New Mexico Geological Society Guidebook, 36th Field Conference, Santa Rosa, 1985

FRACTURE-CONTROLLED GROUND-WATER DISTRIBUTION ADJACENT TO LOS ESTEROS RESERVOIR, GUADALUPE COUNTY, NEW MEXICO

JAY LAZARUS
Glorieta Geoscience, P.O. Box 5727, Santa Fe, New Mexico 87502

INTRODUCTION

The Triassic Santa Rosa Sandstone occurs at shallow depths over much of northeastern New Mexico. Approximately 11 km north of Santa Rosa, New Mexico, bitumen-impregnated Santa Rosa Sandstone is visible at the surface. These outcrops of bitumen-impregnated sandstone are known as the Santa Rosa tar sands. They were mined in the 1930's for an asphalt-like road material, but are not currently produced. In 1982 and 1983, an evaluation of the bitumen reserves was undertaken for SOLV-EX Corporation, on its Riley Ranch lease adjacent to Los Esteros Reservoir, an irrigation and flood-control reservoir (Fig. 1). As part of the resource-evaluation program, 18 exploratory core-holes were cased and used for geohydrologic evaluation of the lease. Data collected indicate that structure features modified by solution/collapse processes in the Santa Rosa region strongly influence ground-water distribution and occurrence.

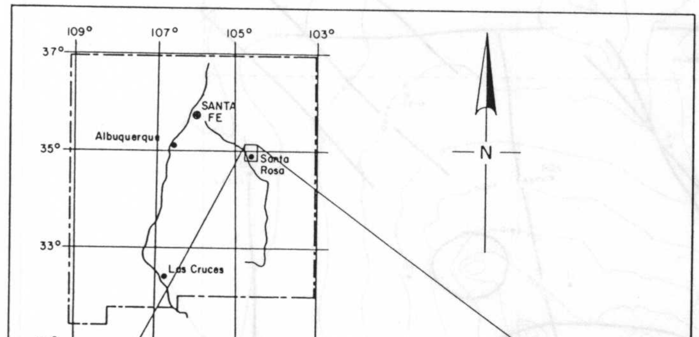

FIGURE 1. Site location map.

REGIONAL GEOLOGY

Stratigraphy

The Riley Ranch lease lies in the Pecos River drainage adjacent to Los Esteros Reservoir, a flood-control and irrigation reservoir. The Pecos River heads in the Sangre de Cristo Mountains in north-central New Mexico and in the lease area flows through a deeply incised canyon in which the dam was built.

The Upper Triassic Santa Rosa Sandstone is the host rock for bitumen saturation. The Santa Rosa Sandstone is a sequence of interfingering, prograding, continental alluvial, floodplain and deltaic deposits. In the vicinity of Santa Rosa, New Mexico, units of the Santa Rosa Sandstone are resistant cap rocks (Fig. 2). The Santa Rosa Sandstone underlies most of the upland into which the Pecos River has cut its canyon. The Santa Rosa Sandstone is on the average 76 m thick in this area and consists of crossbedded, calcareous quartz sandstone interbedded with siltstone and shale beds and several conglomerate zones. The Santa Rosa Sandstone contains large quantities of soluble sulfates and carbonates. The Santa Rosa Sandstone has been divided into the upper sandstone, upper shale, middle sandstone and lower sandstone members (Gorman and Robeck, 1946). Due to facies changes within the Santa Rosa Sandstone, correlation of individual units in drill-holes is difficult, especially where the shale member is absent. A generalized geologic map of the region is shown in Figure 2 (Kelley, 1972).

Rocks underlying the Santa Rosa Sandstone are, in order of increasing age, the Permian Bernal Formation and Permian San Andres Limestone. These formations are exposed in the canyon walls of the Pecos River and contain large amounts of soluble sulfates and carbonates (Sweeting, 1972). The upper Triassic Chinle Formation conformably overlies, and interfingers with, the Santa Rosa Sandstone. The Chinle is predomi-

