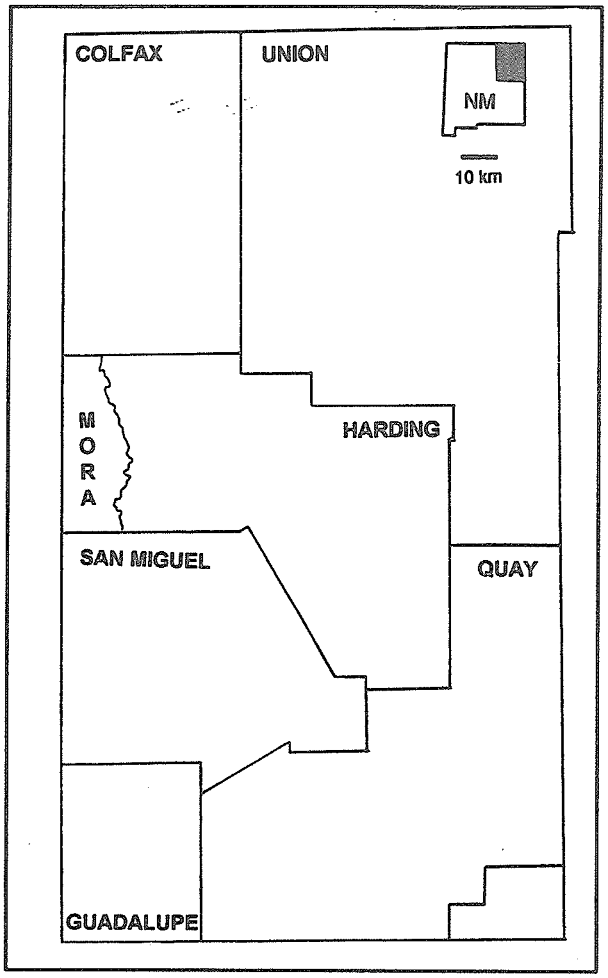

Figure 1. Location of study area in northeastern New Mexico.

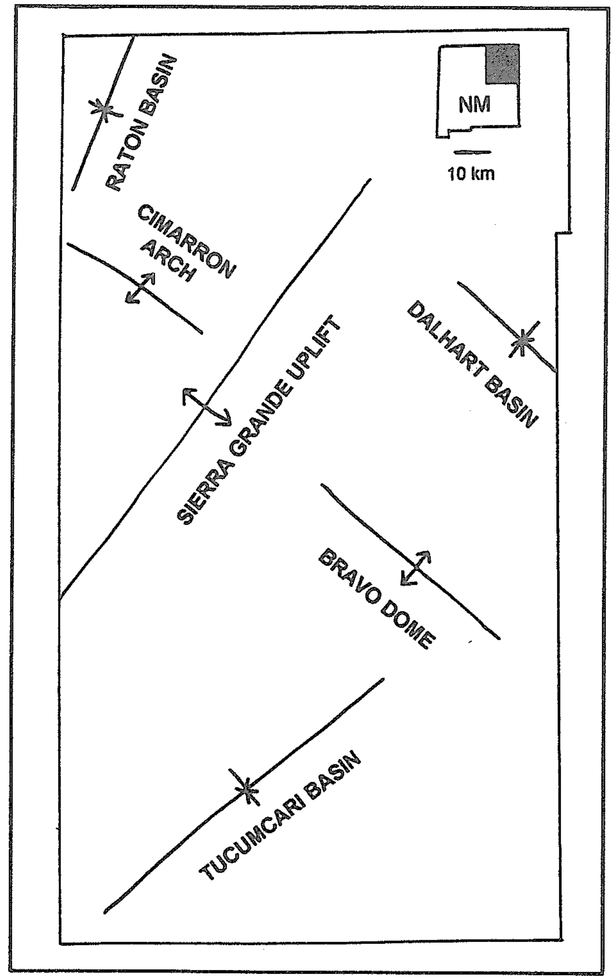

Figure 2. Major structural features in northeastern New Mexico.

