GROUND WATER DATA

LAKE MEREDITH SALINITY CONTROL PROJECT

Prepared for

CANADIAN RIVER MUNICIPAL WATER AUTHORITY

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ENVIRONMENTAL PLANNING • RESOURCE MANAGEMENT

CONTENTS

DATA SUMMARIES AND EXTRACTS

EXECUTIVE SUMMARY

Ground water brine enters the Canadian River just below Ute Reservoir, near Logan, New Mexico. The brine inflow accounts for much of the excessive salt which reaches Lake Meredith, Texas, and thus is an important cause of degradation of the primary drinking water supply for 11 cities in the Texas Panhandle and South Plains which are members of the Canadian River Municipal Water Authority (CRMWA). CRMWA has a long-standing interest in developing a project to reduce or prevent the brine inflow, by intercepting and safely disposing of the brine before it reaches the river.

This notebook compiles available information on the brine distribution and flow. Important information sources include: studies of regional brine hydrogeology conducted by the Texas Bureau of Economic Geology, along with BEG's newly completed hydrogeologic cross-sections of the Logan area; studies related to Ute Reservoir conducted by the New Mexico State Engineer Office; and studies (including unpublished notes) specific to the brine inflow, conducted by or for the U.S. Bureau of Reclamation.

Selected information (e.g. stratigraphic columns; geologic and hydrologic maps; cross-sections) has been photo-copied from the source documents and organized by subject. We have built new data tables to present information on well characteristics, water levels and water quality. And, we have written short abstracts and an overall summary of the key documents.

No previous study effectively characterizes the local brine flow system. By piecing together information from many sources, and applying our own judgment, we believe that the evidence supports the following concepts.

- The Canadian River near Logan is the natural discharge zone for ground water which originates over a large part of northeastern New Mexico. Most ground water in the region flows laterally (rather than vertically) and with a gradient which includes a low but consistent net easterly component.

- Brine originates from dissolution of Permian evaporite deposits which are dominantly sodium and chloride in composition. Active dissolution occurs over a large area, including a broad front which parallels the Canadian River in the Logan area.

- Regionally, the dense brine can't flow through the relatively impermeable evaporites, so most moves downward and discharges to deep underflow beneath the Panhandle. Locally, brine moves upwards to the Santa Rosa Sandstone, the most permeable rock unit overlying the Permian evaporites in this area.

- Most of the brine found near Logan probably originates south and southwest of Logan, e.g. towards Tucumcari. It flows northeasterly and comingles with and is diluted by fresh water before discharging to the river.

- The Santa Rosa includes an upper and lower sandstone, the Trujillo and Tecovas respectively. Although no published study says so, it seems clear that the 150-foot thick Tecovas is the "brine aquifer" in the Logan area.

- The Tecovas brines are under artesian pressure. The total rate of brine inflow is 0.9 cfs, of which 0.6 cfs may originate from the evaporite dissolution and the rest is local fresh water which dilutes the brine. There are no structures which provide a known control over where the inflow occurs.

- The Tecovas slopes upwards from a depth of several hundred feet at Ute Reservoir to near the land surface at Revuelto Creek. Thus the brine aquifer is just beneath the Canadian River along the "gravel pit reach", which is the linear south-north reach 1 mile east of Logan.

- Upstream of the gravel pit reach, brine reaches the river by flowing upward across a 50-foot thick layer of shale and mudstone, then mixing with fresh water in the Trujillo and alluvium. But at the gravel pit reach, the clay rock is thin or absent, and flow is directly through the alluvium.

- Information on hydraulic properties of the brine aquifer is conflicting and in particular the permeability value utilized by USBR in their ground water model probably is in error. The model itself does not simulate a realistic flow condition.

- We interpret the water-level data as demonstrating that artesian pressure is greatest near Ute Reservoir, but the overall flow gradient is easterly toward a major discharge zone in the vicinity of the gravel pit reach.

- We interpret other data - including previous geophysical studies and data on brine in the alluvium - as being consistent with the conclusion that lateral flow through the brine aquifer to the discharge zone along the gravel pit reach is a key part of the brine flow system.

- The geologic conditions similar to those which cause brine inflow near Logan also occur farther east, near the New Mexico state line. This is consistent with findings in the surface water notebook, which identified a probable "new" brine source between Logan and the state line.

- As established in the surface water notebook, the Logan brine aquifer is not as important to Lake Meredith as represented in previous reports, and a single control project will <u>not</u> adequately address salt inflows to the lake.

The literature does not provide a solid foundation upon which to design a brine control project. Fortunately, a stream survey recently conducted by CRMWA has generated the first set of data capable of quantifying key elements of the brine flow system. We recommend a detailed analysis of the data to confirm the importance of the gravel pit reach to the brine flow system, and to determine if this is the reach where a control project could be most effective. If CRMWA authorizes such an analysis, and it is successful, the next steps would be undertaken in the second half of 1992 and would include geophysical surveys and exploratory drilling.

1. INTRODUCTION

The Canadian River Municipal Water Authority (CRMWA) has contracted with Parkhill, Smith and Cooper Inc., and Lee Wilson and Associates Inc., to assist in implementation of the Lake Meredith Salinity Control Project. The Project objective is to reduce salinity in Lake Meredith, located NNE of Amarillo, Texas. The project method is to intercept and dispose of flow from a brine aquifer located near Logan, New Mexico.

This notebook contains readily available information on the brine aquifer, and more generally on geologic and ground water conditions along the Canadian River from Logan to Lake Meredith. In addition to a brief text summary of the information, selected data summaries and extracts are provided in the tabbed sections of the notebook. The Logan area is shown in **TAB 1**. This map includes the location of wells and other sites where data specific to the Project have been gathered; see subsequent discussions. Published documents from which information was extracted are listed in **TAB 2**.

The notebook was prepared for two different reasons: first, to compile and organize data and interpretations from many different sources, so that in the future it will be easier to find and use the information; and second, to allow the contractors to become more familiar with the Project. While the notebook summarizes what <u>others</u> have observed, it also contains our own interpretations of key aspects of the available data. A separate notebook provides information related to Canadian River surface water. Unlike the surface-water notebook, our interpretations are not provided in the context of specific references and informtion sources, but are consolidated together into a general discussion of the brine problem, which is presented in Chapter 3.

In general, the available information provides valuable insights regarding salinity problems at Lake Meredith and the brine aquifer near Logan. In particular, the hydrology of the brine flows to the river can be explained in a logical if somewhat generalized way. However, there is a lack of detailed information on the brine aquifer which makes it difficult to design a control project or predict project benefits. Interpretation of recently obtained stream survey data, and additional geophysical and subsurface exploration are all needed if CRMWA is to have a realistic prospect of implementing a cost-effective salinity control project.

2. LITERATURE SUMMARY

2.1 Basic data compilations and tabulations

The bibliography provided in **TAB 2** was developed through review of documents provided by CRMWA and the Texas Bureau of Economic Geology (BEG), and by cross-checking libraries such as those in our office and at the New Mexico Interstate Stream Commission; we have not done a detailed check of State libraries in Texas. Many studies were identified but not reviewed in detail because of their relatively early date or limited relevance; these are not listed on the bibliography.

For purposes of a reference notebook such as this one, it is useful to assemble basic data compilations and interpretations (such as tables which list well records, or cross-sections which interpret geologic logs) in some systematic way. Here, the choice has been to compile similar information from all germane reports into a particular tabbed section of the notebook. The organization of this information is as follows.

- **TAB 3** compiles stratigraphic columns of the study area.
- **TAB 4** compiles geologic, geomorphic and structure maps which include the study area.
- **TAB 5** compiles geologic cross-sections of the study area.
- **TAB 6** compiles hydrostratigraphic columns of the study area.
- **TAB 7** compiles additional maps of the study area, especially those relating to ground-water conditions.
- **TAB 8** compiles hydrogeologic cross-sections of the study area.
- **TAB 9** compiles well and spring inventories from the study area. The first three tables in **TAB 9** were prepared for this report, through careful integration of data from reports prepared by or for the U.S. Bureau of Reclamation (see subsequent discussion of Project Reports).
- **TAB 10** compiles well log data for wells drilled in the study area.
- **TAB 11** compiles water-level data from the study area. It includes an important graph showing that water levels in the brine aquifer appear to respond to to changes in storage in Ute Reservoir.
- **TAB 12** compiles aquifer test data and analyses from the study area.

- **TAB 13** compiles data on ground-water quality from the study area. The table in **TAB 13** summarizing brine aquifer water quality was prepared for this report, through careful integration of data from reports prepared by or for the U.S. Bureau of Reclamation (see subsequent discussion of Project Reports). This tab also includes all records we have located which provide data on the quality of water in the Logan area brine aquifer.

- **TAB 14** compiles maps, charts and graphs related to quality of ground water.

Note that additional tabs are provided in this notebook. For example, **TAB 15** presents specific data on salt dissolution rates and river salt loads from Gustavson, et al. (1980a); and **TAB 16** contains various USBR field data. Note also that all documents presented in the tabs come from reports cited in **TAB 2**, but only the most relevant reports are abstracted in the next sections.

2.2 Regional studies

Several reports provide useful regional perspectives on the hydrogeological conditions of the Canadian River Basin and/or the Logan area. These include: Berkstresser and Mourant (1966); Foster, et al. (1972); Spiegel (1972a, 1972b); Trauger and Bushman (1964); Kessler (1972); Gustavson, et al. (1980a); Gustavson and Finley (1985); Collins and Luneau (1986); Bassett and Bentley (1983); Orr, et al. (1985); Dutton and Orr (1986); and Dutton (1987). With limited exceptions, the following discussions present the major conclusions of these references, without criticism or comment.

Berkstresser and Mourant (1966) provide the earliest regional study that includes specific information on hydrogeologic conditions in the Logan area. The report includes a brief description of hydrogeologic units exposed in Quay County but the report otherwise lacks interpretation; the emphasis is on compilation and presentation of basic data. The data are largely adapted from earlier studies and all of it dates from the mid-1950's or earlier. Thus the information provides background on conditions that existed before the construction of Ute Reservoir. **TAB 4** includes a portion of one of the geologic maps; **TAB 5** includes relevant portions of two cross-sections; **TAB 7** includes a portion of a water-level map; **TAB 9** includes the spring inventory and parts of the well inventory; and **TAB 13** includes relevant parts of the tabulation of chemical analyses of water samples.

The report identifies the Entrada Sandstone and various Cenozoic sedimentary units as the principal aquifers in the region. The Entrada is not exposed near the Canadian River, but Quaternary deposits are near or at the north side of the river from Logan to the state line. The Santa Rosa Sandstone and Chinle Formation, which are exposed along the river, were characterized as yielding 1 to 50 gpm to wells and springs.

Our review of the reference identified three noteable characteristics of ground water near Logan, as conditions existed before construction of Ute Dam.

- the Santa Rosa Sandstone southwest of Logan was under artesian pressure;
- ground water moved toward the river from both the north and south along its entire length from Logan to the state line;
- water levels north of the river near Logan were 50 to 100 feet higher than water levels a comparable distance south of the river.

Foster, et al. (1972) provide a fairly detailed summary of stratigraphy in surface exposures and subsurface rocks in east-central New Mexico. Although this study has a regional scope it includes details that are relevant to subsurface conditions along the Canadian River. Isopach maps of Triassic and older units and a contour map constructed on the top of the Precambrian surface are included in **TAB 4**.

Foster, et al. report salt deposits in the Artesia Group (Bernal Formation), San Andres-Glorieta interval and the Yeso Formation. In all cases, salt beds are absent north and west of Logan, and present to the southeast. The northern boundary of the salt-bearing area parallels the Canadian River from near Logan to the state line and lies under or just north of the river. Regional studies of the Palo Duro Basin indicate that the boundary parallel to the Canadian River is a dissolutional rather than depositional boundary.

The Precambrian surface is offset between Logan and Tucumcari by a west-northwest trending fault with displacement down to the southwest, as illustrated by the map in **TAB 4**. Near Logan, the displacement is approximately 1750 feet. Approximately 10 miles west of the state line the Precambrian surface is offset by a north-trending fault with displacement down to the east. The displacement is approximately 2500 feet where the Canadian River crosses the subsurface fault. Between these two faults the Canadian River crosses a buried horst.

Spiegel (1972a, 1972b) The New Mexico Geological Society Guidebook of East-Central New Mexico (Kelley and Trauger, 1972) contains several articles that describe geology in the Canadian River basin. Two articles by Zane Spiegel (who had done basic hydrogeology studies as part of the planning and design work for Ute Dam) are particularly important.

Spiegel (1972a) describes and attempts to resolve questions over the stratigraphy of Triassic rocks exposed along the Canadian River. He concludes that sandstones prominently exposed near Logan and along the river to the east are part of the Santa Rosa Sandstone and correlate eastward to the lower sandstone of the Trujillo Formation in Texas. Red mudstone and "friable white sandstone" underlie the prominent sandstone commonly exposed along the river and are correlated on the basis of lithology and position to the Tecovas Formation in Texas. The red mudstone and white sandstone were also correlated to the Santa Rosa Sandstone. Later in the article, Spiegel confused his findings by correlating the Alibates of Texas to the San Andres Formation in New Mexico, which clearly is not correct. Well logs from Spiegel's report are included in **TAB 10**.

Spiegel (1972b) describes construction problems at dam and reservoir sites along the Pecos and Canadian Rivers, with particular attention on problems created by dissolution of gypsum or salt in the Permian section and collapse in the overlying Triassic section. The Dunes dam site located above the State Line (section 2, T13N, R35E) was described as the crest of a local anticline created by the collapse of adjacent areas. Collapse features in the reservoir site were specifically described.

Trauger and Bushman (1964) describe the hydrogeology of a portion of Quay County, New Mexico, extending generally southwest from Tucumcari. The report does not cover any area immediately along the Canadian River and most of the hydrogeologic units important in the area of the study have only limited occurrences elsewhere along the Canadian River. Only some aspects of the report will be abstracted and these mainly because we are very familiar with the report based on our work in the Tucumcari area.

The Santa Rosa Formation is present at depth within the study area and was not addressed by the authors because "the sandstone lies generally at depths of 1,500 feet or more beneath the land surface and has yielded only water of high salinity to oil-test wells...". (emphasis added)

Bedding in the Tucumcari area dips generally 1 to 3 degrees, but locally may dip as much as 30 degrees. The major structure is a large, northeast trending synclinal trough, locally modified by smaller east-trending anticlines and synclines. The convergence and divergence of the folds creates four distinct closed basins.

Trauger and Bushman attribute the folds to dissolution of bedded salt at depth and the subsidence of overlying units. Subsidence began at least by the Jurassic and is evidenced by the thickening of both the Entrada and Morrison Formations in the structural lows. Subsidence during the Quaternary is evidenced by the large thickness of alluvium (more than 500 feet) in a very local basin beneath Tucumcari. Quaternary alluvium beneath Tucumcari contains more clay than is typical in the area for other deposits of similar age. The clay beds probably were deposited in lakes or ponds analogous to existing Tucumcari Lake. A distinct sink hole, also attributed to salt dissolution in the underlying strata, was identified in the hills south of Tucumcari and described as evidence for recent collapse.

Trauger and Bushman describe only one small fault in the study area. Structural contours on the top of the Chinle Formation (**TAB 4**) illustrate 400 feet of structural relief across a one-mile wide, north-northeast trending zone on the west side of Tucumcari Mountain. The relief can be explained by a westward continuation of the relatively steep dip of beds on the west side of Tucumcari Mountain. A fault is not required to explain the offset.

Kessler (1972) described variations in channel geometry, gradient and sediment along the Canadian River in eastern New Mexico and the Texas panhandle. In New Mexico and western Oldham County, Texas, the river is sinuous, with relatively coarse sediments. In western Oldham County the river gradient is 7.2 feet per mile. The gradient drops to 5.5 feet per mile in the eastern panhandle, where the river is braided and less sinuous.

The Canadian River in New Mexico and western Oldham County is actively downcutting through earlier channel deposits. The river valley downstream from a point in central Oldham County preserves a fairly complete record of catastrophic flood and appears to be aggrading.

Gustavson, et al. (1980a) describe the rate, distribution and structural effects of salt dissolution in the Texas panhandle. Salt dissolution has affected parts of the Salado, Seven Rivers, San Andres, Glorieta and Clear Fork Formations (all Permian) in a zone along the Canadian River from New Mexico to near Amarillo, Texas, and along the caprock escarpment south of Amarillo. Dissolution has removed as much as 1,100 feet of bedded salt deposits.

Dissolution creates several types of structural displacements in overlying beds, including extensive breccias, breccia-filled collapse chimneys, faults, sinkholes and folded terrains. Collapse chimneys are common near Lake Meredith. Twenty seven collapse chimneys were discovered during the construction of Sanford Dam and others occur along the lake above the dam. Cross-sections through the Bonita and Alamosa faults in New Mexico show a marked thinning of the salt-bearing Artesia Group on the downthrown sides of the faults (**TAB 5**). Dissolution may cause or enhance the offset on the faults.

Dissolution began in the Dalhart and Anadarko Basins after deposition of the Kiowa Formation and Dakota Group (Cretaceous) and probably continued through the Tertiary. Dissolution during and after deposition of the Ogallala Formation created numerous large solution basins up to 120 square miles in area and troughs up to 50 miles long. Contours on the base of the Ogallala in the Anadarko and Dalhart Basins show broad depressions with as much as 400 feet of relief attributed to the dissolution of salt in underlying strata (**TAB 4**). The Canadian River flows through a series of basins and troughs that locally are more than 250 feet deep. Regionally, dissolution lowered the Great Plains surface north of the Canadian River by more than 250 feet.

Active dissolution in the Palo Duro Basin delivers a salt load of 2,800,000 tons per year to streams draining the basin. Almost half of the total load is carried by the Prairie Dog Town Fork of the Red River. The Canadian River at the Amarillo station carries nearly 700,000 cubic feet of dissolved salt a year, with about 450,000 of that originating above Tascosa, Texas and the remainder originating in the reach between Tascosa and the Amarillo station (**TAB 15**).

A preliminary conceptual model of salt dissolution in the Palo Duro Basin requires downward percolation of freshwater from the Ogallala Formation into the Permian section through vertical fractures cross-cutting the Dockum Group. The formation of the fractures and the extent of fracture development are influenced by prior dissolution and collapse. Dissolution is most active in the highest salt-bearing unit preserved in an area. Dissolution occurs along a steep front that gradually advances toward the center of the basin.

Gustavson and Finley (1985) describe the development of the existing drainage pattern in and around the Palo Duro Basin. Major streams that existed at the time of Ogallala deposition flowed southeast from highlands in New Mexico, directly down the land surface gradient. The present Canadian and Pecos rivers flow at high angles to the regional gradient.

Subsidence due to salt dissolution on the western margin of the Palo Duro Basin formed a series of lake depressions aligned along the north-south structural margin of the basin. The ancient Portales River was diverted into the lakes and subsequent integration of the drainage formed the present Pecos River.

Similarly, subsidence along the northern margin of the Palo Duro Basin formed a series of lakes aligned along the east-trending structural margin of the basin. Lacustrine deposits preserved at the top of the Ogallala section in the Rita Blanca drainage north of the Canadian River may be a remnant of those lakes. The southeasterly flow of a proto-Canadian River was diverted into the lake basins and subsequent integration of the system formed the existing Canadian River.

The report includes a roughly north-south geologic cross-section through Harding, Quay, Curry and Roosevelt Counties (New Mexico) that crosses Ute Reservoir west of Logan (**TAB 5**). The sections shows salt dissolution south of the reservoir near Tucumcari in the Artesia Group and subjacent upper San Andres Formation. It shows salt dissolution immediately below the reservoir in the lower San Andres Formation.

Collins and Luneau (1986) describe regional fracture patterns in the Palo Duro Basin and present detailed studies of joints in exposures and fractures and veins in cores. Fractures in exposures of Triassic and Permian rocks are commonly oriented parallel to faults and folds. The principal directions are east-west (275 to 295 degrees azimuth) and northwest-southeast (305 to 320 degrees azimuth). Northeast-striking fractures and faults (30 to 60 degrees azimuth) are found in Triassic units in the western part of the study area (including Quay County, New Mexico) but are rare elsewhere (**TAB 4**).

The in-situ principal compressive stress was measured by hydraulic fracturing of Permian beds at the SWEC Holtzclaw No. 1 well (southern Randall County, Texas). The principal compression was oriented on a northeast azimuth. Open fractures parallel to the principal stress are the most likely conduits for ground water flow.

Gypsum veins in Permian strata are normally found in units affected by salt dissolution. The veins were formed in response to collapse accompanying late-stage dissolution of underlying salts. Halite veins within the salt-bearing sequence formed soon after deposition. The orientation of some veins also indicates an influence from the regional stress system.

Bassett and Bentley (1983) describe the general hydrogeology and geochemistry of brines in the Palo Duro Basin. They divide the stratigraphic section into three hydrostratigraphic units on the basis of known or estimated hydraulic properties. The three units are: 1) a deep basin brine aquifer; 2) an evaporite aquitard, and 3) an upper freshwater aquifer (**TAB 6**).

The deep basin brine aquifer contains all pre-Leonardian (early Permian and older) strata in the basin. Major sedimentation began in the Pennsylvanian, synchronous with tectonism that formed the basin. Most of the aquifer consists of open-marine platform carbonates and fluvial-deltaic arkosic sandstones interbedded with mudstone. The distribution of the lithologies (**TAB 4**) was controlled by the structural development of the basin. Fluvial-deltaic sandstones were deposited on the basin margins from sediments derived on the adjacent highlands and from deltas extending into the basin from the northeast. Shelf and shelf-margin carbonates occur basinward from the deltaic deposits and intertongue with them. The basin center was filled with mud. The rate of subsidence diminished over time and by the late Wolfcamp the shelf-margin carbonates had prograded into the basin center and lapped over the basin-bounding uplifts. The average permeability of the deep brine aquifer was estimated at 0.02 gpd/ft^2.

The evaporite aquitard consists of Middle and Upper Permian (mostly Leonardian and Guadalupian) strata containing halite, anhydrite, dolomite and fine-grained siliciclastic red beds. The average permeability of the evaporite aquitard was estimated at 2×10^{-6} gpd/ft^2.

The fresh water aquifer consists of fluvial, deltaic and lacustrine deposits in the Triassic Dockum Group and alluvial deposits in the Tertiary Ogallala Formation. The properties of sandstones within the Dockum Group are not well known because of limited development. The approximate permeability (apparently of the sandstones alone) is 2 to 20 gpd/ft^2. The Ogallala is well characterized and its average permeability was estimated at 200 gpd/ft^2.

Freshwater flows in the upper aquifer generally eastward and some of it discharges at springs and seeps along the eastern escarpment of the high plains. Beds in the evaporite aquitard are exposed east of the escarpment, where dissolution of the evaporites and attendant collapse of the interlayered red beds has enhanced their permeability.

Data from drill stem tests show that the piezometric surface in the deep brine aquifer slopes generally eastward at about 6.3 feet per mile with little effect from topographic features, including the caprock escarpment. Under the existing gradient, with a permeability of 2 millidarcy and a porosity of 0.5 percent, the deep brine aquifer would flush approximately every million years.

The Wolfcampian units in the Panhandle Gas Field had an initial pressure of 435 psi, about 265 psi lower than adjacent beds toward the central basin. The hydraulic separation is created by faults that effectively isolate the reservoir area.

Brines in the deep aquifer are consistently dominated by sodium and chloride and typically have TDS concentrations between 150,000 and 170,000 mg/l (map in **TAB 14**). Brines from the carbonate and arkosic sections of the aquifer differ in their Ca/Mg ratios (higher in the clastics) and their sulfate concentrations, which are generally 2 orders of magnitude lower in the clastics than in the carbonates. The difference is attributed to sulfate reduction in the clastic deposits.

Equilibrium chemistry computer programs were used to determine the effects controlling the brine chemistry. The salinity was attributed to dissolution early in the ground water flow path of salts from the overlying evaporite sequence. Brines from both carbonates and arkose contained a Na/Cl ratio slightly lower than that expected from the dissolution of pure halite. The modification was attributed to ion exchange.

The available analyses were found to be affected by CO_2 outgassing and iron oxidation. Reconstruction of in situ conditions indicated that water from carbonate host rocks would be in equilibrium with calcite. Brines from the carbonates generally fall on the anhydrite phase boundary, but brines from the arkose are not in equilibrium with anhydrite because of sulfate reduction.

Orr, et al. (1985) provide information on variations of hydraulic conditions within the deep brine aquifer in the Palo Duro Basin.

The deep brine aquifer is generally underpressured; the brine hydraulic head is lower than indicated by a hydrostatic gradient and substantially below the land surface. The hydraulic gradient between the deep aquifer and the shallow freshwater aquifer is downward in all but the southeastern corner of their study area. Head differences between the two aquifers (TAB 7) range from near 0 (southeast) to more that 1,800 feet (northwest, in central Oldham County).

The horizontal hydraulic head gradient within the brine aquifer (TAB 7) is generally northeastward. The gradient turns nearly due east along the south margin of the Palo Duro Basin.

Underpressuring of the brine aquifer was attributed in part to downward flow within the aquifer. Data from drill stem test, a simple hydrostatic model and a previously published flow model of the brine aquifer were combined to predict flow conditions within the aquifer. Upward flow within the aquifer was predicted in the northern part of the basin, while downward flow was expected in the central basin and east of the caprock escarpment. Flow parallel to bedding was predicted in a band around the basin center separating the areas of upward or downward flow along the basin margins from the area of downward flow in the basin center.

The variations in vertical flow components within the aquifer were attributed to lithologic changes.

Dutton and Orr (1986) describe hydraulic conditions and geochemical characteristics of brines in the San Andres Formation, a part of the Palo Duro Basin's evaporite aquitard.

Hydraulic heads within the San Andres are affected by topographic features and by a history of hydrocarbon production. Two maps (TAB 7) show that water levels slope from the northwest to southeast from central and eastern New Mexico to the southeast corner of the Palo Duro Basin. The heads are intermediate between heads in the Ogallala aquifer and heads in the deep brine aquifer.

Vertical flow through the San Andres occurs principally through fractured zones. Areally averaged vertical flow rates were estimated in previous model studies at 2×10^{-7} ft^3/day per square foot. Average lateral flow rates were estimated at 7×10^{-8} ft^3/day per square foot.

Geochemical study indicated that brines in the San Andres probably originated as evaporatively concentrated sea water (connate water). Ion exchange lowered the sodium concentration in the connate water and caused additional halite dissolution. Halite dissolution causes the Cl/Br ratio in the San Andres brine to be higher than in concentrated sea water. Sulfate reduction, which lowers sulfate/chloride ratios, and dolomitization which raises Ca/Mg ratios also affect brine composition.

A meteoric-water evolution path for the brine composition also was considered. Evolution from meteoric water to San Andres brine was considered unlikely because the path required unsubstantiated or speculative reactions.

Dutton (1987) reports the results of testing for hydraulic properties and chemical characteristics of water in salt dissolution zones in the Palo Duro Basin. The tests were conducted at three wells: 1) SWEC Mansfield No. 2, in the Canadian Breaks in eastern Oldham County; 2) SWEC Sawyer No. 2, on the Rolling Plains in Donley County and; 3) SWEC Holtzclaw No. 1, on the High Plains surface in southern Randall County. The SWEC Holtzclaw No. 1 well was used to test two different intervals. Water quality and water levels were reported from several additional wells.

SWEC Mansfield No. 2 was used in single-well tests to measure the transmissivity of an interval in the Seven Rivers Formation. The well was tested in a series of drawdown and recovery cycles (see data plots and curves in **TAB 12**) and results were analysed by type-curve matching or by Theis or Jacobs approximations. Transmissivity ranged from 1.5 to 5.0 m^2/day and permeability was calculated to range from 0.16 to 0.4 m/day. Water from the well contained 67,500 mg/l TDS and had a specific weight of 0.453 psi/ft.

Specific storage was calculated at $1x10^{-6}$ ft^{-1}, based on barometric efficiency (36%), neutron log porosity (30%) and the modulus of elasticity of water. The storage coefficient was calculated at $10^{-4.2}$.

SWEC Sawyer No. 2 was used in a single well test to measure the transmissivity of an interval at the top of the San Andres Unit 4 carbonate. The well was tested in a single drawdown and recovery cycle (see data plots and curves in **TAB 12**) and results were analysed by type-curve matching. Transmissivity varied from 2.3 to 3.7 m^2/day and permeability was calculated at 0.4 to 0.6 m/day. Water from the well contained 94,900 mg/l TDS and had a specific weight of 0.461 psi/ft.

Specific storage was calculated, based on barometric efficiency (58%) using the same porosity and bulk modulus values estimated for the Mansfield well. Uncertainty over possible contribution to the well from the collapse zone overlying the production interval lead to a range of estimated storage coefficients from $10^{-4.8}$ to $10^{-3.6}$.

SWEC Holtzclaw No. 1 was used to complete drill stem tests in two intervals; one in the Seven Rivers Formation and the other including both the Salado and Tansill Formations (**TAB 12**). A type curve approximation was used to estimate the transmissivity of the Seven Rivers interval at 0.1 m^2/day and the permeability at 0.007 m/d. The same method was used to estimate the transmissivity of the Salado-Tansill interval at 0.0008 m^2/day and the permeability at $6x10^{-5}$ m/d.

The hydraulic head in each stratigraphic unit is higher than the head in underlying units, indicating downward flow throughout the section. Chemical analyses of major and minor constituents and hydrogen, oxygen and sulfur isotopic studies indicate that the water in salt dissolution zones originated as meteoric water that entered the ground water system 16,200 to 23,500 years ago. Subsequent chemical evolution involved the dissolution of halite and gypsum, hydration of anhydrite and ion exchange.

2.3 Project Reports

A key element in any literature summary for the Project is the reports conducted by or for USBR in the 1970's and the first half of the 1980's: USBR (1979), HGC (1984a), HGC (1984b), USBR (1984) and USBR (1985). General aspects of this reports, along with specifics related to the Canadian River, are provided in the surface water notebook. For the most part, our comments on these reports are provided in Chapter 3, where we use the reports (or critique them) to help identify key findings regarding the role of ground water in discharging brine to the Canadian River near Logan.

USBR (1979) is an appraisal-level study that summarizes work performed from 1972 to 1978. The studies were intended to identify the sources contributing high concentrations of salts to the Canadian River between Ute Reservoir and Lake Meredith and to identify methods of alleviating salinity problems in the river.

The report includes a summary of geologic conditions along the Canadian River. **TAB 3** includes the geologic column presented in the report. USBR describes the river as being entrenched as much as 100 feet into resistant sandstones in the Dockum Group, which are well exposed along the river. Upland areas north of the river are blanketed by "gravelly and sandy terrace and windblown deposits." Alluvial deposits in the valley consist of fine sand, silty sand and silt. The Canadian River downstream from Revuelto Creek is reported to be entrenched into the Permian Bernal Formation; note that this assertion is not supported by most other studies.

Beds within the Dockum Group downstream from Ute Dam dip at low angles to the west or northwest from the crest of an anticlinal flexure hinged about 1 mile downstream from the confluence of the Canadian River and Revuelto Creek. USBR indicates that the flexure is a depositional feature developed over a topographic high in the Precambrian basement, rather than a compressional or tectonic feature. USBR reports that it observed no faulting or surface evidence of solution collapse features in the Logan area.

Ground water along the Canadian River between Ute Dam and Lake Meredith is reported as generally highly mineralized, probably because of its proximity to soluble deposits within the Permian section. The highly mineralized water occurs at shallow depths in both Triassic and Permian rocks. The total thickness of the brine aquifers range from about 1,500 to 4,000 feet (p. 8). Records from a number of oil test wells indicate that the salt water is under sufficient artesian pressure to flow to the ground surface.

Water in the Canadian River, except for direct runoff, was attributed to baseflow contributions. Streams originating from above the Canadian Breaks carry relatively fresh water from the Ogallala Formation. Baseflow along tributaries in the inner valley or the main stem of the Canadian River originates from the Triassic and Permian beds. Water from the Triassic rocks is typically of fair to poor quality. Water from the Permian rocks is typically highly mineralized.

The report notes saline ground water contributions to the river below Ute Dam and attributes the salt pollution to the upward movement of mineralized water from the Permian through fractures and collapse features. They also note that despite the occurrence of saline seeps and pools along the river, there are no identifiable structural conduits which localize saline inflow. Ute Dam is reported to have caused an increase in seepage due to reservoir leakage and "possibly to hydraulic loading on the Triassic aquifers" (p. 9). Refer to the surface water notebook for information on the USBR stream surveys which identified the saline seeps.

USBR (1979) describes the results of several specific field studies. The earliest investigations were in the period 1972-74, when the agency undertook investigations to locate the source(s) of saline water which reaches the Canadian River above Lake Meredith. A 1972 study sampled riverbed sands and evaluated evapotranspiration at various locations along the river. (These data have been requested from the Bureau of Reclamation and, if obtained, will be included in **TAB 16**.) The studies generally indicated that evapotranspiration, salt storage and salt flushing do not contribute significantly to the salinity problem.

In 1974 the Bureau drilled four groups of five test holes into alluvium along the Canadian River from Logan to the U.S. Highway 87 bridge above Lake Meredith. (These data have been requested from the Bureau of Reclamation and, if obtained, will be included in **TAB 16**.) These showed saline conditions in New Mexico, above the State Line. Later, six groups of test holes were drilled along the channel between Ute Dam and the State Line. (These data have been requested from the Bureau of Reclamation and, if obtained, will be included in **TAB 16**.) Data from the more detailed program suggested the presence of saline inflow concentrated in an area along the channel from 2 to 5 miles below Ute Dam. This finding caused subsequent studies to concentrate exclusively on the identified inflow area.

Two relatively deep wells were drilled in 1975 near Logan, New Mexico and sampled for water quality. Drill hole 1 (DH-1) was drilled near the U.S. Highway 54 bridge at Logan, to a depth of 356 feet. The second hole (DH-2) was located 2,000 feet downstream from the Revuelto Creek confluence, to a depth of 536 feet. Drilling records are included in **TAB 10**.

DH-1 encountered water containing 4,000-5,000 mg/l sodium chloride between 80 to 155 feet. Artesian flows (30 gpm) of saline water (22,000 to >30,000 mg/l sodium chloride) at depths between 261 and 356 feet. The producing unit was a white or light tan, friable sandstone which was described as "Glorieta-like"). DH-2 encountered a minor artesian flow below a depth of 516 feet from fine sandstone and siltstone. It did not encounter a section of friable sandstone comparable to that identified in DH-1. Water from the deep zone in DH-2 contained about 8,000 mg/l sodium chloride, a concentration comparable in quality to water in the river. Neither well encountered any salt beds.

In 1978 the Bureau of Reclamation drilled a test hole (TW-1) and four observation wells (OW-1 through OW-4) near the U.S. 54 bridge south of Logan - the same area in which DH-1 had previously identified the brine aquifer. All wells were reported to be drilled in "Dockum" materials. The top of the brine aquifer was penetrated in each of the wells and correlated between them. Drilling records for the wells are included in **TAB 10**; **TAB 5** includes two cross-sections, using lithologic logs and geophysical well logs. The aquifer was identified as a sequence of friable to well-cemented, generally fine grained or silty sandstones interlayered with shale within the Triassic section. The aquifer occupied an interval from about 200-220 feet to 340-360 feet.

USBR (1979) also summarized results from seismic refraction and surface electrical resistivity studies completed in 1975. The surveys were intended to determine the depth, thickness and extent of the brine aquifer. They reported that the seismic survey identified layering in the subsurface, with the sequence being similar to that in DH-1: alluvium, sandstone, shale, sandstone.

The resistivity survey consisted of 6 soundings in the area along the Canadian River from near Ute Dam to Revuelto Creek. (Location, contours and resistivity profiles are included in **TAB 16**.) A low-resistivity layer, tentatively considered to be the brine aquifer, was identified in four of the six soundings and was reliably characterized in three of the soundings. The layer was absent in two soundings, but only one of those two represented reliable data. The layer thickness was found to vary from 150 to more than 300 feet and to dip generally westward at about 4 degrees.

The depth to the top of the layer varied from about 450 feet at its eastern identified extent to about 800 feet near Ute Dam (elevation from about 3,400 feet to 2,900 feet); see map in **TAB 16**. The layer was absent approximately 1 mile west of Revuelto Creek, but apparently present at an unknown depth east of Revuelto Creek. One sounding produced unreliable results, but appeared to indicate a discontinuity or boundary within the brine aquifer.

The resistivity study may have identified the eastern extent of the brine aquifer found by drilling in DH-1, TW-1 and OW-1 through OW-4. Specifically, well DH-1 may be located near the eastern, upper limit of the unit. The study did not indicate the northern, southern or western extent of the aquifer. In our judgment, the exactly location shown for the eastern boundary of the aquifer may not be accurate.

Hydraulic parameters of the brine aquifer were measured by pumping well TW-1 and measuring drawdown at observation wells OW-3 and OW-4. The well was pumped at 475 gpm for 97 hours, followed by 68 hours of recovery. Drawdown at OW-3 and OW-4 were interpreted (apparently by Theis curve matching, although this is not specified in the report) to arrive at a storage coefficient of 0.00015, a transmissivity of 2500 square feet per day and a hydraulic conductivity of 36 ft/day. If only 425 gpm of the total pumping was derived storage coefficient of 0.00013, transmissivity of 2250 square feet per day and hydraulic conductivity of 32 ft/day. The report does not include any of the measured data, hence it has not been included in the tabbed sections of this notebook. As discussed in Chapter 3, the conductivity value is suspect.

Heads in well TW-1 are artesian and typically above the level of water in the river. The well was sampled during the pumping test. The report includes only two partial analyses (sodium, chloride and sulfate) from that set (**TAB 13**). The analyses average 14,300 mg/l sodium, 22,000 mg/l chloride and 9,150 mg/l sulfate. Apparent problems with the sulfate concentration will be discussed in Section 3.

Conductance was measured at intervals during drilling of DH-1 and reported in a letter memorandum supplement to the 1979 report. The drillers found water from 0 to 71 feet similar to river water at 10,000 to 11,500 micromhos, water from 71 to 136 feet near 6,000 micromhos and water below 261 feet at 50,000 micromhos. They also reported a dry interval from 96 to 116 feet.

Conductance was measured for the artesian flow encountered during drilling DH-2. Water from the interval 466 to 516 feet had a conductivity of 16,000-17,000 micromhos. The river at that site carried water with a conductance of 17,500 micromhos.

A Bureau file memorandum dated August 8, 1975 and written by Jimmy K. Morrison provides the basis for the USBR (1979) analysis of river salt loading from the brine aquifer. The memorandum estimated the brine contribution between Ute Dam and DH-2. Prior to a stormwater runoff event, the river discharge was estimated at 2.5 cfs, with 8,000 mg/l of TDS; about 75% was from dam seepage at 400 mg/l and the remainder (about 0.6 cfs) was from ground water. These values were used to estimate that ground water contributed 31,000 mg/l of TDS, close to the 35,000 actually found at DH-1. After the storm, the river discharged an estimated 7 cfs. The author then used the original values and assumed that the additional 4.5 cfs of runoff carried 490 mg/l. That resulted in an estimated TDS in the river after runoff of 3,200 mg/l. The river actually carried about 2,800 mg/l.

USBR (1979) combined this brine inflow estimate of 0.6 cfs with the average concentrations for sodium, chloride and sulfate measured in TW-1 to estimate the tonnage of each constituent contributed annually by the brine aquifer. In units of tons per year (tpy), the loads are 8,500 tpy sodium, 18,000 tpy chloride and 5,400 tpy sulfate, for a total of 26,900 tpy. In units of kilograms/second, the loads are 0.24 kg/s sodium, 0.37 kg/s chloride and 0.16 kg/s sulfate. The loads were compared to total loads to Lake Meredith; the details of the latter were not provided. The 26,900 tons/year is 32 percent of a total loading of sodium, chloride and sulfate of 84,095 tons/year. Individual percentages are: sodium - 31%; chloride - 44%; sulfate - 20%.

These latter percentages have been used in some subsequent studies to indicate the potential improvement in water quality that might occur if brine inflows in the Logan area could be eliminated. At p. 20, USBR indicates that any improvement would be gradual, because large amounts of salt and salty water are stored in the alluvium and will be flushed out over time. As discussed in Chapter 3, the assessment of sulfate loading is suspect.

HGC (1984a). This is the most extensive interpretation of subsurface conditions related to the Project, including both a regional summary of geologic conditions along the Canadian River from Ute Dam to Lake Meredith and a detailed study of the geology in the Logan area. The stratigraphic column presented on page 14 of the report is provided here in **TAB 3**. The report contains information such as tables with information related to well logs, and interpretative maps (structure contours, isopachs). The most useful of these, a structure contour map for the San Andres Formation, is included in **TAB 4**. **TAB 5** presents three cross-sections along with a location map (these are Figures 12 through 15 in the report). Data from the report also are included in the tables which were compiled for this study: see **TAB 9** and **TAB 13**.

The report indicates that the course of the Canadian River follows fractures and a dissolution zone along the updip edge of Paleozoic age salt deposits. The subparallel (NE) nature of the dissolution front, regional fracture patterns and flexures suggests that the dissolution of salt has been the major control upon the geologic structure in the region.

More specifically, detailed mapping of the Logan area defined two major structural trends (**TAB 4**). Numerous, broad folds trend northeast. South of the river these folds plunge 5 to 10 degrees southwest. North of the river the folds appear to plunge to the northeast. A large anticlinal flexure is mapped roughly parallel to the river and defined by the reversal in the plunge of the northeast-trending flexures. The courses of Revuelto Creek and Tuscocoillo Creek run roughly parallel to the northeast-trending flexures. The east-trending flexure is roughly parallel to the salt dissolution front in underlying Permian rocks.

Aerial photographs and low-level overflights were used to identify a group of depressions aligned on a roughly east-west trend through Logan and along the Canadian River, parallel to the salt dissolution front. Field investigations confirmed the presence of collapse structures along the river.

Fracture studies indicate four dominant trends: N50-70W, N30-10W, N30-50E and N70-90E. The best development is seen in fractures that run parallel and perpendicular to the northeast-trending flexures (N30-50E and N50-70W). These fracture sets - particularly the northeast trending set - appear to be of tectonic origin and may influence the orientation of the salt dissolution front. The northeast trending set also seems to influence the courses of Revuelto Creek and the Canadian River, as both streams flow parallel to this trend through some of the area.

HGC indicates that relatively little is known about ground water conditions in the Permian formations of the area, except on a regional scale. Flows originate as recharge in the Sangre de Cristo Mountains and are eastward at a fairly even gradient between 15 and 20 feet per mile. Ground water in the Yeso and San Andres formations in New Mexico flows stratigraphically downward to the Wolfcamp aquifer in Texas and discharges at salt springs along and east of the caprock escarpment in Texas. Water levels in the Permian near and west of Logan are above ground level, while water levels in the Wolfcamp of Texas are generally below ground level because the water level gradient is steeper than the slope of the land surface. Permeabilities are generally low, but locally can be high due to fractures and dissolution.

Stiff diagrams showing the quality of water in the Permian units are included in **TAB 14**. These show that water in recharge areas typically is dominated by calcium, bicarbonate and sulfate. Sodium sometimes is a major component but chloride generally is minor. West of Logan water from the Permian section is very high in sodium and chloride as the result of halite dissolution. Sulfate is present on an equivalent basis at roughly 1/12th the chloride concentration and bicarbonate is relatively minor. Water from the Wolfcamp section in Potter County generally is similar to water from the Permian in Quay County except that sulfate is found at proportionately lower concentrations. In addition to halite dissolution, sulfate reduction and cation exchange are believed to be responsible for the compositional variations.

Information on ground water in the Triassic units of the area is taken mostly from Berkstresser and Mourant (1966), which is summarized above. Figure 22 in the HGC report is a water-level map for the Triassic; it is reproduced here in **TAB 7**. The flow is markedly toward the Canadian River. Hydraulic conductivity has been estimated to range from 0.25 to 2.5 feet per day. HGC estimates the Triassic transmissivity near the Canadian River at about 300 ft^2/day.

Based on this value and on the water-level map, HGC calculates a discharge from the Triassic into the Canadian River in New Mexico of about 0.15 cfs/stream mile, or a total of 5 cfs between Ute Reservoir and State Line.

There is little additional gain from this unit in Texas (p. 51). A localized gain of about 1 cfs near the Highway 54 bridge was observed on several occasions. Stiff diagrams showing the quality of water in the Triassic units are included in **TAB 14**. They show the water to be dominated by sodium, bicarbonate and sulfate. Chloride is a relatively minor constituent. Dissolution of limestone and gypsum and cation exchange probably are responsible for the water composition. Water from the Triassic section typically has higher concentrations than the local surface water. Some occurrences of relatively high chloride concentration may be caused by mixing with deep ground water.

Based on drilling conducted by USBR, the shallow brine aquifer of the Logan area is located beneath a lower Triassic shale, and above a shale which is near the top of the Permian section. The saturated thickness of the aquifer is about 100 to 150 feet and the hydraulic head appears to be slightly above river level. An aquifer test indicates a transmissivity of roughly 2500 ft^2/day. HGC states that to date there is no known increase in brine inflow caused by the construction of Ute Reservoir. All water-quality data known for the brine aquifer are included in **TAB 13**.

Water from the brine aquifer at USBR well OW-3 is a sodium-chloride brine similar to (though more dilute than) water in the Permian section. Isotopic and minor element analyses also show the water at OW-3 to be similar to saline brines in the Permian section, but with a component of water from the Triassic aquifer. The total discharge to the Canadian River from the shallow brine aquifer near Logan was estimated at 0.90 cfs (p. 94). The chloride load from the shallow brine aquifer was estimated at 0.7 kg/s. Out of the total discharge, 0.57 cfs and virtually all of the chloride load was believed to flow from the Permian section. The remaining 0.33 cfs originates as relatively fresh water from the Triassic aquifer. Refer to Chapter 3 for our modifications of these interpretations.

The channel alluvium of the Canadian River is described as 50 to 75 feet thick (100 feet thick by the State Line) and 400 to 600 feet wide. The stream gradient and water-level gradient are presumably similar, at about 0.0001. Water levels are generally within a foot or two of the land surface and there are no noticeable water-level variations between piezometers open at different depths at the same sites. Throughflow in the alluvium is considered to be small, due to the low gradient. Stiff diagrams showing the quality of water in the channel deposits are included in **TAB 14**, as are charts showing ranges of chloride concentrations in water from wells in channel deposits.

A graph (Figure 36) plots surface water and ground water chloride levels between the Logan and Amarillo gages; see **TAB 14**. Based on this graph, salinity clearly drops by the State line, parallel with a drop in ground-water salinity and stratification. Salinity remains low to Tascosa, indicating no brine inflow. The report does not comment on the fact that there is a marked increase in ground water chlorides at Amarillo, which is not paralleled by an increase in surface water chlorides.

HGC interprets stream survey data from the Logan area as indicating that there are no brine springs as such, but rather upflow through the alluvium ... probably in three locations (presumably miles 0.9, 3.5, 4.2). Construction at the railroad bridge may have disturbed channel sediments such that brine is forced to the surface in the area. At this time, our interpretations of the flow system differ somewhat from that given by HGC; see Chapter 3 of this notebook and Chapter 4 of the Surface Water Notebook.

The movement of salt down the Canadian River channel is a dynamic process, mostly occurring during high flows when channel sediments are flushed. At low flows that channel sediments store and retain the salt inflow because the rate of ground-water salt transport is extremely slow in comparison to transport by the river water. A water budget constructed for Lake Meredith shows that flow in the Canadian River is strongly affected by ground-water losses and bank storage.

A mixing cell model was constructed to predict the timing of salinity reduction on the salt load delivered to Lake Meredith. The model represented the river flow, alluvial ground water flow and the connection between the river and alluvial ground water along the channel from Ute Dam to Lake Meredith. The model simulated base flow conditions and accounted for the river discharge and salt load, tributary inflows and salt loads, alluvial ground water and brine concentrations, storage, flow rates and underflow. The transfer of water and salts from the alluvium to the river was simulated with an empirical transfer coefficient. The transfer coefficient was estimated through model calibration.

The model indicated that the salinity reduction resulting from 100% capture of the brine inflow would occur over a period of time. Salinity in the river above Lake Meredith was reduced by 24% over a ten year period. The maximum salinity reduction (70% of the existing salt load) occurred over a period of about 42 years. Simulations were also completed assuming a 50% brine capture. The results indicated a salinity reduction of about 12% over a ten year period. The model also was used to simulate the effect of pumping the alluvium. Pumping a rate equal to the brine inflow rate (0.9 cfs) produced a 16% reduction in the river salinity over a 10 year period.

The mixing cell model was considered to be conservative because it did not account for flushing of the alluvium during periods of high river flow. As discussed in the Surface Water Notebook, we do not regard the mixing model as being reliable.

HGC (1984b) summarizes the result of geophysical exploration for an injection site southeast of Logan. The first stage of the study consisted of examination and interpretation of electric logs from the National Oil

Company's Ute Anticline No. 1 test well (T12N, R32E, section 11). **TAB 10** shows these logs. They concluded from the study that sands in the Abo Formation and possibly in the underlying Sangre de Cristo Formation provide reasonable injection zones, with the best zones formed by sands in the middle of the Abo Formation. The total porosity of sands within the larger Abo-Sangre de Cristo section was measured at 10 to 17 percent, with shale contents ranging to 30 percent. Data from three additional wells were used to construct correlated sections in the area (**TAB 5**).

In the second stage of the study contractors completed and interpreted two deep seismic reflection profiles south of the river and east of Logan (**TAB 4**). Profile A was approximately 6 miles long and aligned east-west. Profile B was approximately 5 miles long and aligned north-south. Several large, possibly northwest-trending, faults with down-to-the southwest displacement were identified in the section. The Sangre de Cristo Formation north and east of the major faults was about 1500 feet thick. South and west of the fault it was about 4000 feet thick.

The most favorable location for exploration drilling was selected as an area in sections 29, 30 and 32, T13N, R34E (**TAB 4**). The most favorable target (middle Abo sands) are at a depth of 3800 to 4500 feet. They estimate that about 200 feet of sandstone will be required for injection of 450 gallons per minute. That section is available within the middle Abo but it may be necessary to complete the well over a larger section in order to obtain the largest possible capacity.

<u>USBR (1984)</u> summarizes and interprets information presented in HGC (1984a and 1984b) and presents additional data from agency field studies, related particularly to test drilling and collection of data from a piezometer network.

Drill hole DH-3 was drilled north of the Canadian River between Logan and Ute Dam. The well was intended to resolve the question over the stratigraphic position of the brine aquifer and was cored to total depth of 569.5 feet. A 147 foot section of grayish-white to bluish-gray sandstone was cored from about 350 feet to 497 feet and was correlated to the brine aquifer identified by earlier drilling. The top of the Permian section was found at 514 feet. The brine aquifer was separated from overlying sandstones by 54 feet of shale and mudstone and was underlain by about 21 feet of shale. **TAB 10** includes the lithologic and natural gamma ray logs for DH-3.

DH-3 was completed as an observation well. Screen was set in the brine aquifer from 361 to 418 feet. The initial water level measured at DH-3 was about 90 feet below the land surface (i.e. above the top of the aquifer, indicating artesian conditions). Subsequent pumping apparently developed the well and the water level dropped about 5 feet (**TAB 11**). Water from DH-3 was sampled, though not without problems (see discussion on page IV-56). The water is slightly less saline than, but otherwise chemically similar to, the brine sampled at wells on the canyon floor (**TAB 13**).

USBR's experience with DH-3 led them to conclude that the lithologic log from DH-2 was probably incorrect because of caving during drilling. DH-2 was also found to be plugged at 160 feet and to be hydraulically connected to the river, that is, water level changes corresponded to fluctuations in river flow. It was not possible to know for sure where a water sample from DH-2 came from, but it was considered to represent a mixture of Triassic water and Permian brine.

Brine from well OW-3 was analysed for tritium activity (**TAB 13**). No activity was found and USBR concluded that the brine aquifer at OW-3 does not contain modern water from Ute Lake. Samples for OW-3 and OW-4 confirmed water typical of a sodium-chloride brine (e.g. see Stiff diagrams in **TAB 14**).

The USBR report provides a brief interpretative summary of hydrogeologic conditions near Logan. A natural sodium chloride brine is formed in the salt-bearing Permian section. The brine moves upward (probably through fractures) to the overlying Triassic section at a rate of 0.6 cfs. The water is mixed with relatively fresh water in the Triassic section. Water from the Triassic section discharges (also probably through fractures) to alluvial deposits along the Canadian River at a rate of 0.9 cfs. The brine is further mixed with fresher water as it moves upward and downstream through the alluvium. It discharges to surface water at numerous points along the river, particularly within the first 10 miles downstream from Ute Dam.

Limited subsurface data did not allow conclusions about the flow system within the Permian, Triassic and alluvial sections. Comparison of records from Ute Reservoir and from a recorder at well TW-1 did not indicate that the brine aquifer was hydraulically connected to the lake; rather, small water level fluctuations reflected atmospheric pressure changes and earth tides.

USBR established 5 stations on the Canadian River and Revuelto Creek where the chemistry of the river water and alluvial ground water were monitored over a period of 17 months from May, 1983 to September, 1984. Ground water levels were measured in August of 1983. Each site included a nest of two or three piezometers completed at depths from 15 to 55 feet. The wells are all included in the inventory presented in **TAB 9**. Figures showing the locations and construction of the piezometers are included in **TAB 10**; these figures include water-level information. Water quality data, including a statistical analysis, are in **TAB 13**; Stiff diagrams and scattergrams of the data are in **TAB 14**.

Site 1 (at mile 1.6 below Ute Dam, i.e. upstream from the Highway 54 bridge near Logan) included two piezometers completed to 16 and 22 feet, each with 4 feet of screen at the bottom of the hole. USBR questioned whether the deeper piezometer reached the bottom of the alluvium. Ground water quality showed some variation during a spill of Ute Reservoir in June and July, 1983. Composition otherwise showed little variation. The shallow piezometer averaged 15,585 mg/l TDS while the deeper one averaged 13,670 mg/l; as with the other sites, the water was dominated by sodium and chloride, with relatively low sulfate concentrations. At the time the piezometers were completed, there was a strong upward gradient in the alluvium, with the head in the deep piezometer being slightly higher than the river elevation.

Site 2 (2.2 miles below Ute, at the Highway 54 bridge) included three piezometers completed to 22, 40 and 55 feet, each with 4 feet of screen at the bottom of the hole. The alluvium/bedrock contact was at 59 feet. Steel bits were left in two of the holes. As at Site 1, ground water quality varied with river flow. The piezometers show very little vertical variation in water quality, with total dissolved solids averaging slightly over 15,000 mg/l. At the time the piezometers were completed, there was essentially no vertical gradient in head, but water levels were slightly above the river elevation.

Site 3 (5.4 miles below Ute, upstream from the Revuelto Creek confluence) included two piezometers completed to 20 and 34 feet, each with 4 feet of screen at the bottom of the hole. Although the deeper piezometer was completed near bedrock, it was not located at the point of thickest alluvium. The water at the shallow level is only slightly more saline than water in the river at the site; the total dissolved solids averaged 13,229 mg/l. In contrast, water in the deep piezometer was much more saline, averaging 24,846 mg/l. In fact, the deep piezometer at Site 3 shows the most impact of brine of any of the alluvium data points.

Site 4 was on Revuelto Creek, about 0.2 miles above its confluence with the Canadian River. The site included two piezometers completed to 15 and 20.5 feet, each with 4 feet of screen at the bottom of the hole. The deeper piezometer penetrated bedrock. The ground water salinity was much lower than observed at other sites and showed greater variation over time. The shallow piezometer averaged 3688 mg/l TDS while the deeper one averaged 5168 mg/l; unlike other sites, the chloride:sulfate ratio was relatively low, in the range 2:1 to 3:1. All constituent concentrations were relatively high at the outset and fell over a period of three months. They remained low through most of program, but peaked again briefly in June, 1984. At the outset of the study concentrations generally were higher in the deep piezometer than in the shallow piezometer. The difference disappeared as concentrations fell and there is little difference between the piezometers over most of the sampling period. At the time the piezometers were completed, there was no significant head gradient.

Site 5 was not completed.

Site 6 (9.9 miles below Ute, on the Canadian below the Revuelto Creek confluence) includes three piezometers drilled to 21, 31 and 50 feet, each with 4 feet of screen at the bottom of the hole. The alluvium/bedrock contact was at 52 feet. Drill bits were left in the holes. Concentrations in the river are lower than at upstream sites because of dilution from Revuelto Creek. Concentrations in water from the shallow piezometer averaged 8,816 mg/l total dissolved solids, while the intermediate piezometer averaged 13,651 mg/l and the deep piezometer averaged 20,319 mg/l. No significant hydraulic gradient was observed at the site.

Salinity in the river increases from Sites 1 and 2 (which are essentially similar) to Site 3, then decreases to Site 6 because of dilution. Concentrations in shallow piezometers decrease steadily from Site 1 through Site 6. Concentrations in deep piezometers increase from Site 1 through Site 3 then decrease to Site 6. There is a good correlation between chlorides, TDS, and field-specific conductance for the piezometer and surface water data.

At p. IV-51, USBR summarized the data from the piezometer network thusly: "the data points and sampling frequency have not been great enough to answer the questions about the distribution and movement of brine in the alluvium." Among the specific possible problems mentioned in use of the data are: Problems may include: inadequate depth of piezometers; incomplete mixing of waters, freshwater springs, brine pools etc. USBR suggested installing continuously recording conductance meters in a shallow piezometer and adjacent stream reach (e.g. below Revuelto Creek) in order to observe fluctuations in water quality with flow.

USBR also presents information on water quality in the Triassic geologic units and the Permian Brines; for example, see stiffs diagram in TAB 14. Relatively high sulfate levels are reported for Triassic units near the mouth of Revuelto Creek; one speculation is that the brine source in this area is gypsum rather than halite. The brine aquifer samples were discussed at the beginning of the discussion of USBR (1984).

GW Model

To evaluate hydrologic and geologic systems in the Logan area, USBR developed a quasi-three dimension (two-layer) ground water model. The model also was used to test the feasibility of controlling brine seepage to the alluvium. Details of the USBR model in the report were limited, so notes on the model construction and results were obtained by Lee Wilson and Associates from USBR; the discussion below incorporates those notes, as well as the published text. Our critique of the model is provided in Chapter 3.

The model simulated flow in a 4.5 mile (north-south direction) by 5 mile (east-west direction) area near Logan. The area included the Canadian River from Ute Dam to about 9 miles downstream from the dam and the lower 5 miles of Revuelto Creek. The finite-element mesh contained 249 nodes and 314 elements in each layer and was designed to provide a relatively high degree of resolution along the Canadian River.

The system was simulated in two layers. The top layer represented the Logan sandstone. The lower layer represented the brine aquifer. The layers were connected vertically across a 50-foot confining bed. The top layer was considered to be unconfined, but spatial variations in the thickness of the layer were specified by the modeller, rather than computed by the model. The thickness varied from 150 feet to 600 feet. The lower layer was 100 feet thick and was everywhere confined.

The top layer was simulated with a hydraulic conductivity of 0.5 feet per day. Under transient conditions, the top layer was assigned a specific yield of 10% and a specific storage coefficient of $3.0X10^{-5}$ per foot. The brine aquifer was simulated with a hydraulic conductivity of 24 feet per day. Under transient conditions, the brine aquifer was assigned a specific storage coefficient of $1.4X10^{-6}$ per foot. The intervening confining bed was assigned a vertical hydraulic conductivity of 0.0011 feet per day.

The modeler specified constant head boundaries in both layers at nodes along the northern and southern borders of the area. All heads in the lower layer (brine aquifer) were equivalent fresh water heads; water density was not a model variable. The Canadian River throughout the model area was simulated as a leaky boundary. No special conditions were used to simulate Revuelto Creek.

In a steady-state simulation the head in the top model layer conformed to topographic changes. Water movement was toward the Canadian River. The potentiometric surface in roughly the western 2/3 of the model area sloped to the east with some tendency to converge toward the river, particularly just downstream of Ute Dam. In the eastern 1/3 of the model, the potentiometric surface sloped toward the river. Flow between the two layers was everywhere upward.

Constant head boundary flows to the brine aquifer supplied the vast majority of inflow to the model area. Discharge to the Canadian River provided most of the discharge. The mass balance for the steady state simulation is summarized below.

Net flow from constant heads to brine aquifer	7.74 cfs
Upward flow to Logan sandstone	7.74 cfs
Net flow from constant heads to Logan sandstone	0.17 cfs
Ground water discharge to the Canadian River	7.92 cfs

These values fail to sum to zero because of roundoff during conversion from cubic feet/day to cubic feet/second.

Of the total upflow from the brine aquifer to the Logan sandstone, only 0.89 cfs occurs directly beneath the river. The remaining 6.85 cfs of upward flow reaches the river by lateral flow through the Logan sandstone.

The model was run under transient conditions to simulate a salinity control program consisting of a single well at the site of TW-1 pumping 450 gpm for periods up to 10 years. USBR reported that drawdown at the pumping well stabilized within one month at 23 feet; the drawdown was negligible about 1 mile to the west of the well and 2 miles to the northeast.

The modeller's principal conclusion was that the results were highly sensitive to variations in the input and that without further studies to constrain the physical geometry of the system and the aquifer coefficients the system could not be reliably simulated. The transient results also imply that more than one well will be required to adequately control saline seepage to the river and that the pumping rates will probably need to be higher than simulated in order to account for the induced downward flow of fresh water.

USBR (1985) is the main project report, and with respect to hydrology it mostly summarizes information from the 1984 studies discussed above. The following are among the important conclusions or observations made in the report.

- "The hydrogeologic investigations ... determined that a sodium-chloride brine of natural origin produced by dissolution of Permian halite beds flows into the Canadian River near Logan, New Mexico. The brine flows upward from the Permian deposits into a geologic unit in the upper Permian or lower Triassic Formations then upward into the river alluvium. The exact route of movement is not known but is probably through a complex fracture system. The movement of this brine through the alluvial system is not very well understood. Brine appears to discharge into the river at several discrete points; but because of influences from freshwater springs and floodflows, these sites have not been adequately defined. It is possible that brine seepage may be relatively continuous downriver from Ute Dam." (Pages b-c.)

- "The ... analysis of the regional and site geology (New Mexico and Texas) relating to the sources of brine contamination in the Canadian River concludes that about 70 percent of the sodium chloride entering Lake Meredith comes from New Mexico and that most of this contamination enters the river channel near Logan, New Mexico. The report also states that an additional 10 to 15 percent of the total salt load enters the river channel between the Tascosa and Amarillo gauges. Reclamation investigations indicate that this brine appears to flow continuously to the river system. Floodflows do not appear to affect concentration levels within the alluvium." (Page c.)

- "Results of a ... model ... provide estimates of the effect after 10 years of 100-percent reduction in brine inflow near Logan. The reduction is calculated to be about 24 percent (in milligrams per liter) of total dissolved solids (TDS) in the river water reaching Lake Meredith. If the brine inflow was only reduced by 50 percent, the time for the system to respond was nearly the same; but the amount of salinity reduction was about half of that calculated for the 100-percent reduction in brine inflow. The response to the inflow salinity reduction in Lake Meredith would be direct but at a slightly reduced rate." (Pages d-e.)

- "Based on existing information on deep formations in the Logan, New Mexico, area, a suitable disposal zone probably exists for deep-well injection." (Page e.)

- "Additional fieldwork to include exploratory drilling and long-term pump testing is needed to verify the findings presented in this report and the effectiveness of the plan." (Page e, emphasis added. Elsewhere, the need for geophysical work also is noted.)

- The hydraulic conductivity of the alluvial aquifer is estimated at about 30 feet per day and the velocity of ground water is roughly 0.1 foot/day. (Page II-5.)

- The data to support either large storage of salt in the channel alluvium or the flushing of salts from the alluvium by high flows is not available (page IV-3).

- The most important result of the computer model of the brine aquifer is to demonstrate how little is really known about the hydrogeology of the area. (Page IV-9.)

- 35 locations of possible seepage have been identified by EPA based on remote sensing (page V-36; details are not provided).

The report includes a 17-step program to implement the salinity control project, to include geophysical studies, test drilling, installation of additional piezometers, aquifer testing and sampling, and modeling. Report materials dealing with project alternatives are outside the scope of this notebook.

2.4 Other reports

Spiegel (1957) reports a preliminary evaluation of the geology and hydrology of the Dunes damsite (roughly, section 2, T13N, R35E) on the Canadian River, about 84 linear miles upstream of the state line. The available copy contains two geologic maps covering exposures along the river from near Logan to the eastern extent of the dam site area, a descriptive table of local stratigraphic units and two cross sections. **TAB 3** includes the table of local stratigraphic units.

The report describes a large collapse feature, possibly centered in section 34, T14N, R35E, north of the river. The feature is not readily evident from the topographic map.

Geologic maps show that the Canadian River from Logan to the Dunes damsite flows alternately over the Trujillo and Tecovas Formations. The Tecovas Formation is exposed in the lower canyon walls from about 8.5 miles to 9.5 miles downstream from Ute Dam and again from about 24 to 28 miles downstream from Ute Dam. The second reach underlies the Dunes damsite.

SEO (1961) is a preliminary report on the geology of the Ute damsite. It provides an overview of area geology as well as detailed geologic maps and cross-sections of the damsite area, including the east end of the reservoir area and a small reach downstream from the damsite (**TAB 4** and **TAB 5**).

The principal regional structure is a southwest-plunging anticline with its axis passing just west of the Olean No. 1 Woods well (**TAB 4**). Strata west of the axis dip gently westward into an irregularly shaped structural depression locally interrupted by several east-trending anticlines. Strata south of the axis dip south-southeast into the Palo Duro basin. Structural relief on the top of the San Andres Formation in this fold is as much as 1,427 feet.

Alluvial deposits along the Canadian River consist of unconsolidated silts, sands and gravels and were found to be 50 to 60 feet thick along the stream bed from the dam site to the US 54 bridge south of Logan. Older alluvial deposits are preserved on terraces above the river; the oldest locally identified terrace is widely developed north of the river but absent south of the river.

Bedrock exposed at the Ute damsite consists entirely of the Chinle and Trujillo Formations. The Chinle consists of interbedded red shale and light tan to red sandstone. The Trujillo is predominantly light gray to tan sandstone. The sandstone is massive, thick bedded and generally well-cemented.

Detailed cross-sections show that bedding dips generally eastward at a low angle. Several randomly oriented elongated domes and troughs modify the regional dip near the south abutment of the existing dam. Relief on the local folds is at least 70 feet. A high angle fault with dip slip of at least 190 feet (down to the north) was tentatively identified in borings north of the river at the existing dam site. The fault trace is buried under terrace deposits. It trends east northeast-to east through the immediate area of the dam, but its extent in either direction is unknown.

3. SYNTHESIS OF INFORMATION AVAILABLE ON THE BRINE AQUIFER

In our judgment, the project reports (and other references) discussed in Section 2 provide a limited understanding of the geologic and hydrologic conditions which fundamentally explain the brine inflow to the Canadian River which occurs in the Logan area. Consequently, it is difficult to use the available information and design with confidence a system to intercept and dispose of the brine. In this report, we have made an effort to interpret the literature in order to improve the understanding of the brine flow system. We believe this understanding is sufficient to direct more detailed studies of the system, including analyses of existing data and development of new data through field investigations.

3.1 Hydrogeologic setting

The starting point for understanding the brine problem is the regional hydrogeology. We need to know just where the brine comes from, and what kinds of rocks and structures it flows to en route to the discharge area near Logan.

Background information. **TAB 3** provides stratigraphic sections and **TAB 4** provides numerous maps which illustrate the regional geology and geomorphology of the area extending from the Rocky Mountains and central highlands of New Mexico eastward across the Texas Panhandle. Geologically, much of what is important today dates from the Permian when sediments which include salt deposits accumulated in a series of deep basins, such as the Palo Duro Basin; from the Triassic, when sediments (mostly redbeds) were deposited atop the Permian beds; and from relatively recent times, when the Canadian River cut its channel into the Triassic and Permian rocks and deposited modern alluvium.

In the Logan area, the primary aquifers are the Triassic sandstones, but since these units don't themselves contain a brine source, the salt water of the area must originate in the Permian evaporites. Consequently, a successful salinity control project near Logan requires an understanding of how salt flows originate in the Permian rocks, and how they reach the Canadian River through the Triassic units.

Salt dissolution from the evaporites. Rocks of middle to late Permian age are found at relatively shallow depths throughout the area from Logan to Lake Meredith, and are exposed at the land surface in many locations. The rocks are mostly red beds interlayered with varying amounts of limestone, dolomite and gypsum. At depth below the surface and distant from their surface exposures these rocks also contain thick bedded salt deposits. The salt beds originally extended through most of eastern New Mexico and the Texas Panhandle. Surface and ground water have dissolved much of the salt and the beds are now found mostly in the central parts of the major Permian basins. See **TAB 5** for useful cross-sections, particularly Gustavson and Finley (1985, Figure 5).

Collins (1984) provides the most succinct description of the behavior of the evaporites with respect to ground water. Bassett and Bentley (1983) list the permeability of the undisturbed evaporite section at about $1x10^{-4}$ md (essentially impermeable). By comparison, the second most impermeable hydrostratigraphic unit in the region is 10,000 times more permeable than the evaporites. This low permeability restricts ground water movement, so that flow within the evaporite section occurs mostly through fractures in disturbed areas near faults and along the margins of the existing salt beds. Senger, et al. (1987) estimated the permeability in these marginal zones to be 100,000 times higher than in the undisturbed evaporite section. Along the evaporate margins, the ground water dissolves and removes the salts. Overlying and adjacent beds collapse into the resulting voids and the disturbed zone gradually advances into the salt beds.

According to Gustavson, et al. (1980a), dissolution within a single salt bed occurs at a relatively sharp and steeply sloping front. The sequence contains many individual salt beds, each with its own dissolution front. Dissolution has been active longer or at a higher rate in shallow salt beds and the dissolution fronts are more advanced than in lower beds. Salt dissolution in the Palo Duro Basin in Texas has been carefully studied. There the dissolution fronts in the youngest and oldest affected salt beds are separated in places by more than a hundred miles, but most of the dissolution fronts are found in relatively narrow bands along the Canadian River and the eastern escarpment of the High Plains (see maps in **TAB 4**, Part B.3).

The band of dissolution fronts along the Canadian River extends west to near Logan (see maps in **TAB 4**, Part B.3). Salt beds are present in the youngest part of the section (Salado and Seven Rivers of the Artesia Group) several miles south of the river and are absent north of the river. Salt beds occur in the middle of the evaporite section (San Andres Formation) under the river near Logan but are absent just north of the river and to the west. Salt in the Glorieta Formation appears to be only slightly more extensive than in the San Andres. Salt beds are still present in the oldest part of the evaporite section (the Yeso Formation) under the river and for several miles to the north and west.

As noted, removal of the salt beds causes collapse of the overlying units and subsidence at the surface. Collapse forms breccia blankets in the dissolved zone and fractures, faults and folds in the overlying rocks. Breccia pipes may form through overlying rocks where the collapse is sufficiently localized. Sink holes and closed drainage basins sometimes develop as surface expressions. The structures and sediment-filled sink holes and basins can be found wherever dissolution has occurred in the past, but the direct surface expressions remain only where dissolution is active or very recent.

Based on Gustavson, et al. (1980a) and Collins (1984), among others, the structural effects of collapse are found near Lake Meredith and upstream of the lake along the Canadian River in Potter County. Tertiary and younger sediments north of the river obscure structural evidence for collapse. There, an offset on the High Plains surface and variations in the thickness of the Ogallala Formation are evidence for several hundred feet of relatively local collapse during Ogallala deposition and regional subsidence of 250 feet since Ogallala deposition.

Collapse structures were identified along the Canadian River east of Logan, but the absence of surface expressions suggests that dissolution and collapse there may not be active. Collapse features also are found in the Tucumcari area (Trauger and Bushman, 1964) and there the dissolution and subsidence may still be active.

Based on our inspection of topographic maps, several large depressions occur south of the Canadian River along a east-northeast oriented line from Tucumcari to at least section 30, T13N, R35E (i.e. only a few miles southeast of Logan). These depressions have not been investigated in the field. One, in section 5, T12N, R34E, shows clearly on the New Mexico State Highway Department geologic map of the Logan Quadrangle. This depression is shown in **TAB 4**, Part A. The flat floor of the depression is more than 20 feet below surrounding areas, roughly elliptical and covered with young alluvium. The ellipse is about 2/3 of a mile across on its northeast trending major axis. Bedrock is exposed on the sides of the depression and the surrounding area is covered with pediment deposits. The depression contains seven small seasonal ponds, all located on the lower side slopes and margins of the depression floor. This depression and other similar depressions may be evidence for active dissolution and subsidence.

Reflecting regional hydrogeologic gradients, ground water probably flows into the Permian section near Logan from the east and north. It moves through areas where salt dissolution and the structural disturbance associated with collapse have created open vugs and fractures. Upward flow from the pre-evaporite section also is possible but seems less likely since bedded salts (virtually impermeable) are locally still present near the base of the evaporite section. Ground water approaching a dissolution front must flow either within the evaporite section parallel to a dissolution front or upward to the overlying Triassic section.

Without doubt, dissolution of the Permian evaporites can account for the salts which are added to the Canadian River near Logan. The total chloride load, which is roughly 0.7 kilograms/second (see Surface Water Notebook) corresponds to a halite dissolution rate of only 593,000 cubic feet per year. If dissolution occurs only in a 350-foot thick salt section within the Artesia Group and upper San Andres Formation and only along a 21-mile front from Tucumcari to Logan, then this amount of salt could be supplied for 100 years, and the evaporites would dissolve back only 1.5 feet.

The high plains surface north of the Canadian River from Ute Dam to Sanford Dam is about 80 meters lower than it is south of the breaks. Studies in Texas explain this as the result of salt dissolution north of the river, and the same explanation is plausible for New Mexico. Salt is still present along and north of the river in the lower San Andres and Glorieta Formations and in the Clear Fork Group. South of the river, salt is present in stratigraphic units as high as the middle of the Artesia Group (Seven Rivers Formation).

Currently, salt dissolution is most active along the eastern caprock escarpment and adjacent parts of the Rolling Plains. Dissolution also is occuring beneath the Canadian River, but at a lower rate.

Brine movement through the Triassic Section. The evaporite section is overlain by roughly 2,000 feet of Triassic age sedimentary rocks. In New Mexico the section is commonly divided into the Santa Rosa Sandstone and the Chinle Formation. See **TAB 3**.

The Santa Rosa Sandstone occupies the lower part of the Triassic section and is exposed along the Canadian River from Ute Dam to the State Line. It is generally covered north of the river by Tertiary and younger sediments. South of the river the Santa Rosa is exposed or near the surface in a band parallel to the river and along its tributaries. The outcrop band is about a mile across near Logan and expands to about 5 miles across near the State Line. South and east of the outcrop band the Santa Rosa is beneath the Chinle Formation and younger units. It is not exposed elsewhere in Quay County or adjacent areas in New Mexico. At Logan the Santa Rosa can be divided into two units and correlated to formations in Texas.

The lower Santa Rosa has been correlated to the Tecovas Formation in Texas, and we will use that term in this report, because the lower Santa Rosa appears to be the "brine aquifer". At DH-3, the Tecovas consists of about 220 feet of friable to well-cemented, light colored sandstones and interlayered clays. Based on geologic maps, the Tecovas at Logan is primarily sandstone but it becomes generally more fine grained to the east. In Texas the Tecovas is primarily shale. A prominent shale about 50 feet thick lies at the top of the Tecovas near Logan. The shale is reportedly absent to the east at the Dunes damsite and may be missing elsewhere. Exposures of the Tecovas Formation are limited to the immediate vicinity of the Canadian River. From Logan to near Rana Canyon the Tecovas is intermittently exposed along the lower canyon walls. Below Rana Canyon the exposure is more extensive.

The upper Santa Rosa has been correlated to the lowest sandstone unit of the Trujillo Formation in Texas. We will use the term Trujillo here, to distinguish this part of the Santa Rosa from the Tecovas brine aquifer. At DH-3, the Trujillo may be 300 feet thick and consists of well-cemented sandstone and conglomerate with some interlayered clay and coal horizons. The Trujillo Formation forms the prominent bluffs along the Canadian River canyon in New Mexico and underlies the river channel near Ute Dam and in some intervals from Ute Dam to near Rana Canyon.

The upper 1,500 feet (roughly) of the Triassic section contains the Chinle Formation. The Chinle consists of red to brown, sometimes variegated shale with interlayered siltstones. Sandstone similar to the Trujillo occurs in the middle of the section. The Chinle is not exposed along the Canadian River below Ute Dam.

In the published literature, the Santa Rosa Sandstone is generally regarded as an aquifer. It lies between the underlying brine source in the evaporite section and the overlying confining beds of the Chinle Formation. It is the only bedrock unit directly connected with the Canadian River in the Logan area. Because of this geometry, the Santa Rosa is the major ground water outflow area for brine in the Logan area.

The Texas Bureau of Economic Geology has prepared two cross-sections to illustrate the regional geology: see TAB 5. The cross-sections are consistent with our understanding of the geology in the area, although they are not detailed enough to show the brine aquifer and they do not reconstruct probable flow lines for the brine.

Our interpretation is that ground water would enter the Santa Rosa at depth by upward flow from older rocks; along dissolution fronts in the underlying evaporites that upflow would be highly saline. The Santa Rosa near its outcrop probably receives downward flow of relatively fresh water from the overlying Chinle. Where exposed, the Santa Rosa would be recharged by percolating precipitation and runoff.

Ground water within the Santa Rosa at depth probably is influenced by both the prevailing eastward gradient in the underlying units and the convergent flow towards the Canadian River in overlying units. Thus flow at depth would probably vary from eastward to northeastward south of the river and southeastward north of the river. Where the Santa Rosa is exposed along the Canadian River the flow must converge toward the river.

Flow through the alluvium. Recent and active channel deposits of interlayered, unconsolidated silt, sand and gravel occur along the Canadian River. The alluvium is mostly silt and fine sand at the surface, with gravels and coarse sand found at depth. The alluvium is up to about 60 feet thick near Logan and the thickness increases downstream to about 100 feet near the State Line.

White deposits - probably left after the evaporation of water from the capillary fringe - are common in alluvium along the river banks 2 to 4 feet above the river level. The deposits are extensive in some areas where the valley floor is broad and flat and elevated only two or three feet above the river.

The alluvium receives ground water inflow from the Santa Rosa Sandstone and in some areas along the north side of the river from Tertiary and younger units. The alluvium also receives some recharge from precipitation.

Ground water in the alluvium flows, on net, to the river. The average gain under baseflow conditions from below Ute Dam to the state line is approximately 4 cfs. In detail the flows are variable, both spatially and over time. The river gains from the alluvium when and where recharge and ground water flows to the alluvium exceed evapotranspiration from the alluvium. Otherwise the river loses to the alluvium.

3.2 A closer look at the brine aquifer

The USBR salinity control project for Lake Meredith relies on the capture of brine from the "brine aquifer". To evaluate the potential success of the project, it is important to state clearly what we do and don't know about the aquifer.

Stratigraphy and lithology. The nature of the brine aquifer is known from USBR drilling records. The brine aquifer identified at DH-1 and cored at DH-3 is positioned stratigraphically below the distinctive sandstone of the Trujillo Formation, above the salmon red shale in the Permian section and is lithologically similar to sandstones in the Tecovas Formation as described by Spiegel (1972a). The brine aquifer at DH-3 consisted of approximately 150 feet of sandstone with relatively minor interbedded claystone. The sandstone is overlain by 54 feet of shale and mudstone and underlain by 18 feet of shale. The overlying and underlying shales and mudstones probably should be included with the sandstone in the Tecovas Formation.

Brine composition Water in the brine aquifer is highly saline and dominated by chloride and sodium. The specific conductance of brine from OW-3 is usually within the range of 50,000 to 70,000 micromhos; at a conductance of 60,000 micromhos the brine would contain about 1.3 times the salinity of normal sea water (i.e. roughly 45,000 mg/l total dissolved solids). Sea water at this salinity would have a density of 1.035 grams/cm^3 and a relative viscosity (compared to pure water) of 1.094. Water from DH-3 is considerably less saline. Its specific conductance of 36,000 micromhos is about 78% of normal sea water.

Chloride in brine from OW-3 averages more than 25,000 mg/l. The chloride concentration at OW-4, 19,700 mg/l, is slightly lower. At DH-3 chloride averages about 15,600 mg/l. Sulfate is much less prevalent than chloride; 2,790 mg/l at OW-3, 2,660 mg/l at OW-4 and 2,175 mg/l at DH-3. Sulfate/chloride ratios vary somewhat with the salinity; 0.139 at DH-3 (lowest salinity), 0.135 at OW-4 and 0.112 at OW-3 (highest salinity).

Variation in the salinity and the sulfate/chloride ratio probably reflects varying degrees of mixing between a chloride-dominated brine originating from halite dissolution in the evaporite section and relatively fresh water from the Triassic section with a higher sulfate/chloride ratio.

The sulfate concentrations listed above are substantially below the 9,000 mg/l concentration used in USBR (1979) to calculate the sulfate load originating from the brine aquifer. Using a concentration of 2,500 mg/l sulfate and a brine flow of roughly 0.9 cfs (see surface water notebook), the sulfate load would be less than 2,300 tons per year - less than half the 5,400 tons per year load calculated by USBR. The relative importance of the brine aquifer to the sulfate load entering Lake Meredith is correspondingly smaller; less than 9% of the total inflow of 26,910 tons per year rather than the 20% reported by USBR (and note that this ignores losses of salts which occur between Logan and Lake Meredith).

Permeability. The transmissivity of the brine aquifer was tested by USBR at 2,500 square feet per day at TW-1 and the hydraulic conductivity was calculated at 36 feet per day. Brine aquifer permeability was estimated for the USBR flow model at 25 feet per day. These values are extremely high compared to Bassett and Bentley's estimated permeability of 0.27-2.7 feet per day for the Triassic aquifers in Texas. A permeability of 25 to 36 feet per day is possible but it is roughly an order of magnitude higher than might be reasonably expected from a consolidated or semi-consolidated fine-grained sand; rather, it is typical of a good alluvial aquifer.

Permeability of the Trujillo Formation was estimated for the USBR flow model at 0.5 feet per day and a value near that might be considered more likely for the brine aquifer. However, this permeability value could not be reconciled with the transmissivity estimated from the pump test. What does this mean? We judge that either the pump test is flawed or the brine aquifer has exceptional permeability.

Storage. The storage coefficient of the brine aquifer in the TW-1 test was 1.5×10^{-4}. The specific yield of the Trujillo Formation was estimated for the USBR flow model at 10%. Both values are within the reasonable range of expectations, though the specific yield value might be higher than anticipated.

Leakance. Leakance, which is vertical conductivity divided by thickness of a confining layer, is a parameter frequently used in models. It exercises a controlling influence on vertical flows and influences the drawdown in wells, and must be reasonably well known to model (for example) the impacts of a brine control project. The vertical conductivity of the clay above the brine aquifer was estimated by calibration of the USBR flow model at 0.0011 feet per day. Given this value and the 50-foot thickness of the confining bed, leakance across the bed would be 2.2×10^{-5} per day.

It is important to recognize that the stream survey conducted by CRMWA in 1992 was the first to provide both water quality and flow data. Based on these data, it should be relatively easy to perform calculations which balance observed changes in the stream system with probable inputs from various ground-water sources, thus providing for calculation of variations in brine inflow rates in different reaches of the river. In turn, inflow variations could be interpreted in terms of variations in leakance, and variations in leakance could be interpreted in terms of geologic controls of brine flow. In our judgment, quantification of these factors is essential to evaluation of brine sources in the Logan area, and to evaluation of control strategies.

Structure. Bedding dips generally westward from the crest of an anticline that crosses the river in or just east of section 6, T13N R34E (i.e. near the confluence with Revuelto Creek) where, according to Spiegel's maps (Spiegel, 1957), the Tecovas is exposed along the river. The dip is interrupted by several small flexures. Work at the Ute Dam site (SEO, 1961) provided information on structural relief in that area but elsewhere there is little information to indicate the size or relative importance of the many small flexures that have been mapped.

Spiegel mapped the top of the Tecovas at the river level about 18,000 feet northeast of DH-1 at an elevation of 3650 feet. DH-1 encountered shale above the brine aquifer at an elevation of about 3485 feet. The apparent dip of the Tecovas from its exposure along the river to DH-1 is southwest at 48.4 feet per mile (0.5 degrees). The alluvium would lie directly on the Tecovas from its exposure southwest to near the Revuelto Creek confluence. The Tecovas would be well below the alluvium upstream from Revuelto Creek. However, small flexures between the Tecovas exposure and DH-1 could allow for considerable variation in the dip such that, for example, the brine aquifer could be at the base of the alluvium at points upstream of Revuelto Creek.

Small flexures probably also influence the position of the brine aquifer between Ute Dam and DH-1. The top of the Tecovas Formation at DH-3 was found 296 feet below the land surface at an elevation of 3485 feet; there is no apparent dip between DH-1 and DH-3. It is possible that the two wells lie directly on strike but that seems unlikely because it would require that beds dip almost directly to the north or south. It seems more likely that a synclinal axis passes between DH-1 and DH-3. The latter possibility is consistent with the presence of anticlines west of DH-3 at Ute Dam.

Faults have not been observed in exposures along the Canadian River but SEO (1961) did map a fault north of the river near Ute Dam. That fault juxtaposes the Trujillo and the Chinle sections. The fault would also offset the brine aquifer and might act as a boundary to ground water flow. The lateral extent and orientation of the fault are not clear from Spiegel's work. If the fault is extensive it could effectively bound the northern extent of the brine aquifer.

3.3 Characterization of the brine flow system

USBR ground water model. To the extent that the literature may characterize brine flow, that characterization is inherent in the USBR model, which represents a conservative interpretation of the hard data available to the modeller. However, some known or reasonably approximated features - such as the dip of bedding and the existence of fresh water recharge - were not used in the model.

Moreover, the model as constructed simulates unrealistic flow conditions. For the model, virtually all ground water originates in the brine aquifer.

The model shows the brine moving to the river without any mixing with fresh water, even though actual hydrologic conditions make it clear that fresh water in the Trujillo sandstone is a major component of the real-world flow system.

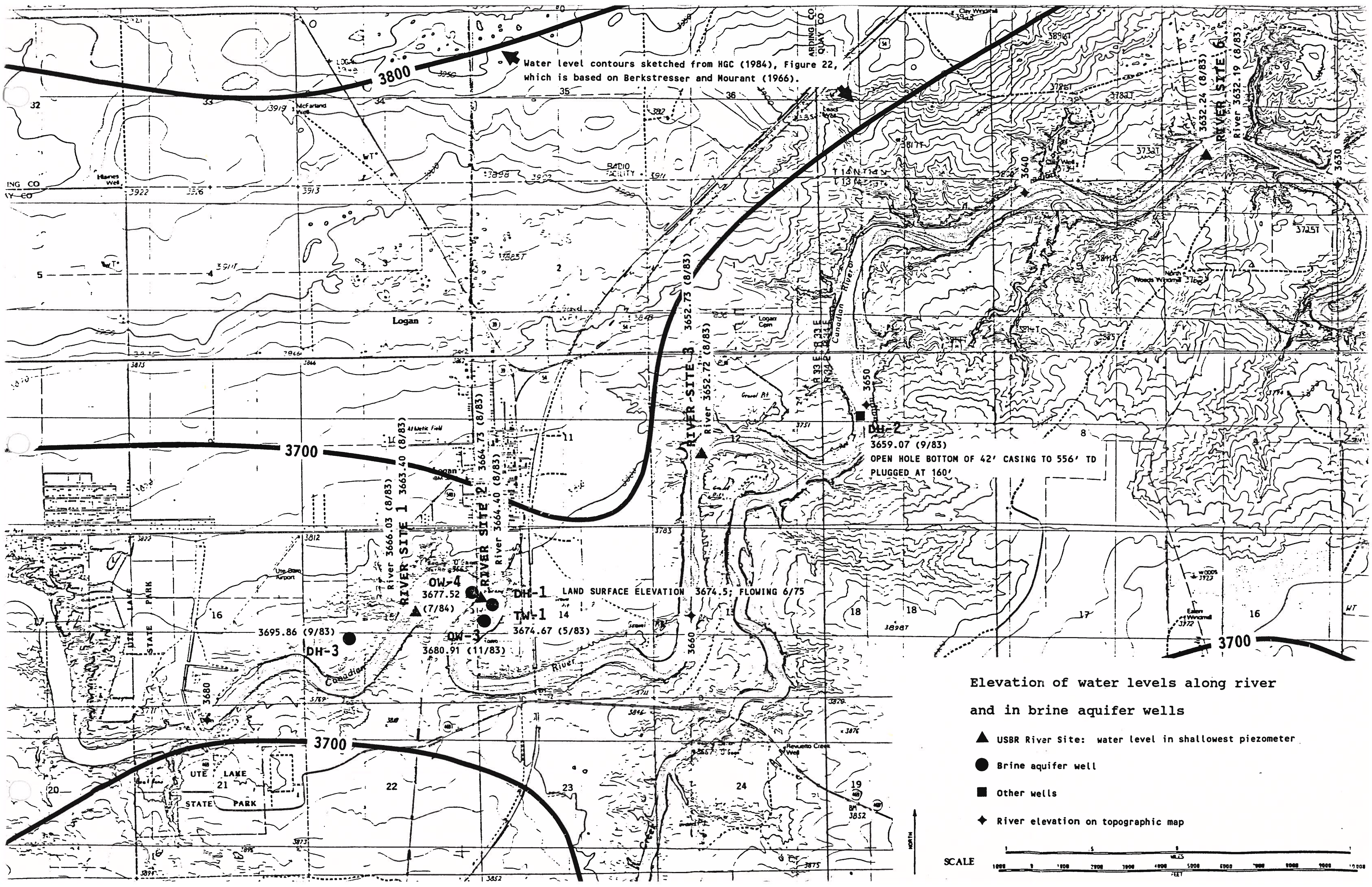
USBR concluded that the model results were undependable and that available information did not define even the fundamental geometry of the system. Additional information is needed before a model can be confidently constructed and applied. But the problems experienced by USBR could have been reduced by incorporating at least some of the omitted details and employing a more accurate construction.

Synthesis of available information. The literature provides little insight to the brine flow system in the Logan area, except that the brines clearly originate in Permian units older than the brine aquifer, pass through the aquifer in the Logan area, and pass through other geologic units (e.g. alluvium) before reaching the river. It also is evident that river inflows include fresh water which must be passing through rock units above the brine aquifer. This fresh water is probably of relatively local origin (recharge) as the Santa Rosa Sandstone (Trujillo and Tecovas) at depths to the west and southwest is reported to contain only highly saline water.

Additional studies have been proposed to CRMWA which should greatly improve the understanding of the flow system. These studies would quantify at least two important components of the system: the response of water levels in the brine aquifer to storage changes in Ute Reservoir **(TAB 11)** and the hydraulic properties (leakance) of the confining layer which in some locations separates the brine aquifer from the Canadian River. Until such studies are completed, we have used the cross-section at the end of **TAB 8** to summarize our understanding of conditions in the Logan area. Key points shown on the section include:

- geologic evidence (well logs, and mapping done by the New Mexico State Engineer) shows that the Tecovas brine aquifer is overlain by a confining layer in much of the Logan area, but that this layer is missing (and the brine aquifer is near the land surface) in the gravel pit reach;
- artesian pressures in the Tecovas force some brine upwards to mix with fresh water and discharge to the Canadian River in the east-west reach which is upstream of the gravel pit reach;
- however the primary flow in the brine aquifer is eastwards toward a discharge zone at or near the gravel pit reach;
- based on geophysical evidence, it is unlikely that much brine flow persists past the gravel pit reach.

The above summary will be greatly expanded in the next edition of the notebook, after the additional work recommended to CRMWA has been completed.



Elevation of water levels along river and in brine aquifer wells

▲ USBR River Site: water level in shallowest piezometer

● Brine aquifer well

■ Other wells

✦ River elevation on topographic map

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Index to **TAB 3**: Stratigraphic columns of the study area

Collins, 1990, Table 1

HGC, 1984a, Figure 4

McGookey, et al., Table 1

Spiegel, 1957, Table 1

USBR, 1979, Figure 1

Collins, 1990

Table 1. General stratigraphic column and lithologies of the Texas Panhandle Palo Duro Basin (from Dutton and others, 1988). Alibates, upper Clear Fork, Tubb, lower Clear Fork, and Red Cave have been informally designated as formations.

System	Series	Group	Formation	Lithology and depositional setting
Quaternary	Holocene			Playa deposits
	Pleistocene		Tule	Eolian and lacustrine clastics, fresh-water limestone
			Blackwater Draw	
Tertiary	Pliocene		Blanco	Fluvial, eolian, and lacustrine clastics
	Miocene		Ogallala	
Cretaceous	Comanchean	Washita	Duck Creek	Marine sandstone, limestone, and shale
		Fredericksburg	Kiamichi	
			Edwards	
			Walnut	
		Trinity	Paluxy	Transgressive sand and gravel
Jurassic*	Upper		Morrison	Marine sandstone and shale
Triassic	Upper (?)	Dockum	Trujillo: Chinle	Fluvial-deltaic and lacustrine clastics
			Trujillo: Santa Rosa	
			Tecovas	
Permian	Ochoan		Dewey Lake	Brine-pool salt, anhydrite, red beds, and peritidal carbonate
			Alibates	
		Artesia	Salado	
	Guadalupian		Tansill	
			Yates	
			Seven Rivers	
			Queen	
			Grayburg	
		Pease River	San Andres (Blaine)	
			Glorieta	
	Leonardian	Clear Fork	upper Clear Fork	
			Tubb	
			lower Clear Fork	
			Red Cave	
		Wichita-Albany		
	Wolfcampian		"Brown dolomite"	Shelf and shelf-margin carbonate, basinal shale, and deltaic sandstone
Pennsylvanian	Virgilian	Cisco		
	Missourian	Canyon		
	Desmoinesian	Strawn		
	Atokan	Bend		
	Morrowan			
Mississippian	Chesterian			Shelf carbonate and chert
	Meramecian			
	Osagean			
	Kinderhookian*			
Devonian*		Hunton		Shelf carbonate and clastics
Silurian*				
Ordovician	Cincinnatian*	Viola		
	Champlainian*	Simpson		
	Canadian	Ellenburger		
Cambrian				Shallow marine sandstone
Precambrian				Igneous and metamorphic

* Unit absent or insignificant in the Palo Duro Basin

QA11499c

HGC, 1984a

SYSTEM	SERIES	NE NEW MEXICO STUDY AREA: GROUP	NE NEW MEXICO STUDY AREA: FORMATION	PALO DURO BASIN: GROUP	PALO DURO BASIN: FORMATION	General Lithology & Depositional setting
QUATERNARY	HOLOCENE				alluvium, dune sand Playa	
	PLEISTOCENE				Tahoka cover sands Tule/"Playa" Blanco	Lacustrine clastics & windblown deposits
TERTIARY	NEOGENE		Ogallala		Ogallala	Fluvial & lacustrine clastics
CRETACEOUS					undiferentiated	Marine shales & limestones
TRIASSIC		DOCKUM		DOCKUM		Fluvial-deltaic & lacustrine clastics
PERMIAN	OCHOA		Alibates?		Dewey Lake (Quartermaster)	Sabkha salt, anhydrite, red beds, & peritidal dolomite
					Alibates	
	GUADALUPE	ARTESIA	Bernal *	ARTESIA	Salado/Tansill *	
					Yates	
					Seven Rivers *	
					Queen/Grayburg	
			San Andres *		San Andres *	
	LEONARD		Yeso *	CLEAR FORK	Glorieta *	
					Upper Clear Fork *	
					Tubb	
					Lower Clear Fork *	
					Red Cave	
				WICHITA		
	WOLFCAMP		Abo		?	Shelf & shelf-margin carbonate, basinal shale, & deltaic sandstone
PENNSYLVANIAN	VIRGIL	MAGDALENA	Sangre de Cristo "granite wash"	CISCO		
	MISSOURI			CANYON		
	DES MOINES		Madera	STRAWN		
	ATOKA			BEND		
	MORROW					
MISSISSIPPIAN	CHESTER					Shelf carbonate & chert
	MERAMEC					
	OSAGE					
ORDOVICIAN				ELLEN-BURGER		Shelf dolomite
CAMBRIAN						Shallow marine (?) sandstone
PRECAMBRIAN						Igneous & metamorphic

*SALT PRESENT

Figure 4. Stratigraphic column

HYDRO GEO CHEM, INC.

McGookey, et al., 1988

Table 1. Stratigraphic chart, Permian to Quaternary strata, Palo Duro Basin and surrounding area.