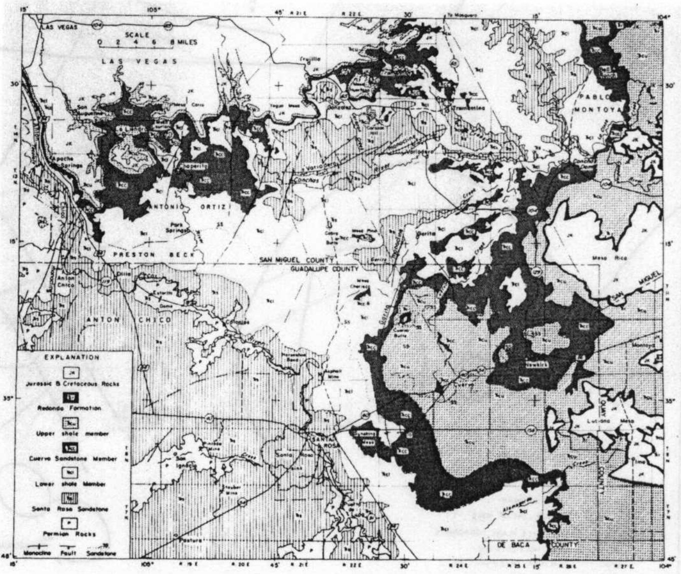

FIGURE 2. Generalized geologic map of the Santa Rosa country (after Kelley, 1972).

nantly a red, brown and purple shale with interbedded sandstone. The Chinle Formation and Santa Rosa Sandstone are often considered regionally to belong to the Dockum Group.

Structural geology

Bedding in the lease area dips one or two degrees to the east–southeast. Although the surface rocks in the Santa Rosa area have not been severely deformed, the structural geology is complex, with regional structural features strongly influencing local structures.

The dominant structures trend east–west, northwest, slightly east of north and northeast. An east–west structural zone is traceable on satellite and high-altitude photographic imagery from the Albuquerque basin eastward to Amarillo, Texas (Gibbons and Ferrall, 1980). This lineament includes major faults along the boundaries of the Anadarko, Palo Verde and Tucumcari basins. Solution/collapse features and photogeological evidence of subsurface dissolution are associated with this feature along most of its trend. Northwesterly trending structures have resulted from northeasterly oriented compression dating back to the Devonian Antler orogeny. North–northeast-trending structural elements are present throughout the southern Rocky Mountains. This trend includes pre-Rio Grande rift trends of the Sandia and Manzano Mountains and the southern portion of the Sangre de Cristo Mountains. The most recent (Cenozoic) structural elements trend northeast, are presently tectonically active and have tectonic affinities with the Basin and Range province (Gibbons and Ferrall, 1980).

All of these structural features are expressed on the lease property as indicated by aerial photography (Fig. 3). The imagery used in the air-photo analysis is U.S. Geological Survey 1986 photos, 1:29,000 scale, flight series GS-VANR. Topographic expression of these features is strongly evidenced by the fracture-controlled meanders of the Pecos River, known as the Goosenecks of the Pecos, upstream from the lease.

GEOLOGY OF THE RILEY RANCH LEASE

The topography of the Riley Ranch lease is characterized by an undulating surface sloping toward the north–northeast (towards Los Esteros Reservoir) and east. Topographic relief is low due to long-term pediment formation. A soil mantle of 0.3 to 1.5 m generally covers the area, limiting geologic exposures to small outcrops. Although outcrops