STRUCTURE

Northeastern New Mexico is a geologically stable terrane that forms part of the western edge of the North American craton. The Precambrian basement is dominated by structures associated with the ancestral Rocky Mountains (Suleiman and Keller 1985). Major structures include the northeast-trending Sierra Grande arch and the similarly trending Tucumcari basin to its south, the northwest-trending Dalhart basin and Bravo dome to the east and the northwest-trending Cimarron arch to the west that divides two sub-basins of the Raton basin (Figure 2). The Tucumcari basin is bounded on the west and east by the Pedernal uplift and Palo Duro basin, respectively, and to the south by the Matador uplift. As a measure of the scale of these structures, the minimum structural relief between the Sierra Grande arch and the Dalhart basin is 2,900 m (Woodward 1987b).

Setter and Adams (1985) suggest that three phases of tectonism had effected east-central New Mexico in the late Proterozoic, early Paleozoic and the late Cenozoic. Tertiary structures in the southern part of the study area include gentle folding in the Tucumcari area and the Bonita fault near San Jon, (Stearns 1972) as well as NNE-trending dikes near Cuervo (Setter and Adams 1985). The Holocene stability of the area is indicated by the rarity of earthquakes in the area (Northrop and Sanford 1972).

PRECAMBRIAN GEOLOGY

There are no exposed Precambrian rocks in northeastern New Mexico, but data from surrounding areas (e.g., Sangre de Cristo Mountains and Pedernal Hills) and from drilling samples allow insight into the basement in this area. By extrapolation, northeastern New Mexico is part of a broad Proterozoic orogenic belt that trends to the northeast through Arizona, the Four Corners area and all but southeasternmost New Mexico (Karlstrom and Bowring 1988). Regionally these rocks range in age from approximately 1800 to 1600 Ma (Hoffman 1988).

Foster and others (1972, Figure 9) produced a preliminary map of Precambrian rocks in northeastern New Mexico that indicated granitic terranes in the northern part of the area. In east-central New Mexico they showed the Panhandle volcanic terrane extending from West Texas into Quay and southeastern San Miguel counties and the Torrance metamorphic group encompassing most of Guadalupe County and southern San Miguel County with a small area of granite east of Santa Rosa. Muehlberger and others (1966) and Setter and Adams (1985) reported a series of radiometric ages on these rocks based on subsurface samples from Guadalupe, Quay, Mora and Union counties. Dates on granites range from 1667-664 Ma and those of other lithologies (gneiss, quartz-feldspar porphyry, basalt) from 848-604 Ma. Setter and Adams (1985) conclude that these data indicate, in part, a late Proterozoic period of extensive plutonism and volcanism.

PHANEROZOIC STRATIGRAPHY

Introduction

Phanerozoic strata are similar throughout the study area. However, the stratigraphic sequence in Union County, particularly in the northeastern corner, exhibits more similarities with that in Oklahoma and southern Colorado than with other parts of the study area. These differences are principally in the pre-Middle Jurassic strata (Figure 3).

Lower Paleozoic

Early Paleozoic strata do not crop out in northeastern New Mexico but sandy and cherty dolomites in the subsurface of northeastern Union County have been identified as pertaining to the Early Ordovician Arbuckle Group (Foster 1972). Other Lower Paleozoic rocks may also underlie portions of east-central Quay County (Armstrong and Mamay 1987, Figure 1).

Upper Paleozoic

Latest Devonian strata of the Williams Canyon Formation are postulated to just extend into northeastern Union County from eastern Colorado (Poole et al. 1967). Marine Mississippian strata were deposited over most of the study area, but large areas were subsequently stripped by erosion during the uplift of positive areas such as the Sierra Grande Arch during the Ancestral Rocky Mountain orogeny (Roberts et al. 1976). Currently Mississippian rocks are only present in the subsurface in northwestern Union County and in a northwest-southeast trending strip from eastern Colfax County to western Quay County (Armstrong and Mamay 1987).

