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STRATIGRAPHY AND PETROLEUM GEOLOGY OF DOCKUM GROUP (TRIASSIC), NORTHEASTERN NEW MEXICO

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INTRODUCTION

The Dockum Group (Triassic) of northeastern New Mexico contains two stratigraphic units of interest as petroleum reservoirs: the Santa Rosa Sandstone and the Cuervo Sandstone Member of the Chinle Formation (Figs. 1, 2). Two accumulations of heavy oil are known to exist in the Santa Rosa Sandstone in northeastern New Mexico: the Santa Rosa tar sands and the Newkirk oil pool (Fig. 3).

The Santa Rosa tar sands (Fig. 3) are a surface exposure of oil-impregnated sandstone that occurs at Santa Rosa Lake in T10N, R21E, Guadalupe County. The Santa Rosa tar sands were mined between 1930 and 1939 by the New Mexico Construction Company. The oil-impregnated sandstone was used for road-surfacing material in New Mexico, Colorado, Oklahoma and Texas. Total production was 153,000 tons (Gorman and Robeck, 1946). The tar sands have been inactive since 1939 because of unfavorable economics. The Santa Rosa tar sands contain an estimated 90.9 million bbl of oil in place; oil gravity is 11.9°API at a temperature of 60°F (Budding, 1980). The geology and petroleum geochemistry of the Santa Rosa tar sands have been discussed by Budding (1979, 1980).

The Newkirk oil pool (Fig. 3) is located in T11N, R25–26E, Guadalupe County. Heavy oil occurs in the Santa Rosa Sandstone at depths of 400–800 ft (120–240 m). Oil gravity is 15–17°API (Martin, 1983). The Newkirk oil pool has never produced commercial amounts of petroleum, but two pilot steamflood projects are currently attempting to recover the heavy oil and produce it commercially. An estimated 39 million bbl of oil are in place at the Newkirk pool (Scott and Joy, 1983). The petroleum geology and sedimentology of the Santa Rosa Sandstone in the Newkirk pool have been comprehensively studied by McKallip (1984).

This article is abstracted from parts of a larger, more comprehensive report (Broadhead, 1984).

STRATIGRAPHY

San Andres Formation (Permian: Leonardian)

In northeastern New Mexico, the San Andres Formation is composed of interbedded dolostone, limestone, anhydrite, salt, mudstone and sandstone. The Glorieta Sandstone Member is a basal, sandstone-rich unit. The San Andres Formation varies in thickness from 400 to 1200 ft (120 to 370 m) in the area covered by this report (Foster et al., 1972, fig. 4).

Artesia Group (Permian: Guadalupian)

The Artesia Group was named by Tait et al. (1962) to embrace five formations that had already been defined in southeastern and east-central New Mexico. In ascending order, the five formations are: Grayburg Formation, Queen Formation, Seven Rivers Formation, Yates Formation and Tansill Formation. Tait et al. (1962) used wireline logs to correlate the Artesia Group and its five formations from southeastern New Mexico into Guadalupe and San Miguel Counties. Kelley (1972) subdivided the Artesia Group in east-central New Mexico into three lithologic and surface-mappable rock units. In ascending order, the three units are: Grayburg–Queen unit (composed of the undivided Grayburg and Queen Formations), the Seven Rivers Formation and the Yates–Tansill unit (composed of the undivided Yates and Tansill Formations). Broadhead (1984) extended Kelley's threefold subdivision of the Artesia Group into the subsurface.