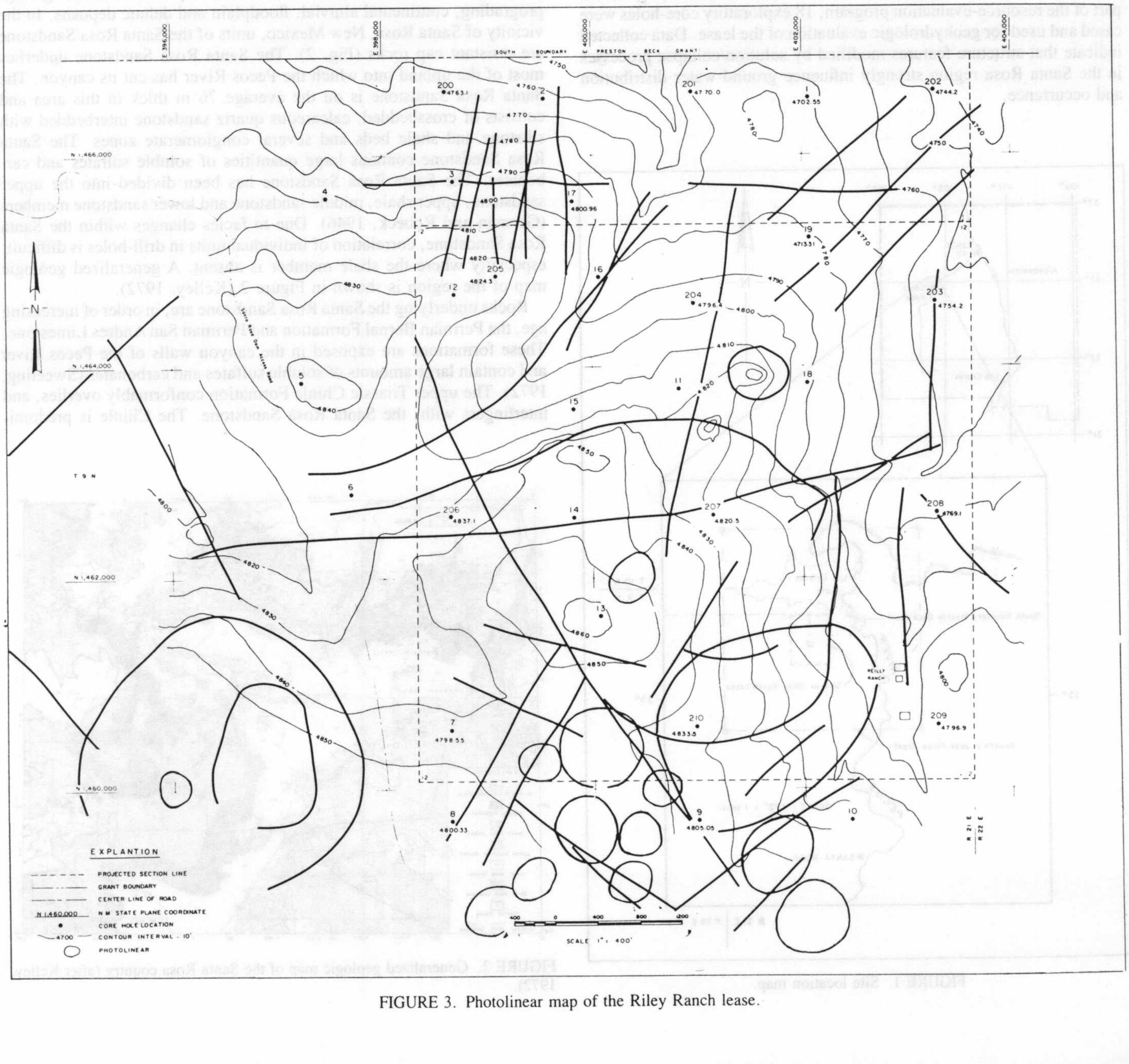

FIGURE 3. Photolinear map of the Riley Ranch lease.

are sparse and discontinuous, their orientations tend to outline local structure elements which are easily recognized from aerial photographs (Fig. 3). As shown in Figure 3, the structural features include both circular and linear trends. The prominent east–west ridge that crosses the property is the southern margin of a large, circular structural depression that contains thick accumulations of bitumen-saturated sandstone. The northern margin of this structure is inundated by the reservoir pool.

The upper sandstone member of the Santa Rosa Sandstone is the host for bitumen saturation. Generally, the host rock is a massive, gray, fine- to coarse-grained, well-sorted, well-cemented quartz sandstone that exhibits crossbedding and occasional thin shale beds. The bitumen imparts a dark-brown to black aspect to the sandstone.

Previous workers have postulated that hydrocarbons in the Santa Rosa Sandstone have migrated upward through solution-collapse features from source beds in the San Andres Limestone (Gorman and Robeck, 1946; Budding, 1979, 1980; Broadhead, 1984). Based on drill-hole data, the tar-sand body is locally overlain and underlain by low-permeability confining shales that are stratigraphic limits on bitumen enrichment. It appears that hydrocarbon migration and deposition were controlled by structural features which provided conduits for vertical hydrocarbon (and subsequent water) migration. Once the hydrocarbons encountered a confining layer, they dispersed laterally through permeable sandstone beds.

The Santa Rosa reigon is known for its well developed karst-type topography. Soluble portions of the San Andres Limestone, Bernal Formation and Santa Rosa Sandstone have been removed by subsurface dissolution intermittently active from Late Permian or Triassic to the present (Sweeting, 1972). The location and size of dissolution features were controlled by fluids migrating vertically and horizontally through regional-scale structural features. The hydrocarbons and in-situ-formed kaolinitic clays plugged interstitial permeability in the sandstone beds, inhibiting interstitial ground-water movement. Ineffective interstitial permeability is indicated by the absence of oxidized minerals in both bitumen-saturated and bitumen-free sandstones.