Pennsylvanian and Permian strata are continuous in subcrop throughout the study area. In the Sangre de Cristo Mountains to the west of the study area exposed rocks of Pennsylvanian age have assigned to the Sandia, Porvenir and Alamitos formations of the Madera Group (Baltz and Meyers 1984), but this usage has not been extended into the subsurface where regional chronostratigraphic units have been defined by fusilinids (Broadhead and King 1985).

Beginning in the Late Pennsylvanian and continuing into the Early Permian (Wolfcampian), increased tectonic activity in the Sierra Grande uplift and related uplifts shed large volumes of red, arkosic sediments into surrounding marine basins. In the northern part of the study area, these are referred to the Sangre de Cristo Formation (Late Pennsylvanian-Early Permian) and to the south to the Abo Formation (wholly Permian). Marine facies of the Hueco Formation underlie the redbeds in many areas except over the tectonic highs such as the Sierra Grande uplift. In Union County the redbeds of the Sangre de Cristo Formation pass laterally into the marine Admire, Council Grove and Chase groups.

The overlying Permian strata are dominantly marine in origin and include the Yeso Formation, San Andres Formation and Artesia Group in the west and south of the study area which range in age from Early to Late Permian (Leonardian to Guadalupian). Artesia Group rocks are exposed along the Pecos River. Permian rocks in the subsurface of Union County are more related to marine strata in Texas and Oklahoma and generally include more evaporites than equivalent rocks elsewhere in the study area. These rocks include, from oldest to youngest, the Nippewalla