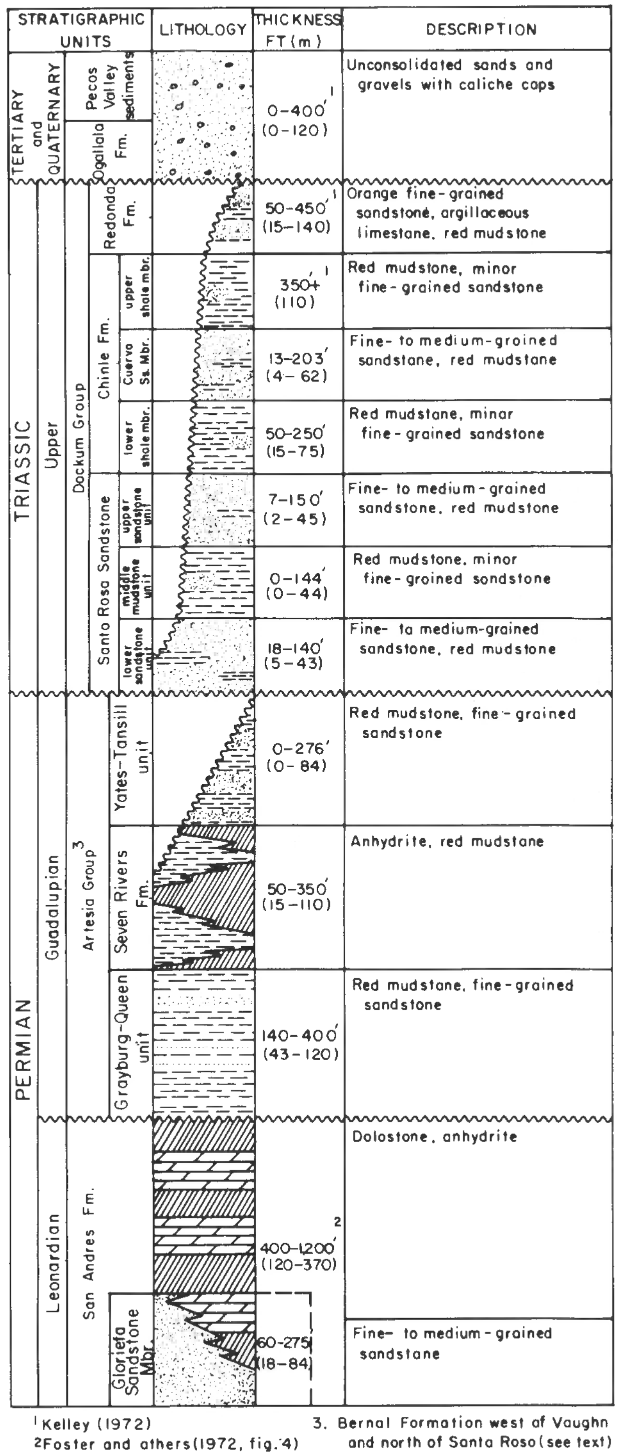

FIGURE 1. Stratigraphic chart of Upper Permian and Triassic rocks in northeastern New Mexico (from Broadhead, 1984, fig. 2).

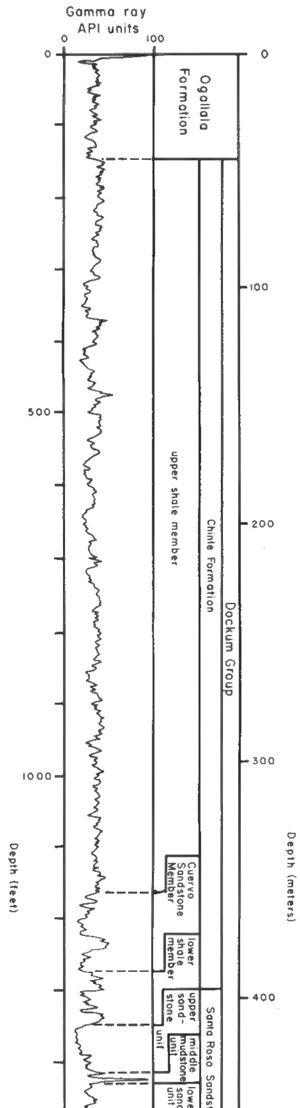

FIGURE 2. Typical gamma-ray log through Upper Permian and Triassic sections in northeastern New Mexico, Amoco Production Co. No. 1 State GM, sec. 16, T6N, R29E, Quay County, New Mexico.

The Artesia Group varies in thickness from 134 to 918 ft (41 to 280 m) in the area covered by this report. It is thickest in the southeastern part of the report area and thins to the north, northwest and west. Some of the thickness variation is due to northwestward depositional thinning of the Grayburg–Queen unit, Seven Rivers Formation and Yates–Tansill unit as they onlap Permian-age paleohighlands. Most of the thinning, however, is caused by an erosional angular unconformity between the Artesia Group and the overlying Dockum Group (Triassic). The contact with the underlying San Andres Formation is sharp and is thought to be unconformable with a "mild erosion surface" (Kelley, 1972).

The Artesia Group is composed mostly of interbedded red siliciclastic mudstone, very fine-grained light-gray sandstone and white microcrystalline anhydrite. It contains minor pink to white microcrystalline dolostone, halite and light-gray microcrystalline limestone. The Grayburg–Queen unit is composed mostly of interbedded mudstone and sandstone and contains only minor anhydrite, dolostone and halite. The Seven Rivers Formation is composed mostly of anhydrite, sandstone and mudstone. The anhydrite is generally dolomitic and is dominant in the eastern and southeastern parts of the study area where halite is also present. As the Seven Rivers thins to the north and west, it grades into a clastic facies of interbedded mudstone, sandstone and minor anhydrite. Contact with the underlying Grayburg–Queen unit is sharp and conformable. The Yates–Tansill unit is composed mostly of mudstone and sandstone. It contains minor amounts of dolostone and limestone. Contact with the underlying Seven Rivers Formation is sharp and conformable.

The top of the Artesia Group is an unconformity. The unconformity has a paleodrainage system developed on it (Broadhead, 1984). In east-central New Mexico, the paleotopography associated with this paleodrainage system has left several erosional "outliers of Yates scattered across a terrain of Seven Rivers" (Kelley, 1972).

Dockum Group (Triassic)

The Dockum Group is mostly Late Triassic in age (Colbert and Gregory, 1957). Fossils from the lowermost Santa Rosa Sandstone indicate a Middle Triassic age (Spencer Lucas, written comm. 1985). In northeastern New Mexico, Lower Triassic rocks are absent and the Dockum rests unconformably on Permian rocks. In northeastern New Mexico, the Dockum Group is divided into three formations (ascending): Santa Rosa Sandstone, Chinle Formation and Redonda Formation. A sandstone-rich unit in the Chinle has been named the Cuervo Sandstone Member (Kelley, 1972).