With interstitial permeability plugged, ground water was predominantly confined to fracture zones. The karst-type topography which characterizes much of the region most likely developed on and in fracture-controlled solution/collapse features as material was progressively removed from fracture zones and bedding planes by subsurface dissolution.

REGIONAL HYDROLOGY

The greatest hydrologic influence on the site now is the pool of Los Esteros Reservoir which lies adjacent to, and covers a portion of, the lease. From 1979 through 1982, the U.S. Geological Survey (1982) monitored ground-water-level fluctuations caused by reservoir-pool fluctuations in an abandoned oil well which was identified as well W-5 (Fig. 4). Well W-5 is located just north of the study area, between the reservoir and the study area, less than 0.4 km north of core-hole 2. The fluctuations of the reservoir pool had been monitored over the same period (U.S. Geological Survey, 1982). As shown in Figure 4, significant leakage from the reservoir to the bedrock occurs when reservoir-pool elevation reaches 4725 ft.

HYDROLOGIC TESTING PROGRAM

In order to establish baseline hydrologic data on the lease, all cased core-holes were jetted with a portable air compressor for clean-out and development. The core-holes were constructed in the following manner: a six-inch-diameter hole was drilled to solid rock with a hollow stem auger. The hole was then cored to total depth with an NX (1.875-inch-diameter core) coring assembly. The resultant three-inch hole was cased with two-inch threaded schedule 40 PVC casing with horizontal slots cut at three-inch intervals (see Table 1 for specific slotted intervals). No gravel/sand pack was installed. All holes bottom in, and produce water from, the Santa Rosa Sandstone. In many holes, the casing was held in place by swelling clay/shale layers. Each hole was jetted by a 750-cfm compressor for approximately one-half hour.

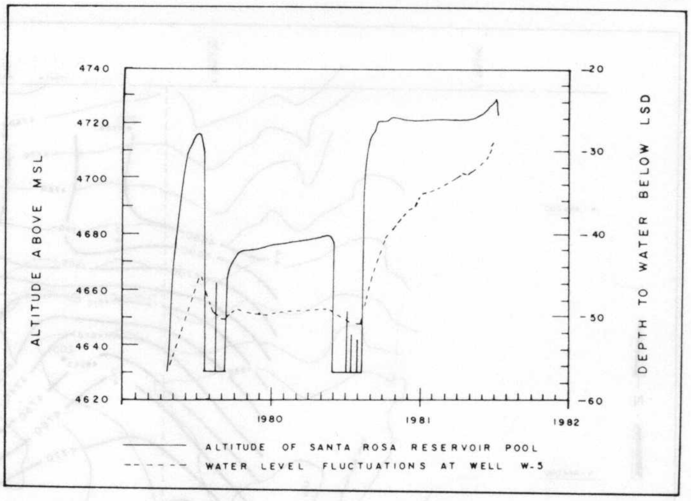

FIGURE 4. Water-level fluctuations in U.S. Geological Survey well W-5 and Los Esteros Reservoir pool elevations.

HYDROLOGIC TEST RESULTS

Field data indicate each core-hole intersected large stratigraphic intervals which may include several water-bearing zones under varying degrees of confinement. Additionally, the area is in a complexly fractured and faulted solution/collapse geohydrologic environment. The geohydrologic complexity of the fracture system is illustrated by the hydrologic response in two core-holes during and after testing. Immediately after jetting, and continuing through the end of this study, core-hole 16 exhibited unique behavior evidenced by the sound of water cascading within the hole. The water flowed into the core-hole on one fracture or solution feature and out of the core-hole along a lower one. While drilling core-hole 16, water was encountered at 50 ft (elevation 4735 ft) and at that point rose to and flowed freely onto the surface. This flow and drilling circulation were lost at 105 ft (elevation 4680 ft) to total depth (147 ft, elevation 4638 ft). An open, nearly vertical fracture was logged at core interval 104–108 ft (elevation 4681–4677 ft). Another open fracture cuts through the hole at a 45-degree angle at 110 ft (elevation 4675 ft). Therefore, water is flowing into the hole from the upper fracture or solution feature at about 50 ft and flowing out along the lower between 104–110 ft. The inflow and outflow in this hole is estimated at 1.5–2.0 gallons per minute, with water gain occurring above the reservoir-pool elevation of 4720 ft and water loss occurring below the reservoir surface. No springs or other discharge sites exist between core-hole 16 and the reservoir.