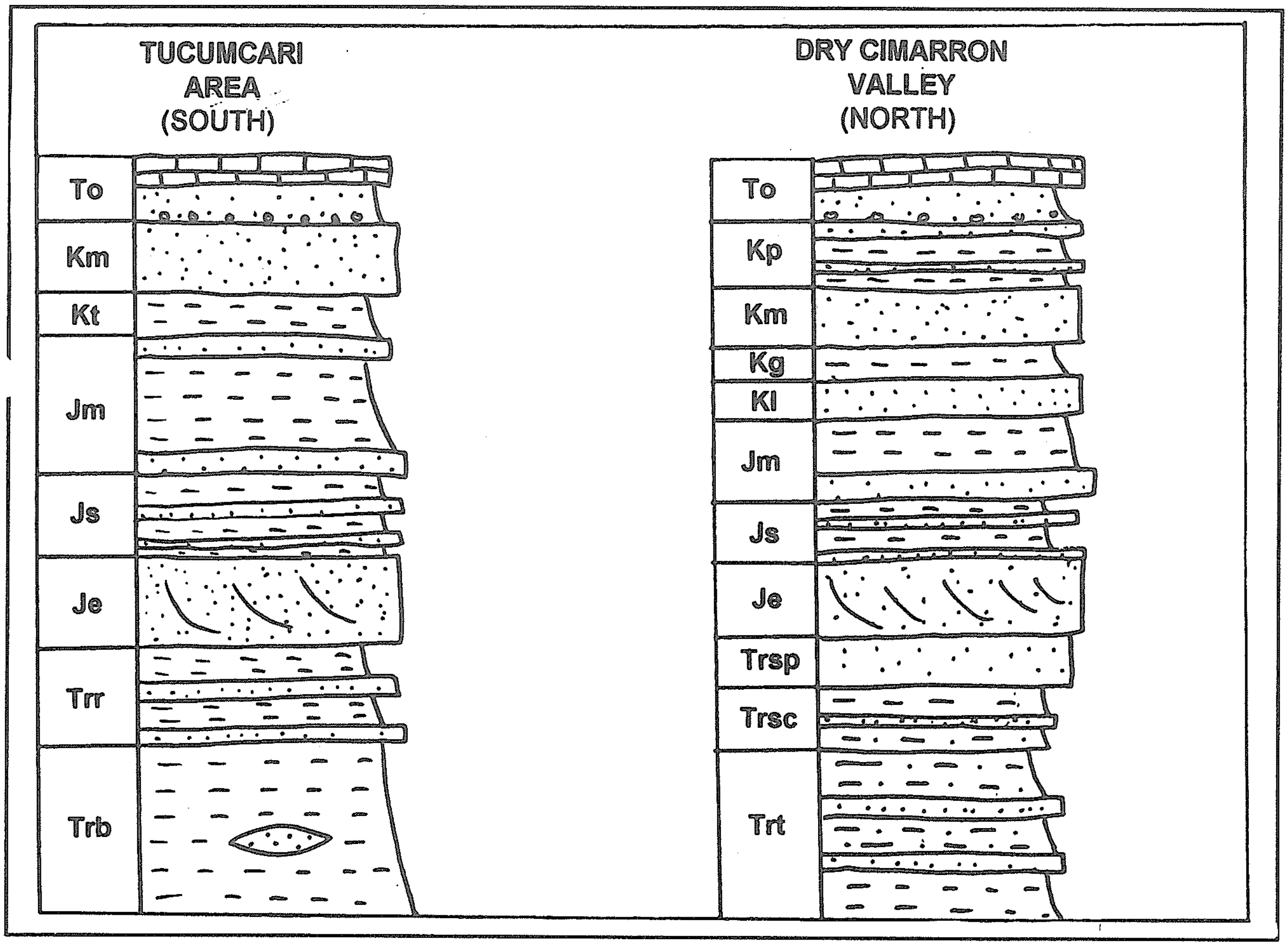

Figure 3. Comparison of the surface stratigraphy in the Tucumcari area in the southern portion of the study area with that of the Dry Cimarron valley in the northeastern portion. Tertiary units are: To, Ogallala Formation. Cretaceous units are: Kg, Glencairn Formation; Kl, Lytle Sandstone; Km, Mesa Rica Sandstone; Kp, Pajarito Formation. Jurassic units are: Je, Entrada Sandstone; Jm, Morrison Formation; Js, Summerville Formation. Triassic units that are all included within the Chinle Group are: Trb, Bull Canyon Formation; Trr, Redonda Formation; Trsc, Sloan Canyon Formation; Trsp, Sheep Pen Sandstone; Trt, Travesser Formation. Note that other units may be present in the area of these generalized sections, particularly immediately below the Ogallala. Deeper portions of the Dry Cimarron valley and Canadian River valley expose older Upper Triassic strata than those indicated in the figure.

Group, the Whitehorse Group, the Cloud Chief Formation and the Quartermaster Formation (Lucas et al. 1987). The Alibates Dolomite is a conspicuous marker bed that separates the Cloud Chief and Quartermaster.

Triassic

Triassic redbeds occur throughout the study area (Figure 3) and provide the red hue to much of the landscape of northeastern New Mexico. In Quay and Guadalupe counties, the Middle Triassic (Anisian) Moenkopi Formation, in subcrop or outcrop, overlies Permian strata, but elsewhere in the area all Triassic rocks are of Late Triassic (late Carnian-Rhaetian) age (Lucas and Hunt 1989b; Hunt and Lucas 1993c). The Upper Triassic rocks comprise the Chinle Group. Throughout most of the western and southern part of the study area the Chinle Group consists of a basal, sandy Santa Rosa Formation overlain by the Garita Creek, Trujillo, Bull Canyon and Redonda formations. In the Dry Cimarron valley of Union County facies differences have resulted in equivalent strata being named, in ascending order, the Baldy Hill, Travesser, Sloan Canyon and Sheep Pen formations.