Santa Rosa Sandstone

The Santa Rosa Sandstone is a blanket deposit that forms the base of the Dockum Group in northeastern New Mexico. It is 67–350 ft (20–107 m) thick in the area covered by this report. Several workers have subdivided the Santa Rosa into members on the basis of surface lithology (Gorman and Robeck, 1946; Kelley, 1972; Read et al. in Kelley, 1972; Finch and Wright, 1984). Subsurface stratigraphic investigations carried out as part of this study indicate that the Santa Rosa Sandstone is divisible into three widespread and recognizable stratigraphic units in northeastern New Mexico (Figs. 1, 2): lower sandstone unit, middle mudstone unit and upper sandstone unit. These units are laterally traceable in the subsurface using gamma-ray borehole logs. My lower sandstone unit is equivalent to the lower and middle sandstone members of Gorman and Robeck (1946); my middle mudstone unit is equivalent to the shale member of Gorman and Robeck; my upper sandstone unit is equivalent to the upper sandstone member of Gorman and Robeck.

The lower sandstone unit is 18–140 ft (5–43 m) thick in the area covered by this report. It is composed of sandstone with minor red mudstone. Net thickness of sandstone ranges from 14 to 127 ft (4–39 m) (Fig. 4). The sandstone is light gray to light brown, fine- to very coarse-grained and moderately to well sorted. It is composed mostly of detrital quartz grains and is poorly to well cemented with calcite. Visual porosity determined from thin sections of drill cuttings ranges from 0 to 10%; density and neutron logs indicate maximum porosities

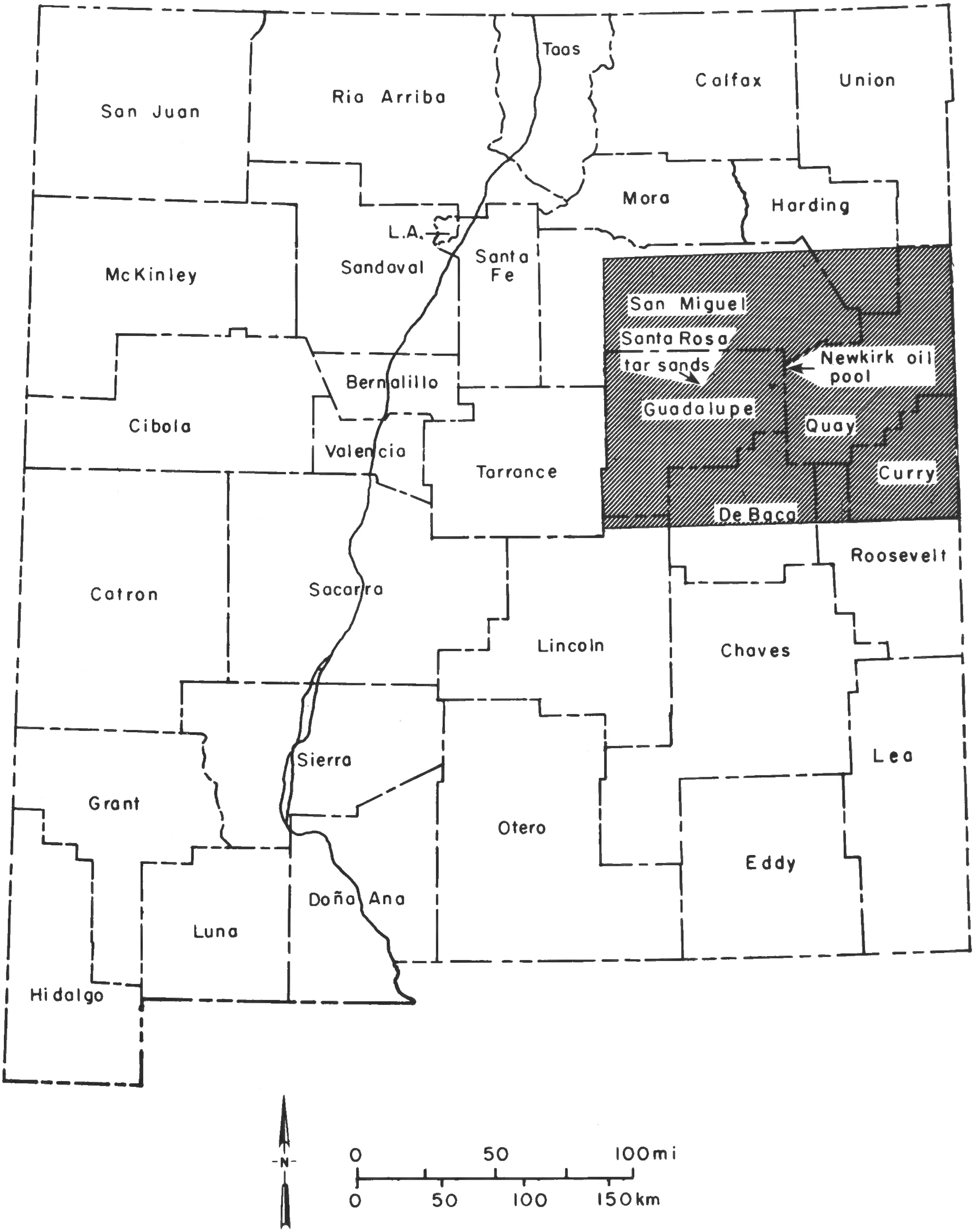

FIGURE 3. Study area (shaded) and locations of the tar-sand deposit at Santa Rosa Lake and the Newkirk oil pool.

of 15–36% for individual wells. The most porous sandstones were not available for thin-section study because they are poorly cemented and disaggregate into individual grains during drilling.