Core-hole 3 also exhibited unique characteristics. One 28-ft interval (42–70 ft; elevation 4750–4722 ft) consumed 1200 gallons of water during drilling. During jetting, no water was blown out of the hole; it was all lost into the highly fractured bedrock with no resultant drawdown from the pre-jetted water level. The water loss in this hole occurred above the reservoir-pool elevation of 4720 ft. No discharge sites exist between core-hole 3 and the reservoir. As shown on the photolinear map (Fig. 3), both core-holes 3 and 16 are located on or near fracture intersections.

The water-table map generated at the end of the program is shown in Figure 5. Although the ground-water elevations may include water from several distinct water-bearing zones under different degrees of confinement, the map shows several significant features. There are two flat or shallow-dipping areas, one in the northeast and one to the southwest. Between these areas is a steep gradient which trends N40°–50°W between core-holes 4 and 11 and drops 70 ft to the northeast. The piezometric gradient of this feature is approximately 264 ft per mile or about 5%, more than twice the topographic gradient of about 2%. The northeast- and northwest-sloping portions of the water table roughly follow the topographic surface, sloping down towards the reservoir.

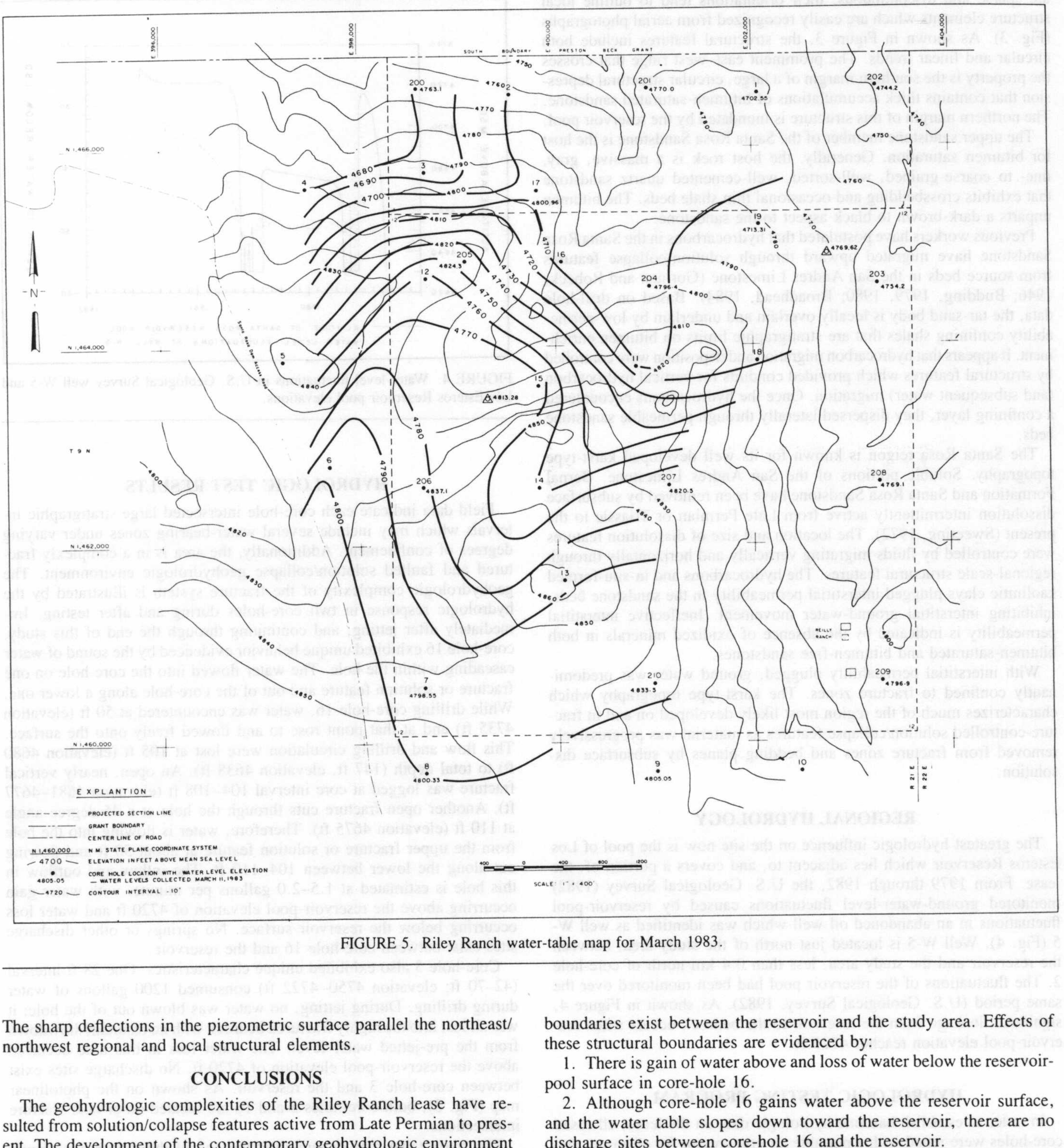

FIGURE 5. Riley Ranch water-table map for March 1983.