System	Series	Eastern New Mexico	Palo Duro Basin	Dalhart Basin	Anadarko Basin
Quaternary		Blackwater Draw Fm.	Blackwater Draw Fm.	Blackwater Draw Fm.	Blackwater Draw Fm.
Tertiary		Ogallala Fm.	Ogallala Fm.	Ogallala Fm.	Ogallala Fm.
Cretaceous		several formations, undifferentiated	several formations, undifferentiated	several formations, undifferentiated	
Jurassic		Exeter Ss.		Exeter Ss.	
Triassic		Dockum Gp.	Dockum Gp.	Dockum Gp.	
Permian	Ochoa	Dewey Lake Fm.	Dewey Lake Fm.	Dewey Lake Fm.	Quartermaster Fm.
Permian	Ochoa	Alibates Fm.[1]	Alibates Fm.[1]	Alibates Fm.[1]	Alibates Fm.[1]
Permian	Ochoa	Salado Fm.	Salado Fm.	Salado Fm.	Cloud Chief Fm.
Permian	Guadalupe	Artesia Gp.	Artesia Gp.: Tansill Fm.[1]	Artesia Gp.	Cloud Chief Fm.
Permian	Guadalupe	Artesia Gp.	Artesia Gp.: Yates Fm.[1]	Artesia Gp.	Cloud Chief Fm.
Permian	Guadalupe	Artesia Gp.	Artesia Gp.: Seven Rivers Fm.[1]	Artesia Gp.	Whitehorse Gp.
Permian	Guadalupe	Artesia Gp.	Artesia Gp.: Queen and Grayburg Fms.[1]	Artesia Gp.	Whitehorse Gp.
Permian	Guadalupe	San Andres Fm.	San Andres Fm.	Blaine Fm.	Blaine Fm.; Dog Creek Fm.[1]
Permian	Guadalupe	San Andres Fm.	San Andres Fm.	Blaine Fm.	Flowerpot Fm.[1]
Permian	Leonard	Glorieta Sandstone	Glorieta Fm.[1]	Glorieta Sandstone	Glorieta Fm.[1]
Permian	Leonard	Yeso Fm. / Sangre de Cristo Fm.	Clear Fork Gp.: upper Clear Fork Gp. undifferentiated	Clear Fork Gp.	Clear Fork Gp.
Permian	Leonard	Yeso Fm. / Sangre de Cristo Fm.	Clear Fork Gp.: Tubb Fm.[2]	Clear Fork Gp.	Clear Fork Gp.
Permian	Leonard	Abo Fm. / Sangre de Cristo Fm.	Clear Fork Gp.: lower Clear Fork Gp. undifferentiated	Clear Fork Gp.	Clear Fork Gp.
Permian	Leonard	Abo Fm. / Sangre de Cristo Fm.	Wichita Gp.	Wichita Gp.	Wellington Fm.

[1]Formation's lithology is not the same as the formally designated stratotype.
[2]The Tubb Sandstone member is informally designated Tubb Formation.

(2) on salt flats that were isolated from open-marine water, and (3) on mud flats where salt crystals grew by displacing the mud matrix. Bein and Land's (1982) petrographic and geochemical study of the San Andres Formation in cores, on the other hand, indicates that evaporite rocks were deposited in a shelf basin or lagoon in which brine composition changed as $CaCO_3$, $CaSO_4$, and NaCl were successively precipitated. Carbonate strata in the upper San Andres and Alibates Formations consist predominantly of dolomite.

Salt beds in the Palo Duro Basin range from a few feet to 200 ft (61 m) thick. Before dissolution of upper salt units in the northern Texas Panhandle and around the northern, eastern, and western margins of the Palo Duro Basin, the most widespread salt beds may have extended over the entire Palo Duro, Dalhart, and Anadarko Basins. Lower San Andres evaporite beds

Spiegel, 1957

TABLE 1. SUMMARY OF GEOLOGIC UNITS ALONG THE CANADIAN RIVER, QUAY COUNTY, NEW MEXICO.

UNIT	DESCRIPTION	THICKNESS (feet)
Chinle formation:	Maroon, purple, and green shale with beds of red sandstone irregularly distributed vertically and horizontally (but generally with important sandstone beds at the base and middle). Present on uplands north and south of the river, in local collapse depressions, and in the river canyon west of Sec. 18, T. 13 N., R. 33 E.	about 1000.
Trujillo sandstone: (similar to the Santa Rosa sandstone in Guadalupe County)	Massive light tan sandstone and conglomerate with occasional maroon or green shale or friable white sandstone lenses; massive lens of friable sandstone that weathers red is commonly present at the base. Forms the canyon wall of the Canadian River from near the state line to about 3 miles west of Logan, where it dips under the river.	75 at the State to 250 near Logan.
Tecovas formation: shale member	Maroon shale.	Reported about 250 in Potter County. About 50 at the state line.
sandstone member	Very friable, coarse- and uniform-grained sandstone, somewhat conglomeratic at base; unconformable on Quartermaster formation.	
Quartermaster formation: upper member	Generally absent on the Bravo dome; no evidence elsewhere in this area.	Reported 0-25 in Potter County, Texas.
Alibates dolomite	Magnesium and calcium carbonate, slightly fractured and permeable.	
"Terra cotta" member	Orange-red (terra cotta) colored siltstone, fine-grained sandstone and shale, with scattered gypsum lenses in upper part, prominent gypsum bed in the lower third.	Reported about 250 in Potter County; not measured in Oldham County, but observed to be similar to the reported section in Potter County.
Bluff gypsum	Thick beds of white gypsum. Numerous collapse structures apparent throughout the Canadian River area have probably been caused by solution of this and other gypsum beds.	Unknown; not known to be exposed in Oldham County, but probably present there and in Quay County.

USBR, 1979

GENERALIZED GEOLOGIC COLUMN
QUAY COUNTY, NEW MEXICO
LAKE MEREDITH SALINITY STUDY, TEXAS-NEW MEXICO

ERA PERIOD GROUP	FORMATION THICKNESS (FT)	CHARACTER
CENOZOIC QUATERNARY	ALLUVIUM 0-50	Sand, silt, and gravel in present Canadian River channel.
	ALLUVIUM 0-100	Silty sand, gravel, and clay of high terrace deposits with some aeolian sand and silt.
CENOZOIC TERTIARY	OGALLALA 0-200	Sand, gravel, and caliche, with some silt and clay.
MESOZOIC TRIASSIC DOCKUM	CHINLE 0-865	Shale, siltstone, and silty sandstone with local thin beds of conglomerate and limestone. Three well-defined members may occur; upper and lower members of predominantly shale and siltstone, and a middle member similar to the Santa Rosa sandstone. Greenish-gray to bluish-gray but weathering to brown, red, or purplish red. In Texas, known as Trujillo formation.
MESOZOIC TRIASSIC DOCKUM	SANTA ROSA 200-450	Silty to clean, fine to coarse-grained, massive to crossbedded gray to bluish-gray sandstone, locally conglomeritic, with thin to thick beds of red and bluish-gray shale and siltstone. Thin beds of carbonaceous shale or soft coal in upper member. In Texas, upper members known as Trujillo formation and lower fine-grained sandstone known as Tecovas formation.
PALEOZOIC PERMIAN ARTESIA	BERNAL 200-500	Salmon, pink to orange-red to gray shale, siltstone, sandstone, limestone, dolomite, halite, and gypsum.
PALEOZOIC PERMIAN	SAN ANDRES 500±	Gray limestone, dolomite, halite, gypsum, and anhydrite.
PALEOZOIC PERMIAN	GLORIETA 0-80	Fine to medium grained well sorted, gray, tan, or white sandstone, usually cross-bedded with minor shale and siltstone.

Figure 1

Index to **TAB 4**: Geologic and geomorphic maps which include the study area

A. Surface geologic maps

BEG, 1983 (portion)

BEG, 1981 (portion)

Berkstresser and Mourant, 1966, Plate 2 (portion)

NMSHD, undated, Logan Quadrangle - 48 (portion)

SEO, 1961, Figure 3

B. Subsurface geologic maps

1. Structure

Collins, 1990, Figure 2

Collins, 1990 Figure A4-1

Collins, 1990, Figure A4-2

Collins, 1990, Figure A4-3

Collins and Luneau, 1986, Figure 4

Dutton and Orr, 1986, Figure 1

Foster, et al., 1972, Figure 10

Gustavson, et al., 1980a, Figure 7

HGC, 1984a, Figure 3

HGC, 1984a, Figure 7

HGC, 1984a, Figure 10

HGC, 1984a, Figure 16

HGC, 1984b, Figure 13

HGC, 1984b, Figure 14

HGC, 1984c, two unnumbered figures

SEO, 1961, Figure 4a and 4b, two each

Trauger and Bushman, 1964, Plate 2 (portion)

2. Isopach

Bassett and Bentley, 1983, Figure 3

Foster, et al., 1972, Figure 2

Foster, et al., 1972, Figure 3

Foster, et al., 1972, Figure 4

Foster, et al., 1972, Figure 5

Foster, et al., 1972, Figure 6

Foster, et al., 1972, Figure 7

HGC, 1984a, Figure 6

HGC, 1984a, Figure 8

HGC, 1984a, Figure 9

3. Salt dissolution

Gustavson and Finley, 1985, Figure 19

Gustavson, et al., 1980a, Figure 29

Gustavson, et al., 1980b, Figure 42

HGC, 1984c, unnumbered figure

4. Lithology

Bassett and Bentley, 1983, Figure 4

Dutton and Simpkins, 1989, Figure 1

C. Geomorphic maps

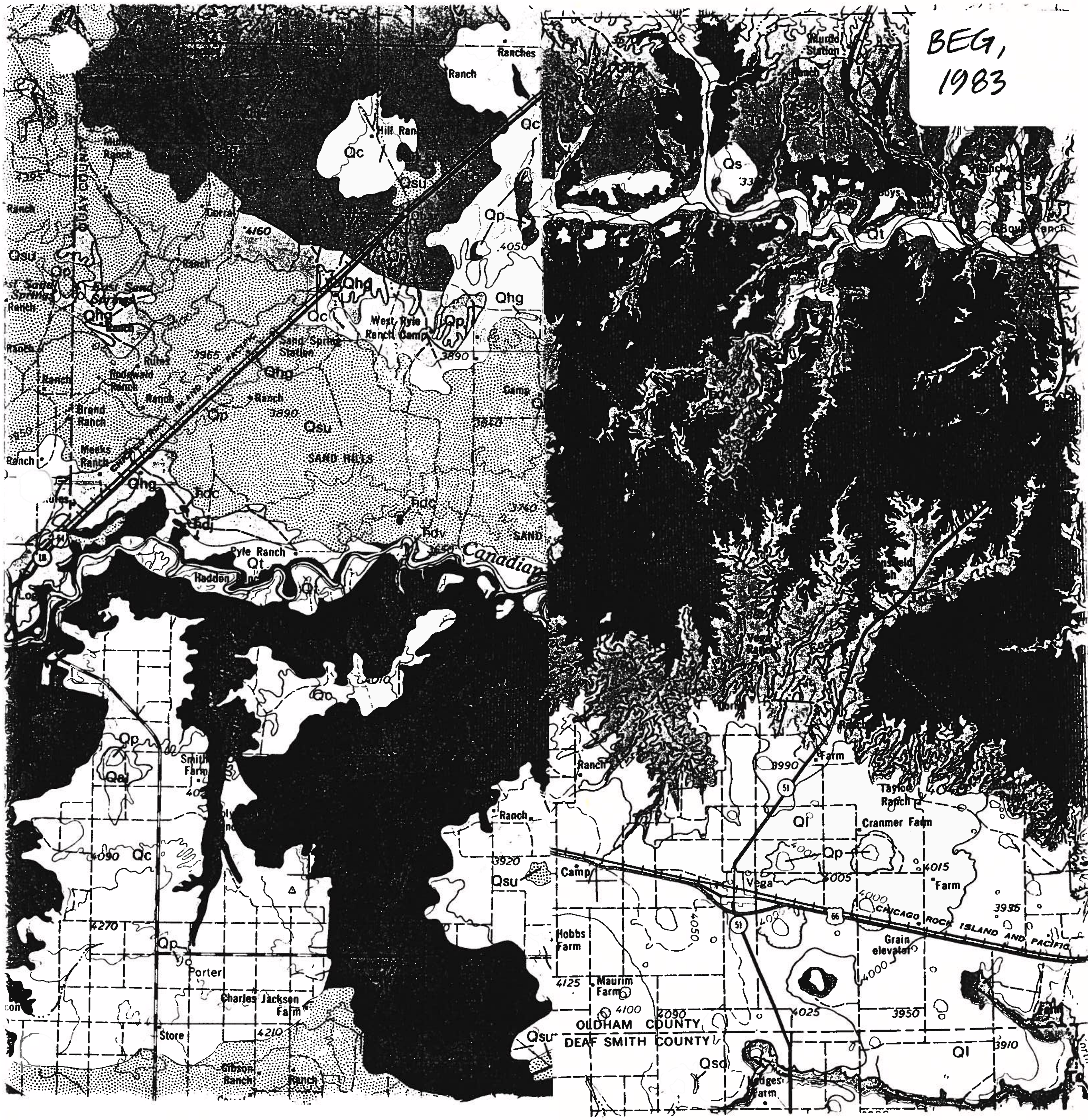
Gustavson and Finley, 1985, Figure 2

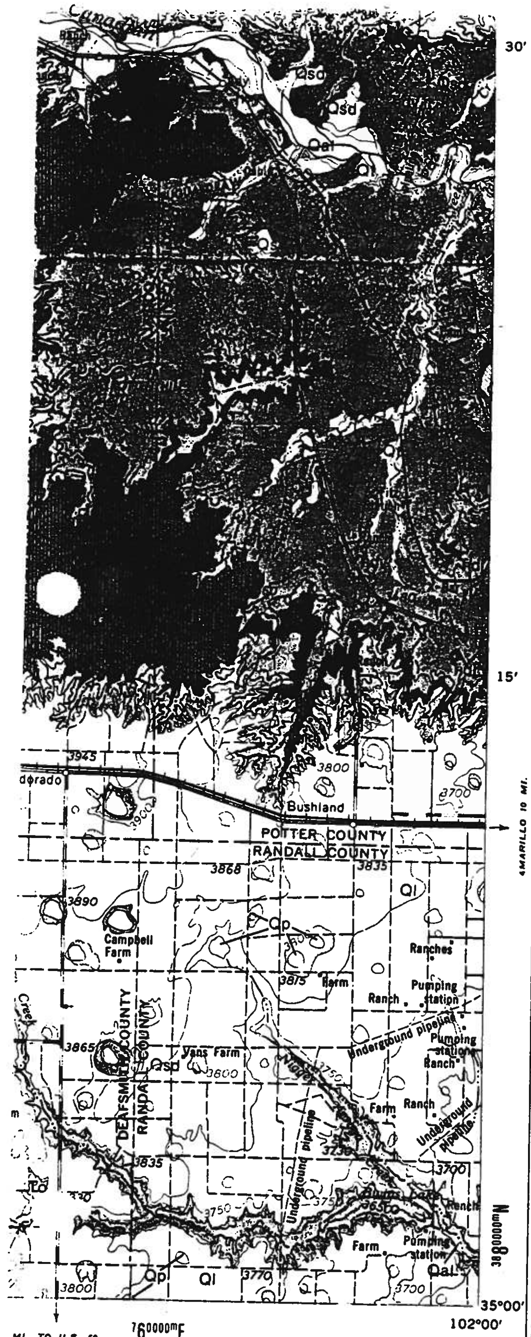
Gustavson, et al., 1980a, Figure 1

Gustavson, et al., 1980a, Figure 9

TAB 4 Part A. Surface geologic maps

BEG, 1983


Ranches
Ranch
Hill Ranch
Qc
Qsu
Qp
Corral
4160
4050
Qhg
West Pyle Ranch Camp
Sand Springs Station
3890
3965
Camp
Rodewald Ranch
Brand Ranch
Meeks Ranch
SAND HILLS
Pyle Ranch
Qt
Haddon Ranch
Canadian
Smith Farm
4090
3920
Camp
4270
Porter
Charles Jackson Farm
Store
4210
Gibson Ranch
Murdo Station
Qs
Farm
3990
Taylor Ranch
Ql
Cranmer Farm
4015
Vega
4005
Hobbs Farm
Grain elevator
CHICAGO ROCK ISLAND AND PACIFIC
4125
Maurim Farm
4100
4090
4025
3950
OLDHAM COUNTY
DEAF SMITH COUNTY
3910
Hodges Farm



Pleistocene and Pliocene — QUATERNARY AND TERTIARY

QTg

Older gravel deposits

Pebbles and cobbles of siliceous sedimentary rocks, intrusive igneous rocks, and metamorphic rocks and sand; caliche zones locally; thickness 50 feet or more. Caps isolated high ridges west of lower Ute Creek (T14-15N, R31E)

Pliocene — TERTIARY

To

Ogallala Formation

Sand, silt, clay, gravel, and caliche. Sand, fine- to coarse-grained quartz, silty in part, caliche nodules locally, cemented locally by calcite and by silica, locally crossbedded, various shades of gray, brown, and red. Minor silt and clay with caliche nodules, sandy in places, massive, white, gray, olive-green, brown, red, and maroon. Gravel, not everywhere present, composed of pebbles and cobbles of quartz, quartzite, minor chert, igneous rock, metamorphic rock, and clay balls in lower part. Caliche, not everywhere present, sandy, pisolitic, white, gray, pink, may include some caliche of Pleistocene age; thickness up to about 400 feet

Tb

Raton Basalt

Southward continuation of basalt mapped as "undifferentiated Clayton Basalt" in southwestern Union County. Medium-grained olivine basalt, contains yellow-brown olivine phenocrysts 2 to 3 mm in diameter, stubby columnar jointing prominent

Lower Cretaceous — CRETACEOUS

Kdp

Dakota Sandstone and Purgatoire Formation

Dakota Sandstone (not separately mapped), gray, conglomeratic, some yellowish-brown shale

Purgatoire Formation (not separately mapped), consists, from top down, of Pajarito Shale, gray to green, locally sandstone at top, thickness 50 to 60 feet; Mesa Rica Sandstone, fine- to coarse-grained, becomes finer grained upward, crossbedded, white to gray, locally reddish, thickness 50 to 100 feet; and Tucumcari Shale, from top down, shale, limestone, sandstone, and conglomerate; shale, black, contains both Kiamichi and Duck Creek faunas; limestone, argillaceous; basal sand and conglomerate unconformably rest on Morrison Formation, thickness up to 20 feet; thickness of Tucumcari Shale up to 60 feet

Upper Jurassic — JURASSIC

Jm

Morrison Formation and Exeter Sandstone

Morrison Formation, Jm, Exeter Sandstone, Je, and Morrison Formation and Exeter Sandstone undivided, J

Morrison Formation, Jm, clay, shale, and sandstone, red to bluish, variegated; mainly shale; sandstone, light-brownish-yellow; thickness 250 feet

Exeter Formation, Je, fine-grained, light-brownish-yellow to white to pale-reddish-brown; thickness 140 feet. Equivalent to Entrada Formation on New Mexico State Geologic Map

Upper Triassic — Dockum Group — TRIASSIC

Chinle Formation

Shale, siltstone, sandstone, thin limestone lentils, and mudstone; mostly dusky-red with thin greenish shales; thickness up to 1,200 feet

Trujillo Formation

Conglomerate, sandstone, and shale. Conglomerate, sandy, composed of granules and pebbles of quartz, limestone, sandstone, siltstone, minor chert, and fragments of petrified wood, massive, gray, brown. Sandstone, conglomeratic, fine to coarse grains of quartz and limestone, micaceous, calcareous locally, crossbedded to massive, gray, greenish-gray, brown. Shale, micaceous, occurs as thin interbeds, gray and red. Forms scarp. Thickness 75 feet, truncated locally

Tecovas Formation

Shale, clay, siltstone, and sand. Shale, clay, and siltstone, sandy in places, micaceous, calcareous locally, reddish-brown, various shades of red, maroon, gray, greenish-gray, yellow, and purple. Sand, fine- to medium-grained quartz; locally large petrified logs, unconsolidated, massive, lenticular, white, light-gray. Thickness 125 feet

PERMIAN

Pqa

Pqw

Quartermaster Formation
Cloud Chief Gypsum and Whitehorse Sandstone

Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone undivided, Pqw, sandstone, sand, siltstone, shale, gypsum, and dolomite interbedded. Sandstone and sand, fine-grained quartz, scattered to locally abundant frosted and polished coarse quartz grains, silty, massive, friable to indurated, various shades of red and orange, orange-brown, and grayish-green. Shale and siltstone, sandy in part, indistinctly bedded to massive, indurated, thin interbeds and veins of satin spar in upper part, various shades of red and orange, reddish-brown, and grayish-green. Gypsum, white, gray, and pink. Alibates Dolomite, Pqa, separately mapped, comprises an upper and lower dolomite separated by shale, upper dolomite locally absent, dolomite locally replaced by chert, which is banded and mottled red, pink, pale blue, pale purple, gray, brown, and black, forms ledges, average thickness 15 feet

U
D

Fault

U, upthrown; D, downthrown side

)F GEOLOGIC MAPPING

ea refers to item in bibliography in "Index to as, 1891-1961," by Brown, T. E. (1963) Bureau ersity of Texas, Austin. For New Mexico, area nd Summerson, C. H. (1946) Geology of New Mexico, U.S. Geol. Survey, Oil and Gas heet 1; for area **B**, see Baldwin, B., and eologic studies of Union County, New Mexico, l Mineral Res., Bull. 63, Plate 1d.

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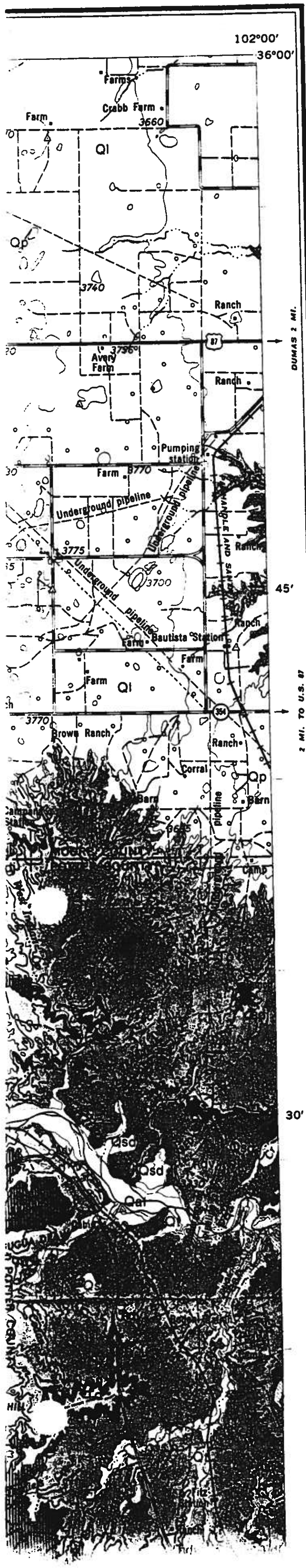
GEOLOGIC ATLAS OF TEXAS
TUCUMCARI SHEET



EXPLANATION

QUATERNARY

Holocene

Qal

Alluvium

Floodplain deposits, includes lowest terraces along Canadian River

Qsu | Qsd | Qs

Windblown deposits

In Texas, sand and silt, in sheets, Qs, *locally modified by surface wash, and dunes and dune ridges,* Qsd, *locally; in New Mexico, sand sheets, dunes, and dune ridges undivided,* Qsu

Holocene and Pleistocene

Qpd | Qc

Pediment and other covering deposits

Pediment deposits, Qpd, *silt, sand, and coarser debris derived chiefly from Triassic rocks and from minimal amounts of overlying rocks; rests on Triassic rocks; occurs in southwestern part of sheet. Other covering deposits,* Qc, *include colluvium, alluvial fans, and slopewash deposits in lowlands and along valley walls; in uplands mostly windblown sand*

Qls

Landslide deposits

Pleistocene

Qt

Fluviatile terrace deposits

Gravel, sand, and silt. Gravel, sandy, composed of pebbles of quartz, quartzite, chert, igneous rock, metamorphic rock, and caliche. Sand, fine- to coarse-grained quartz, crossbedded to massive, lenticular, reddish-brown, pink, gray. Silt, sandy, lenticular. Contiguous terraces of different ages separated by solid line

Ql

Loess

Windblown silt

Qcs

Blackwater Draw Formation
(Previously mapped as Windblown cover sand)

Sand, fine- to medium-grained quartz, silty, calcareous, locally clayey, caliche nodules, massive, grayish-red; distinct surface soil profile and buried paleosols; thickness up to 90 feet in northwestern Randall County, feathers out locally (mostly Illinoian)

Qp

Playa deposits

Clay and silt, sandy, light-gray, in shallow depressions (Wisconsinan), mostly covered by thin deposit of Holocene sediment
Note: water in depressions not shown

Qhg

High terrace gravel

Reworked from Ogallala and older gravel deposits, with considerable addition of primary material in deposits nearest Ute Creek and Canadian River; with volcanic ash lens northwest of Logan, New Mexico

Qrb

Rita Blanca deposits

Upper part, sand, bentonitic clay, and thin-bedded calcareous sandstone; thickness 50 feet or more; lower part, dark distinctly laminated clay, some interbeds of sand and thin uniform layers of non-marine dolomite; fossils are plants and small fish; thickness 30 feet or more

QUATERNARY AND TERTIARY

Pleistocene and Pliocene

QTg

Older gravel deposits

Pebbles and cobbles of siliceous sedimentary rocks, intrusive igneous rocks, and metamorphic rocks and sand; caliche zones locally; thickness 50 feet or more. Caps isolated high ridges west of lower Ute Creek (T14-15N, R31E)

TERTIARY

Pliocene

Ogallala Formation

Sand, silt, clay, gravel, and caliche. Sand, fine- to coarse-grained quartz, silty in part, caliche nodules locally, cemented locally by calcite and by silica, locally crossbedded, various shades of gray, brown, and red. Minor silt and clay with caliche nodules, sandy in places, massive, white, gray, olive-green, brown, red, and maroon. Gravel, not everywhere present, composed of pebbles and cobbles of quartz, quartzite, minor chert, igneous rock, metamorphic rock, and clay balls in lower part. Caliche, not everywhere present, sandy, pisolitic, white, gray, pink, may include some caliche of Pleistocene age; thickness up to about 400 feet

Tb

Raton Basalt

Southward continuation of basalt mapped as "undifferentiated Clayton Basalt" in southwestern Union County. Medium-grained olivine basalt, contains yellow-brown olivine phenocrysts 2 to 3 mm in diameter, stubby columnar jointing prominent

Kdp

Dakota Sandstone and Purgatoire Formation

...dstone (not ... mapped), gray, ...

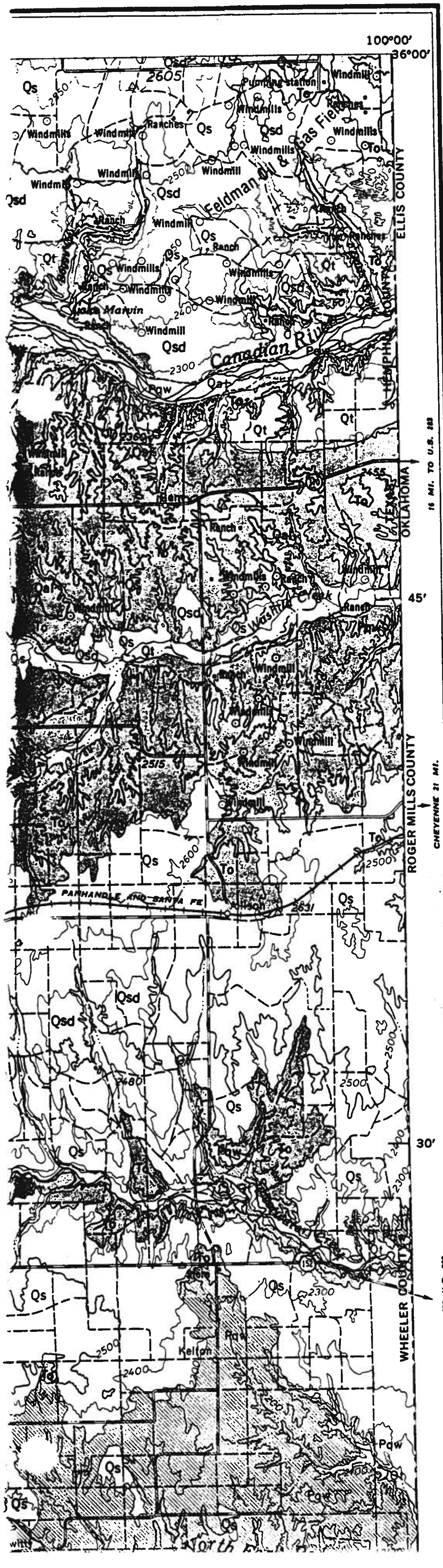
...ous ...us

BEG, 1981

45'
30'
15'
19 MI. TO TEXAS 51
Lake Meredith
MOORE COUNTY
HUTCHINSON COUNTY
POTTER COUNTY
CARSON COUNTY
Panhandle Gas Field
Alibates Flint Quarry
ANTELOPE PEAK
Pueblo Culture Sites
Alibates Ranch
CACTUS FLATS
Helium plant
Masterson
Rockwell Lake
Ice House Lake
Pantex Lake
PANTEX ORDNANCE PLANT
Ordnance plant
Pantex
McGee Lake
St Francis
Amarillo Air Terminal
AMARILLO
Pleasant Valley
Cliffside
Pomeroy Station
Radio tower
Underground pipeline
Booster station
Pumping station
Comp station
Windmill
Ranch

BEG, 1981

GEOLOGIC ATLAS OF TEXAS
AMARILLO SHEET



EXPLANATION

Sedimentary rocks

QUATERNARY

Holocene

Qal

Alluvium

Flood-plain deposits; includes lowest terrace along Canadian River

Qs | Qsd

Windblown sand

Sand and silt, in sheets, Qs, locally modified by surface wash; dunes and dune ridges, Qsd, locally

Pleistocene

Qt

Fluviatile terrace deposits

Gravel, sand, and silt. Gravel, sandy, composed of pebbles and cobbles of quartz, quartzite, chert, igneous rock, metamorphic rock, caliche, and rare abraded Gryphaea. *Sand, fine to coarse-grained quartz, cross-bedded to massive, lenticular, reddish brown, pink, gray. Silt, sandy, lenticular. Contiguous terraces of different ages separated by solid line*

Qp

Playa deposits

Clay and silt, sandy, gray in shallow depressions, usually covered by thin deposit of Recent sediment; weathers light gray. (Wisconsinan) Note: Water in depressions not shown

Ql

Loess

Windblown silt

Qcs

Blackwater Draw Formation

Sand, fine to medium-grained quartz, silty, calcareous, caliche nodules, massive, pink to grayish red, reddish brown, olive gray; distinct soil profile locally; thickness 25 feet, feathers out locally. (Mostly Illinoian, may include younger deposits)

TERTIARY

Pliocene

To

Ogallala Formation

Sand, silt, clay, gravel, and caliche. Sand, fine to coarse-grained quartz, silty in part, caliche nodules locally, cemented locally by calcite and by silica, locally cross-bedded, various shades of gray, brown, and red. Minor silt and clay with caliche nodules, sandy in places, massive, white, gray, olive-green, brown, red, and maroon. Gravel, not everywhere present, composed of pebbles and cobbles of quartz, quartzite, minor chert, igneous rock, metamorphic rock, limestone, clay balls in lower part, and abraded Gryphaea *in intraformational channel deposits and in basal conglomerate. Caliche, not everywhere present, sandy, pisolitic, white, gray, pink, comprises four or five beds up to 12 feet thick in upper part, forms ledges and caprock. Maximum thickness 550 feet, thins westward. (Locally includes Ogallala sand which has moved downslope covering older formations)*

TRIASSIC

Ћd | Ћdj | Ћdv

Dockum Group undivided and
Trujillo and Tecovas Formations

Dockum Group undivided, Ћd, *in Palo Duro Canyon. Thickness 250 feet. (Elsewhere Dockum is divided into Trujillo and Tecovas Formations.)*

Trujillo Formation, Ћdj, *conglomerate, sandstone, and shale. Conglomerate, sandy, composed of granules and pebbles of quartz, limestone, sandstone, siltstone, minor chert, and fragments of petrified wood, massive, gray, brown. Sandstone, conglomeratic, fine to coarse grains of quartz and limestone, micaceous, calcareous locally, cross-bedded to massive, gray, greenish gray, and brown. Shale, micaceous, occurs as thin interbeds, gray and red. Forms scarp. Thickness 30 feet, truncated locally*

Tecovas Formation, Ћdv, *shale, clay, siltstone, and sand. Shale, clay, and siltstone, sandy in places, micaceous, calcareous locally, reddish brown, various shades of red, maroon, gray, greenish gray, yellow, and purple. Sand, fine to medium-grained quartz, locally large petrified logs, unconsolidated, massive, lenticular, white, and light gray. Thickness 275 feet, truncated eastward*

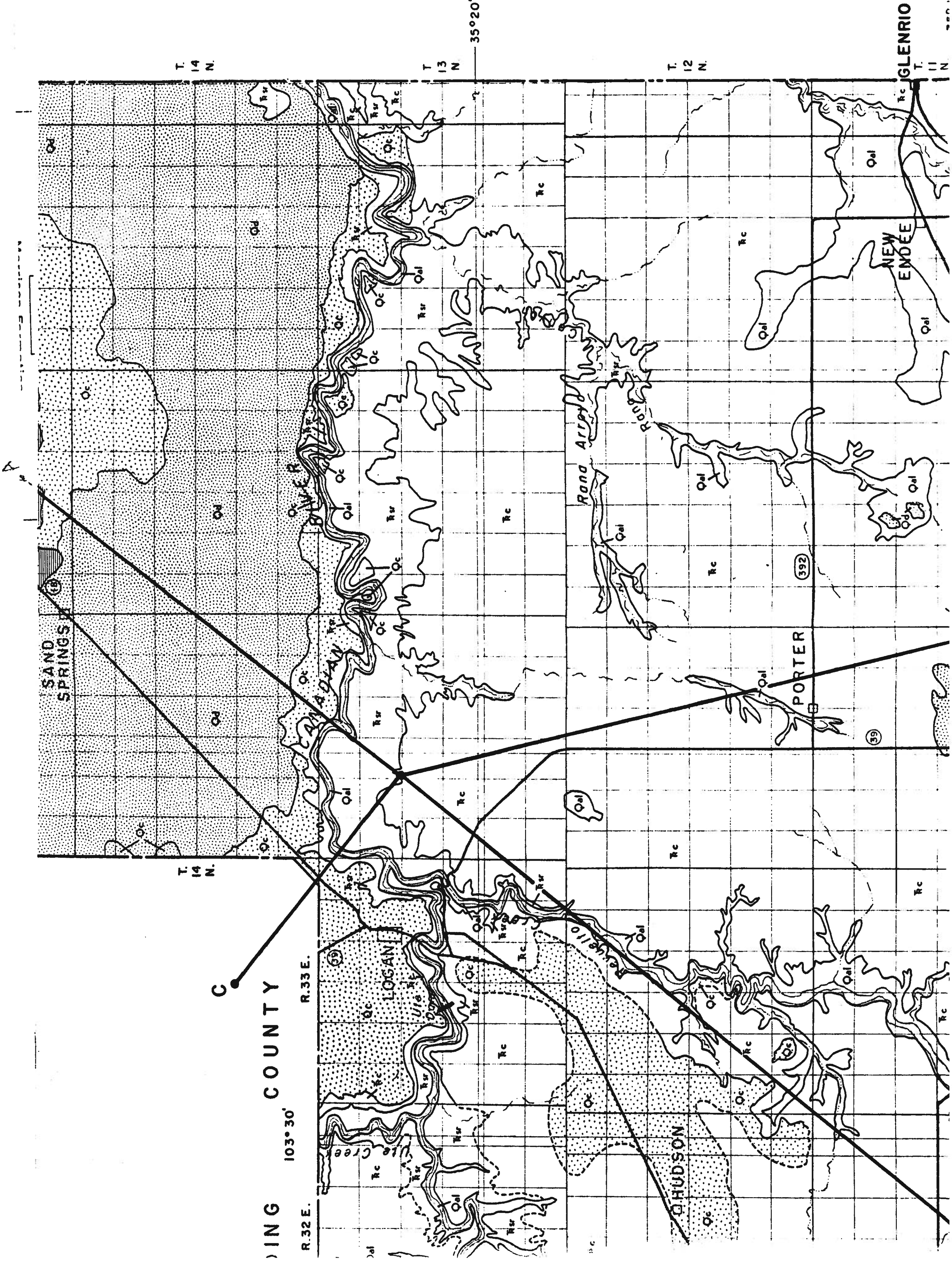
Pq | Pqwa | Pqw | Pqwd

Quartermaster Formation
Cloud Chief Gypsum and Whitehorse Sandstone

Quartermaster Formation, Pq, *mapped separately in Palo Duro Canyon and along Mulberry Creek. Shale, siltstone, sandstone, and gypsum, interbedded. Shale and siltstone, sandy, indurated, evenly bedded, thin interbeds and veins of satin spar, various shades of red, reddish brown, and reddish orange. Sandstone, fine-grained quartz, silty, scattered frosted and polished grains, red, reddish orange. Gypsum beds thin and discontinuous. Maximum exposed thickness 150 feet*

Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone undivided, Pqw, *sandstone, sand, siltstone, shale, gypsum, and dolomite interbedded. Sandstone and sand, fine-grained quartz, scattered to locally*

Berkstresser and Mourant, 1966



Berkstresser and Mourant, 1966

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, BUREAU OF M

EXPLANATION

QUATERNARY

Recent

Qd

Dune sand

Loose windblown sand; 0-100 feet thick. Not known to yield water to wells

Qal

Younger alluvium

Sand, gravel, silt, and clay; 0-80 feet thick. Yields 0.25-9 gpm of good quality water to wells

Pleistocene

Qc

Upland cover of older alluvium

Unconsolidated silty sand, clay, and gravel; 0-600 feet thick. Yields 0.25-325 gpm of poor to good quality water to wells

TERTIARY

Pliocene

To

Ogallala Formation

Caliche and stratified gravel, sand, silt, and clay; 0-250 feet thick. Yields 0.1-1600 gpm of good quality water to wells

CRETACEOUS

Lower Cretaceous

Ks

Sandstone and shale

Pajarito Shale 0-80 feet thick, Mesa Rica Sandstone 0-120 feet thick, and Tucumcari Shale 0-60 feet thick. Yields 0.5-3 gpm of good quality water to wells

JURASSIC

Upper Jurassic

Jm

Morrison Formation

Variegated red and blue clay, blue shale, and buff sandstone; 0-240 feet thick. Yields 1-2 gpm of good quality water to wells

Je

Entrada Sandstone

Fine- to medium-grained, poorly cemented, light-buff to white sandstone; some limestone and siltstone; 0-240 feet thick. Yields 1.5-250 gpm of good quality water to wells

Js

Shale and siltstone

Age relation to other Jurassic rocks is unknown. Not water-bearing

TRIASSIC

Upper Triassic

Ꞧc

Redonda and Chinle Formations

Red shale, siltstone, sandstone, variegated red and blue clay, and limestone; 0-1230 feet thick. Yields 0.1-20 gpm of very poor to fair quality water to wells

Ꞧsr

Santa Rosa Sandstone

Gray or red irregularly bedded sandstone, clay, shale, and conglomerate; 220-450 feet thick. Yields 1-50 gpm of good quality water to wells

Contact

Dashed where approximately located

Fault

Dashed where approximately located; dotted where concealed

A — A'

Line of diagrammatic section

Section A-A' shown on Plate 3

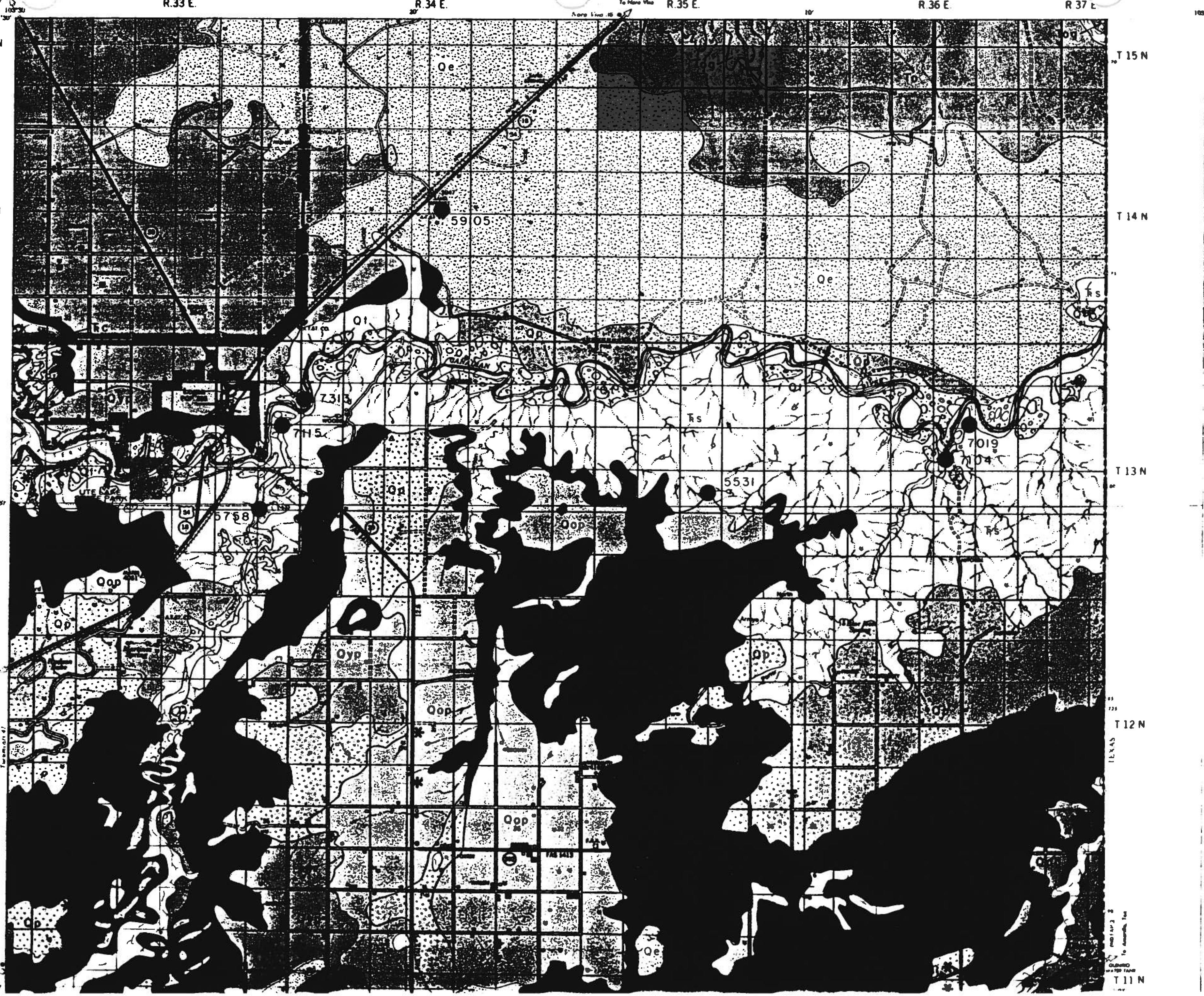
Section B-B' shown on Plate 4

Section C-C' shown on Plate 5

NEW MEXICO STATE HIGHWAY DEPARTMENT
PLANNING AND PROGRAMMING DIVISION
FEDERAL HIGHWAY ADMINISTRATION

GEOLOGY / AGGREGATE RESOURCES

LOGAN QUADRANGLE-48
QUAY & COUNTIES



NMSHD, undated

NMSHD, undated

EXPLANATION

Period	Symbol	Unit
QUATERNARY	Qal	Alluvium
	Qe	Eolian deposits
	Qyp	Younger Pediment deposits
	Qp	Pediment deposits
	Qt	Terrace deposits
	Qpg	Pediment deposits
	Qop	Older Pediment deposits
TERT.	To	Ogallala Formation undifferentiated
	Tog	Ogallala Formation Gravel
TRIASSIC		Chinle Formation
	₮s	Santa Rosa Sandstone

SEO, 1961

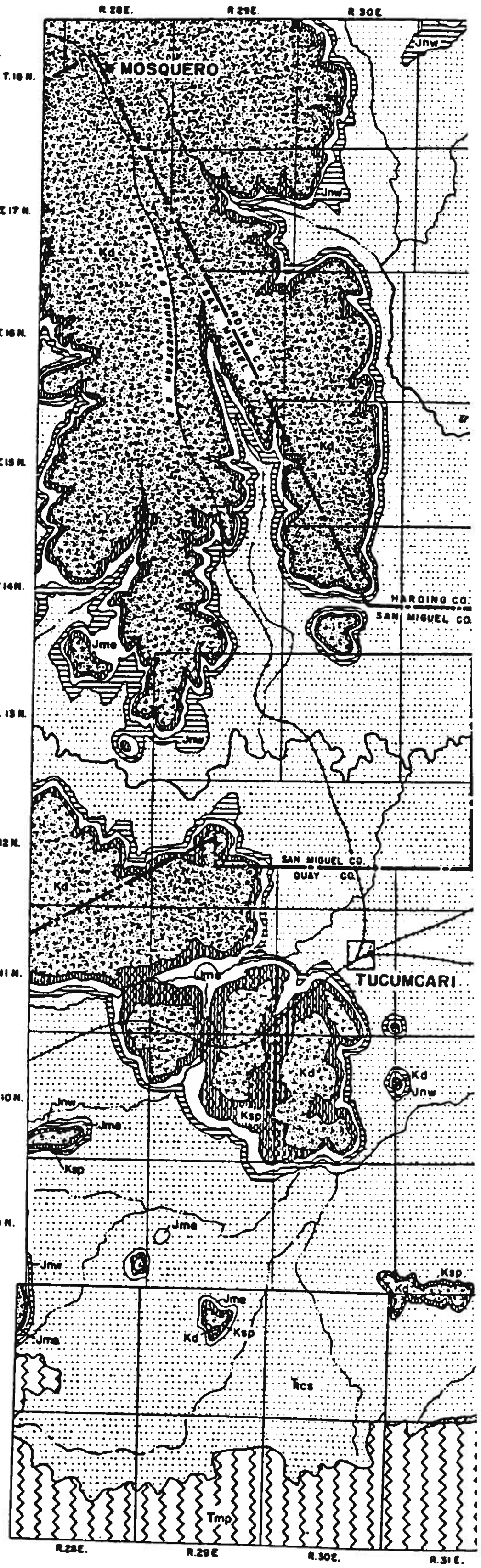


FIGURE 3

TAB 4 Part B.1 Subsurface geologic maps: structure maps

Collins, 1990

Regional Geologic Setting

The area investigated encompasses the Palo Duro Basin and adjacent regions within the Texas Panhandle, eastern New Mexico, and the Oklahoma Panhandle (fig. 2). The general stratigraphic section of the Palo Duro Basin is shown in table 1. The Palo Duro Basin is bordered on the north by the Amarillo Uplift and Bravo Dome, on the south by the Matador Arch, and on the west by the Roosevelt positive and Tucumcari Basin (fig. 2). North of the Bravo Dome and Amarillo Uplift are

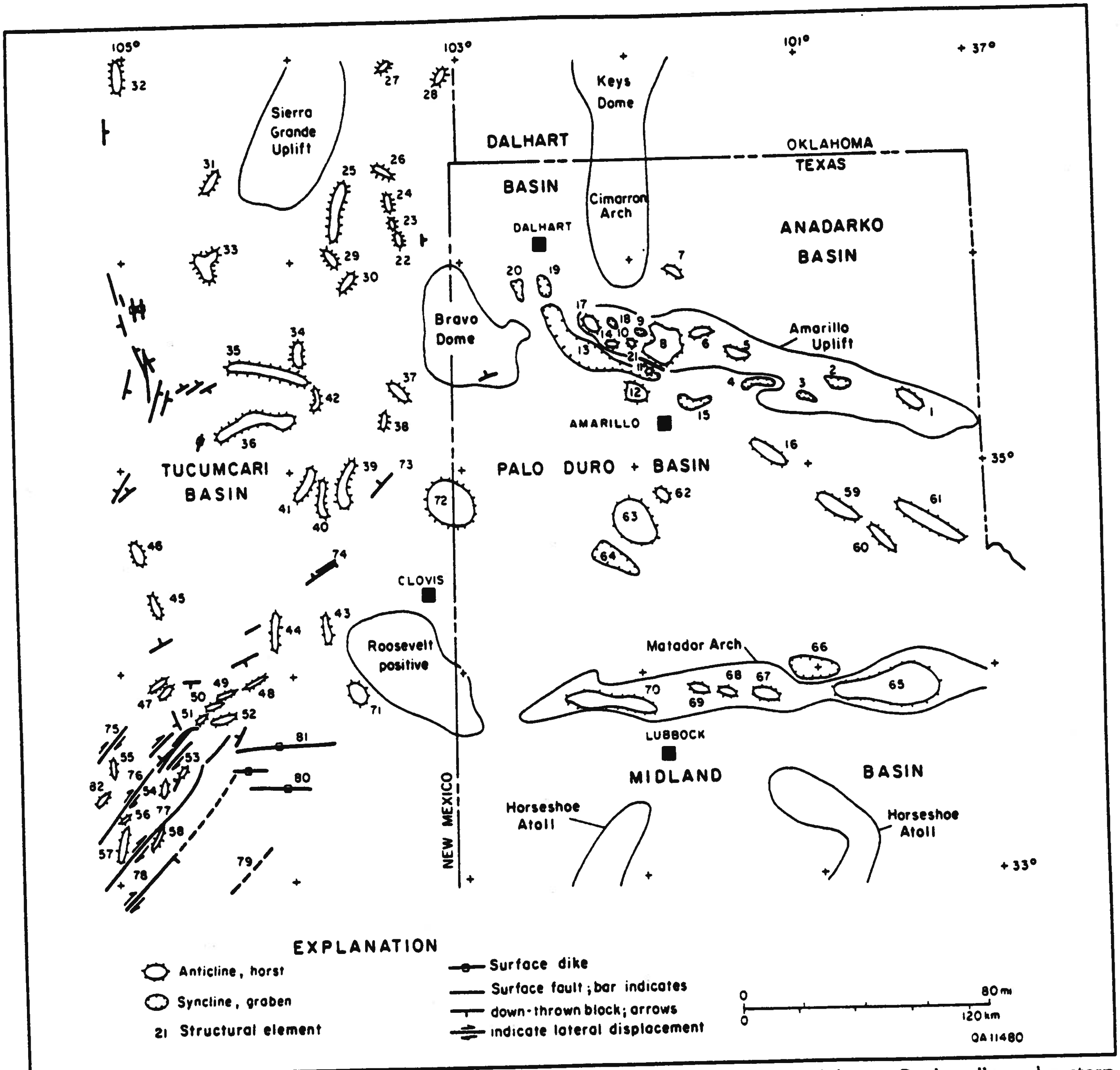


Figure 2. Major structural features of the Texas Panhandle and adjacent areas of Oklahoma Panhandle and eastern New Mexico. Numbered structural elements are listed in appendix 2.

Collins, 1990

Appendix 4. Selected structure-contour maps on the Texas Panhandle region.

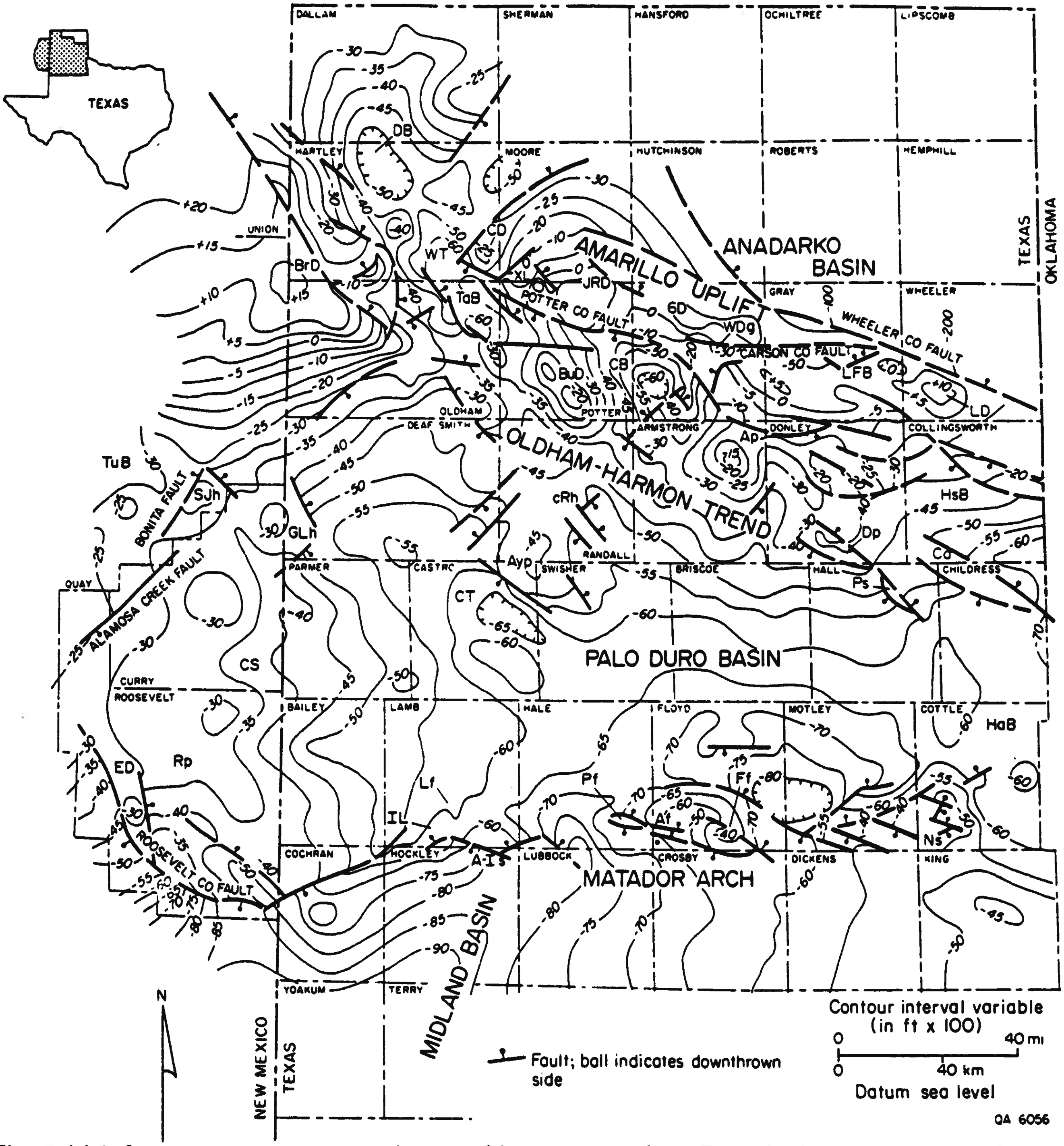


Figure A4-1. Structure-contour map on the top of basement, southern Texas Panhandle (from Budnik, 1989). The structures are abbreviated as follows: 6D = 6666 Dome; Af = Arick field; A-Is = Anton-Irish structure; Ap = Armstrong positive; Ayp = Arney positive; BrD = Bravo Dome; BuD = Bush Dome; Ca = Childress anticline; CB = Carson Basin; CD = Channing Dome; CS = Clovis Sag; CT = Castro Trough; cRh = central Randall high; DB = Dalhart Basin; Dp = Donley positive; ED = Elida Dome; Ff = Floydada field; GLh = Garcia Lake high; HaB = Hardeman Basin; HsB = Hollis Basin; IL = Illusion Lake structure; JRD = John Ray Dome; LD = Lela Dome; Lf = Littlefield structure; LFB Lefors Basin; Ns = Narcisso structure; Pf = Petersburg field; Ps = Plaska structure; Rp = Roosevelt positive; SJh = San Jon high; TaB = Tascosa Basin; TuB = Tucumcari Basin; WDg = White Deer graben; WT = Whittenburg Trough; XL = Exell Dome.

Collins, 1990

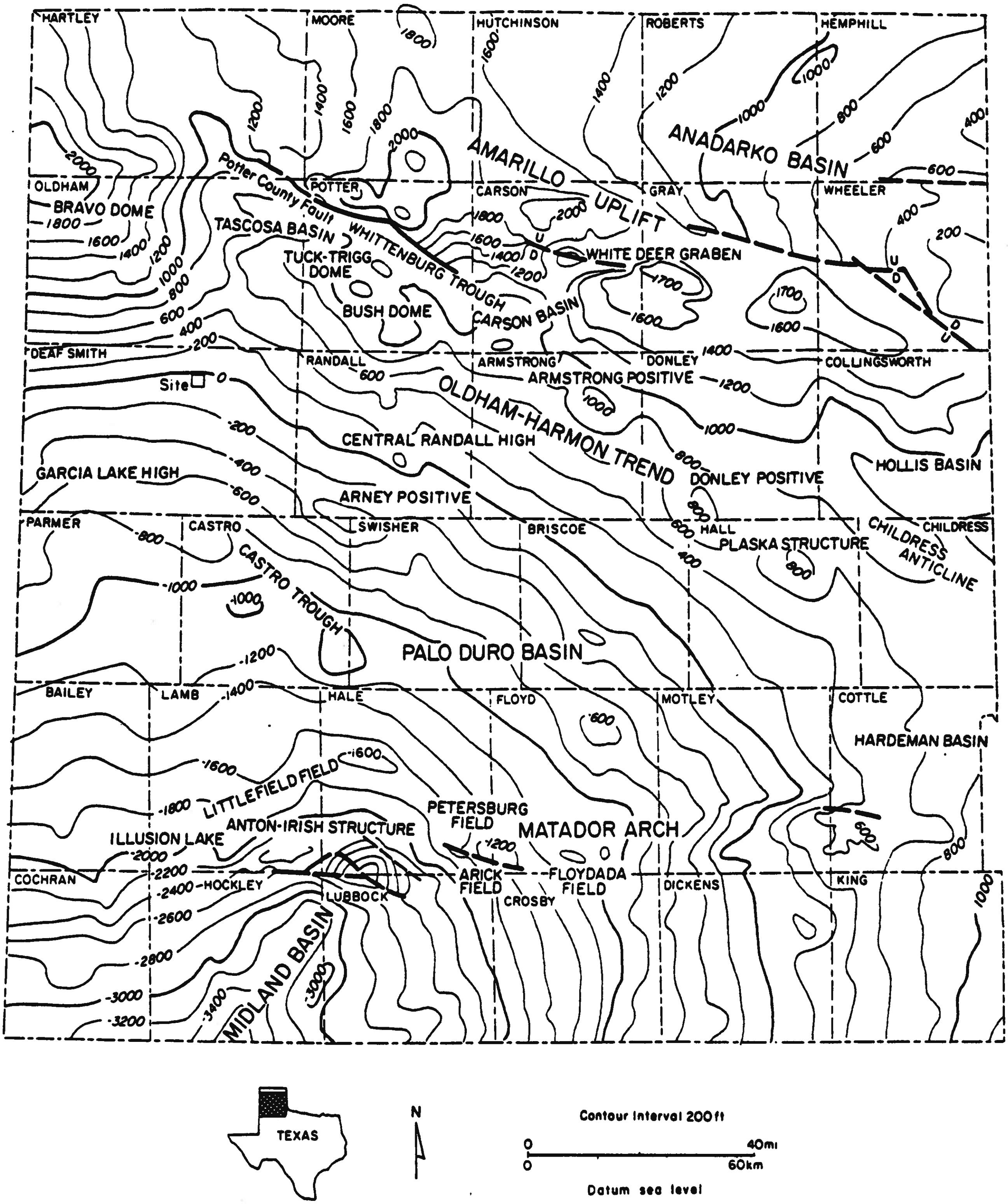


Figure A4-2. Structure-contour map on the top of the Tubb interval, Palo Duro Basin. From Budnik (1989).

Collins, 1990

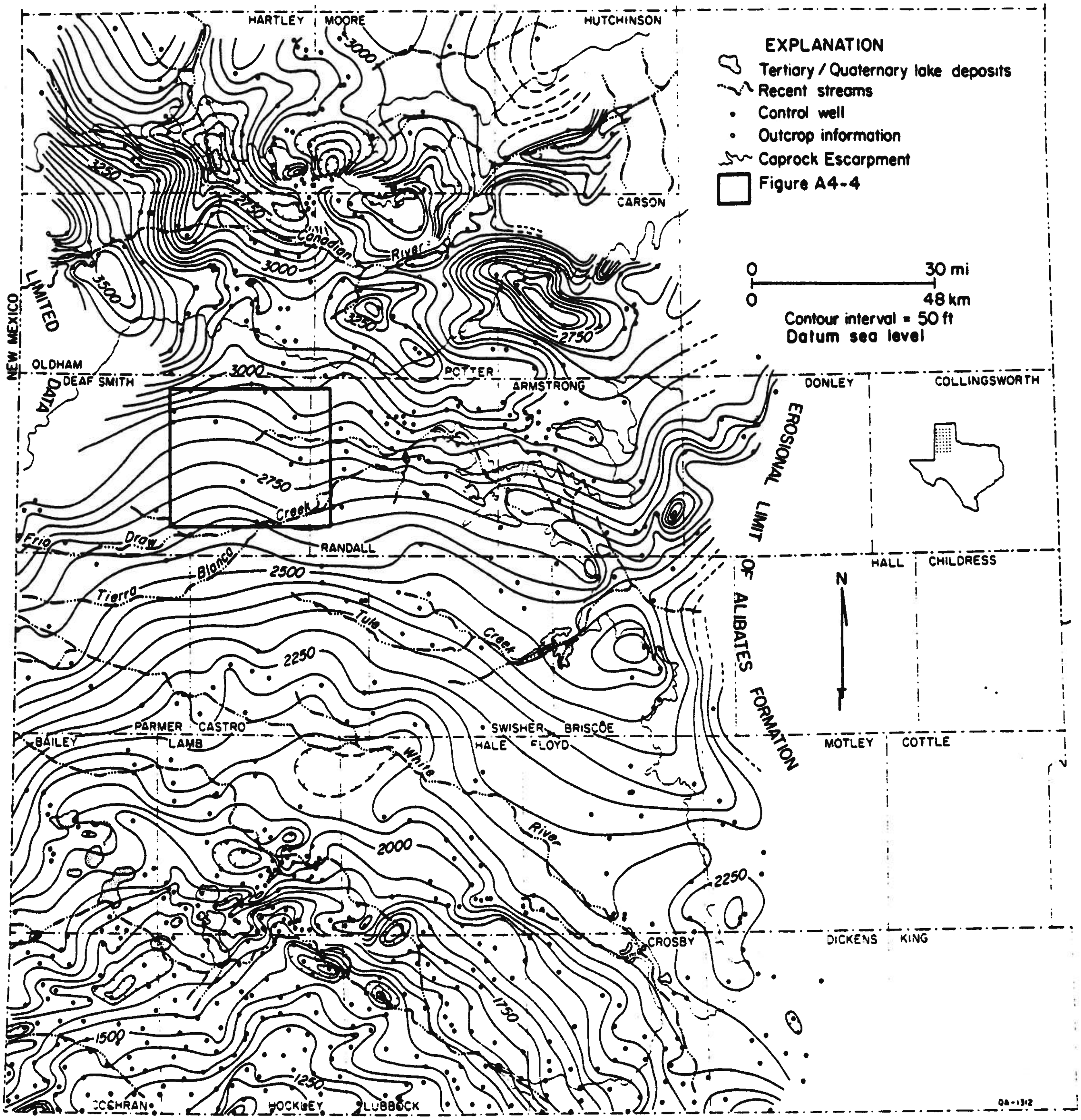


Figure A4-3. Structure-contour map on the top of the Alibates formation. Note that structures are complex and well defined in areas of sufficient data but show little structural detail in areas of sparse data. From Gustavson and Finley (1985).

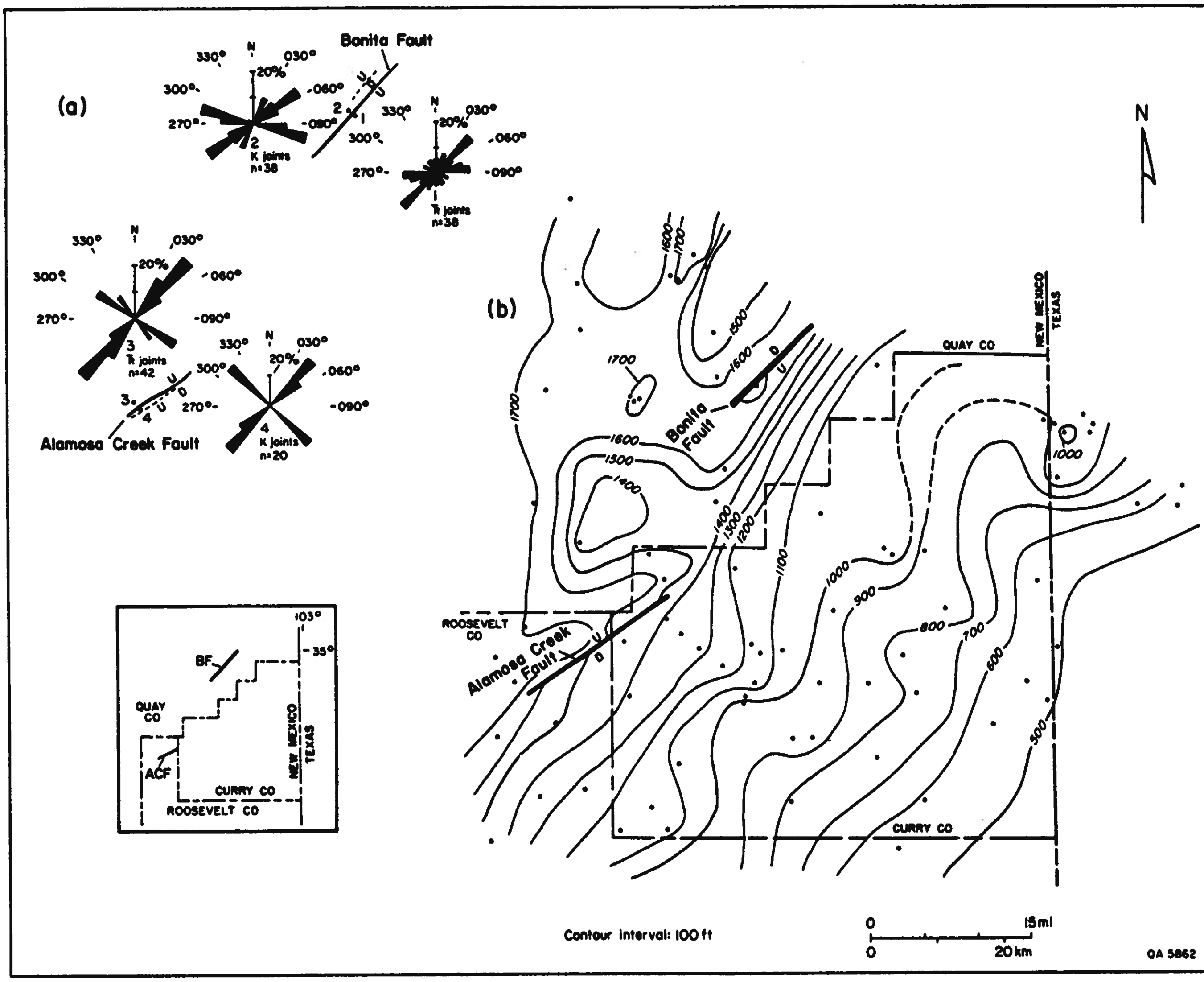


FIGURE 4. (a) Strikes of faults and joints at the western margin of the Palo Duro Basin, eastern New Mexico. Rose diagram data are plotted as percentages of total number of measurements (n) for 10° intervals. (b) Structure-contour map on the base of the Permian San Andres Formation, Quay, Curry, and Roosevelt Counties, eastern New Mexico.

flank of John Ray Dome is a fault exposed at the surface that displaces Permian against Triassic rocks (Eifler, 1969). The strike of this fault is 295°–310°.

Along the southwestern flank of John Ray Dome, joints in Permian Quartermaster (Dewey Lake), Triassic Dockum, and Tertiary Ogallala strata were analyzed using azimuth versus traverse distance plots (AVTD) to detect variability in the strike and in the occurrence of joints along a traverse (Wise and McCrory, 1982). The locations of three traverses used for data collection are shown in figure 5b. The strike of a representative joint from each set was measured at intervals along each traverse. The joints are almost perpendicular to the sandstone beds; thus even in the gently dipping strata the joints are nearly vertical. Wise and McCrory (1982) describe the methods for plotting and contouring data for AVTD plots.

In the Permian strata, joints occur in two sets (fig. 6a and d). The predominant set strikes 300°–320°. The AVTD plot (fig. 6a) indicates that this set is well defined. Other joints, striking 050°–100°, are less common and appear irregularly along the traverse.

Two joint sets are also in the overlying Triassic Dockum sandstones (fig. 6b and e). Most of the joints strike 300°–320°; this set is well defined along

Dutton and Orr, 1986

INTRODUCTION

This report discusses the origin of water and the flow potential of water in low-permeability carbonate rock in the San Andres Formation. The San Andres Formation makes up approximately one-third of an evaporite confining system in the Palo Duro Basin (fig. 1). The 1,800-ft- to 5,000-ft-thick (550-m- to 1,520-m-thick) confining system includes halite, anhydrite, red siltstone and mudstone, limestone, and dolostone (fig. 2) of Leonardian to Ochoan (Permian) age. The research was part of studies to characterize possible sites for a high-level nuclear waste repository in bedded halite (U.S. Department of Energy, 1984a, 1984b). Hydrologic tests and studies of chemical composition of San Andres brine in the Palo Duro Basin were conducted simultaneously with a regional study of San Andres hydrogeology. The regional picture supports our interpretation of two water samples and of hydrologic tests at six wells in the San Andres Formation in the Palo Duro Basin.

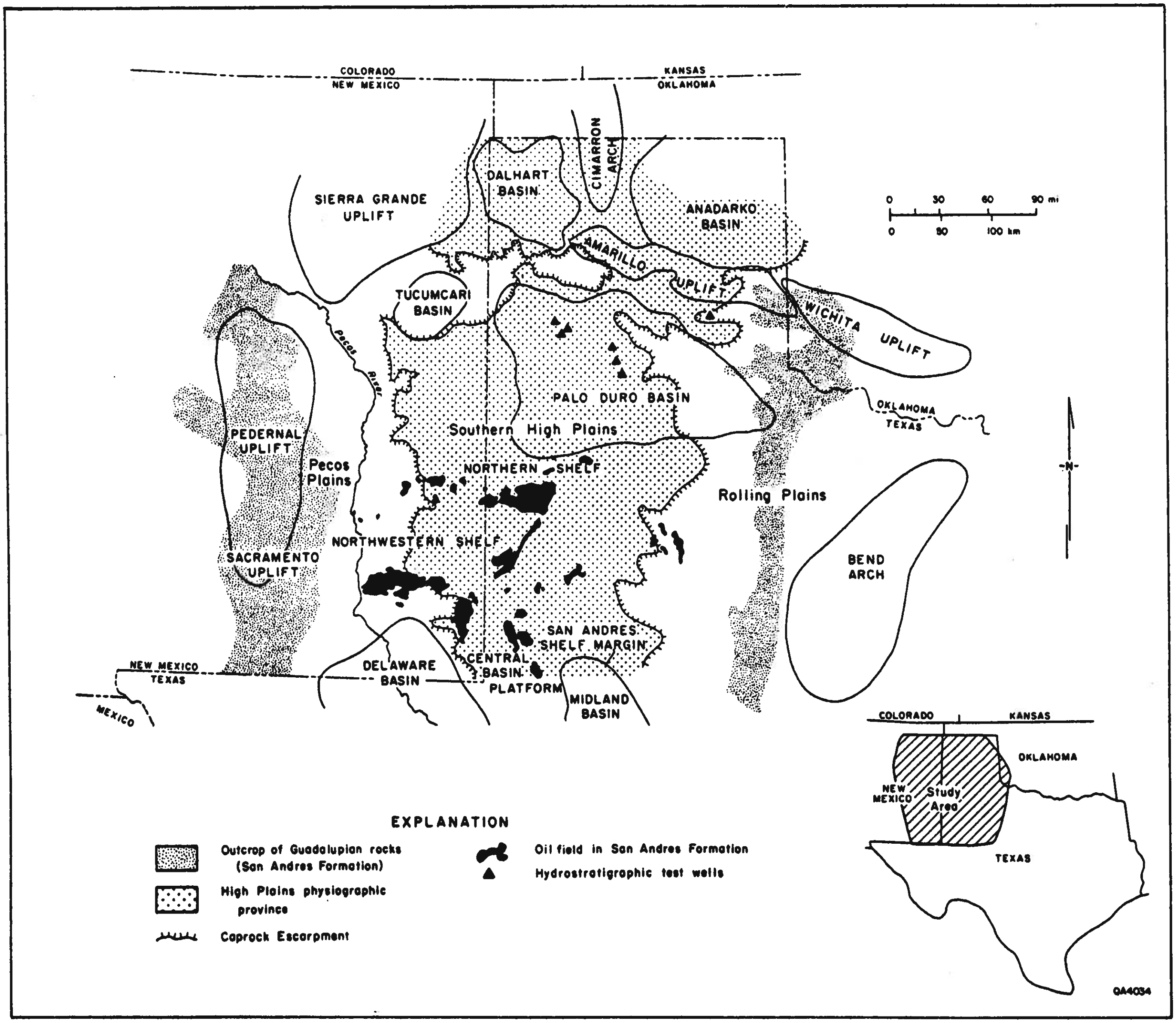
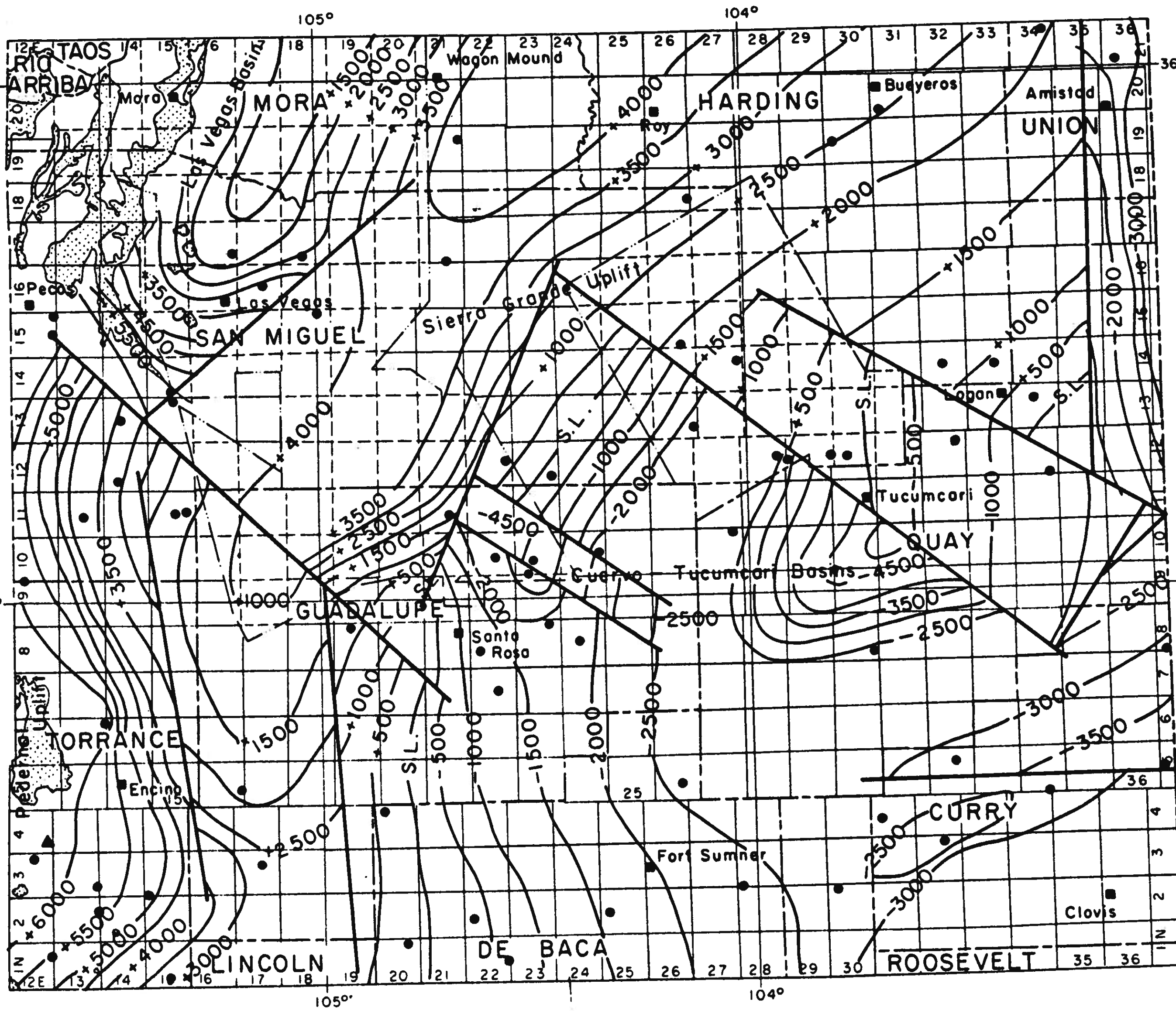


Figure 1. Study area, lying between outcrops of Guadalupian rocks in eastern New Mexico and the Texas Panhandle, includes the Palo Duro Basin, Northern Shelf, Northwestern Shelf, and the northern parts of the Midland Basin, Central Basin Platform, and Delaware Basin.

Foster, et al., 1972



- Well Control
- Surface Control
- Outcrop Distribution
- Faults

10 0 10 20 30 40 MILES

Contour Interval: 500 feet

Figure 10. Structure Contour Map on Precambrian Surface.

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Gustavson, et al., 1980a

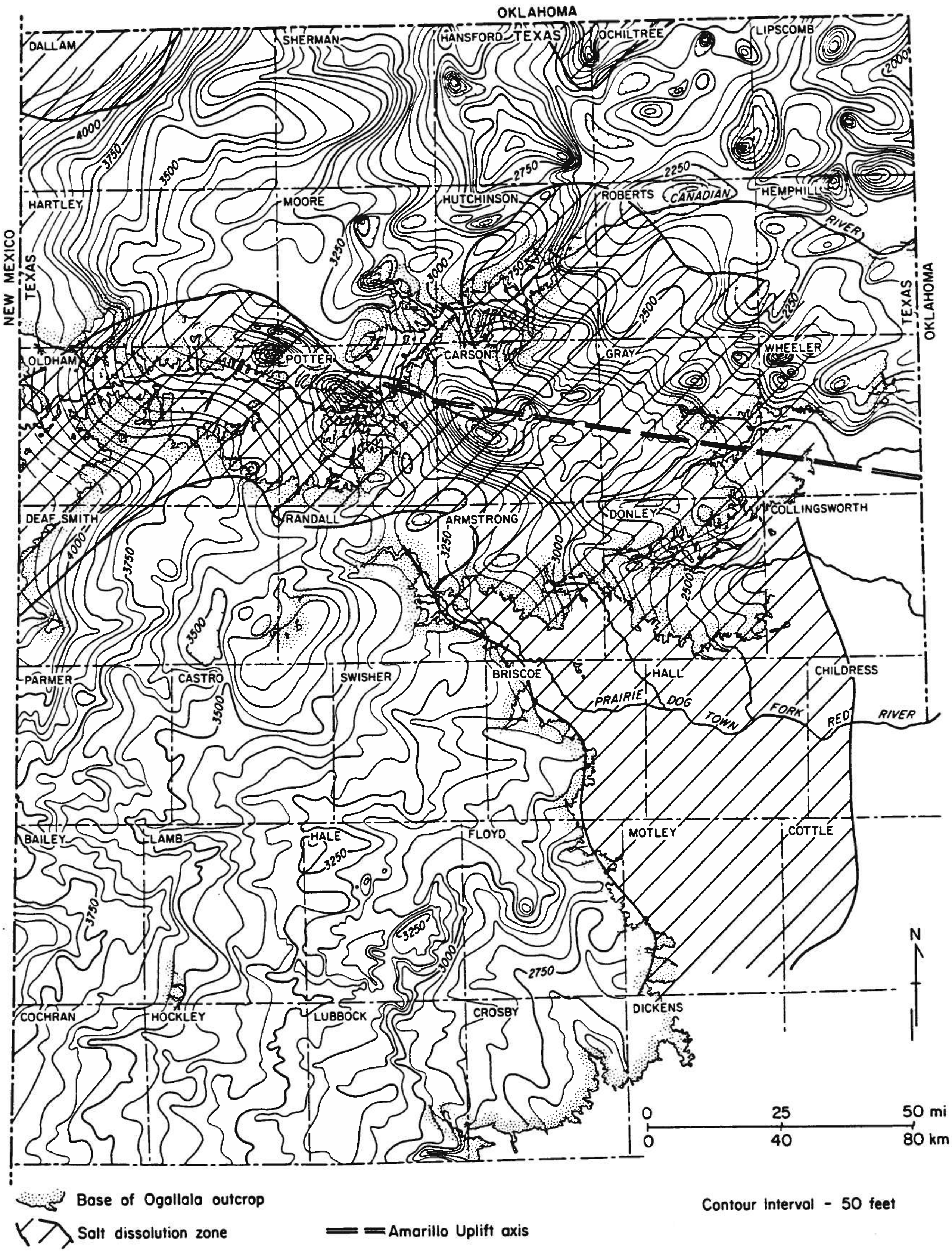
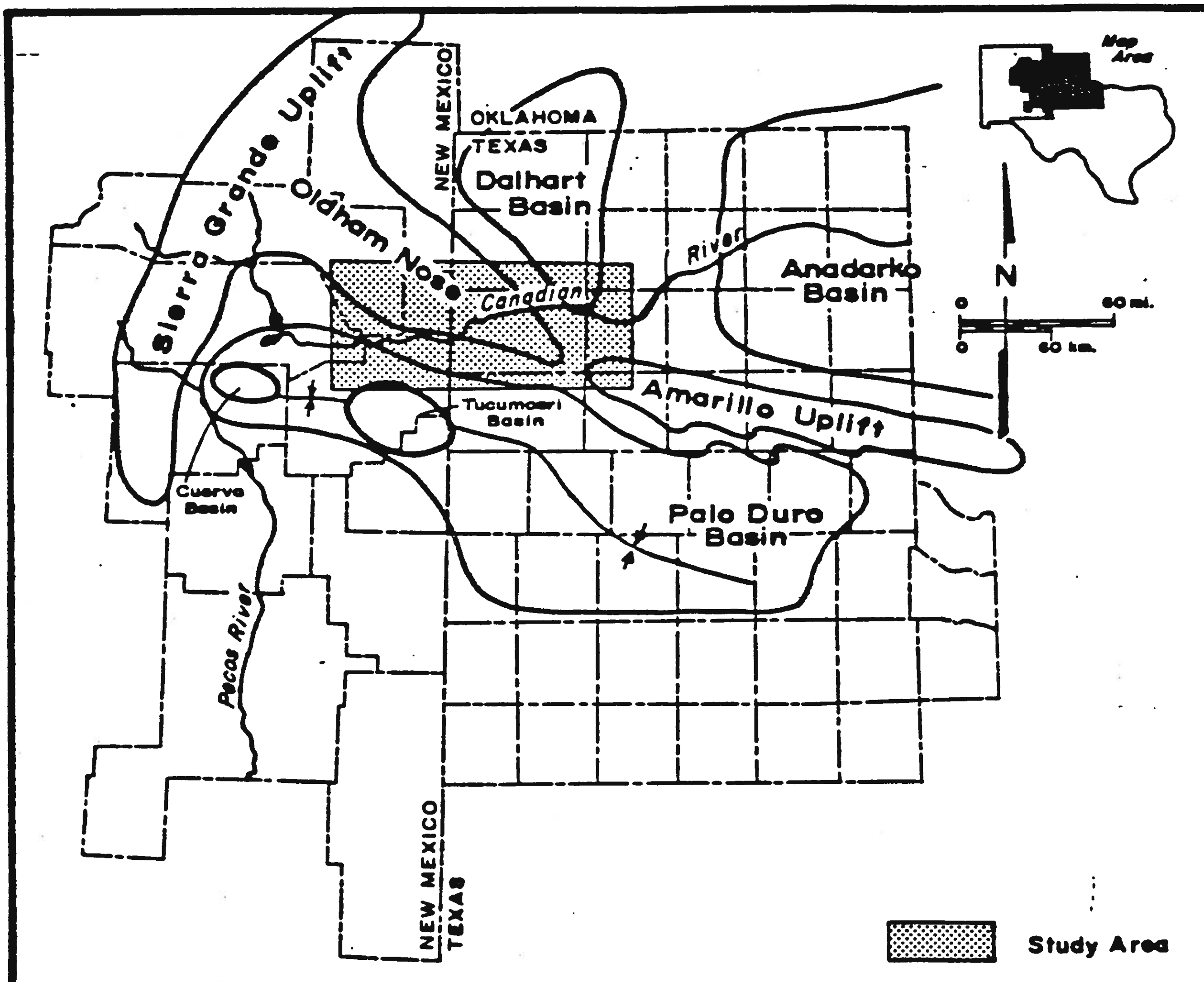


Figure 7. Structure-contour map on the base of the Ogallala Formation (in part from Cronin, 1961). Map also indicates the active salt dissolution zone for the Salado, Seven Rivers, San Andres, and Glorieta Formations.

HGC, 1984a



Adapted from Nicholson, 1960; Gustavson and others, 1982

Figure 3. Structural elements in the vicinity of the study area

HGC, 1984a

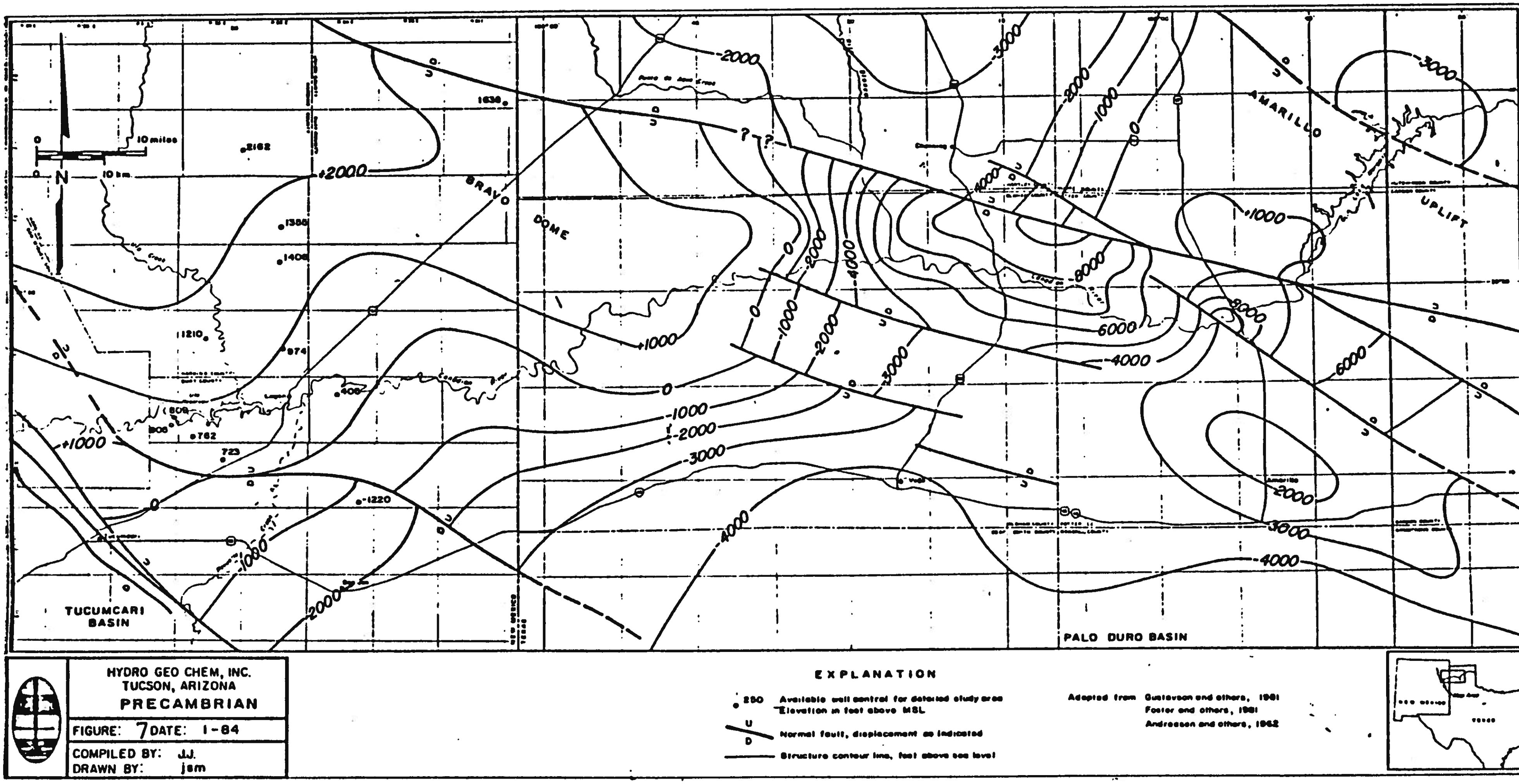


Figure 7. Structure contour map of Pre-cambrian surface

HGC, 1984a

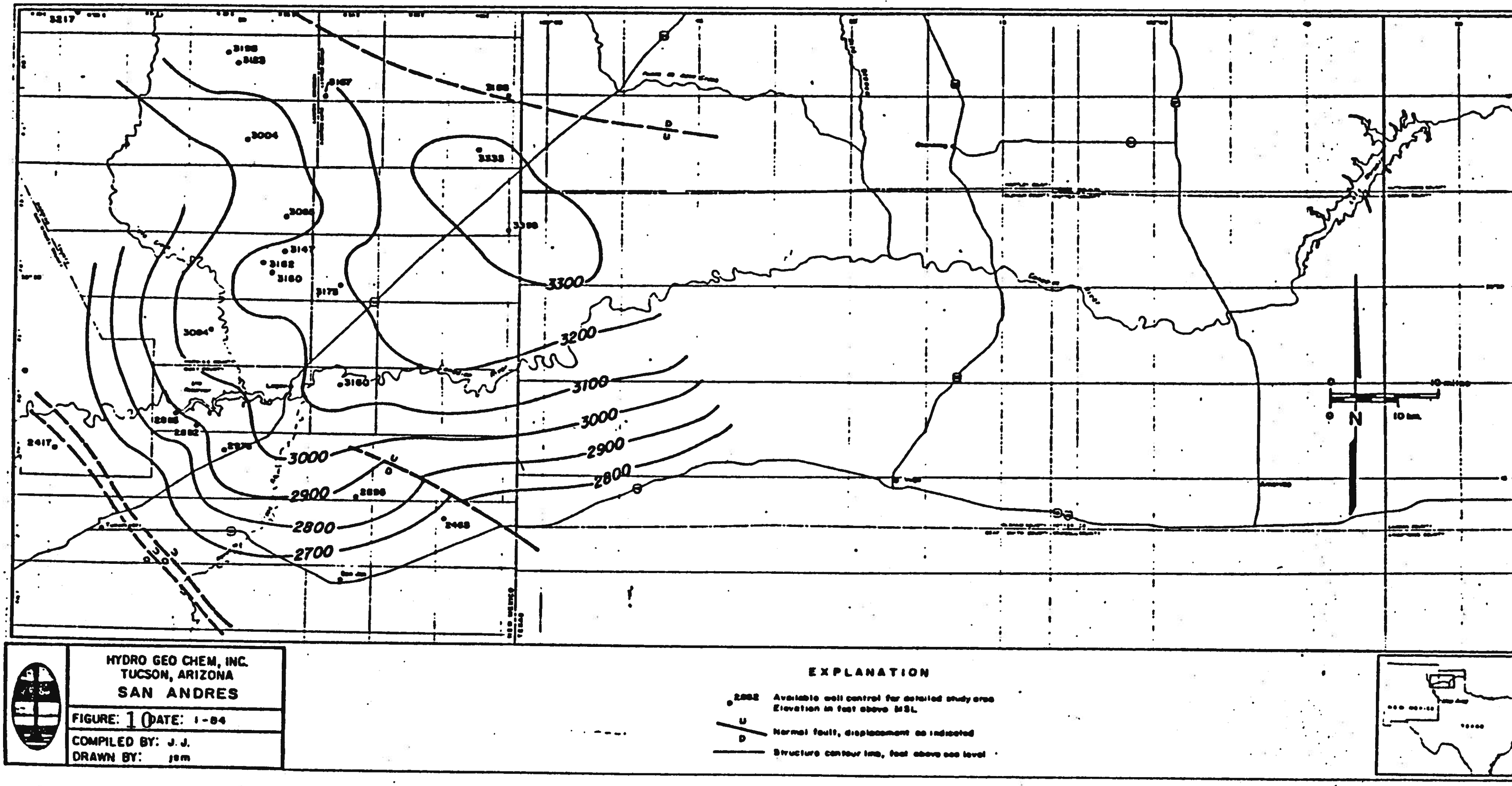


Figure 10. Structure contour map of San Andres Formation

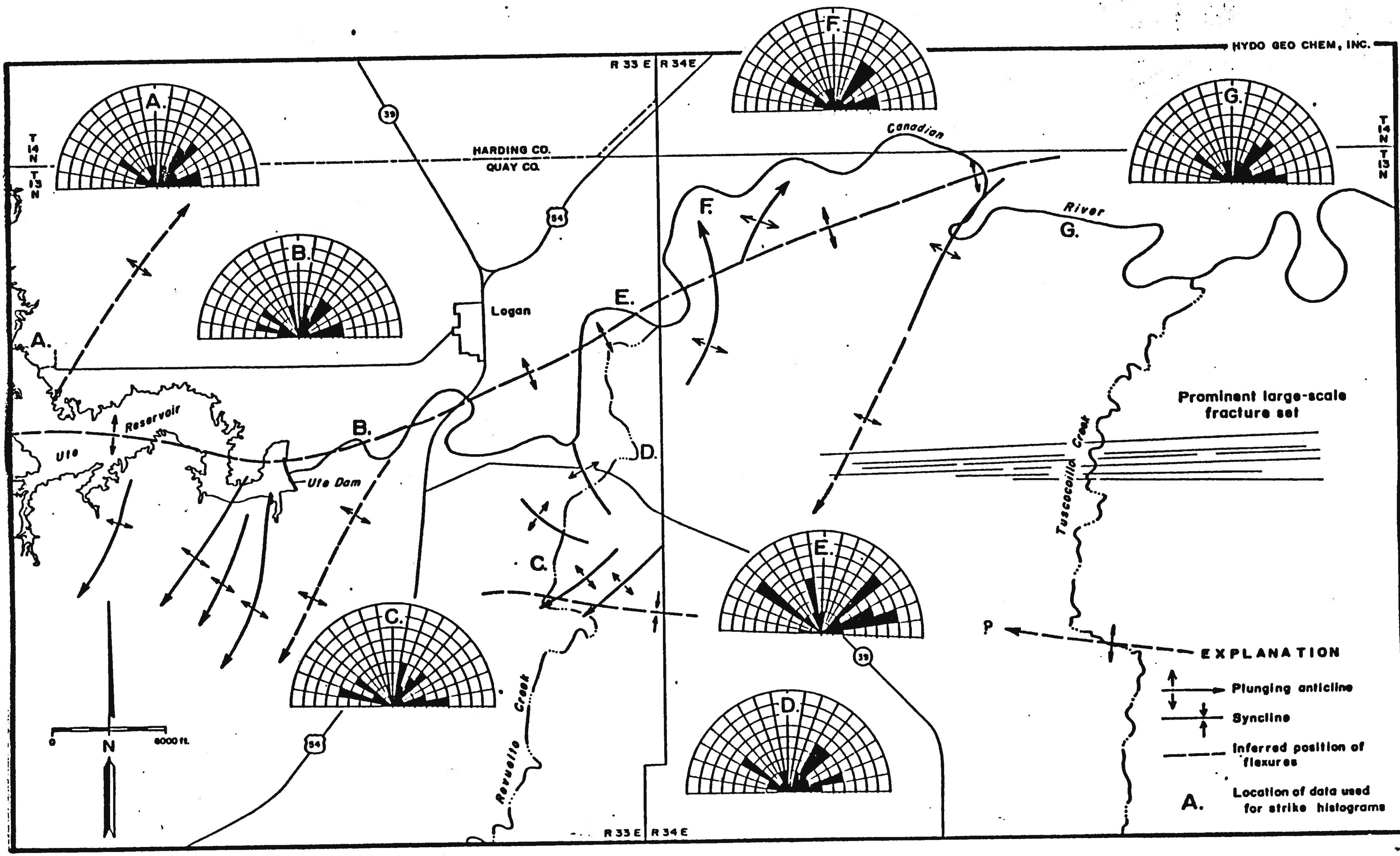
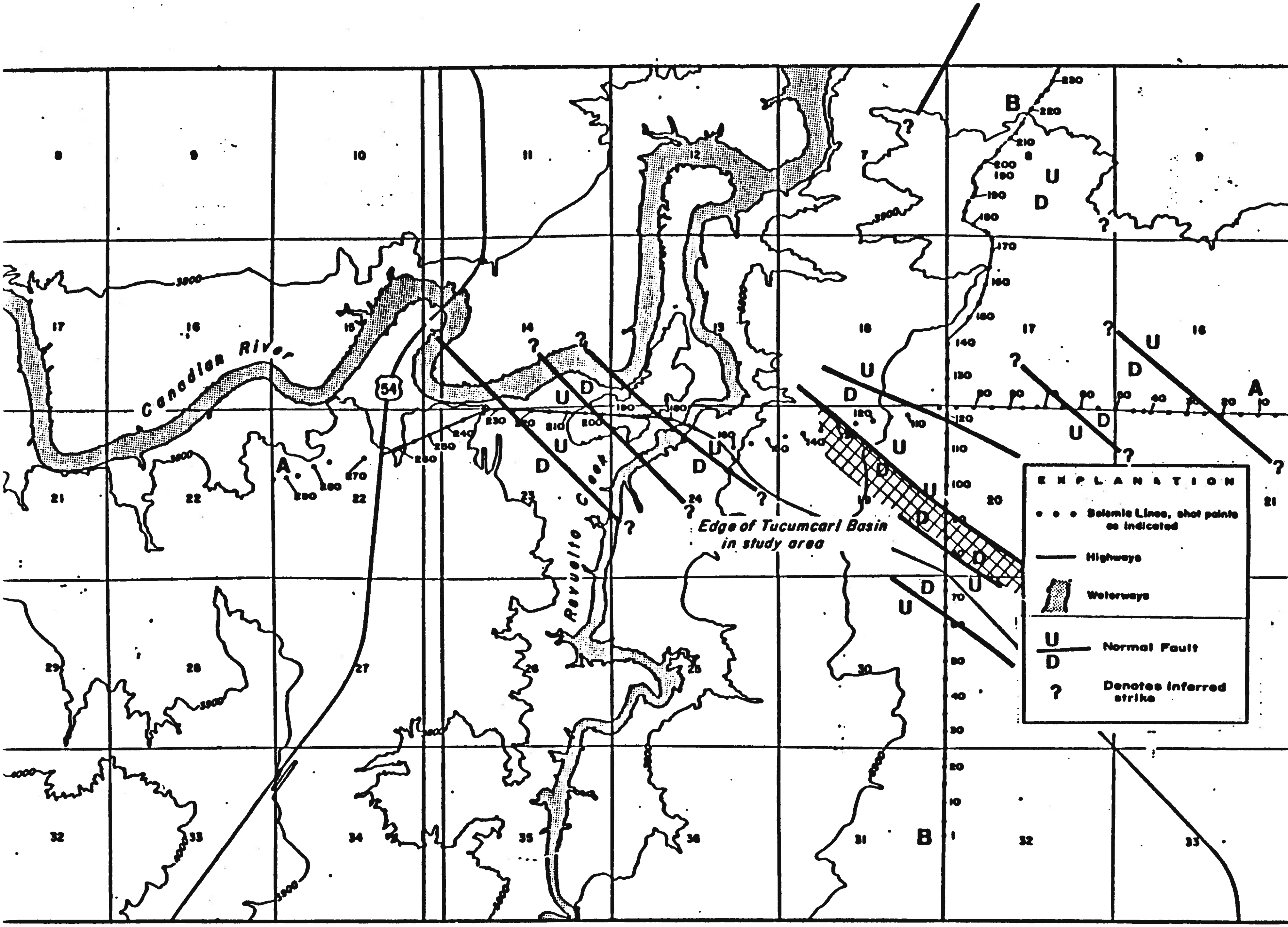


Figure 16. Map showing structural features in the detailed study area

HGC, 1707c



HGC, 1984b

Figure 13. Faults inferred from the seismic data.