The middle mudstone unit is 0–144 ft (0–44 m) thick in the area covered by this report. It conformably overlies the lower sandstone unit and in most places is sharply and unconformably overlain by the upper sandstone unit. It is composed mostly of red mudstone and minor gray mudstone, fine-grained lenticular sandstone and white to light-gray microcrystalline limestone.

The upper sandstone unit is 7–150 ft (2–46 m) thick in the area covered by this report. It is composed of sandstone and minor red mudstone. Net thickness of sandstone ranges from 0 to 138 ft (0 to 42 m) (Fig. 5). The sandstone is light gray, fine- to very coarse-grained and moderately to well sorted. It is composed mostly of detrital quartz grains and is poorly to well cemented with calcite. Visual porosity determined from thin sections of drill cuttings ranges from 0 to 20%; density and neutron logs indicate maximum porosities of 15–36% for individual wells. The most porous sandstones were not available for thin-section study because they are poorly cemented and disaggregate into individual grains during drilling.

Chinle Formation

The Chinle Formation conformably overlies the Santa Rosa Sandstone. The contact with the Santa Rosa is somewhat gradational, but can be picked consistently with gamma-ray borehole logs. Kelley (1972) subdivided the Chinle on the surface of east-central New Mexico into a lower shale member, Cuervo Sandstone Member and an upper shale member (Figs. 1, 2). Kelley's subdivisions of the Chinle can be traced laterally in the subsurface with gamma-ray borehole logs.

The lower shale member is approximately 50–250 ft (15–76 m) thick in the area covered by this report. It is composed mostly of calcareous red mudstone, minor gray mudstone and lenticular, fine-grained sandstone.

The Cuervo Sandstone Member is 13–203 ft (4–62 m) thick in the area covered by this report. It is composed mostly of sandstone and