Jurassic

Middle and Upper Jurassic strata are widely exposed in northeastern New Mexico (Figure 3). White cliffs of the Callovian (Middle Jurassic) Entrada Sandstone overlie the redbeds of the Chinle Group and display the large scale crossbeds characteristic of eolian deposition. In the southwestern portion of the study area, limestones of the Luciano Mesa member of the Todilto Formation overlie the Entrada Sandstone. In eastern Guadalupe County Formation the exeter tongue of the Entrada overlies the Todilto and to the east the Todilto pinches out (Lucas et al. 1985, Figure 9). Elsewhere in the study area the "Todilto notch"—a thin, finer grained interval in the medial Entrada—can be recognized in the same stratigraphic position as the Todilto (Lucas et al. 1985, Figure 9). The Summerville Formation overlies the Todilto Formation or the Entrada Sandstone and consists of thinly bedded sandstone and siltstone. Previously this unit was referred to as the Bell Ranch Formation or brown silt-stone member, but it is now recognized as equivalent to the Callovian-Oxfordian Summerville Formation of the Four Corners area (Anderson and Lucas 1992).

The majority of the thickness of the Jurassic sequence in northeastern New Mexico is represented by the Morrison Formation which is probably wholly Jurassic in age but which might extend into the basal Jurassic. The Morrison pinches out south of Tucumcari but rapidly thickens to the north to reach thicknesses of up to 180 m on the Harding/Mora county line (Lucas et al. 1985). Morrison strata are dominated by green and red mudstones and siltstones and lenticular sandstone bodies of the Brushy Basin member. In some areas, a lower sand-dominated salt wash member is present. In the southern portion of the study area there is often a conspicuous white sandstone at the top of the Morrison sequence (Holbrook et al. 1987).

Cretaceous

During the late Early and Late Cretaceous, northeastern New Mexico lay on or near the western margin of the Western Interior epeiric seaway and strata of these ages represent marine, transitional and nonmarine environments.

The pre-Dakota Group sequence is represented by marine shale that is referred to as the Tucumcari Shale in the Tucumcari basin and the Glencairn Formation in the Dry Cimarron valley of Union County (Kues and Lucas 1987). In the Dry Cimarron valley this unit is underlain by a prominent sandstone unit that is referred to as the Lytle Sandstone. A relatively diverse marine fauna constrains the Tucumcari/Glencairn as late Albian (late Early Cretaceous: Kues et al. 1985), although the poorly fossiliferous and dominantly nonmarine Lytle may be slightly older. The western edge of the study area approximates the western limit of Albian marine strata in New Mexico.

The Dakota Group has long been recognized to have a tripartite division in northeastern New Mexico which are in ascending order: Mesa Rica Sandstone; Pajarito Formation; and Romeroville Sandstone. These units range in age from latest Albian (late Early Cretaceous) to Cenomanian (early Late Cretaceous: Kues and Lucas 1987).

The Romeroville represents the onset of the first transgressive systems tract associated with the Late Cretaceous sea that engulfed much of New Mexico. Although the Romeroville outcrops throughout the study area, outcrops of younger Cretaceous deposits are generally limited to eastern Colfax and Mora counties associated with the Raton basin with outliers in other areas (e.g., the Bonito fault zone of eastern Quay County). The post-Dakota Group strata include the marine Graneros Shale (Cenomanian), Greenhorn Formation (Cenomanian-Turonian), Carlisle Shale (Turonian), Niobrara Formation (Turonian-Campanian), Pierre Shale (Campanian-Maastrichtian), the shoreline Trinidad Sandstone (Maastrichtian) and the paludal, coal-bearing Vermejo and Raton formations.

Tertiary

The Ogallala Formation is widespread in northeastern New Mexico where this resistant unit caps the High Plains (Figure 3). The Ogallala is dominantly of Miocene age although it may extend into the early Pliocene (Hawley 1984). Its most prominent lithologies are massive calcretes although it also includes sands and gravels.

Quaternary

Quaternary deposits are widespread in northeastern New Mexico and include alluvium, terrace gravels, eolian sand and loess that range in age from Pliocene to Holocene (Hawley et al. 1976). Few stratigraphic names have been proposed for these units except in the southern portion of the study area where the Blackwater Draw Formation, Blanco, Double Lakes, Tule and Tahoka formations occur on the Llano Estacado and the Gatuna Formation in the Pecos Valley.