HGC, 1984b

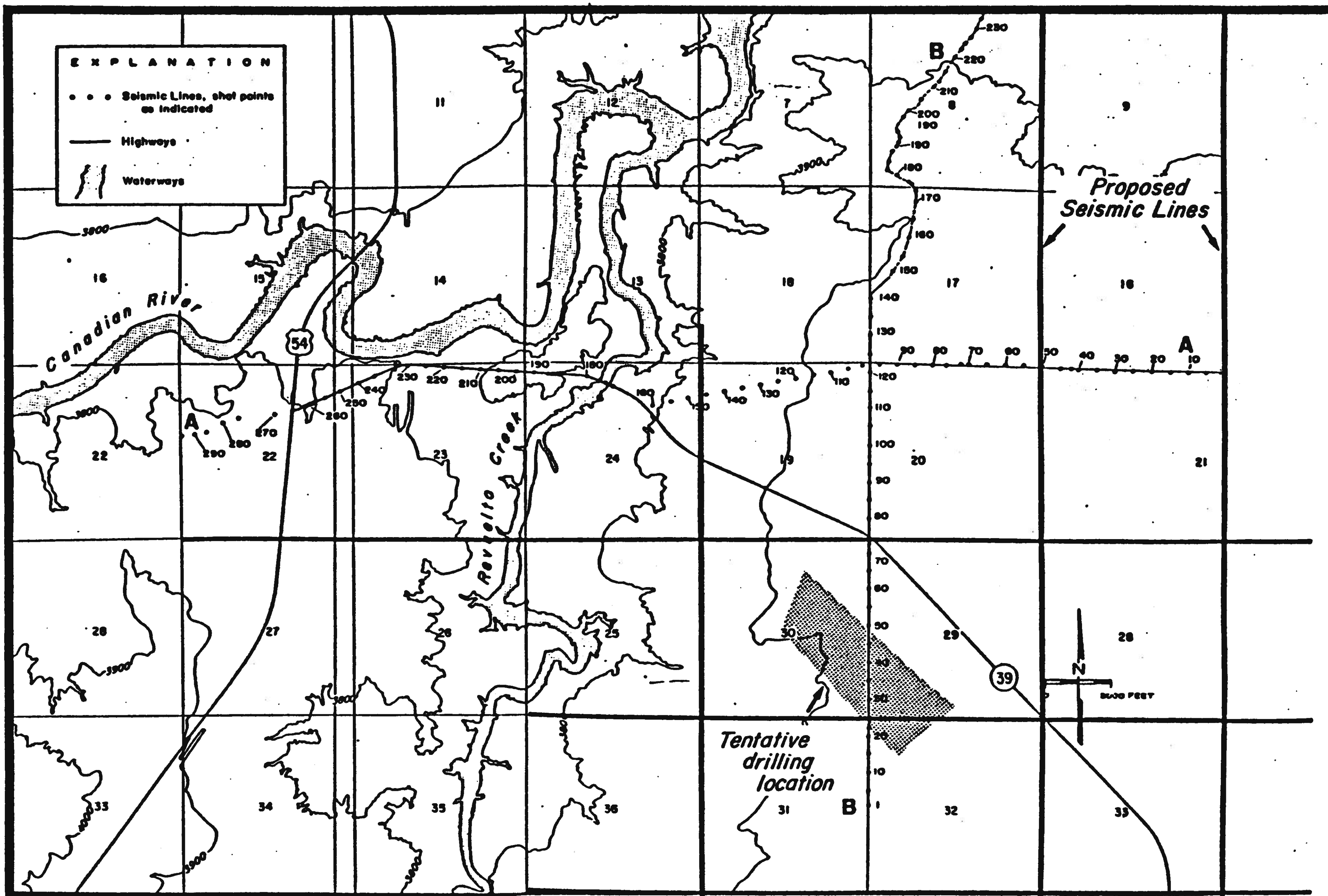
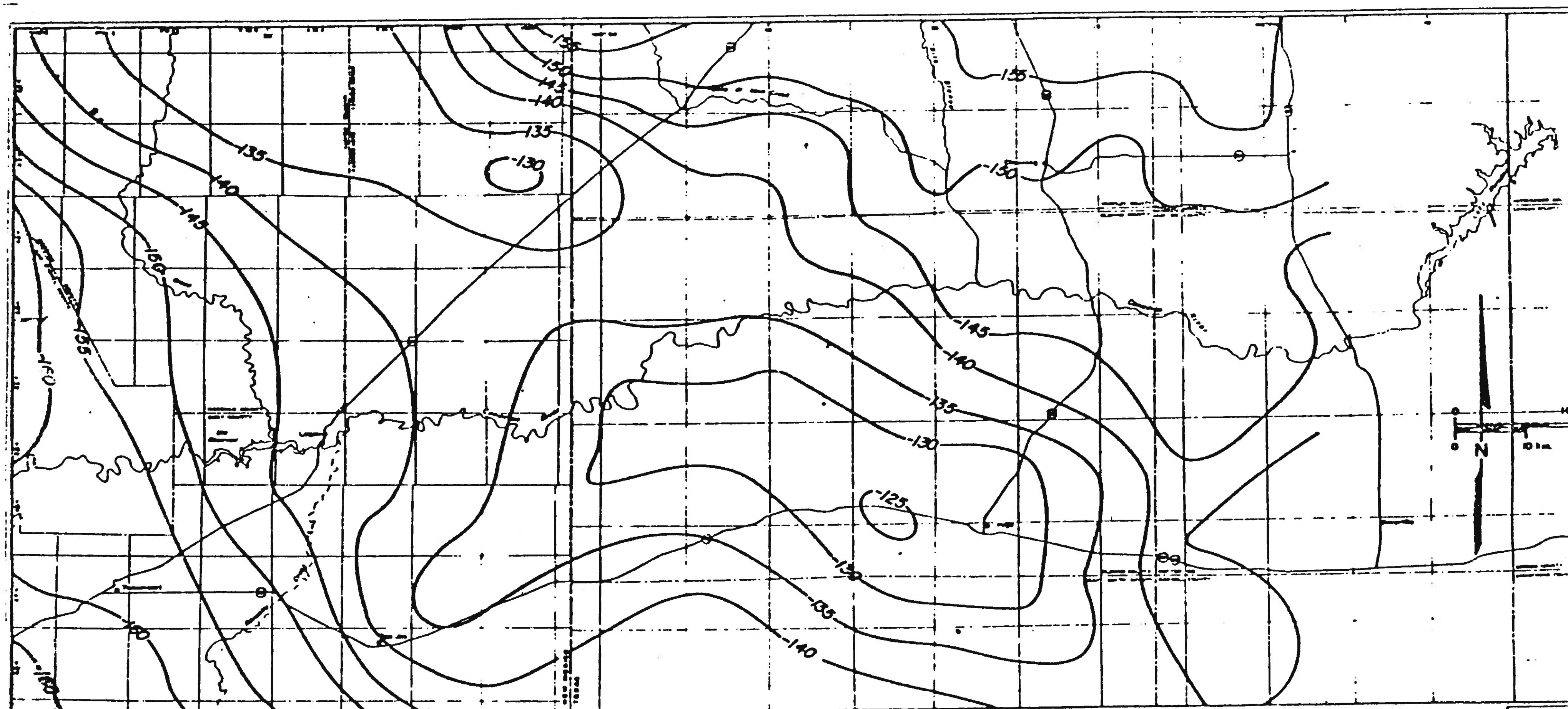
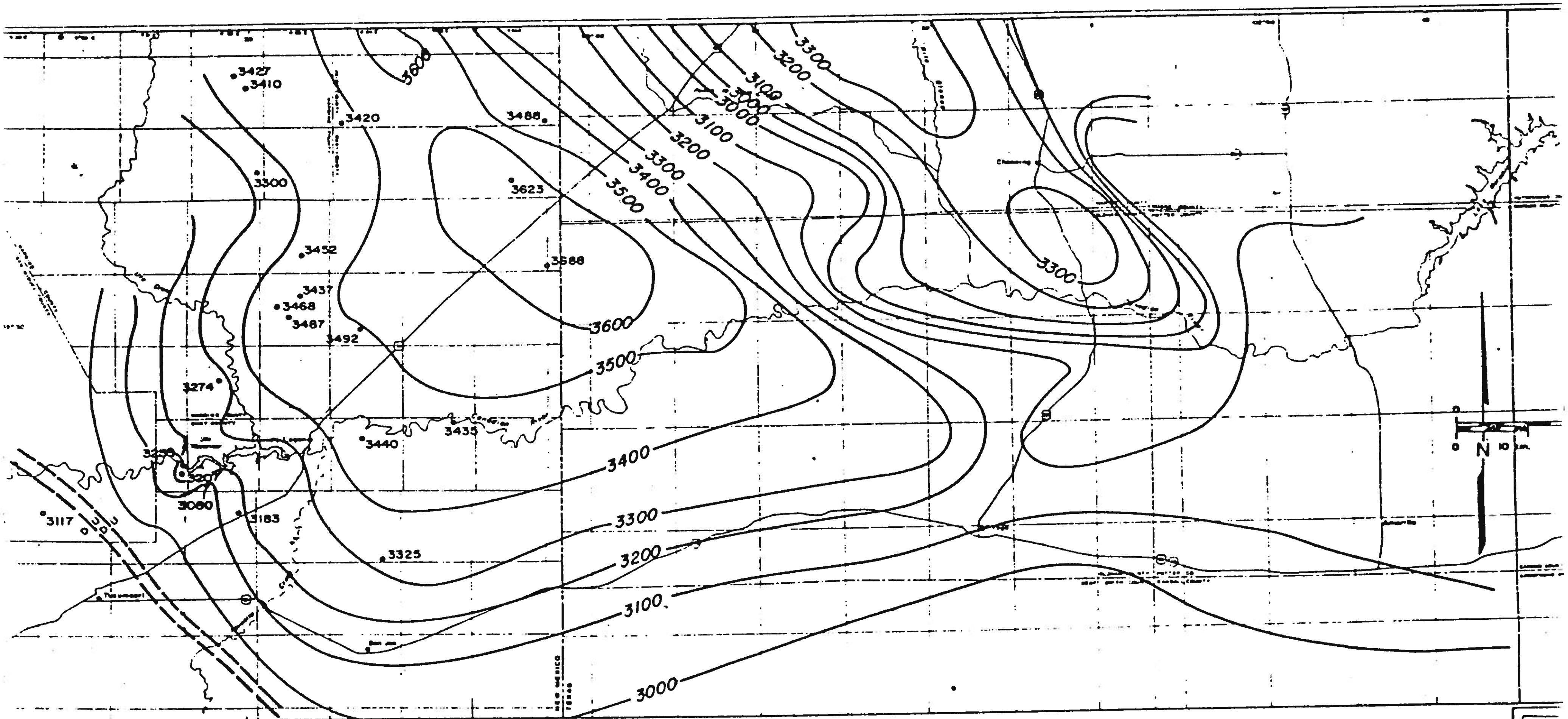


Figure 14. Recommended additional seismic coverage and tentative drilling locations.



GRAVITY MAP; CONTOURS IN MILLIGALS

HGC, 1984c



STRUCTURE CONTOURS ON TOP OF PERMIAN

HGC, 1984c

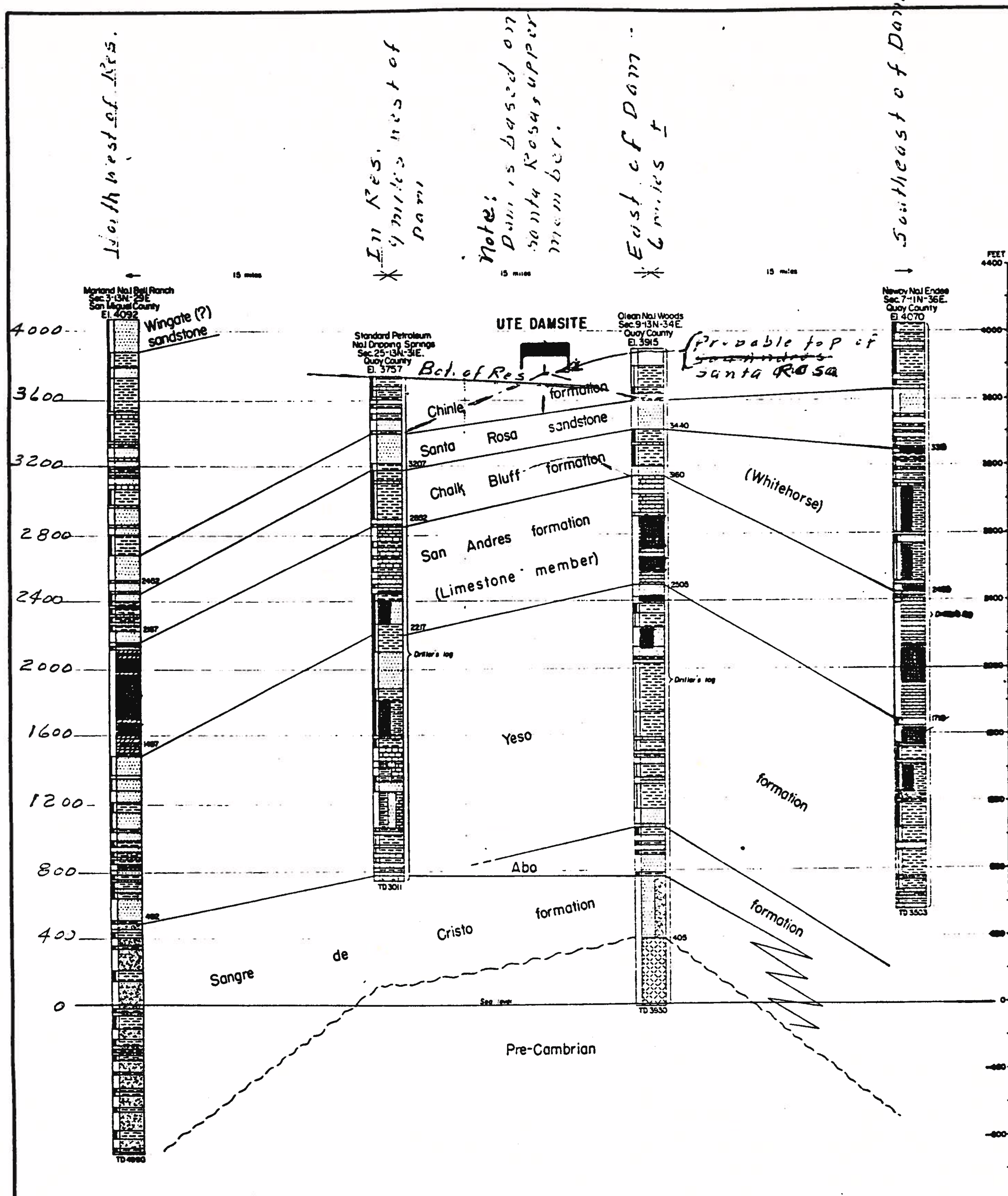
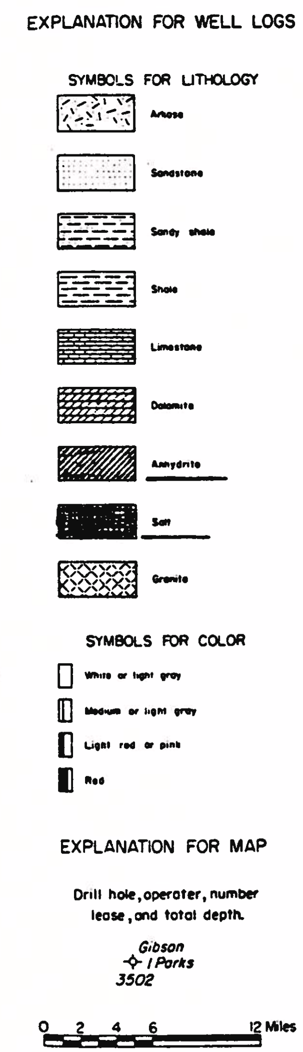


FIGURE 4a. GRAPHIC SECTIONS SHOWING CORRELATION OF TRIASSIC, PERMIAN, AND PENNSYLVANIAN STRATA THAT UNDERLIE NORTH-CENTRAL QUAY AND ADJACENT PORTIONS OF SAN MIGUEL COUNTIES, NEW MEXICO

Location of drill holes and line of section is shown on figure 4b



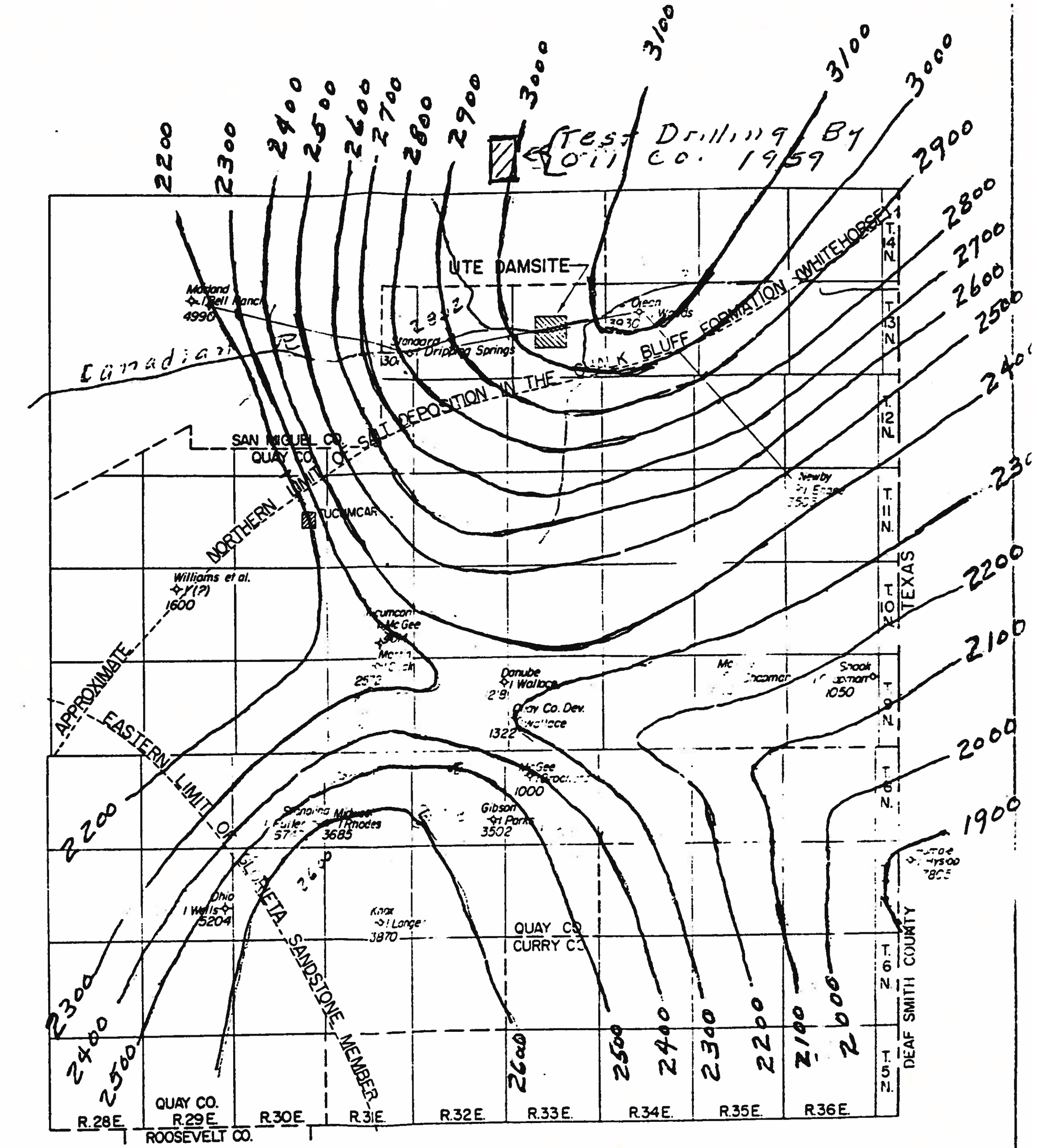


FIGURE 4b. MAP OF PARTS OF QUAY, SAN MIGUEL, AND CURRY COUNTIES, NEW MEXICO, SHOWING DRILL HOLES AND LOCATION OF GRAPHIC SECTION SHOWN ON FIGURE 4a.

Red top of San Andres

Note: Contours are inferred from logs of deep wells in the area.
A. Watson

FIGURE 4a and 4b

Note:
see preceding map for
Inferred Conditions at dam
site

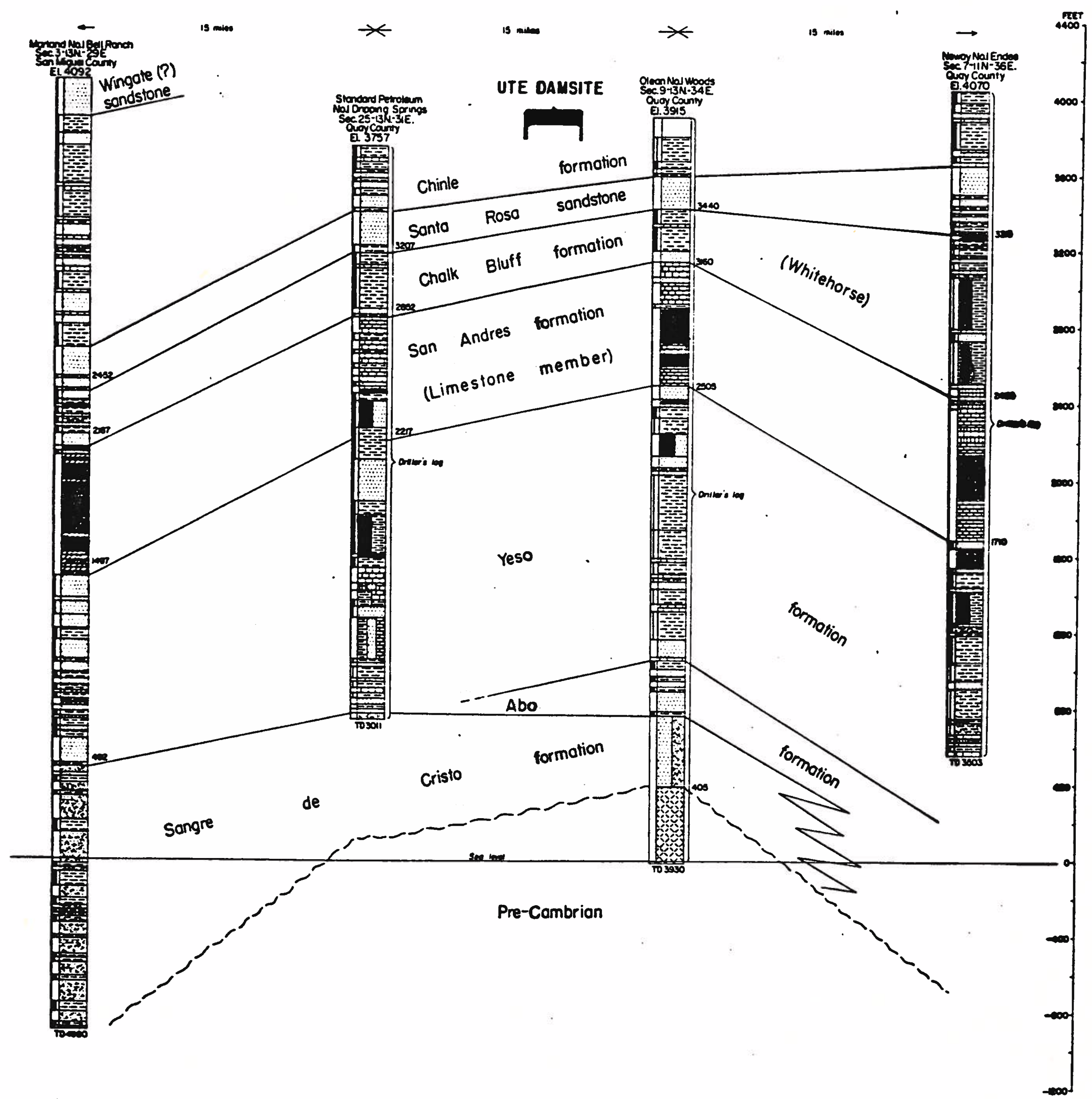
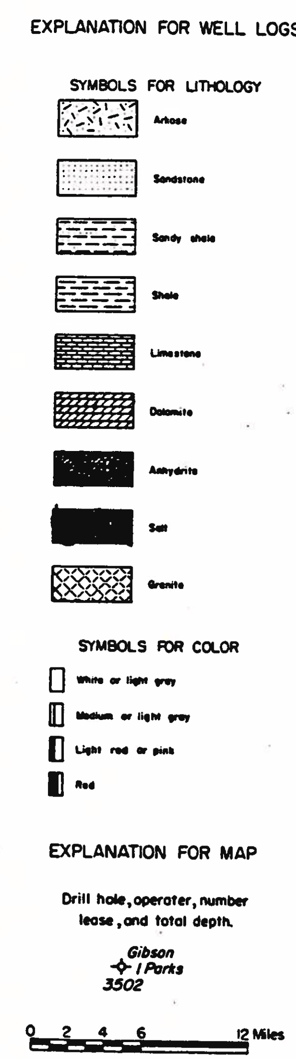


FIGURE 4a. GRAPHIC SECTIONS SHOWING CORRELATION OF TRIASSIC, PERMIAN, AND PENNSYLVANIAN STRATA THAT UNDERLIE NORTH-CENTRAL QUAY AND ADJACENT PORTIONS OF SAN MIGUEL COUNTIES, NEW MEXICO

Location of drill holes and line of section is shown on figure 4b



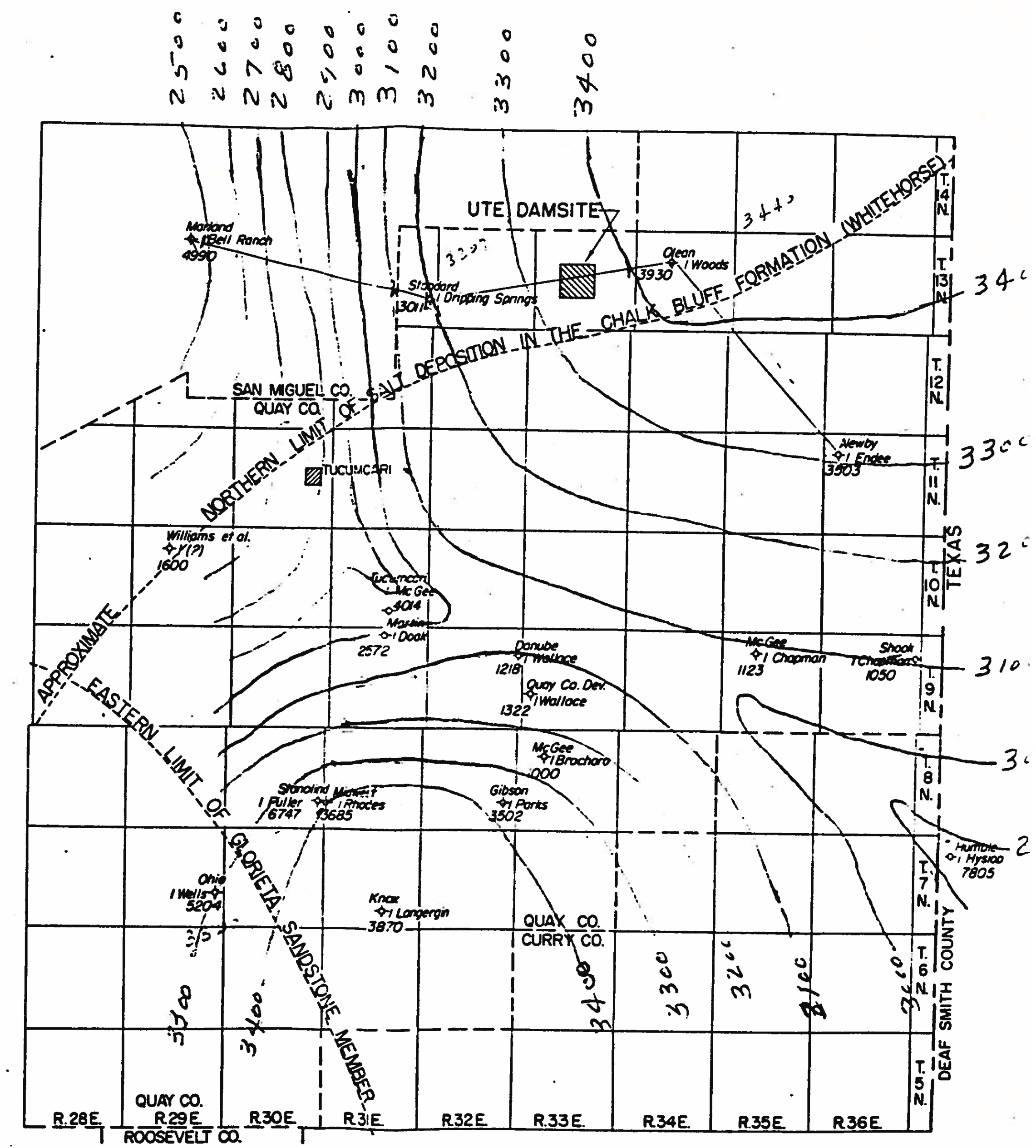


FIGURE 4b. MAP OF PARTS OF QUAY, SAN MIGUEL, AND CURRY COUNTIES, NEW MEXICO, SHOWING DRILL HOLES AND LOCATION OF GRAPHIC SECTION SHOWN ON FIGURE 4a.

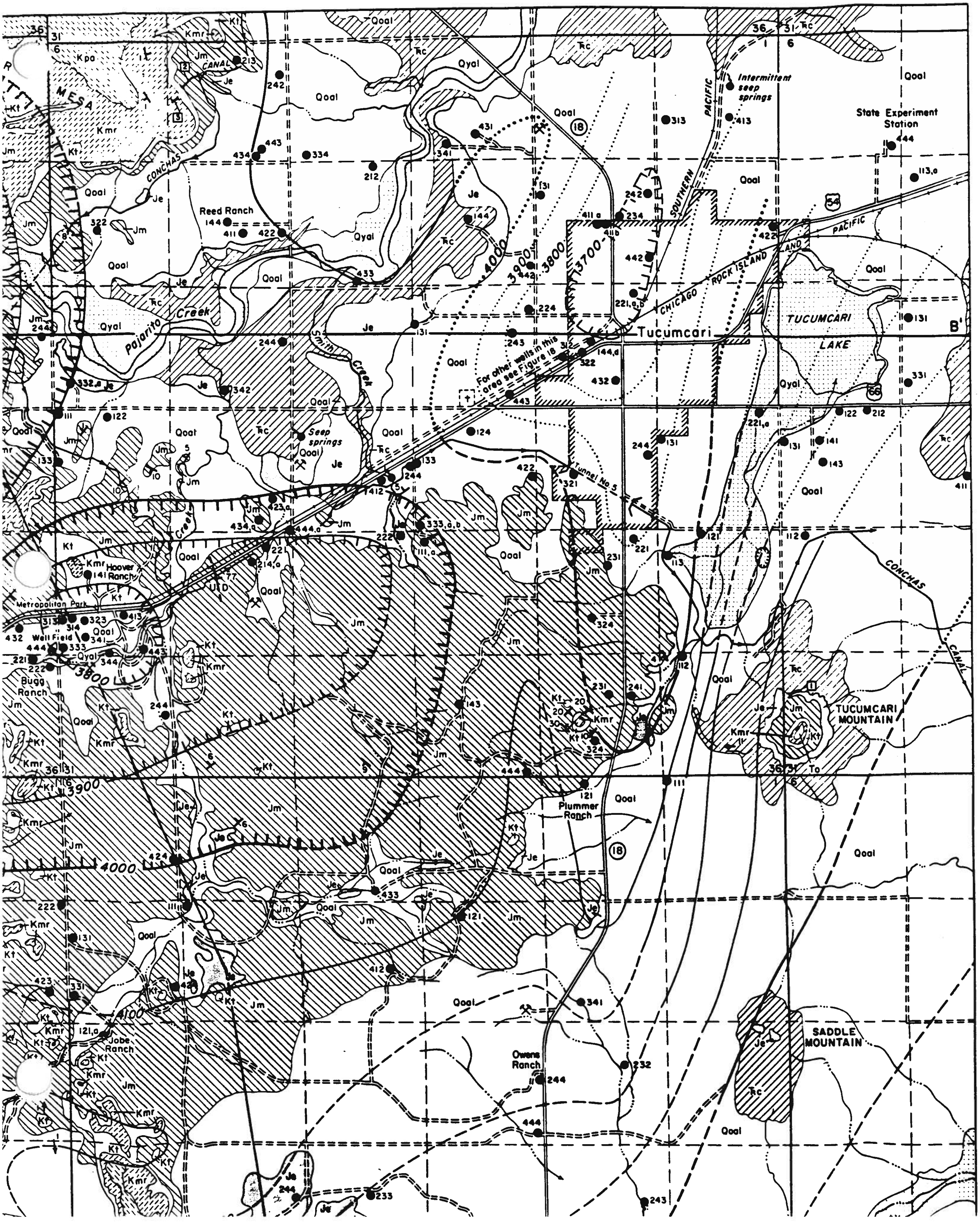
Top of Chalk Bluff

note:
See preceding map for top of
San Andres - Inferred from logs
of deep wells.
Contours are inferred from logs of
deep well in the area

G. Watson

Trauger & Bushman, 1964

R.30E.



Trauger & Bushman, 1964

EXPLANATION

QUATERNARY

Recent

Qyal

Younger alluvium

Silt, sand, gravel, and windblown sand; not mapped where it exists only as a thin cover over older deposits. Water bearing along principal drainageways

Pleistocene

Qoal

Older alluvium

Cobbles, pebbles, and sand, some clay; generally unconsolidated but locally firm to moderately well cemented. Water bearing along principal drainageways, and locally where it occurs as thick deposits under the plains or upland basins

TERTIARY

Pliocene

To

Ogallala Formation

Caliche caprock on Tucumcari Mountain, gravel, sand, and conglomerate elsewhere. Not water bearing

CRETACEOUS

Lower Cretaceous

Kpa

Pajarito Shale

Sandy shale, and sandstone, locally conglomeratic near base; generally soft. Not water bearing

Kmr

Mesa Rica Sandstone

Fine- to medium-grained, generally well cemented, cliff-forming. Not water bearing

Kt

Tucumcari Shale

Mostly a shaly sandstone or siltstone, commonly calcareous and fossiliferous. Not water bearing

JURASSIC

Upper Jurassic

Jm

Morrison Formation

Sandstone, shale, and clay; mostly hard, fine- to coarse-grained sandstone in the upper part, shaly in the middle section and clayey at the base. Yields water to wells locally but generally in small quantities

Je

Entrada Sandstone

White fine- to very fine-grained, soft, generally unconsolidated. Principal aquifer of the area

Trauger & Bushman, 1964

Mostly a shaly sandstone or siltstone, commonly calcareous and fossiliferous. Not water bearing

JURASSIC

Upper Jurassic

Jm

Morrison Formation

Sandstone, shale, and clay; mostly hard, fine- to coarse-grained sandstone in the upper part, shaly in the middle section and clayey at the base. Yields water to wells locally but generally in small quantities

Je

Entrada Sandstone

White fine- to very fine-grained, soft, generally unconsolidated. Principal aquifer of the area

TRIASSIC

Upper Triassic

Ŧc

Redonda Formation and Chinle Formation

Mostly red shale and clay in the upper part; sandstone and siltstone reported in drill cuttings from the lower part. The Chinle locally yields small quantities of water to wells

4200

Structure contour

Drawn on top of the Chinle Formation; dashed where approximate; dotted where based on inadequate control. Contour interval 100 feet. Datum is mean sea level

Geologic contact

U D 77

Fault, showing dip

Dashed where approximate. U, *upthrown side;* D, *downthrown side*

8

Strike and dip of beds

1

Direction of prevailing dip

Measured section

A A'

Line of geologic section

241

Well or bore hole -

Number indicates location within section (see figure 2)

Spring

TAB 4 Part B.2 Subsurface geologic maps: isopach maps

Bassett and Bentley, 1982

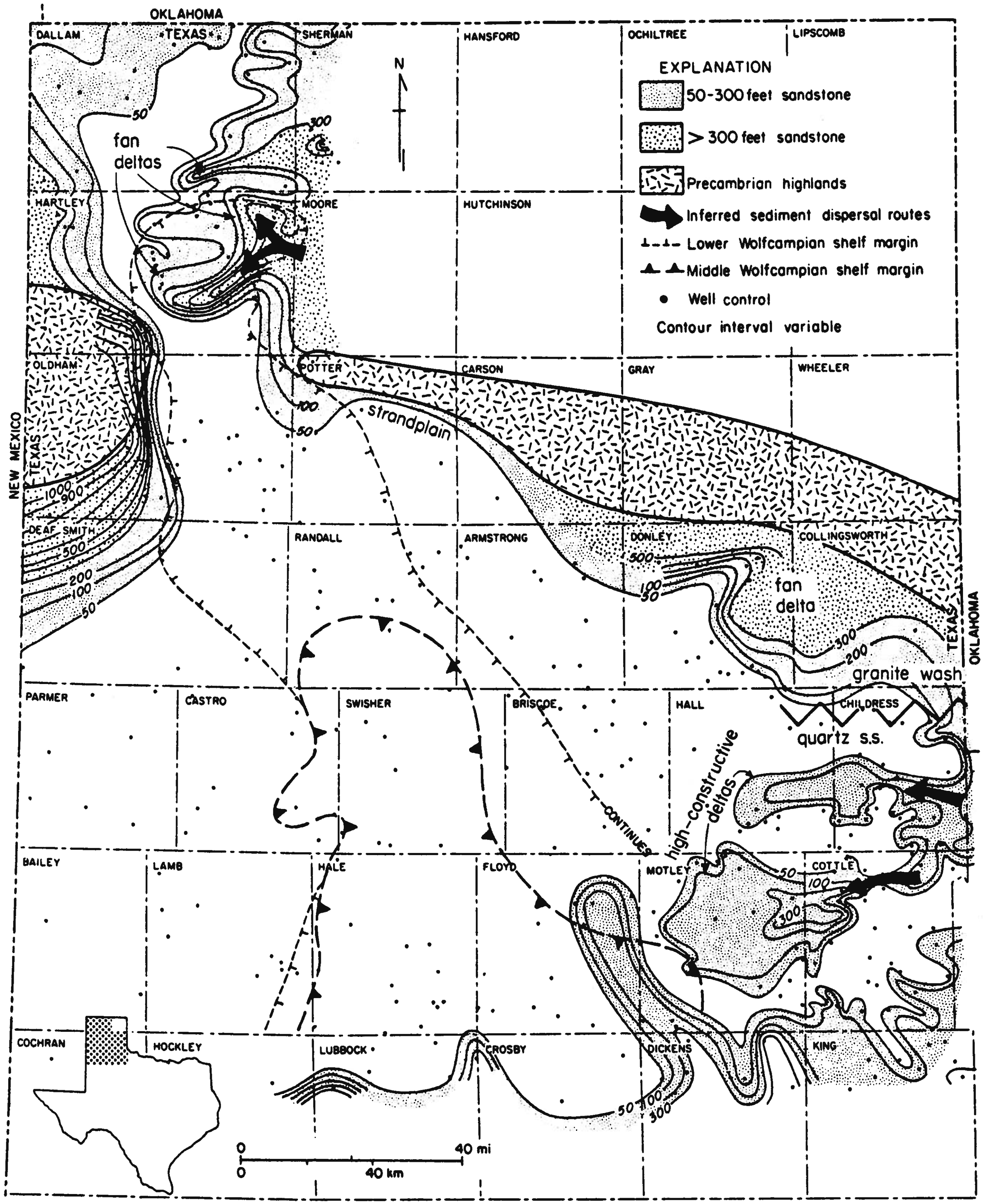


Figure 3. Net-sandstone map of Wolfcampian Series (from Dutton and others, 1979).

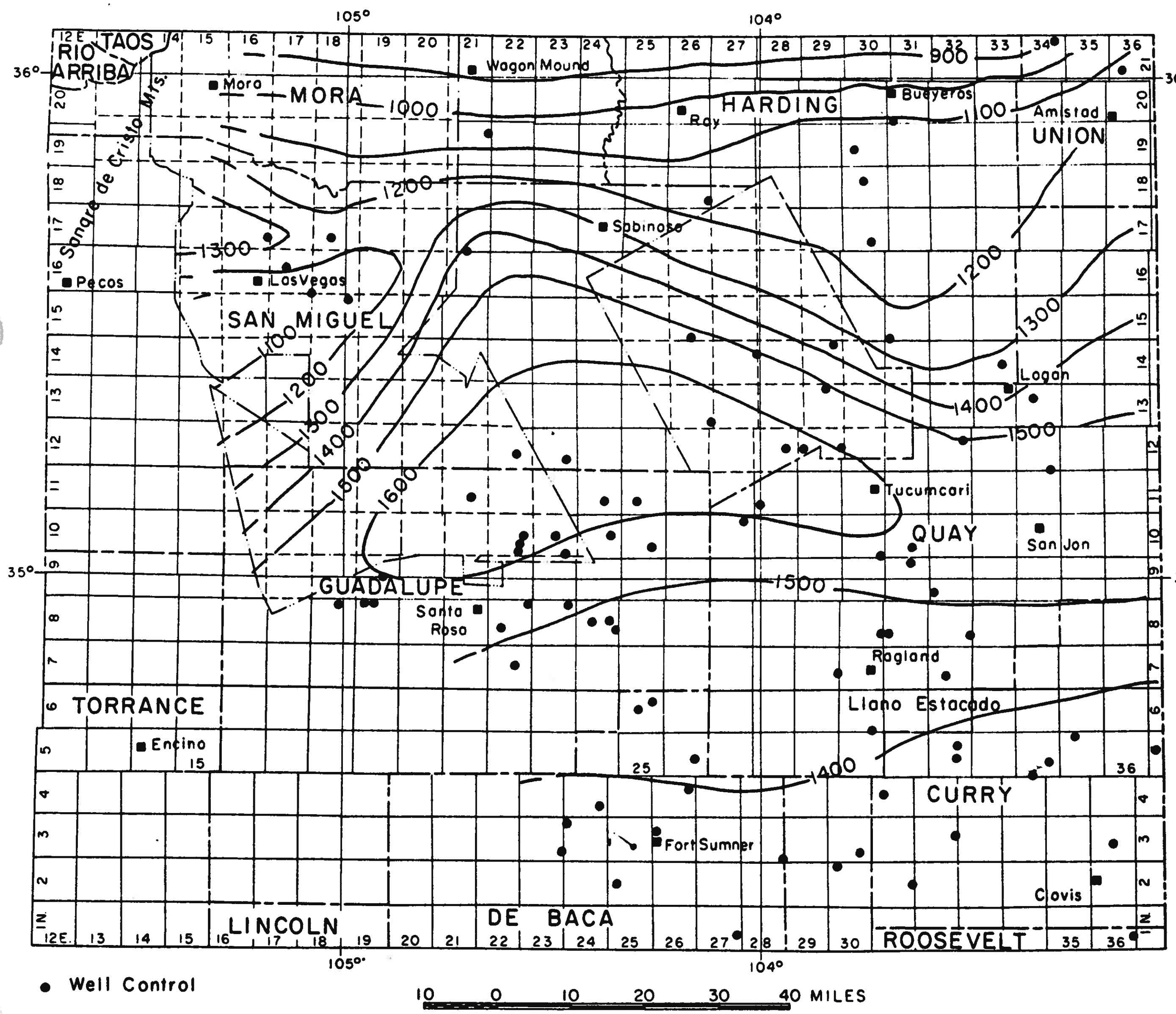
Exeter Sandstones. He described the Exeter (Ocate) as a gray, medium to massive-bedded cross-laminated sandstone about 50 feet thick. Wanek (1962) observed that it consists of massive beds of conspicuously cross-laminated fine-grained grayish-orange to reddish-orange sandstone again about 50 feet thick. Wanek suggests the origin is eolian based on cross-lamination and uniform lithology. From well data a range in thickness from 40 to 228 feet is indicated although the thickness is normally less than 100 feet. It is about 175 feet thick on the north face of Tucumcari Mountain. The maximum thickness of 228 was noted in well logs in Metropolitan Park west of Tucumcari (Trauger and Bushman, 1964, p. 149).

TRIASSIC SYSTEM

Rocks of Triassic age are extensively exposed in east-central New Mexico.

Figure 2 is an attempt to restore the thickness of Triassic rocks left following pre-Exeter and pre-Cretaceous erosion cycles. The interval thickens to the south, and there is a suggestion of the beginnings of the thinning south of the overlap of the Jurassic by the Cretaceous. In western New Mexico the thinning is very abrupt south of the Cretaceous overlap. The absence of Cretaceous rocks beneath much of the Llano Estacado probably will limit the determination of events of similar nature in this area.

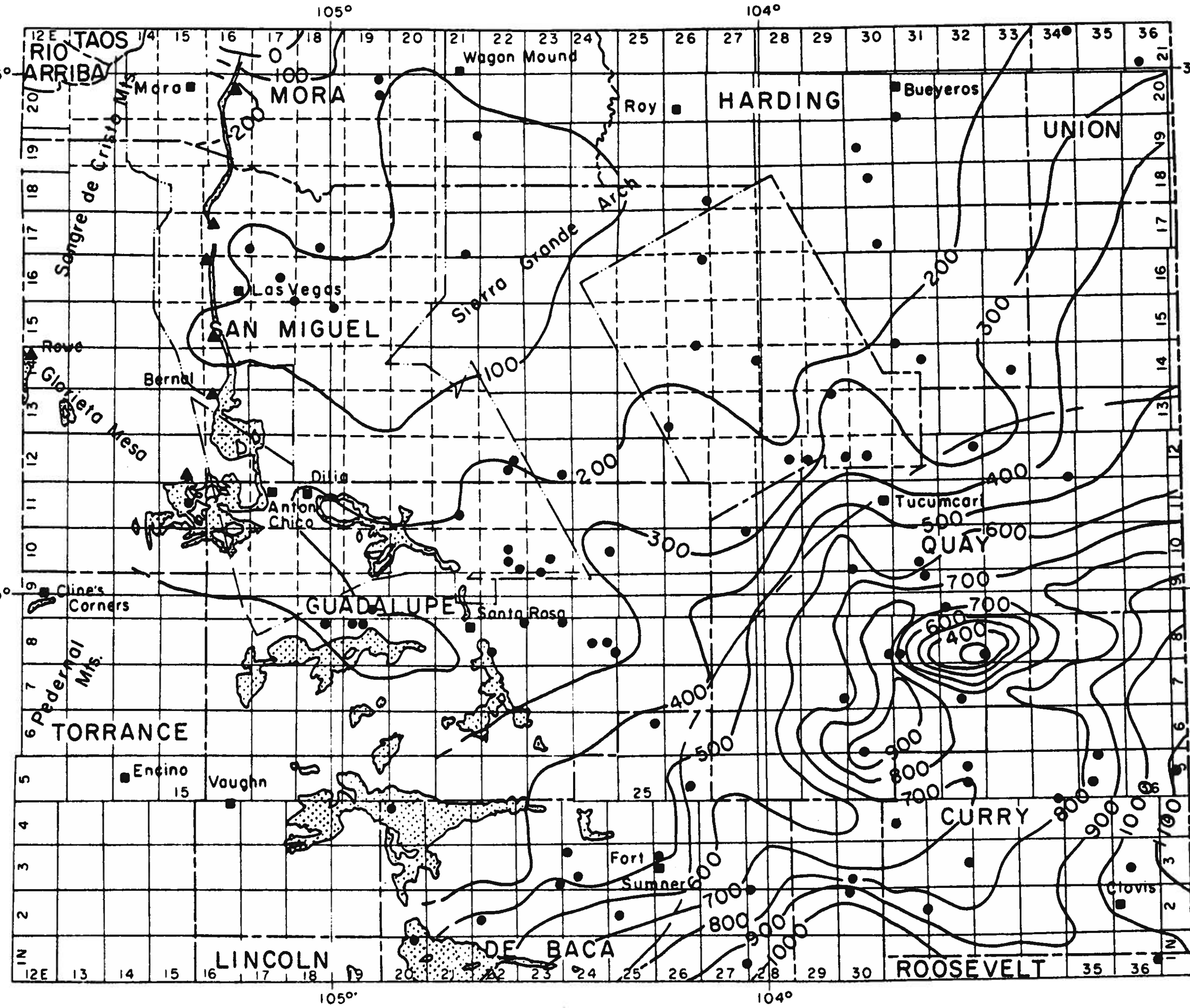
In general the Triassic has been subdivided into the Santa Rosa Sandstone at the base and the Chinle Formation above, or the entire interval is referred to as the Dockum Group. In the Tucumcari area Dobrovolny and Summerson (1946) named a contrasting upper interval the Redonda Member. Later Griggs and Read (1959) elevated this interval to formational status. In addition to these more formalized units a middle sandstone-conglomerate interval has been recognized in much of the area.



Contour Interval: 100 feet

Figure 2. Isopach Map of Triassic Rocks (Restored).

Foster, et al., 1972



● Well Control
▲ Surface Control
Outcrop Distribution
---Approximate northern limit of salt

10 0 10 20 30 40 MILES

Contour Interval: 100 feet

Figure 3. Isopach Map of Bernal-Artesia Group.

Glorieta-like sandstones. Beds of salt extend west to the Cuervo-Fort Sumner area and as far north as the vicinity of Logan. The extent of salt is shown on the isopach map.

Similar to the Artesia Group sediments the thickest sections of the San Andres occur in the southeastern part of the area where it locally is as much as 1,200 feet thick. From here it thins to the north and west with some rather striking areas of local thinning. The thin areas southeast of Santa Rosa and northwest of Tucumcari probably reflect continuing adjustments along the structural features discussed later. Whether this represents continued movement along the suggested faults or compaction in basinal areas interspersed with structurally stable high areas is not known. In any event the potential for combined stratigraphic-structural traps would appear to be good. The high northwest of Tucumcari also is reflected in the isopach maps of underlying units but the same is not true of the thin area of San Andres-Glorieta south of Santa Rosa. In part of course this may represent a facies change into Yeso-like sediments and thus the apparent thinning may be misleading as far as the over-all Permian thickness is concerned. In any event the typical facies of the San Andres does thin in this area.

At Rowe the Glorieta consists of 190 feet of fine-grained, cross-bedded sandstone with minor dark-red and greenish-gray shale at the top. West of Las Vegas Northrop et al. (1946) show a range in thickness from a little over 100 feet at Montezuma to 290 feet at La Manga. Sections north of Montezuma are in excess of 200 feet thick so a general northward thinning cannot be demonstrated in this area. At the Mora River Gap the Glorieta consists of 205 feet of fine-grained sandstone with minor thin shales and some siltstone. In the Ocate area Bachman (1953) describes the Glorieta as gray to light-brown, medium-grained, cross-laminated sandstone. In a section four miles northwest of Ocate he measured 256 feet but notes that it is absent in the Cimarron Mountains

Foster, et al., 1972

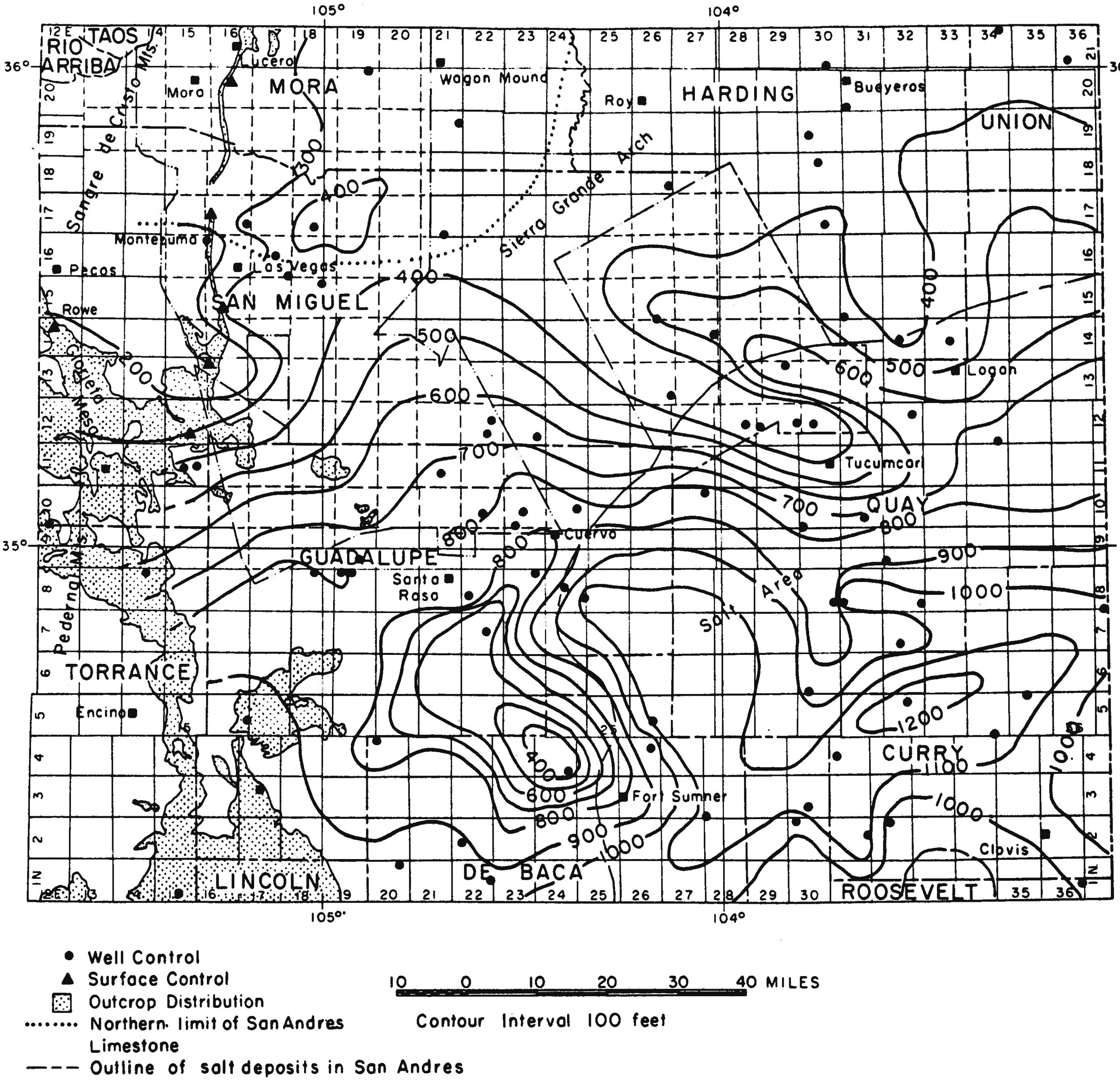


Figure 4. Isopach Map of San Andres-Glorieta Formations.

15 miles north of Mora County. He suggests the possibility that the Glorieta intertongues to the north with the Sangre de Cristo Formation. Baltz and Bachman (1956) note that north of the Mora River Gap the Glorieta coarsens in its lower part and in the vicnity of Lucero Gap contains some conglomerate at the base. They state that the Glorieta grades laterally into the Sangre de Cristo Formation between Guadalupita and Black Lake (north of the map area).

In the Tucumcari area of Quay County the Glorieta is thin or absent. As observed by Bates (Dobrovolny and Summerson, 1946) the eastern extent of Glorieta-like sandstone is approximately R. 31 E. Locally to the east there are sandstones resembling the Glorieta in the approximate position of this sandstone but these may represent isolated development of offshore bars beyond the general limit of Glorieta deposition.

Yeso Formation

For the most part the Yeso Formation has not been subdivided into the various members used in the oil field areas or those used to the west in central New Mexico. Meseta Blanca and San Ysidro members were used by Read et al. (1945) and others on Glorieta Mesa and locally in the subsurface of east-central New Mexico. Some geologists have used Clear Fork, Tubb, Cimarron and Fullerton for various parts of the Yeso indicating possible correlations with subsurface and surface

Foster, et al., 1972

sections to the south and northeast. The Cimarron Anhydrite is a useful marker bed in most of the area.

As can be seen on the isopach map (Fig. 5) the thickest sections are to the southeast and the unit thins quite uniformly to the north and northwest. The thinning is considerable from 3000 feet in the southeast to only 160 feet in a well drilled west of Wagon Mound. On the higher parts of the Sierra Grande arch it is less than 400 feet in thickness. Earlier structural elements also are reflected in the Tucumcari-Logan areas and west of Santa Rosa.

The Yeso Formation crops out in the slopes of Glorieta Mesa, along the foothills west of Las Vegas and extensively around the Pedernal Mountains where it overlaps the Abo Formation onto the Precambrian. At the Rowe section it consists of orange to dark-red sandstone, siltstone and shale. Sandstones are mostly very fine-grained with coarser grains occurring in some beds and apparently increasing in amount toward the base of the section. In the upper part of the Yeso there are three thin silty carbonate intervals, the lower of which contains chert nodules. The section remains quite uniform in exposures to the east along Glorieta Mesa and continues to contain some carbonate in the upper part. North of Agua Zarca the unit thins rapidly but still contains one or two thin beds of dolomite. At Mora River Gap dolomites are lacking. The upper part contains very fine- to fine-grained sandstone with thin intervals of dark-red shale. Grain size increases in the lower part and the basal thirty feet contains small pebbles of quartz, quartzite, and feldspar. Baltz and Bachman (1956) note that a short distance north of Mora the Yeso grades laterally into arkose and red siltstone that cannot be distinguished from the Sangre de Cristo Formation.

The Yeso is 546 feet thick at Rowe; 230 feet at

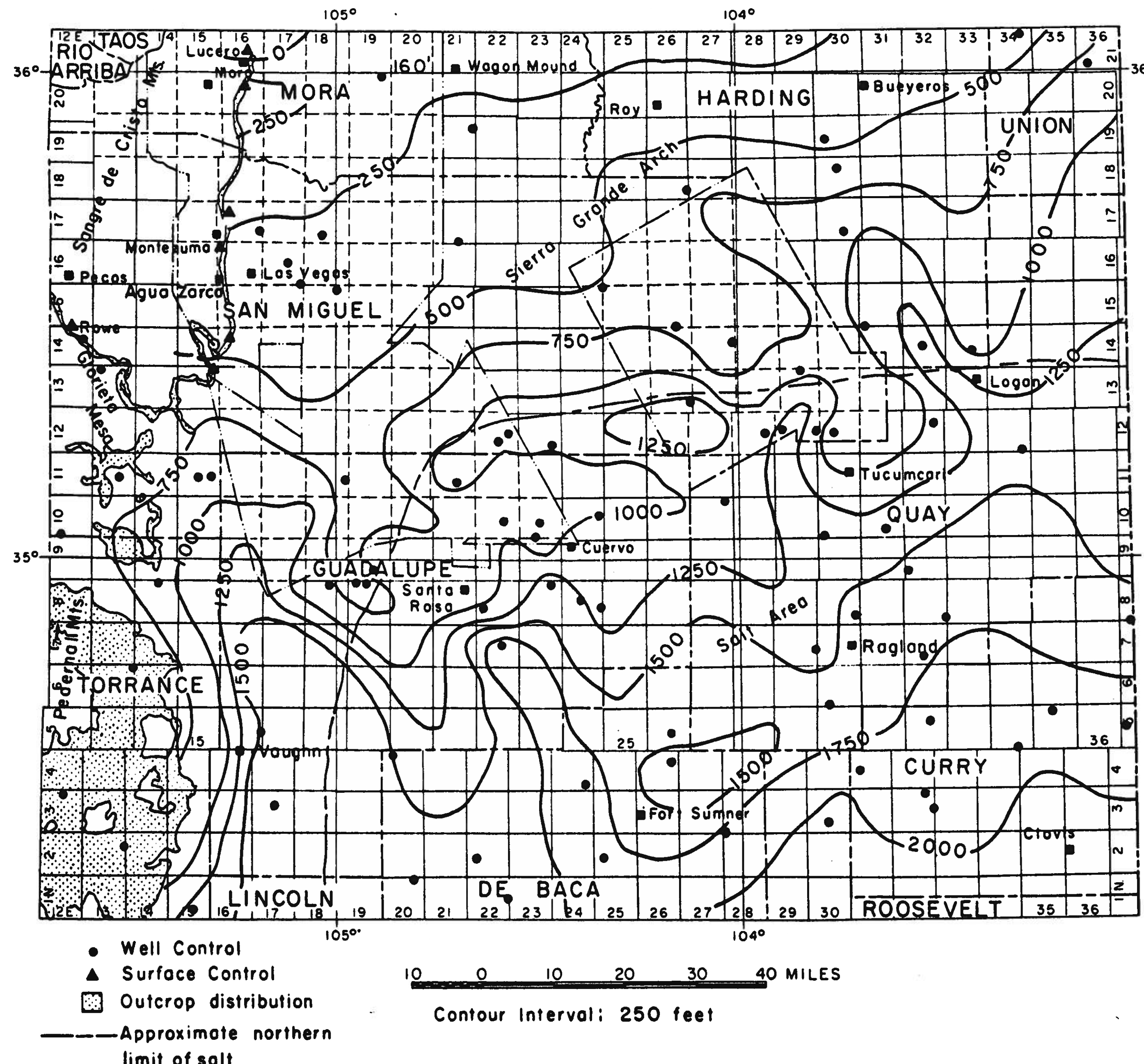


Figure 5. Isopach Map of Yeso Formation.

Foster, et al., 1972

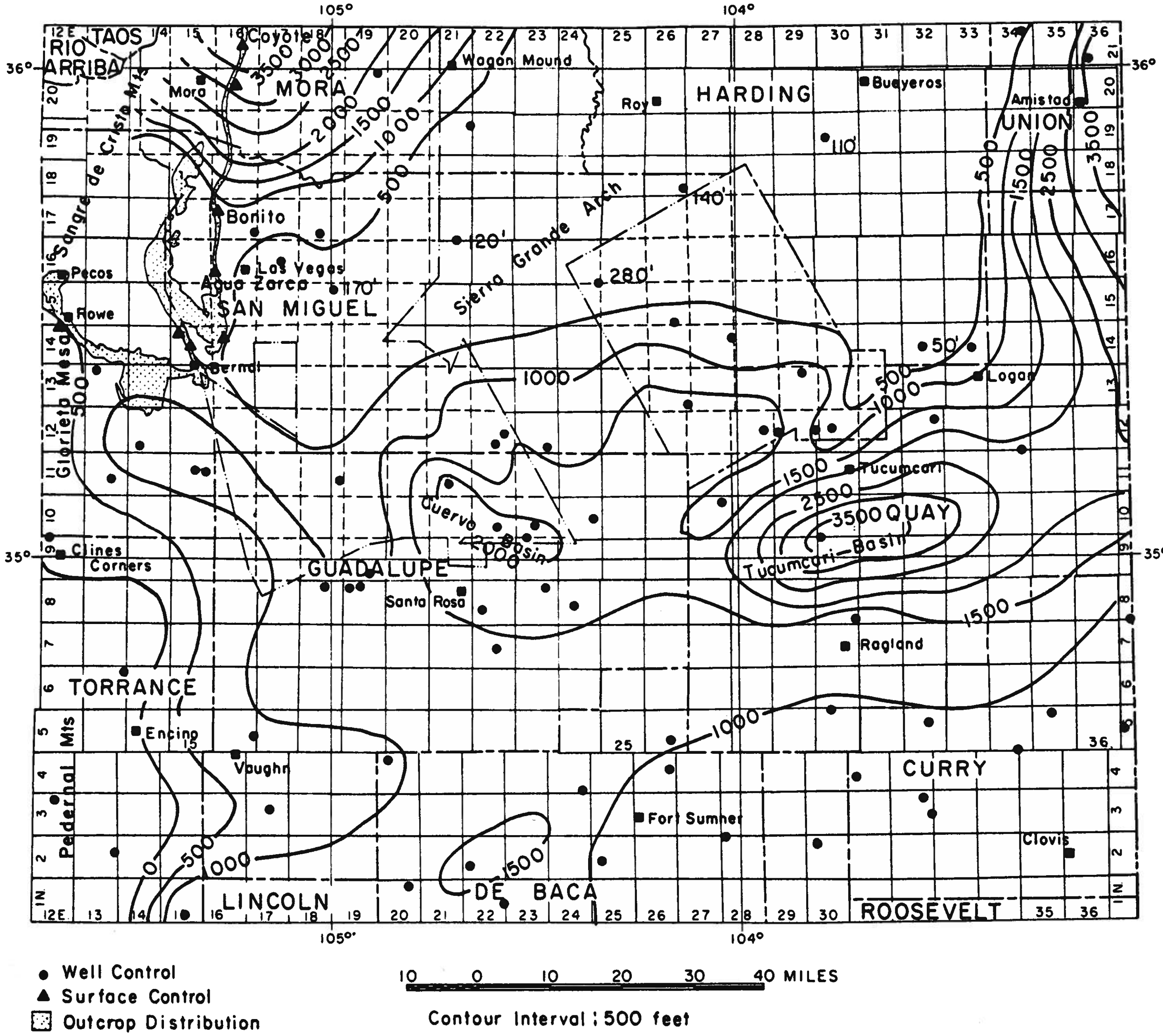


Figure 6. Isopach Map of Sangre de Cristo-Abo Formation.

the La Pasada thickens abruptly and the entire section is dominated by terrigenous material (Flechado Formation). Limestones are sparse in the lower part of the Flechado but similar to those of the Pecos Canyon section.

The La Pasada-Flechado formations are Morrowan to middle Desmoinesian in age. The source of the clastic material was the Uncompaghre highland to the west. Sutherland suggests that the source area consisted of Precambrian metasediments because of the low percentage of feldspar in this part of the Pennsylvanian. The La Pasada was deposited on a marine shelf named the Pecos shelf by Sutherland. This shelf was flanked on the north by the Taos trough (Rowe-Mora basin of previous workers), that extended east of Las Vegas and west at least as far as Santa Fe. The shelf was bordered on the south by the Pedernal uplift; a positive element that apparently remained above sea level during most or all of Pennsylvanian time. The lower part of the Flechado Formation consists of a series of alluvial deposits alternating with minor near-shore marine units. The upper part consists of anastomosing alluvial fans, that thin eastward, and include a few interbeds of shallow water near-shore marine deposits.

The Alamitos Formation consists of arkosic sandstones and conglomerates, limestones, shales, and siltstones. Almost all the limestones are sandy biosparudites to biosparites and in addition to quartz almost all contain some feldspar. The Uncompaghre highland continued to be active during deposition of the Alamitos Formation and remained high during the rest of Pennsylvanian time and at least locally well into Mesozoic time.

Extensive granite outcrops supplied the coarse arkosic material of the Alamitos Formation. The lower part of the interval consists of alluvial fan and deltaic deposits with periodic shallow marine invasions. The upper part represents the final major marine invasion of the southern part of the

Foster, et al.,

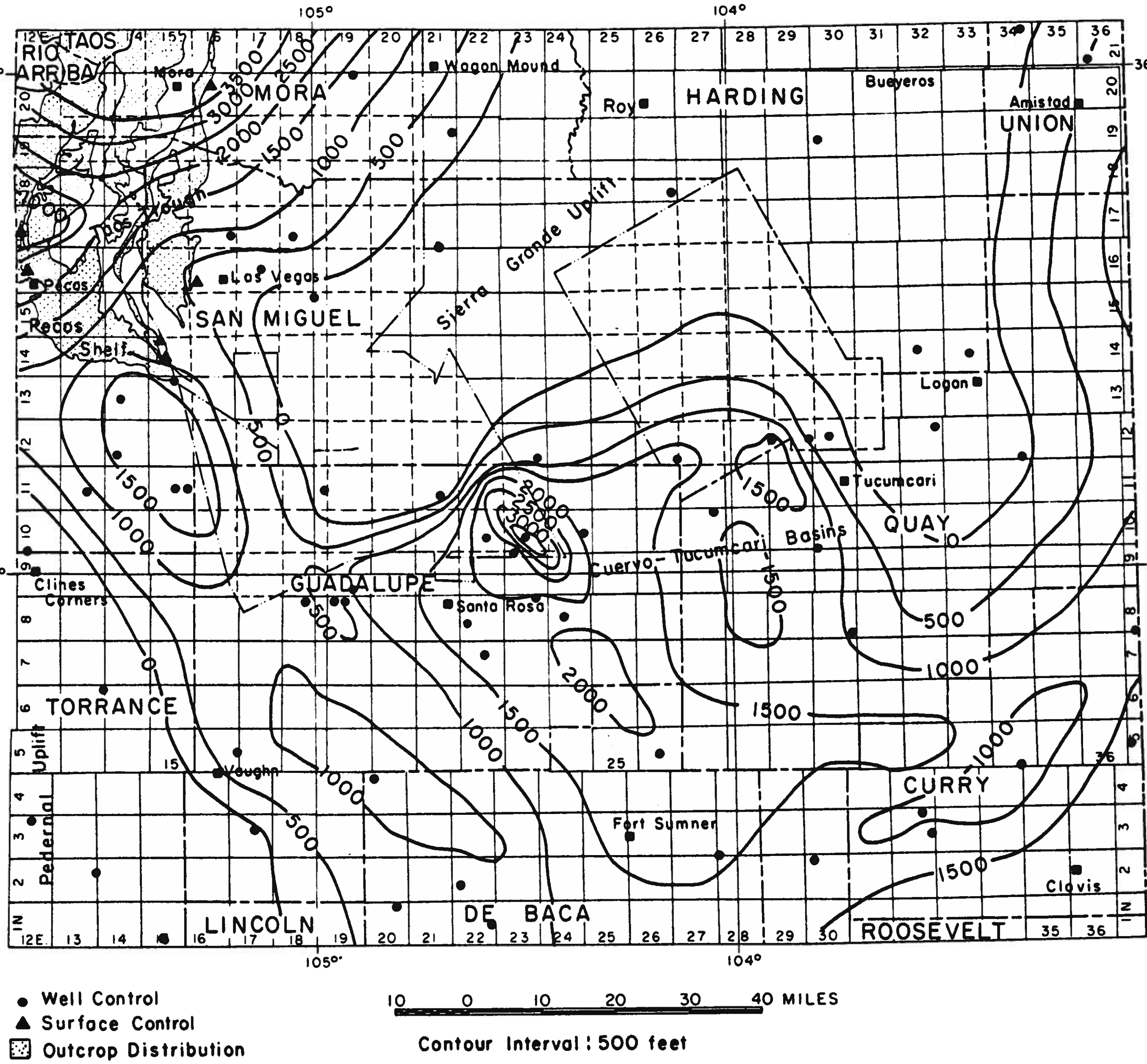


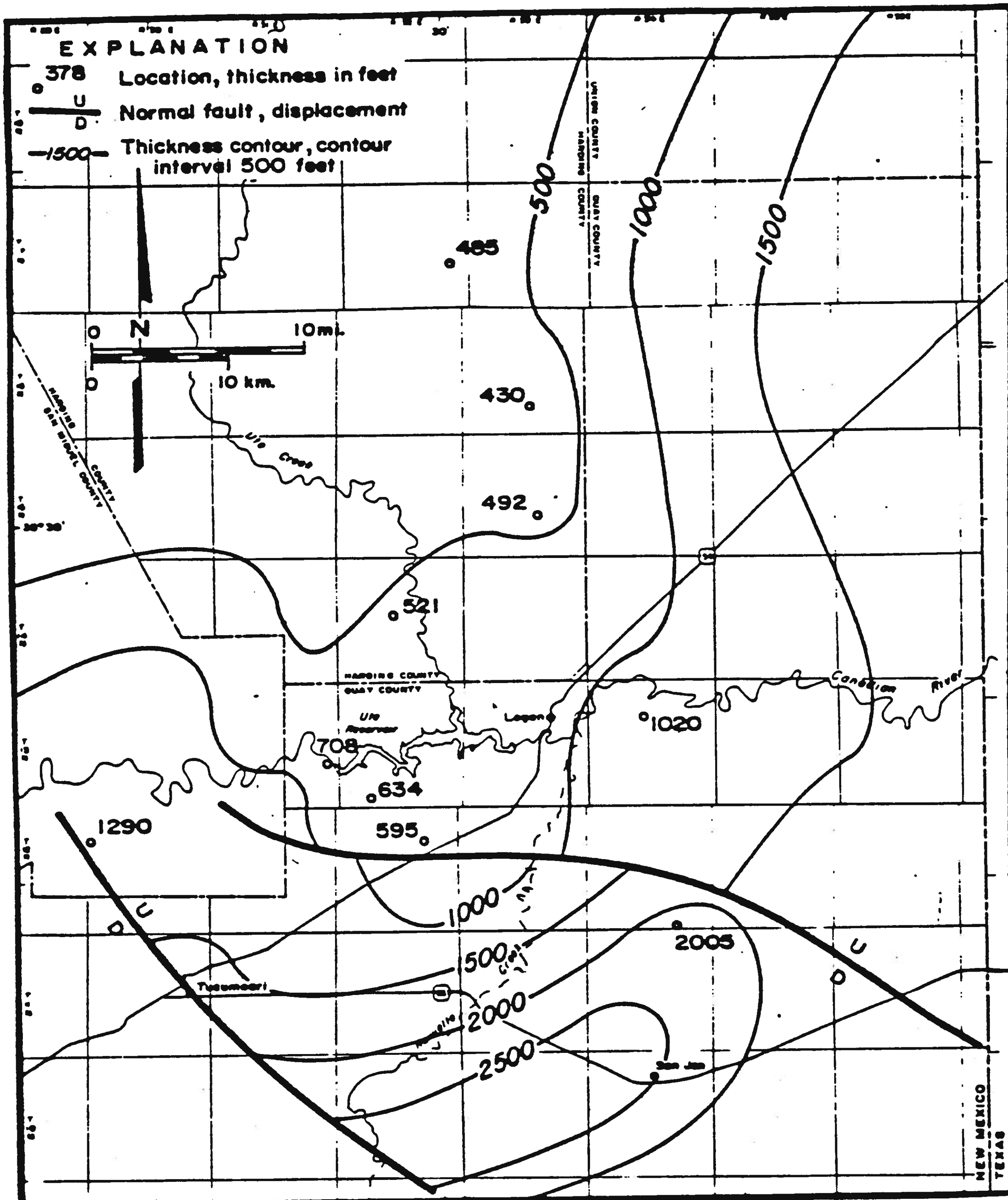
Figure 7. Isopach Map of Pennsylvanian Sediments (Restricted).

of this interval in the Pecos Valley. The section thins to the east in the subsurface of Mora County. Total thickness of known Pennsylvanian strata are 3,655 feet in the Mora River Gap section but part of the sequence may have been cut out by thrusting. The total thickness measured by R. L. Bates and R. W. Foster in Pecos Canyon is 2,303 feet.

MISSISSIPPIAN SYSTEM

Rocks of Mississippian age crop out in the Sangre de Cristo Mountains and have been penetrated in numerous wells in east-central New Mexico. The area underlain by these rocks is shown in Figure 8. Mississippian strata consist for the most part of carbonate with minor shale and sandstone. In the area from Tucumcari to Santa Rosa and south to Fort Sumner rocks of this age range in thickness from approximately 25 to 170 feet. From Santa Rosa west the thickness varies from about 20 to slightly over 140 feet. Thus throughout the area of preserved Mississippian strata about 100 feet of section can be expected although normally the interval would be somewhat thinner.

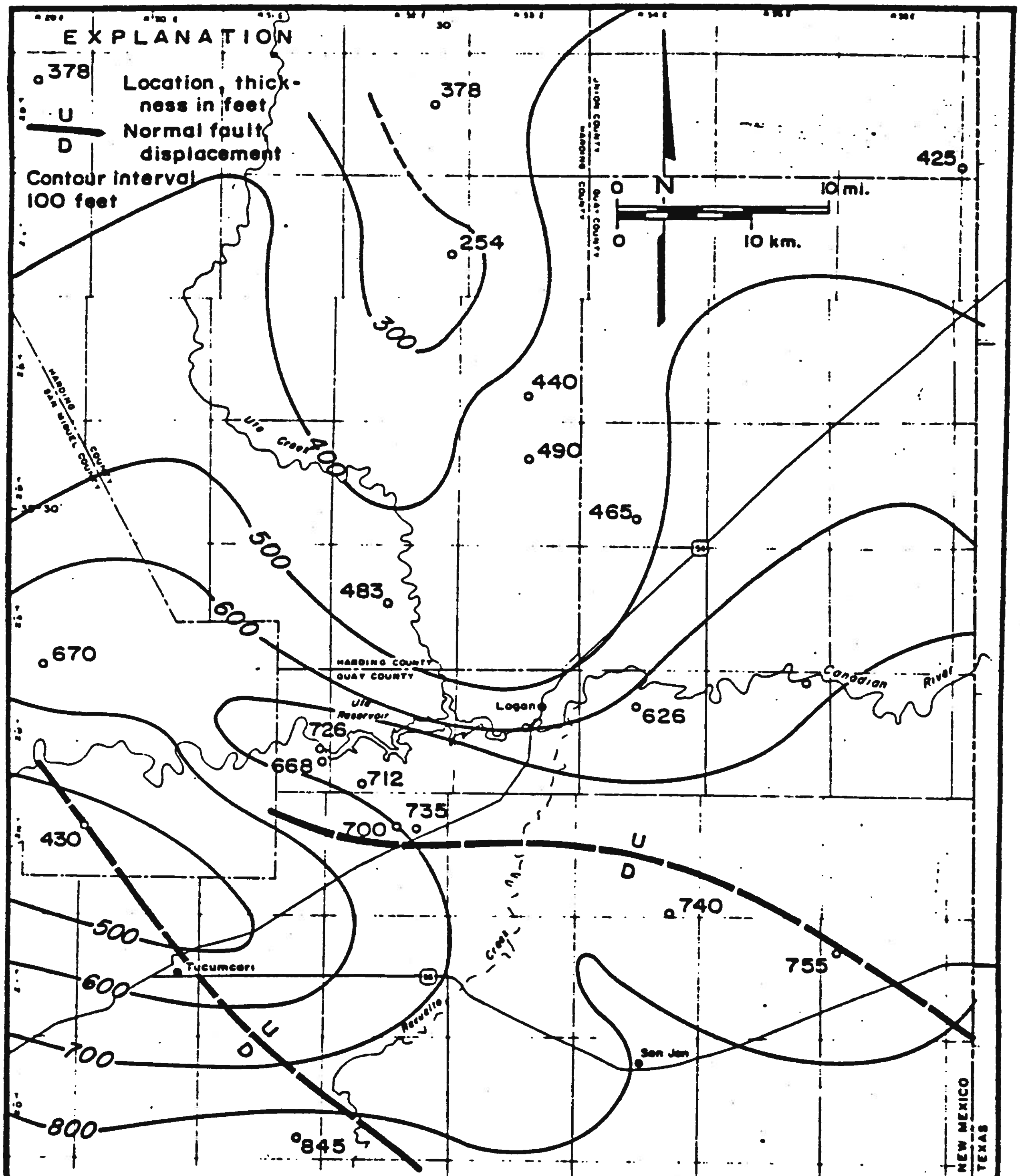
Mississippian rocks were originally assigned to the basal member of the Sandia formation and considered Pennsylvanian in age. Many early geologists realized that this member likely was of pre-Pennsylvanian age and Henbest (1946) reported *Endothyra baileyi* (Hall) from the lower member of the Sandia in the Sangre de Cristo Mountains and on the basis of this foraminifera correlated this member with the Leadville Limestone of the San Juan Mountains. Armstrong (1955, 1958, 1967) correlated the Mississippian of the Sangre de Cristo Mountains with his Arroyo Penasco Formation with type locality in the Nacimiento Mountains, and on the basis of foraminifera considered the rocks to be late Osage and early



Adapted from Foster and others, 1972

Figure 6. Isopach map of combined Abo-Sangre de Cristo Formations

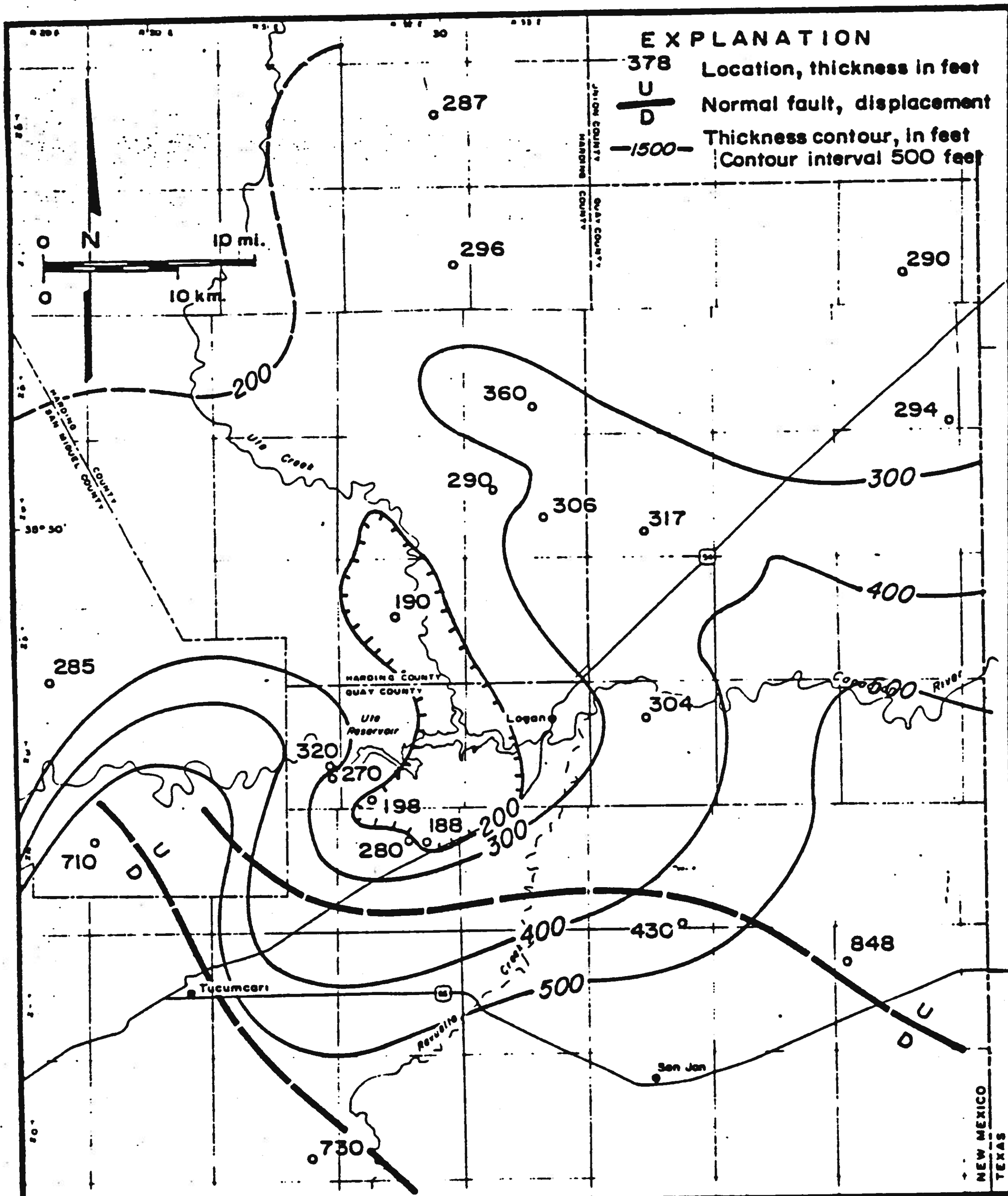
HGC, 1984a



Adapted from Foster and others, 1972

Figure 8. Isopach map of San Andres

HGC, 1984a



Adapted from Foster and others, 1972

Figure 9. Isopach map of the Artesia Formation

HYDRO GEO CHEM, INC.

TAB 4 Part B.3 Subsurface geologic maps: salt dissolution

Gustavson and Finley, 1985

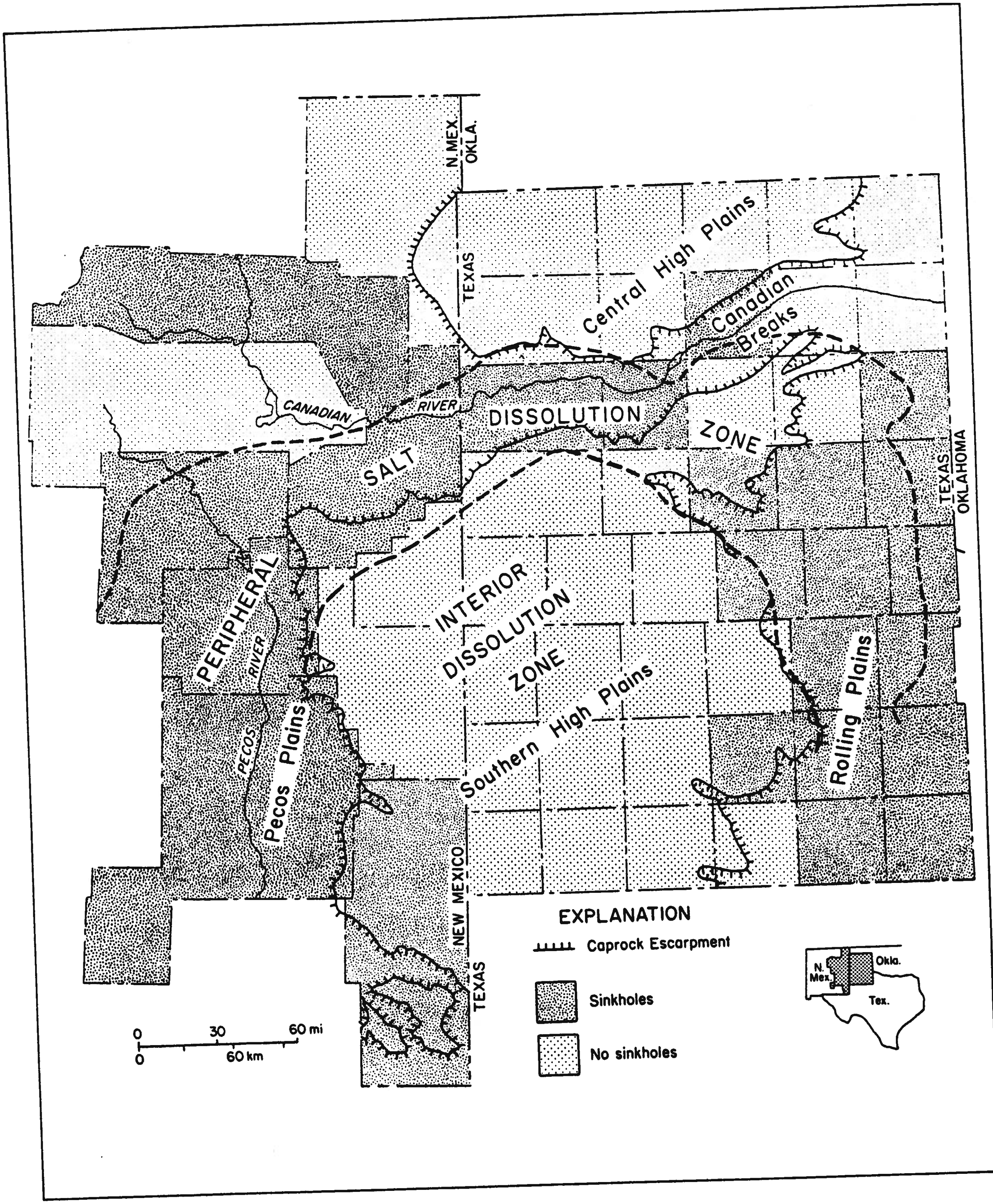


Figure 19. Texas and New Mexico counties, from which sinkholes and fractures have been reported, lying mostly within a peripheral dissolution zone that encompasses the Pecos Plains, the Canadian River Breaks, and the Rolling Plains. Sinkholes and open fractures have not been reported from the Southern High Plains or the Central High Plains within eastern New Mexico or the Texas Panhandle.

Gustavson, et al., 1980 a

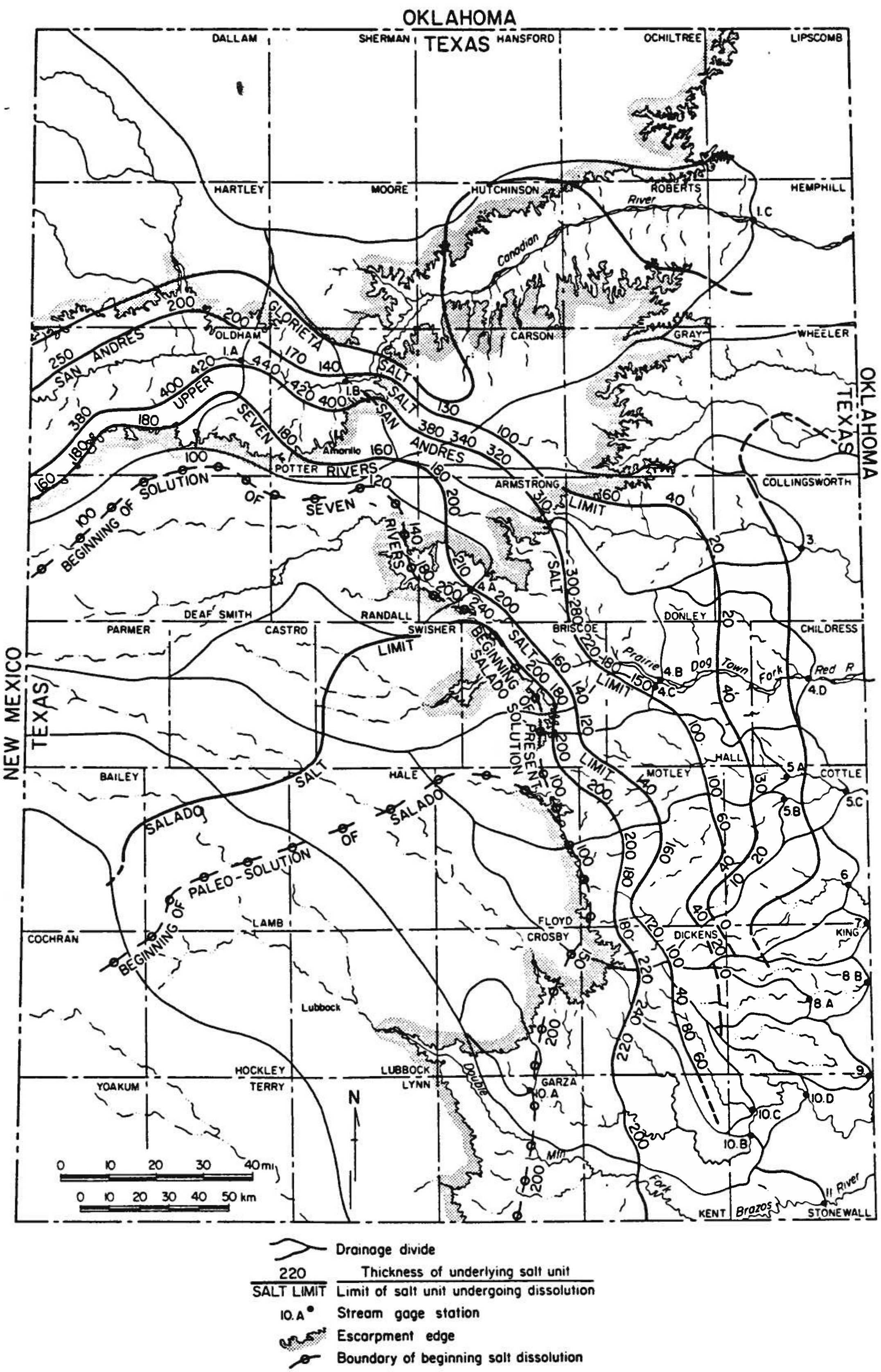


Figure 29. Watersheds and associated water quality sampling stations. Lines marked "beginning of dissolution" indicate the limit of the complete salt section for the Salado and Seven Rivers Formations. Salt dissolution occurs north and east of these lines.