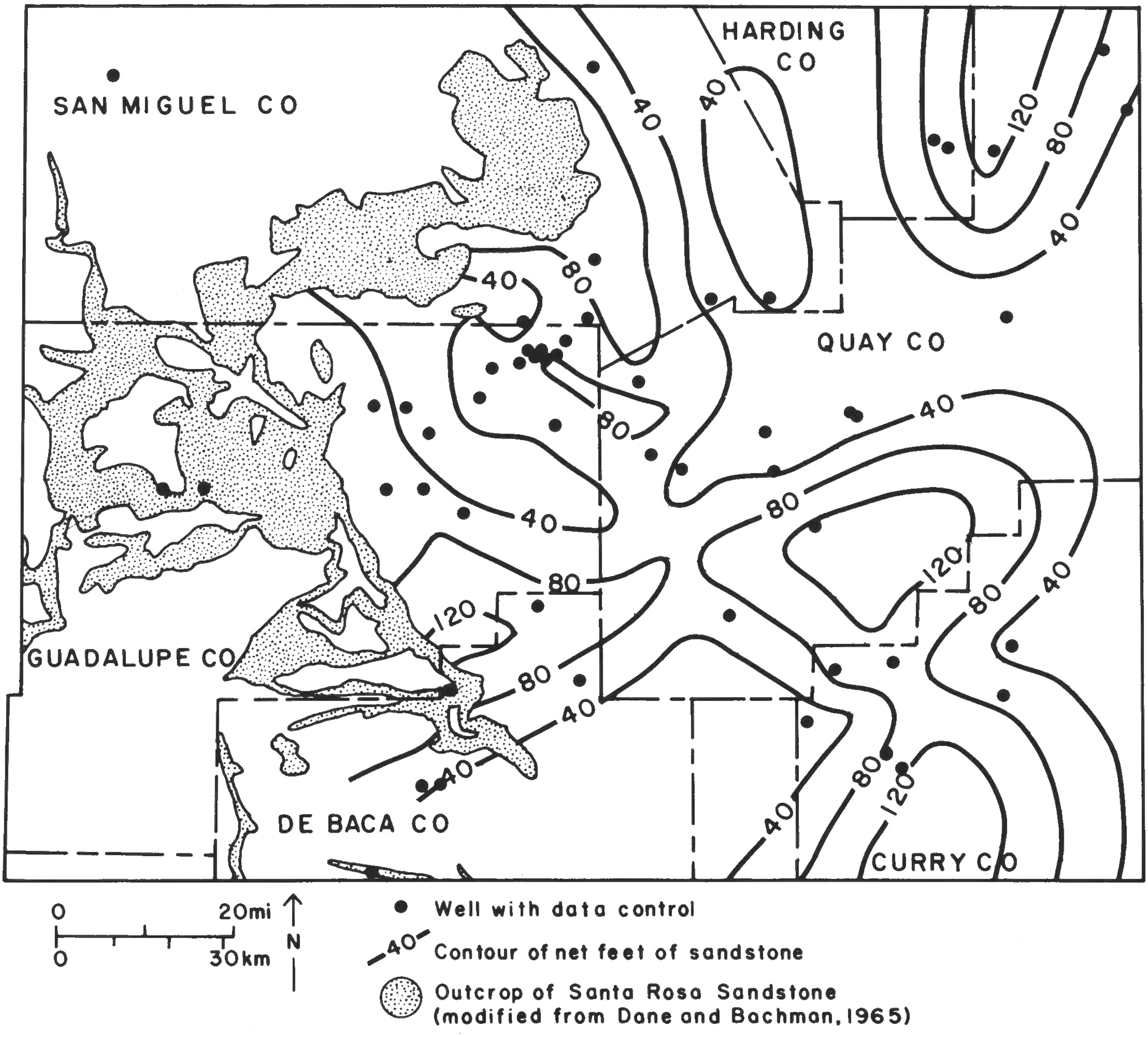

FIGURE 4. Sandstone isolith map of lower sandstone unit of Santa Rosa Sandstone (modified from Broadhead, 1984, fig. 8). Contour interval = 40 ft.

has a subordinate amount of red mudstone that is locally dominant. Net thickness of sandstone ranges from 4 to 201 ft (1 to 61 m) (Fig. 6). Although it is dominantly mudstone in places, the Cuervo is laterally traceable with gamma-ray logs in the subsurface. The contact with the underlying lower shale member of the Chinle Formation is sharp and apparently erosional in most wells, but is gradational in a few wells. Cuervo sandstones are light gray ro reddish brown, fine- to very fine-grained and moderately- to well-sorted. The sandstones are similar to those of the Santa Rosa, are composed mostly of detrital quartz and are poorly to well cemented by calcite. Maximum porosity determined from density and neutron logs ranges from 14 to 33% for individual wells. Generally, Cuervo sandstones are better cemented, have less porosity and are thinner than Santa Rosa sandstones.

The upper shale member of the Chinle Formation is at least 350 ft (110 m) thick in northeast New Mexico (Kelley, 1972). It is exposed over approximately 50% of the area covered by this report. It is composed chiefly of red mudstone and contains only minor amounts of lenticular, fine-grained sandstone.

Redonda Formation

The Redonda Formation is the uppermost stratigraphic unit of the Dockum Group in northeastern New Mexico. Its occurrence in northeastern New Mexico is limited because of extensive pre-Cretaceous and Cenozoic erosion. Where it is present in northeastern New Mexico, it is approximately 50–450 ft (15–140 m) thick (Kelley, 1972). It is composed of evenly bedded, orange–red sandstone and mudstone. McGowen et al. (1983) considered the contact with the underlying Chinle Formation to be disconformable, but Griggs and Read (1959) considered the contact to be conformable. The Redonda Formation is unconformably overlain by the Exeter Sandstone (Jurassic), but in most places the latter has been eroded.

STRUCTURE

Detailed surface structure of the entire study area has not been reported in the literature, and the paucity of subsurface data makes detailed structural mapping of the subsurface difficult. The few structures that