DEVELOPMENT OF THE MODERN LANDSCAPE

The landscape of northeastern New Mexico is dominated by the extensive High Plains surface capped by the Ogallala Formation and by the river valleys of the Pecos, Canadian and Dry Cimarron rivers that dissect the plains and expose colorful Mesozoic strata. This area is part of the Great Plains physiographic province. A low-relief alluvial plain began aggrading with middle to late Miocene uplift of the southern Sangre de Cristo Mountains and deposition of coalescing alluvial fan lobes (gravels, sands) continued between about 7 and 4 Ma. Subsequently, there was a period of tectonic stability with a more arid climate resulting in the massive calcrete of the upper Ogallala Formation which formed from about 2.5 to 3 Ma (Hawley 1984; Dolliver 1985). The Ogallala surface slopes to the southeast. Incision of the Ogallala landscape by the major rivers of the region began with abrupt and successive episodes of Pliocene-Pleistocene uplift and climatic change (Dolliver 1985).

Subsurface dissolution of Permian evaporites has been an important factor in the development of the modern landscape resulting in the spectacular six-mile wide sink that is centered on Santa Rosa and more subtle features (Sweeting 1972).

PALEONTOLOGY

Marine invertebrates are known from Paleozoic rocks from the subsurface (Broadhead and King 1985), but obviously the majority of fossils are known from the Mesozoic and late Cenozoic strata that have surface exposures. The Middle Triassic Moenkopi Formation has yielded a small number of significant terrestrial tetrapods (Lucas and Morales 1985). The Upper Triassic Chinle Group is richly fossiliferous in northeastern New Mexico and it includes a nonmarine fauna with diverse fish and tetrapods as well as plants and invertebrates and coprolites and footprints (Hunt 1994). Jurassic fish are locally abundant in the Middle Jurassic Todilto Formation and dinosaur bones and less common bivalves and footprints occur in the Upper Jurassic Morrison Formation (Lucas et al. 1985; Hunt and Lucas 1993b).

The majority of Cretaceous fossils from northeastern New Mexico represent marine invertebrates. The faunas of the Tucumcari/Glencairn are particularly well studied (Kues et al. 1985), but significant fossils are also known from other units including the Greenhorn Limestone and the Niobrara Formation (Hattin 1987; LaFerriere 1987). Significant nonmarine fossils include dinosaur footprints in Harding and Union counties and abundant petrified wood in the Mesa Rica Sandstone (Hunt and Lucas 1993a; Lockley and Hunt 1995).

ECONOMIC GEOLOGY

Oil and Gas

Northeastern New Mexico has failed to yield substantial quantities of oil and natural gas despite sporadic exploration. The Wagon Mound field, that produced limited gas in the 1970s, has been the best producer in the area (Woodward 1987a), although there are prospects for the Tucumcari basin (Broadhead and King 1985). Coalbed methane production in the Raton basin, to the west of the study area is currently showing great potential.

Coal

The substantial coal reserves of the Raton basin are dominantly located just to the west of the study area. Coal has been extensively mined from both the Upper Cretaceous Vermejo and Upper Cretaceous-Paleocene Raton formations in western Colfax County and in Las Animas County, Colorado.

Carbon Dioxide

Naturally occurring carbon dioxide has been produced from three fields in Union and Harding counties (Broadhead 1987). The small Des Moines field is now abandoned, but the Bueyeros and Bravo Dome fields continue to produce. Several plants produce dry ice and liquid carbon dioxide and Amoco has piped gaseous carbon dioxide to the Permian basin for enhanced oil recovery. Estimates of recoverable reserves in the Bravo dome and Bueyeros fields are from 5.3-9.8 trillion ft^3 (Broadhead 1987). The origin of the carbon dioxide is controversial and hypotheses have included juvenile magmatic gases and breakdown of carbonate rocks by intrusions of groundwater (Broadhead 1987).