Gustavson, et al., 1980b

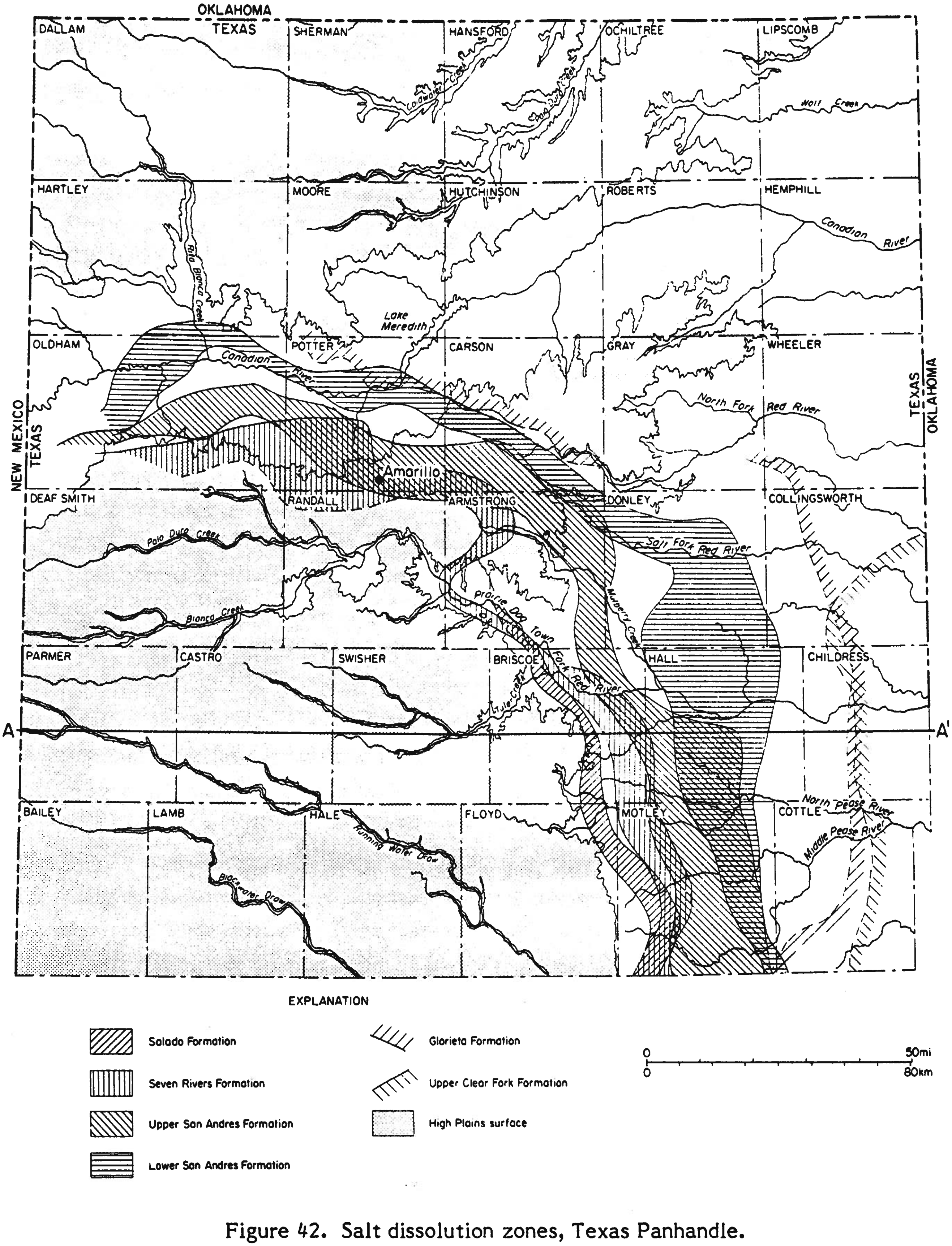
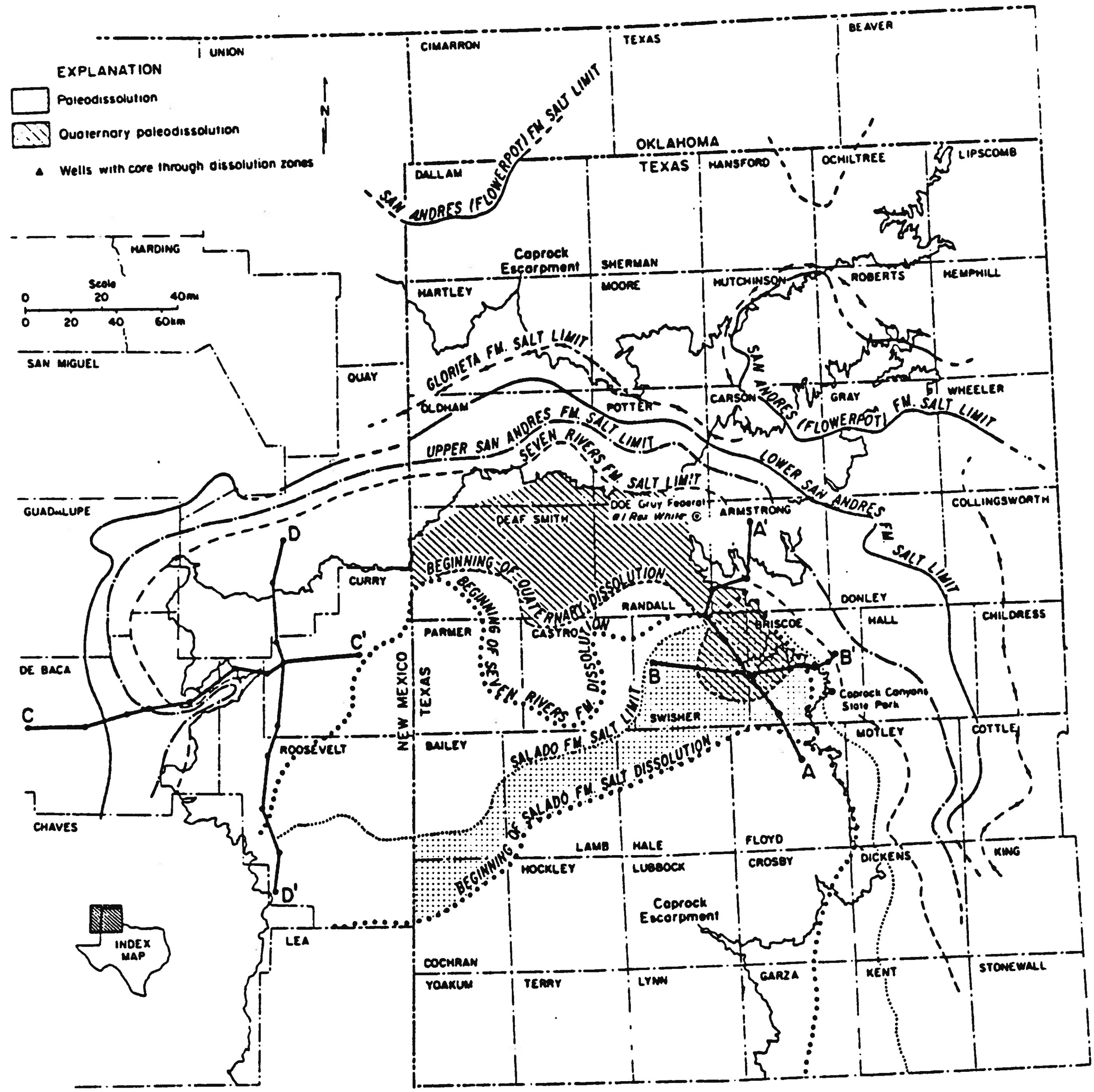


Figure 42. Salt dissolution zones, Texas Panhandle.

HGC, 1984c



EXPLANATION
Paleodissolution
Quaternary paleodissolution
Wells with core through dissolution zones
N
Scale
0 20 40mi
0 20 40 60km
UNION
CIMARRON
TEXAS
BEAVER
OKLAHOMA
TEXAS
DALLAM
HANSFORD
OCHILTREE
LIPSCOMB
HARDING
SAN MIGUEL
HARTLEY
SHERMAN
MOORE
HUTCHINSON
ROBERTS
HEMPHILL
Caprock Escarpment
QUAY
OLDHAM
POTTER
CARSON
GRAY
WHEELER
GUADALUPE
DEAF SMITH
ARMSTRONG
COLLINGSWORTH
DOE Gruy Federal #1 Rex White
CURRY
RANDALL
DONLEY
PARMER
CASTRO
BRISCOE
HALL
CHILDRESS
DE BACA
NEW MEXICO
TEXAS
SWISHER
Caprock Canyons State Park
ROOSEVELT
BAILEY
MOTLEY
COTTLE
CHAVES
LAMB
HALE
FLOYD
HOCKLEY
LUBBOCK
CROSBY
DICKENS
KING
LEA
COCHRAN
YOAKUM
TERRY
LYNN
GARZA
KENT
STONEWALL
INDEX MAP
SAN ANDRES (FLOWERPOT) FM. SALT LIMIT
GLORIETA FM. SALT LIMIT
UPPER SAN ANDRES FM. SALT LIMIT
SEVEN RIVERS FM. SALT LIMIT
LOWER SAN ANDRES FM. SALT LIMIT
BEGINNING OF QUATERNARY DISSOLUTION
BEGINNING OF SEVEN RIVERS FM. DISSOLUTION
SALADO FM. SALT LIMIT
BEGINNING OF SALADO FM. SALT DISSOLUTION
A
A'
B
B'
C
C'
D
D'

TAB 4 Part B.4 Subsurface geologic maps: lithology

Bassett and Bentley, 1983

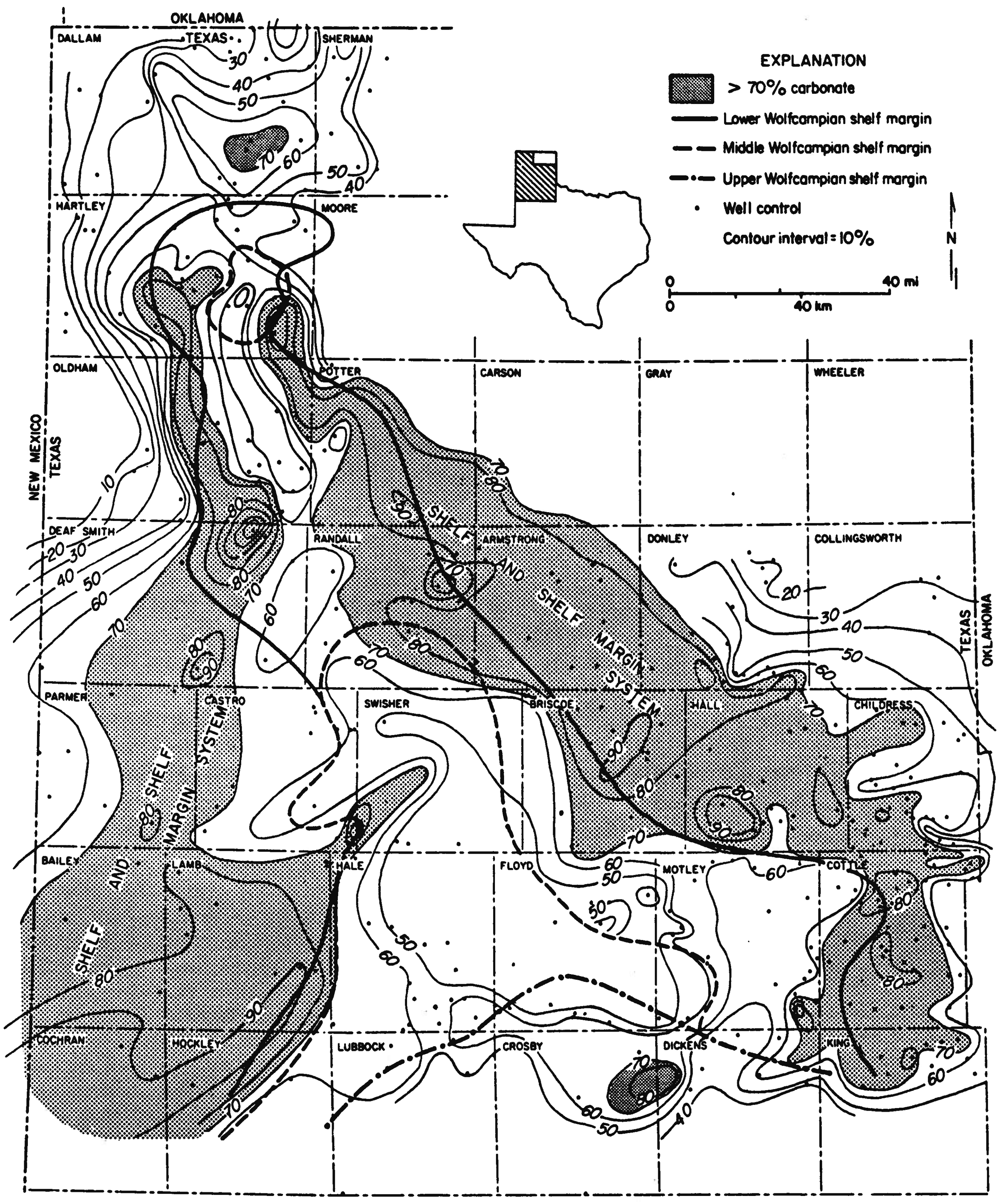


Figure 4. Percent carbonate map of Lower Permian Wolfcamp strata. Position of the shelf margin is shown by dashed line (from Handford, 1980).

Dutton and Simpkins, 1989

Isotopic evidence for paleohydrologic evolution of ground-water flow paths, southern Great Plains, United States

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Bureau of Economic Geology, University of Texas, Austin, Texas 78713

ABSTRACT

A confined aquifer in Triassic Dockum Group sandstone beneath the southern Great Plains was isolated from hypothesized paleorecharge areas in eastern New Mexico by Pleistocene erosion of the Pecos and Canadian river valleys and formation of hydrologic divides. Truncation of the flow system left meteoric water in the confined aquifer with mean δD and $\delta^{18}O$ values that are 17‰ and 2.0‰, respectively, lighter than those in the overlying High Plains aquifer. Thick upper Dockum mudstone retards downward flow from the High Plains aquifer, which has been recharged by isotopically heavy precipitation during the Holocene. Recharge to the confined aquifer occurred at altitudes of 1600 to 2200 m in proximal Dockum sandstone facies since eroded in eastern New Mexico, at a mean temperature 3 °C cooler than present temperature across the southern High Plains. Effects of Pleistocene climatic change on isotopic composition of Dockum ground water could be superposed over geomorphologic effects.

INTRODUCTION

Conceptual hydrogeologic models of regional aquifers seldom consider whether paleohydrologic conditions are responsible for observed hydraulic-head and solute distributions. However, hydraulic-head distribution can gradually change during geologically long durations in response to physiographic evolution (England and Freeze, 1988). If ground water has a long residence time, stable isotopes and dissolved solutes can reflect a preceding flow regime even when hydraulic head is equilibrated with recharge and discharge rates.

The purpose of this paper is to discuss the significance of isotopically light δD and $\delta^{18}O$ compositions of ground water in the Triassic Dockum Group in the Texas Panhandle and eastern New Mexico (Fig. 1). Physiographic and climatic changes are obvious possible explanations of the isotopic depletion. The Pecos and Canadian river valleys were incised during the late Tertiary and Pleistocene (Gustavson and Finley, 1985; Gustavson, 1986). Isotopically light ground waters in other basins have been interpreted as Pleistocene in age and related to climatic variation (Clayton et al., 1966; Perry et al., 1982; Friedman, 1984; Rozanski, 1985). Whether the Pleistocene climate in the southwestern U.S. was generally cooler and wetter than the Holocene climate is uncertain (Barry, 1983; Friedman, 1983), particularly in the study area (Holliday, 1987).

HYDROGEOLOGIC SETTING

The Dockum Group is composed of more than 610 m of conglomerate, sandstone, and mudstone deposited in fan, fluvial, deltaic, and lacustrine environments in a continental basin (McGowen et al., 1979).

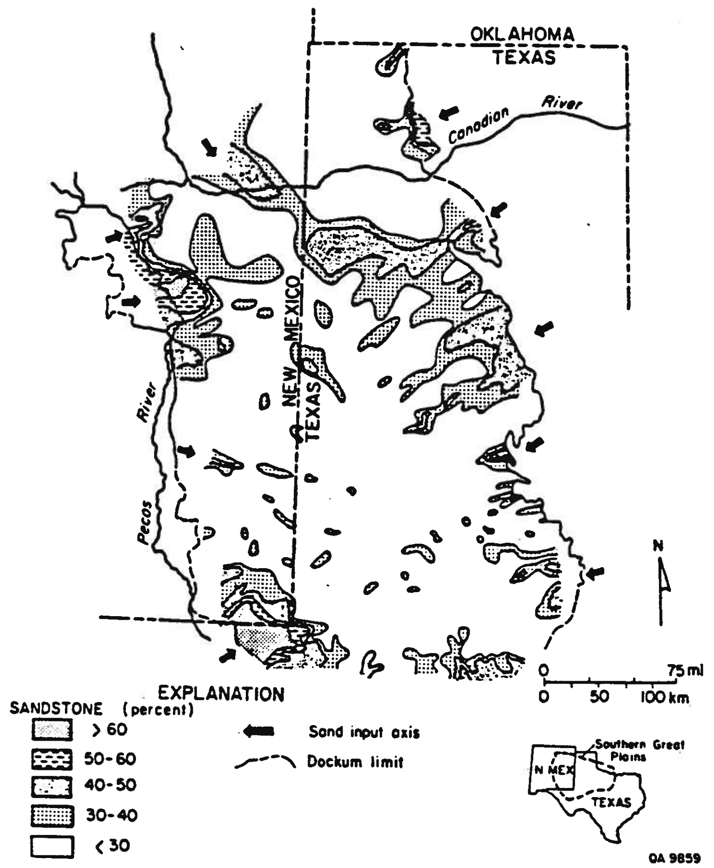


Figure 1. Percent sandstone in lower Dockum Group (modified from J. H. McGowen et al., unpublished map).

Sandstone and conglomerate beds in the lower Dockum Group are discontinuous and occur mainly around the basin perimeter (Fig. 1). In the muddy upper Dockum Group, which acts as a confining unit, thickest sandstone deposits are in southeastern New Mexico and the south-central part of the Texas Panhandle and are not extensive elsewhere (McGowen et al., 1979).

The essentially flat surface of the southern High Plains is inclined to the southeast and bounded by an erosional escarpment (Fig. 2) that has a relief of as much as 265 m. Beneath most of the southern High Plains, the Dockum is overlain by the Miocene Ogallala and Pleistocene Blackwater Draw Formations. Cretaceous Edwards and Trinity Groups subcrop beneath the younger formations in the southern part of the southern High Plains. Similarity of hydraulic head in the Ogallala Formation and Cretaceous rocks suggests that hydrostratigraphic units in these formations are interconnected in the so-called High Plains aquifer (Gutentag et al., 1984; Nativ and Smith, 1987). The Dockum Group overlies Permian evaporites

*Present address: Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706.

TAB 4 Part C. Geomorphic maps

Gustavson and Finley, 1985

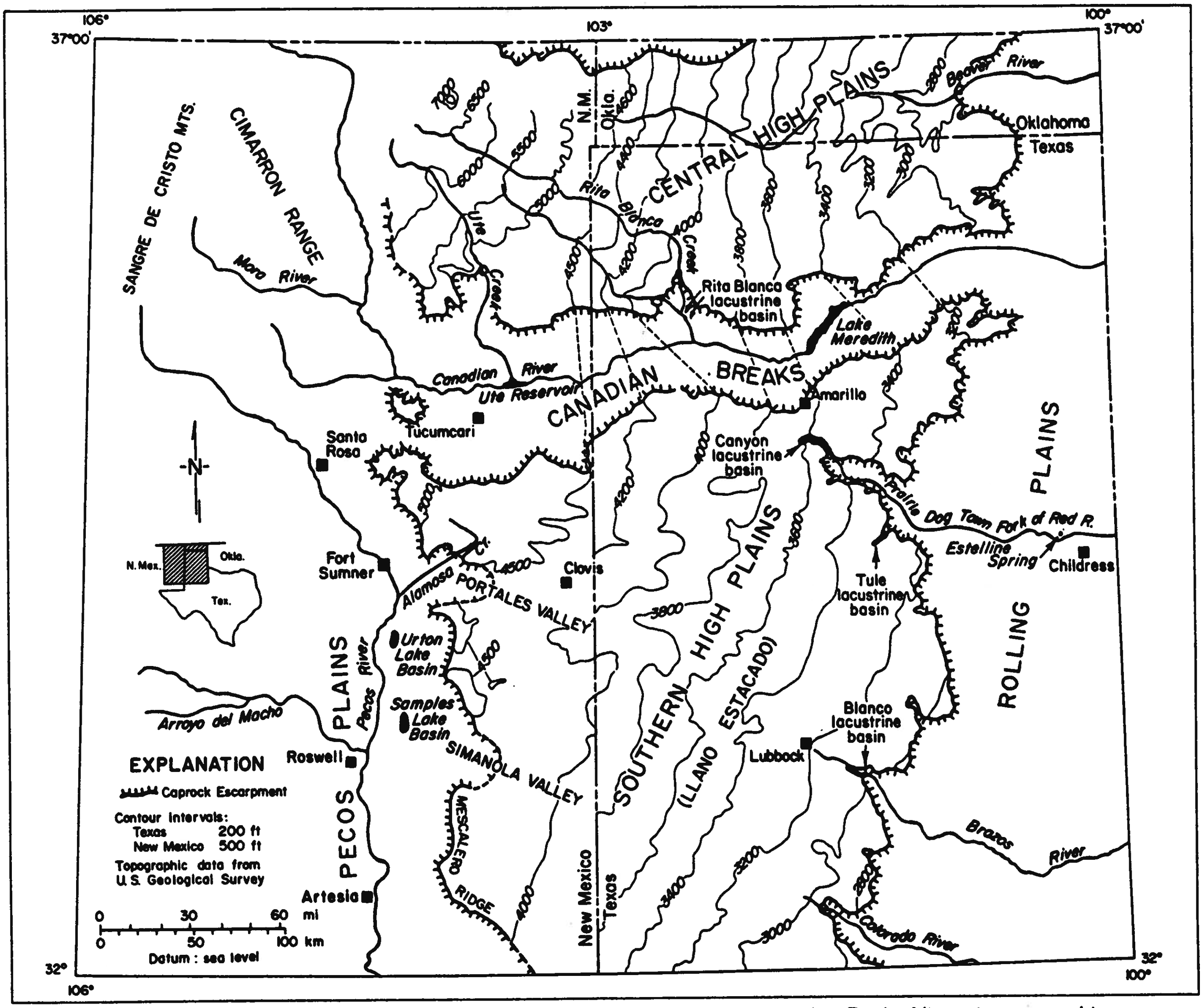


Figure 2. Physiography of eastern New Mexico and the Oklahoma and Texas Panhandles. Dashed lines tie topographic contours across the Canadian Breaks. If the strike of contour lines on the Southern High Plains is projected across the Canadian River valley, it becomes apparent that the northern side of the valley is approximately 80 m (250 ft) lower in elevation than the south rim of the valley.

PHYSIOGRAPHIC DEVELOPMENT OF EASTERN NEW MEXICO AND THE TEXAS PANHANDLE

Methods

The following discussion of the geomorphic evolution of eastern New Mexico and the Texas Panhandle is presented as case studies of drainage systems including the Pecos, Canadian, and Prairie Dog Town Fork Rivers, Tierra Blanca Creek, and other streams draining the Southern High Plains and the Rolling Plains. For each of these areas, field studies were integrated with subsurface studies based on interpretation of geophysical logs and seismic reflection profiles, hydrologic and water quality data obtained from stream-gauging stations, interpretations of aerial photographs and Landsat images, and topographic maps.

Evidence of Dissolution

Regional salt dissolution and the subsequent collapse of overlying strata affected substantial parts of the Texas

Gustavson, et al. 1980a

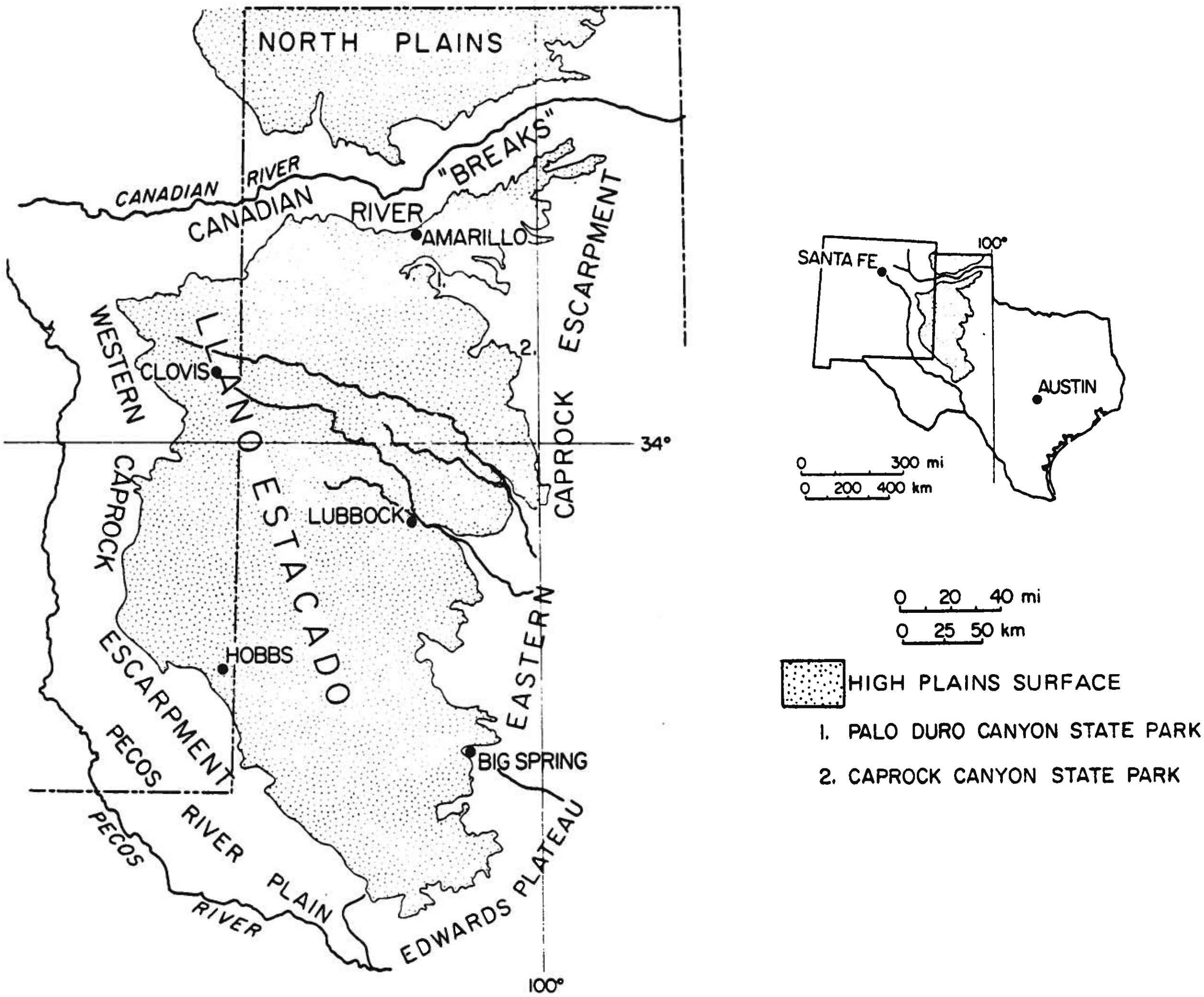


Figure 1. Physiographic units of the Texas Panhandle and eastern New Mexico.

River that is called the Canadian River Breaks. The Great Plains south of the Canadian River are also called the Southern High Plains or the Llano Estacado. To the east and west, the High Plains are truncated at the Caprock Escarpment, an erosional scarp where relief locally exceeds 500 m (1,500 ft). East of the escarpment lie the Rolling Plains. The High Plains of the Texas Panhandle are developed on the Tertiary Ogallala Formation, the remnants of a large alluvial apron that spread eastward as a result of uplift and erosion of the southern Rocky Mountains of New Mexico. Several tens of feet of Pleistocene eolian sediment cap the Ogallala in many areas. Drainage is poorly developed on the Southern High Plains and is mostly internal into the thousands of playas that cover its surface (Woodruff and others, 1979). Integrated drainage exists mainly as a series of extremely elongated rectilinear draws. The Caprock Escarpment is supported by a massive caliche horizon that marks the top of the Ogallala Formation and to a lesser extent by well-indurated sandstones that occur in the upper part of the Triassic Dockum Group. Eastward from the Caprock Escarpment, the Rolling Plains are developed on structurally disturbed Permian red beds. The Pecos River Valley and the Pecos River Plain lie westward of the Southern High Plains.

The major positive tectonic elements that surround the Anadarko, Dalhart, and Palo Duro Basins in the Texas Panhandle (fig. 2) have been described by Nicholson (1960) and Johnson (1976). Tectonic activity that created the series of arches, domes, and uplifts defining the basins occurred primarily during the Pennsylvanian Period and was largely completed by the end of that period. Minor movements have occurred since the Permian, but they may have resulted from differential compaction of basin sediments or from post-tectonic adjustments in the earth's crust.

Gustavson, et al., 1980a

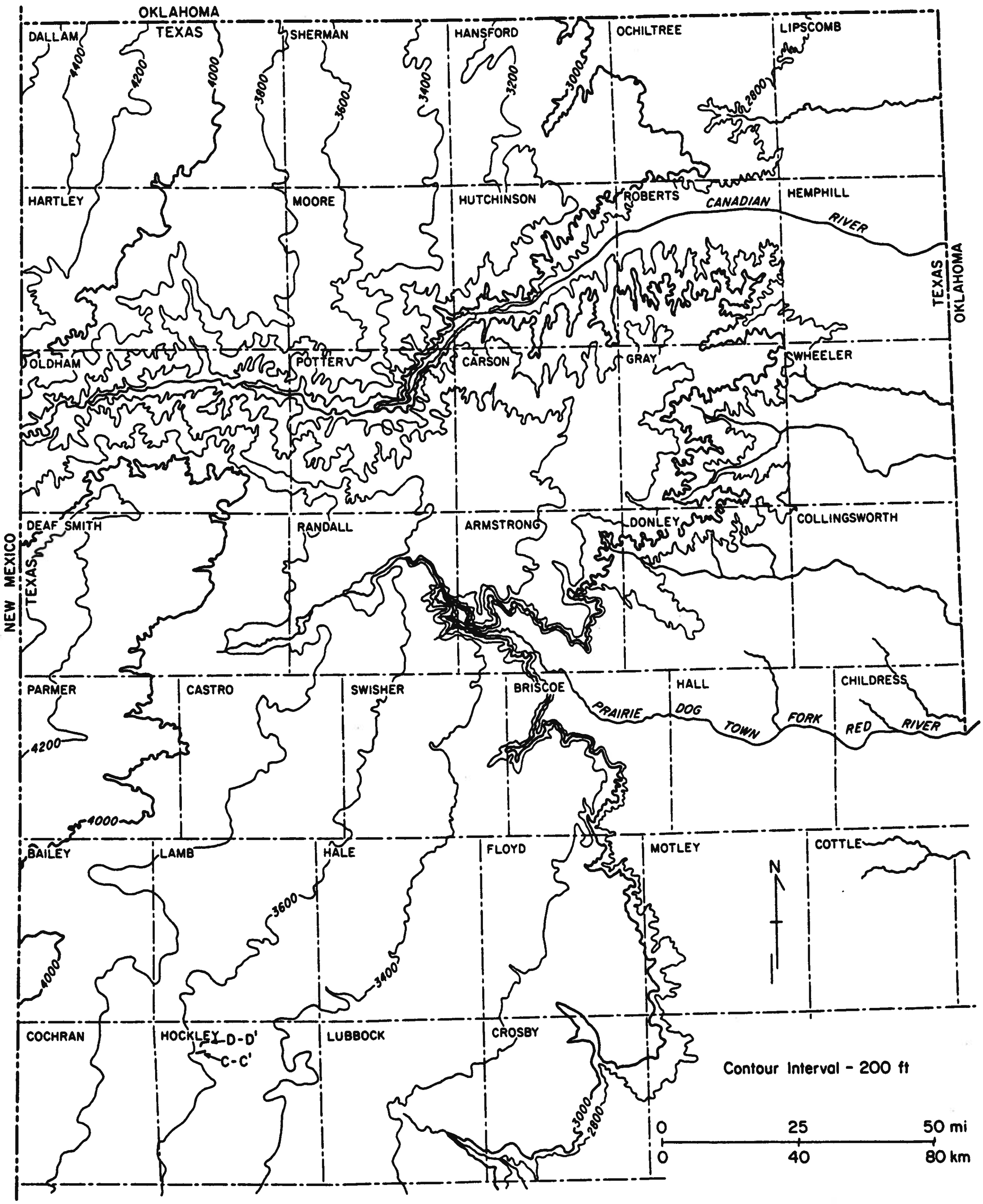


Figure 9. Topography of the High Plains, Texas Panhandle.

Index to **TAB 5**: Geologic cross-sections of the study area

Gustavson and Finley, 1985

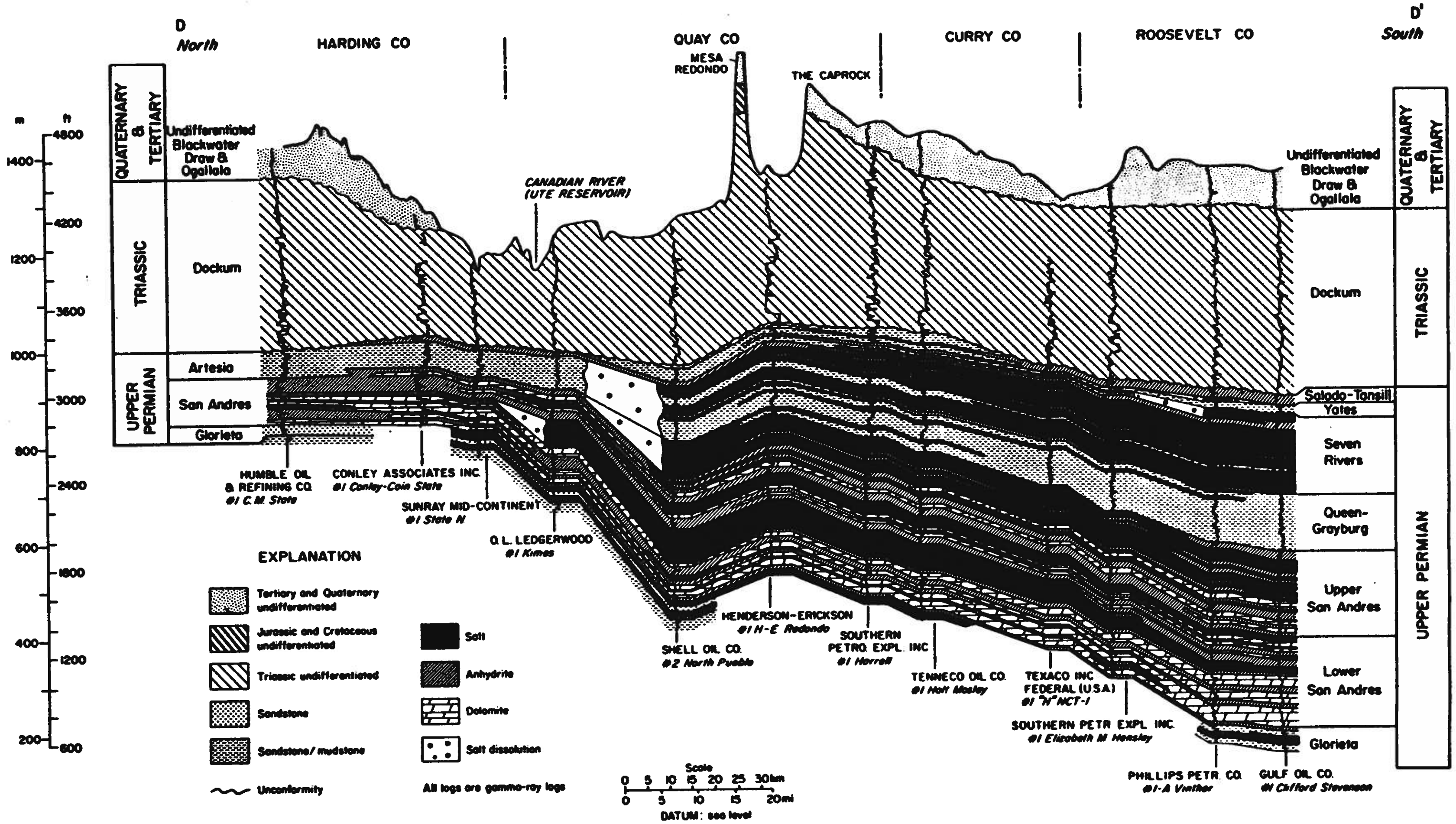


Figure 5. Stratigraphic cross section illustrating salt dissolution and collapse of strata beneath the Canadian River. See figure 3 for the location of section D-D'.

Gustavson and Finley, 1985

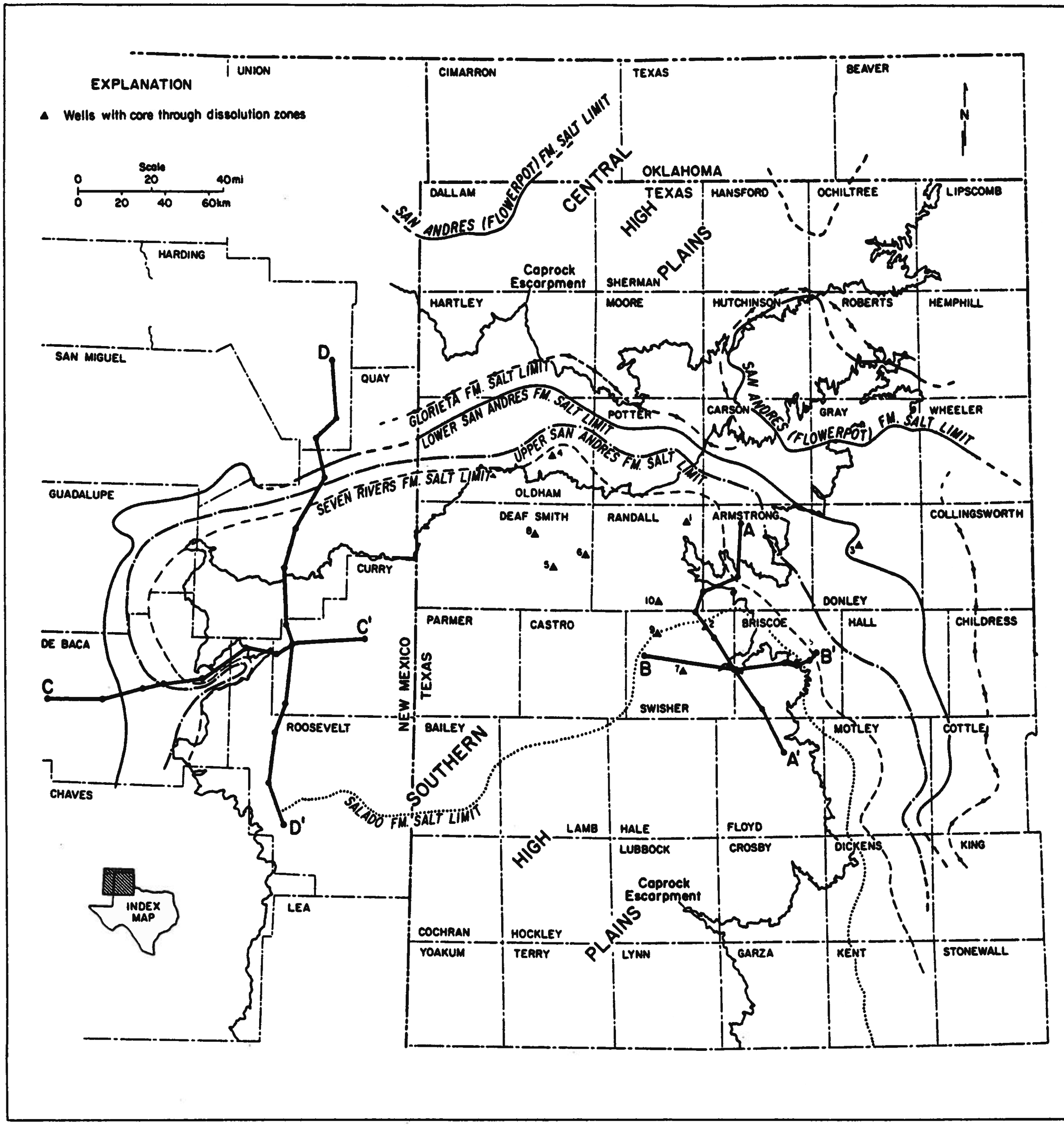


Figure 3. Zones of salt dissolution in eastern New Mexico and the Texas and Oklahoma Panhandles. Lines indicate the present extent of salt in the study region. In stratigraphic succession upward from the Glorieta to the Salado Formation, increasing amounts of salt are preserved toward the southwest corner of the Texas Panhandle. Some San Andres Formation salts are preserved in northwestern Dallam County, and some Glorieta and San Andres Formation salts are preserved near Hutchinson County. A peripheral dissolution zone is approximately located by salt-limit lines of the Seven Rivers, San Andres, and Glorieta Formations. An interior dissolution zone is approximated by the area overlain by the Southern High Plains. Wells with core through strata from which salt has been dissolved are indicated by numbered triangles: (1) DOE-Gruy Federal Rex H. White No. 1. (2) DOE-Gruy Federal Grabbe No. 1. (3) Stone and Webster Engineering Corp. Sawyer No. 1. (4) Stone and Webster Engineering Corp. Mansfield No. 1. (5) Stone and Webster Engineering Corp. Detten No. 1. (6) Stone and Webster Engineering Corp. G. Friemel No. 1. (7) Stone and Webster Engineering Corp. Zeeck No. 1. (8) Stone and Webster Engineering Corp. J. Friemel No. 1. (9) Stone and Webster Engineering Corp. Harman No. 1. (10) Stone and Webster Engineering Corp. Holtzclaw No. 1. Line A-A′ is figure 7, line B-B′ is figure 6, line C-C′ is figure 4, and line D-D′ is figure 5.

Gustavson, et al., 1992

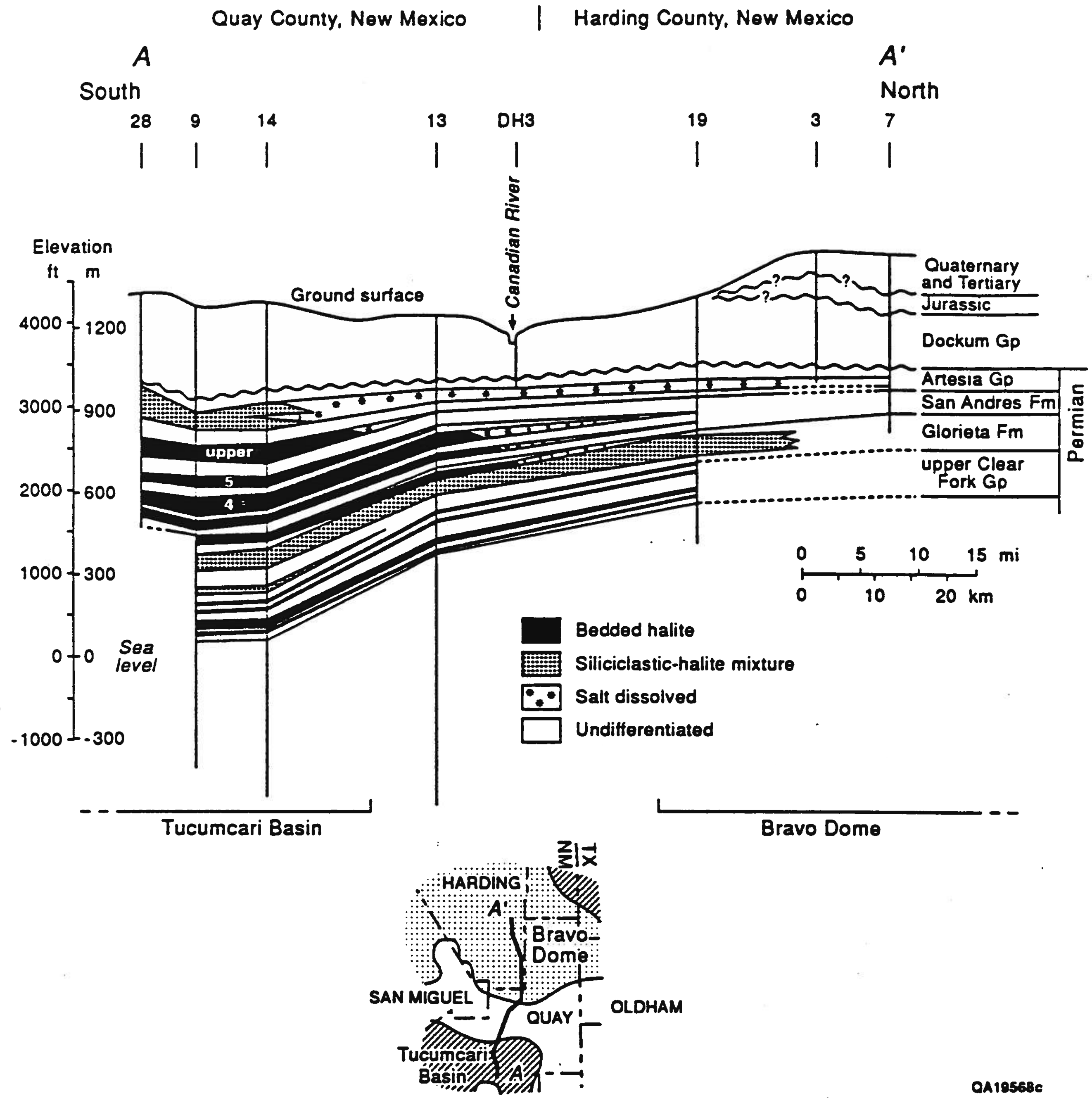


Figure 2. North-South structural cross section through the Ute Dam area.

Gustavson, et al., 1992

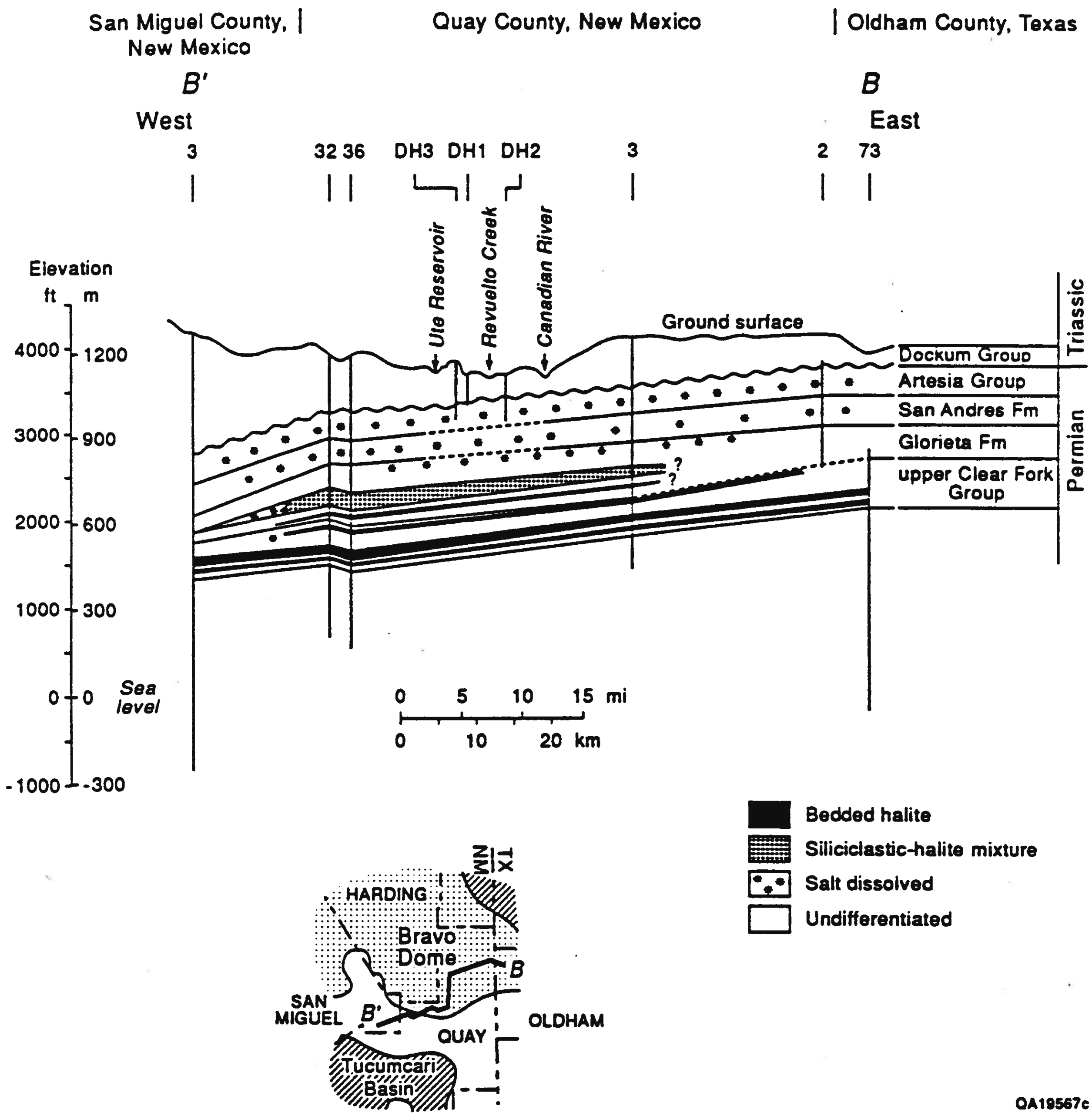


Figure 3. East-West structural cross section through the Ute Dam area.

Gustavson, et al., 1980a

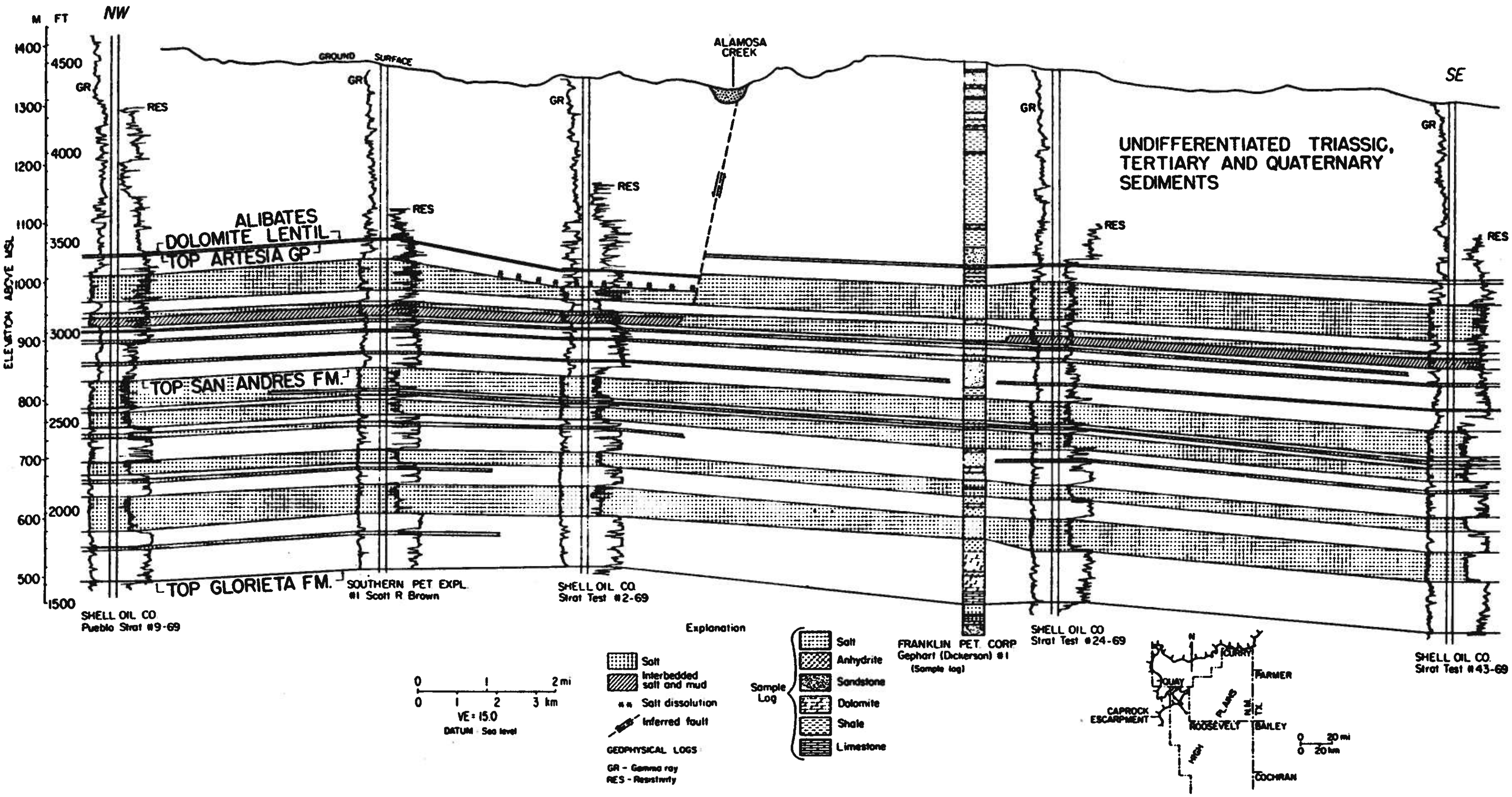


Figure 25. Structural cross section showing thinning of Artesia Group. Thinning and resultant faults are probably due to salt dissolution in the Artesia Group northwest of the fault. Cross section location is given in the inset map in this figure.

Gustavson, et al., 1980a

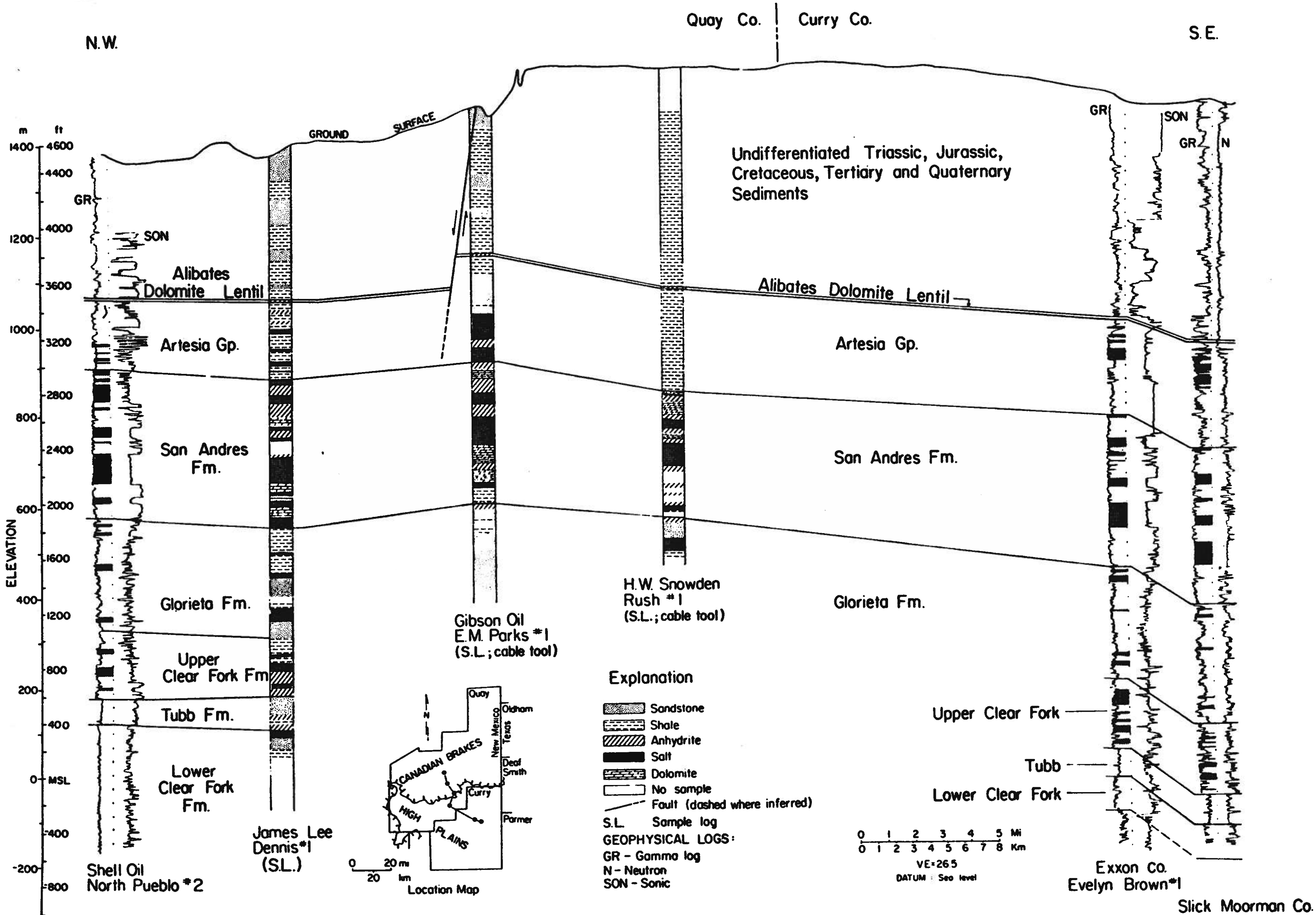


Figure 26. Structural cross section showing thinning of Artesia Group. Thinning and resultant fault are probably due to salt dissolution in Artesia northwest of the fault. Cross section location is given in the inset map in this figure.

Gustavson, et al., 1980b

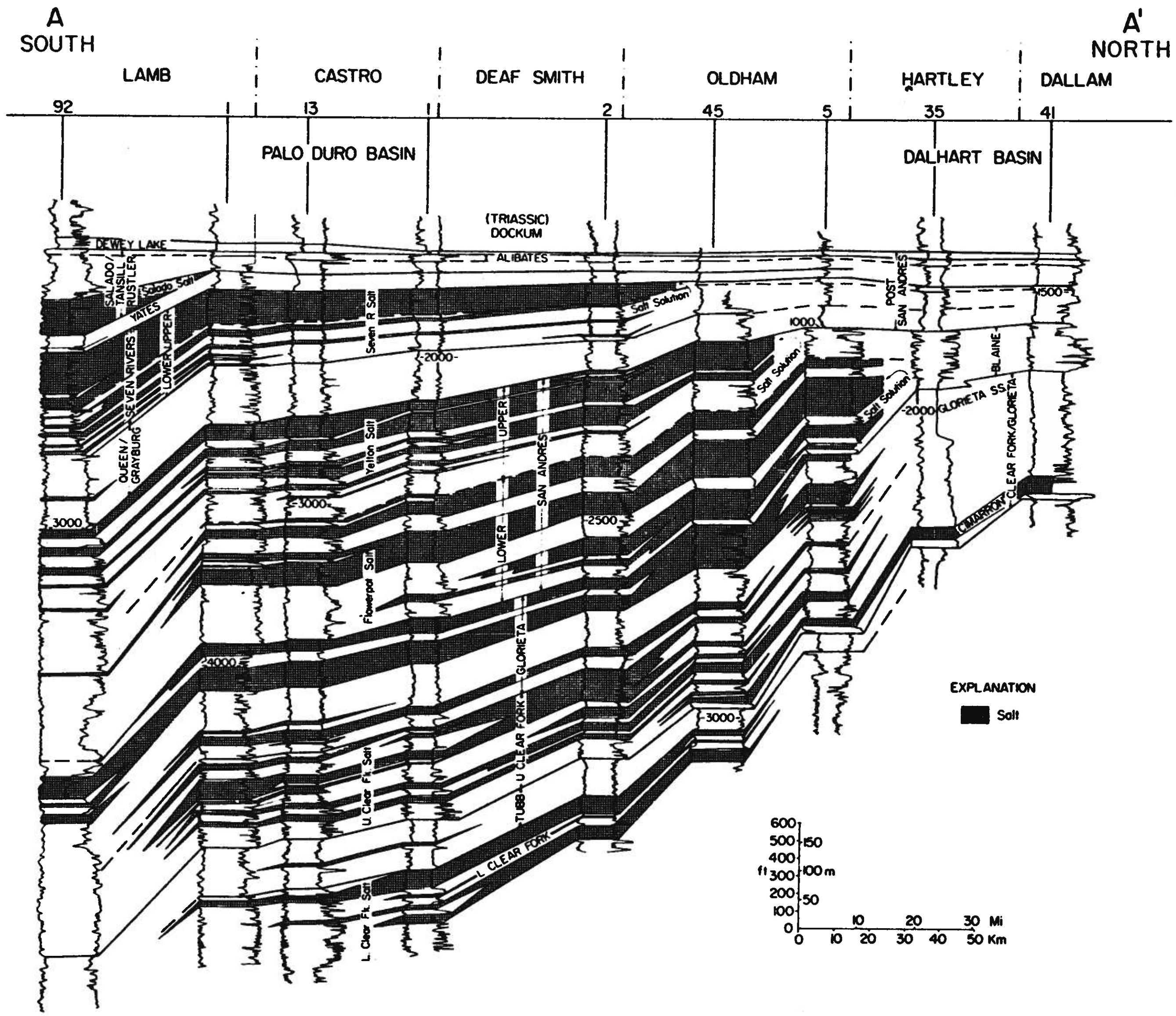


Figure 5. North-south cross section, Upper Permian salt-bearing strata, Texas Panhandle. Generalized salt units are correlated. Location of section in figure 4.

Gustavson, et al., 1980b

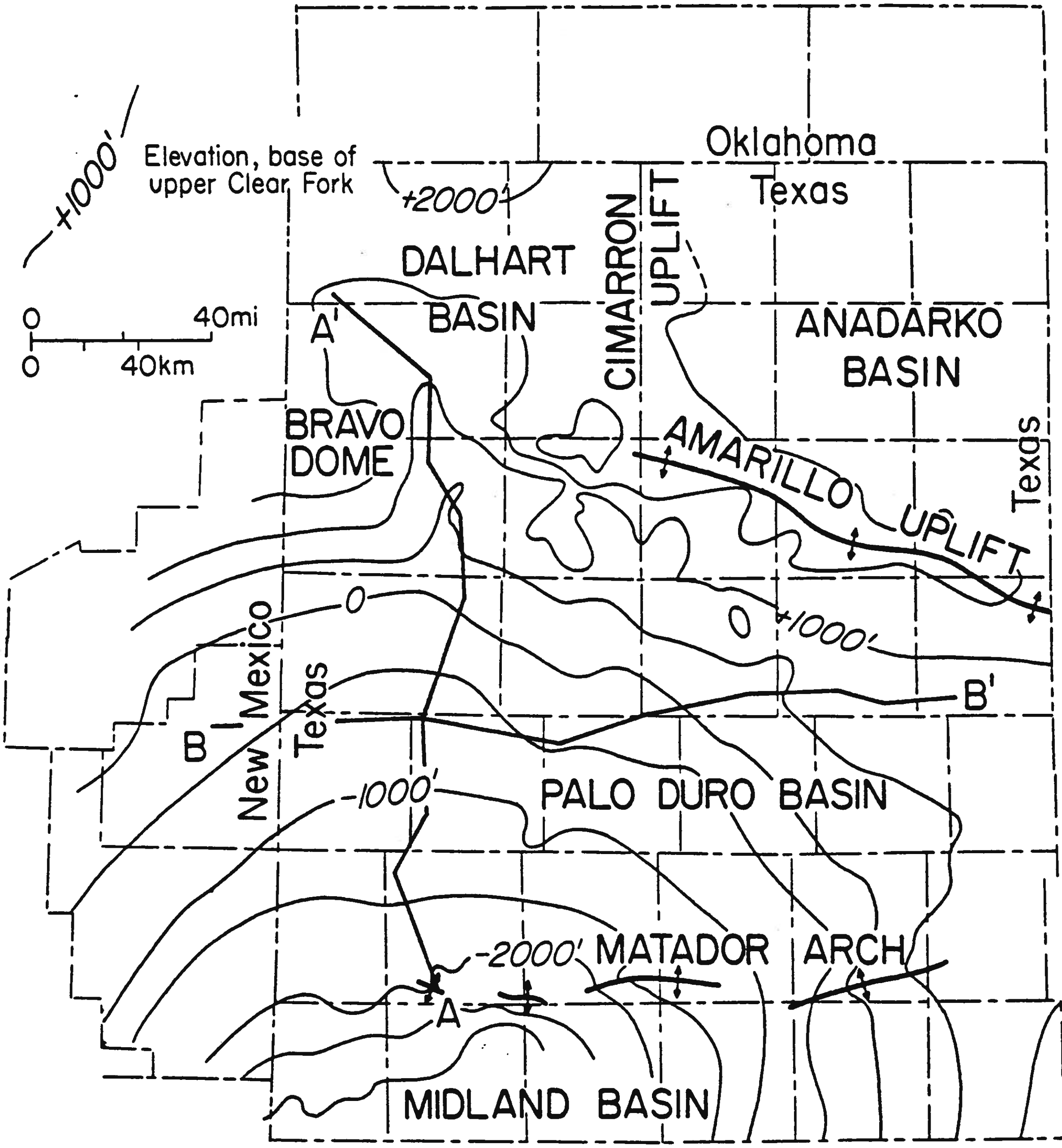


Figure 4. Regional structural setting of the Palo Duro and Dalhart Basins.

Gustavson, et al., 1980

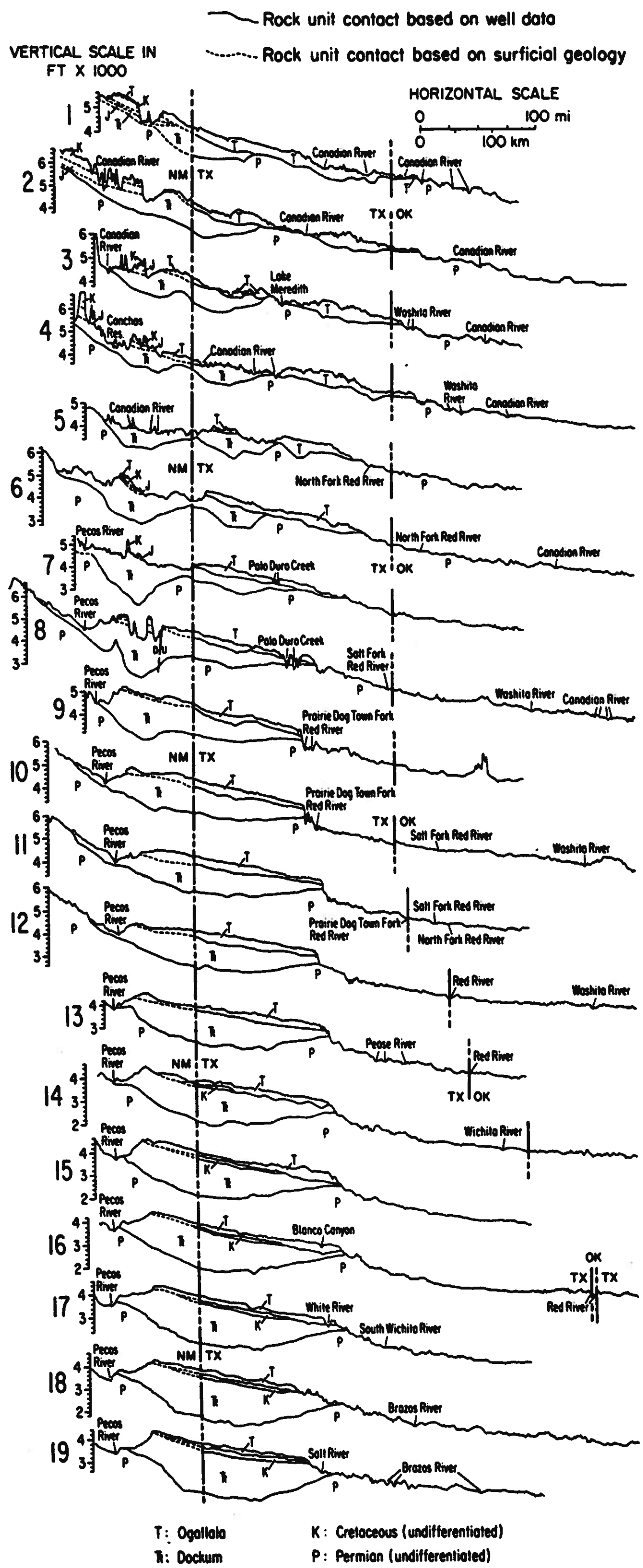


Figure 44. Topographic and geological profiles across the Texas Panhandle and adjacent parts of New Mexico and Oklahoma.

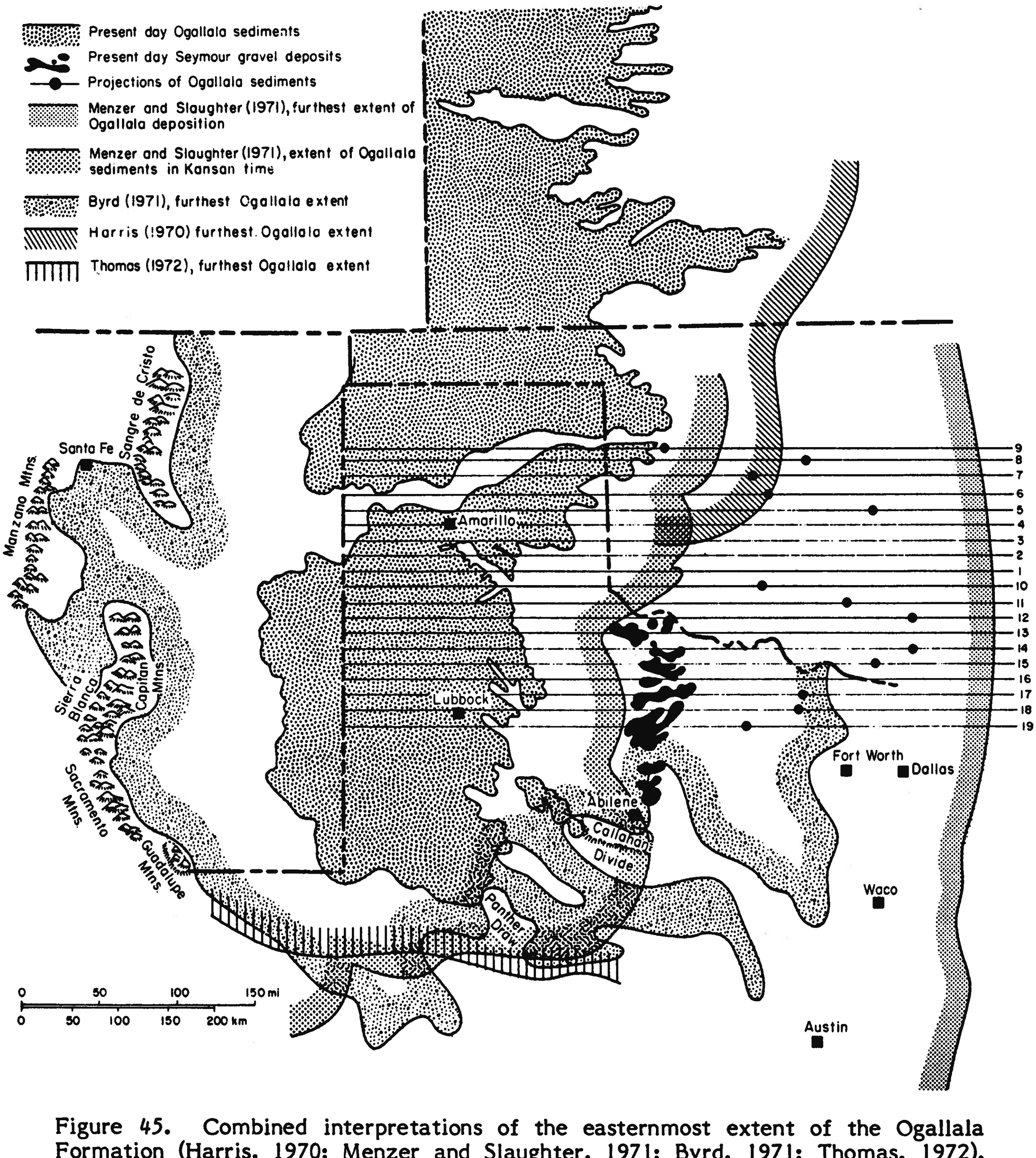


Figure 45. Combined interpretations of the easternmost extent of the Ogallala Formation (Harris, 1970; Menzer and Slaughter, 1971; Byrd, 1971; Thomas, 1972). Position of topographic profiles (9-19) in figure 44 are shown. Black dots show points of intersection of projected Southern High Plains surface, with the surface of the Osage Plains in Oklahoma.

HGC, 1984a

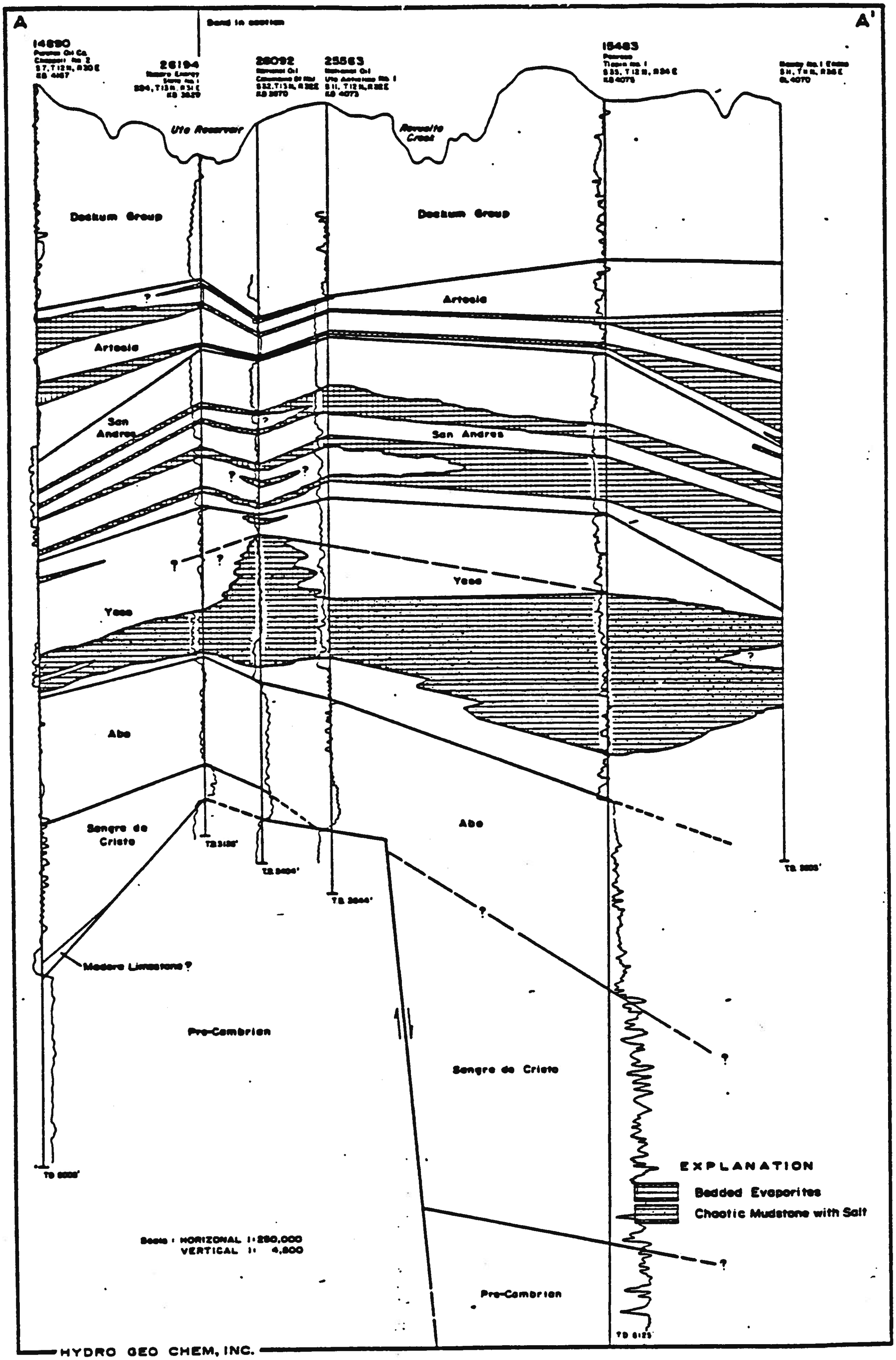


Figure 13. East-West geologic section

HGC, 1984a

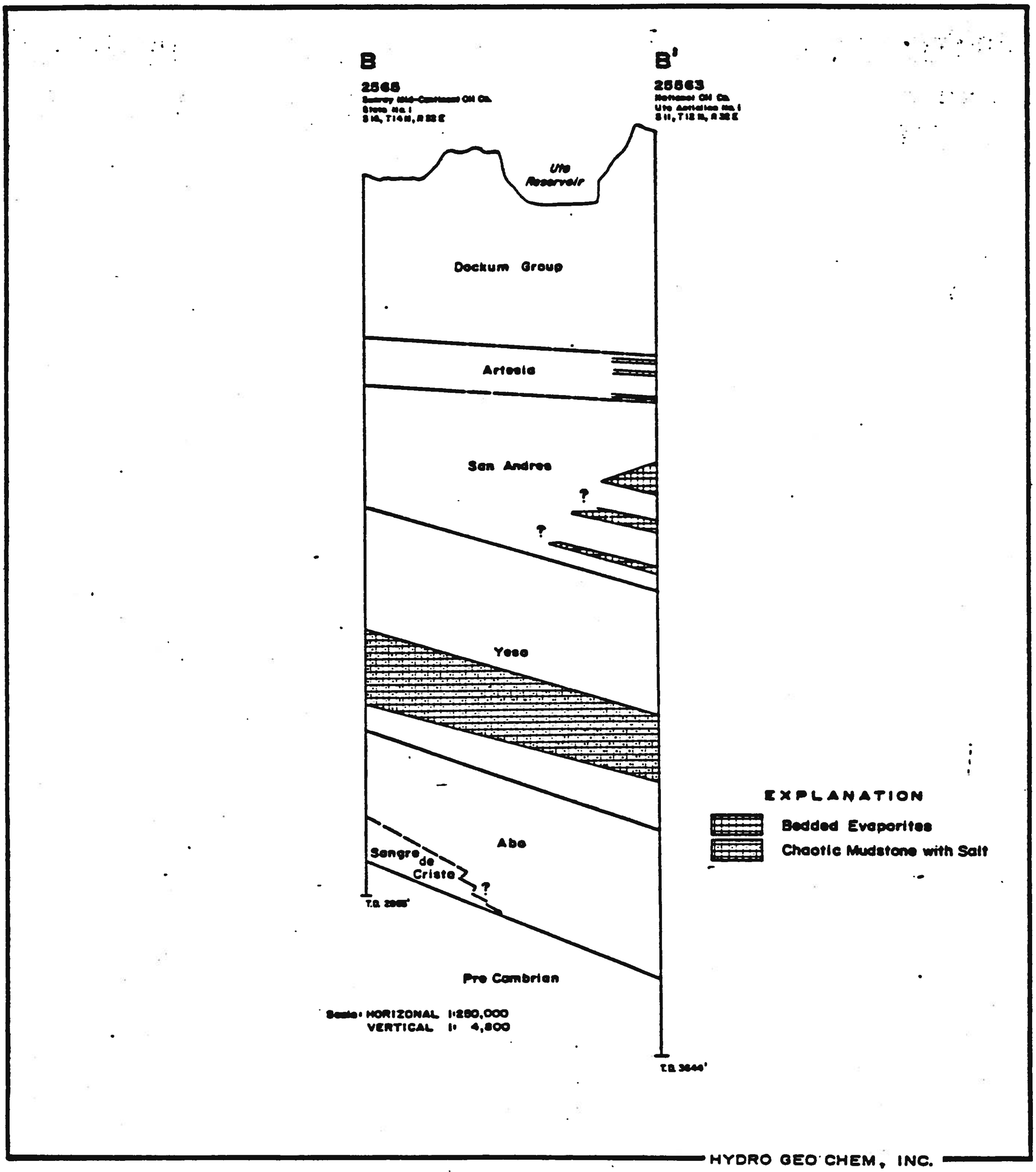


Figure 14. North-South geologic section through Ute Reservoir

HGC, 1984a

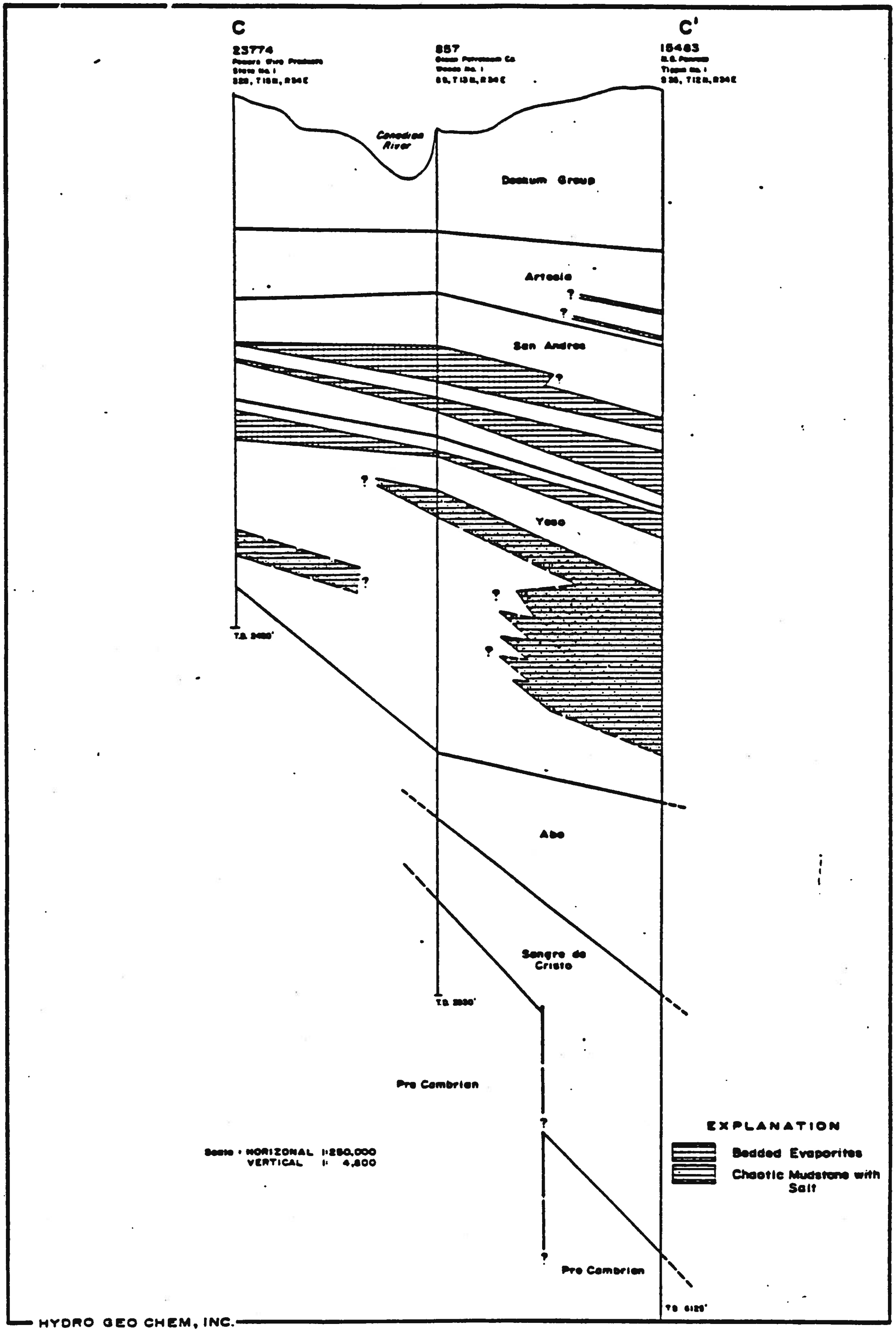


Figure 15. North-South geologic section through Canadian River

HGC, 1984a

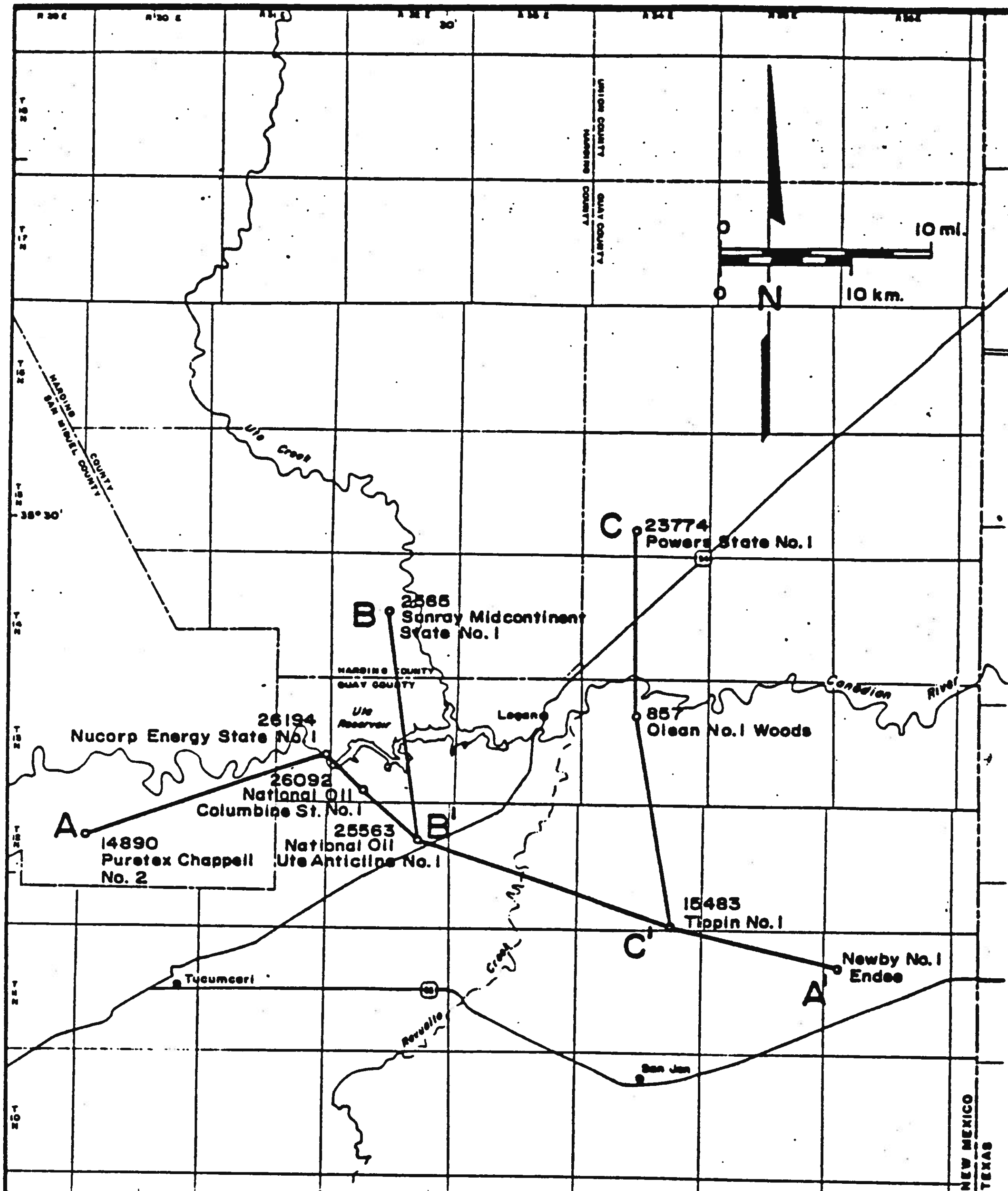
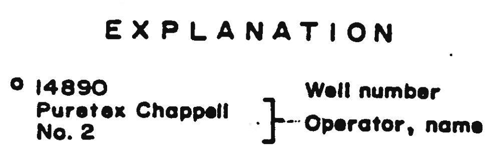


Figure 12. Map showing locations of cross-sections



HGC, 1984b

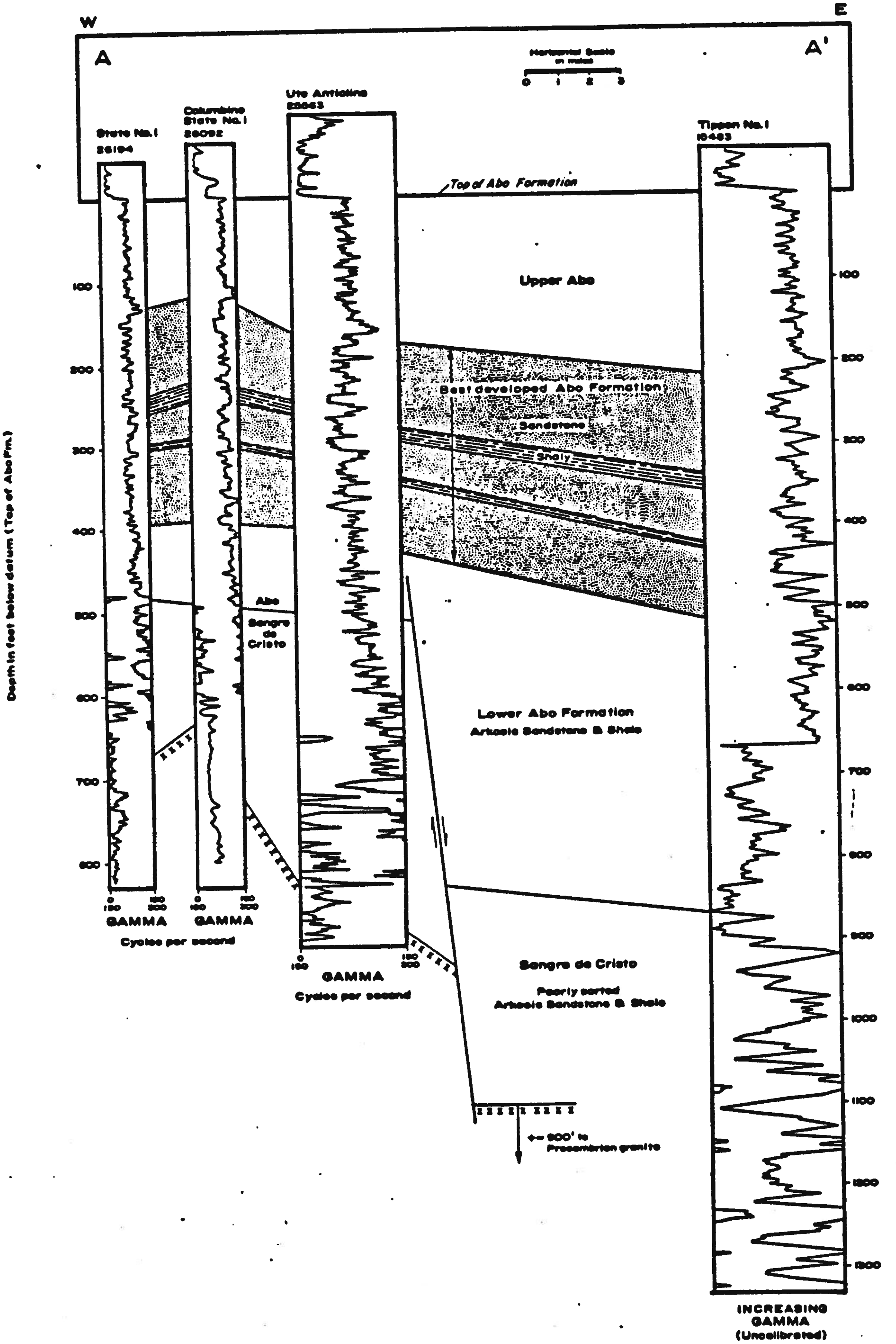


Figure 7. Cross-section A-A'.

HGC, 1984b

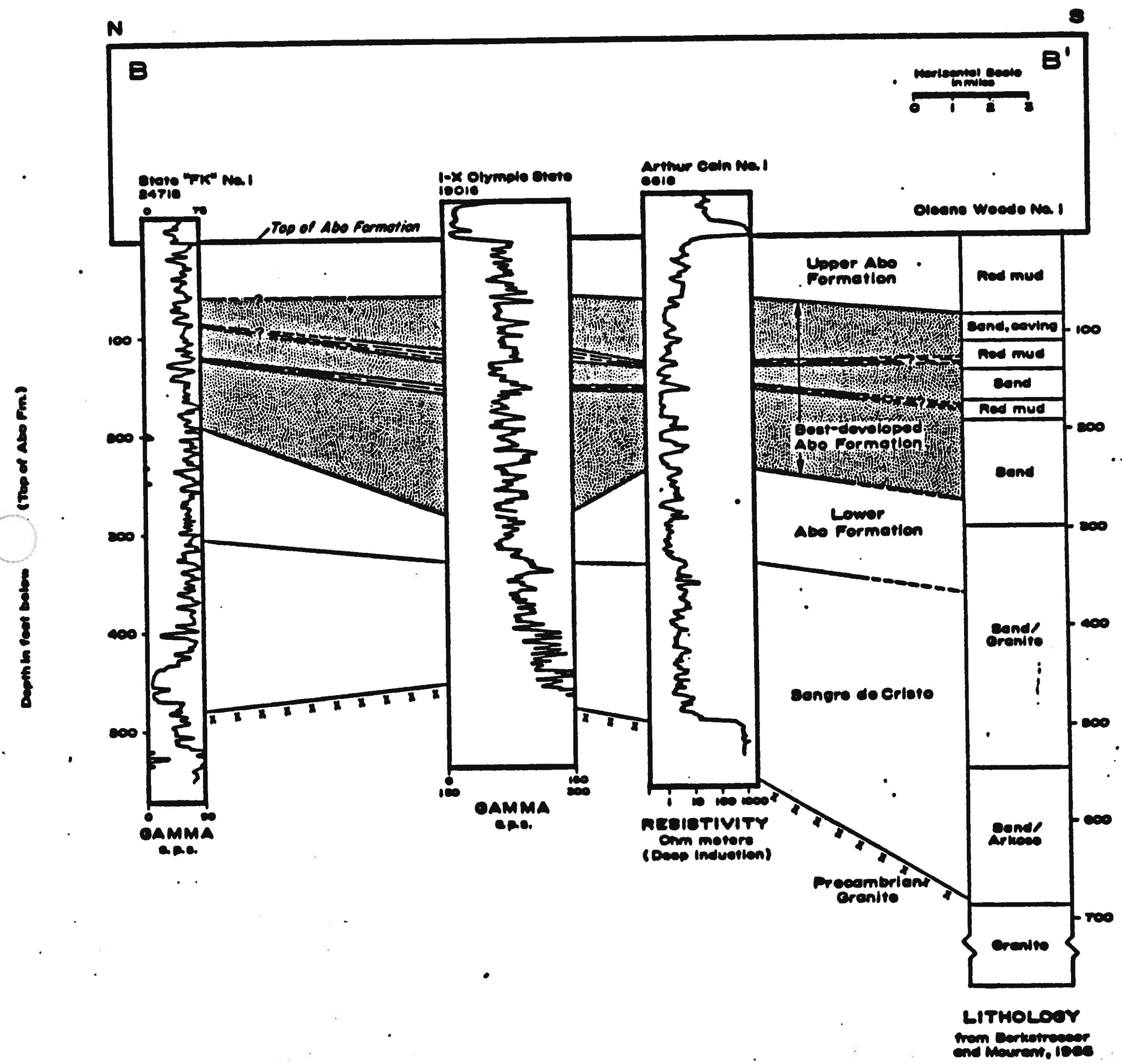


Figure 8. Cross-section B-B'.