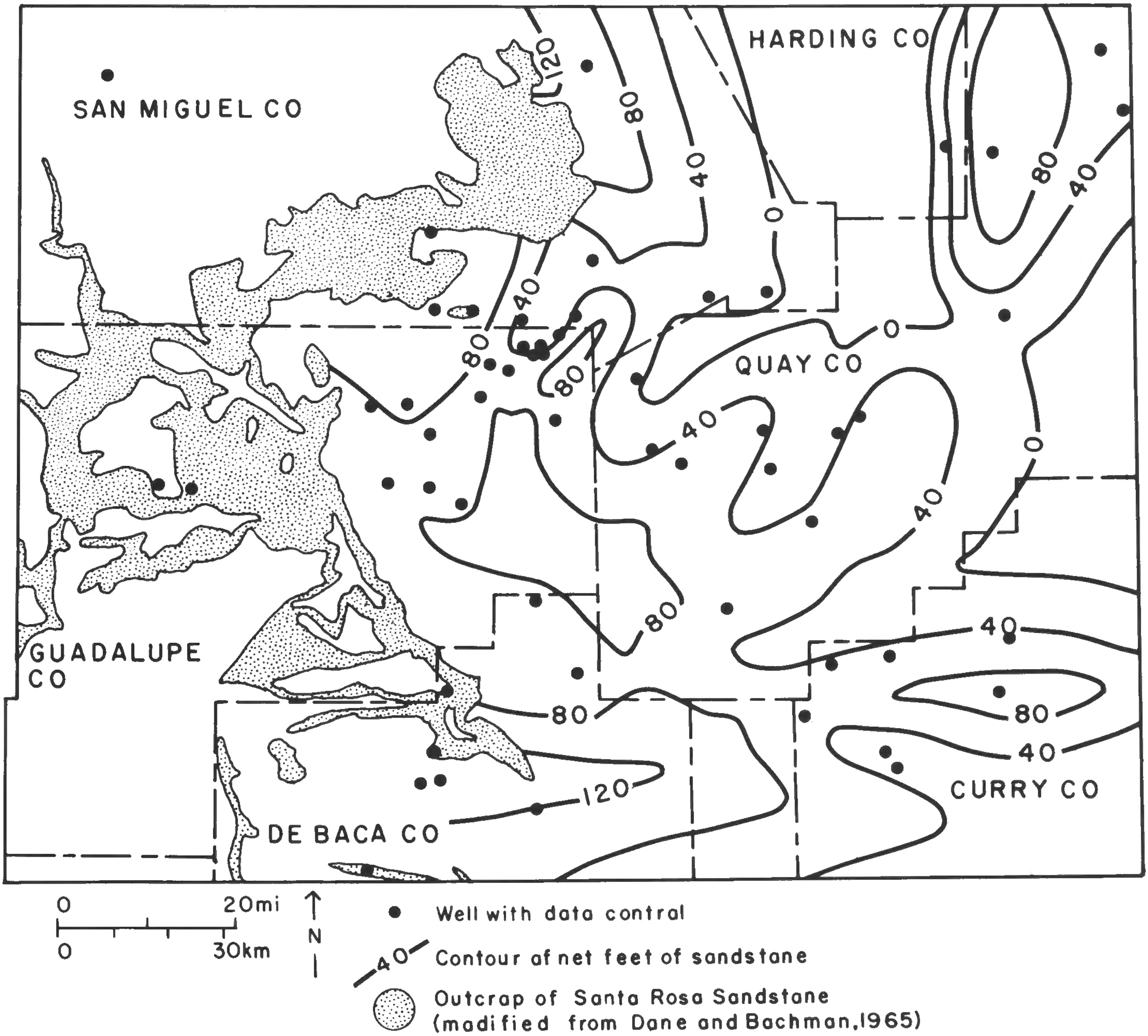

FIGURE 5. Sandstone isolith map of upper sandstone unit of Santa Rosa Sandstone (modified from Broadhead, 1984, fig. 9). Contour interval = 40 ft.

have been mapped on the surface (Dobrovolny et al., 1946; Gorman and Robeck, 1946; Wanek, 1962; Dane and Bachman, 1965) have northwest- to northeast-trending strikes. Most surface structures are gentle folds, although a few north-trending faults have been mapped in western San Miguel County (Dane and Bachman, 1965). The northeast-trending Bonita fault has been mapped in southeastern Quay County (Dobrovolny et al., 1946).

Structure of the San Andres Formation was contoured for this study (Fig. 7). San Andres structure was mapped for three reasons. First, the top of the San Andres is a good geophysical log marker that is readily recognized even on logs of poor quality. Second, the San Andres is present throughout most of the study area, even where the stratigraphically higher Santa Rosa Sandstone has been partly or entirely removed by Cenozoic erosion. Third, the structure of the Santa Rosa Sandstone was found to be similar to the San Andres Formation. The structure map was prepared primarily from tops picked on wireline logs, but contours were adjusted to accurately reflect known surface structures, which are generally too small to be mapped with the present well density.

San Andres structures generally strike northeast–southwest. The dominant structure is the southeast-dipping regional slope off the Sierra Grande uplift to the north and the Pedernal uplift to the west. Three northeast-trending, high-angle faults are superimposed on the regional slope. Also apparent are east- to northeast-trending anticlines and synclines.

Larger San Andres structures follow the outlines of the major Pennsylvanian- to Wolfcampian-age structural elements in New Mexico, which defined the late Paleozoic Tucumcari basin. San Andres structure is similar to Precambrian basement structure, but is not nearly as pronounced. High-angle faults with vertical displacements of several thousand feet on the Precambrian surface generally cut the Pennsylvanian section and are generally Pennsylvanian in age. These faults appear to be reflected in the overlying San Andres as relatively gentle drape folds that have far less relief than they do on the Precambrian surface. The