Metals

There are several types of metallic mineral deposits in northeastern New Mexico but none currently are being exploited. The most widespread deposits are stratabound, sedimentary copper deposits in late Paleozoic-Mesozoic strata that are widespread in northeastern New Mexico (McLemore and North 1985, 1987). The vast majority of past production was from the Stauber (or Guadalupe) mine in the Pastura district southwest of Santa Rosa which amounted to 13 million lbs of copper as well as 42,000 oz. of silver and minor lead and gold (McLemore and North 1985). Uranium mineralization is also widespread in the same strata and could become economically viable if uranium prices were to rise substantially. Both copper and uranium, as well as associated minerals, were probably transported as low temperature solutions along fractures and precipitation occurred at favorable oxidation-reduction interfaces (McLemore and North 1985).

In eastern Colfax County, there are Thorium/rare earth veins associated with a phonolite intrusion (McLemore and North 1987). Northern Union County has more diverse metallic deposits including volcanic epithermal gold deposits and mineralized clastic plugs (McLemore and North 1987). However, at present there are no metallic mineral resources in northeastern New Mexico of high enough grade or of large enough size to be economic.

Aggregate

Calcrete has been a major source of road-building aggregate since before the advent of the automobile (Lovelace 1972). Calcrete is almost ubiquitous throughout northeastern New Mexico on the High Plains. In addition, terrace and stream gravels are abundant in the major drainages of the Pecos and Canadian rivers. Aeolian sands of Quaternary age also are quarried northeast of Logan.

Building Stone

The principal sources of building stone in northeastern New Mexico are sandstones of the Cretaceous Mesa Rica and Romeroville formations. In Quay County, the Triassic Redonda Formation is a local source of flat-bedded sandstone.

HYDROLOGY

The Ogallala Formation represents the most significant aquifer in the area. The saturated thickness is often several tens of feet and the depth to water is less, usually much less, than 200 feet (Kilmer 1987). In some areas, productivity is highest where paleochannels exist in the lower part of the unit that is incised into the pre-Ogallala surface.

Shallow bedrock throughout northeastern New Mexico is generally nonmarine/nonmarine Mesozoic sandstone and mudstone. Triassic and Upper Jurassic strata are dominantly fluvial in origin and the discontinuous nature of the channel sandstone bodies makes them poor aquifers. The eolian Entrada Sandstone is locally an important aquifer (e.g., city of Tucumcari). In Union and eastern Colfax counties, water is produced from Cretaceous sandstones (Kilmer 1987).

IGNEOUS ACTIVITY

Volcanic rocks in Colfax, Union, Mora and northern Harding counties constitute the eastern extent of late Cenozoic volcanism in the western United States. These rocks are divided into two principal volcanic fields, the Ocate field and the Raton-Clayton field (Calvin 1987). These volcanic fields define the eastern extend of the Jemez lineament and coincide in time with a major tectonic rejuvenation of the northern Rio Grande rift (Nielsen and Dungan 1985).

The Ocate field of Mora and Harding counties was active over a time span of about 7 My (8.3-0.8 Ma) and produced five main rock types: (1) alkali olivine-basalt; (2) transitional olivine-basalt; (3) xenocrystic basaltic andesite; (4) olivine andesite; and (5) dacite (Nielsen and Dungan 1985). Resultant topographic features include Wagon Mound. The

Raton-Clayton field extends across Colfax and Union counties and into Colorado and Oklahoma. Volumetrically the dominant rock types are alkali-olivine basalt and transitional olivine-basalt with significant amounts of olivine andesite and dacite (Stormer 1972). The Capulin basalts are only 18,000-4,500 years old but dates of the other rocks range from 1.8-7.2 Ma.

Poorly studied igneous rocks are known from Guadalupe County. Setter and Adams (1985) report ages of 12.5 and 12.6 Ma for a basalt and a diabase respectively from dikes near Cuervo. One dike connects to a small volcanic neck (Setter and Adams 1985). Other indications of igneous activity in Guadalupe County include intrusive bodies associated with the Santa Rosa tar sands and the Newkirk oil field (McKallip 1985) and postulated sills extending south from Guadalupe County along 105W longitude (Suleiman and Keller 1985).

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