HGC, 1984b

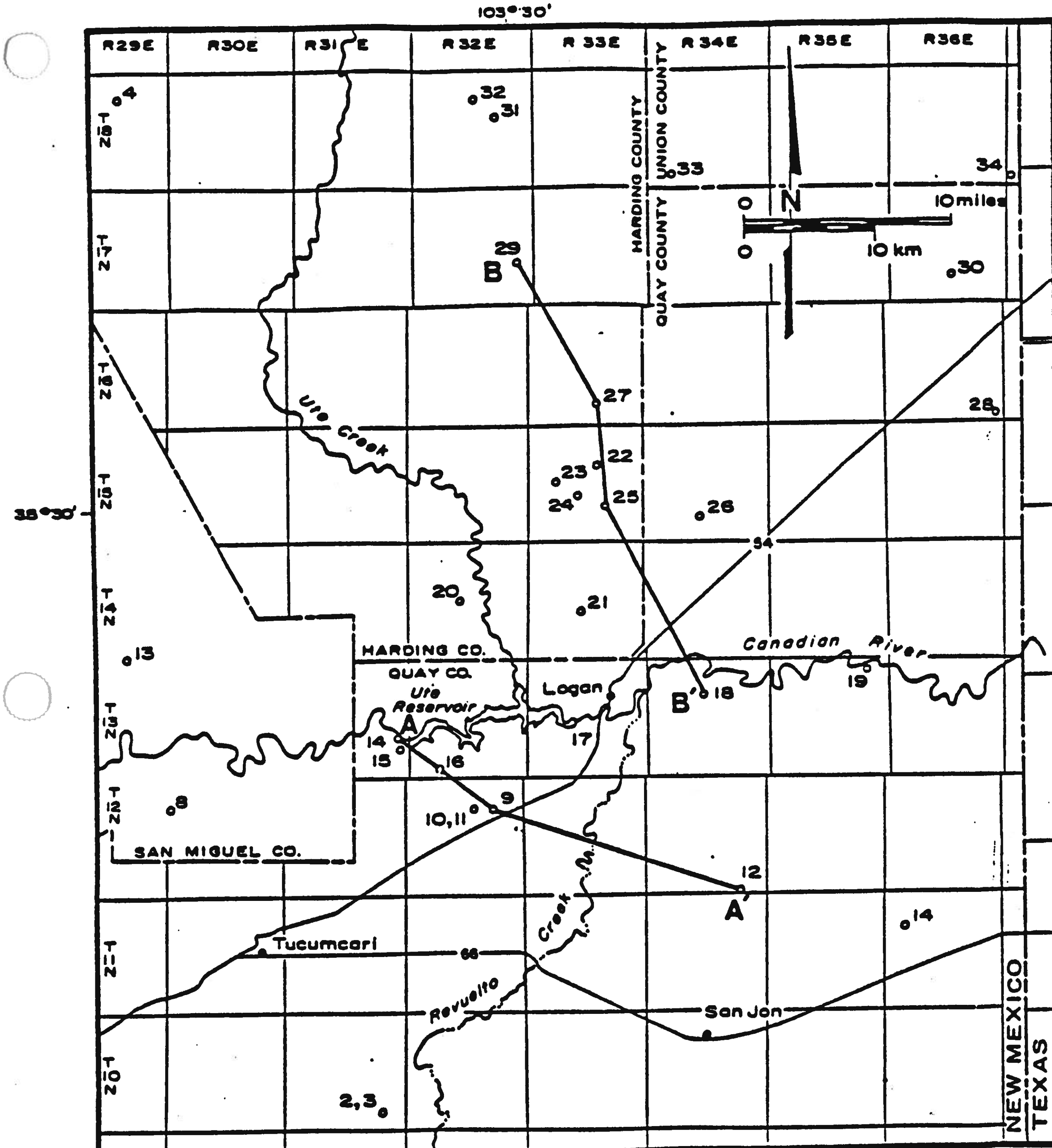
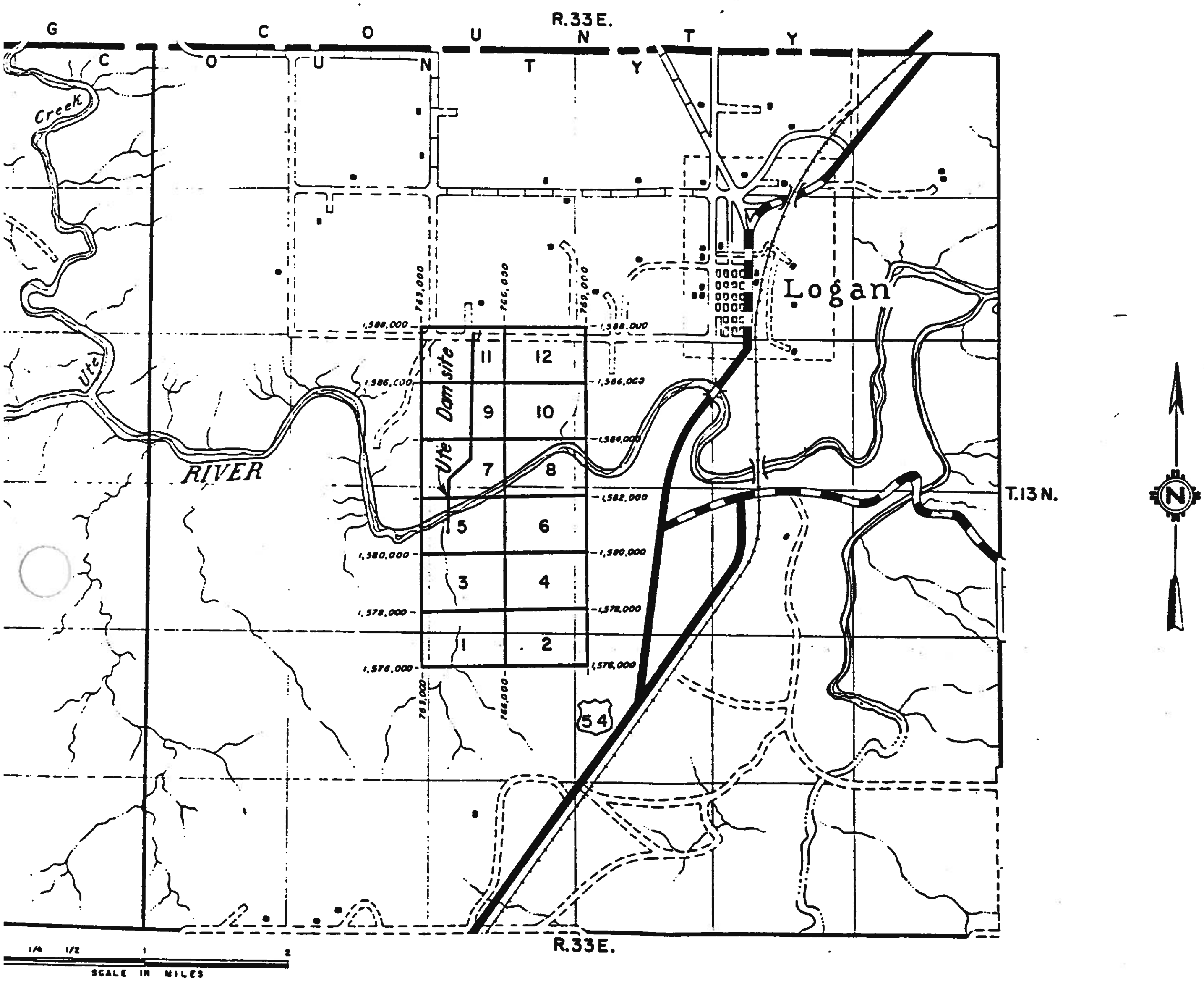


Figure 6. Location of regional cross-sections A-A' and B-B':

HYDRO GEO CHEM, INC.

SEO, 1961



EXPLANATION

318 ELEVATION

-26 HOLE NUMBER;
E AT HOLE

NT, NUMBER INDICATES
S LEFT, CENTER OR
IS IDENTIFIED WITH THE

TRIANGULATION POINT (BRASS CAP)

TRIANGULATION POINT (PIPE)

REFERENCE MARKER

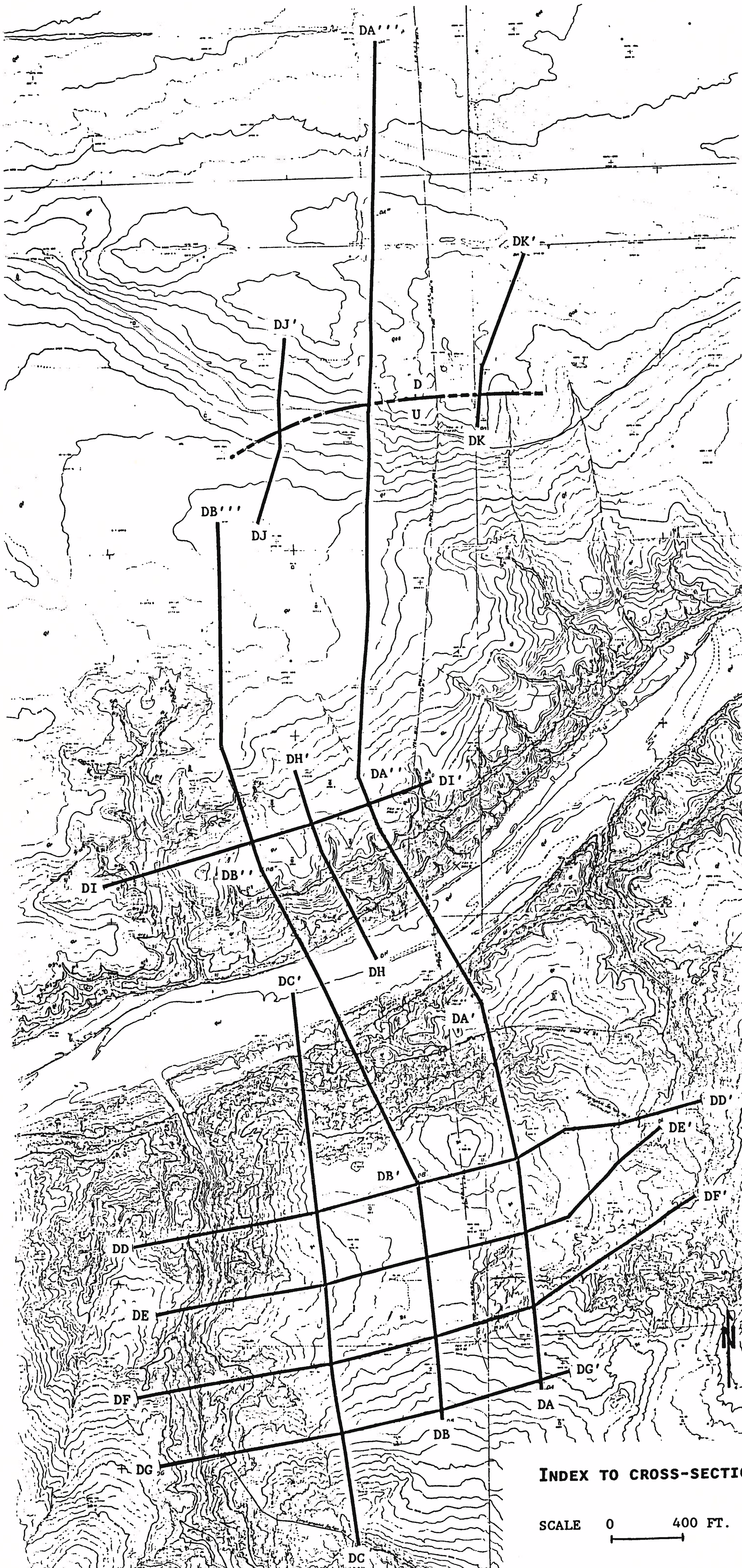
PBM PERMANENT BENCH MARK

2 SHEET NUMBER AND LOCATION OF UTE DAM SITE MAPS

T-X KELSH ELEVATION OF HIGHEST POINT IN VICINITY

FIGURE 6a

STATE ENGINEER OFFICE
DIAN RIVER INVESTIGATION
KEY MAP



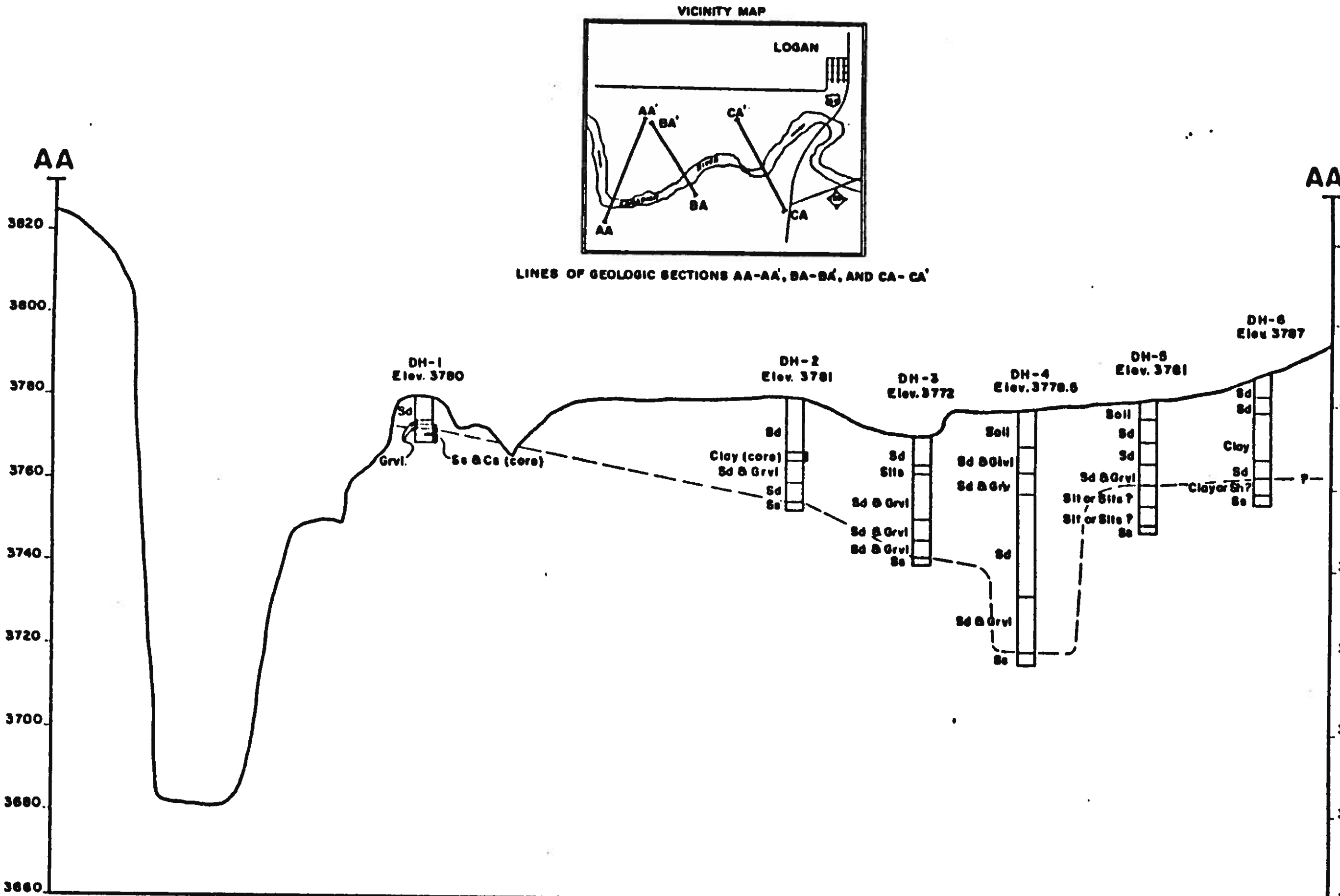
INDEX TO CROSS-SECTIONS IN SEO, 1961

SCALE 0 400 FT.

EXPLANATION OF LOG SYMBOLS
(Figures 7a through 7g)

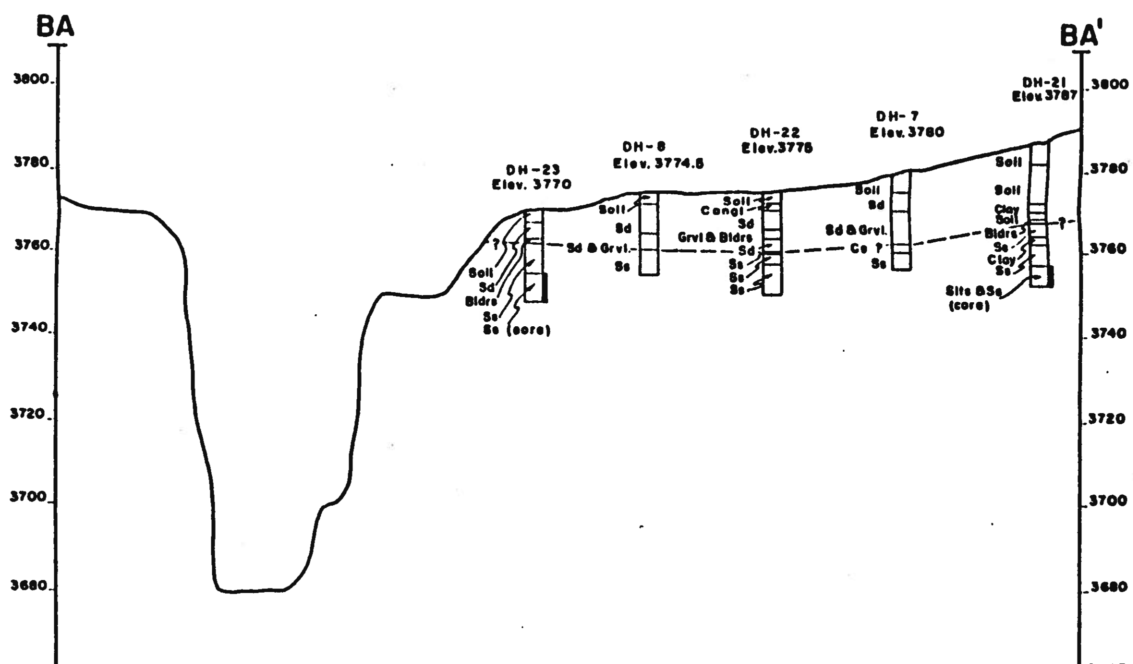
DH - 4 Elev. 3778.5	Exploratory drill-hole number and elevation of land surface at hole
RA - 20 Elev. 3764	Reconnaissance auger-hole number and elevation of land surface at hole
Grvl	Gravel
Bldrs	Boulders
Sd & Grvl	Sand and gravel
Congl	Conglomerate
Soil	Soil
Sd	Sand
Slt	Silt
Clay	Clay
Ss	Sandstone
Slts	Siltstone
Cs	Claystone
Ms	Mudstone
Sh	Shale
Caliche	Caliche
Ls	Limestone
	Cored interval

Precedes Figure 7a



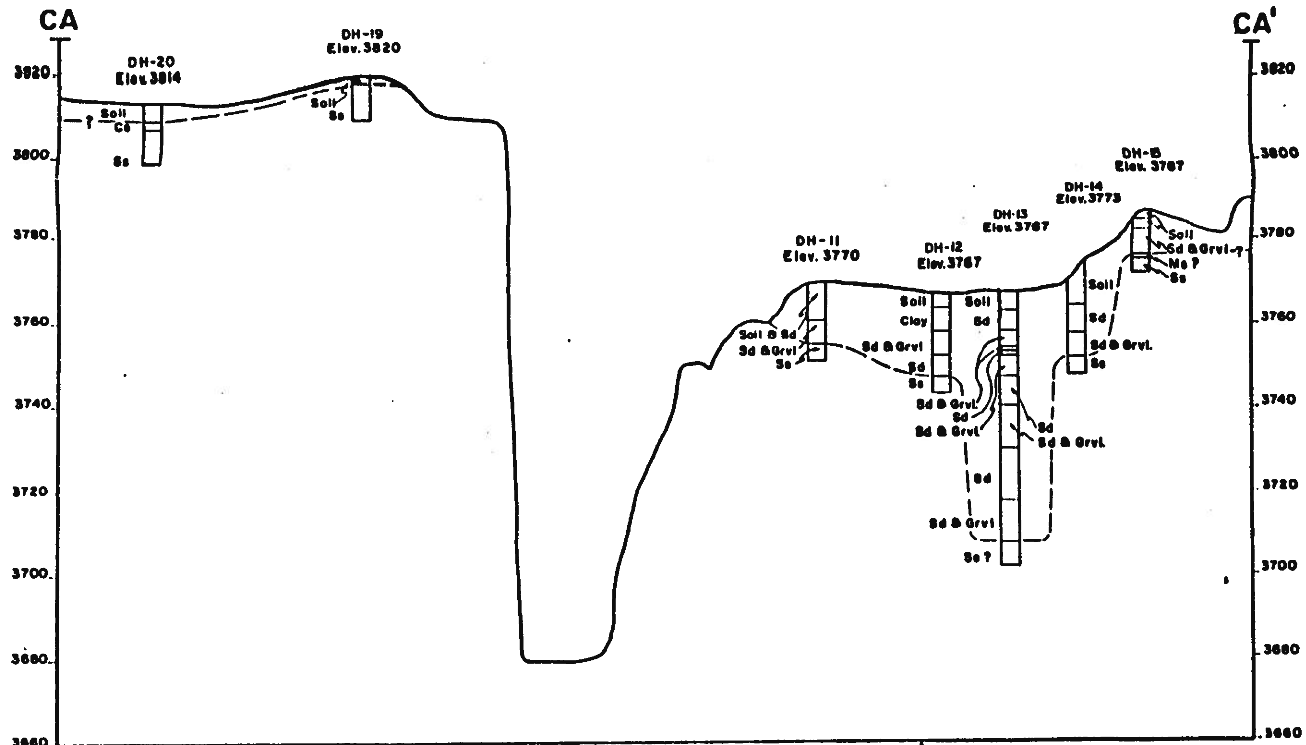
GEOLOGIC SECTION AA-AA'

LINE OF SECTION SHOWN ON VICINITY MAP



GEOLOGIC SECTION BA-BA'

LINE OF SECTION SHOWN ON VICINITY MAP



GEOLOGIC SECTION CA-CA'

LINE OF SECTION SHOWN ON VICINITY MAP

400 200 0 400 800 1200

SCALE IN FEET

STATE ENGINEER OFFICE

CANADIAN RIVER INVESTIGATION

GEOLOGIC SECTIONS - UTE DAM SITE

FIGURE 7a

SEO, 1961

SEO, 1961

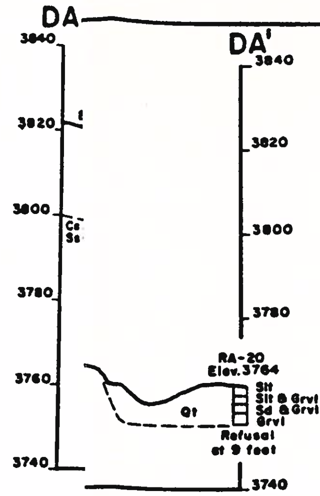
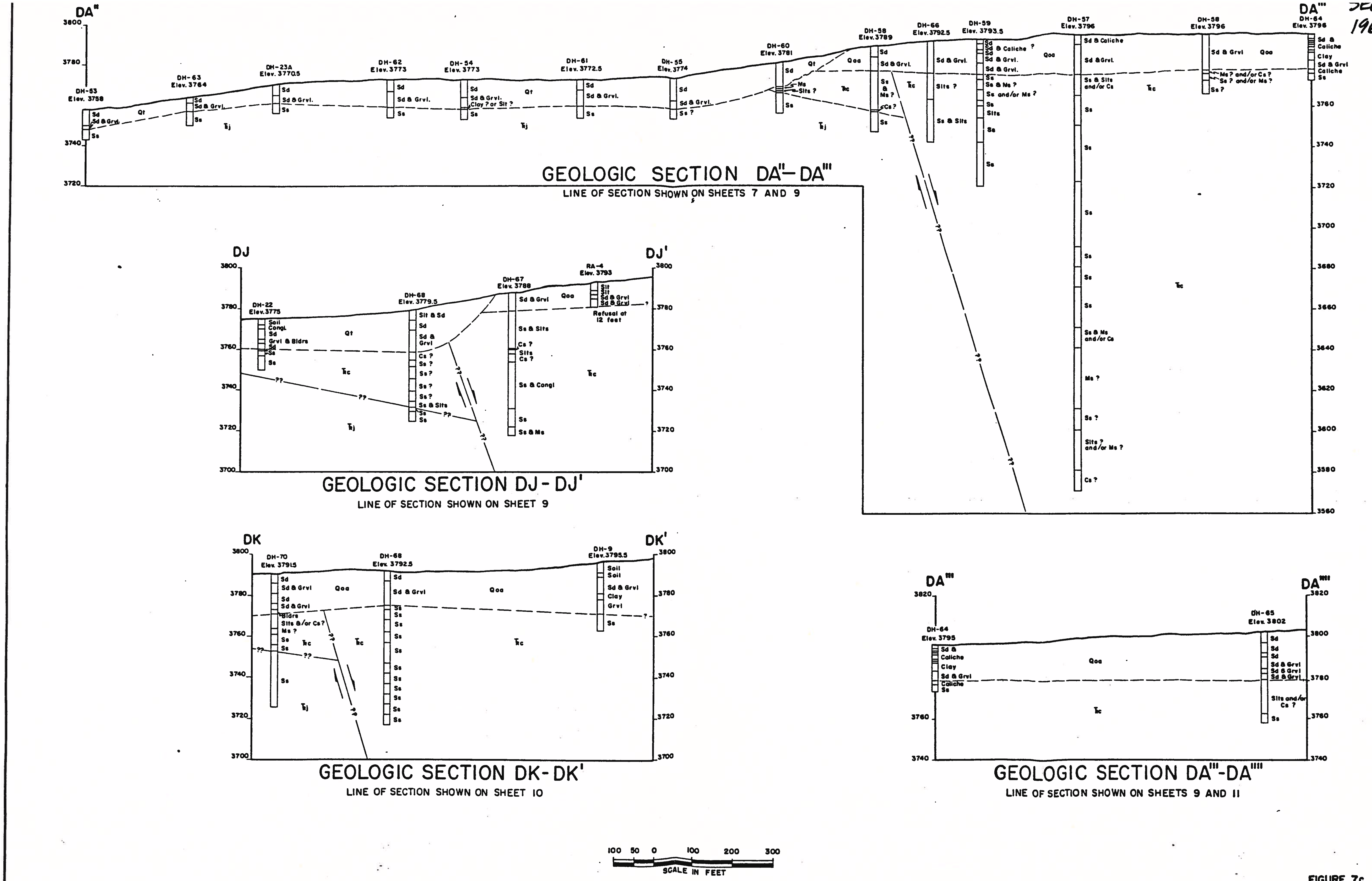
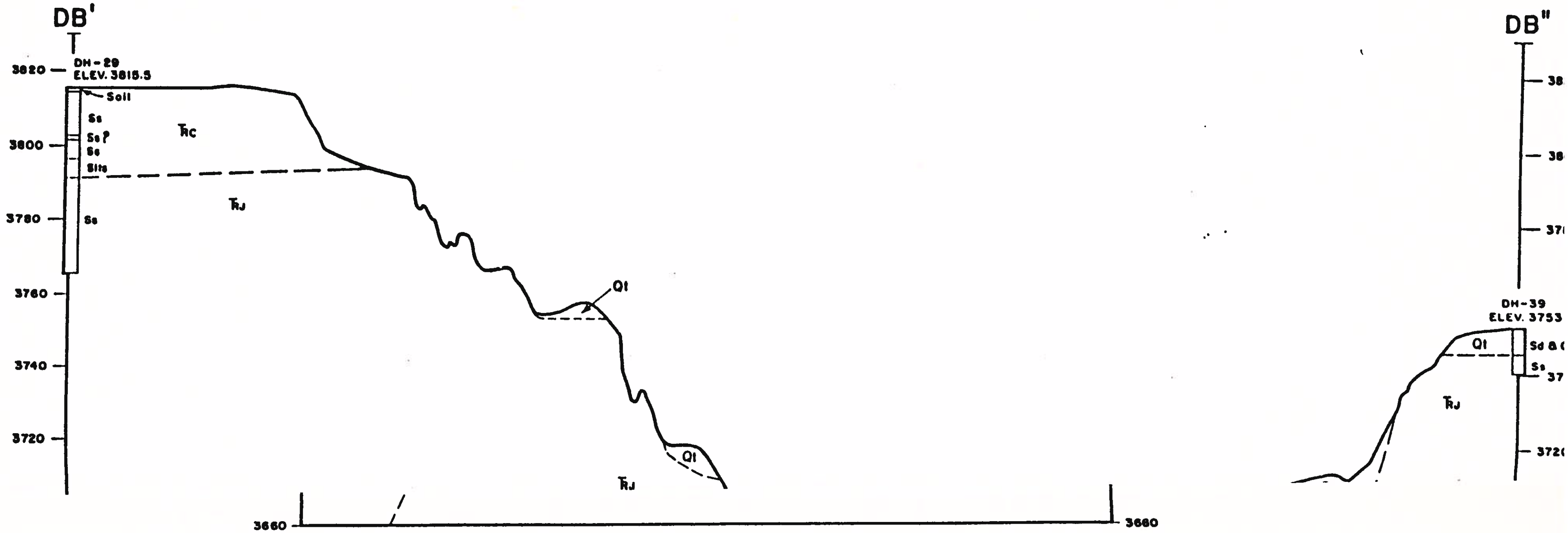


FIGURE 7b

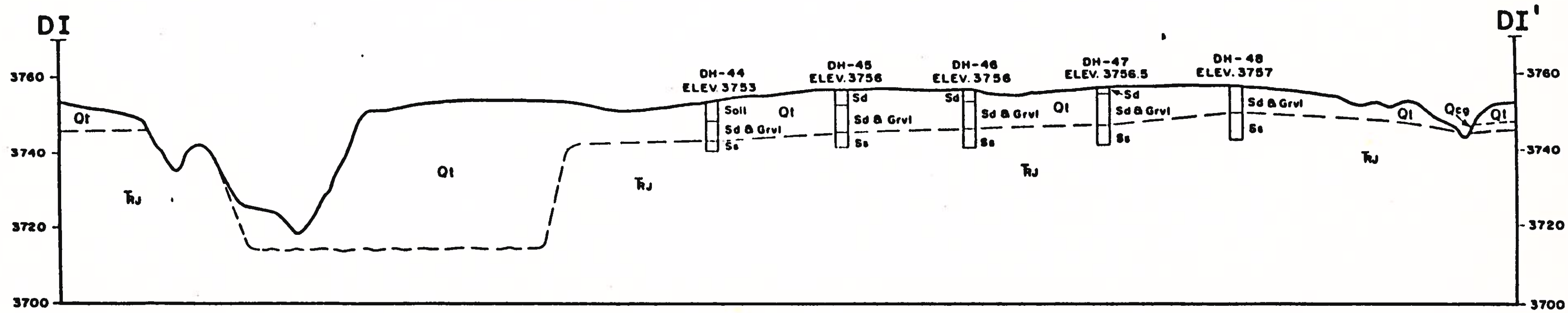


STATE ENGINEER OFFICE
CANADIAN RIVER INVESTIGATION
GEOLOGIC SECTIONS - UTE DAM SITE



GEOLOGIC SECTION DH-DH'

LINE OF SECTION SHOWN ON SHEETS 5 AND 7



GEOLOGIC SECTION DI-DI'

LINE OF SECTION SHOWN ON SHEET 7

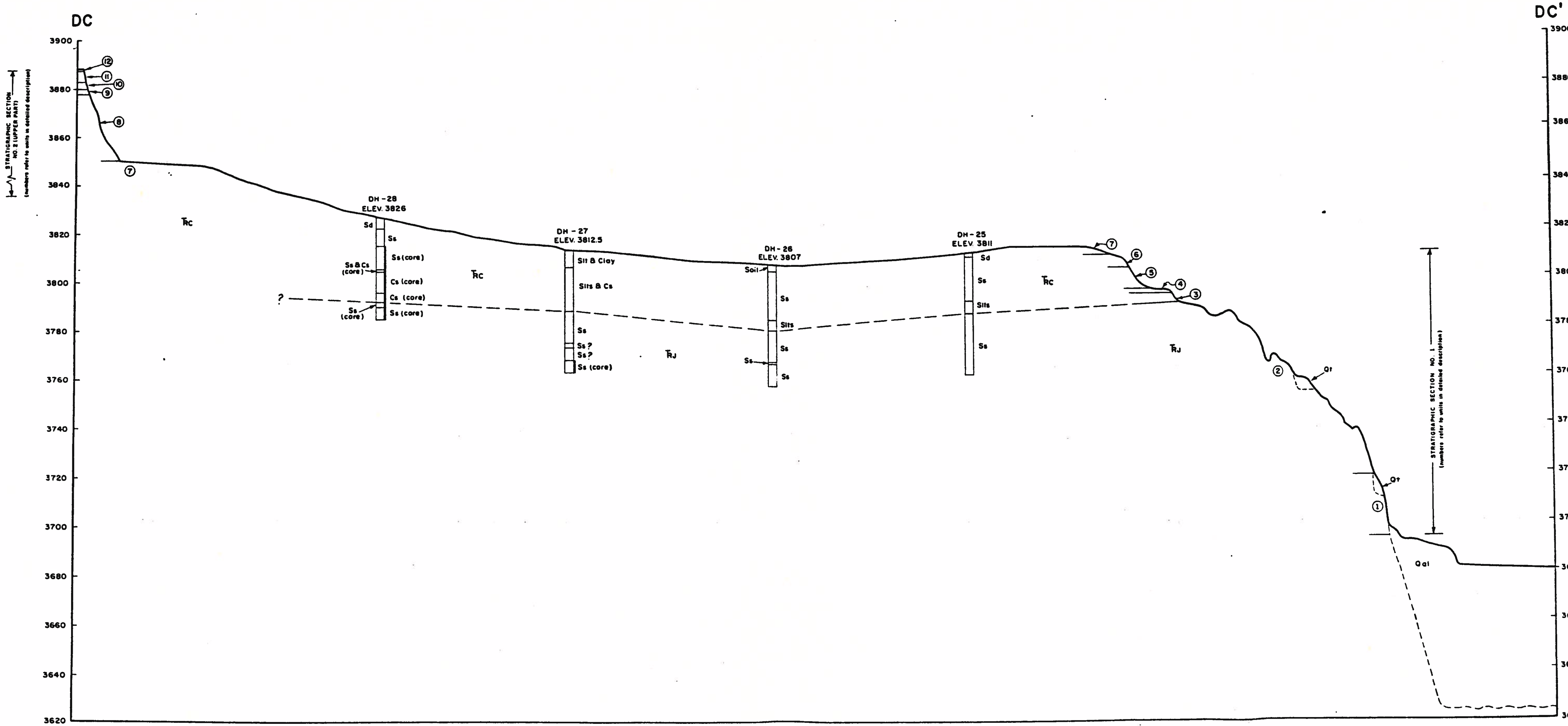
100 50 0 100 200 300

SCALE IN FEET

FIGURE 7d

SEO, 1961

SEO, 1961



GEOLOGIC SECTION DC-DC'

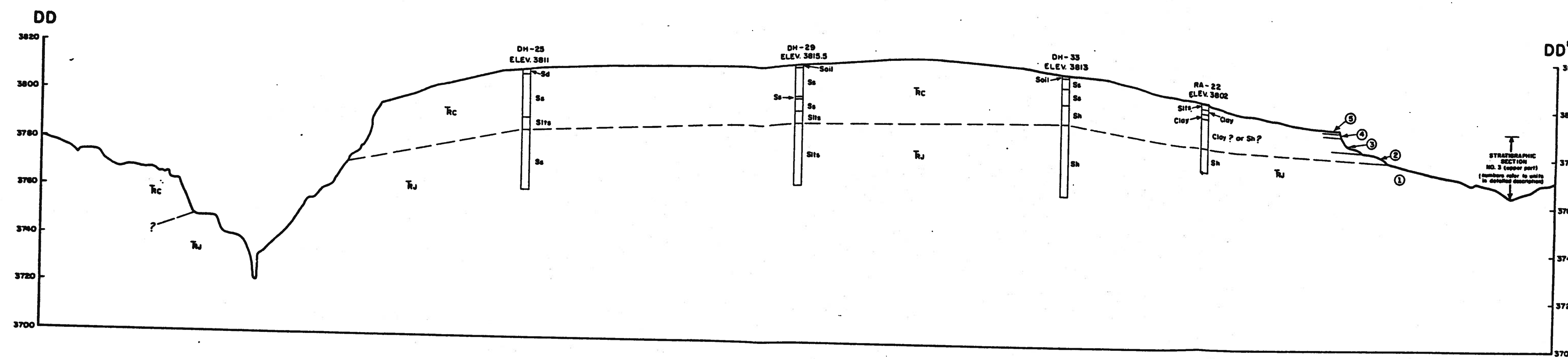
LINE OF SECTION SHOWN ON SHEETS 3 AND 5

100 50 0 100 200 300
SCALE IN FEET

FIGURE 7e

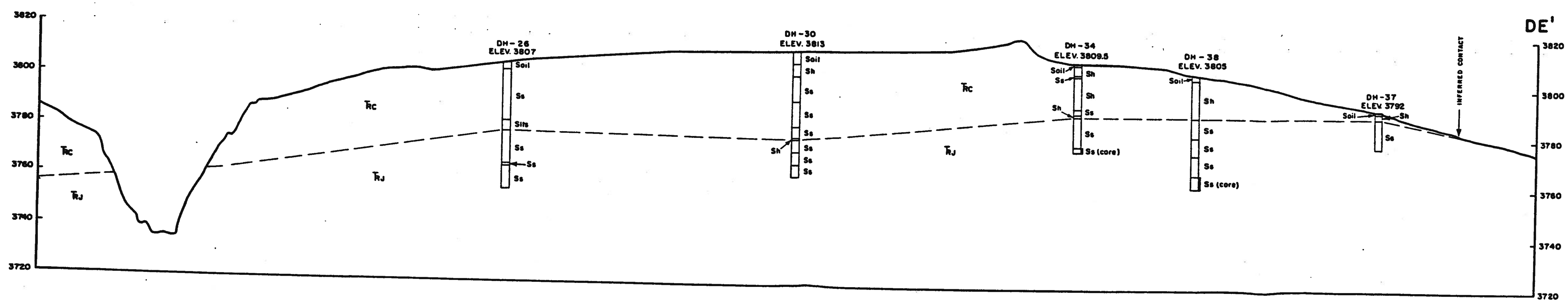
STATE ENGINEER OFFICE

CANADIAN RIVER INVESTIGATION



GEOLOGIC SECTION DD-DD'

LINE OF SECTION SHOWN ON SHEETS 5 AND 6



GEOLOGIC SECTION DE-DE'

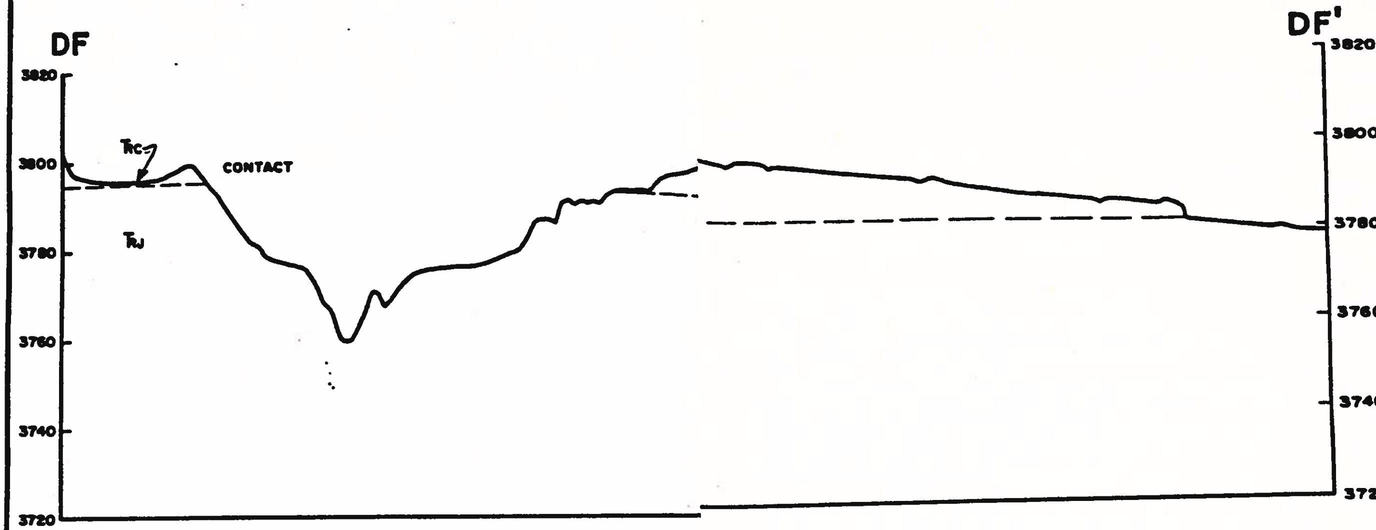
LINE OF SECTION SHOWN ON SHEETS 3, 5 AND 6

100 50 0 100 200 300

SCALE IN FEET

SEO, 1961

SEO, 1961



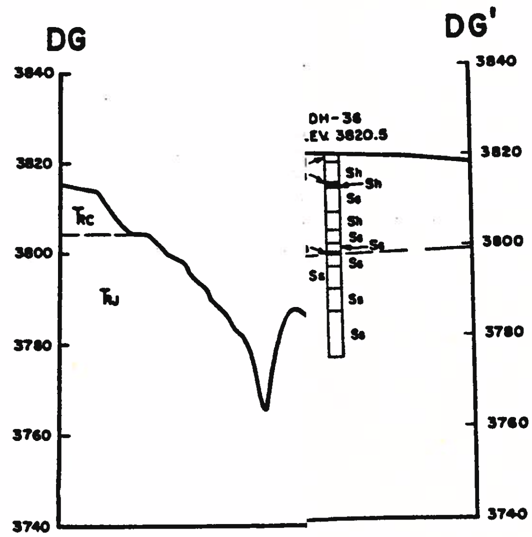
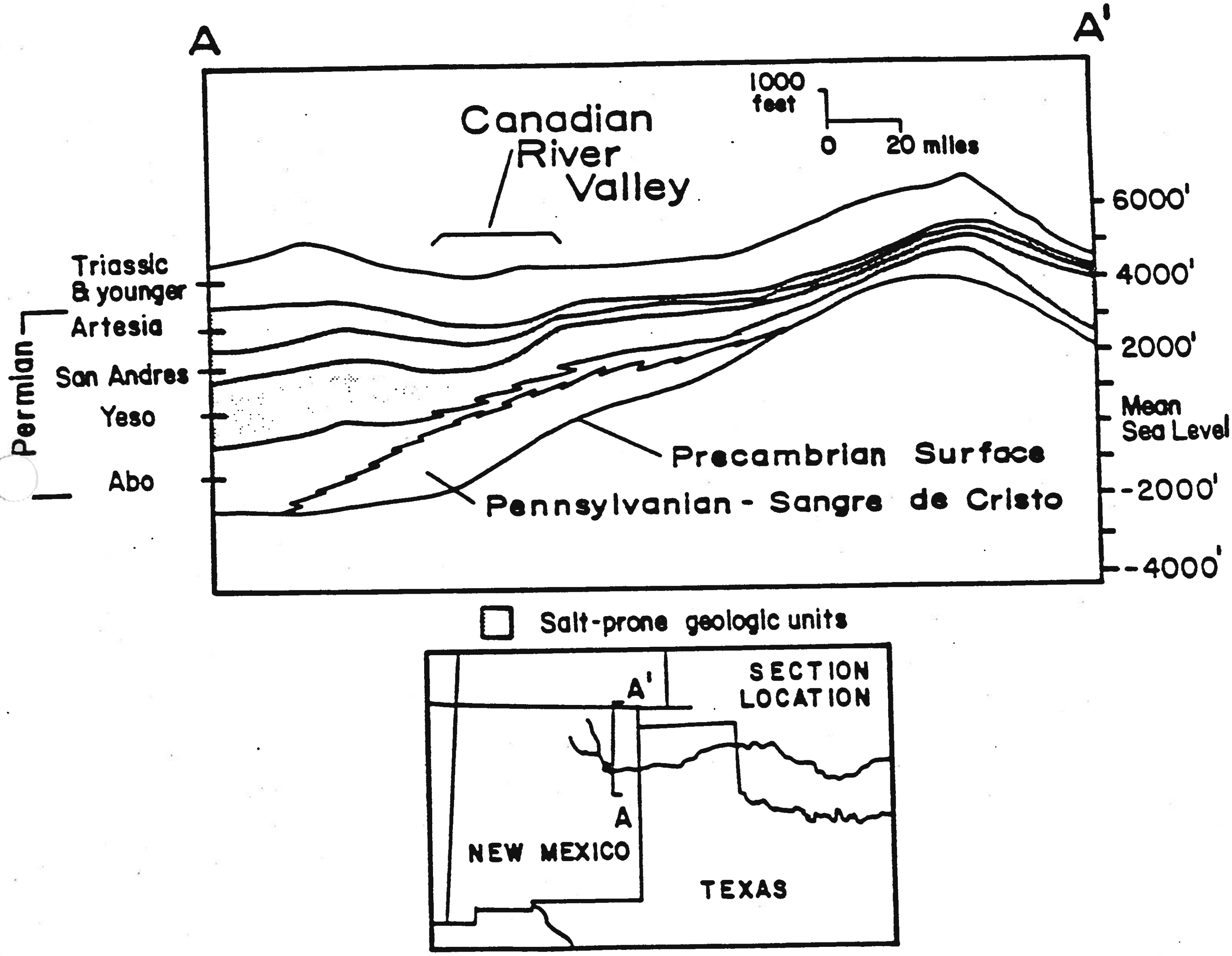


FIGURE 7q

USBR, 1985

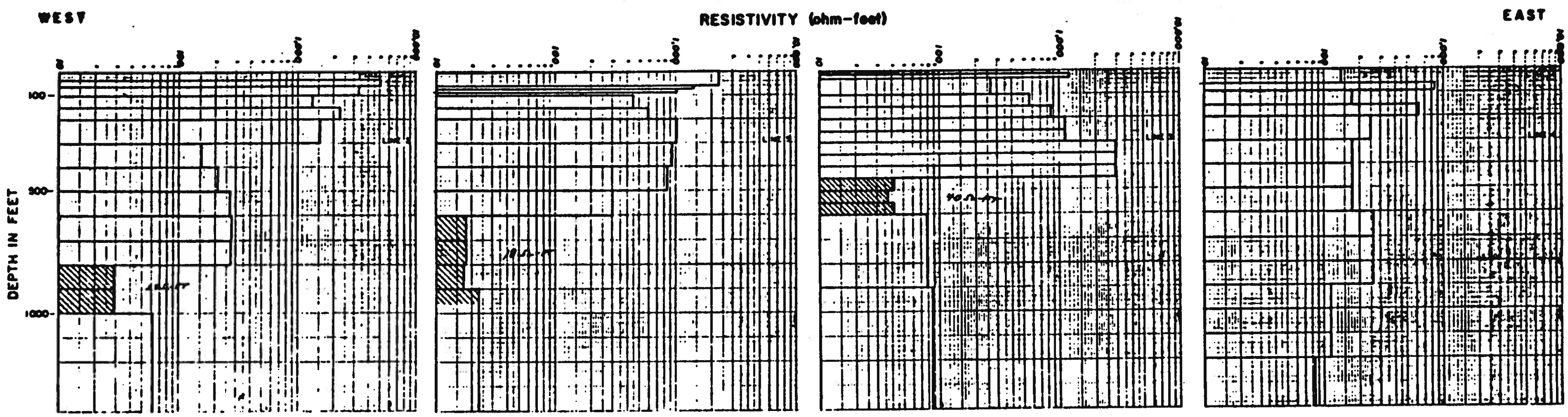


SUBSURFACE GEOLOGIC FORMATIONS
Logan, New Mexico Area

Source: Hydro Geo Chem, Inc., January, 1984

Figure II-1

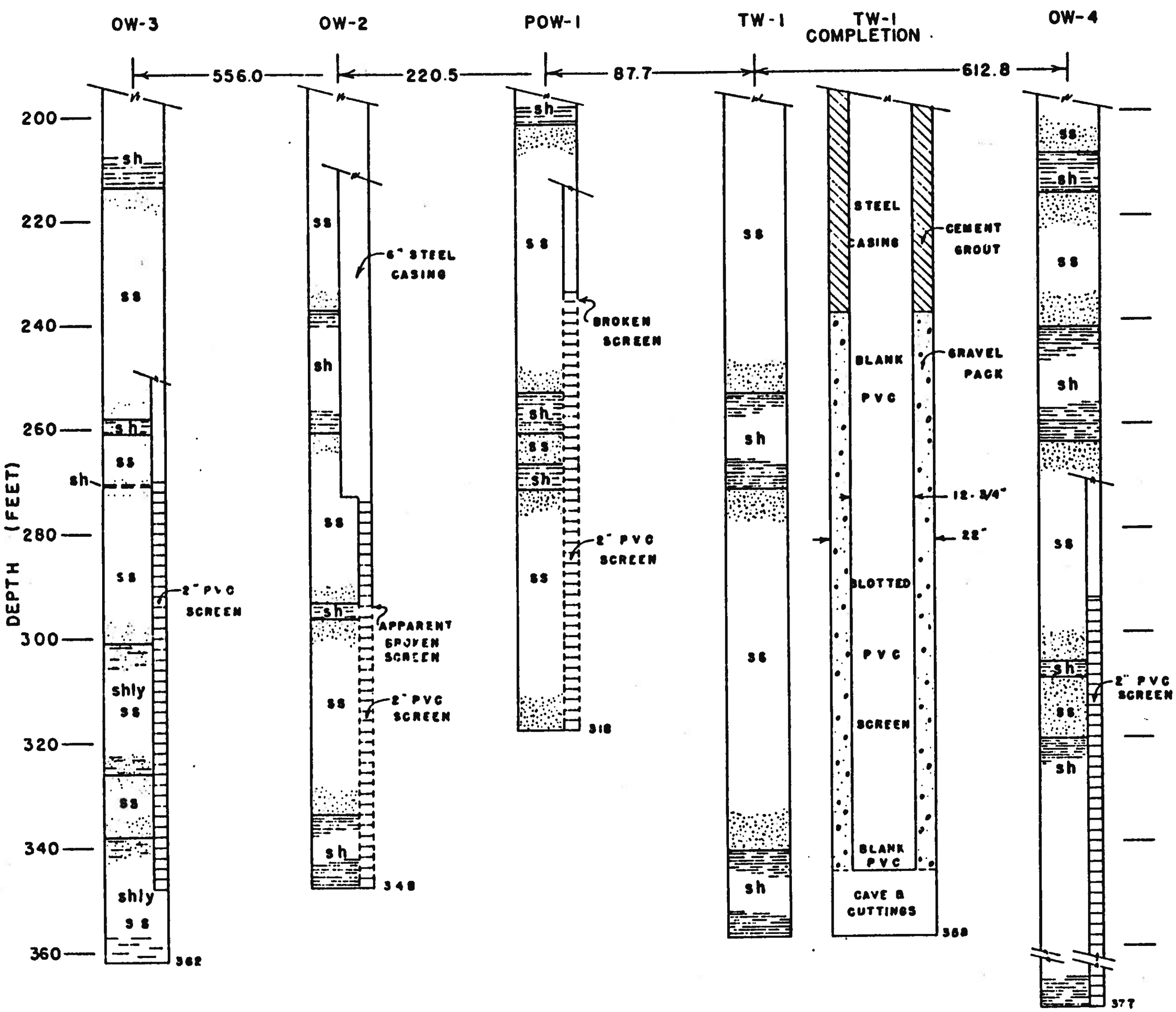
USBR, 1979



Cross-section of resistivity soundings, lines 2, 3, 4, 5, the brine aquifer has been cross-hatched.

FIGURE 4

USBR, 1979
Appendix C



Notes:
No horizontal scale.

LAKE MEREDITH SALINITY
STUDY PROJECT – TEXAS
LOGAN, NEW MEXICO BRINE
AQUIFER TEST

Figure 2 Brine aquifer lithology at aquifer test site

USBR, 1979
Appendix D

OW NO. 4

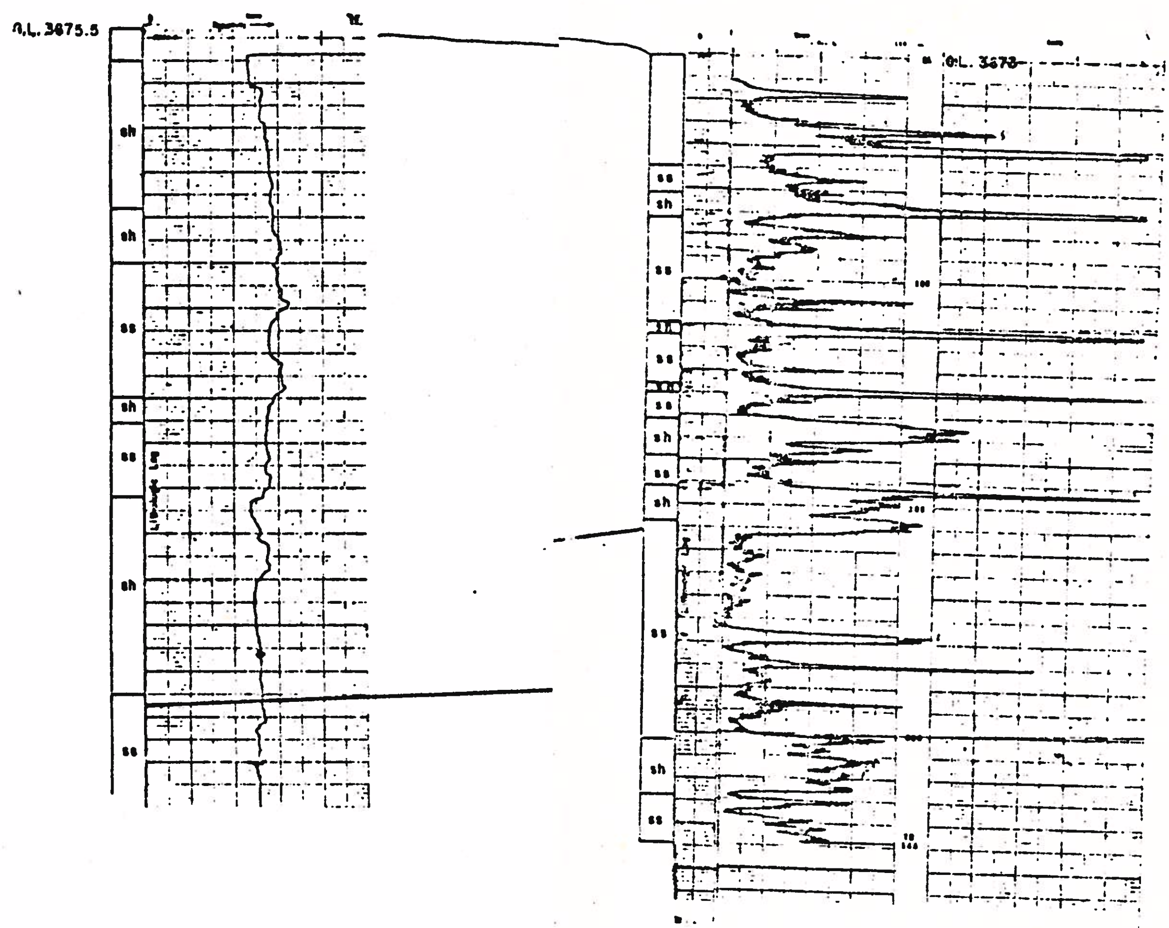
STAPP-HAMILTON ASSOC.
Quay County, New Mexico

	Resistivity
Date	12-13-77
First Reading	326
Last Reading	0
Bit Size	4 3/4
Resistivity Scale	20 ohm m/m^2
Recording Speed	30 FPM

OW NO. 3

STAPP-HAMILTON ASSOC.
Quay County, New Mexico

	Gamma Ray
Date	1-20-78
First Reading	348
Last Reading	0
G.R. Scale	100 API
Time Constant	2
Recording Speed	20 FPM



ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LAKE MEREDITH SALINITY STUDY-TEXAS, N.M.

GEOLOGIC SECTION
LOGAN AREA

DESIGNED............ SUBMITTED............
DRAWN............ RECOMMENDED............
CHECKED............ APPROVED............
AMARILLO, TEXAS 1253-500-14

Index to **TAB 6**: Hydrostratigraphic columns of the study area

Bassett and Bentley, 1983, Table 1

Senger, et al., 1987, Table 1

Wirojanagud, et al., 1986, Table 2

Wirojanagud, et al., 1986, Table 3

Bassett and Bentley, 1983

Table 1. Generalized stratigraphic column, depositional environment, and general hydrologic properties, Palo Duro Basin.

System	Series	Group	General lithology and depositional setting	Hydrogeologic element	Hydrogeologic unit	Approximate permeability (gpd/ft²)	Relative permeability
Quaternary			Fluvial and lacustrine clastics	Ogallala aquifer	Upper aquifer	200 ⓐ	10^8
Tertiary							
Cretaceous			Nearshore marine clastics				
Triassic		Dockum	Fluvial deltaic and lacustrine clastics and limestones	Dockum aquifer		2-20(?) ⓑ	10^6-10^7(?)
Permian	Ochoa		Salt, anhydrite, red beds and peritidal dolomite	Evaporite aquitard	Evaporite aquitard	2×10^{-6} ⓒ	1
	Guadalupe	Artesia					
		Pease River					
	Leonard	Clear Fork					
		Wichita					
	Wolfcamp		Shelf and platform carbonates, basin shale and deltaic sandstones	Wolfcamp carbonate aquifer	Deep-basin brine aquifer	2×10^{-2} ⓓ	10^4
Pennsylvanian			Basin shale aquitard	Pennsylvanian carbonate aquifer; Upper Paleozoic granite wash aquifer	Basin shale aquitard		
Mississippian			Shelf limestone and chert	Lower Paleozoic carbonate aquifer			
Ordovician		Ellenburger	Shelf dolomite				
Cambrian			Shallow marine (?) sandstone	Lower Paleozoic sandstone aquifer			
Precambrian			Igneous and metamorphic	Basement aquiclude	Basement aquiclude	0	0

ⓐ Cronin and Wells (1960), Myers (1969), Cronin (1961)
ⓑ Stevens (1980, written communication)
ⓒ Geotechnical Engineers (1978)
ⓓ This study

permeabilities (for further discussion, see p. 10); therefore all pre-Leonardian formations were grouped together into a single hydrogeologic unit for this preliminary regional analysis.

Middle and Upper Permian strata consist almost entirely of halite, anhydrite, dolomite, and fine-grained siliciclastic red beds, which grade southward into shallow-marine carbonates in the Midland Basin (Dutton and others, 1979). Together these formations compose the evaporite aquitard (table 1).

Overlying the Permian evaporites and red beds are the fluvial, deltaic, and lacustrine deposits of the Triassic Dockum Group and alluvial deposits of the Tertiary Ogallala Formation (fig. 5; table 1). The Dockum Group records the final stages of filling of the Permian Basin (McGowen and others, 1979). Hydrogeologic information on Dockum sandstones is limited; wells over the basin tapping these beds have low specific capacities and produce waters that range widely in salinity. In contrast, potable ground water in the overlying Ogallala aquifer has been heavily pumped for agricultural, industrial, and domestic purposes. The Ogallala is an extensive alluvial apron of sand, gravel, and clay that extends eastward from the Rocky Mountains in the form of coalescing alluvial fan lobes (Seni, 1980). The upper part of the Ogallala Formation is cemented with calcium carbonate or "caliche" that forms the resistant "caprock" rim of the Caprock Escarpment along the eastern boundary of the High Plains (fig. 5).

Shallow, fresh ground waters generally move eastward under the influence of the regional

Senger, et al., 1987

TABLE 1. Generalized stratigraphic column of the Palo Duro Basin (modified from Bassett and Bentley, 1982).

Era	System	Series	Group	Formation	General lithology and depositional setting	Hydrogeologic element	Hydrogeologic unit
Cenozoic	Quaternary			Blackwater Draw	Eolian sand and silt		
	Tertiary	Pliocene-Miocene		Blanco Ogallala	Eolian, fluvial, and lacustrine clastics	Ogallala aquifer	Shallow aquifer
Mesozoic	Cretaceous				Nearshore nonmarine and marine clastics, carbonates		
	Triassic		Dockum		Fluvial-deltaic and lacustrine clastics	Dockum aquifer	
Paleozoic	Permian	Ochoan			Cyclic sequences: shallow marine carbonates, hypersaline shelf, anhydrite, halite, and continental red beds	Evaporite aquitard	Evaporite aquitard
		Guadalupian	Artesia				
			Pease River	San Andres		San Andres unit 4 carbonate aquifer	
		Leonardian		Glorieta			
			Clear Fork	Cimarron anhydrite		Evaporite aquitard	
				"Tubb zone"			
				Red Cave			
			Wichita				
		Wolfcampian		"Brown Dolomite"	Shelf and shelf-margin carbonates, basinal shale, and deltaic sandstones	Wolfcamp carbonate aquifer	Deep-Basin Brine aquifer
	Pennsylvanian				Basinal-shale aquitard	Pennsylvanian carbonate aquifer; Upper Paleozoic granite-wash aquifer	
	Mississippian				Terrigenous clastics, shelf carbonates, and chert	Lower and Middle Paleozoic carbonate aquifer	
	Ordovician		Ellenburger		Shelf dolomite		
	Cambrian				Shallow marine (?) sandstone	Lower Paleozoic sandstone aquifer	
Pre-cambrian					Igneous and metamorphic	Basement aquiclude	Basement aquiclude

consequently, observed hydraulic heads may reflect some past paleohydrologic state of the system. Further, reservoir-pressure decline from production of oil and gas fields along the margins of the basin may have caused large-scale transient underpressuring. The role of these various processes and their impact on the hydrodynamics of the basin were addressed in this study.

Scope

A two-dimensional ground-water flow model was constructed along a cross section through the Palo Duro Basin to characterize regional ground-water flow paths as well as to investigate causes of underpressuring below the Evaporite aquitard, to evaluate mechanisms of recharge and discharge to and from the Deep-Basin Brine aquifer, and to examine transient effects of erosion and hydrocarbon production. This study was designed to investigate various factors affecting the overall ground-water flow pattern in the basin and was not necessarily aimed at producing a fully calibrated predictive model.

In the first phase, the model was used to simulate steady-state ground-water flow conditions using data on hydraulic conductivity from various hydrologic units in the section and hydraulic heads and recharge rates along the boundaries of the model. Objectives were to evaluate the effects of hydrostratigraphy and topography on the

Wirojanagud, et al., 1986

Table 2. Permeability of hydrogeologic units, Palo Duro Basin.

Hydrogeologic unit		y = ln(k) Average md value, $\bar{y}$	Variance, s^2	Geometric mean of k ($e^{\bar{y}}$), md	Number and source of data	Typical value, md
Evaporite strata		-	-	-	-	.00028 (vertical permeability)
Deep-Basin Brine aquifer	Wolfcamp carbonate	2.19	2.89	8.90	25 - DST data 70 - TWDB core data 6 - Sawyer No. 1 pumping-test data	.07-300*
	Pennsylvanian carbonate	2.88	3.73	17.90	25 - DST data 118 - TWDB core data	
	Shale	-	-	-	-	.00001-.08*
	Granite wash	1.27 (2.15 without Mobeetie data)	6.17 (4.15 without Mobeetie data)	3.55 (8.60 without Mobeetie data)	10 - DST data 10 - Sawyer No. 1 pumping-test data 415 - Mobeetie field core data 11 - TWDB core data	.01-380*
	Pre-Pennsylvanian rock	1.56	2.87	4.76	11 - DST data 14 - Sawyer No. 1 pumping-test data	-

* *From Davis and DeWiest (1966), Freeze and Cherry (1979), and Davis (1980).*
Note: (1) 1 md = 0.00115 m/day for saline water having salt concentration of 127,000 mg/L at 115°F.
(2) DST = drill-stem test; TWDB = Texas Water Development Board (Core Laboratories, 1972).

10 DST, 10 pumping tests in a single granite-wash interval in the Sawyer No. 1 test well, and 426 laboratory core analyses. Of the core sample analyses, 415 are from 6 wells in the Mobeetie field in the Anadarko Basin. Pre-Pennsylvanian permeability data are limited and consist of values from 4 DST of the Ellenburger Group, 6 DST of Mississippian carbonates, 1 pumping test of the Ellenburger Group, and 14 pumping tests in a single Mississippian carbonate interval in the Sawyer No. 1 test well. From this data base, Smith (1983) summarized the permeability values of each hydrogeologic unit and computed the geometric mean, arithmetic mean, and variance of the permeability for each type of data. Additional permeability data from five pumping tests in the Pennsylvanian granite wash at the Stone and Webster J. Friemel No. 1 well in Deaf Smith County, Texas, indicate a permeability range of 10 to 400 md and an average of 140 md. Laboratory tests on a granite-wash core sample from the same well indicate a permeability range of 97 to 267 md.

It should be noted that none of the aforementioned permeability data represent a vertically averaged permeability of the hydrogeologic unit at a given location, which is the desired nodal point value in two-dimensional areal flow simulations. Although pumping tests give permeability values that represent the average fluid-conducting property of a larger volume of the medium than do permeability tests for core samples, the tested zone of the medium is only a small part of the entire thickness of the hydrogeologic unit. No attempt was made to compute the vertically averaged permeability at data points having more than one permeability value because of the insufficiency of information and the variety of testing techniques used to obtain the permeability data. Instead, all the permeability data on each hydrogeologic unit (including those of

Wirojanagud, et al., 1986

the neighboring basins) were used to compute the unit's geometric mean and variance.

Table 2 summarizes the effective permeability values and variances of each hydrogeologic unit of the Palo Duro Basin. The large variance values indicate a large natural variation in the permeability of each hydrogeologic unit. By including permeability data from neighboring basins, the effective-average permeability value is slightly increased for the Wolfcamp and Pennsylvanian carbonates but slightly decreased for the granite wash. A conservative approach is maintained by using the larger value for each hydrogeologic unit.

The vertical permeability of 2.8×10^{-4} md for the Evaporite aquitard was derived from the harmonic means of permeabilities of its substrata in two typical cross sections through the evaporite strata. Typical or measured permeability values were used for each substratum: 0.0001 md for red-bed shale (Davis and DeWiest, 1966), 0.0073 to 0.012 md for salt and anhydrite (Davis and DeWiest, 1966; Peterson and others, 1981), and 0.24 md for dolomite (Dutton and Orr, 1985). Table 2 includes the typical permeability values of carbonates, shale, and granite wash taken from the literature.

Porosity

No direct porosity measurements are available for the Deep-Basin Brine aquifer of the Palo Duro Basin. An indirect method using neutron-density logs yielded quantitative porosity determinations of the Wolfcamp and Pennsylvanian strata (Conti and Wirojanagud, 1984). From two neutron-density logs, which penetrate the Pennsylvanian strata at the Stone and Webster Sawyer No. 1 test well in Donley County and the Stone and Webster Mansfield No. 1 test well in Oldham County, porosity values of the Wolfcamp and Pennsylvanian carbonates and granite wash were estimated at 50-ft (15-m) intervals according to the procedure described by Schlumberger (1979). Results of the analyses and some typical porosity values are given in table 3. Using 20 neutron-density logs in the Palo Duro Basin, Conti (1984) made preliminary determinations of Wolfcamp carbonate porosity distributions (fig. 7).

***Table 3.** Porosity of hydrogeologic units, Palo Duro Basin.*

Hydrogeologic unit		Porosity from neutron-density log analysis: Mean	Standard deviation	Number of data	Typical value*
Evaporite strata		-	-	-	Less than .01
Deep-Basin Brine aquifer	Wolfcamp carbonate	.08 (.064)**	.055	53 data points from a 50-ft interval at Sawyer No. 1 and Mansfield No. 1 wells	.063 - .12
	Pennsylvanian carbonate	.08	.055		
	Shale	-	-	-	.05 - .25
	Granite wash	.23	.12	18 data points from a 50-ft interval	.11 - .27
	Pre-Pennsylvanian rock	-	-	-	-

**From Davis and DeWiest (1966) and Davis (1980).*
***Average value for Wolfcampian strata (Conti and others, 1985).*

Index to **TAB 7**: Maps related to ground water conditions

Berkstresser and Mourant, 1966, Plate 1, part

Dutton, 1987, Figure 16

Dutton and Orr, 1986, Figure 5

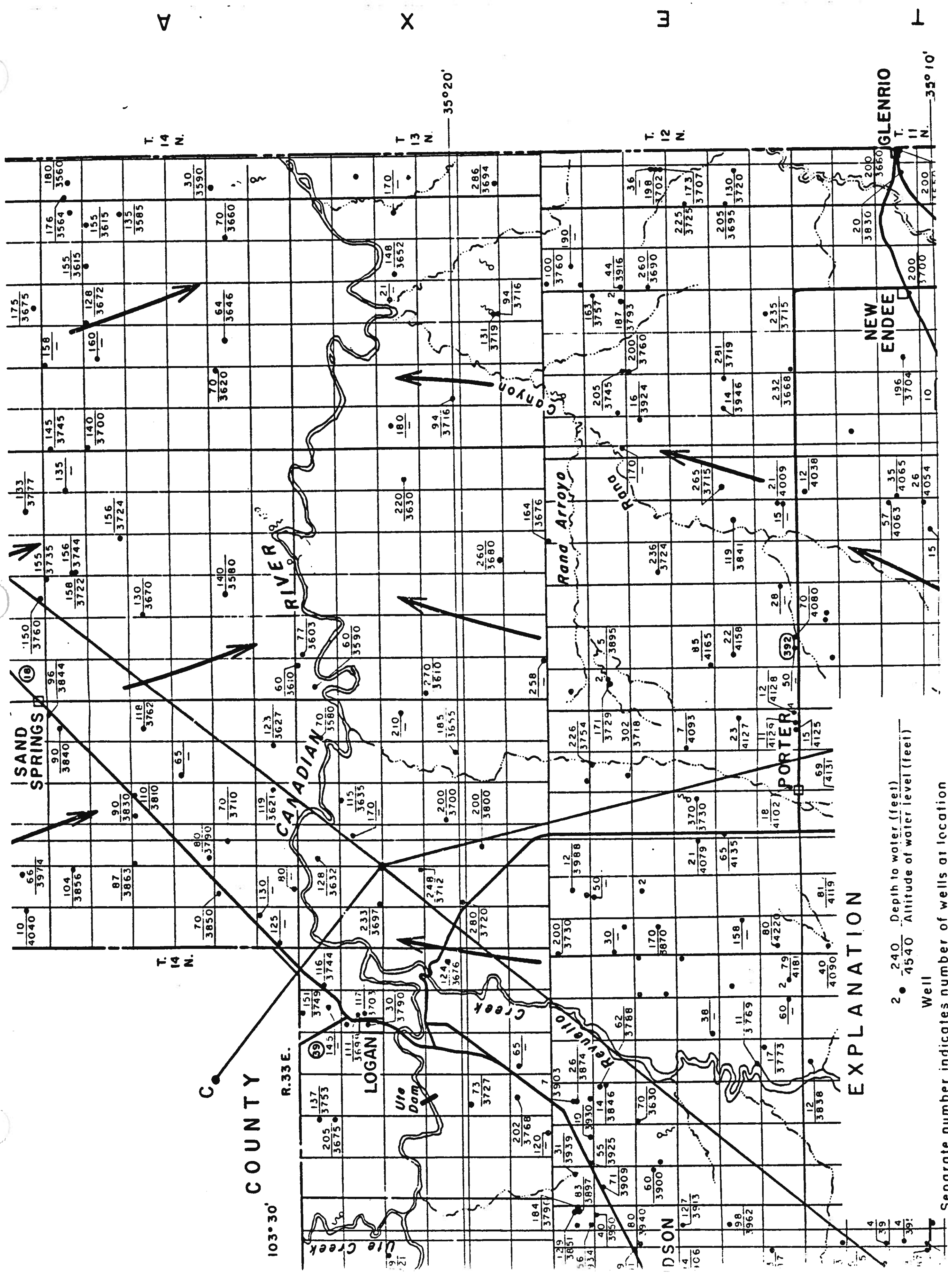
Dutton and Orr, 1986, Figure B1

HGC, 1984a, Figure 22

Orr, et al., 1985, Figure 1

Orr, et al., 1985, Figure 3

Berkstresser and Mourant, 1966



Dutton, 1987

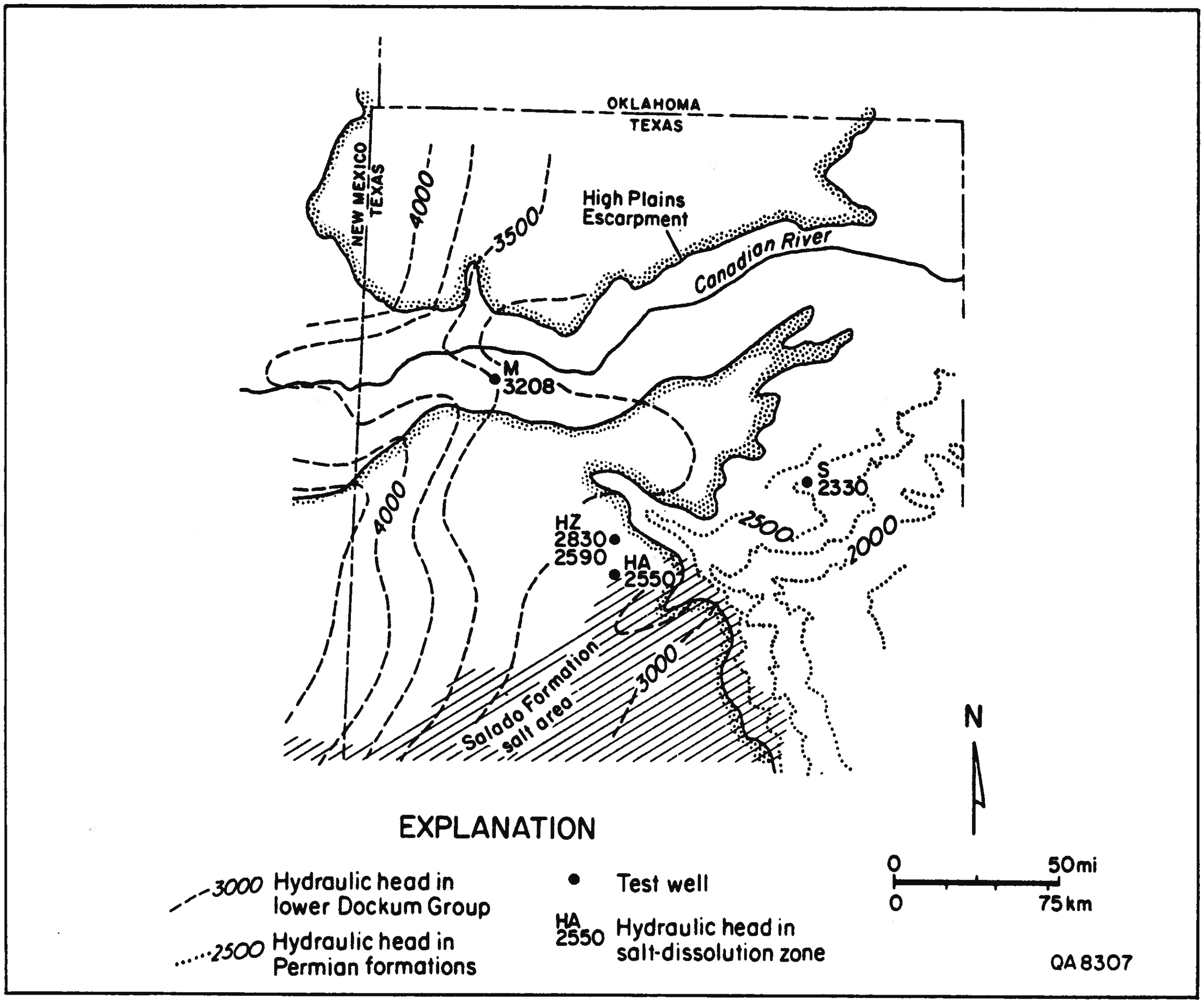


Figure 16. *Potentiometric surface of ground water in aquifers overlying salt-dissolution zones and point values of hydraulic heads in salt-dissolution zones. (Modified from Dutton and Simpkins, 1986.)*

the Upper Permian section. Reasons for the continuous downward decrease in hydraulic head include (1) ground-water flow through Triassic and Upper Permian mudstones of low permeability results in a loss of hydraulic head; (2) recharge areas for salt-dissolution zones occur at lower elevations around the Southern High Plains than do recharge areas for the upper aquifers, and this limits the maximum hydraulic head in each hydrologic unit; and (3) the discharge rate from the salt-dissolution zones is greater than the recharge rate to each hydrologic unit and prevents hydraulic head from building up to a hydrostatic level at equilibrium with the overlying column of water.

There are too few wells to map potentiometric surfaces of ground water in salt-dissolution zones in different formations that vary in hydrogeologic properties and hydraulic heads. However, because topography strongly influences potentiometric surfaces of ground water in near-surface aquifers (Tóth, 1962, 1963, 1978; Hitchon, 1969), the general shape of potentiometric surfaces of salt-dissolution zones can be inferred from the potentiometric surfaces of ground water in the Dockum Group beneath the Southern High Plains and in Permian formations at shallow depth beneath the Rolling Plains. Potentiometric surfaces of ground water in the overlying aquifers (fig. 16) are clearly influenced by topography. For example, folds in the potentiometric surface of the lower Dockum Group along the northern and western limits of the Southern High Plains mark topographically controlled ground-water-basin divides that separate Dockum Group ground water beneath the Canadian River and Pecos River valleys from ground water beneath the Southern High Plains (Dutton and Simpkins, 1986). Because of the overriding influence of topography, the

Dutton and Orr, 1986

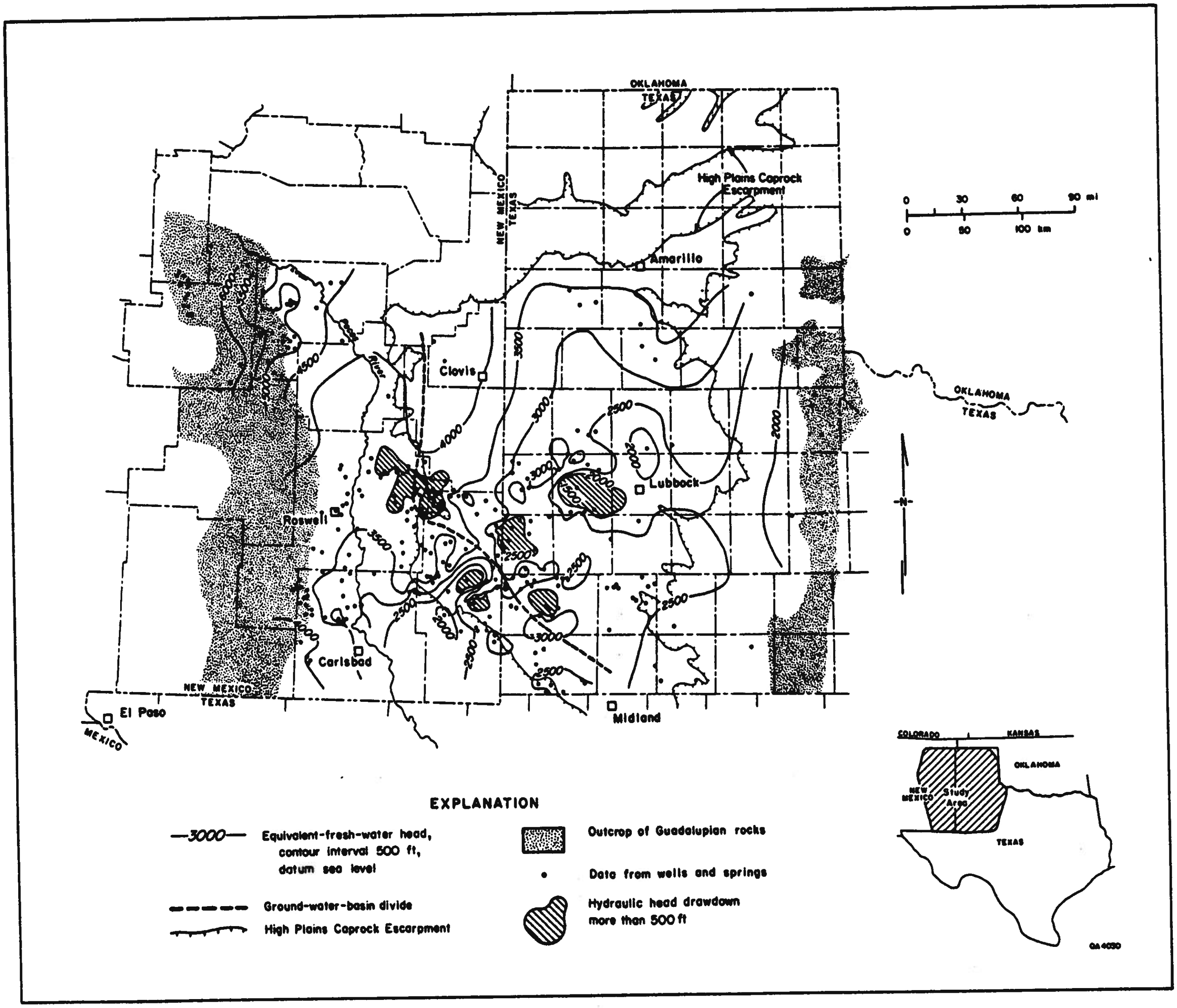


Figure 5. Potentiometric-surface map of the San Andres Formation prepared by hand-contouring hydraulic-head data calculated from shut-in pressures and weight of fresh water.

Chemical Data

We took 50 chemical analyses of ground water in the San Andres Formation below the Pecos Plains from compilations by Griggs and Hendrickson (1951), Hendrickson and Jones (1952), Smith (1957), Nicholson and Clebsch (1961), Berkstresser and Mourant (1966), Hem (1970, p. 145), Mourant and Shomaker (1970), and Dinwiddie and Clebsch (1973). We culled chemical analyses of 161 samples of saline ground water in oil fields from surveys by Hiss (1975) and by Petroleum Data Service of the University of Oklahoma. The chemical analyses are listed in appendix C. Chemical analyses of San Andres water vary in completeness and in conditions of sample treatment. Samples of brine from oil fields are of two types: those collected during drill-stem tests and those obtained from a wellhead or storage tank at producing wells. Oil field brine samples may be contaminated by drilling mud or by reaction with well hardware or storage tanks (Bassett and

Dutton and Orr, 1986

Table B1. Geostatistical parameters used to determine the potentiometric surface of the San Andres Formation by kriging.

Parameter	This study*	Orr and Dutton (1983)*
Class size	7,000 m	5,000 m
Block width	20,000 m	20,000 m
Radius	40,000 m	10,000 m
Range of influence	41,250 m	21,500 m
Nugget	50,000 ft^2	44,309 ft^2
Sill	240,000 ft^2	164,309 ft^2

* Units are those originally used in calculations.

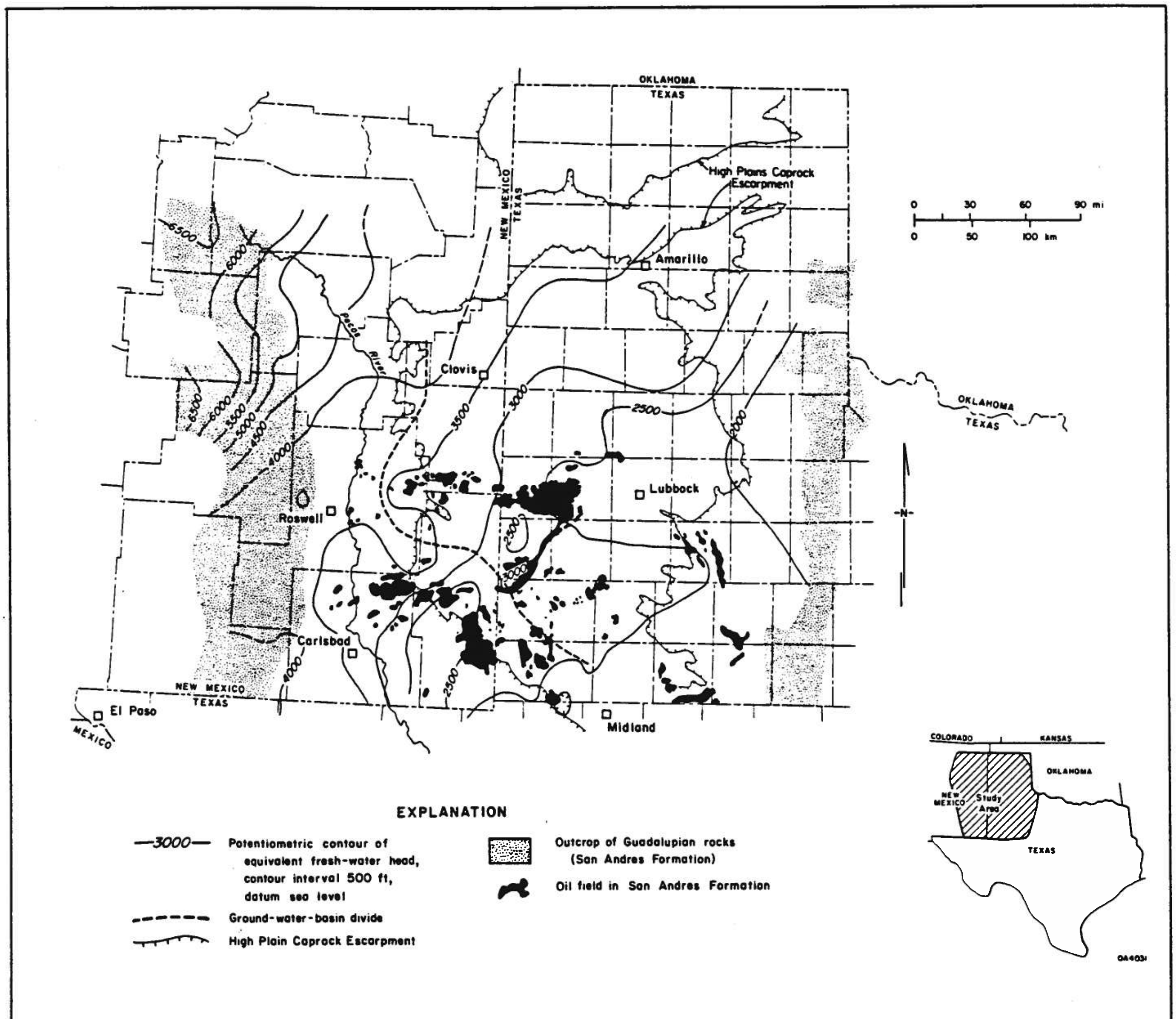


Figure B1. Potentiometric-surface map of the San Andres Formation made by kriging data on equivalent fresh-water head.

HGC, 1984a

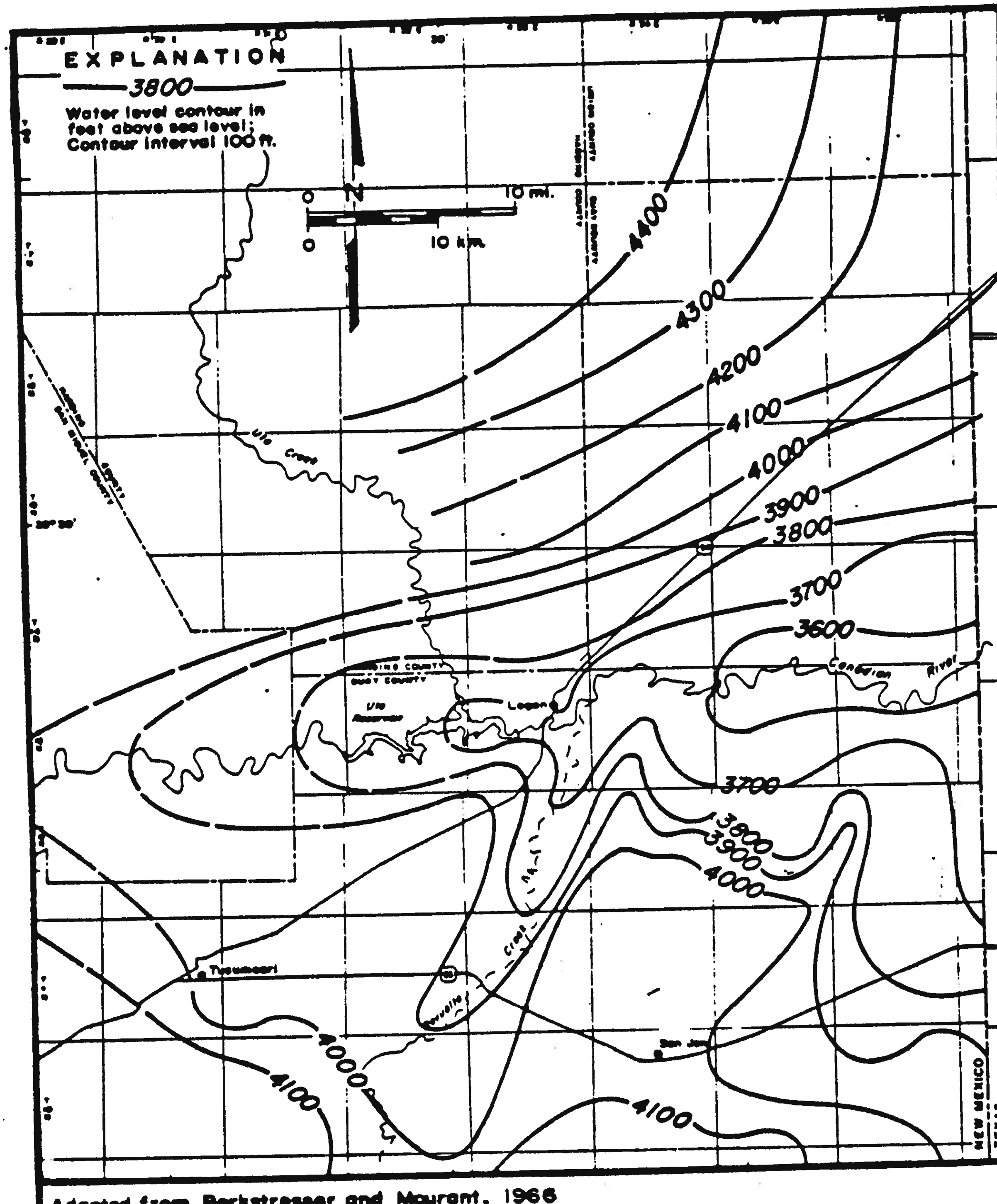


Figure 22. Triassic water-level surface within detailed study area

HYDRO GEO CHEM, INC.

Orr, et al., 1985

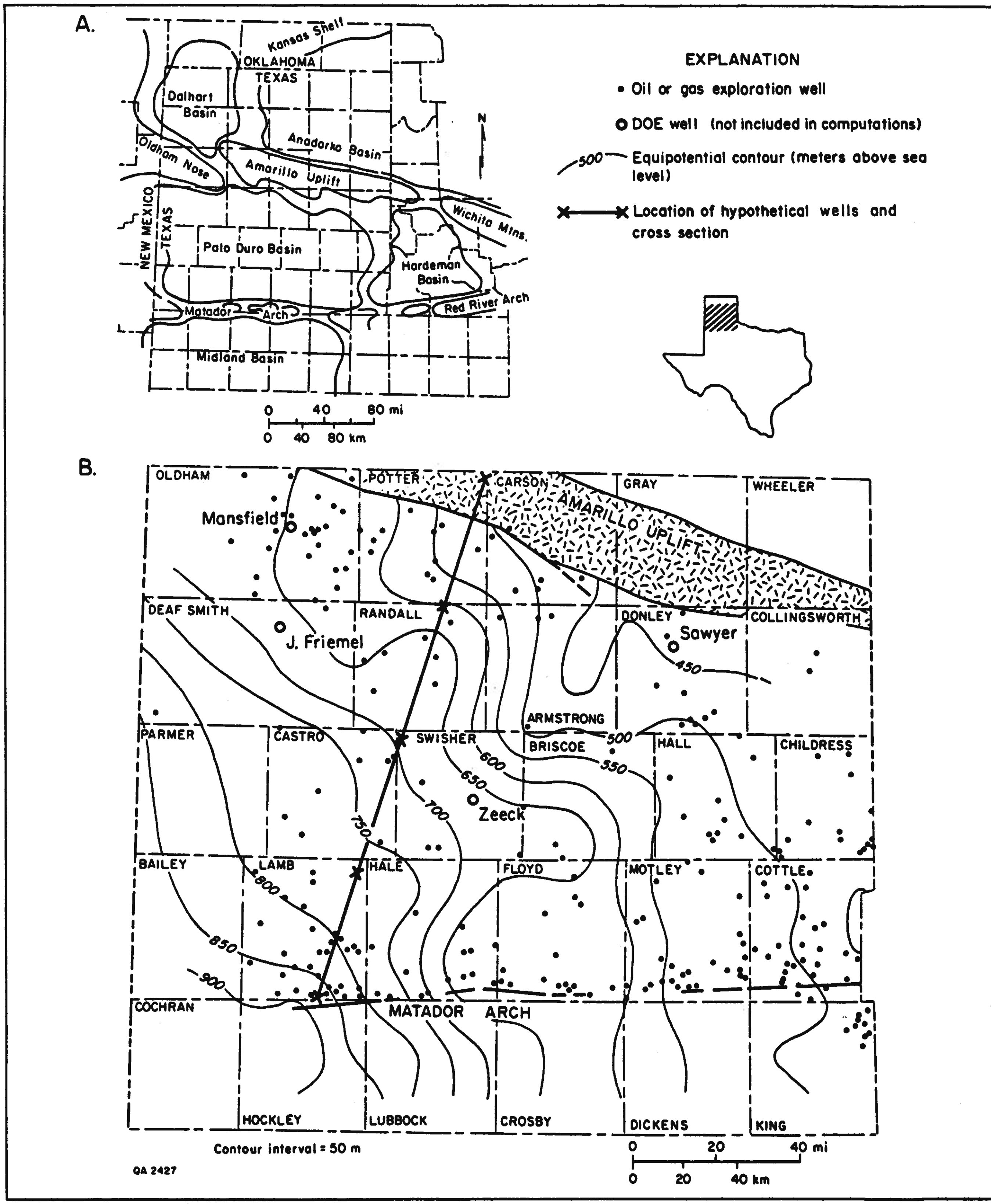


***Figure 1.** The study area: (A) Structural features of the Texas Panhandle and adjacent areas. (B) Average potentiometric surface of the Deep-Basin Brine aquifer (Wirojanagud and others, 1984) and location of drill-stem tests used in this study. The map indicates that ground water flows from the southwestern part of the Palo Duro Basin northeastward toward the Amarillo Uplift. In the southeastern part of the basin, flow is more easterly. Location of hypothetical cross section depicted in figure 5B is shown.*

Orr, et al., 1985

possible sources of variation, such as data quality and the hydrogeologic setting, (4) document and areally delineate any varying potentials for vertical flow within the Deep-Basin Brine aquifer, and (5) evaluate the significance of any potential components of vertical flow by estimating vertical flux and flow volumes. By accomplishing these objectives, the present-day potentiometric surfaces, pressure-depth conditions, and vertical hydraulic gradients of the Deep-Basin Brine aquifer can be better understood.