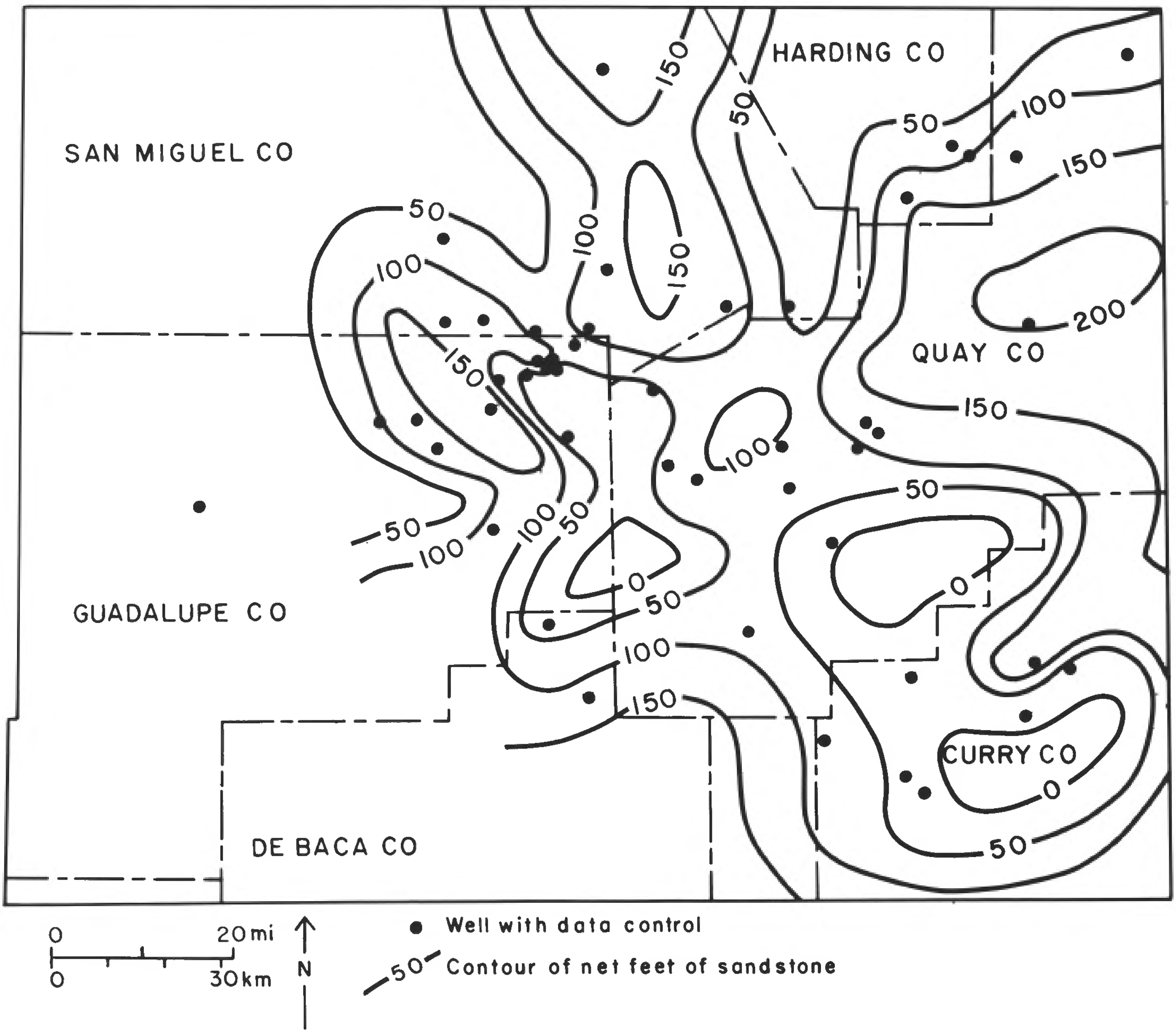

FIGURE 6. Sandstone isolith map of Cuervo Sandstone Member of Chinle Formation (modified from Broadhead, 1984, fig. 10). Contour interval = 50 ft.

draping of the San Andres (and also the Santa Rosa and Cuervo) over Pennsylvanian-age structures indicates that those structures were reactivated after Santa Rosa and Cuervo deposition.

PETROLEUM POTENTIAL

The Dockum Group of northeastern New Mexico has three stratigraphic units that may be good petroleum reservoirs: the lower and upper sandstone units of the Santa Rosa Sandstone and the Cuervo Sandstone Member of the Chinle Formation. The upper sandstone unit of the Santa Rosa Sandstone is the reservoir at both the Santa Rosa tar sands and the Newkirk oil pool. An anticline is the primary trapping mechanism at the Newkirk pool, but lateral facies changes of the reservoir to mudstone also limit and define the pool (McKallip, 1984). Uneven oil saturation in the reservoir is caused by unevenly distributed calcite cement in the sandstone. Shows of oil and gilsonite have been reported from all three reservoir units in northeastern New Mexico.

Reservoir quality of sandstones from the three reservoir units varies from poor to good. Generally, the reservoir quality of sandstones in both the lower and upper sandstone units of the Santa Rosa Sandstone is good. The sandstones have well-developed primary pores that have not been destroyed by compaction or occluded to any significant extent by silica or calcite cements. Good permeability is indicated by a well-developed network of primary pores. However, porosity of some of the Santa Rosa sandstones has been completely occluded by calcite cement. Calcite cementation does not appear to follow any regional trends.

Sandstones of the Cuervo Member are generally well cemented by calcite. They are generally less porous than sandstones of the Santa Rosa and are generally only poor to fair reservoirs.