The sharp deflections in the piezometric surface parallel the northeast/northwest regional and local structural elements.

CONCLUSIONS

The geohydrologic complexities of the Riley Ranch lease have resulted from solution/collapse features active from Late Permian to present. The development of the contemporary geohydrologic environment evolved in the following manner. Hydrocarbons developed in the Permian San Andres Limestone. These hydrocarbons migrated vertically along fractures with subsequent lateral migration and emplacement into permeable sandstone beds, plugging interstitial permeability. The solution/collapse features developed as ground water migrating behind the hydrocarbons followed structural elements and dissolved large portions of the Permian San Andres Limestone, Permian Bernal Formation and Triassic Santa Rosa Sandstone.

Locally, the contemporary hydrologic complexity is compounded by the presence of Los Esteros Reservoir. Based on hydrologic information from the test holes, numerous structurally controlled geohydrologic boundaries exist between the reservoir and the study area. Effects of these structural boundaries are evidenced by:

1. There is gain of water above and loss of water below the reservoir-pool surface in core-hole 16.
2. Although core-hole 16 gains water above the reservoir surface, and the water table slopes down toward the reservoir, there are no discharge sites between core-hole 16 and the reservoir.
3. There is loss of large volumes of drilling water and formation water above the reservoir surface in core-hole 3 with no discharge sites between this hole and the reservoir.
4. The orientation of piezometric contours parallels regional and local structural features. These structural geohydrologic boundaries strongly influence ground-water distribution and occurrence on the lease property.

ACKNOWLEDGMENTS

The author is grateful to Kalvin W. Martin who provided technical assistance and analysis of bitumen saturation. In reaching the conclu-

TABLE 1. Riley Ranch water-level and well data.

CORE HOLE	ELEVATION, FEET ABOVE MEAN SEA LEVEL	TOTAL DEPTH IN FEET	SLOTTED INTERVAL IN FEET	ESTIMATED PRODUCTION GPM	WATER LEVEL 3/11/83	WATER TABLE ELEVATION, FEET ABOVE MEAN SEA LEVEL
CH 1	4770.02	140	60-140	0.5	67.47	4702.55
CH 2	4761.25	145	45-145	2-3	60.42	4700.83
CH 3	4792.14	148	48-148	-	109.14	4683.00
CH 4	4798.30	148	48-148	0.5-1	118.53	4679.77
CH 5	4842.91	150	UNCASED	-	-	-
CH 6	4822.76	124	44-124	0.5	22.79	4799.97
CH 7	4843.20	103	33-103	-	44.65	4798.55
CH 8	4856.30	103	33-103	-	55.97	4800.33
CH 9	4834.72	103	33-103	4-5	29.67	4805.05
CH 10	4824.17	113	UNCASED	-	-	-
CH 11	4817.04	137	47-137	-	109.45	4709.11
CH 12	4828.44	132	42-132	1	66.05	4762.39
CH 13	4857.84	138	48-138	0.5	68.39	4789.45
CH 14	4843.40	118	48-118	-	82.95	4760.45
CH 15	4812.96	153	53-153	5	37.48	4775.48
CH 16	4785.68	147	47-147	1	79.54	4706.14
CH 17	4794.75	154	54-154	0.5	91.66	4703.09
CH 18	4793.17	133	53-133	1-2	74.49	4718.68
CH 19	4779.26	128	48-128	0.5	74.00	4713.31

sions in this paper, I relied heavily on discussions with Mr. Martin, Clay N. Culver, who also provided technical assistance, and Dr. John F. Gibbons II. Appreciation is extended to the U.S. Geological Survey, Albuquerque, New Mexico, Water Resources Division for unpublished data on water-level fluctuations. This paper was critically reviewed by Dr. John F. Gibbons II, Devon Jercinovic and Dr. Bruce G. Wachter.

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