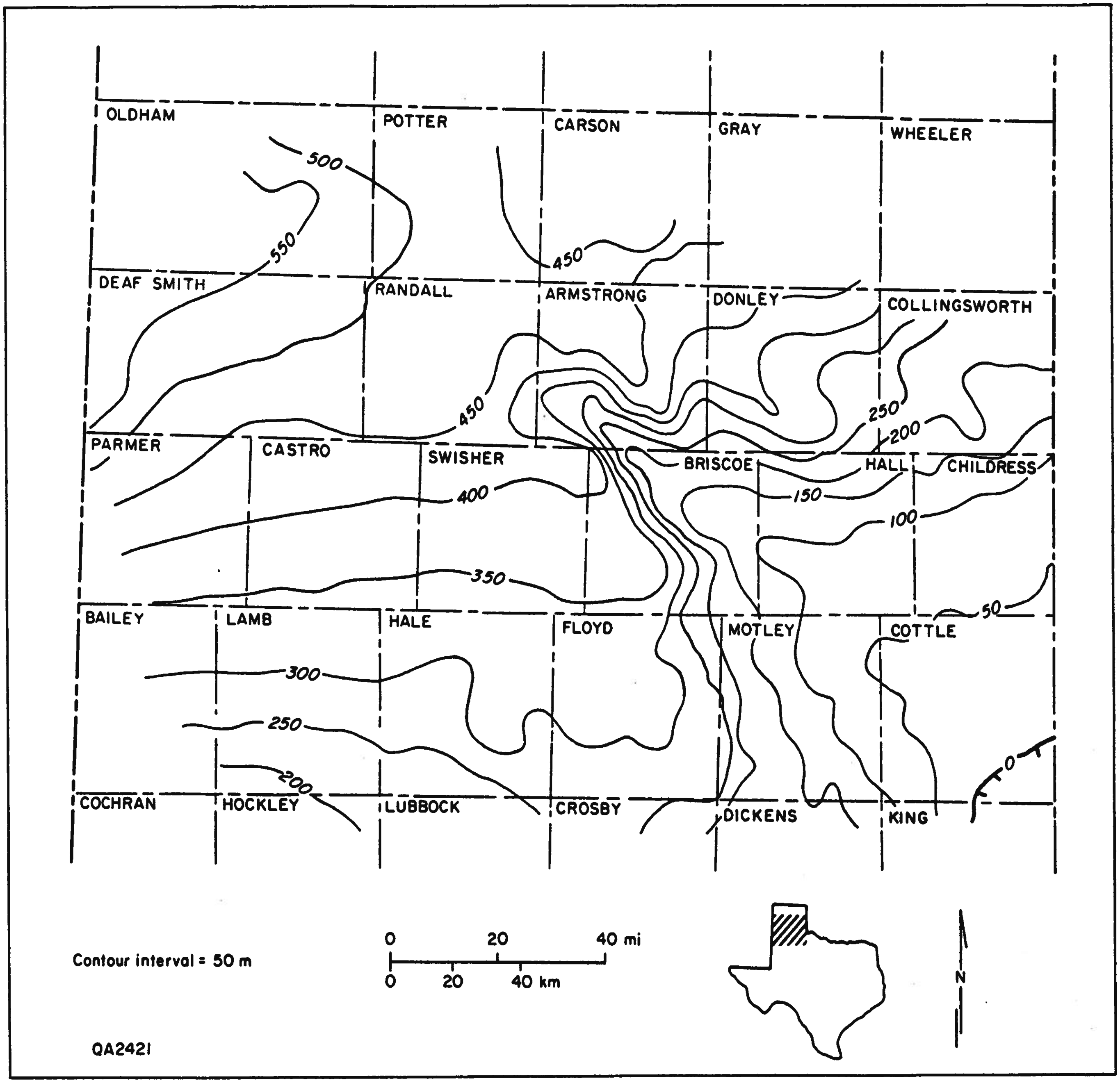
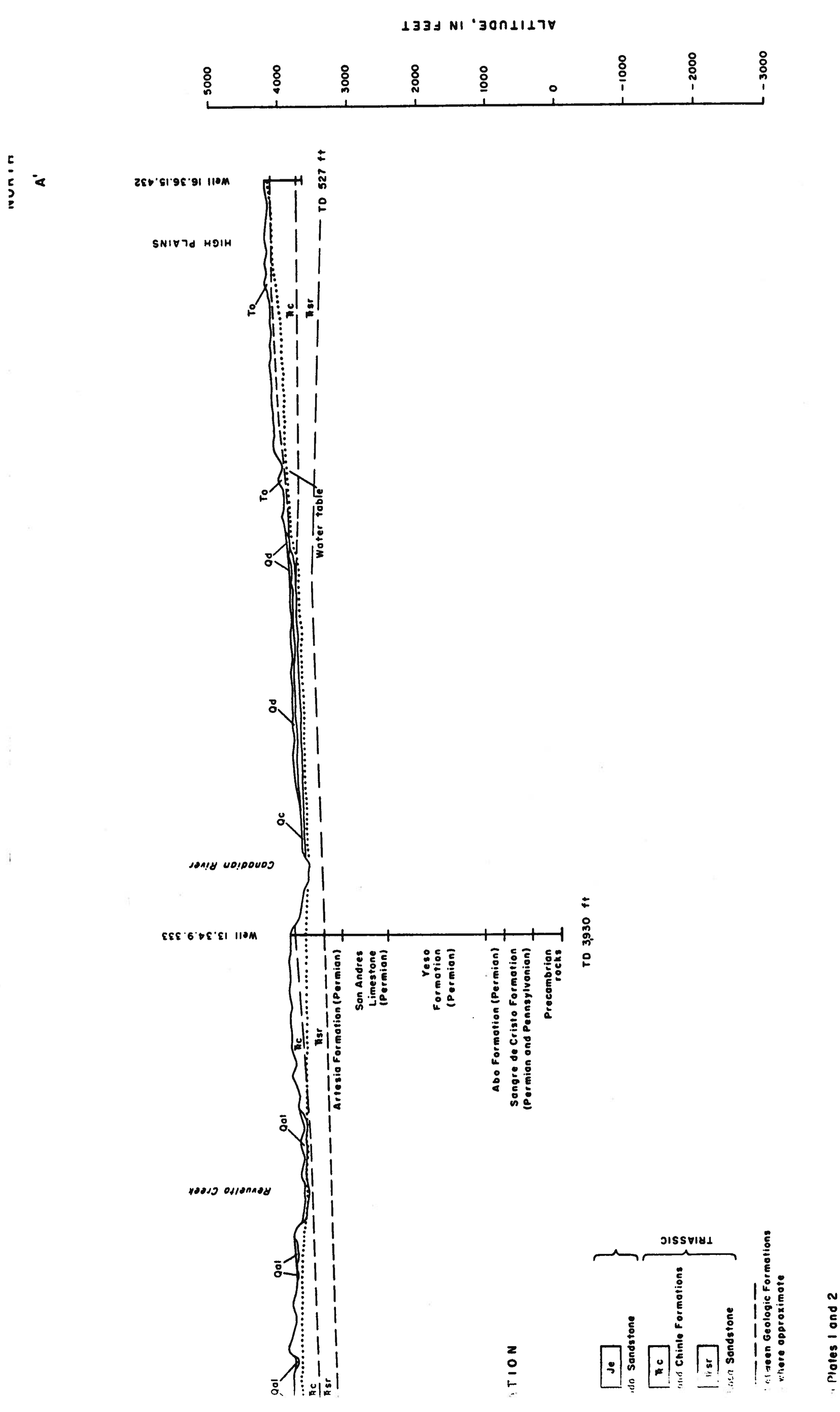


Figure 3. *Contour map of differences between potentiometric surfaces of the Ogallala and Dockum aquifers and the Wolfcampian aquifer (Wirojanagud and others, 1984). Potential for downward ground-water flow through the Evaporite aquitard is greatest in the northwestern part of the Palo Duro Basin, where head differences are high, and least in the southeastern part of the Palo Duro Basin, where head differences are low.*

Index to **TAB 8**: Hydrogeologic cross-sections

Berkstresser and Mourant, 1966



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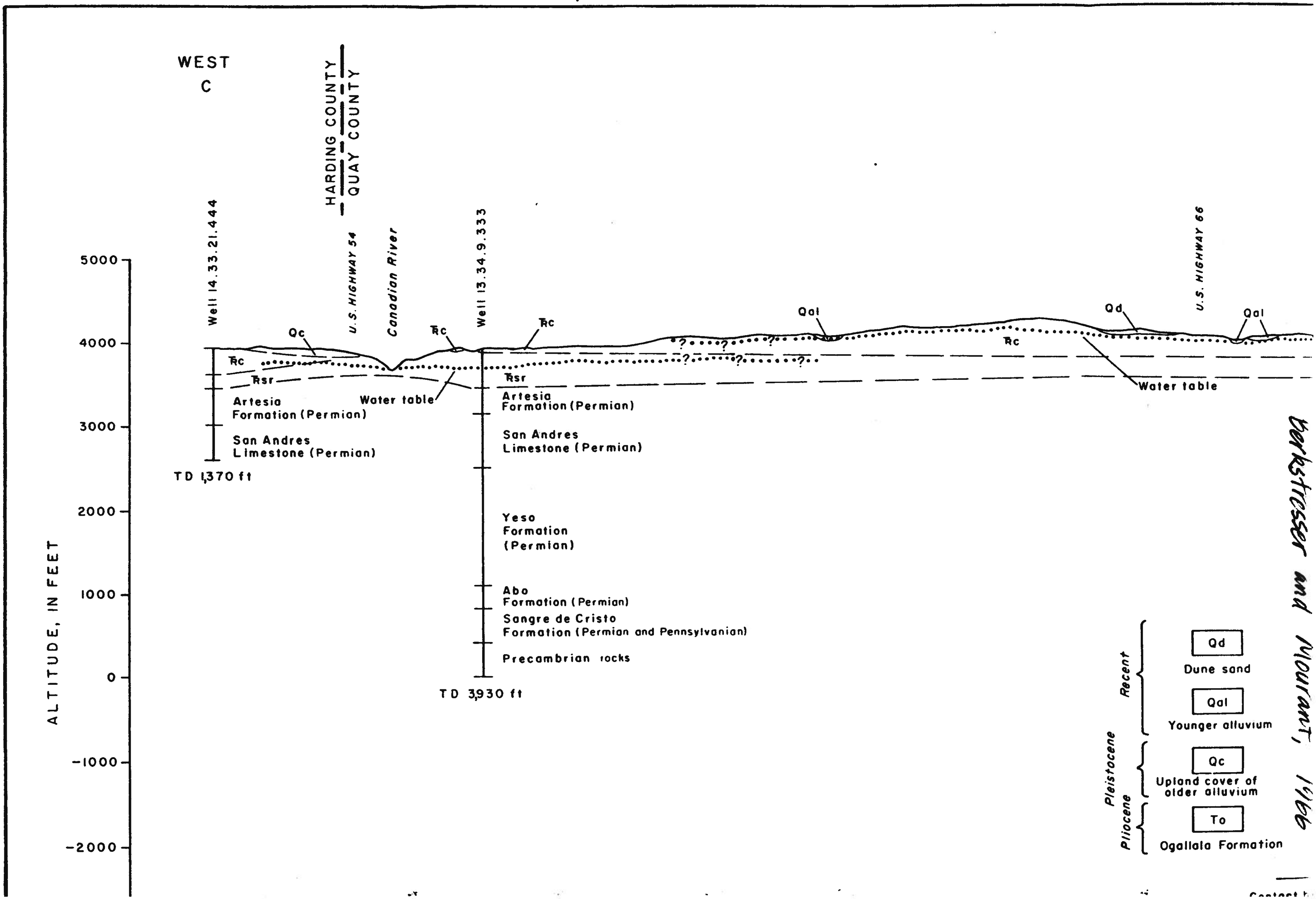
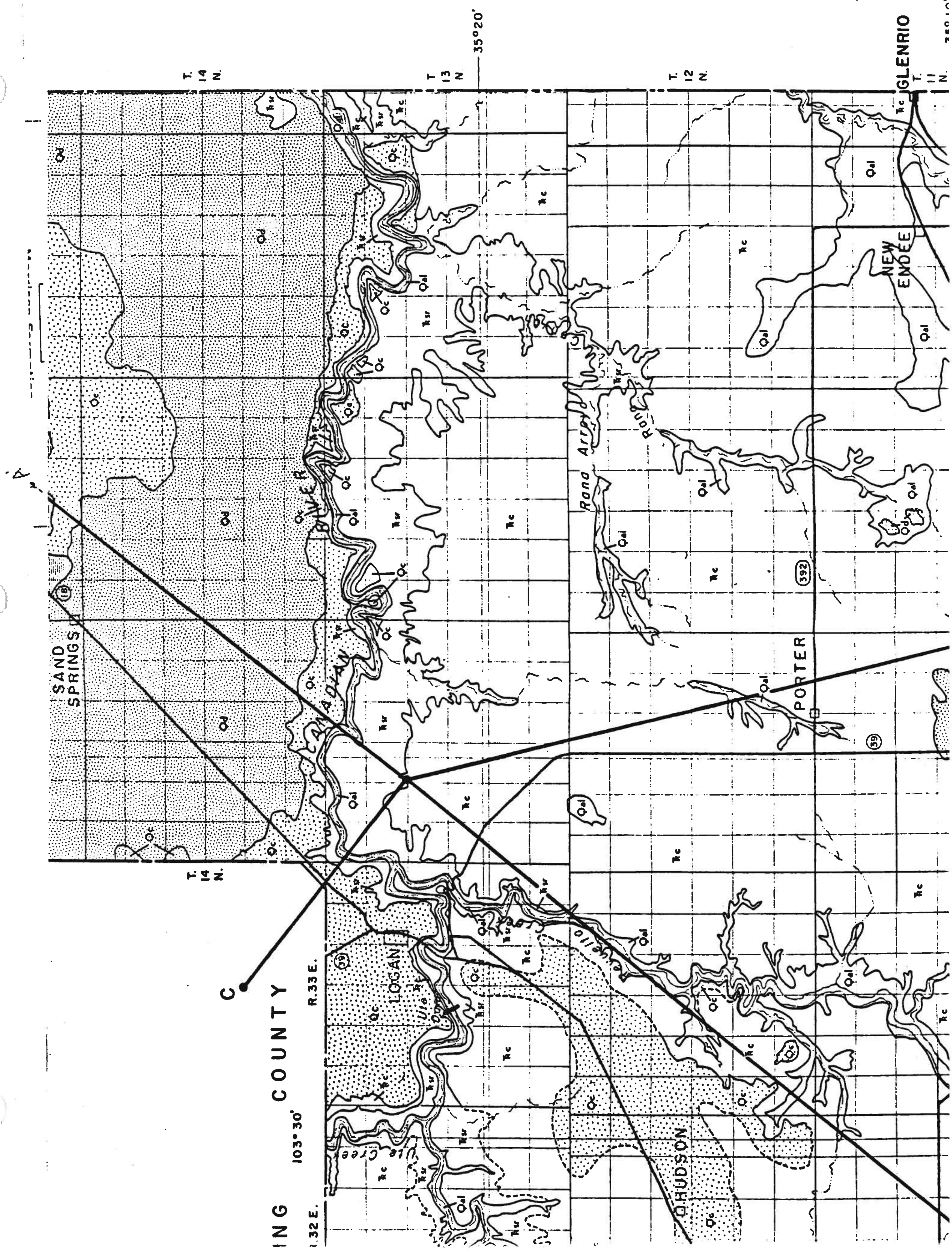


Berkstresser and Mourant, 1966



Dutton, 1987

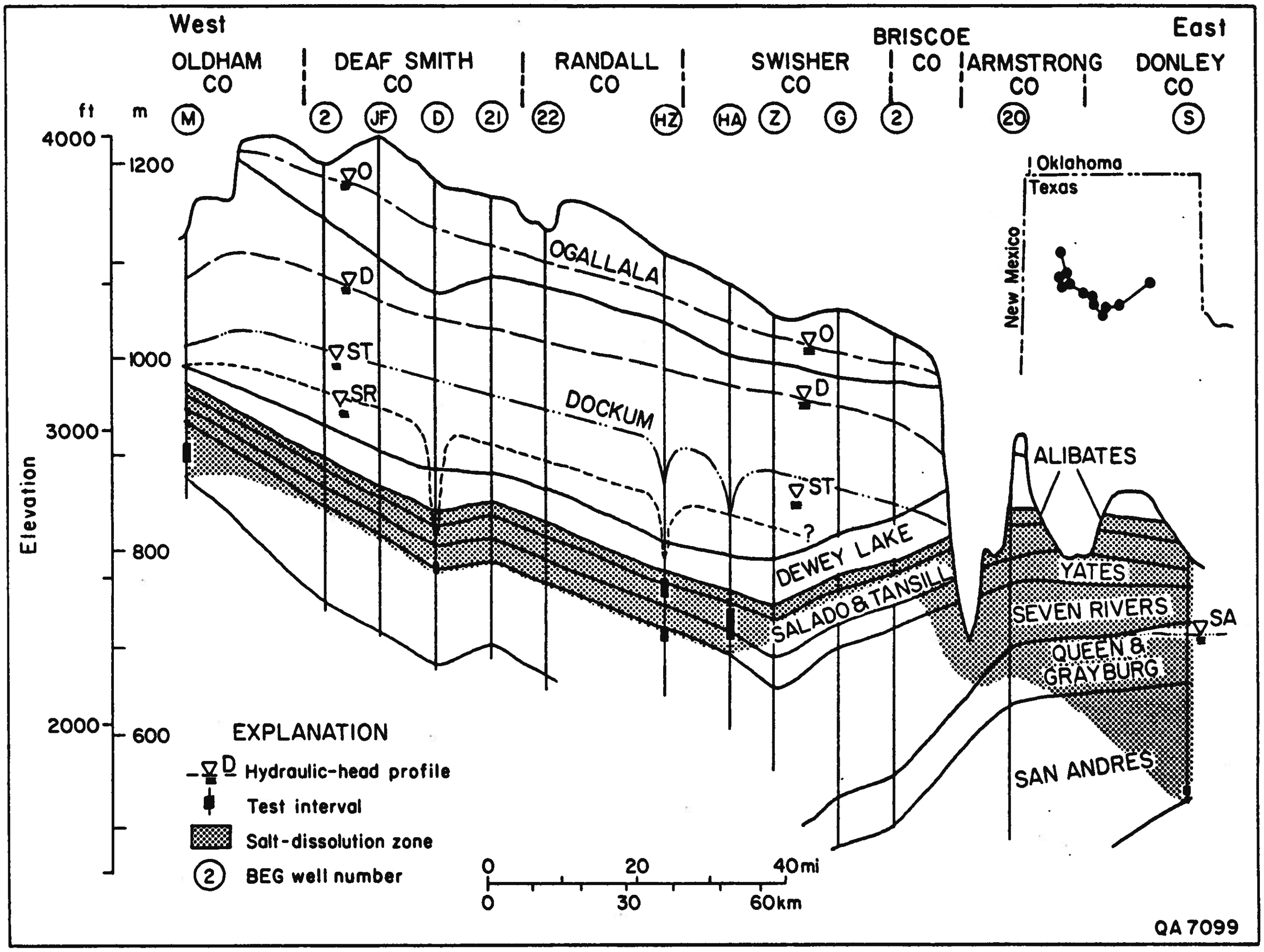


Figure 8. Profiles of hydraulic head in salt-dissolution zones (SA = San Andres, SR = Seven Rivers, ST = Salado and Tansill) and in aquifers in the Dockum Group (D) and Ogallala Formation (O).

RESULTS

Hydrologic Testing

Hydrologic testing indicates that hydraulic conductivity of salt-dissolution zones in Permian formations is low to moderate (2×10^{-4} to 1.6 ft/d; 6×10^{-5} to 0.5 m/d). Hydraulic head of ground water in dissolution zones is lower than the hydraulic head in overlying aquifers (fig. 8), confirming the potential for downward movement of ground water from aquifers in the Dockum Group and Ogallala Formation into the Upper Permian section. The coefficient of storage estimated at two wells is about 10^{-4}, indicating that these salt-dissolution zones are confined. The following sections detail hydrologic properties at each test well.

SWEC Sawyer No. 2 well

The strong influence of wellbore storage on water levels in the SWEC Sawyer No. 2 well during drawdown and recovery periods is indicated by the linear relatior between water-level change and elapsed time on logarithmic plots (fig. 9). Discharge during the first 100 mir of each test came from storage. As shown in figure 9a, the drawdown was 10.0 psi after 5½ min. From equation 5

$$C = \frac{QB\Delta t}{\Delta P} = \frac{(10.8\ \text{gal/min})\ (1.0)\ (5.5\ \text{min})}{(10\ \text{psi})\ (7.48\ \text{gal/ft}^3)}$$

$$C = 0.794\ \text{ft}^3/\text{psi} = 0.366\ \text{ft}^3/\text{ft}$$

assuming that the dimensionless formation-volume factor (B) is 1.0 for the pumping well and that specific weight of the brine is 0.461 psi/ft. The actual well capacity of the 8⅝-inch casing (I.D.=8.097 inches [20.566 cm]) is 0.358 ft^3/ft (0.033 m^3/m). The close agreement between

Gustavson, et al., 1980a

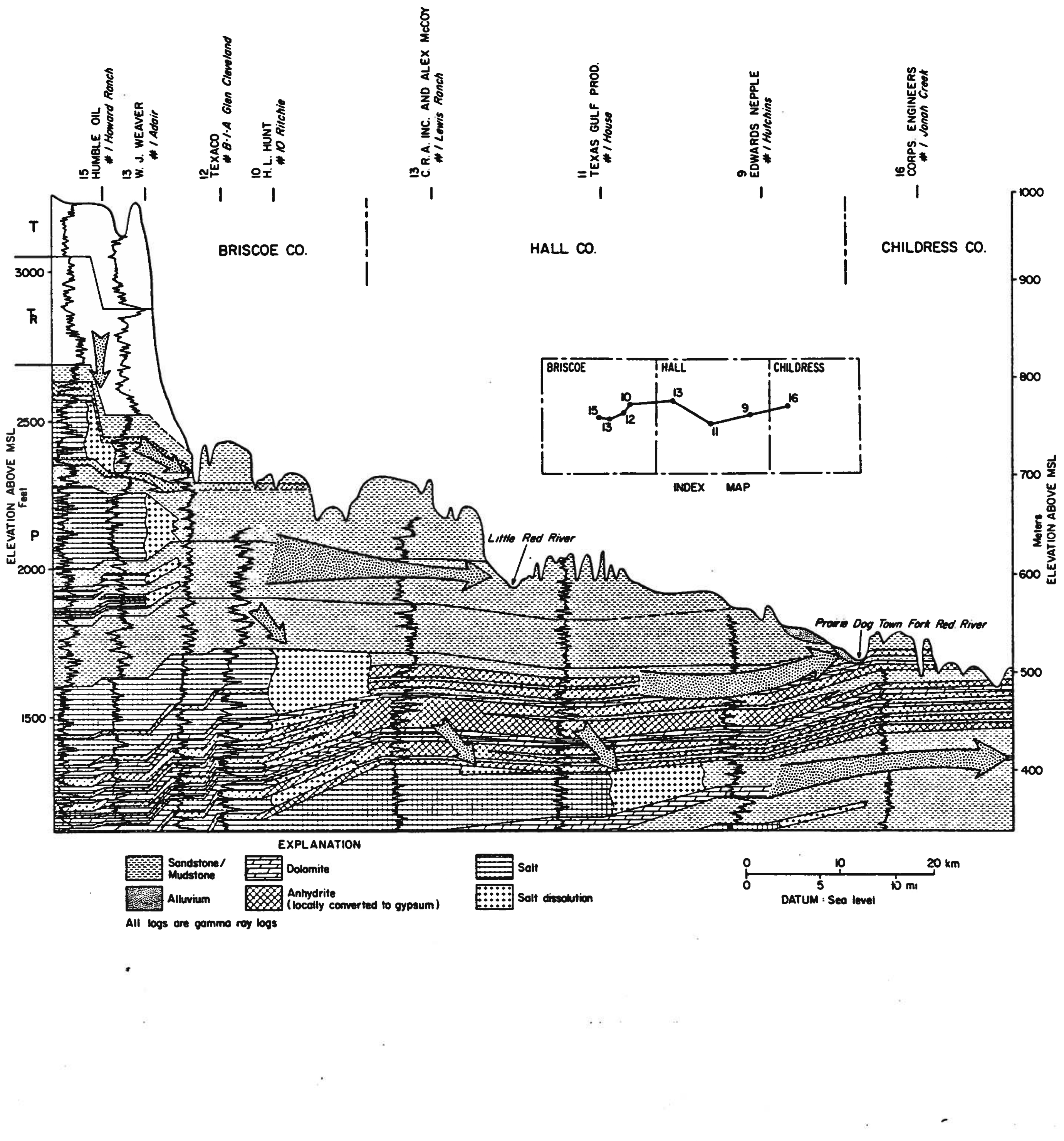


Figure 31. Conceptual model of ground-water movement and its impact on Permian salt units beneath the eastern Caprock Escarpment. Inferred movement paths are indicated by the arrows. Stratigraphic units are identified in figure 6.

Orr, et al., 1985

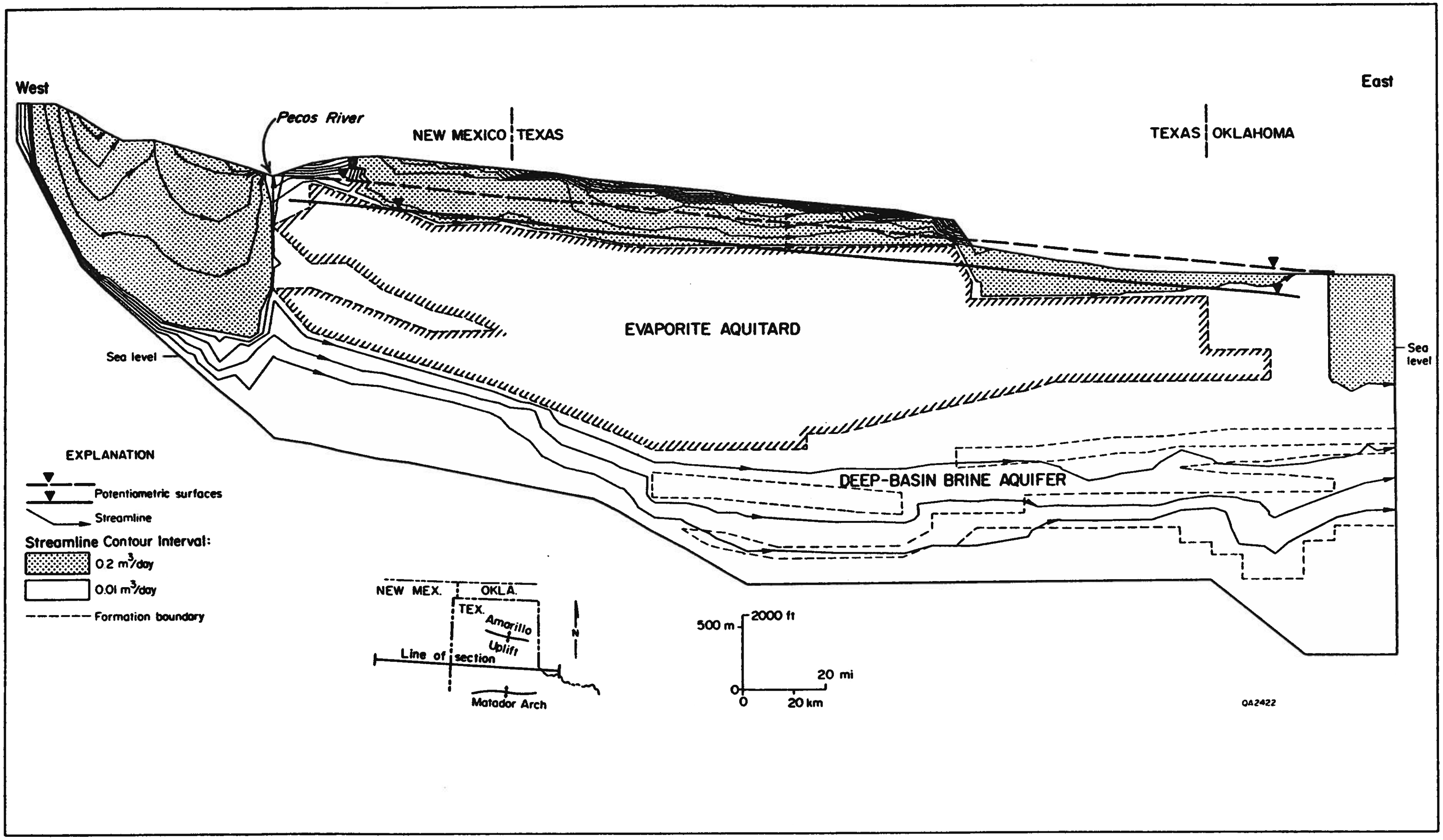


Figure 7. *Simplified cross section through the Palo Duro Basin from eastern New Mexico to western Oklahoma. Heavy dashed line indicates the expected potentiometric surface of the Deep-Basin Brine aquifer. Solid line indicates the approximate level of the actual potentiometric surface. Flow tubes calculated by cross-sectional modeling indicate that much of the potential recharge to the Deep-Basin Brine aquifer is discharged in the Pecos River valley.*

Index to **TAB 9**: Well and spring inventories from the study area

Significant wells in Logan area

Deep wells in Logan area with both water level and water quality data

Shallow wells in Logan area with both water level and water quality data

Berkstresser and Mourant, 1966, Table 1, (parts)

Berkstresser and Mourant, 1966, Table 2

HGC, 1984a, Table 1

Significant Wells in Logan Area

Name	Location	Land Surface Elevation	Total Depth	Date Drilled	Log Data	Water Level Measurements	Water Quality: Number of Analyses	Water Quality: Parameters	Comments
USBR DH-1[a]	Lat 35°21'13"N Long 103°24'51"E	3674.5?[b]	356	6/75	Geologic Log	Water levels of packered intervals in hole during drilling	19[c]	Cl,NaCl,SO_4, total Fe, conductance	Artesian flow of about 30 gpm encountered at 261 feet; river water samples collected during drilling.
USBR DH-2[a]	Lat 35°22'10"N Long 103°22'35"E[d]	3655.72?[e]	556	7/75	Geologic Log	Water level recorder 2 months 1983[f]	2[g] 2[h]	Cl,NaCl,SO_4,total Fe, conductance Field: conductance, T; Lab: Na,Mg,Ca,K,Cl,SO_4 HCO_3,CO_3,TDS,pH	Artesian flow of about 3 gpm encountered at 466 feet; river water samples collected during drilling.
USBR DH-3[i]	Lat 35°21'05"N Long 103°25'40"E	3781.0	569.5	8 & 9/83	Geologic Log Gamma Ray Log	Measured just after completion and monthly 10/83-7/84; pumped; measured 8 & 9/84	2[j]	Field: conductance, T; Lab: Na,Mg,Ca,K,Cl,SO_4, HCO_3,CO_3,TDS,pH	Triassic shale caved continuously; core sample 409.3-569.5 feet. Pumping in 7/84 may have dislodged drilling mud or foreign materials, resulting in more representative water level readings.
USBR TW-1[a]	adjacent to DH-1 Lat 35°21'12"N Long 103°24'50"E	3674.01	358	2-3/78	Gamma Ray Log	Water levels measured during aquifer test; 4 measurements in 8/82; water level recorder 5/83-8/84[f]	?[k]	pH,Na,Cl,SO_4, others?	Pumped for 97 hours 3/78 at 475 gpm; water-quality and completion data suggest both brine aquifer & higher, less-saline aquifer were tested; assuming 425 gpm from brine aquifer $T = 2250 ft^2/d$, $S = .00013$.
USBR POW-1[a]	88 feet SW of TW-1	3674.73?[l]	318	9-10/77	Geologic Log Gamma Ray Log Electric Log?[m]	Water levels measured during aquifer test			Artesian flow encountered at 294 feet; core sample 261-318 feet; soundings indicate broken casing near top of screen is open to aquifer above brine aquifer; drilled with bentonite mud.

Significant Wells in Logan Area, cont'd.

Name	Location	Land Surface Elevation	Total Depth	Date Drilled	Log Data	Water Level Measurements	Water Quality: Number of Analyses	Water Quality: Parameters	Comments
USBR OW-2[a]	220 feet SW of TW-1	3676.88?[n]	348	10/77-1/78	Geologic Log Gamma Ray Log Electric Log?[m]	Water levels measured during aquifer test			Core sample 300-348 feet; drilled with bentonite mud; no water-level response during pump test, so presumed plugged with drilling mud.
USBR OW-3[a]	556 feet SW of TW-1	3678.3?[o]	362	1/78	Geologic Log Gamma Ray Log Electric Log?[m]	Water levels measured during aquifer test; also monthly 11/83-9/84[f]	2[p]	Field: conductance, T; Lab: Na,Mg,Ca,K,Cl,SO_4, HCO_3,CO_3,TDS,pH	
							1[q]	stable O and H isotopes	
							1[q]	carbon-14	
							1[p]	tritium	
							1[q]	Cl,Br,I	
							1[q]	Field: T, pH, alkalinity, conductance; Lab: Ca,Mg,Na,K, CO_3,HCO_3,Cl,SO_4,NO_3, TDS by summation, B	
USBR OW-4[a]	613 feet NW of TW-1	3676.5?[r]	382	1/78	Geologic Log Gamma Ray Log Electric Log?[m]	Water levels measured during aquifer test; also 7/19/84	1[s]	Field: conductance, T; Lab: Na,Mg,Ca,K,Cl,SO_4, HCO_3,CO_3,TDS,pH	
USBR River Site O[i]	Piezometer at toe of Ute Dam Lat 35°20'40"N Long 103°27'36"E	3682.7	22				2	Field: conductance, T; Lab: Na,Mg,Ca,K,Cl,SO_4; HCO_3,CO_3,TDS,pH	Pumped once - clogged. Lake samples also collected.

Significant Wells in Logan Area, cont'd.

Name	Location	Land Surface Elevation	Total Depth	Date Drilled	Log Data	Water Level Measurements	Water Quality: Number of Analyses	Water Quality: Parameters	Comments
USBR River Site 1[i]	1.6 miles below Ute Dam Lat 35°21'12"N Long 103°25'17"E								
Piezometer A		3668.9	22	1983	Driller's Log	1 measurement in each piezometer on 8/24/83	19[t] 7	At each piezometer - Field: conductance, T; Lab: Cl, TDS, pH, conductance Besides the parameters listed above, Lab: Na, Mg,Ca,K,SO_4,HCO_3,CO_3	Piezometer A TD in bedrock; water quality samples obtained by air lifting. River samples also collected.
Piezometer B		3668.8	16	1983	Driller's Log				
USBR River Site 2[i]	2.2. miles below Ute Dam Lat 35°2'14"N(?) Long 103°24'52"E								
Piezometer A		3668.7	55	1983	Driller's Log	1 measurement in each piezometer on 8/24/83	19[t] 7 1[q] 1[q]	<u>At each piezometer</u> - Field: conductance, T; Lab: Cl, TDS, pH, conductance Besides the parameters listed above, Lab: Na, Mg,Ca,K,SO_4,HCO_3,CO_3 <u>At piezometer A only</u> - Field: T, pH, alkalinity, conductance; Lab: Ca,Mg,Na, K,CO_3,HCO_3,Cl,SO_4,NO_3, TDS by summation, B Lab: Cl,Br,I	Steel drill bits left in holes A & B; bedrock at 59.3 feet; water quality samples obtained by air lifting. River samples also collected.
Piezometer B		3668.7	40	1983	Driller's Log				
Piezometer C		3668.5	22	1983	Driller's Log				

Significant Wells in Logan Area, cont'd.

Name	Location	Land Surface Elevation	Total Depth	Date Drilled	Log Data	Water Level Measurements	Water Quality: Number of Analyses	Water Quality: Parameters	Comments
USBR River Site 3[i]	5.4. miles below Ute Dam Lat 35°22'00"N Long 103°23'30"E								
Piezometer A		3655.1	34	1983	Driller's Log	1 measurement in each piezometer on 8/24/83		At each piezometer -	Bedrock at 34 feet; water quality samples obtained by air lifting. River samples also collected.
Piezometer B		3655.1	20	1983	Driller's Log		19[t]	Field: conductance, T; Lab: Cl, TDS, pH, conductance	
							7	Besides the parameters listed above, Lab: Na, Mg,Ca,K,SO_4,HCO_3,CO_3	
							1[q]	At piezometer A only - Field: T, pH, alkalinity, conductance; Lab: Ca,Mg,Na K,CO_3,HCO_3,Cl,SO_4,NO_3,	
							1[q]	TDS by summation, B Lab: Cl,Br,I	
USBR River Site 4[i]	Revuelto Creek 0.2 mile above confluence Lat 35°21'48"N Long 103°22'58"E								
Piezometer A		3653.7	20.5	1983	Driller's Log	1 measurement in each piezometer on 8/24/83		At each piezometer -	Bedrock at 18-20 feet; bedrock soft sandstone; water quality samples obtained by air lifting. River samples also collected.
Piezometer B		3653.7	15	1983	Driller's Log		18[u]	Field: conductance, T; Lab: Cl, TDS, pH, conductance	
							7	Besides the parameters listed above, Lab: Na, Mg,Ca,K,SO_4,HCO_3,CO_3	

Because of access problems, piezometers planned for River Site 5, Revuelto Creek about 2.1 miles above confluence, were never installed.

Significant Wells in Logan Area, cont'd.

Name	Location	Land Surface Elevation	Total Depth	Date Drilled	Log Data	Water Level Measurements	Water Quality: Number of Analyses	Water Quality: Parameters	Comments
USBR River Site 6[i]	9.9. miles below Ute Dam Lat 35°23'30"N Long 103°20'22"E								
Piezometer A		3638.0	50	1983	Driller's Log	1 measurement in each piezometer on 8/24/83		At each piezometer -	Steel drill bits left in all three holes; bedrock at 52 feet; Piezometer A failed early in 1984; water quality samples obtained by air lifting. River samples also collected.
Piezometer B		3637.9	31	1983	Driller's Log		19[v]	Field: conductance, T; Lab: Cl, TDS, pH, conductance	
Piezometer C		3637.6	21	1983	Driller's Log		7	Besides the parameters listed above, Lab: Na, Mg,Ca,K,SO_4,HCO_3,CO_3	
								At piezometer A only -	
							1[q]	Field: T, pH, alkalinity, conductance; Lab: Ca,Mg,Na, K,CO_3,HCO_3,Cl,SO_4,NO_3, TDS by summation, B	
							1[q]	Lab: Cl,Br,I	

a All data from USBR, 1979, unless noted otherwise.

b USBR (1979), Appendix D, lists ground level elevation as 3680 feet; USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists elevation as 3674.5 feet.

c 8 samples to depths of 156 feet collected by air lift, 2 after adding water to hole; 11 samples of artesian flow collected from 261-356 feet, 2 after circulating (USBR, 1979).

d USBR, 1979, Appendix D, lists location as Longitude 103°22'35" E; USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists location as Longitude 103°22'32"E.

e USBR (1979), Appendix D, lists ground level elevation as 3665 feet; USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists elevation as 3655.72 feet.

f USBR, 1984 (Hydrology/Hydrogeology Appendix).

g Samples of minor artesian flows collected during drilling; note that drilling fluid returns were monitored for electrical conductivity. (USBR, 1979).

h USBR, 1984 (Hydrology/Hydrogeology Appendix): Samples collected from artesian flow at wellhead; CO_2 outgassing and problems with well completion make representativeness of samples suspect. Note that when data were reported in HGC, 1984a, parameters NO_3, Fe and F were included; data source listed was USBR file data.

i All data from USBR, 1984 (Hydrology/Hydrogeology Appendix), unless noted otherwise.

j Well was airlifted for about 1 hour; conductance had not stabilized when samples were collected. These facts, and the possiblity of CO_2 outgassing, make the representativeness of samples suspect (USBR, 1984 - Hydrology/Hydrogeology Appendix).

k USBR, 1979 (p. 19) states that "numerous" samples were taken directly from the pump discharge line during the aquifer test; only the results of two "partial" analyses were reported.

l USBR (1979), Appendix D, lists ground level elevation as 3674.73 feet; USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists elevation as 3675.9 feet (pipe).

m USBR, 1979,(p. 17) states that "electric logging" was done in the four obervation wellbores; gamma ray logs are presented in Appendix D of the report.

n USBR (1979), Appendix D, lists ground level elevation as 3676.88 feet. USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists elevation as 3682.8 feet (pipe); then notes that 1 foot of pipe has been cut off since elevation was determined.

o USBR (1979), Appendix D, lists ground level elevation as 3672.81 feet; USBR, 1984 (Hydrology/Hydrogeology Appendix) lists elevation as 3673.0 feet (Figure 3) and 3678.3 feet (Table 1).

p Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix).

q Reported in HGC, 1984a.

r USBR (1979), Appendix D, lists ground level elevation as 3675.51 feet; USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3, lists elevation as 3676.5 feet.

s USBR, 1984 (Hydrology/Hydrogeology Appendix). Data also reported in HGC, 1984a except additional parameter Fe included; data source listed was USBR file data.

t USBR, 1984 (Hydrology/Hydrogeology Appendix) does not include precisely 19 analyses for each of these parameters, but the data do break into these two main groups. Note that additional parameters NO_3, Fe and F were included when some of the analyses were reported in HGC, 1984a; data source listed was USBR file data.

u USBR, 1984 (Hydrology/Hydrogeology Appendix) does not include precisely 18 analyses for each of these parameters, but the data do break into these two main groups. Note that additional parameters NO_3, Fe and F were included when two of the analyses were reported in HGC, 1984a; data source listed was USBR file data.

v USBR, 1984 (Hydrology/Hydrogeology Appendix) does not include precisely 19 analyses for each of these parameters, but the data do break into these two main groups. Because Piezometer A failed early in 1984, there are fewer samples in both groups for it. Note that additional parameters NO_3, Fe and F were included when some of the analyses were reported in HGC, 1984a; data source listed was USBR file data.

DEEP WELLS IN LOGAN AREA WITH BOTH WATER LEVEL AND WATER QUALITY DATA

Well/Interval	Land surface elevation, ft	Water level, ft below land surface/(date)	Water level elevation, ft/(date)	Range of TDS values, mg/l/(number of analyses)	Range of conductivity values, umhos/cm/(number of analyses)	Comments
DH-1/[a]	3674.5?[b]					
51-76 ft		-	-	-/(0)	10,200-11,000/(2)	Samples air-lifted during drilling of well.
71-96 ft		8 ft below top of casing, about river level/(6/75)	-	-/(0)	6,100/(1)	Sample air-lifted during drilling of well.
91-136 ft		4 ft below top of casing/(6/75)	-	-/(0)	6,750/(2)	Samples air-lifted during drilling of well.
131-156 ft		3.75 ft in pipe/(6/75)	-	-/(0)	10,000-10,100/(3)	Samples air-lifted during drilling of well.
Open hole at 296 ft		Flowing/(6/75)	-	-/(0)	8,600-37,000/(4)	Well flowed at est. 30 gpm during drilling.
Open hole at 316 ft		Flowing/(6/75)	-	-/(0)	45,000/(1)	
Open hole at 336 ft		Flowing/(6/75)	-	-/(0)	52,000/(1)	
Open hole at 356 ft		Flowing/(6/75)	-	-/(0)	49,000-51,000/(4)	
DH-2/[a]	3655.72?[c]					
Open hole at 516 ft		Flowing/(7/75)	-	-/(0)	16,300/(1)	Est. 3 gpm flow encountered at 466 ft. during drilling.
Open hole at 534 ft		Flowing/(7/75)	-	-/(0)	16,900/(1)	Artesian pressure 0.5 psi.

DEEP WELLS IN LOGAN AREA WITH BOTH WATER LEVEL AND WATER QUALITY DATA, CONT'D.

Well/Interval	Land surface elevation, ft	Water level, ft below land surface	Water level elevation, ft/ (date)	Range of TDS values, mg/l/ (number of analyses)	Range of conductivity values, umhos/cm/ (number of analyses)	Comments
DH-2 (cont'd)/ Bottom of 42 ft of casing to 556 ft TD	3655.72?[c]	3.35 above[d] 2.40 above[d]	Max. 3659.07/(9/83)[e] Min. 3658.12/(7/83)[e]	11,985-12,138/(2)[f]	17,500-17,800/(2)[f]	Water-level recorder installed 2 months in 1983; removed because hydrograph appears to be reflection of stream flows. No hydrograph presented in USBR, 1984 (Hydrology/Hydrogeology Appendix). When re-entered for logging in 1983, could not get tool below 160 ft.
DH-3/ Screened 368-417.5 ft	3781.0	85.14[d] 91.9[d]	Max. 3695.86/(9/83)[e] Min. 3689.10/(9/84)[e]	26,434-27,892/(2)[f]	36,000/(2)[f]	Water levels measured 13 times between 9/83 and 9/84; level fell more than 5 ft after well pumped for sampling by air lift for 1 hour and foreign matter dislodged. See hydrograph. Conductivity had not stabilized at time samples were collected.
OW-3/ Screened 270-350 ft	3678.3?[g]	2.96 above[d] 2.39 above[d]	Max. 3681.26/(5/84)[e] Min. 3680.69/(6/84)[e]	49,072-51,005/(3)[h]	>60,000-78,400/(3)[h]	Water levels measured during aquifer test in 1978 and 11 times between 11/83 and 9/84. See hydrograph. Data for aquifer test not reported in USBR (1979).
OW-4/ Slotted 292-376 ft	3676.5?[i]	1.02 above[d]	3677.52/(7/84)[e]	36,406/(1)[f]	57,000/(1)[f]	Water levels measured during aquifer test in 1978 and once 7/19/84. Data for aquifer test not reported in USBR (1979).
TW-1/ Not reported	3674.01	2.0 above[e] 1.4 above[e] 0.66 above[e] 0.05 above[e]	Max. 3676.0/(8/82)[e] Min. 3675.4/(8/82)[e] Max. 3674.67/(5/83)[e] Min. 3674.06/(8/84)[e]	44,900-46,000/(2)[j]	-/(?)	Water levels measured during aquifer test in 1978, 4 times in August of 1982 and by recorder 5/83-8/84. Data for aquifer test not reported in USBR (1979). No hydrograph presented in USBR, 1984 (Hydrology/Hydrogeology Appendix). "Numerous" samples of brine collected from flow line during aquifer test, but only 2 partial analyses reported in USBR (1979). "TDS" from these analyses is sum of Na, Cl and SO_4. Aquifer test report notes that completion apparently includes part of an upper aquifer.

NOTES:

a Data from geologic log in USBR (1979), Appendix D, unless otherwise noted.

b USBR (1979), Appendix D lists ground level elevation as 3680 feet. USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3 lists elevation as "3674.5 (bolt)."

c USBR (1979), Appendix D lists ground level elevation as 3665 feet. USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3 lists elevation as "3655.72 (top spigot-approximately land surface)."

d Calculated

e Data from USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 1.

f Data from USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21.

g USBR (1979), Appendix D lists ground level elevation as 3672.81 feet. USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3 lists elevation as "3673.0 (land surface)", while Table 1 lists surface elevation as 3678.3 feet.

h Data from USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21 and HGC, 1984a, Appendix B.

i USBR (1979), Appendix D lists ground level elevation as 3675.51 feet. USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 3 lists elevation as "3676.5 (land surface)."

j Data from USBR (1979), p. 19.

SHALLOW WELLS IN LOGAN AREA WITH BOTH WATER LEVEL AND WATER QUALITY DATA

Well/Interval (ft)	Land surface elevation, ft [a]	Water level, ft below surface [b]	Water level elevation, ft (8/24/83) [c]	River elevation, ft (8/24/83) [c]	TDS, mg/l range/(no. of analyses)/[mean][d]	Field conductivity, umhos/cm @ 25° C range/(no. of analyses)/[mean][d]	Average $Cl:SO_4$ Ratio[e]	Comments
River Site 1, mile 1.6								Gradient upward in alluvium, but shallow piezometer water level below river level.
Piezometer A Screen 17.5 - 21.5	3668.9	2.2	3666.69	3666.03	11,920-15,737/(19) [13,670]	17,200-25,000/(19) [20,613]	9.3	Bedrock at 22 feet, so may not be in deepest part of channel.[c]
Piezometer B Screen 11.5 - 15.5	3668.8	5.4	3663.40	3666.03	14,457-16,942/(19) [15,585]	19,000-31,000/(19) [23,360]	11.5	31,000 umhos/cm conductivity value regarded as questionable by USBR; next highest value is 26,000.
River Site 2, mile 2.2								Gradient mixed in alluvium; water level in all piezometers above river level.
Piezometer A Screen 50.5 - 54.5	3668.7	3.9	3664.85	3664.40	14,172-15,947/(19) [14,950]	20,044-25,000/(19) [22,358]	7.4	Steel bit left in bottom of hole. Bedrock at 59.3 feet.[c]
Piezometer B Screen 35.5 - 39.5	3668.7	4.0	3664.70	3664.40	14,881-17,224/(19) [15,872]	21,040-36,000/(19) [23,395]	8.0	Steel bit left in bottom of hole.[c] 36,000 umhos/cm conductivity value regarded as questionable by USBR; next highest value is 26,000.
Piezometer C Screen 17.5 - 21.5	3668.5	3.8	3664.73	3664.40	13,902-17,224/(19) [15,260]	19,948-26,000/(19) [22,813]	8.7	17,224 mg/l TDS value regarded as questionable by USBR; next highest value is 17,124.
River Site 3, mile 5.4								Gradient downward in alluvium; water level in piezometers at or below river level.
Piezometer A Screen 29.5 - 33.5	3655.1	2.6	3652.48	3652.72	8047-26,617/(19) [24,846]	23,500-40,000/(19) [34,624]	8.0	Bedrock at 34 feet, so may not be in deepest part of channel.[c] 8047 mg/l TDS value regarded as questionable by USBR, as are values of 10,827 and 15,996; next value is 23,613. 23,500 umhos/cm

SHALLOW WELLS IN LOGAN AREA WITH BOTH WATER LEVEL AND WATER QUALITY DATA, CONT'D.

Well/Interval (ft)	Land surface elevation, ft [a]	Water level, ft below surface [b]	Water level elevation, ft (8/24/83) [c]	River elevation, ft (8/24/83) [c]	TDS, mg/l range/(no. of analysis) [mean][d]	Field conductivity umhos/cm @ 25°C range (no. of analyses) [mean][d]	Average Cl:SO_4 Ratio [e]	Comments
River Site 3 (cont'd)								
Piezometer B Screen 15.5 - 19.5	3655.1	2.4	3652.73	3652.72	4343-16,414/(19) [13,229]	16,124-26,000/(19) [19,837]	6.9	4343 and 6029 mg/l TDS values regarded as questionable by USBR; next value is 10,714.
River Site 4 (Revuelto Creek)								
Piezometer A Screen 16-20	3653.7	0.4	3653.27	-	1601-25,774/(18) [5168]	2800-21,000/(18) [7868]	3.2	Bedrock 18-20 feet, believed to be near lowest point of bedrock channel.[c] 14,863, 15,701 and 25,774 mg/l TDS values regarded as questionable by USBR; next value is 14,921.
Piezometer B Screen 10.5 - 14.5	3653.7	0.3	3653.18	-	1256-28,075/(18) [3688]	1600-16,500/(18) [5082]	2.5	15,685 and 28,075 mg/l TDS values regarded questionable by USBR; next value is 10,955. 1600 umhos/cm conductivity value regarded as questionable by USBR; next value is 2500.
River Site 6, mile 9.9								Gradient downward in alluvium, but shallow piezometer water level above river level.
Piezometer A Screen 45.5 - 49.5	3638.0	6.0	3631.99	3632.19	13,115-34,558/(12) [20,319]	22,500-32,000/(12) [30,218]	7.2	Bedrock at 52 feet. Steel bit left in hole.[c] Piezometer failed early in 1984. 13,115, 17,796 and 34,558 mg/l TDS values regarded as questionable by USBR; next measured values are 20,077 (low) and 20,846 (high). 22,500 and 25,000 umhos/cm conductivity values regarded as questionable by USBR; next measured value is 28,000.

SHALLOW WELLS IN LOGAN AREA WITH BOTH WATER LEVEL AND WATER QUALITY DATA, CONT'D.

Well/Interval (ft)	Land surface elevation, ft [a]	Water level, ft below surface [b]	Water level elevation, ft (8/24/83)[c]	River elevation, ft (8/24/83) [c]	TDS, mg/l range/(no. of analysis) [mean][d]	Field conductivity umhos/cm @ 25°C range (no. of analyses) [mean][d]	Average Cl:SO_4 Ratio [e]	Comments
River Site 6 (cont'd)								
Piezometer B Screen 26.5 - 30.5	3637.9	5.7	3632.20	3632.19	10,034-22,613/(19) [13,651]	16,844-24,000/(19) [21,167]	5.7	Steel bit left in hole.[c] 10,034 and 22,613 mg/l TDS values regarded as questionable by USBR; next measured values are 12,035 (low) and 15,048 (high). 16,844 and 16,928 umhos/cm conductivity values regarded as questionable by USBR; next value is 18,500.
Piezometer C Screen 16.5 - 20.5	3637.6	5.4	3632.24	3632.19	6366-11,842/(19) [8816]	10,800-17,852/(19) [13,583]	6.3	Steel bit left in hole.[c] 11,250 mg/l TDS value regarded as questionable by USBR, though three other values are higher; 13,688 umhos/cm conductivity value regarded as questionable by USBR, though six other values are higher.

NOTES

a Land surface elevations from USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 1.

b Water level elevations only are reported in USBR, 1984 (Hydrology/Hydrogeology Appendix). Water levels below land surface have been calculated for this table.

c Screened intervals, water level elevations, river elevations and some of comments from USBR, 1984 (Hydrology/Hydrogeology Appendix), Figure 2.

d Only values reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Tables 5 through 20, are compiled here. Additional analyses were made on single samples from the deepest piezometers at Sites 2, 3 and 6, and are reported in HGC, 1984a. Samples collected by USBR were obtained by air lifting. Mean values are those reported in USBR, 1984 (Hydrology/Hydrogeology Appendix); they include USBR corrections to questionable values.

e Calculated from mean Cl value (mg/l) divided by mean SO_4 value (mg/l). These means are of complete analyses only; some analyses had chloride but not sulfate. USBR, 1984 (Hydrology/Hydrogeology Appendix), Tables 5 through 20.

Berkstresser and Mourant, 1966

TABLE 1. RECORDS OF SELECTED WELLS IN QUAY AND ADJOINING COUNTIES, N. MEX.

Location number: See text for explanation of well numbering system.

Year completed: Wells designated "old" drilled generally before 1925.

Depth: Depths are in feet below land surface. Reported depths are given to nearest foot. Measured depths are given to nearest tenth of a foot.

Diameter: The diameter of the casing, or the mean diameter of the well if uncased, to nearest inch.

Altitude: Altitude of land surface at well. Altitude interpolated from topographic maps, or aneroid determination to nearest 10 feet.

Water level: Reported depths are given to nearest foot. Measured depths are given to nearest tenth of a foot.

Stratigraphic unit: Qal, younger alluvium; Qc, upland cover of older alluvium; To, Ogallala Formation; Ks, Cretaceous sandstone and siltstone; Jm, Morrison Formation; Je, Entrada Sandstone; TRc, Chinle Formation; TRsr, Santa Rosa Sandstone; Pr, Permian rocks.

Type of pump and power source: E, electric; I, internal combustion; J, jet; N, none; P, plunger or cylinder; S, submersible; T, turbine; W, windmill.

Use of Water: D, domestic; I, irrigation; Ind, industrial; O, observations; PS, public supply; RR, railroad; S, stock; N, none.

Remarks: All wells are drilled and cased with steel casing unless otherwise indicated. Ca, chemical analysis in table 3; dd, drawdown; est, estimated; gpm, gallons per minute; log, log in table 6; meas, measurement; perf, perforated, perforations given in feet below land surface; rept, reported, reportedly; T 61°F, temperature in degrees Fahrenheit; USBR, U.S. Bureau of Reclamation; yields are reported unless otherwise indicated.

Location No.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Type of pump and power source	Use of water	Remarks
5.26.22.320	Abercrombie and H Hawkins No. 1—Nappier	1949	7149	9	4518	—	—	—	—	—	Oil test; in DeBaca Co., 2½ miles west of Quay Co. line; log
5.27. 1.341	L. W. Barnhill	—	200	5	4950	131.0	8-23-55	To	P,W	D,S	—
3.312	—	—	77.1	5	4650	49.6	4-15-55	Qal, TRc	P,W,I	S	—
9.333	L. W. Barnhill	—	33.3	6	4530	28.5	8-25-53	Qal	P,W	S	Ca
12.444	L. W. Barnhill	1951	182	6	4920	170	1951	To	P,W	S	T 61°F
15.424	Dick Ballew	1945	64.8	4	4640	43.9	4-15-55	Qal, TRc	P,W	D,S	T 62°F. Ca
17.441	Mrs. N. G. Koll	—	7.6	48	4510	5.3	4-15-55	Qal, TRc	P,W	S	Pumping water level
25.242	D. O. Bomar	Old	86	5	4890	75	1954	To	P,W	D,S	Dug. T 51°F
29.212	Guy Shipely	—	35.1	7	4470	25.7	4-15-55	Qal	P,W	D,S	T 63°F
30.242	Mrs. N. G. Koll	—	13.3	48	4440	12.9	4-15-55	Qal, TRc	P,W	S	—
31.122	Mrs. N. G. Koll	—	13.2	30	4420	13.2	4-15-55	Qal	P,W	S	Dug. Pumping water level. Est yield 4 gpm; Dug. Est yield 1 gpm. T 58°F
5.28. 1.111	G. E. Murphy	1950	90	6	4750	70	1950	To	P,W	S	John Maddox, driller
1.212	D. C. Wyatt	1943	102	10	4730	48.6 50.9	11-23-43 12-3-47	To	N	N	Yield 100 gpm, dd 40 ft. Rept destroyed; R. F. Davis, driller
1.221	D. C. Wyatt	1946	133.0	16	4720	46.6 54.9	3-29-46 1-11-56	To	T,I	I	R. F. Davis, driller
5.222	W. R. Crawley	Old	97	6	4900	80	—	To	P,W	D,S	Not cased; T 60°F
5.442	B. R. Hood	Old	100	—	4890	80	—	To	P,W	D,S	—
8.222	—	—	89.9	5	4880	87.8	8-23-55	To	P,W	D,S	—
18.131	L. W. Barnhill	Old	136.9	5	4910	120.2	8-23-55	To	P,W	D	Water level rising when measured. Weak
19.422	R. R. Adams	1952	110	6	4890	100	1952	To	P,W	D,S	Yield I gpm. John Maddox, driller
22.212	C. A. Morrow	1940	102.8	6	4820	91.0	8-23-55	To	P,W	S	—
30.212	R. R. Adams	1955	107.9	6	4870	73.5	8-23-55	To	P,W	S	Perf. 50 to 110 ft. Rept yield 5 gpm. John Maddox, driller
31.222	Mr. Baxter	Old	121.0	4	4860	94.6	8-23-55	To	P,W	S	—
33.421	—	—	106.3	5	4820	98.9	8-23-55	To	P,W	S	T 61°F
36.331	State of N. Mex.	—	95.6	10	4770	92.8	8-23-55	To	P,W	S	Water stains pipe yellow.
5.29. 1.000	Charlie Vance	1940	103	18	4730	—	—	To	N	N	Not cased. Yield 20 gpm. S. J. Davis, driller
2.131	O. G. Miller	1947	132	14	4710	24.2 25.2	1-19-48 1-11-56	To	P,W	S	Yield 35 gpm. R. F. Davis, driller
4.333	W. Y. Head	1949	128	18	4690	36.5 47.9	6-3-49 1-11-56	To	T,I	I	Not cased, red clay at 125 ft. A. L. Akin, driller
5.111	Wm. Young estate	1948	120	16	4720	—	—	To	T,I	I	R. L. Davis, driller
5.211	R. H. Currence	1943	108.0	12	4720	49.9 67.4	11-22-43 1-11-56	To	T,I	I	R. F. Davis, driller
5.231	R. H. Currence	1943	134	—	4710	42.4 47.9	1-24-44 1-15-49	To	T,I	I	R. F. Davis, driller
5.312	Willard Carpenter	1940	115	15	4710	41.2 64.5	4-30-41 1-11-56	To	T,I	I	—
5.312a	Willard Carpenter	1955	122	18	4710	63.9	1-11-56	To	T,I	I	Lee Williams, driller
5.321	Spence Morris	1945	108	16	4710	44.8 64.1	6-13-45 1-11-45	To	T,I	I	R. F. Davis, driller
5.341	I. D. Linville	1941	140	16	4700	33.6 54.6	4-29-41 1-11-56	To	T,I	!	Yield 1600 gpm. Mr. [illegible]

Berkstresser and Mourant, 1966

TABLE 1. RECORDS OF SELECTED WELLS IN QUAY AND ADJOINING COUNTIES, N. MEX. (cont)

Location No.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Type of pump and power source	Use of water	Remarks
12.34.36.444c	L. C. Jackson	1953	36	13	4140	12.6	5-21-53	Qal, ℞c	N	N	Ca. Yield 40 gpm. Earl Flint, driller. Not cased
36.444d	L. C. Jackson	—	29	13	4140	—	—	Qal, ℞c	N	N	Not cased. Earl Flint, driller
12.35. 2.111	Griffin, Trew, and Cooper	Old	167.1	4	3840	163.8	5-17-56	℞c	P,W	D,S	Pumping water level. Rept water level 55 ft. Ca
6.143	Griffin, Trew, and Cooper	—	300	—	—	—	—	℞c, ℞sr	P,W	S	—
7.234	Griffin, Trew, and Cooper	—	258.0	5	3900	170.6	5-17-56	℞c, ℞sr	P,W	S	Rept depth 380 ft. Rept water level 345 ft. Rept tastes salty
7.234a	Griffin, Trew, and Cooper	—	6.6	48	3900	4.5	10-15-54	Qal	N	N	Dug. Rock casing
7.234b	Griffin, Trew, and Cooper	—	8	48	3900	5	—	Qal	P,W	S	Dug. Rock casing
15.323	—	—	279.4	—	3960	235.9	10-15-54	℞c, ℞sr	P,W	S	—
20.333	Frank Warmuth	1949	200	6	4250	85	—	℞c	P,W	D,S	Water at 85 ft.; drilled to 200 ft for storage. Weak
25.123	W. W. Sweeney Estate	1939	300	6	4000	285	1939	℞c, ℞sr	—	—	Cased to 276 ft. Yield 4 gpm. Rept water slightly alkaline
26.233	—	Old	244.2	5	3960	118.9	10-28-54	℞c, ℞sr	P,W	S	—
29.143	T. E. Terry	1919	35.1	48	4180	22.1	11-6-54	℞c	P,W	D,S	Dug. Rept depth 45 ft. Not cased
32.344	Joe Yarborough	—	65	—	—	50	—	℞c	P,W	D,S	—
32.434	H. E. Norred	—	90	—	4150	70	—	℞c	—	D,S	R. J. Thrasher, driller
33.422	E. S. Norred	—	32	—	—	28	—	℞c(?)	P,W	D,S	Water rept hard and alkali
35.422	—	—	21.4	42	4030	20.7	11-5-54	℞c	N	N	Dug. Culvert-pipe casing
35.424	T. G. Rose	1950	15.2	6	—	15	—	Qal	P,W	S	Rept depth 26 ft. Partly caved. Yield 5 gpm. Ca
12.36. 2.112	A. C. Ward	—	165	—	3860	100	—	℞sr(?)	S,E	D,S	—

Location No.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Type of pump and power source	Use of water	Remarks
2.334	Bill Smithers	—	300	—	—	—	—	℞sr	N	N	Destroyed. Rept unusable water even for stock
2.413	Bill Smithers	1938	225	—	—	190	—	℞sr	P,W	D,S	—
7.334	A. C. Ward	—	190	5	—	170	—	℞sr	P,W	S	—
8.313	Louis Lee	—	150	5	—	—	—	℞c, ℞sr	P,W	D,S	—
9.334	Louis Lee	—	225	—	3950	205	—	℞sr	P,W	D,S	—
10.224	A. C. Ward	—	175	—	3920	163	—	℞sr	P,W	S	—
10.434	Bill Smithers	—	227	5	3980	187	—	℞sr	P,W	S	—
11.333	J. L. Liles	1954	59.5	8	3960	44.2	11-6-54	℞c	P,W	D,S	Not cased, 1954. R. J. Trasher, driller
11.333a	J. L. Liles	1945	28	36	3960	—	—	℞c	P,W	D,S	Dug. Rept inadequate yield
14.311	Ray Adams	1954	285.4	6	3950	260.0	10-11-55	℞sr	N	N	R. J. Thrasher, driller
16.111	Louis Lee	—	245	—	3960	200	—	℞sr	P,W	D,S	—
18.242	—	—	20.2	14	3940	15.9	11-5-54	Qal	P,W	S	Dug. Steel casing
29.132	D. S. Gentry	—	18.6	6	3960	14.0	11-5-54	Qal	P,W	S	Rept depth 26 ft.
29.242	L. O. Gentry	1914	296	4	4000	281.4	11-6-54	℞sr(?)	P,W	D,S	—
33.222	L. O. Gentry	Old	250	—	3900	232	—	℞sr(?)	P,W	S	—
34.142	Henry Sasser	1955	540	—	3950	235	—	℞sr	N		Yield 10 gpm with 25 ft drawdown during bailing test. Rieddell and Suggs, drillers
12.37.18.424	—	1940	38.1	36	—	36.5	10-11-54	Qal	N	N	Dug
18.424a	Ira Johnson	—	208.8	5	3900	197.6	10-11-54	℞sr	N	N	—
18.442	Ira Johnson	1954	193.4	6	3880	173.4	10-11-54	℞sr	P,W	S	—
19.133	R. L. Martin	1946	250	6	3950	225	—	℞sr	P,W	S	T 63°F
30.133	R. L. Martin	1914	225	—	3900	205	—	℞sr	P,W	D,S	Rept poor quality. Ca
30.422	R. L. Martin	1951	150	—	3850	130	—	℞sr	P,W	S	Lamb and Hill, drillers
13.31. 1.124	R. R. Simms	—	50	—	3900	40	—	Qal, ℞c	P,W	S	Yield 3.5 gpm. T 62°F. Ca
25.344	R. S. Bell	1918	140	6	4020	126	1918	℞c	P,W	D,S	Perf 128 to 140 ft. Weak
26.123	H. E. Osborne	1924	195	5	3950	150	—	℞c	P,W	S	Perf 171 to 195 ft. Est yield 2 gpm. T 65°F
26.244	H. E. Osborne	1912	85	5	4020	75	—	℞c	P,W	—	Perf 73 to 85 ft. weak. T 62°F
34.244	H. J. Ellis	1952	175	6	3980	152	—	℞c	P,E	D,S	Yield 6 gpm. Pete Knowles, driller
34.444	H. W. Brady	1952	34	10	4030	12	—	Qc	J,E	D,S	Pete Knowles, driller
36.211	R. S. Bell	1920	76	6	4010	56	—	℞c	P,W	S	Yield 1 gpm
13.32. 4.311	R. R. Simms	1940	279.3	4	4000	230.4	11-23-53	℞c	P,W	S	—
5.131	R. R. Simms	—	200	—	3940	—	—	℞c	N	N	Destroyed. Rept very salty water
[illegible]	[illegible]	[illegible]	[illegible]	—	3840	119.2	11-23-53	℞c	P,W	S	—

Berkstresser and Mourant, 1966

TABLE 1. RECORDS OF SELECTED WELLS IN QUAY AND ADJOINING COUNTIES, N. MEX. (cont)

Location No.	Owner or name	Year completed	Depth (feet)	Diameter (inches)	Altitude (feet)	Water level: Depth below land surface (feet)	Water level: Date	Stratigraphic unit	Type of pump and power source	Use of water	Remarks
13.32.16.211	R. R. Simms	1932	200	6	3910	—	—	TR c	P,W,E	D	Dick Seddon, driller
18.200	R. R. Simms	1940	222.6	5	3880	179.3	11-23-53	TR c	P,W	S	Seddon and Crouch, drillers
1.311	—	—	176.1	6	3860	116.0	5-14-54	TR sr	P,W	S	—
2.122	Sim McFarland	1951	700	8	3900	151.4	7-22-54	Qc, TR sr	N	N	Laughlin and Harris No. 1 McFarland oil test
13.33. 2.413	Mrs. Barker	Old	160	—	—	145	—	TR sr(?)	P,W	D,S	—
5.244	Bob Rogers	—	138.0+	4	3890	137.4	9-17-54	TR c(?)	P,W	S	—
5.442	Arthur Hamby	1927	235	6	3880	205	—	TR sr(?)	P,W	D,S	—
11.112	Robert McFarland	1952	200	8	—	—	—	Qc, TR sr	T,E	I	Cased to 70 ft. Yield 60 gpm
11.144	Chicago, Rock Island and Pacific Railroad	1930	244.4	12	3810	110.9	4-1-54	TR sr	N	N	—
11.312	Mrs. Ann Bigelow	1920	50	6	3820	30	—	Qc	J,E	D,I	Used to irrigate lawn
11.322	Chicago, Rock Island and Pacific Railroad	—	240.8	16	3820	117.3	8-4-53	TR sr	T,E	P,S	Yield 50 gpm, dd. 87.5 ft. T 64°F; Ca
24.412	—	—	150.9	5	3800	123.7	3-2-55	TR sr	P,W	D,S	—
28.121	R. L. Stansbury	—	76.8	6	3800	72.8	3-7-55	TR c, TR sr	P,W	S	—
32.433	R. C. Chance	1947	140	5	—	120	—	TR c, TR sr	P,W	D,S	—
33.124	L. O. White	—	211.2	7	3970	202.1	3-4-55	TR sr	P,W,E	D,S	Rept soft water
34.114	—	—	81.4	5	—	65	—	TR sr(?)	P,W	S	—
13.34. 1.133	Pyle Ranch	1938	80	—	3650	70	—	TR sr	P,W	S	—
4.134	J. A. Cox	—	140	6	3760	128.2	8-5-53	TR sr	P,W	S	T 67°F
8.333	J. A. Cox	1947	250	6	3930	233.4	8-5-53	TR sr	P,W	S	Perf 230 to 250 ft. Yield 6 gpm. Water has poor taste and odor, 69°F. R. J. Thrasher, driller
9.232	R. H. Haddon	1951	185	6	—	170	—	TR sr	P,W	S	—
9.333	Olean No. 1 Woods	1926	3930	—	3920	—	—	—	N	N	Oil test. Log
10.211	R. H. Haddon	1936	150	—	3750	115	—	TR sr	P,W	S	—
13.234	Griffin, Trew, and Cooper	1952	231	6	—	210	—	TR sr	P,W	S	Ca
17.444	J. A. Cox	—	320	6	3960	248.1	8-4-53	TR sr	P,W	S	Perf 280 to 300 ft. Dick Seddon, driller
20.333	B. J. Lawrence	1951	287	6	4000	280	—	TR sr	P,W	D,S	Rept poor quality. Dick Seddon, driller
22.311	W. L. Bloodworth	1907	240	—	3900	200	—	TR sr	P,W	S	—
23.432	C. A. Eiland	1951	222.3	6	3840	184.6	10-20-54	TR sr	P,W	S	—
28.144	Tom Ayers	—	230	—	4000	200	—	TR sr	P,W	S	Rept poor taste
13.35. 5.113	Pyle Ranch	—	93.0	6	3680	76.7	4-8-54	TR sr	N	N	Good
6.143	Pyle Ranch	1910	78.1	5	3650	60.3	4-8-54	TR sr	N	N	Good
6.221	Pyle Ranch	1914	70	6	3670	60	—	TR sr	P,W	D	—
13.321	Griffin, Trew, and Cooper	Old	250	—	3850	220	—	TR sr	P,W	D,S	Rept poor quality; salty taste; disagreeable odor
19.112	Elmer Wallin	1935	280.0	6	3880	269.8	5-17-56	TR sr	P,W	D,S	—
27.343	Tom Ayers	—	285.9	—	3940	260	10-20-54	TR sr	P,W	S	—
31.444	Griffin, Trew, and Cooper	—	280	6	3920	258.1	10-14-54	TR sr	P,W	S	Pumping water level; est yield 1 gpm
13.36.13.234	A. C. Ward	—	185	—	—	170	—	TR sr	P,W	S	—
14.134	A. C. Ward	—	185.0	5	3800	147.5	10-12-55	TR sr	P,W	S	—
15.231	A. C. Ward	Old	22.7	—	—	21.0	11-3-54	Qal, TR sr(?)	P,W	D,S	Dug. 65°F
18.231	A. C. Ward	—	190	—	—	180	—	TR sr	P,W	S	—
20.332	A. C. Ward	—	284.5	5	3810	94.4	2-25-55	TR sr	P,W	S	Est yield 2 gpm with 40.2 ft drawdown
27.332	A. C. Ward	1955	167.2	6	3850	131.3	2-25-55	TR sr	S,E	D,S	Perf 65-185 ft. Yield 8.5 gpm. 62°F. Ca. Log. Thrasher and Flint, drillers
27.334	A. C. Ward	—	172.5	5	3810	94.4	11-3-54	TR sr	S,E	D	Yield 15 gpm
3.37. 7.144	A. C. Ward	1920	20	—	—	—	—	Qal(?)	P,W	N	Dug. Inadequate supply
30.343	A. C. Ward	Old	300.4	5	3980	286.4	11-3-54	TR sr	P,W	S	Pumping water level. Yield 4.5 gpm. 65°F
14.33.21.444	Underwood No. 1 Cornett	1938	1370	—	3940	—	—	—	—	—	Oil test in Harding County, 2 miles No. of Quay county line, log
14.34. 1.141	W. M. Barnes	1902	100	6	3930	90	—	Qc, To	P,W	D,S	—
1.212	C.R.I. and P. RR.	—	196	5	3940	96	—	Qc, To	N	N	—
5.422	Bonnie Gallegos	—	120.0	6	3960	104.5	6-10-54	Qc	P,W	S	Ca
13.141	Pyle Ranch	—	130	—	3880	118	—	Qc	P,W	S	—
[illegible]	[illegible]	[illegible]	[illegible]	6	3920	90	—	Qc	P,W	S	Est yield 2.5 gpm. 64°F

Berkstresser and Mourant, 1966

TABLE 2. RECORDS OF SPRINGS IN QUAY COUNTY, N. MEX.

Location number: See explanation in text.
Altitude: Altitude of land surface at spring. Altitude interpolated from topographic maps or aneroid determination to nearest 10 feet.
Stratigraphic unit: Qal, younger alluvium; Qc, upland cover of older alluvium; To, Ogallala Formation; Ks, Cretaceous sandstone and shale; Je, Entrada Sandstone; TRc, Chinle Formation; TRsr, Santa Rosa Sandstone.

Location number	Owner	Name	Topographic situation	Altitude (feet)	Stratigraphic unit	Yield (estimated gpm)	Date	Use of water	Temperature (°F)	Remarks
7.30.15.432	—	—	Below cliff in gully	4720	To	Seep	8-25-53	None	—	Reported good quality and to have supplied 25 families 1910 to 1930
8.27. 6.430	H. G. Johnson	—	Side of cliff	5100	Je	2	11-2-55	Stock	—	Perched water, piped to tank
8.31.12.320	—	—	Stream channel	4220	Qal	2	4-21-55	—	—	—
8.32.18.223	—	—	Stream channel	4220	Qal	5	4-16-55	Stock	—	—
35.114	Elder Dennis	—	Stream channel	4480	Ks	5	4-2-55	None	—	Spring at fault contact of Cretaceous and Triassic rocks
9.27.36.244	Mr. Hortenstein	Louisiana Spring	Side of cliff	5220	Ks	2	10-27-53	Stock	55	Chemical analysis in Table 3
9.32.24.322	Mrs. Hut Wallace	—	Stream channel	4200	Qal	1	4-8-55	Stock	58	—
33.333	S. S. Hodges	—	Stream channel	4190	Qal	25	4-16-55	Stock	—	—
9.33.24.312	Mr. Pierce	Hopkins Spring	Stream channel	4480	Ks	Seep	2-14-55	None	—	—
10.33.14.212	Mr. Stams	Starns Spring	Side of cliff	4080	Qc	Seep	2-15-55	Stock	—	—
10.35.32.422	Chapman Bros.	—	Stream channel	4020	Qal	3	12-1-54	Stock	—	Piped to tank
10.36. 8.233	Chapman Bros.	—	Steep slope	3920	TRc	3	11-29-54	Domestic and stock	—	Piped to tank
18.224	Chapman Bros.	—	Stream channel	3970	TRc	1	11-29-54	Stock	—	—
11.33.29.211	Otto Collins	—	Side of cliff	3920	TRc	0.5	2-18-55	Domestic and stock	51	Piped to tank
11.36.30.412	Grady Oldham estate	—	Steep slope	3950	TRc	0.5	11-5-54	Stock	—	—
12.32. 6.213	Jacob Van Sweden	Cow Springs	Stream channel	3920	TRc	10	3-8-55	Domestic and stock	—	Piped to tank
12.33.17.234	Joe Hettinger	—	Stream channel	3920	TRc	10	3-4-55	Stock	—	—
12.34.22.241	Homer Koonsman	—	Gentle slope	4070	TRc	0.5	11-8-54	Stock	—	—
12.36. 5.231	A. C. Ward	Blue Hole	Stream channel	—	TRc	100	11-6-54	Stock	—	
13.32. 1.434	—	—	Stream channel	—	TRsr	0.25	3-9-57	Stock	—	Chemical analysis in Table 3
13.36.27.332	A. C. Ward	—	Side of cliff	3820	TRsr	1	7-26-57	Stock	—	Piped to tank
14.35.34.343	Pyle Ranch	—	Stream channel	—	TRsr	30	3-8-57	Stock	62	Chemical analysis in Table 3
35.311	Pyle Ranch	—	Stream channel	—	TRsr	150	3-8-57	Stock	64	Chemical analysis in Table 3
14.37.31.211	Ollie Mae Pyle	Coggin Spring	Stream channel	3580	TRsr	5	3-31-54	Domestic and stock	59	Chemical analysis in Table 3
15.34.30.310	Gallegos Estate	Sand Springs	Gentle slope	4110	Qc, To	300	6-3-54	Stock and irrigation	—	—
15.36.24.230	E. A. Stringfellow	—	Stream channel	3850	Qal	100	4-7-54	—	—	—
15.37.19.134	E. A. Stringfellow	—	Stream channel	3840	Qal	50	4-7-54	Stock	—	—
16.37.18.421	R. C. Bell	—	Stream channel	4130	To	1	5-22-53	Stock	—	Chemical analysis in Table 3

HGC, 1984a

Table 1: Log Availability from Exploration Wells in New Mexico

Map No.	Location	Well Name	Operator	New Mexico Well ID No.	Availabile Logs
1	9.36.12	Chapman No 1	C.T. Shook	-	Drillers (no 2951)
2	10.31.23	N. Pueblo No 1	Shell Oil	14513	Acoustic, Gamma Caliper
3	10.31.25	N. Pueblo No 2	Shell Oil	14616	Neutron-porosity Gamma, Caliper
4	11.36. 7	Endee No 1	L.B. Newby	-	Drillers (no 855)
5	12.28.14	Hoover R. No 1	Miami Pet. Co.	15849	SP, Induction
6	12.29.13	Chapell No 1	Puretex Oil Co.	19324	Induction, Neutron-Porosity, Gamma, Caliper
7	12.29.18	Hoover R. No 1	Miami Pet. Co.	15850	Gamma, Laterolog
8	12.30. 7	Chapell No 2	Puretex Oil Co.	14890	Neutron-porosity, Gamma, Caliper
9	12.32.11	Ute Anticline 1	National Oil Co.	25563	Dual-Laterolog, Gamma, Acoustic, Neutron
10	12.32.11	Kimes No 1	O.L. Ledgerwood	15851	Neutron, Gamma
11	12.32.11	Ulmer No 1	S.T. Silverstein	6249	Drillers (no 6249)
12	12.32.35	Tippen No 1	N.G. Penrose	15483	Gamma, Neutron, Drillers (no 6876)
13	13.29. 3	No 1 Ranch	Marland	-	Drillers,
14	13.31.24	State No 1	Nucorp Energy	26194	Dual-Laterolog, Micro-Laterolog, Gamma
15	13.31.25	Dripping Spgs 1	Standard Pet. Co.	-	Drillers (no 858)
16	13.32.32	Columbine St. 1	National Oil Co.	26092	Gamma, Acoustic
17	13.33.15	USBR DH-3	U.S. Bureau Rec.	-	Drillers, Gamma
18	13.34. 9	Olean No 1 Woods	Olean Pet. Co.	-	Drillers
19	13.35. 2	N.M. Eng. DH-10	New Mex. St. Eng.	-	Drillers
20	14.32.16	State No 1	Sunray Mid-Cont.	2565	Mud-Log, Gamma, Neutron
21	14.33.21	Underwood No 1	Cornett	1000	Drillers
22	15.33.10	Arthur Cain No 1	J.A. Talley	6618	SP, Laterolog, Dual-Induction
23	15.33.17	Federal 1-17	Paul Haskins	21644	Gamma, Neutron
24	15.33.21	Conley Cain No 1	Conley Assoc.	21643	Neutron-Porosity, Gamma, Caliper, Density
25	15.33.22	Arthur Cain No 2	Edmonds, Peters	6619	Gamma, Caliper, Interval-Acoustic
26	15.34.28	State No 1	Powers Wire	23774	Gamma-Gamma Gamma, Caliper
27	16.33.27	1-X Olympic St.	Astro-Tex	19016	Caliper, Neutron-Porosity, Density, Gamma
28	16.36.36	State "CP" No 1	Humble Oil	13957	Gamma, Gamma-Gamma, SP, Laterolog, Dual-Laterolog

Table 1: Continued

Map No.	Location	Well Name	Operator	New Mexico Well ID No.	Availabile Logs
29	17.32.24	State "FK" No 1	Amoco Oil	24178	Gamma, Neutron
30	17.36.28	State "CO" No 1	Humble Oil	14899	Gamma, Gamma-Gamma SP, Laterolog, Dual-Laterolog
31	18.32.14	"CM" State No 1	Humble Oil	14900	Gamma, Acoustic SP, Laterolog, Dual-Laterolog
32	18.34.31	"CK" State No 1	Humble Oil	14901	Gamma, Acoustic, Caliper
33	18.36.36	BDCDGU1836361K	Amoco Oil	23259	Gamma
34	19.34.16	State "EL" 1	Amoco Oil	24126	Gamma, Caliper, Bulk-Density

iated northwest trending block faulting. Regional isopach maps constructed for the region by Foster and others (1972) and Gustavson and others (1982) indicate that many of the sedimentary systems of the Palo Duro basin can be extended into New Mexico along a synclinal trough defined by the Tucumcari and Cuervo basins.

STRATIGRAPHY

1. Paleozoic Section

The Paleozoic section in Quay and Oldham counties, shown in the stratigraphic column (Figure 4), is comprised of the Sangre de Cristo Formation and the Abo, Yeso, San Andres, and Bernal formations. These units lie unconformably upon the Precambrian surface. The unconformity is marked by arkosic sandstones often referred to as the granite wash, and it reflects tectonic uplift and ero-

Index to **TAB 10**: Well log data

HGC, 1984b, Figure 4

Spiegel, 1972a, well logs 1-3

USBR, 1984, Hydrology/Hydrogeology Appendix, Figure 1

USBR, 1984, Hydrology/Hydrogeology Appendix, Figure 2

USBR, 1984, Hydrology/Hydrogeology Appendix, Figure 3

USBR, 1984, Hydrology/Hydrogeology Appendix, Figure 5

USBR, 1984, Hydrology/Hydrogeology Appendix, Figure 6

USBR, 1979, Appendix D

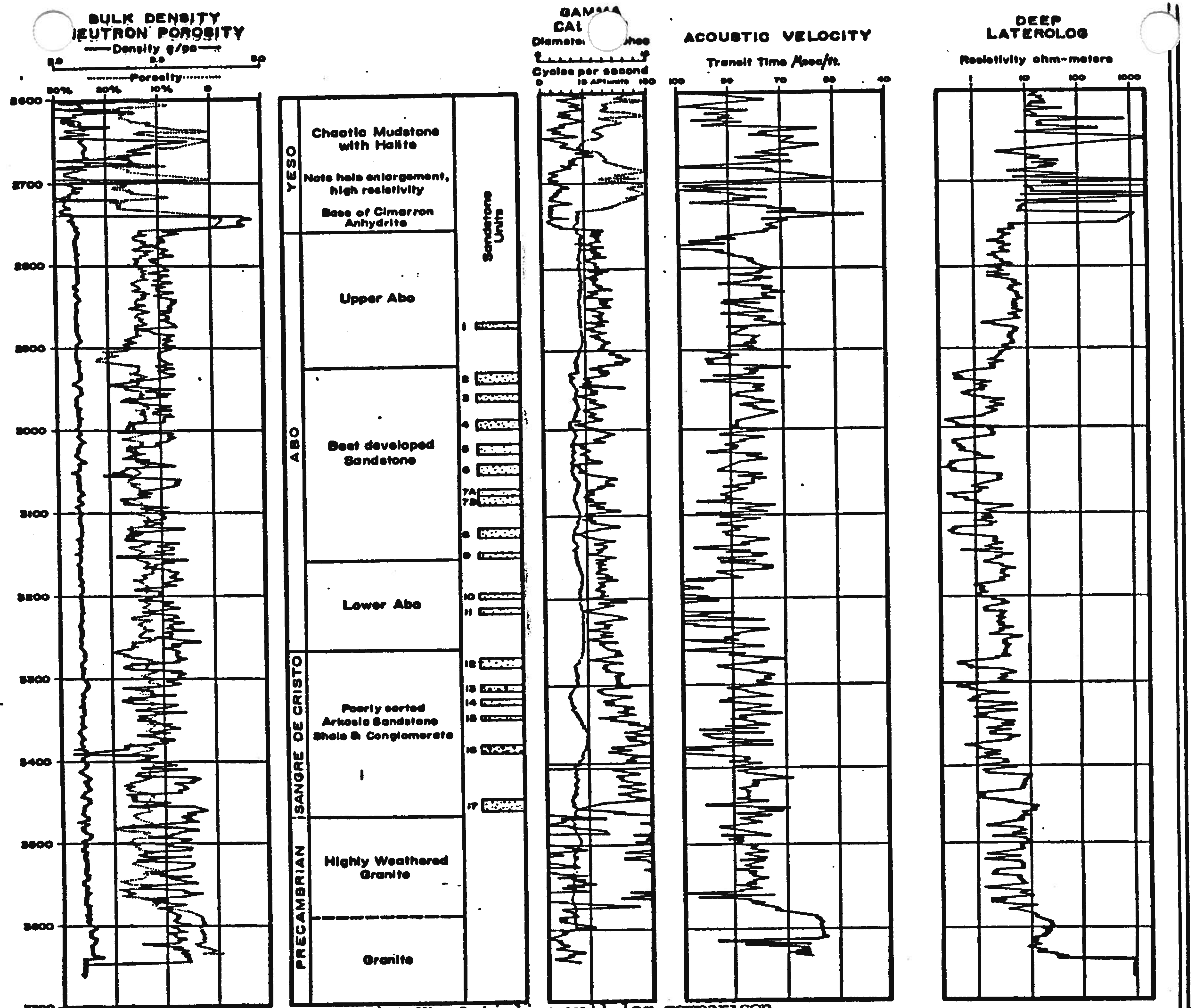


Figure 4. Ute Anticline well log comparison.

HGC, 1984b

Spiegel, 1972a

westward between Logan and bonafide Santa Rosa outcrops in the Pecos Valley.

CONCLUSIONS

The solution, essentially as proposed by Trauger in a memorandum of November 4, 1971, and concurred in by the writer, is to redefine Gould's Trujillo Formation to include only the lower sandstones north of Glenrio (equivalents of the Logan Sandstone) and to assign the upper beds of Gould's Trujillo to the Chinle.

The Santa Rosa in the Pecos Valley probably is equivalent to the combined section of Tecovas and Gould's lower sandstones of the Trujillo, but the sandstone members of the Santa Rosa may not be physically continuous into the Logan Sandstone and are definitely not equivalent to the "canyon sandstone" at Conchas, or the sandstone at Sabinoso dome.

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WELL LOG 1

SAMPLE DESCRIPTION OF DUNES #10 TEST HOLE

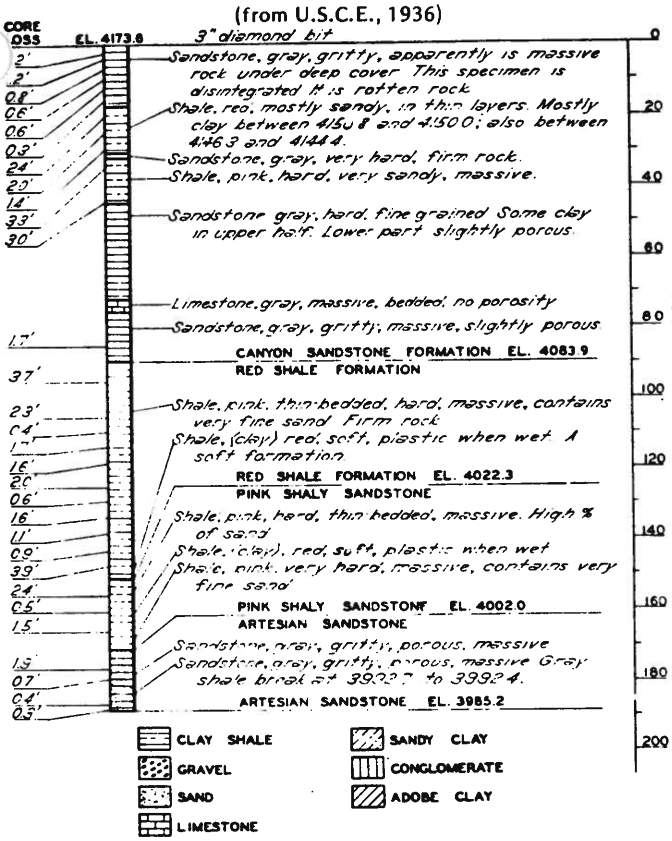
Section 2, T. 13 N., R. 35 E., NMPM
(Elevation 3585 ft., on east slope of knob on north bank)
E. A. Chavez, August 1957

Interval	*Description*
Alluvium:	
0 - 5	ss., f.g. to v.g.f., lt. tan to buff (probably wind blown dune sand)
Tecovas:	
5 - 10	ss., v.f.g. lt. tan, micaceous, subrounded grains
10 - 25	Cored: Recover 5.4'—All ss., lt. tan to white, clean, soft friable but consolidated, porous, micaceous
25 - 35	Cored: Recovery 5.7'—All ss., as above
35 - 45	Cored: Recovery 4.55'—All ss., as above but with occasional laminae of micaceous gray siltstone.
45 - 55	Cored: Recovery 4'—All ss., lt. tan to white, clean, friable but consolidated, porous, with occasional inclusions of calcium carbonate forming incrustations and tiny clacite filled cavities.
55 - 65	Cored: Recovery 3.25'—(Top) 2.55' is ss., lt. tan to white, hard compact, slightly calcareous grading to 0.7 of conglomerate, small pebbled, gray to yellowish gray, vy. calcareous with large fragments of gray dolomite at base.
65 - 70	ss., m.g. to v.g.f., white to lt. gray, clean
70 - 75	ss., v.g.f. tan, argillaceous, slightly micaceous.
75 - 80	ss., f.g. to v.f.g. buff to bwn., slightly micaceous.
80 - 85	ss., v.f.g., bwn., rounded grains
85 - 90	ss., as above but vy. clean, well sorted grains
90 - 100	Cored: Recovery 1' 10"—ss., white, m.g., vy. porous and clean w/1" lens of gray siltstone near bottom.
100 - 105	Cored: Recovery 2'—ss., as above
105 - 110	No sample
110 - 125	Cored: Recovery 1' 9"—Top 18½" ss., as above 2½" Dk. gray soft, sticky shale
125 - 145	ss., f.g. to v.f.g. lt. tan to white, micaceous, rounded grains.
145 - 150	ss., v.f.g., tan, micaceous, subangular grains
Alibates:	
150 - 155	Cored: Recovery 1'5" Lt. gry, crystalline and vy. tight ls. w/occasional intrusions of soft white pyritic gypsum. Vugular in places.
155 - 160	Cored: Recovery 1' 10" Lt. Gry. ls. as above grading to dolomite, sporadically vugular.
Quartermaster:	
160 - 161	Shale, gray
161 - 170	Ss., v.f.g., soft, friable lt. bwn., argillaceous, and slightly micaceous
170 - 175	Ss., as above with a lense or red and gray variegated shale at 170'
175 - 180	Ss., as above grading into
180 - 183	Cored: Recovery 2', 1½"—Hard, well consolidated sandy red shale with occasional streaks of blue-gray coloration.
183 - 190	Siltstone, brown, arenaceous
190 - 195	Ss., brown, v.f.g., rounded grains
195 - 209	Ss., as above and argillaceous
209 - 210	sh., red w/blue-gray variegations
210 - 220	Ss., v.f.g., brown, argillaceous and slightly carbonaceous
220 - 230	Siltstone, reddish tan, minutely arenaceous
230 - 235	Siltstone, reddish tan, strongly arenaceous
235 - 240	Shale, red with white variegations

Spiegel, 1972a

WELL LOG 2

U.S. Corps of Engineers Core Boring H-4
North dike of Conchas Dam, New Mexico
(from U.S.C.E., 1936)



WELL LOG 3

Waggoner and Wharton, Upton #1, 1946
NW Cor. Sec. 25, T. 18 N., R. 26 E., NMPM
(Elev. 4875 ft., reported)
Log from files of NMOCC

FROM	TO	THICKNESS IN FEET	
MIDDLE SANDSTONE MEMBER OF THE CHINLE FM (Top eroded):			
0	20	20	Surface, boulders & hard sand rock
20	35	15	Hard sand
35	45	10	Broken shale & sand
45	70	25	Red sand hard
70	80	10	Red sand
80	90	10	Broken sandy shale
90	105	15	Red rock, blue shale
105	122	17	Broken sandy shale
122	158	36	Shale & sand
158	200	42	Red rock and sand
LOWER SHALE MEMBER OF THE CHINLE FM:			
200	290	90	Red shale
290	305	15	Red shale with green shale breaks
305	340	35	Green shale breaks
340	360	20	Red & blue shale & rock brks.
360	385	25	Sandy shale, hd.
385	431	46	Green shale, blue shale and sand
431	490	59	Grey shale, hard sand
490	520	30	Blue sandy shale
520	529	9	Hard red rock broken
529	550	21	Shale, sandy shale
550	575	25	Bentonite green
575	590	15	Bentonite green
590	650	60	Green shale sand breaks
650	681	31	Sand & shale
TRUJILLO SANDSTONE (restricted, this paper):			
681	700	19	Hard sand
700	705	5	Shale (blue)
705	724	19	Hard sand
724	752	28	Sand and green shale
752	783	31	Hard sand & shale
783	801	18	Hard sand
TECOVAS FORMATION (Note that Trujillo and Tecovas combined equal Santa Rosa ss.):			
801	842	41	Sand & shale
842	876	34	Sand & red & green shale
876	920	44	Sand & red & blue shale
920	940	20	Sand
940	955	15	Sand & shale
UPPER MEMBER OF THE QUARTERMASTER FM (Bernal fm.):			
955	1022	67	Anhydrite
1022	1037	15	Red shale
1037	1050	13	Broken Anhy
1050	1098	48	Green shale, sand breaks
1098	1130	32	Broken shale
1130	1131	1	Crevis
1131	1135	4	Sand rock
ALIBATES LENTIL OF THE QUARTERMASTER FM. (San Andres fm.):			
1135	1145	10	Dolomite
1145			
1155	1159	4	Hard sand (Dolomite)
LOWER MEMBER OF THE QUARTERMASTER FM. (Glorieta ss.):			
1159	1179		Sand hard
1179	1184		Broken sand
1184	1239	55	Hard sand
YESO FM:			
1239	1312	73	Broken sand
1312	1351	39	Sand
1351	1364	13	Hard sand
1364	1380	16	Brkn sand
1380	1407	27	Sand & lime
1407	1437		–
1437	1451	14	Broken sand & shale
1451	1494	43	Sand & shale
SANGRE DE CRISTO FM. AND MAGDALENA GROUP, UNDIFF:			
1494	1517	23	Red rock
1517	1539	22	Red rock & sand
1539	1566	27	–
1566	1632	66	Red rock
1632	1663	31	Red rock sandy
1663	1713	50	Red rock
1713	1720	7	Red & blue shale
1720	1743	23	Anhy & Dolomite brks.
1743	1768	25	Broken Anhy & shale
1768	1780		–
1780	1820	40	Anhy & shale red
1820	1853	33	Sandy shale, red & blue, with andhy breaks
1853	1873	20	Red rock
1873	1900	27	–
1900	1941	41	Brkn formation gyp, gravel, shale (granite wash)? Show of gas 1937'
1941	1994	53	Granite Wash
1994	2022	28	Granite wash lime (gas bubbles on pit 1995-2002)
2022	2080	58	Granite wash
2080	2100	20	Shale, gyp, silate, granite wash
2100	2114	14	Granite wash
2114	2132	18	Granite wash, hard
2132	2148	16	Granite wash
2148	2158	10	Hard granite wash
2158	2171	13	Granite Wash
	2171		T. D.