The oil accumulations at the Newkirk pool and the Santa Rosa tar sands indicate that petroleum source rocks are definitely present in the Tucumcari basin. The source of the oil in the Santa Rosa tar sands appears to be either the San Andres Formation (Permian) or Pennsylvanian rocks (Budding, 1979). The oil in the Santa Rosa tar sands is heavy because it is thermally immature and has been biodegraded (Bud-

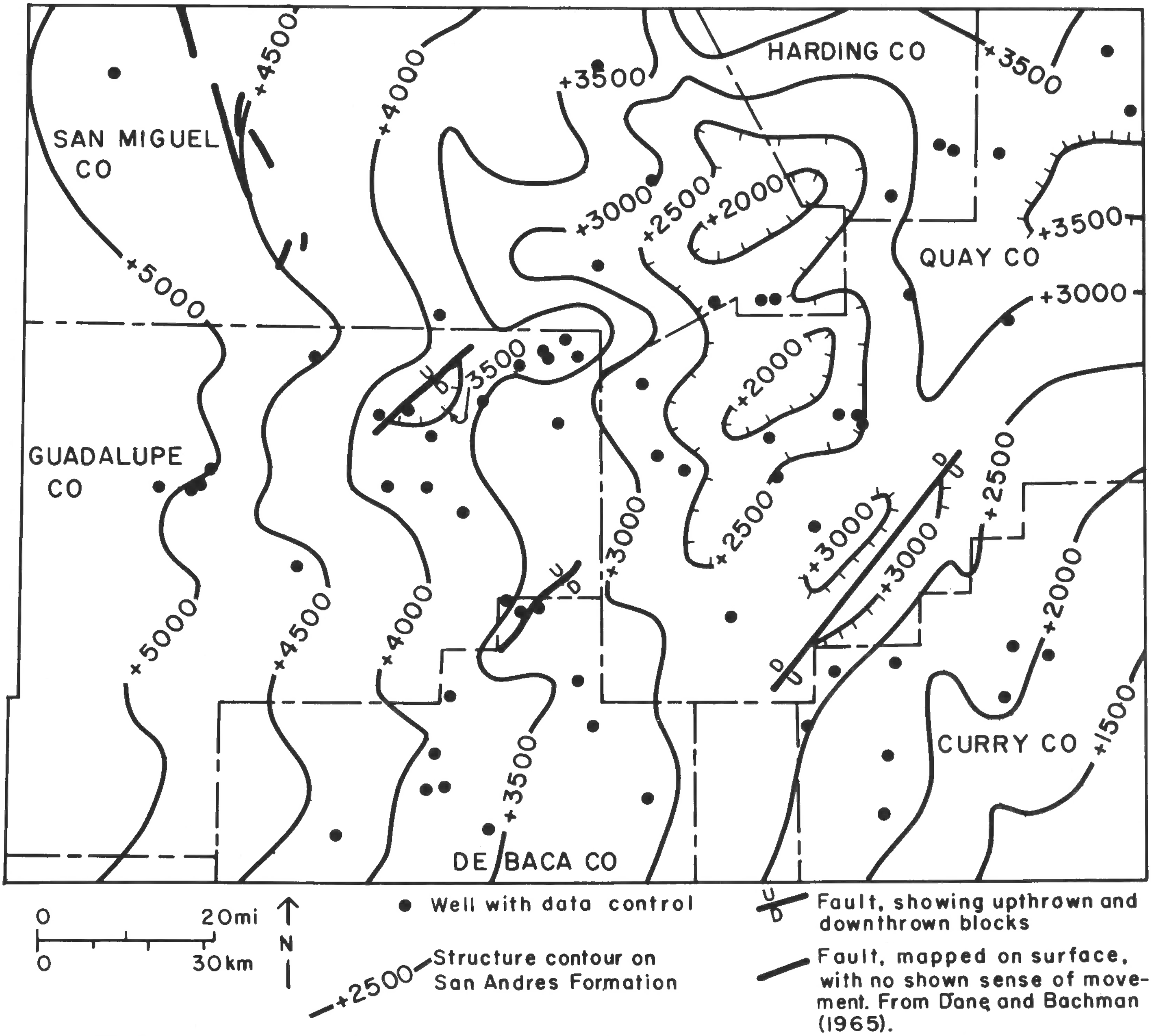

FIGURE 7. Structure contour map of top of San Andres Formation (modified from Broadhead, 1984, fig. 12). Contour interval = 500 ft.

ding, 1979, 1980). Biodegradation was probably by aerobic bacteria in a near-surface environment. Biodegradation may have also caused the oil in the Newkirk pool to be heavy. Wildcat wells drilled in the last three years in northeastern Guadalupe and western Quay Counties have discovered small volumes of oil and natural gas in Pennsylvanian rocks at depths of approximately 7000 ft (2100 m). Those discoveries indicate that there are Pennsylvanian source rocks in the Tucumcari basin, but their richness, distribution and volume are unknown.

Oil presumably migrated upward through faults or joints from the Pennsylvanian or Permian source rocks into the Santa Rosa Sandstone. Possible migration pathways at the Newkirk pool are deep-seated, late Paleozoic-age faults. Possible migration pathways at the Santa Rosa tar sands are fractures and faults that formed when the Santa Rosa Sandstone collapsed into solution cavities which were formed in anhydrites of the Artesia Group and San Andres Formation.

The blanket geometry of the lower and upper sandstone units of the Santa Rosa Sandstone indicates that the Santa Rosa should be a good petroleum reservoir throughout a large part of the study area. There may be local facies changes that create local permeability barriers, but analyses of cores, drill cuttings and wireline logs indicate that good Santa Rosa reservoirs are widespread (Figs. 4, 5). Because of this, structure probably plays an important or even dominant role in trapping hydrocarbons in the Santa Rosa Sandstone of northeastern New Mexico.

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