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT	SHEET 1 OF 2
C. Newcomb	7-13-83	Lake Meredith Salinity	
CHKD BY	DATE	FEATURE: Figure 1 - Sampling Site Locations near Logan, NM	

DETAILS: Piezometer locations & Elevations

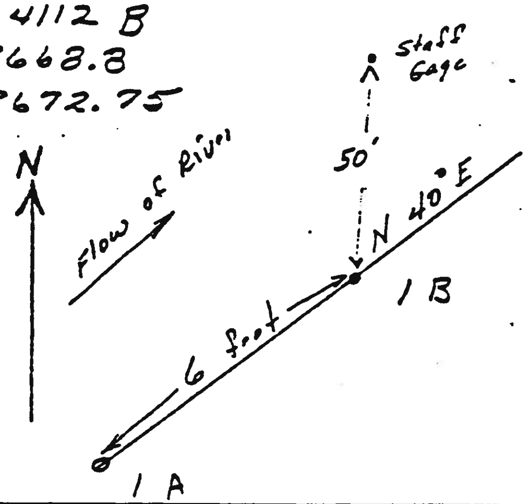
Piezometer # 0 site   103° 27' 36" — 35° 20' 40"

Location = 13·33·21·1224   @ Toe of UTE DAM
Elevation Ground = 3682.7
Elevation Top Pipe = 3685.48 w/cap off

Piezometer # 1 Site   103° 25' 17" — 35° 21' 12"

Location = 13·33·15·4112 A   "0" on Staff Gage = 3665.62
Elevation Ground = 3668..9
Elevation Top PVC = 3672.59

Location = 13·33·15·4112 B
Elevation Ground = 3668.8
Elevation Top PVC = 3672.75



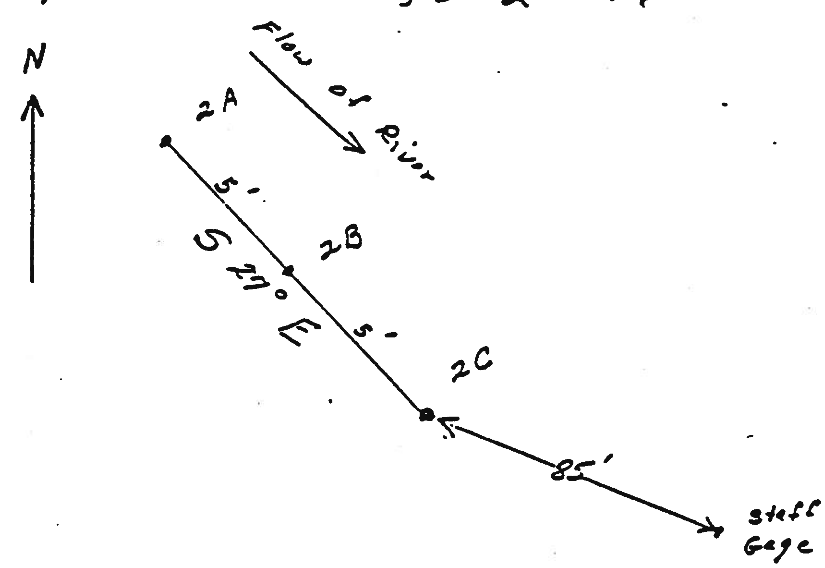
Piezometer # 2 site   103° 24' 52" — 35° 2'' 14'

Location = 13·33·14·1332 A
Elev. Ground = 3668.7
Elev Top PVC = 3672.55

Location = 13·33·14·1332 B
Elev. Ground = 3668.7
Elev. Top PVC = 3670.41

Location = 13·33·14·1332 C
Elev. Ground = 3668.5
Elev. Top PVC = 3672.73

"0" on Staff Gage = 3663.32



"0" on USGS Staff Gage = 3665.61

USBR, 1984

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT	SHEET 2 OF 3
CKD BY	DATE	FEATURE Figure 1 (continued)	
DETAILS			

TW-1

103° 24' 50" – 35° 21' 12"

13-33-14-1333

Location = N 1585252.5 E 774291.3
Elev. on outer ring = 3674.01 white paint on west side

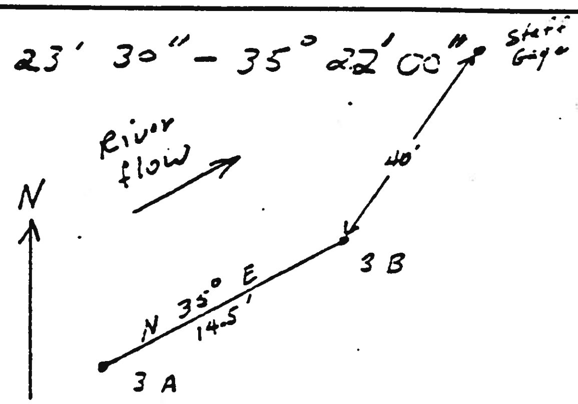
Piezometer #3 Site

103° 23' 30" – 35° 22' 00"

Location = 13·33·12·3214 A
Elev. on Ground = 3655.1
Elev. Top PVC = 3658.38

Location = 13·33·12·3214 B
Elev. Ground = 3655.1
Elev. Top PVC = 3658.08

"0" on Staff Gage = 3651.86



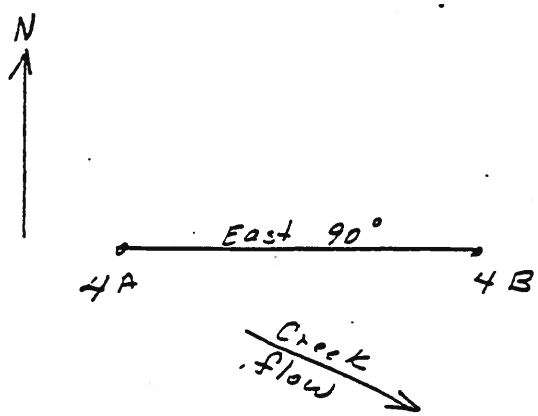
Piezometer #4 Site

103° 22' 58" – 35° 21' 48"

Location = 13·33·12·4412 A
Elev on Ground = 3653.7
Elev Top PVC = 3658.77

Location = 13·33-12-4412 B
Elev. Ground = 3653.7
Elev Top PVC = 3656.68

No Staff Gage



Piezometer #6 Site

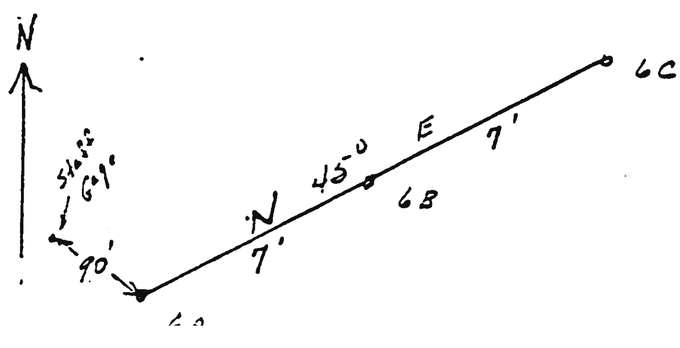
103° 20' 22" – 35° 33' 30"

"0" on Staff Gage = 3631.98

Location = 14·34·33·3324 A
Elev. Ground = 3638.0
Elev. Top PVC = 3640.99

Location = 14·34·33·3324 B
Elev. Ground = 3637.9
Elev. Top PVC = 3640.70

Location = 14·34·33·3324 C
Elev Ground = 3637.6



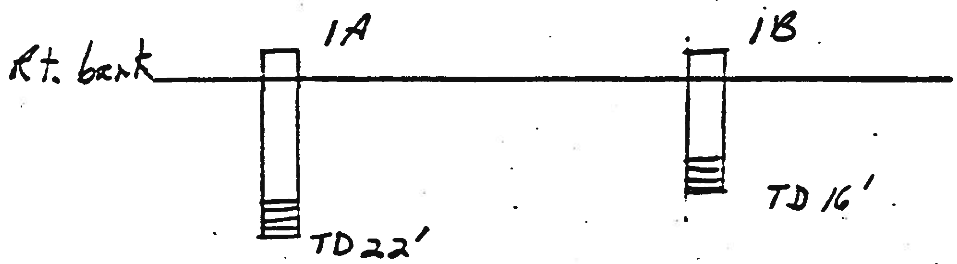
7-1654 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT Lake Meridith Salinity	SHEET 1 OF 7
CHKD BY	DATE	FEATURE River Alluvial Holes RAH 1A, 1B	
DETAILS Figure 2 ( ) -River Site 1-			

→ River flow direction



~4' pipe ab. ground

Screen 17.5 - 21.5' 11.5'-15.5'
6' gal pipe in top hole

22' at bedrock

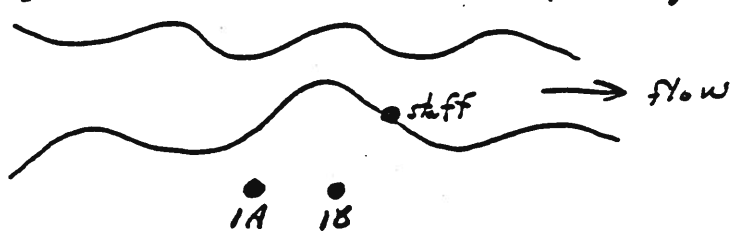
drilled in sand w/ gravel interbeds
11' gal pipe below ground level to protect plastic pipe

Staff gage placed ~ 25' downstream on rt bank

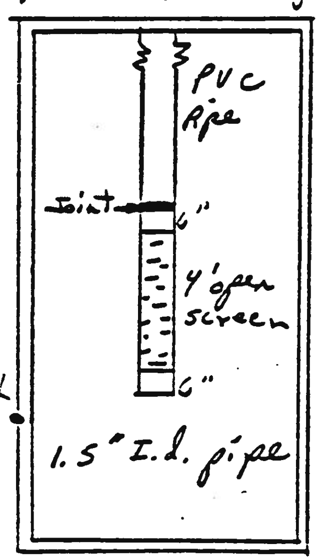
water level elevation 8/24/83
No density corrections

River	3666.03'
1A	3666.69'
1B	3663.40'

gradient up



Note: screen configuration



River Mile - 1.6 mi below Ute Dam

Note: piez. Prob Not in deepest part of channel deepest is prob 100 yds south - May effect QW

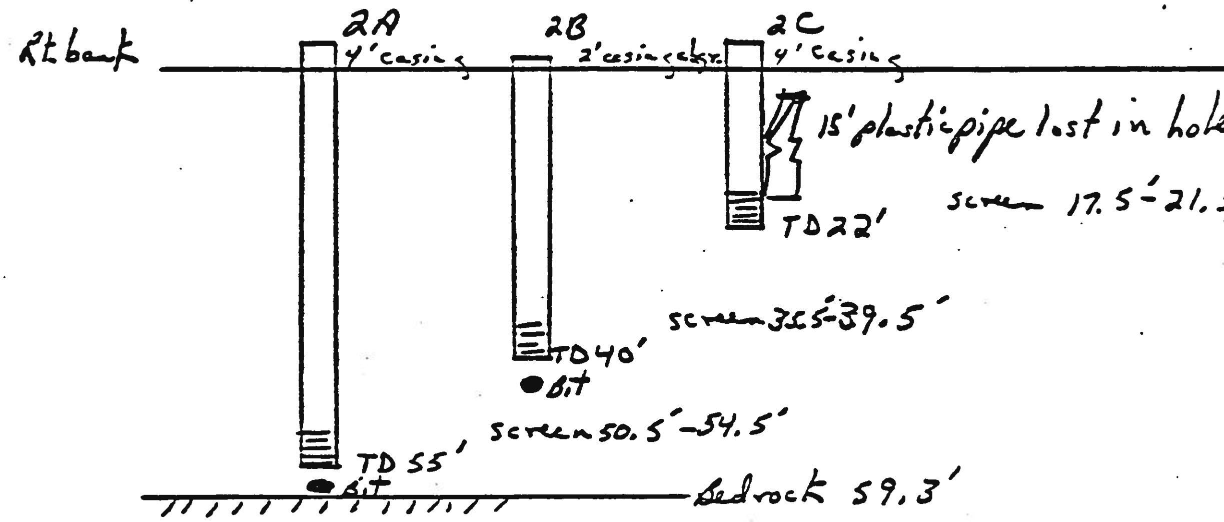
7-1654 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

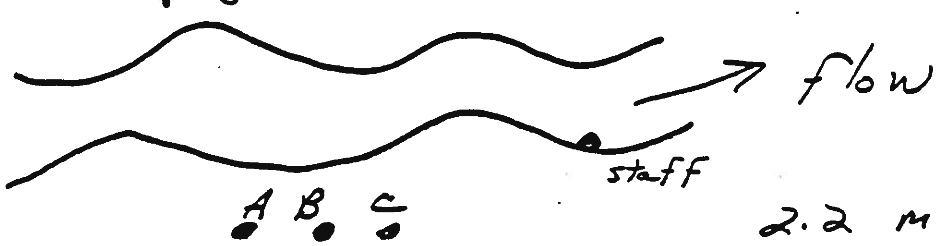
BY	DATE	PROJECT Lake Maridith Salinity	SHEET 2 OF 7
CHKD BY	DATE	FEATURE RAH 2A, B, C	
DETAILS Figure 2 (continued) — River Site 2 —			

→ River flow



Steel bit was left in the bottom of holes A + B
11' galvanized casing was placed in top of hole
Drilling in Sand w/ pea size gravel lenses

Holes were drilled in sand bar ~10' ab river surface on Rt. bank.
Staff gage ~40' downstream on Rt bank



2.2 mi below Ute Dam

water level elevations 8/24/83
No Density Corrections

River	3664.40'
2A	3664.85
2B	3664.70
2C	3664.73

gradient up

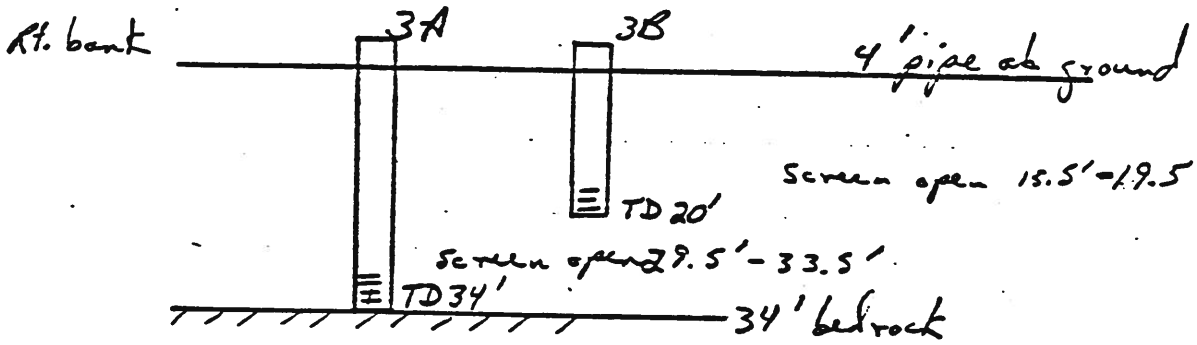
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT Lake Maridith Salinity	SHEET 3 OF 7
CHKD BY	DATE	FEATURE RAH 3 A, B	
DETAILS Figure 2 (continued)		—River Site 3—	

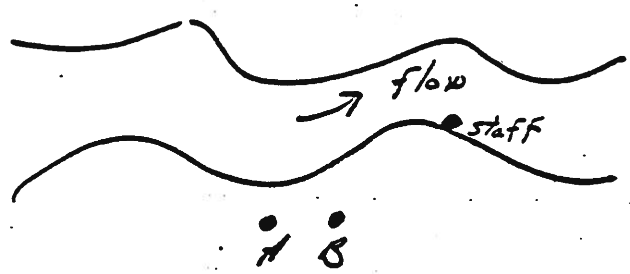
→ River flow



11' galvanized pipe in top of holes

Drilled in ~~Sand~~ & clayey ~~Sand~~ w/some pea size gravel, red and lt. grey cley

staff gage ~ 10' downstream



5.4 mi below Ute Dam

water level elevations 8/24/83
no density corrections

River 3652.72'
3A 3652.48'
3B 3652.73'
gradient down?

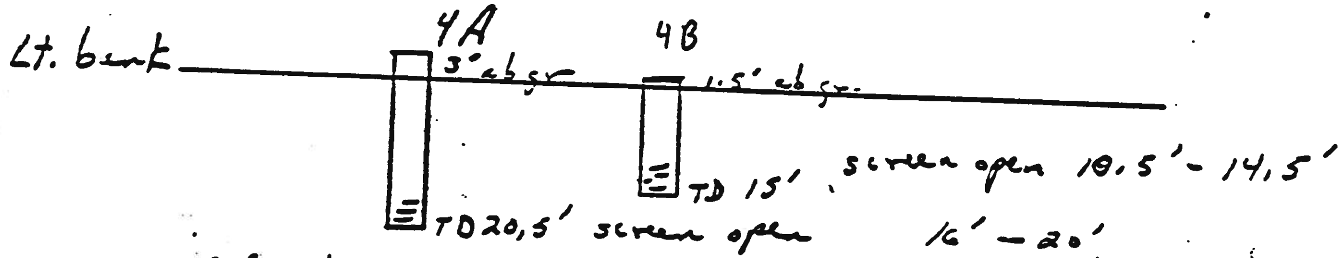
7-1654 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

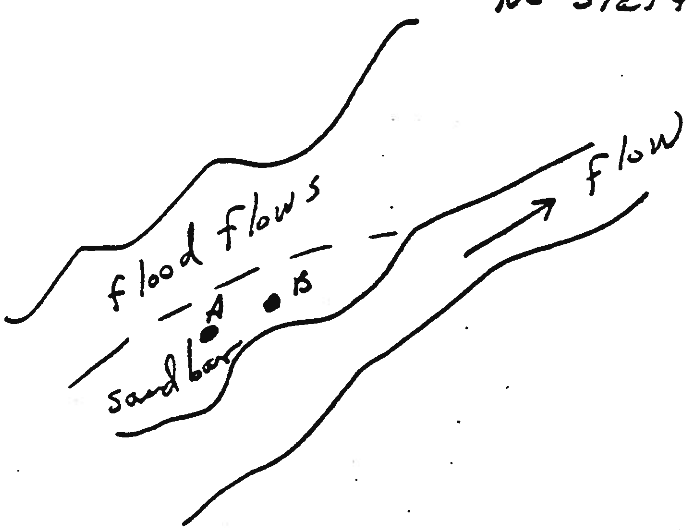
BY	DATE	PROJECT Lake Meridith Salinity	SHEET 4 OF 7
CHKD BY	DATE	FEATURE RAH 4, A, B -Revuelto Cr.	
DETAILS Figure 2 (continued)		-River site 4-	

→ flow



Bedrock ~18 - 20' very soft contact
drilled in sand & pea size gravel
A-has 15.5' galvanized pipe in top of hole
B-has 8' galv pipe in top of hole
holes drilled in sand bar ~3' above Cr. surface
hole "B" is ~9' directly downstream of A

No staff gage



0.2 mi ab. Mouth

Canadian R. Mi 6.3

Water Level elevations 8/24/83
No density corrections

River —
4A 3653.27
4B 3653.18
gradient-up

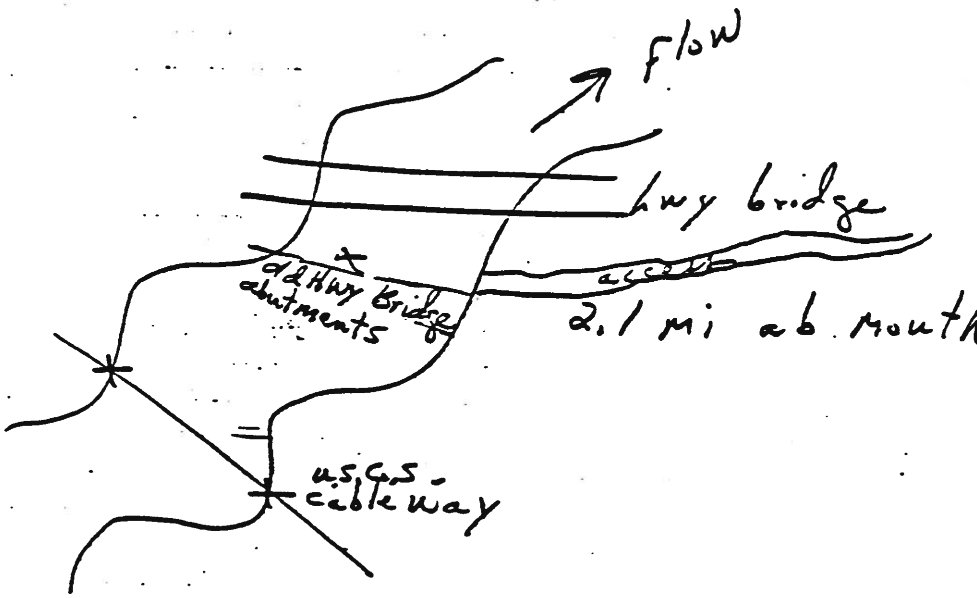
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT Lake Meridith Salinity	SHEET 5 OF 7
CHKD BY	DATE	FEATURE RAH 5A Rivealto Cr	
DETAILS Figure 2 (continued)		-River Site 5-	

Not completed as of 6/7/83



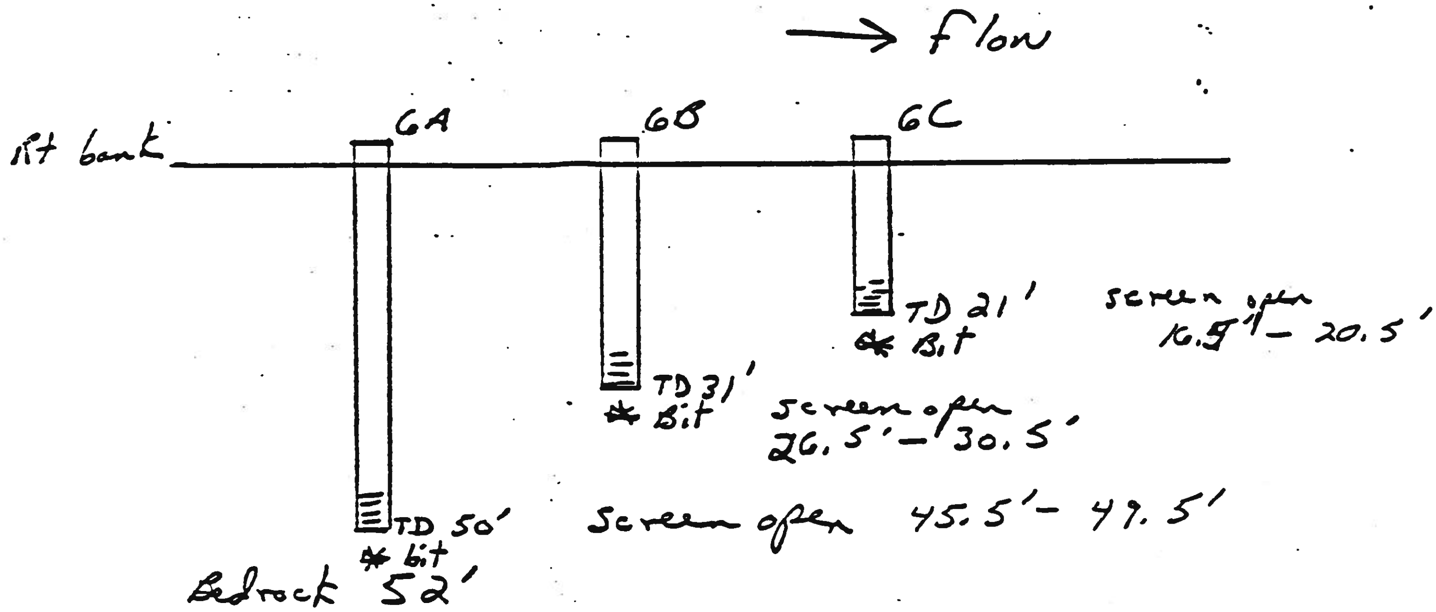
7-1654 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT Lake Meridith Salinity	SHEET 6 OF 7
CHKD BY	DATE	FEATURE RAH 6 A, B, C	

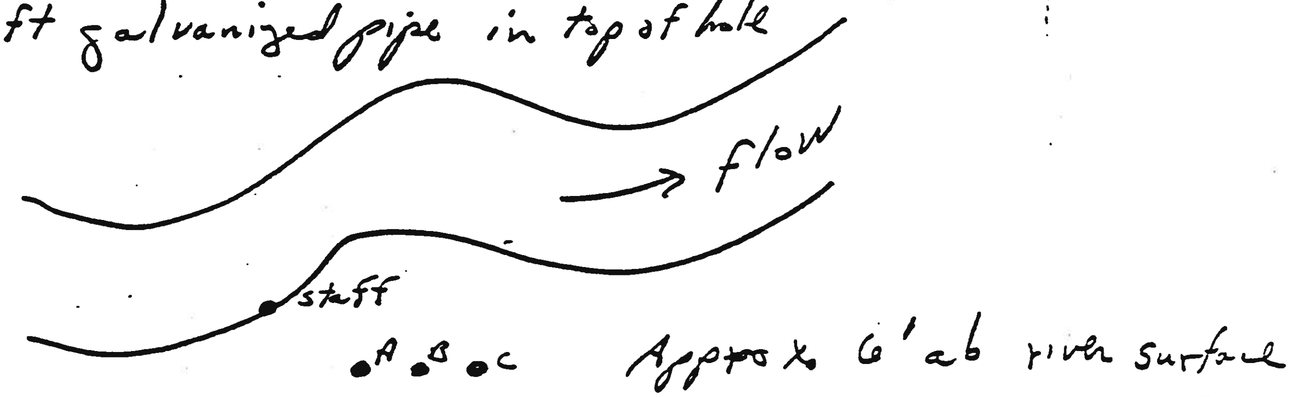
DETAILS Figure 2 (continued) -River Site 6 -



Bits in bottom of each hole

drilled in clayey sand at surface, gravel at 10',
Sand w/clay lenses
gravel on top of bedrock

11 ft galvanized pipe in top of hole



Approx. 6' ab river surface

9.9 mi below ute dam

Water level elevations 8/24/83
No Density Corrections

River – 3632.19'
6A – 3631.99'
6B – 3632.20'
6C – 3632.24'
gradient?

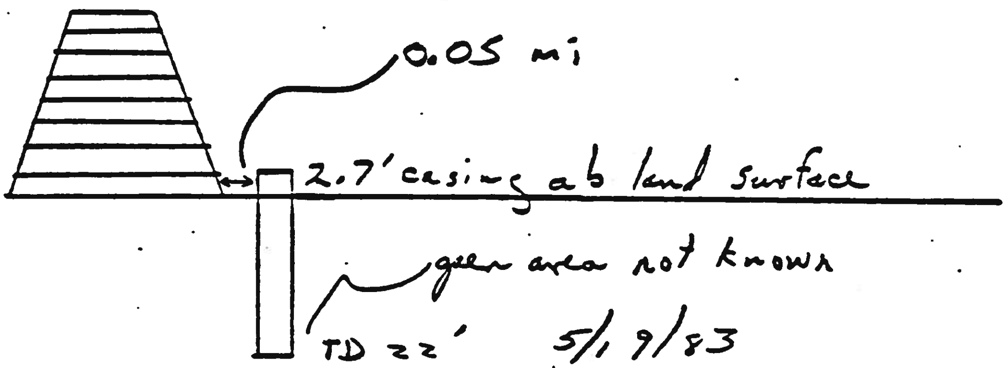
7-1854 (7-73)
Water and Power

COMPUTATION SHEET

USBR, 1984

BY	DATE	PROJECT Lake Meridith Salinity	SHEET 7 OF 7
CHKD BY	DATE	FEATURE Piezometer below Ute Dam	
DETAILS Figure 2 - Sampling Site Descriptions Near Logan, NM			

Site 0 River mi 0 (River Site 0)



OD pipe $1\frac{13}{16}$"

reasonably good road to w/in 50' of piez.

USBR, 1984

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT Lake Meredith Salinity Control	SHEET ___ OF ___
CHKD BY	DATE	FEATURE Observation Well Locations	

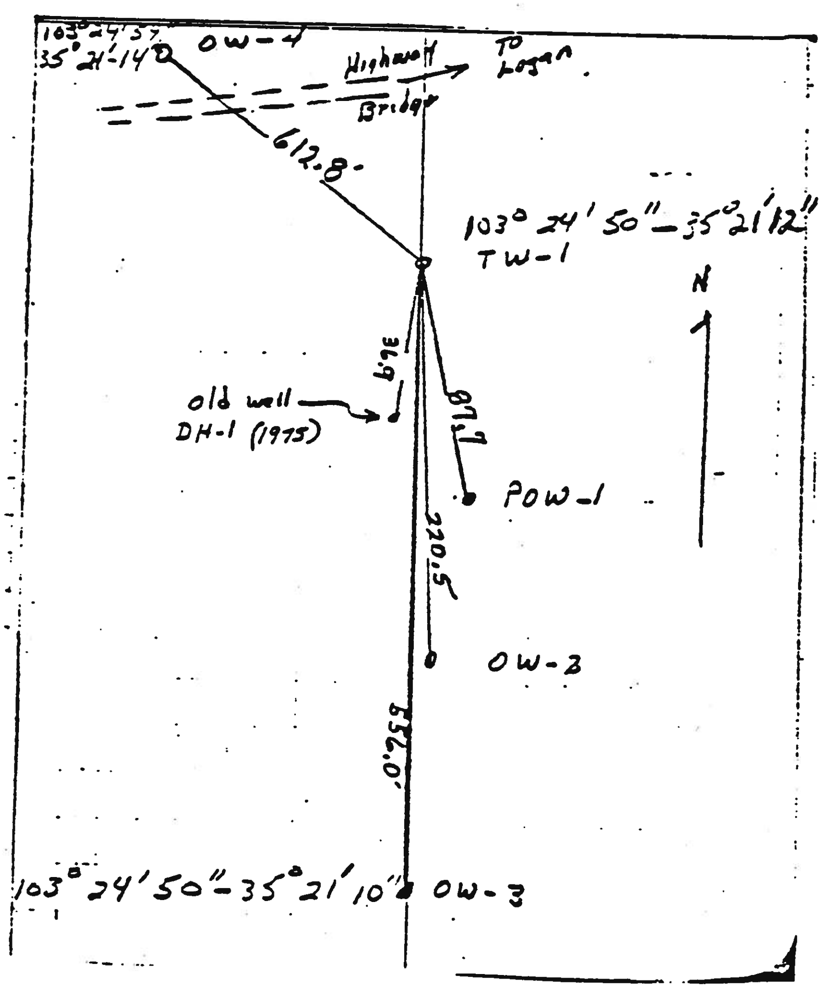
DETAILS
Figure 3 – Observation Well Locations Near Logan, NM

Well No.	State Plane Coordinates North	State Plane Coordinates East	Elevation
DH-1	1585226.9	774266.3	3674.5 (bolt)
DH-2			3655.72 (Top spigot-Land Surface)
DH-3	1585902	770028	3781.0 (Land Surface)
TW-1	1585252.5	774291.3	3674.01 (Top outer ring-Land Surface)
POW-1	1585178.6	774245.7	3675.9 (pipe)
OW-2	1585081.1	774153.6	3682.8 (pipe)*
OW-3	1584830.4	773931.6	3673.0 (Land Surface)
OW-4			3676.5 (Land Surface)

*~1 foot of pipe has been cut off since elevation was determined

DH-2 Location – 13-34-17-1342 or 103°22′32″, 35°22′10″

DH-3 Location – 13-33-15-3124 or 103°25′40″, 35°21′05″



"Figure 5 USBK, 1984

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 1 OF 8

PROJECT: LAKE MEREDITH SALINITY STUDFEATURE: DEEP CORE HOLE .... AREA: LOGAN AREA .... STATE: NEW MEXICO

COORDS. N. 1505502 .... E. 770020 .... GROUND ELEV. 3781.0 ANGLE FROM HORIZ. 90.0 DOWN

BEGUN 8/17/83 ... FINISHED 9/13/83 ... DEPTH TO BEDROCK 11.0 ... TOTAL DEPTH 569.5 BEARING ....

DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL): DEPTH (FEET) FROM (P, CS, or CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS: GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

NOTES

DRILLED USING 54H DRILLING RIG, BEAN PUMP (24 GPM MAXIMUM CAPACITY) AND CORE DRILL OPERATOR FROM BRANTLEY PROJECT, NEW MEXICO:

USED 3-7/8 INCH ROCK BIT 0.0-16.2 FT.
USED NQ DIAMOND BIT 16.2-335.9 FT.
USED NQ CARBIDE BIT 335.9-370.2 FT.
DRILLED 350.0-370.2 AND DRILLED 370.2-569.5 FT. USING NQ DIAMOND BIT. TOP OF ROCK DEPTH BASED ON DRILL ACTION AND CUTTING.

WATER LOSS DURING DRILLING:

INTERVAL (FT.)	PERCENT
48.0-50.0	50
122.0-160.0	40
273.0-273.5	100
273.5-306.0	40
327.0-332.5	50
(BEFORE CASING TO 362.0 FT.)	
350.0-370.2	40
430.0-450.0	80

DRILLED WITH CLEAR WATER EXCEPT IN INTERVALS AS FOLLOWS:

E-Z MUD	DEPTH(FT.)
2 GAL.	61.0
5 GAL.	319.8
5 GAL.	360.0
5 GAL.	370.0
50 LBS REVERT 370.2 FT.	
5 GAL.	529.4
8 GAL.	568.2

HOLE BEGAN CAVING AT 335.0 FT. IN RED MUDSTONE AND GREEN SHALE FROM 297.0-340.0 FT. AT 419.3 FT., HOLE CAVED BACK TO APPROX. 366.0 FT. EACH TIME RODS WERE PULLED. AFTER CASING SET TO 362.0 FT., HOLE DEVIATED FROM PREVIOUSLY DRILLED HOLE. CONSOLIDATED CAVING AND FORMATION ROCK FROM SIDE OF HOLE WERE RECOVERED FROM 362.0 TO 409.3 FT. FORMATION ROCK WAS CORED FROM 409.3 TO 569.5 FT.

PERCENT CORE RECOVERY: 100

DEPTH SCALE (FEET): 10, 20, 30, 40, 50, 60, 70, 80, 90

ELEVATIONS (FEET): 3780.4, 3779.4, 3777.0, 3770.0, 3767.0, 3762.7, 3754.2, 3750.5, 3734.0, 3727.4, 3715.6, 3697.0, 3695.0, 3690.9, 3688.7

CLASSIFICATION AND PHYSICAL CONDITION

0.0-11.0 FT.: QUATERNARY ALLUVIUM.

0.0-0.6 FT.: TOPSOIL.

0.6-1.6 FT.: GRAVELLY SAND.
NUMEROUS CALICHE FRAGMENTS AND PEBBLES.

1.6-4.0 FT.: SANDY GRAVEL WITH COBBLES.

4.0-11.0 FT.: SILTY SAND.

11.0-514.0 FT.: TRIASSIC DOCKUM GROUP.

11.0-14.0 FT.: SANDSTONE.
SILTY, MICACEOUS, MEDIUM GRAINED. BROWN.

14.0-18.3 FT.: CLAYSTONE.
CLAYEY. RED TO RED-BROWN, WITH INTERBEDS OF RED-BROWN SILTSTONE (17.1-17.7 FT.) AND FINE GRAINED, MICACEOUS CROSSBEDDED SANDSTONE (16.2-16.7 FT.) AND (17.7-17.9 FT.). STRONG REACTION WITH HCL. TAN.

18.3-30.5 FT.: SANDSTONE.
SILTY, MICACEOUS. FINE-GRAINED, CROSSBEDDED. LIGHTLY TO MODERATELY CEMENTED. ONE HAMMER BLOW CRUSHES SMALL PIECE. LONGEST CORE STICK 1.7 FT. STRONG REACTION WITH HCL. TAN TO BROWN, E. PT YELLOW FROM 29.0-30.5 FT.

26.8-26.85 FT.: CLAYSTONE.
GREENISH GRAY.

27.3-27.4 FT.: CLAYSTONE.
RED.

30.5-47.0 FT.: SHALE.
SANDY, MICACEOUS. SLIGHTLY FISSILE TO BLOCKY STRONG REACTION WITH HCL. PREDOMINANTLY RED WITH GREENISH GRAY LAYERS AT 41.7-42.6 FT. AND 43.0-45.0 FT. WITH SOME GREENISH GRAY YELLOW BROWN MOTTLING AND BANDING. CONSIDERABLY LESS SAND IN GRAY COLORED INTERVALS.

47.0-53.6 FT.: SANDSTONE.
FINE TO MEDIUM GRAINED, MICACEOUS, CROSSBEDDED. MODERATE TO STRONG REACTION WITH HCL. 70 DEGREES TO VERTICAL FRACTURES WITH IRON AND MANGANESE STAINING. FEW THIN BEDS BELOW 50.6 FT. CONTAIN ROUNDED TO OBLONG FRAGMENTS OF BROWN AND GRAY CLAYSTONE (<1 INCH). TAN TO BROWN.

53.6-65.4 FT.: SHALE.
CLAYEY. SLIGHTLY FISSILE TO BLOCKY. MODERATELY WELL-CONSOLIDATED. SLIGHT REACTION WITH HCL. CORE STICKS UP TO 1.1 FT. IN LENGTH BROWN TO REDDISH BROWN WITH THIN GREENISH GRAY LAYERS AND MOTTLING.

65.4-92.3 FT.: SANDSTONE.
SILTY TO CLAYEY. MICACEOUS. FINE TO MEDIUM GRAINED. THIN SANDY SILTSTONE LAYERS THROUGHOUT. CARBONACEOUS MATERIAL AND MICA ON BEDDING PLANES. 50-70 DEGREE FRACTURES 72.2-77.5 FT., SLIGHTLY CEMENTED. WEAK TO STRONG REACTION WITH HCL. GRAY TO BROWN WITH LIMONITE STAINING AND SPOTS.

83.2-84.0 FT. SHALE.
CLAYEY. FISSILE, WELL CONSOLIDATED. CORE STICK 0.8 FT. LONG. GRAY.

88.0-90.1 FT.: SANDSTONE.
MEDIUM GRAINED. THIN TO MEDIUM BEDDED. NEAR VERTICAL FRACTURES THROUGHOUT, BUT STRONGLY FRACTURED 87.6-88.9 FT. SLIGHTLY CEMENTED. YELLOW.

92.3-118.4 FT.: SHALE.
CLAYEY. FISSILE. THIN LAYERS (0.7 FT. THICK) OF GREENISH GRAY SHALE AT 92.3 FT., 109.0 FT. AND 118.0 FT. AND 118.0 FT. AND THIN LAYERS OF FINE-GRAINED, WELL CEMENTED GRAY SANDSTONE AT 93.4 FT. AND 97.4 FT. STRONG REACTION TO HCL BECOMING MODERATE BELOW 116.0 FT. RED BROWN.

118.4-149.7 FT.: SANDSTONE.
SILTY. MICACEOUS. CARBONIZED WOOD LAYERS AND LAMINATIONS OF MICA AND CARBONACEOUS MATERIAL WITH ASSOCIATED PYRITE AND CHALCOPYRITE ON BEDDING PLANES. FINE GRAINED, MODERATELY TO SLIGHTLY CEMENTED. SLIGHT TO NO REACTION WITH HCL. NEAR VERTICAL FRACTURES AT 121.5-125.0 FT., 132.5-133.0 FT. AND 145.0-146.0 FT. 45 DEGREE FRACTURES

COMMENTS:

SET 14.0 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 18.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM T.D. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 49.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.0 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 381.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 FT. AND NEAT CEMENT GROUT FROM 381.5 FT. TO GROUND LEVEL. PLACED 5 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2\pi LH} \log_e \frac{L}{r}$$ WHEN L GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2\pi LH} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

PERMEABILITY VALUES SHOWN ARE COMPUTED FROM THESE THEORETICAL FORMULAS AND DO NOT CONSIDER SYSTEM HEAD LOSSES AND OTHER FACTORS INHERENT IN THE TESTING. THEREFORE, THESE ARE NOT TRUE PERMEABILITIES, MERELY RELATIVE VALUES.

P = PACKER CS = CASING CM = CEMENT

GEOLOGIC LOG OF HOLE NO DH-3

PROJECT: LAKE MEREDITH SALINITY STUDY FEATURE: DEEP CORE HOLE AREA: LOGAN AREA STATE: NEW MEXICO

COORDS. N. 1989802 E. 7..020 GROUND ELEV. 3781.0 ANGLE FROM HORIZ. 90.0 DOWN

BEGUN 8/17/83 FINISHED 9/19/83 DEPTH TO BEDROCK 11.0 TOTAL DEPTH 569.5 BEARING

DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL): DEPTH (FEET) FROM (P, CS or CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS: GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

Depth scale (feet): 110, 120, 130, 140, 150, 160, 170, 180, 190

Elevations (feet): 3862.6, 3831.3, 3829.8, 3813.9, 3812.8, 3805.4

Handwritten: AQUIFER (350.0–498.7 ft.); 418'–361' screen

CLASSIFICATION AND PHYSICAL CONDITION

AT 147.7 FT. AND 148.2 FT. FRAGMENTS OF GRAY SHALE AND SUBANGULAR TO SUBROUNDED PHOSPHATIC AND QUARTZITIC GRAVEL (-1/2 INCH) AT 119.7 FT. AND 132.5 FT. GRAY.

148.7-151.1 FT.: CLAYSTONE.
BLOCKY. BLUISH GRAY.

151.1-296.0 FT.: SANDSTONE.
MICACEOUS. FINE TO COARSE-GRAINED. THIN CONGLOMERATIC LAYERS WITH SUBANGULAR TO SUBROUNDED FINE GRAVEL AND ANGULAR FRAGMENTS WITH ASSOCIATED CHALCOPYRITE AND PYRITE (168.2, 171.0, 176.0, 219.0, 234.1 AND 246.9 FT.) GRADING INTO WELL-CEMENTED CONGLOMERATE 274.4 TO 277.0 FT. CARBONACEOUS LAMINATIONS ON HORIZONTAL BEDDING PLANES. MOSTLY THIN BEDDED. SLIGHTLY TO WELL CEMENTED. SLIGHT TO MODERATE REACTION WITH HCL. 75 DEGREES FRACTURE AT 177.3 FT., VERTICAL FRACTURE AT 273 - FT. VUGS UP TO 1/8 INCH DIAMETER AND .12 INCH DEEP IN WELL CEMENTED CONGLOMERATIC SANDSTONE AT 234.1-238.3 FT. AT 246.9-250.7 FT., GRAY TO LIGHT GRAY.

167.1-168.2 FT.: SHALE.
CLAYEY. GRAY.

175.6-176.0 FT.: SHALE.
CLAYEY. GRAY.

200.6-200.8 FT.: SHALE.
CLAYEY. GRAY.

203.3-203.5 FT.: SHALE.
CLAYEY. GRAY.

205.9-208.1 FT.: SHALE.
CLAYEY. GRAY.

223.8-224.8 FT.: SHALE.
CLAYEY. BLACK LAMINATIONS ON BEDDING PLANES. GRAY.

296.0-297.0 FT.: SHALE.
CLAYEY. GREENISH-GRAY.

297.0-341.0 FT.: MUDSTONE.
CLAYEY. SANDY. BLOCKY. AIR SLAKES RAPIDLY. STRONG REACTION WITH HCL. PURPLISH RED.

341.0-350.0 FT.: SHALE.
CLAYEY. GREENISH-GRAY.

350.0-498.7 FT.: SANDSTONE.
CLAYEY. MICACEOUS. CARBONACEOUS MATERIAL AND SHALE FRAGMENTS (-1 INCH) OCCUR IN CONGLOMERATIC LAYERS. FINE GRAINED SUBROUNDED TO SUBANGULAR GRAINS. MICA AND CLAY COATED BEDDING PLANES DIP 10 DEGREES. CROSSBEDDED BELOW 462.8 FT. PIN POINT VUGS 449.3-450.9 FT. VERTICAL FRACTURE AT 360.0 FT. AND 415.? FT., 70 DEGREES FRACTURE AT 306.0 FT. AND 60 DEGREE FRACTURES AT 410.0 FT. AND 412.0 FT. SLIGHT TO NO REACTION WITH HCL. CORE STICKS UP TO 2.0 FT. GRAYISH WHITE TO BLUISH GRAY.

402.2-404.4 FT.: CLAYSTONE.
SANDY. GREENISH TO BLUISH GRAY.

434.8-435.3 FT.: CLAYSTONE.
SANDY. GREENISH GRAY.

450.5-450.9 FT.: CLAYSTONE.
SANDY. GREENISH GRAY.

472.9-475.0 FT.: CLAYSTONE.
SANDY. GREENISH GRAY.

(NOTE:) EACH CLAYSTONE BED IS OVERLAIN BY CONGLOMERATIC SANDSTONE WHICH BECOMES FINER GRAINED UPWARD.

498.7-514.0 FT.: SHALE.
CLAYEY. FRAGMENTS OF GREENISH LIMESTONE AND WHITE DOLOMITE. INTERBEDS OF HARD WELL CEMENTED LIGHT RED SANDSTONE. HARD. WELL CONSOLIDATED. SLIGHT REACTION WITH HCL. RED

514.0-569.5 FT.: PERMIAN ARTESIA GROUP.

514.0-518.0 FT.: SHALE.
WELL CONSOLIDATED. MODERATE REACTION WITH HCL. SALMON RED.

COMMENTS:

SET 14.0 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 18.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM T.D. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 48.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.0 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 351.5 FT. PLACED 3.0 FT. BENTONITE 348.5-351.5 FT. AND NEAT CEMENT GROUT FROM 381.5 FT. TO GROUND LEVEL. PLACED 5 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2 \pi L H} \log_e \frac{L}{r}$$ WHEN L GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2 \pi L H} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

PERMEABILITY VALUES SHOWN ARE COMPUTED FROM THESE THEORETICAL FORMULAS AND DO NOT CONSIDER SYSTEM HEAD LOSSES AND OTHER FACTORS INHERENT IN THE TESTING. THEREFORE, THESE ARE NOT TRUE PERMEABILITIES, MERELY RELATIVE VALUES.

P = PACKER CS = CASING CM = CEMENT

PROJECT: LAKE MEREDITH SALINITY STUDY FEATURE: DEEP CORE HOLE AREA: LOGAN AREA STATE: NEW MEXICO

COORDS. N. 1509002 E. 770020 GROUND ELEV. 3781.0 ANGLE FROM HORIZ. 90.0 DOWN

BEGUN 8/17/83 FINISHED 9/19/83 DEPTH TO BEDROCK 11.0 TOTAL DEPTH 589.5 BEARING

DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL): DEPTH (FEET) FROM (P, CS, or CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS: GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
											3580.4		518.0-535.5 FT.: SILTSTONE. SANDY. GREENISH REDUCTION SPOTS. 1-INCH LAYER AT 535.0 FT CONSISTING OF VERY THIN LAYERS OF GREENISH FINE GRAINED SANDSTONE AND SHALE. HARD. STRONG REACTION WITH HCL. SALMON-RED.
											3577.7		
											3575.1		535.5-541.1 FT.: SANDSTONE. GREENISH REDUCTION SPOTS. FINE-GRAINED. MOSTLY ROUNDED GRAINS. HARD. STRONG REACTION WITH HCL. SALMON-RED.
								210					541.1-544.4 FT.: SHALE. SANDY. FEW FRAGMENTS LIMESTONE [illegible]. WELL CONSOLIDATED. GREENISH TO SALMON-RED.
								220					544.4-589.1 FT.: SILTSTONE. SANDY. GREENISH REDUCTION SPOTS. INTERCALATED WITH LIGHT RED SHALE AND DARK GREENISH GRAY SHALE. FEW CALCITE-FILLED FRACTURES. MODERATE REACTION WITH HCL. HARD. WELL CONSOLIDATED. ONE HAMMER BLOW FRAGMENTS SMALL PIECE. LIGHT-RED.
											3557.2		
											3556.1		
								230					
								240					
								250					
								260					
								270					
								280					
								290					
											3485.0		
											3484.0		

COMMENTS:

SET 14.0 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 18.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM T.D. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 40.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.0 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 381.5 FT. PLACED 3.0 FT. BENTONITE 378.5-381.5 FT. AND NEAT CEMENT GROUT FROM 381.5 FT. TO GROUND LEVEL. PLACED 5 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2\pi LH} \log_e \frac{L}{r}$$ WHEN L GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2\pi LH} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

PERMEABILITY VALUES SHOWN ARE COMPUTED FROM THESE THEORETICAL FORMULAS AND DO NOT CONSIDER SYSTEM HEAD LOSSES AND OTHER FACTORS INHERENT IN THE TESTING. THEREFORE, THESE ARE NOT TRUE PERMEABILITIES, MERELY RELATIVE VALUES.

P = PACKER CS = CASING CM = CEMENT

GEOLOGIC LOG OF HOLE NO DH-3

PROJECT: LAKE MEREDITH SALINITY STUDY FEATURE: DEEP CORE HOLE AREA: LOGAN AREA STATE: NEW MEXICO

COORDS. N. 1505902 E. 770020 GROUND ELEV. 3781.0 ANGLE FROM HORIZ. 90.0 DOWN

BEGUN 8/17/83 FINISHED 9/19/83 DEPTH TO BEDROCK 11.0 TOTAL DEPTH 500.9 BEARING

DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL) DEPTH (FEET) FROM (P, CS or CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS: GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
									310				
									320				
									330				
									340		3440.8		
									350		3431.0		
									360				
									370				
									380				
									390				

COMMENTS:

SET 14.0 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 10.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM T.D. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 49.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.0 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 381.5 FT. PLACED 3.0 FT. BENTONITE 378.5-381.5 FT. AND NEAT CEMENT GROUT FROM 381.5 FT. TO GROUND LEVEL. PLACED 5 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2 \pi L H} \log_e \frac{L}{r}$$ WHEN L GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2 \pi L H} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

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P = PACKER CS = CASING CM = CEMENT

GEOLOGIC LOG OF HOLE NO DH-3

PROJECT LAKE MEREDITH SALINITY STUDY FEATURE DEEP CORE HOLE AREA LOGAN AREA
COORDS. N. 1509002 E. 770020 STATE NEW MEXICO
GROUND ELEV. 3701.8 ANGLE FROM HORIZ. 90.0 DOWN
BEGUN 8/17/83 FINISHED 9/19/83 DEPTH TO BEDROCK 11.0 TOTAL DEPTH 900.5 BEARING
DEPTH TO WATER 99.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL) DEPTH (FEET) FROM (P, CS OR CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
											3378.0		
											3378.8		
									410				
									420				
									430				
											3347.0		
											3345.7		
									440				
									450		3330.5		
									460				
									470				
											3308.1		
											3308.0		
									480				
									490				
											3284.3		

COMMENTS:

SET 14.0 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 18.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM 1.0. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 49.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.8 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 FT. AND NEAT CEMENT GROUT FROM 381.5 FT. TO GROUND LEVEL. PLACED 9 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2 \pi L H} \log_e \frac{L}{r}$$ WHEN L GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2 \pi L H} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

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P = PACKER CS = CASING CM = CEMENT

GEOLOGIC LOG OF HOLE NO DH-3

PROJECT LAKE MEREDITH SALINITY STUDY FEATURE DEEP CORE HOLE AREA LOGAN AREA STATE NEW MEXICO

COORDS. N 1599902 E 770520 GROUND ELEV. 3781.0 ANGLE FROM HORIZ. 90.0 DOWN

BEGUN 8/17/83 FINISHED 9/14/83 DEPTH TO BEDROCK 11.0 TOTAL DEPTH 588.5 BEARING

DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	FIELD PERMEABILITY TEST (DESIGNATION E-18, EARTH MANUAL): DEPTH (FEET) FROM (P, CS, or CM)	TO	DIAMETER (INCHES)	LOSS (GPM)	DIFFERENTIAL PRESSURE (FEET)	LENGTH OF TEST (MIN)	PERMEABILITY (K) FEET/YEAR	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS: GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
									510				
											3267.0		
											3263.0		
									520				
									530				
											3245.5		
									540				
											3239.0		
											3236.0		
									550				
									560				
									570		3211.0		
									580				
									590				

COMMENTS:

1. SET 14.5 FT. OF 4 INCH SURFACE CASING 8/17/83. SET 18.0 NW CASING TO 18.5 FT. ON 8/18/83. SET ADDITIONAL 343.5 FT. NW CASING TO 362.0 FT. ON 8/31/83. 9/11 THROUGH 9/13/83: GROUTED HOLE FROM T.D. TO 418.5 FT. PLACED 1 FT. SAND FROM 417.5-418.5 FT. SET 49.5 FT. OF 1-1/2 INCH DIAMETER PVC SCREEN AND 371.0 FT SCHEDULE 80 1-1/2 INCH DIAMETER BLANK PVC TO 417.5 FT. PLACED SAND PACK IN HOLE FROM 417.5 TO 161.9 FT. PLACED 3.0 FT. BENTONITE 358.5-161.5 FT. AND NEAT CEMENT GROUT FROM 361.5 FT. TO GROUND LEVEL. PLACED 5 FT. OF 2 INCH STEEL PROTECTIVE CASING WITH 2-FT. STICKUP.

EXPLANATIONS: GENERAL FORMULAS USED TO COMPUTE PERMEABILITY:

$$K = \frac{Q}{2 \pi L H} \log_e \frac{L}{r}$$ WHEN : GREATER THAN OR EQUAL 10r

$$K = \frac{Q}{2 \pi L H} \sinh^{-1} \frac{L}{2r}$$ WHEN L LESS THAN 10r AND GREATER THAN OR EQUAL r

PERMEABILITY VALUES SHOWN ARE COMPUTED FROM THESE THEORETICAL FORMULAS AND DO NOT CONSIDER SYSTEM HEAD LOSSES AND OTHER FACTORS INHERENT IN THE TESTING. THEREFORE, THESE ARE NOT TRUE PERMEABILITIES, MERELY RELATIVE VALUES.

P = PACKER CS = CASING CM = CEMENT

G. GAILLOT
9/9/83

USBR, 1984

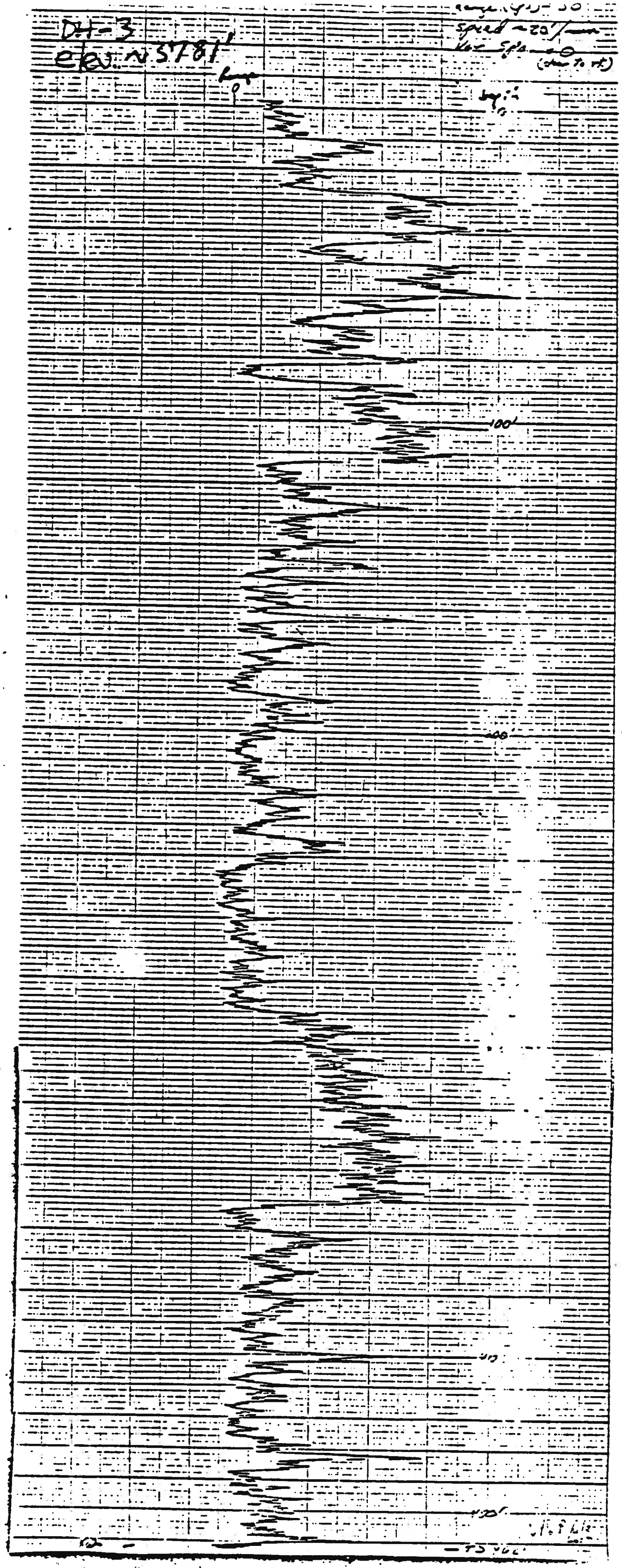

Figure 6 – Natural Gamma Log of Core Hole DH-3 [illegible] NM

USBR, 1979

7-1333 (6-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 5

FEATURE Canadian River Below Ute Dam PROJECT Canadian River Salinity Study STATE New Mexico

HOLE NO. DH-1 LOCATION COORDS. N. 35° 21' 13" E. 103° 24' 51" GROUND ELEV. 3680' A.M.S.L. DIP (ANGLE FROM HORIZ.) 90

BEGUN 6/24/75 FINISHED 6/30/75 DEPTH OF OVERBURDEN 30.0' TOTAL DEPTH 356' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian 30 GPM 6/28/75 LOGGED BY D. Smith and J. K. Morrison LOG REVIEWED BY S. E. Kluender

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (R. Cs. or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drill Rig: Failing 1500 Casing: Set 30.7" of 6" casing; upon hole completion 6" casing pulled, set 31.5' of 4" casing and cemented to ground level and welded cap on to seal. Drill Fluid Loss: 0' - 106' 0% 106' - 116' 10% 116' - 256' 0% 256' - 356' Artesian-No loss Sampling: Sampled cuttings approximately at 10' intervals from drill fluid return ditch. Water samples taken at irreguair intervals from casing; river water samples also taken. Water Samples: 1. Packered hole 51' - 76', blew hole. Chloride 3,450 mg/l NaCl 5,692 " Sulfate 700 " Total Fe 0.12 " Conductance 11,000 2. Packered hole 51' - 76'; after blow-rest cycle sample cleared. Chloride 3,060 mg/l NaCl 5,049 " Sulfate 700 " Total Fe 0.12 " Conductance 10,200 3. River water 6/25/75. Chloride 3,150 mg/l NaCl 5,198 " Sulfate 500 " Total Fe 0.08 " Conductance 10,200	7-7/8" Rock Bit 10 20 30 CS-4-3/4" Drag Bit 40 50 60 70 80 90								3.0 10 10.0 14.0 20 30.0 40 50 56.0 60.0 70 72.0 76.0 80 90			0' - 30' Quaternary Alluvium 0' - 3' Sand, poorly sorted. Contains some very fine gravel, some fine to very fine sand, mostly medium sand. Strong HCL reaction. Contains some quartzite, and feldspars, all less than 5% of total. Mottled reddish color. 3' - 10' Sand, coarse and poorly sorted. Contains some very fine gravel, some fine to very fine sand, mostly medium to coarse. Strong HCL reaction. Contains some quartzite, opal, mica, and chalcopyrite, all less than 5% of total. Mottled reddish color. 10' - 14' Gravelly Clay, coarse fragments to greater than 5 mm indicate gravel interbedded. Contains a few calcareous oolites, some opal, mica, and chalcopyrite, all less than 5% of total. Strong HCL reaction. Mottled reddish color. 14' - 30' Gravel, poorly sorted; very fine gravel and cobbles; coarse sand with minor amount of fine to very fine sand. Contains some calcareous oolites, mica flakes, small concretions and chalcopyrite, all less than 5% of total. Staining on some fragments, mottled buff color. 30' - 196' Triassic Santa Rosa Sandstone 30' - 56' Sandstone, medium to coarse grained, small fraction of very coarse sand and some clay and silt. Good HCL reaction. Calcareous and argillaceous cement. Fair induration. Contains some opal, a few small concretions, and a few mica flakes (muscovite). Grades into shale. Buff to gray color. 56' - 60' Sandstone, medium to coarse grained, with shale layers interbedded. Weak HCL reaction; argillaceous and calcareous cement; fair induration. Dark buff to brown color. 60' - 72' Shale, silty with high argillaceous content. Contains a few coarser sand grains. Weak HCL reaction; fairly well indurated. Variegated dark buff to brown color.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

FEATURE .... PROJECT .... STATE New Mexico

HOLE NO. DH-1 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
4. Packered hole 71' - 96' and blew hole; water rose to 8' below top casing, approximately river level. Chloride 2,400; NaCl 3,960; Sulfate 200; Total Fe 0.13; Conductance 6,100	4-3/4"											72' - 76' Sandy Shale, some medium to coarse sand, and silt with high argillaceous content. Fair HCL reaction; fairly well indurated. Mottled gray color.
5. Packered hole 91'-116'-interval made no water. Packered hole 91-136; water rose to 4' below top of casing. Chloride 2,200 mg/l; NaCl 3,663 "; Sulfate 500 "; Total Fe 0.10 "; Conductance 6,750												76' - 146' Sandstone, poorly sorted. Very fine sand to coarse sand, mostly medium to fine sand. Some shale interbedded. Poor HCL reaction; argillaceous and calcareous cement. Contains some quartzite, igneous rock fragments, mica, opal, and chalcopyrite. Calcareous matter also noted. Fairly well indurated. Gray to mottled buff color.
6. Same as 5, taken 30 minutes later. Chloride 2,100 mg/l; NaCl 3,465 "; Sulfate 500 "; Total Fe 0.02 "; Conductance 6,750									146.0			146' - 156' Sandstone, very coarse grained. Some interbedded shale and conglomerate. No noticable HCL reaction, argillaceous cement; fairly well indurated. Chalcopyrite deposits on some fragments. Mottled buff to gray color.
7. Packered hole 131'-156', blew hole, hole dry; hole took water 24 gal/min; again blew hole and sampled. Chloride 3,200 mg/l; NaCl 5,280 "; Sulfate 700 "; Total Fe 0.13 "; Conductance 10,000									156.0			156' - 196' Sandstone, medium to coarse. A little very coarse to fine gravel material. Quite a bit of shale interbedded. Little or no HCL reaction. Fairly well indurated; argillaceous cement. Contains quite a bit of quartzite and other siliceous material, other than quartz. Mottled grayish white to buff color.
8. Same as 7, pumped in water, blew hole, and took sample. Chloride 3,300 mg/l; NaCl 5,445 "; Sulfate 200 "; Total Fe 0.13 "; Conductance 10,100									196.0			196' - 261' Permian Bernal Formation. 196' - 261' Gravelly Shale, contains many coarse fragments to fine gravel size, some fine to very fine sands. Fair HCL reaction; fairly well indurated. Limonite particles and some particles limonite stained. Grayish to whitish mottled color.
												261' - 356' Permian San Andres Formation (Glorieta Sandstone). 261' - 316' Quartzose Sandstone. Sucrose-textured fine to very fine sands. Very well sorted. No HCL reaction. Argillaceous cement; poorly indurated. Contains some chalcopyrite and a few mica flakes. Light grayish to white color.
												316' - 326' Quartzose Sandstone. Sucrose textured fine to very fine, well sorted sand. No HCL reaction. Seams of shale interbedded. Contains some mica flakes. Grayish-white color.

EXPLANATION

CORE LOSS / CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
Bureau of Reclamation

GPO 884-401

GEOLOGIC LOG OF DRILL HOLE

SHEET...3... OF...5...

FEATURE .... PROJECT .... STATE ....

HOLE NO. ..DH-1... LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

NOTES ON WATER LOSSES AND LEVELS, ETC.

9. Same as 7, next day. Water level 3.75' in pipe; blew hole, took sample.
Chloride 3,350 mg/l
NaCl 5,528 "
Sulfate 300 "
Total Fe 0.06 "
Conductance 10,100

10. River water 6/28/75. Hard rain during previous night.
Chloride 1,150 mg/l
NaCl 1,898 "
Sulfate 300 "
Total Fe 0.08 "
Conductance 4,000

11. At 296' hole flowed est. Q=30 gal/min. Sampled while flowing.
Chloride 11,800 mg/l
NaCl 19,470 "
Sulfate 1,650 "
Total Fe 0.80 "
Conductance 34,000

12. At 296' after flowing more than one hour.
Chloride 11,800 mg/l
NaCl 19,470 "
Sulfate 1,450 "
Total Fe 0.24 "
Conductance 37,000

13. At 296' after flowing all night.
Chloride 12,950 mg/l
NaCl 21,368 "
Sulfate 2,150 "
Total Fe 0.42 "
Conductance 36,000

14. At 296' after circulating to clear hole.
Chloride 2,350 mg/l
NaCl 3,878 "
Sulfate 500 "
Total Fe 0.08 "
Conductance 8,600

15. At 316' flowing 32 gal/min.
Chloride 16,450 mg/l

TYPE AND SIZE OF HOLE: 4-3/4" Drag Bit

DEPTH (FEET): 10, 20, 30, 40, 50, 60, 70, 80, 90 — 261

CLASSIFICATION AND PHYSICAL CONDITION

326' - 336' Quartzose Sandstone. Sucrose textured fine to very fine, well sorted sand. No HCL reaction. Seams of shale with much mica. Grayish-white color.

336' - 346' Quartzose Sandstone. Sucrose textured fine to very fine, well sorted sand. Thickly interbedded shale. No HCL reaction. Argillaceous cement; poorly indurated. Grayish-white color.

346' - 356' Shale, with same sucorse sand and silt. No HCL reaction. Poorly indurated. Grayish-white color.

Explanation of Graphic Log:

INDURATED ROCK

- Sandstone
- Shale
- Sandy Shale

CONSTITUENT PARTICLES

- Clay
- Pebbles, Gravel, Cobbles or Boulders
- Sand
- Silt

MISCELLANEOUS SYMBOLS

- Mica

EXPLANATION

CORE LOSS / CORE RECOVERY

Type of hole .... D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
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GEOLOGIC LOG OF DRILL HOLE

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-1 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
NaCl 27,142 " Sulfate 2,000 " Total Fe 0.48 " Conductance 45,000	4-3/4" Drag Bit											
16. At 336' circulated 30 minutes, took sample. Chloride 18,500 mg/l NaCl 30,525 " Sulfate 1,950 " Total Fe 0.80 " Conductance 52,000									316			
17. At 356' after flowing 15 minutes. Chloride 16,100 mg/l NaCl 26,565 " Sulfate 1,900 " Total Fe 0.27 " Conductance 51,000									320			
18. At 356' after flowing 30 minutes. Chloride 15,950 mg/l NaCl 26,318 " Sulfate 500 " Total Fe 0.10 " Conductance 50,000									336 346			
19. At 356' after flowing all night.' Chloride 17,600 NaCL 28,875 Sulfate missing Total Fe 0.48 Conductance 49,080									356			
20. Sample of drinking water. Chloride 245 mg/l NaCl 404 " Sulfate 60 " Total Fe 0.03 " Conductance 500-600												
21. Mix of drinking water 50% and water from well 50%. Chloride 8,850 mg/l NaCl 14,602 " Sulfate 900 " Total Fe 0.10 " Conductance 26,000												
22. River water 5/30/75. Chloride 2,900 mg/l NaCl 4,785 "												

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2"; Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 5 OF 5

FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-1 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Sulfate 500 mg/1 Total Fe 0.03 " Conductance 11,000 23. At 356' after flowing 24 hours. Chloride 16,250 mg/l NaCl 26,812 " Sulfate 1,750 " Total Fe 0.29 " Conductance 49,000 24. River water 8/21/75. Chloride 3,000 mg/l NaCl 4,950 " Sulfate 500 " Total Fe 0.10 " Conductance 11,900 Note: Conductance in micromhos /cm @ 25° C									10 20 30 40 50 60 70 80 90			

EXPLANATION

CORE LOSS

CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

USBR, 1979

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 6

FEATURE Canadian River Below Ute Dam PROJECT Canadian River Salinity Study STATE New Mexico

HOLE NO. DH-2 LOCATION 13N - 34E - 7BCD1 COORDS. N. 35° 22' 10" E. 103° 22' 35" GROUND ELEV. 3665' A.M.S.L. DIP (ANGLE FROM HORIZ.) 90

BEGUN 7/01/75 FINISHED 7/06/75 DEPTH OF OVERBURDEN 33.7' TOTAL DEPTH 556.0' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED 3 GPM 7-6-75 Artesian LOGGED BY D. Smith \ J. K. Morrison LOG REVIEWED BY S. E. Kluender

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Drill Rig: Failing 1500 Casing: Set 40.5' of 6", upon completion of drilling; casing pulled, set 42' of 4" casing, cemented to ground level and welded cap on to seal. Cap has pet-cock. Drill Fluid Loss: 0' - 466' 0% 466' - 554' artesian-no loss. Sampling: Sampled cuttings at approx. 10' intervals from drilling fluid return ditch. Water samples taken at irregular intervals from casing. River water samples also taken. Water Samples: 1. River water 7/2/75. Chloride 6,100 mg/l; NaCl 10,065 "; Sulfate 540 "; Total Fe 0.06 "; Conductance 11,400 2. River water 7/3/75. Chloride 4,550 mg/l; NaCl 7,508 "; Sulfate 610 "; Total Fe 0.08 "; Conductance 13,900 3. River water 7/4/75. Chloride 5,050 mg/l; NaCl 8,332 "; Sulfate 710 "; Total Fe 0.12 "; Conductance 15,200 4. River water 7/5/75. Chloride 5,700 mg/l; NaCl 9,045 "	7-7/8" Rock Bit (0-33.7) 4-3/4" Drag Bit C8								10, 20, 30, 33.7, 40, 46.0, 50, 56.0, 60, 66.0, 70, 80, 90			0' - 33.7' Quarternary Alluvium 0' - 33.7' Sand, fine to medium. Some gravel and cobbles. Fair HCL reaction. Contains a few mica flakes. Many particles limonite stained. Mottled reddish color. 33.7' - 56' Triassic Santa Rosa Sandstone 33.7' - 46' Sandy Shale, some fine to very fine and medium sands. Many particles limonite stained. Poorly indurated. Yellowish-gray color. 46' - 56' Sandstone, fine to very fine. Fair HCL reaction, calcareous and argillaceous cement. Seams of shale interbedded; poorly indurated. Yellowish gray color. 56' - 536' Permian Bernal Formation 56' - 66' Shale, fine to very fine sand layers interbedded. Poor HCL reaction. Contains some limonite and chalcopyrite; poorly indurated. Grayish-yellow color. 66' - 105' Shale, some fine to very fine sand. Seams of chalcopyrite encountered. Contains small limonite particles and a few mica flakes. Limonite staining evident. Fair HCL reaction. Fair to poor induration. Whitish-gray color. 106' - 126' Shale, some fine to very fine sands. Seams of clay interbedded. Clay non-indurated. Fair HCL reaction, fair induration, limonite staining evident. Contains some chalocopyrite. Whitish-gray color. 126' - 136' Sandy Shale, a lot of fine to very fine sand. Fair HCL reaction. Contains some chalocopyrite and lots of mica flakes. Whitish-gray color. 136' - 156' Sandy Shale, some fine to very fine sand. Fair HCL reaction. Contains some mica and chalcopyrite, also a little smoky quartz. Light grahish-white color. 156' - 176' Shale, seams of fine to very fine sand interbedded. Fair HCL reaction. Fairly well indurated. Grayish-white color.

EXPLANATION

CORE LOSS / CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

GEOLOGIC LOG OF DRILL HOLE

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Sulfate 790 mg/l Total Fe 0.06 " Conductance 17,600 5. From 516', artesian encountered at 466', 3gpm. Chloride 4,800 mg/l NaCl 7,920 " Sulfate 1,015 " Total Fe 0.24 " Conductance 16,300 6. From 534', flowing from casing. Chloride 4,950 mg/l NaCl 8,168 " Sulfate 1,013 " Total Fe 1.08 " Conductance 16,900 Artesian pressure - 0.5 lb/in^2 7. River water 7/7/75 Chloride 6,000 mg/l NaCl 9,900 " Sulfate 650 " Total Fe 0.10 " Conductance 17,600 Note: Conductance in micromhos /cm @ 25° C.	4-3/4" Drag Bit								106.0 10 20 126.0 30 136.0 40 50 156.0 60 70 176.0 80 90 196.0			176' - 196' Shale, a little fine to very fine sand and some clay. Fair HCL reaction; fair induration. White to grayish-red color. 196' - 211' Sandy Shale, sand mostly very fine to fine, increasing clay fraction near bentonite consistency. Grades to ferruginous shale. Fair HCL reaction; fair induration. Reddish-gray color. 211' - 216' Ferruginous Shale, a little fine to very fine sand. Argillaceous content increasing as evidenced by thickening of drill mud. Contains some chalcopyrite and mica. Fair induration. Light reddish-brown color. 296' - 326' Ferruginous Shale, some fine to very fine sand, high argillaceous content. Fair HCL reaction; fairly good induration. A few mica-rich seams are interbedded. Light reddish-brown color. 326' - 356' Ferruginous Shale, some very fine sand to silt, fairly high argillaceous content. Fair HCL reaction; fair induration. Contains a few chalcopyrite crystals. Brownish-red color. 356' - 396' Ferruginous Shale, a few medium to coarse sand grains, fairly high argillaceous content. Seams of non-indurated clay interbedded, bentonitic consistency. Poor induration; slight HCL reaction. Brownish-red color. 396' - 436' Ferruginous Shale, a little medium to coarse sand. Contains a few chalcopyrite crystals. Fairly well indurated. Slight HCL reaction. Brownish-red color. 436' - 456' Ferruginous Shale, some fine to very fine sand interbedded. Contains some mica and chalcopyrite. Argillaceous content high. Slight HCL reaction; fair induration. Brownish-red color.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

GEOLOGIC LOG OF DRILL HOLE

FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	4-3/4 Drag Bit								211.0 216.0 296.0			456' - 516' Ferruginous Sandy Shale. Some very fine sand to silt size particles. Argillaceous content high. Good HCL reaction; fairly good induration. Contains chalcopyrite crystals. Brownish-red color. 516' - 536' Ferruginous Siltstone, fairly sandy, fine to very fine sand. Argillaceous content lessening. Fair HCL reaction. Contains some chalcopyrite and mica flakes. Reddish-brown color.

EXPLANATION OF GRAPHIC LOG:

INDURATED ROCK

- Sandstone
- Shale
- Sandy shale
- Sandstone and shale

CONSTITUENT PARTICLES

- Clay
- Pebbles, gravel, cobbles, or boulders
- Sand
- Silt

MISCELLANEOUS SYMBOLS

- Pyrite
- Mica
- Coal

EXPLANATION

CORE LOSS / CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
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GEOLOGIC LOG OF DRILL HOLE

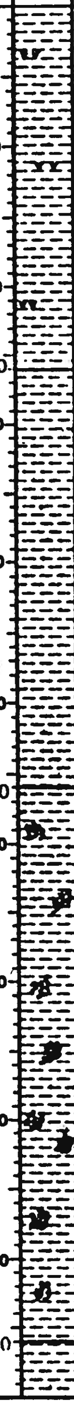
FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	4 3/4" Drag Bit								126.0			
									356.0			
									396.0			



EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

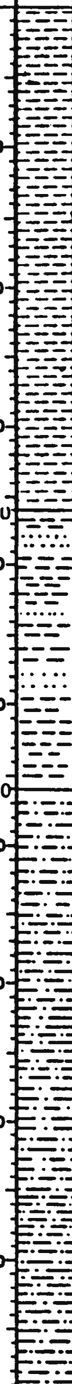
FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	4 3/4" Drag Bit											
									436.0			
									456.0			



EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
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GPO 854-401

GEOLOGIC LOG OF DRILL HOLE

SHEET 6 OF 6

FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	43/4" Dra Bit (0–35)											
								[illegible] (at 16)				
								[illegible] (at 35)				

Depth scale: 10, 20, 30, 40, 50, 60, 70, 80, 90

EXPLANATION

CORE LOSS

CORE RECOVERY

Type of hole .... D = Diamond, H = Hoyatollite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

USBR, 1979

7-1337 (8-74)
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GEOLOGIC LOG OF DRILL HOLE POW-1

SHEET 1 OF 2

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico

HOLE NO. POW-1 LOCATION Below Ute Dam GROUND ELEV. 3,674.73' DIP (ANGLE FROM HORIZ.) 90.0°

COORDS. N. .... E. ....

BEGUN 9-23-77 FINISHED 10-13-77 DEPTH OF OVERBURDEN 26.5' TOTAL DEPTH 318.0' BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Stapp-Hamilton Inc.
Austin, Texas

Solicitation No.
7-07-50-S0970

Damco 1250 Drilling rig.

Drill Fluid Additives and Drill Water Return.

(Ft.)	(%)
0.0- 6.0	0.0
(600.0 lbs. revert)	
6.0-~~40.0~~	90.0
40.0-120.0	100.0
120.0-140.0	70.0
140.0-142.0	35.0
142.0	0.0
(600.0 lbs. revert)	
142.0-210.0	100.0
210.0-220.0	80.0
220.0-230.0	30.0
230.0-240.0	60.0
(400.0 lbs. revert)	
240.0-258.0	50.0
(700.0 lbs. salt mud)	
258.0	0.0
(800.0 lbs. salt mud)	
(200.0 lbs. revert and 50.0 lbs. salt)	
258.0-266.0	0.0
(1,500.0 lbs. bentonite)	
266.0-318.0	0.0

Artesian flow below 294.0' between periods of drilling operations.

Sampled cuttings at approximately 10.0' intervals from drill fluid return ditch from 0.0' - 261.0'. Logged using binocular microscope.

Geophysical logging on 10-7-77.

Core samples obtained from 261.0' - 318.0'.

Depth scale (TYPE AND SIZE OF HOLE column): 20 (~~10~~), 40 (~~20~~), 60 (~~30~~), 80 (~~40~~), 100 (~~50~~), 120 (~~60~~), 140 (~~70~~), 160 (~~80~~), 180 (~~90~~), 200

DEPTH (FEET) / GRAPHIC LOG contacts: 11.0, 15.0, 26.5, 28.7, 32.0, 58.0, 63.5, 68.0, 73.0, 78.4, 78.7, 86.0, 90.0, 200.0

CLASSIFICATION AND PHYSICAL CONDITION

0.0' - 26.5': QUATERNARY ALLUVIUM.

0.0' - 11.0': Sand.
Approximately 80% medium to coarse sand, approximately 20% fine gravel, hard, subrounded to subangular rock and mineral fragments, buff. SP

11.0' - 15.0': Clayey Gravel.
Approximately 70% fine, hard, subrounded to subangular rock and mineral fragments, maximum size 1.2", approximately 30% medium plasticity fines of medium dry strength, medium toughness, no dilatancy, weak to moderate reaction with HCl, reddish-gray. GC

15.0' - 26.5': Sand.
Approximately 75% medium to coarse, some clay, approximately 25% fine, hard, subrounded to subangular rock and mineral fragments, reddish-gray. SP

26.5' - 318.0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS)

26.5' - 90.0': Sandstone.
Medium to coarse-grained, silty, micaceous, moderately indurated, calcareous cement, layers and stingers of interbedded shale, buff to grayish-tan.

28.7' - 32.0', 58.0' - 63.5', 68.0' - 73.0', and 86.0 - 90.0': Shale
Argillaceous, sandy, small amount of gravel, sticky when wet, calcareous, red-brown and gray layers.

78.4' - 78.7': Soft Coal.

90.0' - 251.0': Sandstone.
Medium to very coarse-grained, silty, poorly sorted, calcareous, moderately indurated, conglomeritic from 203.5' - 208.0' and from 220.0' - 230.0', blue-gray.

251.0' - 271.0': Shale.
Argillaceous, sticky when wet, some calcareous cement, with interbedded sandstone, blue-gray.

256.0' - 258.0' and 263.0' - 264.0': Sandstone.
Medium to coarse-grained, silty, some calcareous cement, well indurated, very hard, blue-gray.

EXPLANATION

CORE LOSS / CORE RECOVERY

Used 6" rock bit to 261.0'; NX core and standard split-tube penetration resistance to 318.0'; set 25' of 6" surface casing, with top 1.5' below ground surface; pulled surface casing 10-13-77, installed 79.0' PVC 1.25" well screen attached at bottom of 234.0' of 2" steel casing to 1.0' above surface, gravel packed to top of screen, sand packed 1.0' over gravel and neat cement grout to surface. Watertight steel cover placed over stick-up of steel casing.

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (6-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE POW-1

SHEET 2 OF 2

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico

HOLE NO. POW-1 LOCATION Below Ute Dam COORDS. N. E. GROUND ELEV. 3,674.73' DIP (ANGLE FROM HORIZ.) 90.0°

BEGUN 9-23-77 FINISHED 10-13-77 DEPTH OF OVERBURDEN 26.5' TOTAL DEPTH 318.0' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

Depth (feet)	Core recovery (%)
	49
	0
	70
	10
	0
	100
	0
	0
	27
	60
	20
	100
	20
	75

Depth contacts (graphic log): 251.0, 256.0, 258.0, 263.0, 264.0, 271.0, 318.0

CLASSIFICATION AND PHYSICAL CONDITION

271.0' - 318.0': Sandstone. Fine-grained, well sorted, very lightly indurated to well indurated, very slightly cemented to highly cemented, mica, thin intermittent shale seams with pyrite crystals and limonite staining, blue-gray.

EXPLANATION

CORE LOSS / CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

USBR, 1979

7-1337 (6-74)
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GEOLOGIC LOG OF DRILL HOLE OW-2

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico

HOLE NO. OW-2 LOCATION Below Ute Dam COORDS. N. E. GROUND ELEV. 3,676.88' DIP (ANGLE FROM HORIZ.) 90.0°

BEGUN 10-27-77 FINISHED 1-4-78 DEPTH OF OVERBURDEN 20.0' TOTAL DEPTH 348.0 BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	CORE RECOVERY (%)	DEPTH (FEET)	CLASSIFICATION AND PHYSICAL CONDITION
Stapp-Hamilton Inc. Austin, Texas Solicitation No. 7-07-50-S0970 Damco 1250 Drilling rig initially drilled to total depth; Failing Drilling rig reamed to total depth. Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0' - 300.0'. Logged using binocular microscope. Geophysical logging on 12-16-77. Core samples obtained from 300.0' - 348.0'. Hole completion included gravel pack around 6.0" casing from bottom of hole to unknown depth (242.0') according to as-built diagram in file). Added 88 cubic feet grout to G.L. in three stages, last two sacks 3-1-78. Special watertight cap placed on 6" steel casing.	55 18 51 95 0	20.0 91.0 232.0 261.0 333.0 348.0 400.0	0.0' - 20.0': QUATERNARY ALLUVIUM. 0.0' - 20.0': Silty Sand. Approximately 80% fine to coarse, angular to subrounded sand, maximum size 0.2", approximately 20% low to medium plasticity fines, low toughness, low dry strength, quick dilatency, strong to moderate reaction with HCl, buff. SM 20.0' - 348.0': SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS) 20.0' - 91.0': Sandstone. Medium to coarse-grained, silty, poorly sorted, calcareous cement, with layers of shale at 28.0' - 30.0' and 78.0' - 91.0', and small amount of coal within 80.0' - 90.0' interval, tan. 91.0' - 230.0': Sandstone. Medium to coarse-grained, silty, poorly sorted, calcareous cement, with gray shale layer 145.0' - 153.0' and very thin gray shale layers interbedded in 200.0' - 220.0' interval, blue-gray. 230.0' - 261.0': Shale. Sandy, blocky, sticky when wet, cuttings are Lean to Fat Clay, medium to high plasticity, medium toughness, with thin interbedded gray sandstone, gray. 261.0' - 333.0': Sandstone. Fine-grained, well-sorted, slightly cemented to highly cemented, with gray shale layer 288.0'- 291.0', light gray. 333.0' - 348.0': Shale. Sticky when wet, gray.

Other column headings (blank): TYPE AND SIZE OF HOLE; PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm), TO; LOSS (G.P.M.); PRESSURE (P.S.I.); LENGTH OF TEST (MIN.); ELEVATION (FEET); GRAPHIC LOG; SAMPLES FOR TESTING. Depth scale: 40, 80, 120, 160, 200, 240, 280, 320, 360, 400 (altered from 10–100).

EXPLANATION

Used 4-1/2" rock bit 0.0' - 300.0'; NX core barrel with diamond bit from 300.0' - 348.0'. Set 2.0' of 12" surface casing 10-31-77. Set surface casing to 24.0' with 1.0' above G.L. on 11-2-77. Grouted 12" casing in hole on 2-9-78. Placed below G.L. 260.0' of 6" casing with 6.0' above G.L. and with 80.0' of 2" PVC screen attached to bottom. Driller did not measure casing or hole before placing 6" casing and subsequent measurements show bottom of 6" casing 272.7' below G.L.

CORE LOSS / CORE RECOVERY

Type of hole: D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed: P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series): Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series): Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series): Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series): Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

USBR, 1979

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GEOLOGIC LOG OF DRILL HOLE OW-3

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico
HOLE NO. OW-3 LOCATION Below Ute Dam GROUND ELEV. 3,672.81' DIP (ANGLE FROM HORIZ.) 90.0°
COORDS. N. E.
BEGUN 1-5-78 FINISHED 1-28-78 DEPTH OF OVERBURDEN 48.1' TOTAL DEPTH 362.0' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Stapp-Hamilton Inc. Austin, Texas

Solicitation No. 7-07-50-S0970

Failing 1500 Drilling rig.

Used 7-7/8" tricone rock bit to 362.0'. Set 49.6' of 6" surface casing 1-12-78. Set 270.0' of 2" steel casing with 80.0' of 2" screen below to 350.0'. Gravel pack (0.7 cubic yards) from bottom of hole to 260.0' depth, cement grout emplaced to within 3/4" of G.L. Watertight steel cap placed on steel casing.

Geophysical logging on 1-20-78.

Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0' - 362.0'. Logged using binocular microscope.

Drilled with clear water.

DEPTH (FEET)

48.1
60.0
72.0
162.0
170.0
191.0
212.0
302.0
326.0
350.0
362.0

CLASSIFICATION AND PHYSICAL CONDITION

0.0'- 48.1': QUATERNARY ALLUVIUM.

0.0' - 48.1': Silty Sand.
Approximately 80% fine to coarse, angular to subrounded sand, approximately 20% none to low plasticity fines, low toughness, quick dilatancy, trace gravel, strong reaction with HCl, buff to tan. SM

48.1' - 362.0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATION OF TEXAS)

48.1' - 60.0': Sandstone.
Fine to coarse-grained, subangular to subrounded grains, strong reaction with HCl, tan.

60.0' - 72.0': Gravelly Shale.
Sticky when wet, medium to coarse sand and gravel up to 5/8" maximum size, gray.

72.0' - 162.0': Sandstone.
Medium to coarse-grained, silty, poorly sorted, mica, calcareous cement, contains apatite, thin gray shale layers interbedded, blue-gray.

162.0' - 170.0': Shale.
Sticky when wet, argillaceous, cuttings are Lean to Fat Clay with medium to high plasticity and high toughness, blue-gray.

170.0' - 191.0': Sandstone.
Fine-grained, well-sorted, light gray.

191.0' - 212.0': Shale.
Sticky when wet, argillaceous, cuttings are Lean to Fat Clay, medium to high plasticity, medium toughness, blue-gray.

212.0' - 302.0': Sandstone.
Fine-grained, well-sorted, rounded to subrounded grains, mica, some 1.0 to 3.0' interbedded shale layers 258.0', 269.0', and 286.0', light gray.

302.0' - 326.0': Shale.
Sandy, argillaceous, sticky when wet, gray.

326.0' - 350.0': Sandstone.
Fine-grained, silty, red-brown.

350.0' - 362.0': No Sample.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE Canadian River PROJECT Lake Meredith STATE New Mexico SHEET 1 OF 1 HOLE NO. OW-3

USBR, 1979

7-1337 (6-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE OW-4

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico

HOLE NO. OW-4 LOCATION Below Ute Dam COORDS. N. E. GROUND ELEV. 3,675.51' DIP (ANGLE FROM HORIZ.) 90.0°

BEGUN 1-28-78 FINISHED 1-31-78 DEPTH OF OVERBURDEN 11.0' TOTAL DEPTH 382.0' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	DEPTH (FEET)	CLASSIFICATION AND PHYSICAL CONDITION
Stapp-Hamilton Inc. Austin, Texas Solicitation No. 7-07-50-S0970 Failing 1500 Drilling rig. Used 7-7/8" tricone rock bit 0.0-15.0'. Set 15.0' of 6-5/8" surface casing, with 1.0' above G.L. Used 4-1/2" tricone rock bit 15.0' to T.D. Set 293.0' of 2" steel casing, with 0.95' above G.L. and 84.0 of 2" slotted steel casing attached to bottom. Gravel packed from bottom of hole to 287.0', sand 287.0'-285.0', and neat cement to G.L. Left surface casing in hole. Watertight steel cap placed on steel casing. Geophysical logging on 12-13-78. Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0'-382.0'. Logged using binocular microscope. Drilled with clear water.	11.0 62.0 75.0 100.0 204.0 290.0 355.0 382.0	0.0' - 11.0': QUATERNARY ALLUVIUM 0.0' - 11.0': Sand. Predominantly fine to medium, maximum size 1/8", round to subangular, hard, rapid reaction with HCl, trace of fines, buff color. SP 11.0' - 382.0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS) 11.0' - 62.0': Sandstone. Fine to medium-grained, subangular to subrounded grains, moderately indurated, slightly to highly cemented, calcareous cement, hard, tan. 62.0' - 75.0': Sandstone. Fine to medium-grained, subangular to subrounded grains, silty, clayey, hard, blue-gray. 75.0' - 100.0': Shale. Very sticky when wet, well cuttings could be described as Lean to Fat Clay with high toughness, calcareous cement, with fine to medium gray sandstone layers interbedded, mostly gray, but some red-brown. 100.0' - 204.0': Sandstone. Fine to coarse-grained, angular to subangular grains, argillaceous, rock and mineral fragments, well indurated, approximately 1.0" seam of soft coal in upper 10.0' and thin bed of gray shale within interval 162.0' - 172.0', gray. 204.0' - 290.0': Shale. Thin lenses of gray shale, predominantly red-brown, sticky when wet. Well cuttings are Lean to Fat Clay, high toughness and medium to high plasticity. Thinly interbedded gray sandstone. Fine to coarse-grained, some calcareous cement. 290.0' - 355.0': Sandstone. Fine-grained, rounded to subrounded grains, well-sorted, mica, tan to gray. 355.0' - 382.0': Shale. Sandy, sticky when wet, blue-gray.

Other columns (TYPE AND SIZE OF HOLE; CORE RECOVERY (%); PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm), TO, LOSS (G.P.M.), PRESSURE (P.S.I.), LENGTH OF TEST (MIN.); ELEVATION (FEET); GRAPHIC LOG; SAMPLES FOR TESTING) are blank. Scale marks 40, 80, 120, 160, 200, 240, 280, 320, 360, 400.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

Index to **TAB 11**: Water-level data

Water level elevations in wells OW-3 and DH-3, September 1983 through September 1984 (data and graph)

Water level elevations in Ute Reservoir and TW-1, September 1984 through April 1991 (data and graph)

NOTE: Water-level data for USBR piezometers are listed in **TAB 10** - USBR, 1984, Figure 2; water-level data for all significant wells in Logan area are summarized in **TAB 9** - "Deep wells in Logan area with both water level and water quality data" and "Shallow wells in Logan area with both water level and water quality data."

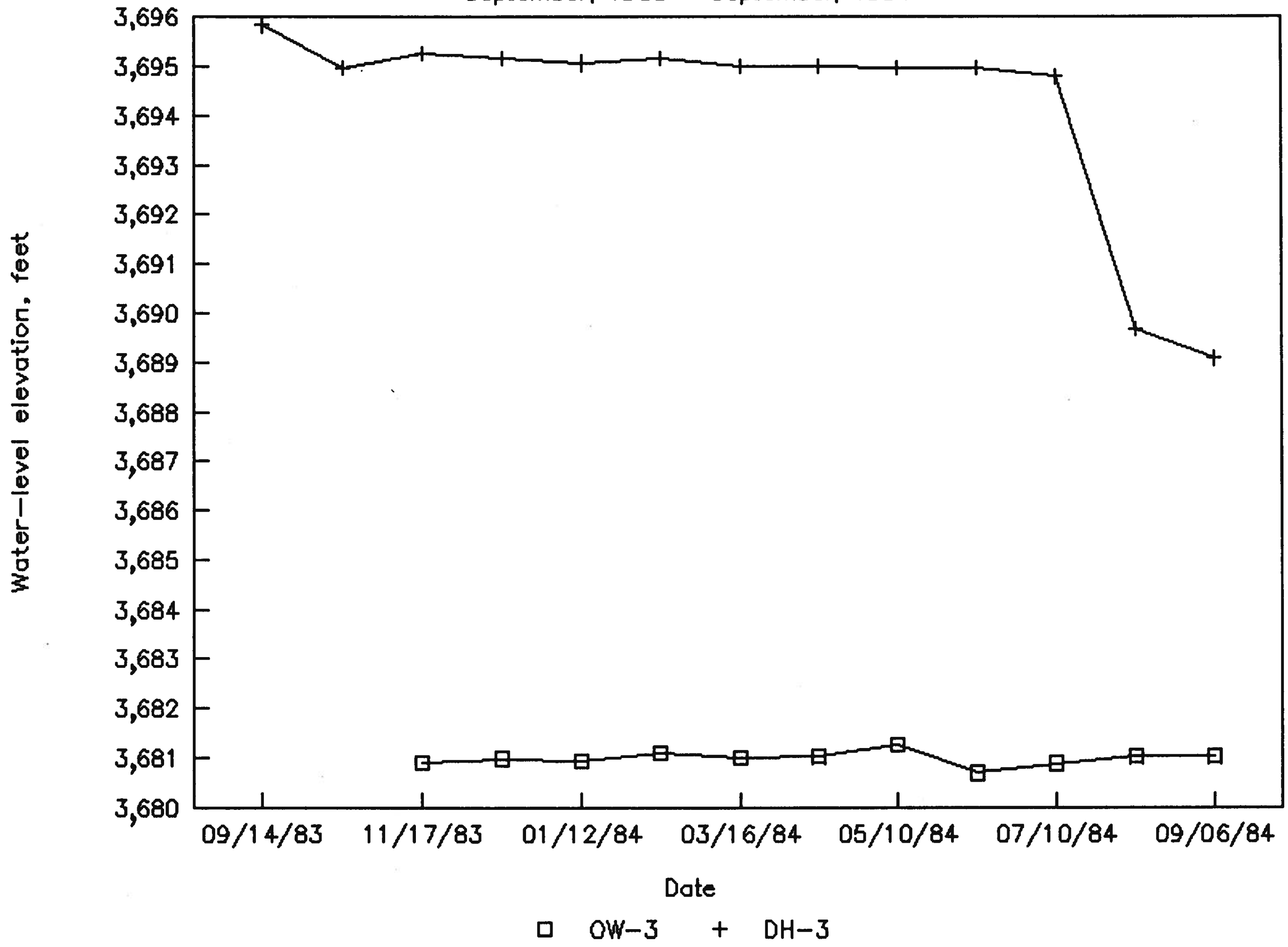
	Water level elevations, ft.	
Date	OW-3	DH-3
09/14/83		3695.86
10/17/83		3694.96
11/17/83	3680.91	3695.26
12/13/83	3680.98	3695.16
01/12/84	3680.95	3695.08
02/15/84	3681.10	3695.16
03/16/84	3681.01	3695.01
04/13/84	3681.03	3695.00
05/10/84	3681.26	3694.96
06/08/84	3680.69	3694.96
07/10/84	3680.88	3694.80
08/17/84	3681.04	3689.67
09/06/84	3681.03	3689.10

NOTES: Surface elevation of OW-3 is 3678.3 ft; surface elevation of DH-3 is 3781 ft.

Air lifted DH-3 on 7/19/84 1 hour. Black fluid (floating, lighter materials?) like drilling mud blown out of hole, then clear water. Hole may not have been properly cleaned after drilling. Piezometer should be pumped and tested before using for testing.

Water levels in two observation wells,

September, 1983 – September, 1984



Ute Reservoir Elevation, observation well and river discharge
Reservoir and observation well levels from worksheet STATEQUA.WK1
River discharge, 7-day geometric mean, Logan Station daily values file

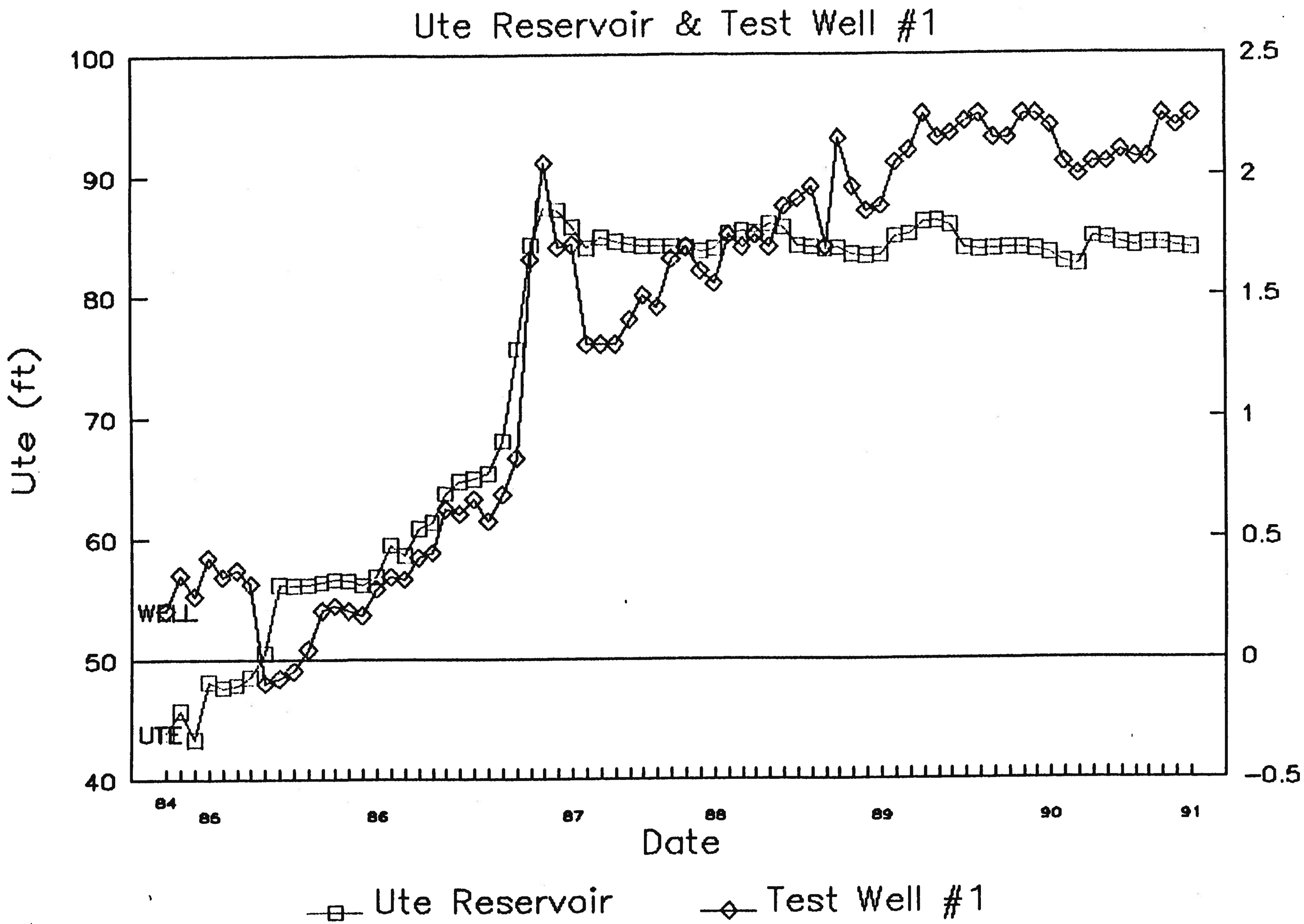
DATE	UTE[1] (ft)	WELL[2] (ft)	RIVER (cfs)	YEAR	WELL (ft X 25)	RIVER (cfs X 10)
09/08/84	43.85	0.20	1.61	84	5	16.07
03/21/85	45.69	0.35	1.78	85	8.75	17.83
04/23/85	43.38	0.26	2.00		6.5	19.98
06/21/85	48.12	0.42	3.64		10.5	36.41
07/18/85	47.65	0.34	4.73		8.5	47.25
08/15/85	47.86	0.37	3.55		9.25	35.54
09/13/85	48.50	0.31	2.65		7.75	26.48
10/15/85	50.53	−0.10	2.12		−2.5	21.20
11/13/85	56.15	−0.08	2.10		−2	21.00
12/17/85	56.04	−0.05	1.79		−1.25	17.88
01/17/86	56.14	0.04	1.88	86	1	18.84
02/13/86	56.34	0.20	1.97		5	19.73
03/13/86	56.54	0.22	2.25		5.5	22.52
04/10/86	56.50	0.20	2.50		5	25.05
05/09/86	56.11	0.18	2.69		4.5	26.90
06/06/86	56.80	0.29	2.06		7.25	20.63
07/10/86	59.41	0.34	2.00		8.5	20.00
08/08/86	58.59	0.33	1.96		8.25	19.58
09/05/86	60.80	0.42	1.92		10.5	19.20
10/07/86	61.28	0.44	2.28		11	22.84
11/05/86	63.67	0.62	2.44		15.5	24.36
12/05/86	64.67	0.60	2.33		15	23.28
01/06/87	64.91	0.66	2.61	87	16.5	26.12
02/05/87	65.36	0.57	1.21		14.25	12.13
03/05/87	68.04	0.68	0.84		17	8.38
04/03/87	75.59	0.83	0.49		20.75	4.89
05/05/87	84.22	1.65	359.11		41.25	3591.10
05/18/87	87.34	2.05	138.82		51.25	1388.21
06/03/87	87.15	1.70	449.57		42.5	4495.70
07/01/87	85.71	1.71	335.56		42.75	3355.63
08/06/87	83.96	1.30	3.44		32.5	34.40
09/02/87	84.83	1.30	3.31		32.5	33.14
11/04/87	84.47	1.30	4.15		32.5	41.47
12/03/87	84.19	1.40	3.74		35	37.45
01/08/88	84.06	1.50	6.28	88	37.5	62.81
02/05/88	84.05	1.45	3.98		36.25	39.77
03/04/88	84.07	1.65	4.85		41.25	48.55
04/04/88	83.98	1.70	5.03		42.5	50.28
05/09/88	83.68	1.60	3.68		40	36.75
06/03/88	83.83	1.55	2.80		38.75	27.96
07/01/88	85.11	1.75	3.92		43.75	39.17
08/05/88	85.36	1.70	4.12		42.5	41.16
09/02/88	85.22	1.75	4.63		43.75	46.28
10/07/88	85.91	1.70	5.30		42.5	53.05
11/04/88	85.62	1.87	12.59		46.75	125.92
12/02/88	84.08	1.90	2.25		47.5	22.48
01/06/89	84.00	1.95	3.51	89	48.75	35.07
02/03/89	83.80	1.70	4.31		42.5	43.13
03/03/89	83.92	2.15	4.46		53.75	44.61
04/07/89	83.33	1.95	4.11		48.75	41.08
05/05/89	83.22	1.85	4.63		46.25	46.28
06/02/89	83.29	1.87	4.11		46.75	41.08
06/29/89	84.87	2.05	5.56		51.25	55.57
07/28/89	85.08	2.10	4.82		52.5	48.17
08/31/89	86.07	2.25	4.26		56.25	42.65
09/29/89	86.15	2.15	2.55		53.75	25.52
10/27/89	85.79	2.17	5.20		54.25	52.03
12/01/89	83.86	2.22	3.70		55.5	37.00
12/21/89	83.71	2.25	3.82		56.25	38.24

Ute Reservoir Elevation, observation well and river discharge
Reservoir and observation well levels from worksheet STATEQUA.WK1
River discharge, 7–day geometric mean, Logan Station daily values file

DATE	UTE[1] (ft)	WELL[2] (ft)	RIVER (cfs)	YEAR	WELL (ft X 25)	RIVER (cfs X 10)
01/26/90	83.80	2.15	4.61	90	53.75	46.13
02/23/90	83.88	2.15	5.06		53.75	50.60
03/30/90	83.84	2.25	5.04		56.25	50.39
04/27/90	83.75	2.25	4.22		56.25	42.22
05/28/90	83.43	2.20	3.73		55	37.28
06/29/90	82.73	2.05	3.50		51.25	35.00
07/27/90	82.48	2.00	3.56		50	35.63
08/29/90	84.80	2.05	3.91		51.25	39.14
09/28/90	84.65	2.05	3.70		51.25	36.97
11/30/90	84.24	2.10				
12/21/90	84.03	2.07				
01/25/91	84.24	2.07		91		
02/28/91	84.25	2.25				
03/29/91	83.96	2.20				
04/26/91	83.80	2.25				
05/22/91	83.77					

1 Ute datum is 3700 above mean sea level (MSL); thus, on September 8, 1984, Ute reservior elevation was 3743.85 above MSL.

2 Well TW–1 datum is ground level, 3674.01 above MSL. Positive numbers are water levels above ground level; negative numbers are water levels below ground level.



Ute Dam enlargement was completed in '86
Enlarged dam spilled 5/16/87

Index to **TAB 12**: Aquifer test data

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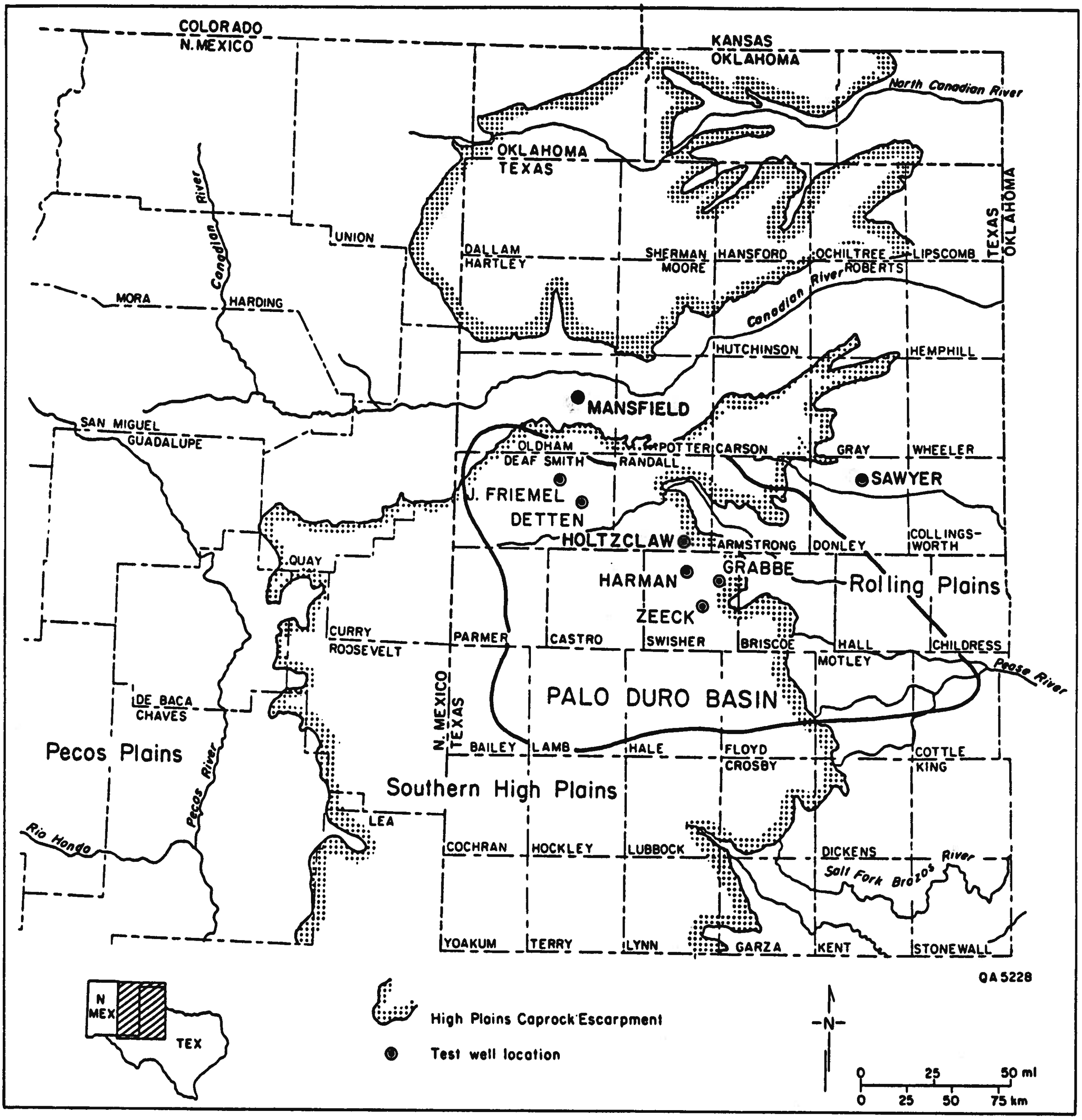

***Figure 1.** Locations of hydrologic test wells in salt-dissolution zones in the Palo Duro Basin.*

completely characterize salt-dissolution zones throughout the Palo Duro Basin.

Four wells were drilled for hydrologic testing and geochemical sampling of salt-dissolution zones in the Texas Panhandle: the Stone and Webster Engineering Corporation (SWEC) Sawyer No. 2, SWEC Mansfield No. 2, SWEC Detten No. 2, and SWEC Harman No. 1 wells (figs. 1 and 2). The objectives of field activities at these wells were to obtain and chemically analyze uncontaminated, representative samples of ground water from the salt-dissolution zones and to conduct drawdown and recovery tests to determine hydrologic properties. In addition, drill-stem tests in salt-dissolution zones at the SWEC Holtzclaw No. 1 and SWEC J. Friemel No. 1 test wells (figs. 1 and 2) were conducted to measure permeability and hydraulic head. Data from the SWEC

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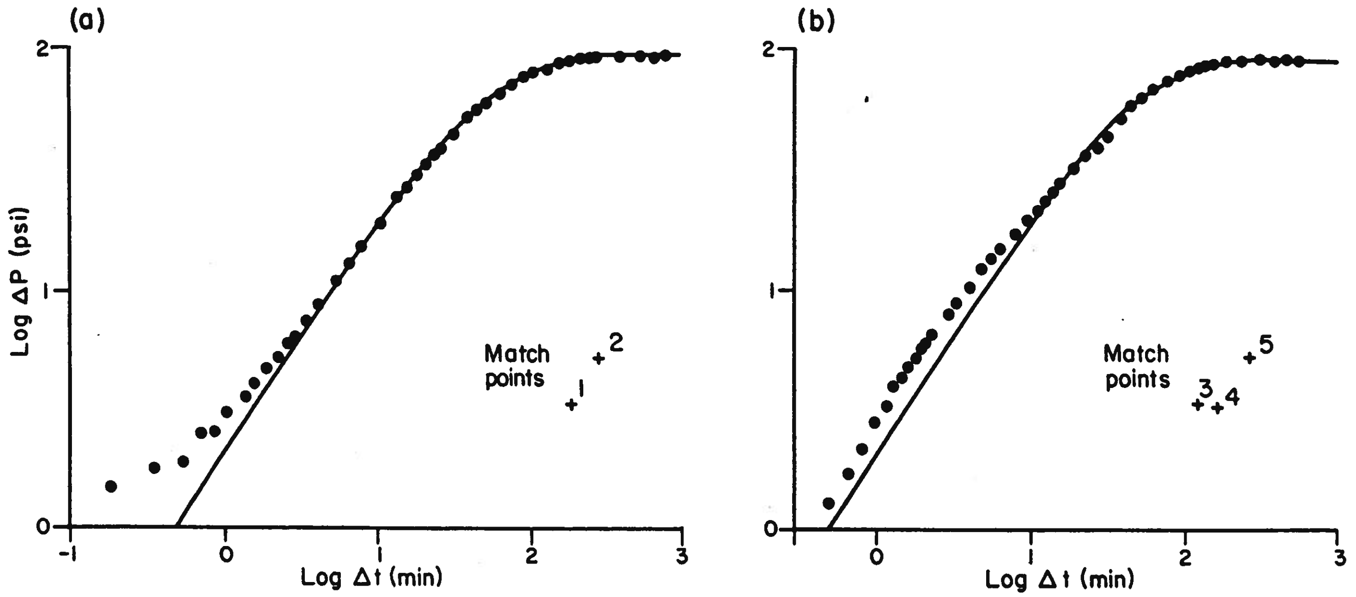

(c)

Type curve and test data match points

Match point	t_D	P_D	Δt (min)	ΔP (psi)	C_D	s
1	10^6	1	179	3.36	10^4	20
2	10^6	1	271	5.25	10^4	10
3	10^6	1	124	3.45	10^4	20
4	10^6	1	167	3.42	10^4	20
5	10^6	1	270	5.43	10^4	10

QA 7101

Figure 9. Logarithmic plots of hydrologic test data from the SWEC Sawyer No. 2 well. (a) Water-level drawdown data. (b) Water-level recovery data. (c) Type-curve and test-data match points. Results of calculations shown in table 2.

calculated and actual values of wellbore storage indicates that no open dissolution caverns are hydrologically continuous with the well. From equation 6,

$$C_D = \frac{CE_w}{2\pi nhr^2} = \frac{(0.794)\,(300{,}000)}{(2\pi)\,(0.3)\,(22)\,(0.2813)^2}$$

$$C_D = 10^{4.9}$$

The data trace matches type curves with C_D values of 10^4 to 10^5.

Hydraulic conductivity was calculated by matching a plot of test results with a type curve for radial flow to a well with wellbore storage and skin effects (Agarwal and others, 1970, fig. 1). Match points are shown in figure 9. The positive skin effect shown by the match possibly reflects partial penetration of the well into the unit 4 carbonate or partial penetration into the salt-dissolution zone, which includes the unit 4 carbonate and the overlying collapse breccia. Hydraulic conductivity was not estimated by the Jacob semilogarithmic approximation (Kruseman and De Ridder, 1976, p. 59-65) because wellbore storage influenced data throughout test duration.

Wellbore storage factor changed during the early part of the recovery period (fig. 9b) as a result of water draining out of the production tubing above the pump; the pump lacked a check valve. The match of a type curve with data from the recovery period is less certain than the match with drawdown data, but the results of both matches are similar (table 2).

SWEC Mansfield No. 2 well

Test data from drawdown and recovery periods at the SWEC Mansfield No. 2 well match type curves for slight wellbore storage and negative skin effects (fig. 10). Negative skin effect probably reflects the stimulation of fluid inflow that occurred during drilling and well

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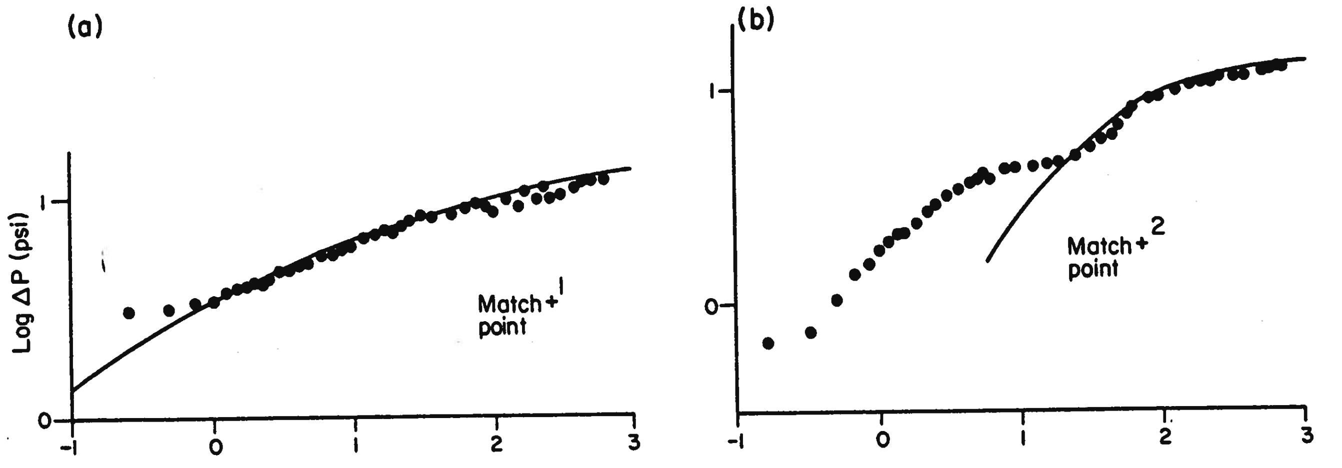

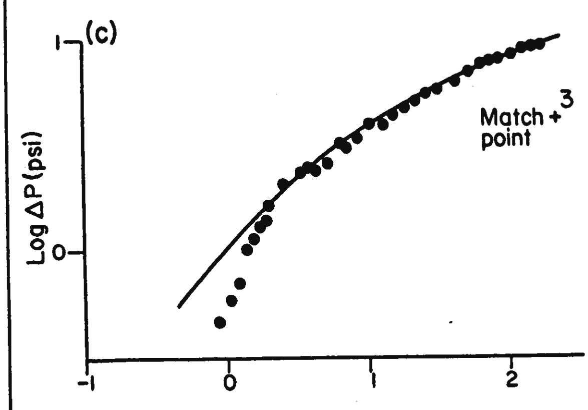

(d)

Type curve and test data match points

Match point	t_D	P_D	Δt (min)	ΔP (psi)	C_D	s
1	10^7	1	250	3.3	10^2	0
2	10^4	1	63	1.95	10^3	0
3	10^6	1	1,100	6.4	10^2	0
4	10^6	1	145	4.95	10^2	0
5	10^4	1	280	2.05	10^3	0

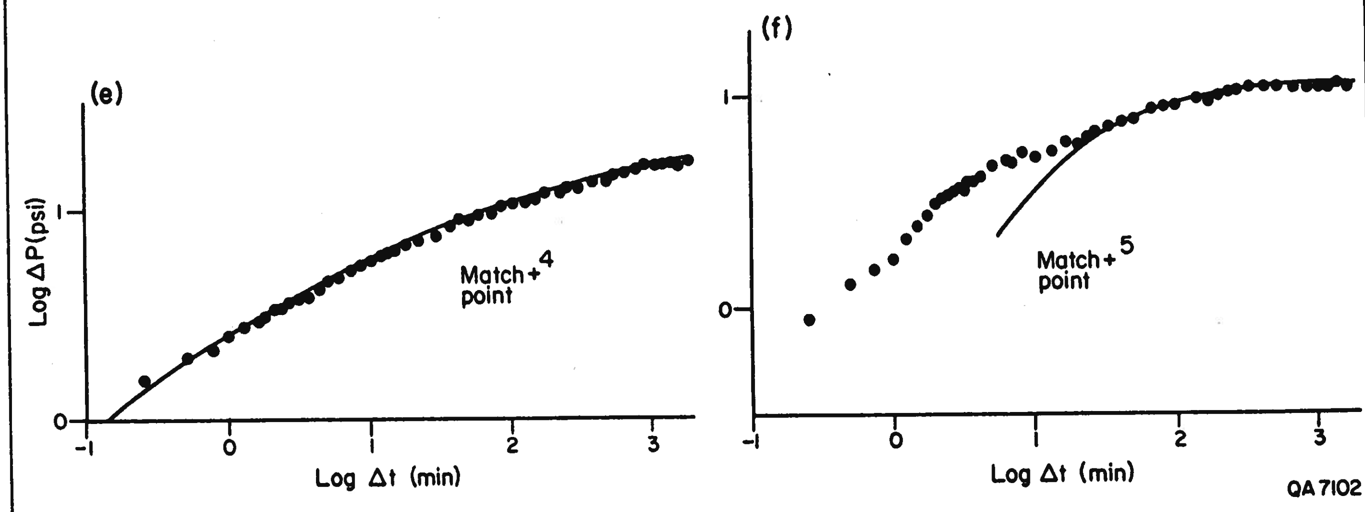

Figure 10. Logarithmic plots of hydrologic test data from the SWEC Mansfield No. 2 well. (a) Water-level drawdown data, test no. 1. (b) Water-level recovery data, test no. 1. (c) Water-level drawdown data, test no. 3. (d) Type-curve and test-data match points. (e) Water-level drawdown data, test no. 4. (f) Water-level recovery data, test no. 4. Results of calculations shown in table 2.

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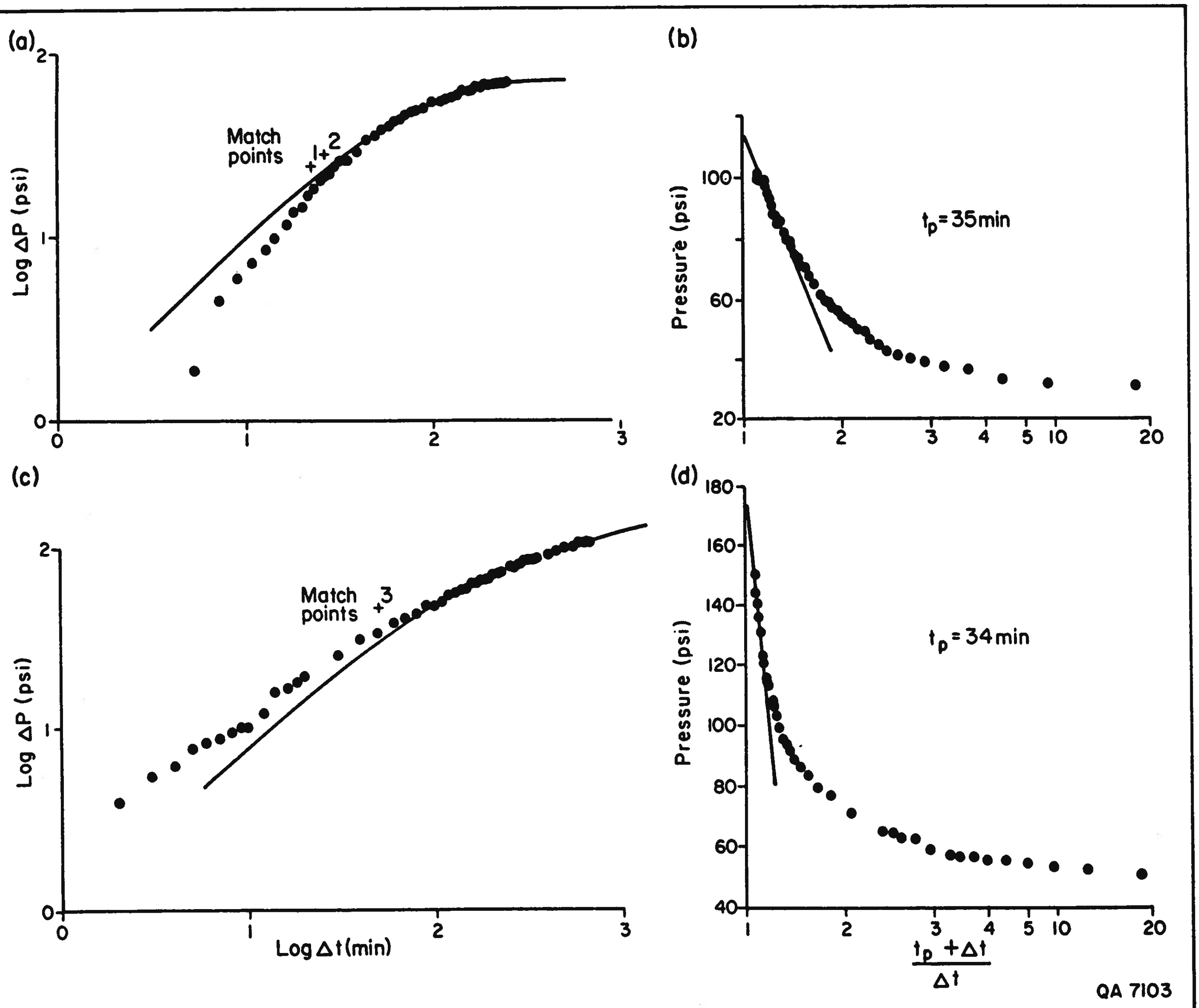

(e)

Type curve and test data match points

Match point	t_D	P_D	Δt (min)	ΔP (psi)	C_D	s
1	10^5	10	25	25	10^4	20
2	10^3	10	29.9	28.9	10^2	20
3	10^5	1	50	46.2	10^2	-5

Figure 11. Plots of pressure-buildup data from drill-stem tests in the Seven Rivers Formation (a and b) and the Salado and Tansill Formations (c and d) at the SWEC Holtzclaw No. 1 well. (e) Type-curve and test-data match points.

estimate is only about ±25 psi (±0.17 MPa) and accuracy of hydraulic head is only about ±50 ft (±15 m).

Data from the drill-stem test in the Salado and Tansill Formations at the SWEC Holtzclaw No. 1 well match a type curve (Agarwal and others, 1970, fig. 1) with a skin effect value of -5 (fig. 11c), indicating that fluid inflow was probably stimulated by an enlarged wellbore diameter caused by caving of the production interval. Calculated permeability is about 0.04 md (4×10^{-17} m^2), and hydraulic conductivity is about 2×10^{-4} ft/d (6×10^{-5} m/d). Formation-fluid pressure was extrapolated to be 175 psi (1.19 MPa) (fig. 11d); final shut-in pressure was 150 psi

Dutton, 1987

Table 2. Summary of hydrologic tests.

Test period	Q (m^3/d)	b (m)	P_D	ΔP (psi)	s/cycle (m)	T (m^2/d)	K (m/d)	Method
				SWEC Sawyer No. 2 well				
drawdown 1	58.875	6.71	1.0	5.25 & 3.36	-	2.4 to 3.6	0.4 to 0.6	type-curve match
recovery 2	58.875	6.71	1.0	5.43 & 3.42	-	2.3 to 3.7	0.4 to 0.6	type-curve match
				SWEC Mansfield No. 2 well				
drawdown 1	49.55	16.76	1.0	3.3	-	3.2	0.19	type-curve match
	49.55	16.76	-	-	2.83	3.2	0.19	Jacob approximation
recovery 1	49.55	16.76	1.0	3.7	-	2.8	0.34	type-curve match
	49.55	16.76	-	-	3.32	2.7	0.16	Theis approximation
drawdown 3	53.73	16.76	1.0	4.15	-	2.7	0.11	type-curve approximation
	53.73	16.76	-	-	3.25	3.0	0.18	Jacob approximation
drawdown 4	58.57	16.76	1.0	4.95	-	1.5	0.16	type-curve approximation
	58.57	16.76	-	-	3.38	3.2	0.19	Jacob approximation
recovery 4	58.57	16.76	1.0	2.47	-	5.0	0.4	type-curve approximation
	58.57	16.76	-	-	3.102	3.5	0.19	Theis approximation
				SWEC Holtzclaw No. 1 well: Seven Rivers Formation				
test 1	0.37	14.04	10.0	25.0	-	0.1	0.007	type-curve approximation
				SWEC Holtzclaw No. 1 well: Salado and Tansill Formations				
test 2	0.62	14.04	1.0	46.2	-	8×10^{-4}	6×10^{-5}	type-curve approximation

Q = flow rate; b = test-zone thickness; P_D = type-curve pressure match point; ΔP = data match point; s/cycle = straight-line slope on semilogarithmic plot; T = transmissivity; K = hydraulic conductivity

development, when a large amount of sand was produced, enlarging the test-zone diameter. The unit storage factor estimated from SWEC Mansfield No. 2 well diameter is

$$C = 0.975\ ft^3/psi = 0.442\ ft^3/ft$$

and the wellbore storage coefficient predicted from equation 6 is

$$C_D = 10^{4.6}$$

However, data traces best match type curves with C_D values of 10^1 to 10^2. This indicates that wellbore storage did not strongly influence water-level response rate during drawdown periods. Semilogarithmic approximation of the radial flow equation was used for data analysis because wellbore storage had only a small effect during the test. Water emptying from the production tubing into the wellbore early in recovery period also influenced test results at the SWEC Mansfield No. 2 well (fig. 10). The Jacob semilogarithmic method (Kruseman and De Ridder, 1976, p. 59-65) for analysis of long-term data was used to estimate transmissivity from plots of drawdown versus the logarithm of elapsed time; the Theis recovery method (Kruseman and De Ridder, 1976, p. 66–69) was used with data from recovery periods. Approximations from recovery data used a straight line segment of data from late in each test after the production tubing was drained. Estimates of hydraulic conductivity using data from different tests and different analytic methods are similar (table 2).

SWEC Holtzclaw No. 1 well

Figure 11a shows the match between a type curve (Agarwal and others, 1970, fig. 1) and pressure-buildup data from the drill-stem test in the Seven Rivers Formation at the SWEC Holtzclaw No. 1 well. The data best match a type curve with a skin effect value of +20. This positive skin value possibly reflects a damaged wellbore face that retards fluid inflow; this is common among drill-stem tests in low-permeability formations. Assuming the test interval equals the transmissive zone in the formation, calculated permeability is about 0.4 md ($4 \times 10^{-16}\ m^2$) and hydraulic conductivity is about 2×10^{-2} ft/d (7×10^{-3} m/d). The semilogarithmic plot (fig. 11b) of pressure data from the shut-in test suggests that undisturbed formation-fluid pressure is about 115 psi (0.78 MPa). The final shut-in pressure was 107 psi (0.74 MPa). Hydraulic head determined from the extrapolated pressure is 2,588 ft (788.8 m) msl, using the specific weight of drilling mud (0.535 psi/ft; 0.012 MPa/m) that flowed into the drill string. Because the drill-stem test data were influenced by wellbore storage (fig. 11a), accuracy of the extrapolated pressure

Index to **TAB 13**: Ground-water quality data for the study area

A. Tabulations which include more than one aquifer

Berkstresser and Mourant, 1966, Table 3 (parts)

HGC, 1984a, Appendix B, Table B.1 (parts)

HGC, 1984a, Appendix B, Whittemore report, Table 1, p. 172

B. Tabulations limited to aquifers in single geologic unit

1. Alluvium

USBR, 1984, (Hydrology/Hydrogeology Appendix), Tables 3-20

Analyses of samples collected 10/18/83 from 3 piezometers; much of data also on Table B.1, above; HGC, 1984a p. 162-164

Extracts of soil samples from tributaries, Ashby Lewis 1973 river survey

Analysis of a sample of alluvial sand collected in 1969 for chloride

Analyses of samples from piezometers drilled as part of USBR early work, from CRMWA files

2. Triassic aquifers

HGC, 1984a, Table 6

Analyses of samples collected 9/22/83 from 2 Triassic wells; much of data also on Table B.1, above; HGC, 1984a p. 159, 166

3. Brine aquifer

Summary of brine aquifer water quality data

4. Permian aquifers

Analysis of a sample collected 9/22/83 from Dripping Springs; much of data also on Table B.1, above; HGC, 1984a p. 158

TAB 13 Part A. Tabulations which include more than one aquifer

Berkstresser and Mourant, 1966

TABLE 3. CHEMICAL ANALYSIS OF WATER FROM WELLS AND SPRINGS IN QUAY COUNTY, N. MEX.

(Analyses by U.S. Geological Survey. Chemical constituents are in parts per million)

Explanation:

Location number: See explanation in text. (S) preceding number denotes spring in this table only. Depths are in feet below land surface. Reported depths are given to nearest foot. Measured depths are given to nearest tenth of a foot.

Stratigraphic unit: Qal, younger alluvium; Qc, upland cover of older alluvium; To, Ogallala Formation; Ks, Cretaceous sandstone and shale; Jm, Morrison Formation; Je, Entrada Sandstone; TRc, Chinle Formation; TRsr, Santa Rosa Sandstone; Pr, Permian rocks.

Location number	Owner, tenant, or name	Depth of well (feet)	Stratigraphic unit	Date collected	Temp. (°F)	Silica (SiO_2)	Iron (Fe) In solution	Iron (Fe) Total	Calcium (Ca)	Magnesium (Mg)	Sodium Potassium (Na) (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids Parts per million (ppm)	Dissolved solids Tons per acre-foot	Hardness as $CaCO_3$ Calcium magnesium	Hardness as $CaCO_3$ Noncarbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
5.27. 9.333	L. W. Barnhill	33.3	Qal	12-10-58	60	19	0.01	—	39	25	620	388	0	717	330	6.3	1.5	1950	2.65	200	0	87	19	2940	7.9
15.424	Dick Ballew	64.8	Qal, TRc	12-10-58	62	—	—	—	—	—	—	271	0	126	48	—	—	—	—	178	0	—	—	806	7.5
5.29. 6.222	L. L. Poe	125	To	7-27-54	—	69	—	—	33	25	32	220	0	35	22	2.0	2.3	328	.45	186	5	27	1.0	469	—
	L. L. Poe	125	To	9-18-56	62	—	—	—	—	—	—	209	0	40	24	—	—	—	—	202	30	—	—	481	7.8
6.444	L. L. Poe	50	To	9-25-52	—	60	—	—	52	23	46	217	0	69	46	2.0	4.0	409	.56	224	46	31	1.3	613	—
9.421	J. R. Gollehon	60	To	7-27-54	—	71	—	—	41	26	47	234	0	64	32	2.4	2.7	401	.55	210	18	33	1.4	560	—
	J. R. Gollehon	60	To	9-18-56	—	—	—	—	—	—	—	227	0	49	31	—	—	—	—	222	36	—	—	554	7.7
5.30. 1.212	C. F. Tatum	208.3	To	12-10-58	62	28	.03	—	42	21	33	228	0	37	19	2.2	4.7	299	.41	192	4	27	1.0	488	7.7
6.27.21.444	K. Y. Lawrence	153.3	To	8-24-55	60	—	—	—	—	—	—	192	0	35	25	—	—	—	—	186	28	—	—	443	7.4
6.28.21.132	T. J. Upton	100	To	12-9-58	—	—	—	—	—	—	—	200	0	42	31	—	—	—	—	199	35	—	—	484	7.7
7.28.21.224	L. O. Hudson	30.5	To	8-25-55	59	—	—	—	—	—	—	218	0	75	22	—	—	—	—	196	18	—	—	544	7.4
7.30.17.244	T. N. Lawson	525	TRc	4-25-55	66	—	—	—	—	—	—	257	0	1090	745	—	—	—	—	200	0	—	—	4610	8.0
7.31.25.341	Howard Waterfield	195	To	8-24-55	—	—	—	—	—	—	—	242	0	27	6	—	—	—	—	206	8	—	—	440	7.2
7.33.13.422	Clyde Queener	249	To	8-24-55	60	—	—	—	—	—	—	260	0	34	17	—	—	—	—	116	0	—	—	511	7.6
8.29.24.321	J. H. Wallis	155.5	TRc	5-23-55	63	—	—	—	—	—	—	363	0	1700	620	—	—	—	—	118	0	—	—	5560	7.3
29.443	Mrs. Florence Campbell	37.5	Qal	4-20-55	63	—	—	—	—	—	—	324	0	39	13	—	—	—	—	120	0	—	—	633	7.9
8.31. 7.331	Beck Bros.	440	TRc	12-10-58	57	—	—	—	—	—	—	778	0	461	212	—	—	—	—	13	0	—	—	2660	8.2
8.32. 7.114	R. H. McFarland	81.6	TRc	4-16-55	64	—	—	—	—	—	—	616	27	309	78	—	—	—	—	16	0	—	—	1840	8.9
8.34.17.244a	Roy Chapman	285	To, Ks	12-9-58	—	—	—	—	—	—	—	225	0	28	12	—	—	—	—	170	0	—	—	424	7.9
9.27. 3.111	Louis Kinkead	214.3	TRc	4-28-55	64	—	—	—	—	—	—	515	12	616	420	—	—	—	—	19	0	—	—	3320	8.4
9.27.36.240	Mr. Hortenstein	—	Ks	12-27-53	55	28	—	—	63	12	31	175	0	77	30	—	9.9	337	.46	206	63	25	—	528	—
9.28.17.244	Louis Kinkead	171.5	TRc	4-28-55	63	—	—	—	—	—	—	825	0	849	570	—	—	—	—	33	0	—	—	4470	8.2
23.212	Parker Cattle Co.	43.9	Qc	5-16-55	62	—	—	—	—	—	—	917	0	576	85	—	—	—	—	64	0	—	—	2660	7.5
9.29.11.122	I. J. Briscoe	33.8	Qc	12-10-58	—	—	—	—	—	—	—	420	0	45	31	—	—	—	—	319	0	—	—	848	7.9
9.32. 1.433	Mrs. Will Wallace	198.4	TRc	9-1951	—	5.7	—	—	46	15	1620	593	0	2540	390	3.1	2.6	4910	6.68	176	0	95	53	6670	—
9.35.33.231	L. M. Boney	100	Qal, TRc	12-9-58	—	—	—	—	—	—	—	417	0	266	82	—	—	—	—	104	0	—	—	1400	7.9
10.28.15.143	J. A. Kinkead	138.0	TRc	12-10-52	62	16	.02	—	16	8.7	212	388	14	120	44	1.0	7.8	631	.86	76	0	86	11	1000	8.2
10.29. 7.313	J. A. Kinkead	198.7	Jm	12-10-52	64	17	.01	—	34	26	218	499	0	217	20	1.0	1.0	779	1.06	192	0	71	6.8	1200	7.7
8.332	R. J. Kilgore	97.6	Jm	12-9-52	63	24	.03	—	62	47	53	346	0	112	36	1.4	11	516	.70	348	64	25	1.2	833	7.8
10.30. 7.424	A. H. Bugg	161.9	Je	12-9-52	62	21	.02	—	30	28	38	305	0	11	5	.7	3.6	287	.39	190	0	31	1.2	467	8.0
34.444	I. W. Parker	30	Qc	12-10-58	64	—	—	—	—	—	—	683	0	79	17	—	—	—	—	42	0	—	—	1190	8.1
10.31.12.333	C. L. O'Quinn	63	TRc	7-30-48	—	—	—	—	117	59	227	257	0	581	143	.9	11	1270	1.73	534	324	—	4.3	1820	—
36.333	State of N. Mex.	114.2	TRc	4-23-57	63	—	—	—	—	—	—	390	0	81	24	—	—	—	—	55	0	—	—	884	7.7
10.32.17.313	George Whitaker	112.1	TRc	10-8-48	—	—	—	—	2	3.7	431	636	49	267	53	—	1.2	1120	1.52	20	0	—	42	1760	—
19.212	Troy Whatley	124.8	TRc	4-23-57	63	—	—	—	—	—	—	599	0	352	73	—	—	—	—	80	0	—	—	1830	7.9
28.334	Troy Whatley	57.2	TRc	4-23-57	—	—	—	—	—	—	—	439	0	784	322	—	—	—	—	210	0	—	—	3110	7.5
10.34. 9.200	Village of San Jon	[a]55-100	Qal, TRc	11-17-54	—	14	—	—	27	9.3	414	552	0	277	174	4.4	8.3	1200	1.63	106	0	89	18	1880	—
10.233	Ernest Slade	270	TRc	12-8-58	—	12	.01	0.0	3.6	.0	424	460	57	184	187	1.4	.7	1100	1.50	9	0	99	61	1810	9.3
10.35. 5.222	Harry Whatley	24.2	TRc	12-8-58	—	—	—	—	—	—	—	355	0	65	52	—	—	—	—	63	0	—	—	906	7.7
21.211	Frank Morgan	104.1	TRc	11-15-54	63	—	—	—	—	—	—	869	0	1310	505	—	—	—	—	—	—	—	—	5170	—

TABLE 3. CHEMICAL ANALYSIS OF WATER FROM WELLS AND SPRINGS IN QUAY COUNTY, N. MEX. (cont)

Location number	Owner, tenant, or name	Depth of well (feet)	Stratigraphic unit	Date collected	Temp. (°F)	Silica (SiO_2)	Iron (Fe) In solution	Iron (Fe) Total	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids Parts per million (ppm)	Dissolved solids Tons per acre-foot	Hardness as $CaCO_3$ Calcium magnesium	Hardness as $CaCO_3$ Non-carbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
11.32. 8.113	Barton Ramsey	180	TRc	7-16-48	—	—	—	—	8.0	4.8	:060	816	81	1450	26	0	18	3030	4.12	40	0	—	74	4180	—
11.113	W. T. Hamman	125	TRc	10-13-48	—	—	—	—	7.5	6.3	564	340	9.8	501	308	—	23	1590	2.16	44	0	—	37	2550	—
	W. T. Hamman	125	TRc	4-26-57	—	—	—	—	—	—	461	322	0	891	458	—	—	—	—	835	571	—	—	3620	7.4
11.430	H. A. Askew	145	TRc	7-28-48	—	—	—	—	—	—	—	532	59	—	107	—	—	—	—	—	—	—	—	1870	—
13.130	M. H. Sours	—	TRc	7-28-48	—	—	—	—	—	—	—	548	31	—	252	—	—	—	—	—	—	—	—	3250	—
15.444	J. W. Williams	105	TRc	10-13-48	—	—	—	—	332	141	342	356	0	1670	80	—	9.5	2750	3.74	1410	1120	—	4.0	3290	—
17.343	Roy Foote	160	TRc	7-16-48	—	—	—	—	—	—	—	648	59	695	84	—	—	—	—	—	—	—	—	2740	—
19.442	Greer Cottingham	165	TRc	10-8-48	—	—	—	—	—	—	—	540	35	830	80	—	—	—	—	—	—	—	—	2750	—
20.121	G. M. Reading	164	TRc	7-16-48	—	—	—	—	—	—	—	876	30	2060	67	—	—	—	—	—	—	—	—	5270	—
21.311	Ellis Hall	—	TRc	10-13-48	—	—	—	—	2.5	1.3	453	528	61	348	71	—	.5	1200	1.63	12	0	—	58	1880	—
22.210	C. A. Carr	—	TRc	10-13-48	—	—	—	—	—	—	—	278	28	—	86	—	—	—	—	—	—	—	—	1530	—
23.443	Dan Kelly, Sr.	120	TRc	7-29-48	—	—	—	—	—	—	—	502	49	—	109	—	—	—	—	—	—	—	—	2260	—
24.211	Dan Kelly, Jr.	165	TRc	7-6-48	—	—	—	—	—	—	—	200	37	368	92	—	—	—	—	—	—	—	—	1550	—
27.330	Curt Graham	—		12-27-54	—	—	—	—	—	—	736	411	0	1580	600	4.5	75	—	—	1300	963	55	8.9	5240	—
28.434	Blevins McKenzie	145	TRc	10-8-48	—	—	—	—	—	—	—	658	45	1210	414	—	—	—	—	—	—	—	—	3530	—
28.434a	Blevins McKenzie	180	TRc	4-26-57	—	—	—	—	—	—	836	685	0	687	415	—	—	—	—	44	0	—	—	3610	8.1
34.442	J. B. Routh	76.2	TRc	10-8-48	—	—	—	—	1.5	.5	285	420	51	121	50	—	.3	716	.97	6	0	—	53	1180	—
11.33.12.241	Frank Smith	60	TRc	12-9-58	—	—	—	—	—	—	—	415	0	227	148	—	—	—	—	271	0	—	—	1560	7.7
11.35. 5.300	Mrs. B. L. Dunshee	—	TRc	3-31-52	—	—	—	—	—	—	427	225	19	1400	970	—	8.0	—	—	2120	1900	30	4.0	4970	7.7
11.37.17.321	Fred Brownlee	264.0	TRc	12-8-58	—	15	.06	.88	45	38	239	496	0	215	111	1.0	.1	908	1.23	269	0	66	6.3	1440	7.6
12.30.32.240	Fred Horne	—	Je	7-14-48	—	—	—	—	—	—	—	328	0	—	120	—	29	—	—	—	—	—	—	1530	—
32.240	L. C. Strawn	—	Je	7-14-48	—	—	—	—	—	—	—	272	20	—	130	—	12	—	—	—	—	—	—	1580	—
33.110	A. B. Roberts	30	Je	7-14-48	—	—	—	—	81	32	187	198	22	363	108	.6	13	904	1.23	334	135	—	4.5	1370	—
34.230	Henry Batterman	—	Je	10-11-48	—	—	—	—	64	88	577	396	12	1060	212	—	36	2240	3.05	522	178	—	11	3190	—
34.310	Jim Cupp	—	—	7-29-48	—	—	—	—	—	—	—	342	0	745	158	—	—	—	—	—	—	—	—	2320	—
35.140	Frank McCauley	—	Qal	7-29-48	—	—	—	—	—	—	—	824	0	—	236	—	—	—	—	—	—	—	—	3970	—
12.32. 1.442b	M. G. Cottingham	278.2	TRsr	6-10-54	64	—	—	—	—	—	—	438	0	240	146	—	—	—	—	—	—	—	—	1580	—
	M. G. Cottingham	278.2	TRsr	4-26-57	63	—	—	—	—	—	—	362	0	254	166	—	—	—	—	308	12	—	—	1570	7.5
20.422	E. V. Felkner	213.1	TRc	4-26-57	63	—	—	—	—	—	—	340	0	196	66	—	—	—	—	392	114	—	—	1040	7.5
12.33.17.311	Eddie Watson	76.8	TRc	4-26-57	64	—	—	—	—	—	—	342	0	167	81	—	—	—	—	252	0	—	—	1090	7.4
12.34.11.344	H. B. Molyneaux	310	TRc, TRsr	12-8-58	63	—	—	—	—	—	—	817	0	326	342	—	—	—	—	746	76	—	—	2630	7.4
36.444b	L. C. Jackson	42	Qal, TRc	5-21-53	—	—	—	—	—	—	—	396	0	656	330	—	—	—	—	—	—	—	—	2660	—
36.444c	L. C. Jackson	36	Qal, TRc	5-21-53	—	—	—	—	—	—	—	341	13	184	96	—	—	—	—	—	—	—	—	1180	—
12.35. 2.111	Griffin, Trew and Cooper	167.1	TRc	12-9-58	62	—	—	—	—	—	—	884	0	637	20	—	—	—	—	1180	456	—	—	2130	7.1
35.424	T. G. Rose	15.2	Qal	12-9-58	59	—	—	—	—	—	—	545	0	1300	302	—	—	—	—	465	18	—	—	3980	8.0
12.37.30.133	R. L. Martin	225	TRsr	12-8-58	—	—	—	—	—	—	—	404	0	604	20	—	—	—	—	858	527	—	—	1570	7.3
13.31. 1.124	R. R. Sims	50	Qal, TRc	7-19-54	62	—	—	—	—	—	—	400	0	308	167	—	—	—	—	—	—	—	—	1620	—
S13.32.1.434	—	—	TRc	3-9-57	—	—	—	—	—	—	—	224	0	79	19	—	—	—	—	270	86	—	—	611	7.8
13.33.11.322	C. R. I. and P. RR.	240.8	TRsr	2-25-55	63	27	—	1.4	109	32	54	314	0	170	51	.6	3.6	601	.82	404	146	21	—	932	7.4
13.34.13.234	Griffin, Trew and Cooper	231	TRsr	12-9-58	63	—	—	—	—	—	—	588	0	886	184	—	—	—	—	1260	778	—	—	2640	7.4

Berkstresser and Mourant, 1966

Berkstresser and Mourant, 1966

TABLE 3. CHEMICAL ANALYSIS OF WATER FROM WELLS AND SPRINGS IN QUAY COUNTY, N. MEX. (cont)

Location number	Owner, tenant, or name	Depth of well (feet)	Strati-graphic unit	Date collected	Temp. (°F)	Silica (SiO_2)	Iron (Fe) In solution	Iron (Fe) Total	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids Parts per million (ppm)	Dissolved solids Tons per acre-foot	Hardness as $CaCO_3$ Calcium magnesium	Hardness as $CaCO_3$ Non-carbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
13.36.27.332	A. C. Ward	167.2	T̄R sr	6-22-55	—	—	—	—	—	—	—	—	333	0	71	19	—	—	—	—	180	0	—	—	697	7.1
14.34. 5.422	Bonnie Gallegos	120.0	Qc	6-10-54	62	—	—	—	—	—	—	—	274	0	98	39	—	—	—	—	—	—	—	—	761	—
16.111	Taylor Litton	97.2	Qc	6-10-54	62	—	—	—	—	—	—	—	255	0	117	24	—	—	—	—	—	—	—	—	677	—
14.35.16.131	Pyle Ranch	150.5	Qc, T̄R sr	5-6-54	—	—	—	—	—	—	—	—	263	0	39	16	—	—	—	—	—	—	—	—	532	—
S14.35.34.343	Pyle Ranch	—	T̄R sr	3-8-57	62	—	—	—	—	—	—	—	249	0	40	9	—	—	—	—	233	29	—	—	491	7.6
S14.35.35.311	Pyle Ranch	—	T̄R sr	3-8-57	64	—	—	—	—	—	—	—	240	0	—	8	—	—	—	—	215	18	—	—	463	7.5
14.36. 4.111	Pyle Ranch	168.4	Qc	6-29-54	—	—	—	—	—	—	—	—	256	0	39	29	—	—	—	—	—	—	—	—	552	—
11.122	Pyle Ranch	175	Qc, T̄R sr	5-13-54	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	583	—
12.122	Pyle Ranch	165	Qc, T̄R sr	5-13-54	65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	621	—
25.133	Pyle Ranch	80	T̄R sr	5-13-54	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	578	—
28.234	Pyle Ranch	72.7	T̄R sr	5-13-54	63	—	—	—	—	—	—	—	228	0	29	28	—	—	—	—	—	—	—	—	534	—
14.37. 6.311	E. A. Stringfellow	190.0	Qc, T̄R sr	5-13-54	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	854	—
6.324	E. A. Stringfellow	220	Qc, T̄R sr	5-13-54	—	—	—	—	—	—	—	—	232	0	47	39	—	—	—	—	—	—	—	—	593	—
30.121	Pyle Ranch	40	T̄R sr	5-13-54	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	459	—
S14.37.31.211	Ollie Mae Pyle	—	T̄R sr	3-31-54	59	26	—	—	—	—	—	38	266	0	47	26	1.4	14	—	—	236	18	26	1.1	591	—
15.34.22.311	Huston McCarty	60	To	6-10-54	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	493	—
30.312	Gallegos Estate	32	To	6-3-54	—	—	—	—	—	—	—	—	242	0	54	28	—	—	—	—	—	—	—	—	567	—
32.241	—	68.5	To	6-10-54	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	560	—
15.35.14.211	Pyle Ranch	290	To	5-19-54	62	—	—	—	—	—	—	—	248	0	46	30	—	—	—	—	—	—	—	—	571	—
15.222	Mrs. Mae Cobb	190	To	5-22-53	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	593	—
22.133	Pyle Ranch	92.6	To	5-5-54	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	605	—
35.411	Pyle Ranch	140	To, T̄R sr	5-6-54	63	—	—	—	—	—	—	—	227	0	75	47	—	—	—	—	—	—	—	—	671	—
15.36.14.144	E. A. Jones	60	To	4-6-54	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	545	—
15.37. 6.311	I. L. McAlister	131.1	To	6-11-54	—	—	—	—	—	—	—	—	260	0	150	69	—	—	—	—	—	—	—	—	878	—
30.112	Ira Ward	34.6	Qal, Qc	4-7-54	60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	826	—
16.34. 1.224	Rock Bros.	228.7	To	6-25-54	—	—	—	—	—	—	—	—	205	0	19	84	—	—	—	—	—	—	—	—	658	—
28.211	Rinestine Bros.	140	To	12-9-58	61	29	.07	.74	39	18	—	68	170	0	80	61	1.3	8.6	394	.53	172	32	46	2.3	640	7.7
16.36. 6.211	R. C. Cline	144.9	To	5-5-54	61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	432	—
6.441	S. H. Fort	110	To	5-5-54	61	—	—	—	—	—	—	—	192	0	31	45	—	—	—	—	—	—	—	—	528	—
14.134	Frank Sharman	107.9	To	6-11-54	—	—	—	—	—	—	—	—	198	0	20	15	—	—	—	—	—	—	—	—	396	—
16.37. 6.121	Fred Coots	65.5	Qal, To	4-1-54	63	—	—	—	—	—	—	—	270	0	—	22	—	—	—	—	—	—	—	—	573	—
S16.37.18.412	R. C. Bell	—	Qal	5-22-53	—	—	—	—	—	—	—	—	209	0	29	24	—	—	—	—	—	—	—	—	452	—
17.34.11.122	Addison Cammack	210	To, Ks	10-12-53	62	51	—	—	48	36	—	28	240	0	23	64	.4	20	388	.53	268	72	18	—	659	—
20.422	Harold Kauffman	180	To	6-28-54	62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	454	—
26.234	Cecil Burks	245	To	6-25-54	—	—	—	—	—	—	—	—	255	0	15	7	—	—	—	—	—	—	—	—	459	—
30.244	Mr. Redinbaugh	160	To	6-28-54	62	—	—	—	—	—	—	—	218	0	47	50	—	—	—	—	—	—	—	—	591	—
30.343	Cecil Burks	200	To	6-28-54	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	720	—

[a] Composite sample of 7 wells. [b] Depth when sampled.

HGC, 1984a

Table B.1: Explanation

a. Type:
W = Well
S = Surface Water
Sp = Spring

b. Formation:
P116 = Piezometer 1, 16 ft depth
P122 = Piezometer 1, 22 ft depth
P222 = Piezometer 2, 22 ft depth
P240 = Piezometer 2, 40 ft depth
P255 = Piezometer 2, 55 ft depth
P320 = Piezometer 3, 20 ft depth
P335 = Piezometer 3, 35 ft depth
P415 = Piezometer 4, 15 ft depth
P421 = Piezometer 4, 21 ft depth
P621 = Piezometer 6, 21 ft depth
P631 = Piezometer 6, 31 ft depth
P650 = Piezometer 6, 50 ft depth
Rev = Revuelto Creek
CaSL = Canadian River at State Line
CaTa = Canadian River at Tascosa
CaAm = Canadian River at Amarillo
CaLM = Lake Meredith
Tr = Triassic
PSA = San Andres
PY = Yeso
PW = Wolfcampian

c. Source:
1 = Collected this study
2 = USGS WATSTORE
3 = Water resources data for New Mexico and Texas, various years
4 = Berkstresser and Mourant, 1966
5 = Bureau of Reclamation files
6 = Griggs and Hendrickson, 1951
7 = Bassett and Bentley, 1983

HGC, 1984a

Table B.1: Selected water-quality analyses of Canadian River and groundwater within and near study area

Location	Type[a]	Date	Fm.[b]	S°	T	pH	S.C.	TDS	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	Fe	F
		Canadian River Channel Piezometers																	
13.33.15.130	W	5/23/83	P116	5	-1	7.9	22500	14736	357	128	5920	21.1	467	0.0	350	6920	0.0	0.0	0.44
13.33.15.130	W	5/23/83	P122	5	-1	7.8	24500	15246	341	126	6160	19.6	634	0.0	830	6760	0.0	0.0	0.49
13.33.14.210	W	5/23/83	P222	5	-1	7.8	24000	15779	365	148	5600	10.6	560	0.0	925	6600	0.0	0.0	0.58
13.33.14.210	W	5/23/83	P240	5	-1	7.9	26000	16037	418	145	5920	23.2	461	0.0	980	7360	0.0	0.0	0.59
13.33.14.210	W	5/23/83	P255	5	-1	8.0	24000	14530	352	164	5200	19.3	457	0.0	1045	6600	0.0	0.0	0.58
13.33.14.210	W	7/07/83	P255	5	-1	7.6	21000	15500	413	129	5370	35.2	362	0.0	949	8280	0.0	0.0	0.10
13.33.14.240	W	10/18/83	P255	4	17	7.0	21000	14273	360	130	4800	19.0	255	0.0	920	7788	0.4	-1	-1
13.33.12.230	W	5/23/83	P320	5	-1	8.1	26000	15564	237	172	5920	23.6	455	0.0	1375	6840	0.0	0.0	0.78
13.33.12.230	W	5/23/83	P335	5	-1	8.2	39500	22947	439	205	8360	31.0	580	0.0	1720	10720	0.0	0.0	0.40
13.33.12.230	W	10/18/83	P335	4	18	6.9	38300	24714	420	170	8700	28.0	520	0.0	1600	13275	0.4	-1	-1
13.33.12.410	W	5/23/83	P415	5	-1	7.9	16500	11145	303	148	3536	15.5	516	0.0	960	5200	0.0	0.0	0.27
13.33.12.410	W	5/23/83	P421	5	-1	8.0	21000	12644	203	129	4980	19.9	565	0.0	1200	5320	0.0	0.0	0.36
13.34.05.120	W	5/23/83	P621	5	-1	8.2	12800	7573	91	50	2792	13.8	666	0.0	560	3720	0.0	0.0	0.67
13.34.05.120	W	5/23/83	P631	5	-1	7.9	23000	13521	255	149	5260	28.2	588	0.0	970	5920	0.0	0.0	0.31
13.34.05.120	W	5/23/83	P650	5	-1	7.7	30100	19135	456	163	7720	43.2	555	0.0	1285	8160	0.0	0.0	0.43
13.34.05.120	W	7/07/83	P650	5	-1	7.2	26700	20600	496	178	7090	62.6	654	0.0	1550	10600	0.0	0.0	0.10
13.34.05.120	W	10/18/83	P650	4	18	6.6	30500	20783	580	145	6900	35.0	849	0.0	1440	10832	0.4	-1	-1
		Revuelto Creek																	
13.33.21.13	S	10/ 1/59	Rev	3	-1	7.8	890	590	74	17	104	0.0	266	0.0	222	25	0.8	-1	-1
13.33.21.13	S	1/ 1/60	Rev	3	-1	7.9	1580	1060	77	24	254	0.0	284	0.0	455	96	2.1	-1	-1
13.33.21.13	S	3/ 6/60	Rev	3	-1	7.8	2290	1540	72	40	407	0.0	314	0.0	579	258	1.6	-1	-1
13.33.21.13	S	7/ 7/60	Rev	3	-1	8.0	565	363	30	5.6	91	0.0	246	0.0	76	15	1.8	-1	-1
13.33.21.13	S	10/26/60	Rev	3	-1	7.8	1540	1030	63	28	252	0.0	268	0.0	455	87	0.4	-1	-1
13.33.21.13	S	4/23/61	Rev	3	-1	7.7	3110	1910	74	59	544	0.0	458	0.0	478	515	0.8	-1	-1
13.33.21.13	S	10/26/61	Rev	3	-1	7.7	1340	889	76	30	183	0.0	232	0.0	397	75	0.4	-1	-1
13.33.21.13	S	6/12/62	Rev	3	-1	8.2	1990	1360	65	27	362	0.0	300	0.0	624	115	0.8	-1	-1
13.33.21.13	S	11/ 8/62	Rev	3	-1	7.7	2680	1620	76	31	477	0.0	344	0.0	352	502	0.3	-1	-1
13.33.21.13	S	2/15/63	Rev	3	-1	7.9	1920	1300	72	40	313	0.0	278	0.0	607	115	2.3	-1	-1
13.33.21.13	S	7/ 7/63	Rev	3	-1	8.0	1060	696	49	16	157	0.0	208	0.0	321	34	1.3	-1	-1
13.33.21.13	S	10/ 1/63	Rev	3	-1	7.4	1240	854	89	31	148	0.0	218	0.0	418	48	0.3	-1	-1
13.33.21.13	S	3/ 1/64	Rev	3	-1	8.1	2330	1530	78	43	393	0.0	312	0.0	598	254	1.3	-1	-1
13.33.21.13	S	11/18/64	Rev	3	-1	8.1	1660	1100	32	17	319	0.0	276	0.0	484	75	6.9	-1	-1
13.33.21.13	S	6/26/65	Rev	3	-1	8.0	662	416	20	4.6	122	0.0	227	0.0	119	21	0.2	-1	-1
13.33.21.13	S	1/10/66	Rev	3	-1	8.2	3680	2150	66	43	680	0.0	424	0.0	374	765	0.2	-1	1
13.33.21.13	S	10/ 2/66	Rev	3	-1	8.1	2240	1350	61	31	390	0.0	314	0.0	362	344	0.1	-1	0.6
13.33.21.13	S	7/26/67	Rev	3	-1	8.0	565	351	40	10	75	0.0	267	0.0	66	10	4.1	-1	0.6
13.33.21.13	S	1/15/68	Rev	3	-1	8.0	1920	1310	80	45	305	0.0	290	0.0	590	137	1.0	-1	0.9
13.33.21.13	S	5/10/68	Rev	3	-1	7.4	988	632	60	18	135	5.4	234	0.0	256	29	2.7	80	0.5
13.33.21.13	S	12/ 2/68	Rev	3	-1	8.1	2460	1560	75	43	421	0.0	316	0.0	504	350	0.2	-1	1.0
13.33.21.13	S	9/ 8/69	Rev	3	-1	7.6	1010	709	51	18	170	0.0	203	0.0	287	72	0.1	-1	0.7
13.33.21.13	S	7/16/70	Rev	3	-1	8.1	1310	871	75	33	171	7.6	188	0.0	360	120	3.6	-1	0.8
13.33.21.13	S	8/13/71	Rev	3	-1	7.9	5320	2940	91	55	910	7.4	233	0.0	550	1200	-1	-1	0.6
13.33.21.13	S	3/ 7/72	Rev	3	-1	8.4	4240	2530	55	45	830	0.0	349	7.0	500	900	-1	-1	1.0
13.33.21.13	S	6/12/72	Rev	3	-1	7.7	1680	1110	60	27	260	7.3	145	0.0	540	130	-1	-1	0.6

Table B.1: Continued

Location	Type[a]	Date	Fm.[b]	S[c]	T	pH	S.C.	TDS	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	Fe	F
07227900	S	2/15/73	CaLM	4	-1	-1	-1	942	56	23	250	-1.0	206	0.0	250	250	-1	-1	0.8
07227900	S	5/ 3/73	CaLM	4	-1	-1	-1	960	61	26	240	6.1	212	0.0	250	270	-1	-1	0.8
07227900	S	6/14/73	CaLM	4	-1	-1	-1	972	62	26	250	6.1	214	0.0	260	260	-1	-1	0.6
07227900	S	10/18/73	CaLM	4	-1	-1	-1	1030	59	27	260	6.6	212	0.0	280	280	-1	-1	0.8
07227900	S	1/ 4/74	CaLM	4	-1	-1	-1	1060	64	27	280	8.1	218	0.0	280	290	-1	-1	-1.0
07227900	S	5/ 1/74	CaLM	4	-1	-1	-1	1050	63	28	280	6.6	217	0.0	270	290	-1	-1	-1.0
07227900	S	7/18/74	CaLM	4	-1	-1	-1	1070	55	28	280	8.1	208	0.0	280	310	-1	-1	-1.0
07227900	S	1/22/75	CaLM	4	-1	-1	-1	1080	56	29	280	6.9	202	4.0	300	300	-1	-1	0.8
07227900	S	5/28/75	CaLM	4	-1	-1	-1	1100	59	30	290	7.9	219	0.0	290	310	-1	-1	0.9
07227900	S	9/ 9/75	CaLM	4	-1	-1	-1	1040	58	28	280	7.8	198	0.0	280	290	-1	-1	0.8
07227900	S	1/21/76	CaLM	4	-1	-1	-1	1090	58	29	290	7.2	211	0.0	290	310	-1	-1	0.9
07227900	S	5/ 5/76	CaLM	4	-1	-1	-1	1150	61	30	300	7.5	204	8.0	300	340	-1	-1	0.9
07227900	S	8/24/76	CaLM	4	-1	-1	-1	1150	58	30	300	7.8	202	4.0	310	340	-1	-1	0.9
07227900	S	1/14/77	CaLM	4	-1	-1	-1	1120	59	30	300	8.2	206	4.0	270	330	-1	-1	0.9
07227900	S	1/ 5/78	CaLM	4	-1	-1	-1	1100	63	31	300	8.8	210	0.0	280	330	-1	-1	0.9
07227900	S	12/29/78	CaLM	4	6	-1	1840	1060	44	27	290	8.0	190	0.0	280	310	-1	-1	0.8
07227900	S	2/ 4/80	CaLM	4	5	-1	1910	1160	49	28	330	7.8	190	0.0	300	350	-1	-1	0.8
07227900	S	2/13/81	CaLM	4	7	-1	2140	1250	57	33	350	6.6	180	0.0	300	390	-1	-1	0.8
07227900	S	12/29/81	CaLM	4	6	-1	1530	906	46	21	250	5.8	160	0.0	210	270	-1	-1	0.7
		Triassic Wells																	
10.28.15.143	W	12/10/52	Tr	1	17	8.2	1000	631	16	8.7	212	-1	388	14	120	44	7.8	-1	1
10.31.12.333	W	7/30/48	Tr	1	-1	-1	1820	1270	117	59	227	-1	257	0	581	143	11.0	-1	0.9
10.32.17.313	W	10/ 8/48	Tr	1	-1	-1	1760	1120	2	3.7	431	-1	636	49	267	53	1.2	-1	-1
10.34.10.233	W	12/ 8/58	Tr	1	-1	9.3	1810	1100	3.6	0.0	424	-1	460	57	184	187	.7	0	0.7
11.30. 3.341	W	10/11/48	Tr	1	-1	-1	871	531	25	29	136	-1	372	0	125	26	6.5	-1	-1
11.31. 1.424	W	7/15/48	Tr	1	-1	-1	2130	1410	3	2.4	518	-1	504	49	494	92	.7	-1	1.9
11.31.14.113	W	7/14/48	Tr	1	-1	-1	4890	3310	13	6.3	1200	-1	824	75	1100	510	2.9	-1	0.9
11.31.19.143	W	9/27/48	Tr	1	-1	-1	1680	1050	29	43	307	-1	572	7.9	249	116	16.0	-1	-1
11.31.20.442	W	10/12/48	Tr	1	-1	-1	5520	3900	9.5	4.5	1370	-1	824	49	1760	300	2.9	-1	-1
11.31.22.122	W	10/13/48	Tr	1	-1	-1	1270	1070	82	54	304	-1	88	0	555	31	.1	-1	-1
11.31.23.330	W	10/13/48	Tr	1	-1	-1	3970	2670	5	5.0	970	-1	852	59	968	238	1.8	-1	-1
11.37.17.321	W	12/08/58	Tr	1	-1	7.6	1440	908	45	38	239	-1	496	0	215	111	-1	.06	1
13.32.01.000	Sp	9/21/83	Tr	4	19.4	7.5	570	456	61	21	23	3.5	229	0	60	23	9.3	-1	-1
13.33.01.000	W	9/22/83	Tr	4	18.0	7.0	1610	1375	210	85	49	4.9	355	0	600	42.5	1.3	-1	-1
13.33.24.000	W	9/22/83	Tr	4	18.0	6.9	2800	2122	140	190	205	7.1	761	0	548	255	0.4	-1	-1
13.33.11.322	W	2/25/55	Tr	1	17.0	7.4	932	404	109	32	54	-1	314	0	170	51	3.6	1.4	0.6
14.32.26.424	W	3/26/63	Tr	2	16.0	7.9	814	-1	69	31	-1	-1	220	0	-1	59	-1	-1	-1
14.32.26.423	W	3/26/63	Tr	2	14.0	7.8	843	511	65	35	59	3.2	220	0	140	60	-1	-1	1.6
14.31. 3.422	W	4/10/70	Tr	2	18.0	7.5	517	363	56	31	-1	-1	320	0	56	3.8	-1	-1	0.8
16.26.01.140	W	10/15/47	Tr	6	-1	-1	1400	912	33	34	265	-1	612	0	180	72	9.7	-1	0.3
17.26.07.300	W	10/15/47	Tr	6	-1	-1	1510	973	30	31	279	-1	445	0	303	80	17.0	-1	1.2
17.27.10.100	W	10/15/47	Tr	6	-1	-1	7110	411	58	34	49	-1	338	0	60	26	17.0	-1	0.4

HGC, 1984a

HGC, 1984a

Table B.1: Continued

Location	Type[a]	Date	Fm.[b]	S°	T	pH	S.C.	TDS	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	Fe	F
Permian Wells																			
Water wells in San Miguel County																			
11.15.21.110	W	9/26/47	Psa	6	-1	-1	511	295	68	22	14	-1	302	0.0	19	6	17.0	-1	0.4
12.12.04.110	W	8/04/47	Py	6	-1	-1	2550	2350	486	135	18	-1	152	0.0	1610	4	0.2	-1	0.3
12.12.11.200	W	8/06/47	Py	6	-1	-1	723	475	67	28	60	-1	331	0.0	130	3	0.3	-1	0.3
12.12.36.100	W	10/24/47	Py	6	-1	-1	1990	1720	351	91	43	-1	186	0.0	1130	9	0.3	-1	0.2
12.14.22.110	W	8/08/47	Py	6	-1	-1	575	374	92	12	18	-1	294	0.0	26	11	42.0	-1	0.2
13.12.26.200	W	10/22/47	Py	6	-1	-1	533	322	46	32	24	-1	218	0.0	102	6	4.2	-1	0.5
15.12.33.100	W	5/20/47	Py	6	-1	-1	1040	645	2	3.4	247	-1	469	0.0	113	35	0.1	-1	1.5
16.12.16.300	W	7/24/47	Pm	6	-1	-1	358	202	60	8.4	3.9	-1	185	0.0	34	3.5	0.7	-1	0.0
18.15.27.100	W	6/20/47	Pm	6	-1	-1	539	334	42	12	76	-1	330	0.0	37	5	0.0	-1	0.8
Ray No 1 Hoover Well																			
11.28.30.232	W	12/11/51	P	1	-1	-1.	10000	7100	890	102	1510	-1	994	-1	1840	2270	-1	-1	-1
Dripping Springs Well																			
13.31.25.120	W	9/22/83	M/P	4	22.8	6.0	70650	80948	1360	610	29000	64	904	0.0	5250	43719	0.4	-1	-1
Well OW-3																			
13.33.15.130	W	7/19/83	P/Tr	5	18.5	-1	50000	49180	792	245	19640	62.9	887	0.0	2810	26800	-1	0.47	0.7
13.33.15.130	W	10/17/83	P/Tr	4	19.0	6.4	69000	49072	800	220	17500	75.0	159	0.0	2880	27435	0.4	-1	-1
Well OW-4																			
13.33.15.130	W	7/19/83	P/Tr	5	17.5	-1	49600	36406	624	182	17940	51.7	830	0.0	2660	19700	-1	0.83	-1
Well DH-2																			
13.34.07.230	W	5/06/83	P/Tr	5	-1	-1	17500	11985	449	102	4240	54.8	1280	0.0	1450	5760	2.8	1.34	0.6
13.34.07.230	W	7/19/83	P/Tr	5	18.0	-1	17800	21138	384	96	7880	36.8	1076	0.0	1710	6580	-1	0.19	0.5
Wells in Wolfcamp aquifer in Texas																			
0258000	W	0/00/00	PW	7	45.6	6.8	-1	164026	1100	1069	60310	-1	302	0.0	13090	88154	-1	-1	-1
0635000	W	0/00/00	PW	7	46.2	7.9	-1	120000	3660	1350	40900	-1	278	0.0	2350	71600	-1	-1	-1
0643000	W	0/00/00	PW	7	47.8	6.8	-1	172000	7960	1540	56200	-1	173	0.0	1600	104000	-1	-1	-1
0651000	W	0/00/00	PW	7	47.3	8.8	-1	142121	6578	841	47193	-1	106	0.0	1735	85566	-1	-1	-1

HGC, 1984a

Table 1. Concentrations and ratios for Canadian River Basin samples.

Sample No.	Sample description	Date collected	Cl mg/L	Br mg/L	I ug/L	Br/Cl x 10^4	I/Cl x 10^6
1A	spring	9-21-83	25.2	0.15	2.3	60	92
2A	Ute Res.	9-21-83	55.2	0.20	41	36	750
3A	SALT WELL	9-22-83	1,130	0.25	30.3	2.2	26.7
4A	REVUELTO CREEK WINDMILL	9-22-83	255	0.50	32.6	4.4	28.8
5A	DRIPPING SPRINGS	9-22-83	38,800	9.7	63	2.5	1.6
7A	TRIASSIC SPRING	9-22-83	57.6	0.26	2.5	45	43
1B	UTE DAM	10-17-83	319	0.35	84	11	263
2B	OW-3	10-17-83	26,600	5.5	70	2.1	2.6
3B	PIEZ 6	10-18-83	10,600	3.0	49	2.8	4.6
4B	PIEZ 3	10-18-83	12,800	3.3	51	2.6	4.0
5B	PIEZ 2	10-18-83	7,340	1.8	19.6	2.5	2.7

Estimated error in concentrations above:

Chloride, less than ±2%

Bromide, ±0.05 mg/L for concentrations less than 0.5 mg/L
±10% for concentrations greater than 0.5 mg/L

Iodide, from ±5% for higher concentrations up to ±10% for low concentrations

TAB 13 Part B.1 Alluvium

USBR, 1984

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT	SHEET
G.G.	9/26/84	Lk Meredith Project	1 OF 4
CHKD BY	DATE	FEATURE Canadian River & Revuelto Cr.	

DETAILS Statistical Analyses – Regression – BR Data 5/83 – 8/84

Group 1 – All Surface Water $y = A + BX$

Table 3 – Summary of Statistical Analyses For Group 1 Water Samples, All Sampling Sites Near Cosson's NM

flow / chlorides (Y / X)

Sample size	= 80
Correlation (R)	= -0.279
R squared	= 0.078
Std. Error of Est.	= 22.949
Intercept (A)	= 17.061
Slope (B)	= -0.003

flow / Field Conductance

Sample size	= 80
Correlation (R)	= -0.308
R squared	= 0.095
Std. Error of Est.	= 22.735
Intercept (A)	= 20.045
Slope (B)	= -0.001

flow / TDS

Sample size	= 80
correlation (R)	= -0.286
R squared	= 0.082
Std. Error of Est.	= 22.897
Intercept (A)	= 17.966
Slope (B)	= -0.002

chlorides / Field Conductance

Sample size	= 80
Correlation (R)	= 0.936
R squared	= 0.877
Std Error of Est.	= 775.969
Intercept (A)	= -348.662
Slope (B)	= 0.352

chlorides / TDS

Sample size	= 80
correlation (R)	= 0.869
R squared	= 0.755
Std. Error of Est	= 1095.103
Intercept (A)	= 241.498
Slope (B)	= 0.471

R – 1 – (-1) – closer to 1 better Linear Relationship; – indicates inverse relationship
R^2 – variance – 0–1 small when variables cluster close to mean
std. Error – std dev of y values from predicted y values

USBR, 1984

Table 3 (Continued)

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT Lk Meredith Project	SHEET 2 OF 4
CHKD BY	DATE	FEATURE	
DETAILS statistical Analyses - Regression y = A + BX			

Field Conductance/TDS

Sample size	=	80
correlation (R)	=	0.877
R squared	=	0.768
Std. Error of Est.	=	2828.171
Intercept (A)	=	2140.874
slope (B)	=	1.266

Group II - Alluvial Piezometers Canad. R ab Revuelto Cr.

y x
flow/chlorides

sample size	=	119
Correlation (R)	=	0.238
R squared	=	0.057
Std Error of Est.	=	1.454
Intercept (A)	=	0.842
slope (B)	=	0.00017

flow / Field Conductance

sample size	=	119
Correlation (R)	=	0.209
R squared	=	0.044
Std. Error of Est.	=	1.464
Intercept (A)	=	0.883
Slope (B)	=	0.00006

flow/TDS

sample size	=	119
correlation (R)	=	0.067
R squared	=	0.004
Std. Error of Est.	=	1.494
Intercept (A)	=	1.935
Slope (B)	=	0.00002

Note: Flow data is from the surface stream near the piezometers.

USBR, 1984

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT LK Meredith Project	SHEET 3 OF 4
CHKD BY	DATE	FEATURE	
DETAILS Statistical Analyses – Regression Y = A + BX			

chlorides/Field Conductance

Sample size	=	119
Correlation (R)	=	0.819
R squared	=	0.670
Std. Error of Est.	=	1235.800
Intercept (A)	=	845.918
Slope (B)	=	0.338

chlorides/TDS

~~Sample~~ size	=	119
Correlation (R)	=	0.657
R squared	=	0.432
Std Error of Est.	=	1621.740
Intercept (A)	=	3449.926
Slope (B)	=	0.348

Field Conductance/TDS

Sample size	=	119
Correlation (R)	=	0.681
R squared	=	0.464
Std Error of Est	=	3320.136
Intercept (A)	=	10174.063
Slope (B)	=	0.874

Group III Alluvial Piezometers, Revuelto Cr. and Canad. R. Below Revuelto Cr. Y = A + BX

flow/chlorides (Y / X)

~~Sample size~~	=	67
Correlation R	=	0.161
R squared	=	0.026
Std ERROR of Est.	=	35.181
Intercept (A)	=	7.598
Slope (B)	=	0.0016

Table 3 (Continued)

USBR, 1984

7-1654 (7-73)
Water and Power

COMPUTATION SHEET

BY	DATE	PROJECT Ck Meredith Project	SHEET 4 OF 4
CHKD BY	DATE	FEATURE	
DETAILS Statistical Analyses - Regression Y=A+BX			

Y / X

flow/Field Conductance
Sample size = 67
Correlation R = 0.030
R Squared = 0.0009
Std. error of Est. = 35.629
Intercept (A) = 13.441
Slope (B) = 0.0001

flow/TDS
Sample Size = 67
Correlation (R) = 0.019
R squared = 0.0004
Std. error of Est. = 35.639
Intercept (A) = 14.014
Slope (B) = 0.0001

chlorides/Field Conductance
Sample Size = 67
Correlation (R) = 0.974
R squared = 0.948
Std. Error of Est. = 836.877
Intercept (A) = -533.114
Slope (B) = 0.375

chlorides/TDS
Sample size = 67
Correlation (R) = 0.858
R squared = 0.737
Std Error of Est. = 1892.622
Intercept (A) = 85.511
Slope (B) = 0.471

Field Conductance/TDS
Sample size = 67
Correlation (R) = 0.862
R squared = 0.743
Std. Error of Est. = 4851.193
Intercept (A) = 1920.625
Slope (B) = 1.227

Table 3-(continued)

Water Quality Analyses, USBR (1984)

SITE 1 River (Mile 1.6): Table 4.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.	Flow (cfs)
05-13-83	2024				2320				5828			9500		
05-23-83	1984	53.4	131.3	10.2	2880				5438	8.06		10700		0.0
06-07-83					2750	830	396.5		5634	7.84	9500	9500	21	1.6
06-22-83					1000				2354	8.16	4500	4400	30	6.2
07-07-83	1604	31.2	80	6.80	1128	1120	304.8	0.6	2500	8.33	4250	4250	29	5.1
07-26-83					3000				5623	7.85	9000	9500	29	1.6
08-24-83					3350 *				5775	7.92	9000	10490	32	1.4
09-28-83					2950				5857	7.78	9000	9500	26	1.4
10-26-83	2172	84.8	136	12.0	2684	745	406.26	0	5643	7.97	8840	9400	19.0	1.6
11-21-83					3100				6201	7.7	9400	10100	13	1.5
12-13-83					3100				6222	7.99	11000	10000	8.9	1.4
01-19-84	2304	95.2	128	9.24	2740	387.6	431.9	0	5396	7.97	9050	11800	0	1.9
02-15-84					4100				8000	7.76	11950	13800	10	1.5
03-14-84					3000				5722	7.93	8500	9200	17	2.0
04-18-84	2186	72.0	148	14.6	3560	475	427.0	0	6711	8.13	11080	10780	22	1.6
05-15-84					3500				5947	7.79	10240	10000	20	1.7
06-08-84					3000				5286	7.86	10088	9328	27	1.0
07-19-84	2281	5.76	122.4	12.0	3696	587.5	378.2	0	6411	8.03	10700	12160	29.0	1.2
08-14-84					3680 *				6098	7.72	11540	11348	30.0	1.2
MEAN	2079	57.1	124	10.8	2923	691	390.8	0.1	5613	8.4	9273	9777	21	2.0

* Value adjusted by USBR.

NOTE: Mean values are calculated from data not reproduced from USBR report.

Water Quality Analyses, USBR (1984)

SITE 1 – 16' Piezometer: Table 5.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05–13–83	5600				7720				16252			19000	
05–23–83	5920	128.2	357.2	21.1	6920	350	467.2	0	16072	7.92		22500	
06–07–83					8350				15849	7.71	24000	24500	18
06–22–83					9000				15665	7.70	24900	25000	15
07–07–83	6840	134.4	308	21.4	8880	352	487.96	0	16942	8.01	25500	25500	16
07–26–83					9000				15949	7.74	23800	26000	17
08–24–83					9500				15867	7.51	22800	26000	17
09–28–83					8400				15408	7.54	22100	25000	17
10–26–83	5320	228.8	336	23.7	8360	950	529.48	0	16123	7.70	24700	24000	16
11–21–83					8250				15440	7.54	22500	24000	15
12–13–83					8250				15216	7.50	22250		15.6
01–19–84	6220	200	324	21.9	8160	825	536.8	0	15034	8.01	23700	21500	15
02–15–84					8100				14980	7.60	21000	23400	14
03–14–84					9500				15439	7.42	21500	22000	15
04–18–84	5249	254.4	380	23.6	8360	885	523.38	0	14801	7.99	24700	24880	14
05–16–84					8500				15123	7.64	23700	22080	16
06–08–84					8500				15030	7.63		22400	17
07–19–84	5417	226	325.6	18.4	8880	950	453.84	0	16477	7.66	21400	21640	17
08–14–84					8200				14457	7.51	22200	21084	17
MEAN	5795.1	195.3	338.5	21.7	8465	719	499.8	0.0	15585	7.7	23172	23360	16

Water Quality Analyses, USBR (1984)

SITE 1 – 22' Piezometer: Table 6.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	Lab pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	5440				6600				14502			22500	
05-23-83	6160	126.3	341.2	19.6	6720	830	634.4	0	15737	7.82		24500	
06-07-83					7950				14738	7.60	23000	22000	15
06-22-83					9000				15029	7.73	23250	23000	15
07-07-83	5800	122.4	280	18.4	7800	760	363.56	0	14948	8.0	21500	21500	16
07-26-83					9000				15248	7.63	22900	25000	16
08-24-83					8500				13411	7.58	19800	21000	17
09-28-83					6400				12025	7.62	16500	19500	17
10-26-83	4920	188.8	297.6	19.6	6160	855	497.76	0	12534	7.65	17300	20000	16
11-21-83					6200				11920	7.52	17000	17200	15
12-13-83					6700				12412	7.70	19000	18000	15.6
01-19-84	5400	182.4	283.2	18.6	6600	787.6	523.3	0	12150	7.92	19500	17900	15
02-15-84					7200				14131	7.64	19510	20000	15
03-14-84					8500				14923	7.62	20000	20900	15
04-18-84	4639	100.8	352	21.9	8760	795	509.96	0	12897	7.95	22200	20680	15
05-16-84					8000				13439	7.63	20950	20800	16
06-08-84					7500				12723	7.62	20000	18348	15
07-19-84	4862	152.6	304	16.6	9120	812.5	469.7	0	14135	7.84	22000	20400	17
08-14-84					8500				12824	7.60	21160	18420	17

Water Quality Analyses, USBR (1984)

SITE 2 River (Mile 2.2): Table 7.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbona mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.	Flow (cfs)
05-13-83	1968				2516				5683			15000		
05-23-83	2120	53.4	134.5	10.6	2990	375	381.86	1.8	5699	8.37		9900		0.45
06-07-83					2850				5840	7.85	9250	10000	24	2.0
06-22-83					1000				2422	8.24	4400	4500	30	5.9
07-07-83	1440	33.6	68	6.62	1004	278	291.6	1.2	2275	8.33	4500	4500	30.5	6.1
07-26-83					2500				5798	7.94	9500	10000	30	1.1
08-24-83					3500				6110	8.0	9000	10880	32	1.6
09-28-83					3250				6354	7.88	9100	10500	24	1.8
10-26-83	2290	105.6	136	12.5	2616	450	413.58	0	5848	8.0	9180	9500	18.0	1.9
11-21-83					3200				6400	7.75	10000	10200	14	2.1
12-13-83					3250				6365	8.06	10000	12500	3.3	2.0
01-19-84	2276	100.8	128	10.5	2700	450	435.54	0	5175	8.01	8850	9600	2.0	1.9
02-15-84					4800				9176	7.72	13700	14500	10	1.3
03-14-84					3000				5987	7.90	9400	9600	17.5	1.4
04-18-84	2242	79.2	148	14.8	3420	450	422.12	0	7275	8.03	11510	10896	22	1.5
05-16-84					4000				6395	7.83	10368	10672	16	1.7
06-08-84					2500				6200 *	7.91	8656	9798	28	1.0
07-19-84	2308	187.7	123.2	12.3	3400 *	500	373.32	0	6648	7.96	11300	12484	33.0	0.9
08-14-84									6332	7.81	11980	11820	30	1.3

Water Quality Analyses, USBR (1984)

Site 2 – 22' Piezometer: Table 8.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l		Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity, umhos	Field Water Temp.
05-13-83		5080				5720				13902			21000	
05-23-83		5600	147.7	365.2	10.6	6600	925	559.6	0	15779	7.83		24000	
06-07-83						8300				15677	7.65	23000	24900	15
06-22-83						9500				15629	7.66	24000	24500	15
07-07-83		6080	165.6	336	20.4	8480	790	352.6	0	16573	7.91	24000	24000	15
07-26-83						9000				15640	7.64	23000	26000	15
08-24-83						9000				15706	7.53	22800	25000	15
09-28-83						8550				15855	7.64	21800	24500	15
10-26-83		7800	260.8	352	18.2	6680	1025	428.22	0	17124	7.94	24200	24000	15
11-21-83						8250				15357	7.63	21500	23500	15
12-13-83						8000				14969	7.63	22100	22100	14.4
01-19-84		6220	238.4	337.6	19.9	7720	995	391.6	0	14892	8.12	33000	21250	14
02-15-84						7600				14786	7.64	20100	21500	15
03-14-84						8000				14778	7.50	20200	21000	17
04-18-84		5029	132	368	22.6	7800	855	470.92	0	15300	7.90	24000	23400	14.75
05-16-84						8000				14532	7.56	21720	21000	17
06-08-84						8000				14619	7.49	22440	19948	17
07-19-84		4869	162.2	276.8	13.9	9240	787.5	425.78	0	14669	7.79	22500	20760	12
08-14-84						9000				14156	7.48	21480	21080	16

Water Quality Analyses, USBR (1984)

SITE 2 – 40' Piezometer: Table 9.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05–13–83	5480				6960				15409			23000	
05–23–83	5920	144.8	418.1	23.2	7360	980	461.1		16838	7.89		26000	
06–07–83					8600			0	16369	7.54	24500	25500	15
06–22–83					10000				16159	7.84	24000	25000	15
07–07–83	5920	183.6	342	20.7	8160	910	336.7		17133	7.88	24500	24500	15
07–26–83					9000			0	16096	7.74	23800		15
08–24–83					9500				16279	7.51	23600	26000	15
09–28–83					8150				16181	7.60	21700	24500	15
10–26–83	6400	267.2	377.6	19.5	7200	1005	448.96	0	16391	8.00	24700	24000	15
11–21–83					8400				15903	7.59	22100	23500	15
12–13–83					8500				15728	7.32	23100	23000	15.6
01–19–84	6680	256	377.6	21.2	8680	1025	307.44	0	15920	8.06	22000	22200	16
02–15–84					8350				15719	7.58	21600	22500	16
03–14–84					9000				15701	7.46	21400	22000	17
04–18–84	5277	141.6	400	22.6	7960	1045	463.6	0	15596	8.0	25200	24400	15
05–16–84					9500				15219	7.49	22600	21760	16
06–08–84					7500				15036	7.39	22120	21040	15
07–19–84	5223	150.7	337.6	19.1	9120	1112.5	416.02	0	15011	8.04	21400	21440	16
08–14–84					8500				14881	7.6	26040	22160	16

SITE 2 – 55' Piezometer: Table 10.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	Field Conduct. umhos	Field Conductivity umhos
05–13–83	5040				5920				14296			21000
05–23–83	5200	164.24	352.4	19.3	6600	1045	457.5	0	15416	7.96		24000
06–07–83					8000				14838	7.53	22100	23000
06–22–83					9500				15273	7.84	23000	23500
07–07–83	5480	176.4	302	19.7	8160	940	339.2	0	15832	7.85	22500	22500
07–26–83					9000				15074	7.69	21900	25000
08–24–83					9000				14946	7.54	22200	24000
09–28–83					8300				15458	7.48	21000	24000
10–26–83	6160	259.2	361.6	17.4	7180	962.5	411.14	0	15947	8.05	23900	23500
11–21–83					8200				15053	7.48	22000	23000
12–13–83					8150				14992	7.28	22000	21200
01–19–84	7600	264	344	22.5	7960	865	412.36	0	15123	7.95	21700	20900
02–15–84					7900				14857	7.47	20200	23000
03–14–84					8000				14843	7.38	20000	21100
04–18–84	4872	144	372	23.8	7440	990	445.3	0	14857	7.78	24100	23000
05–16–84					8500				14419	7.39	21680	21200
06–08–84					8500				14398	7.62	22200	20044
07–19–84	4949	158.4	315.2	18.9	8880	1450	419.68	0	14172	7.98	22600	20560
08–14–84					7700 *				14249	7.59	21420	20296
MEAN	5614	194	341	20	7642	1042	414	0	14200	7.2	20769	21290

Water Quality Analyses, USBR (1984)

SITE 3 River (Mile 5.4): Table 11.

Date	Sodiumdium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbona mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.	Flow (cfs)
05-13-83	4240				4600				5674			7500		
05-23-83	3898	82.6	171.4	16.2	4400	610	397.7	0	10799	8.09		20800		2.8
06-07-83					5550				10420	7.77	16150	17000	23	3.1
06-22-83					2500				1630	8.19	8250	7100	29	6.6
07-07-83	1752	48	88	8.90	1976	388	305.0	0	4109	8.20	6500	6500	25	5.8
07-26-83					6000				10400 *	7.90	15800	16250	26	2.4
08-24-83					6000				10740	7.98	16500	17000	28	1.8
09-28-83					6000				11570	7.81	17000	19000	18	1.5
10-26-83	5040	203.2	203.2	18.6	5320	2150	462.38	0	10600 *	8.14	18300	18800	15	2.3
11-21-83					6750				12665	7.65	18500	20000	11	2.7
12-13-83					6550				12324	7.82	18000	19500	5.5	2.2
01-19-84	4052	147.2	206.4	14.6	4860	590	373.3		9299	8.25	15000	18000	0	4.2
02-15-84					7800			0	14652	7.65	20900	22900	5	2.2
03-14-84					6500				11336	7.82	16100	17500	14	2.3
04-18-84	4229	98.4	236	22.4	6560	895	483.92	0	12111	7.98	20400	19526	16	2.2
05-16-84					6500				11895	7.82	18784	18520	17	2.8
06-08-84					5500				10385	7.91	15836	16168	21	2.4
07-19-84	5213	123.8	225.6	20.8	8280	1150	434.32	0	14294	7.94	20500	22760	25	2.0
08-14-84					7200				13275	7.74	21340	21640	26	4.5

Water Quality Analyses, USBR (1984)

Site 3 – 20' Piezometer: Table 12.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	4080				4600				13415			20000	
05-23-83	5920	172	237	23.6	6840	1375	422.61	7.98	16348	8.46		26000	
06-07-83					8200				16191	7.76	25000	24200	14
06-22-83					9500				16250 *	8.08	25500	24000	14
07-07-83	6000	165.6	208	23.1	8480	1325	429.4		16414	8.06	20000	20000	14
07-26-83					9000				16300 *	7.95	22900	25000	15
08-24-83					7500			0	14377	7.73	21500	23100	15
09-28-83					5900				11183	7.86	15200	18500	16
10-26-83	4600	121.6	112	16.7	4920	800	412.36		10714	8.18	16100	17000	18
11-21-83					6250			0	11889	7.76	17000	18800	17
12-13-83					6500				12198	7.73	18000	16400	18.9
01-19-84	5660	166.4	188.8	20.4	5940	715	307.44		11937	8.29	18700	17250	16
02-13-84					6100			0	11610	7.83	16600	17500	15
03-14-84					6200				11773	7.73	17100	17900	15
04-18-84	4112	200.6	204	24.7	8360	860	444.1		11926	8.02	20100	19568	13
05-16-84					7500			0	12050	7.81	18368	19124	13
06-08-84					6500				11992	7.71	18388	19280	14
07-19-84	4213	109	200	17.1	7040	987.3	464.82	0	12764	7.89	18800	16124	15
08-14-84					6640 *				12029	7.81	18798	17152	15
MEAN	4941	156	192	21	6946	1010	413	1.3	13229	7.93	19297	19837	15.2

Water Quality Analyses, USBR (1984)

Site 3 – 34' Piezometer: Table 13.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	5720												
05-23-83	8360	205	438.9	31.0	10720	1720	580.7	0	26106	8.23		39500	
06-07-83					13550				26319	7.53	38000	39000	14
06-22-83					14500				23000 *	7.74	39000	38000	14
07-07-83	9880	252	392	30.8	14240	1540	451.4	0	26617	7.89	37000	37000	14
07-26-83					15000				24000 *	7.71	32800	40000	15
08-24-83					15500				25460	7.39	36000	34000	15
09-28-83					13250				25218	7.58	33000	36000	15
10-26-83	6560	388	436.8	35.8	11880	1125	585.6	0	25077	7.68	35900	32500	15
11-21-83					13250				25009	7.62	31600	33000	15
12-13-83					13150				24652	7.17	34000	34100	15.6
01-19-84	10280	382.4	448	36.6	13120	1525	594.14	0	25231	7.83	35900	33800	16
02-13-84					13250				24919	7.60	32550	32000	16
03-14-84					12800				24426	7.45	33000	32000	16
04-18-84	8333	232.4	428	32.0	11880	1435	553.88	0	25004	7.58	38200	37096	14
05-16-84					12100 *				23709	7.55	33060	33280	15
06-08-84					13500				23613	7.52	34080	29560	14
07-19-84	8550	220	400	26	12320	1875	485.56	0	24305	7.73	36000	30520	14
08-14-84					11800				24569	7.61	29400	31880	15
MEAN	8240	280	424	32	13101	1537	542	0	24846	7.63	34676	34624	14.9

Water Quality Analyses, USBR (1984)

SITE 4 River (Mile 6.3): Table 14.

Date	Sodiumdium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbona mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.	Flow (cfs)
05-13-83	290				165				1276			2000		
05-23-83	210	24.3	78.4	9.2	123	680	224.0	3.0	1260	8.56	1750	1460		26.0
06-07-83					95				1300 *	8.14	1800	1900	24	6.7
06-22-83					100				1250 *	8.25			35.5	0.01
07-07-83														
07-26-83														
08-24-83					20				1089	8.34	1000	1500	28	3.3
09-28-83					65				829	8.24	1300	1400	21	7.8
10-26-83	163.2	46.4	60.8	6.85	68.5	345	240.3	0	767	8.26	1180	1350	16	14.3
11-21-83					100				937	8.19	1550	1500	12	5.6
12-13-83					240				1492	8.28		2300	10	1.7
01-19-84	894	97.6	89.6	5.33	656	662	386.74	0	2294	8.17	3350	4300	0	
02-15-84					370				1911	8.25	2800	3200	4	0.4
03-14-84					825				2618	8.19	4000	4000	17	0.1
04-18-84	315	50.4	72	8.7	229	520	219.6	1.2	1397	8.39	2430	2068	19	4.3
05-16-84					100				1051	8.17	1493		16	11.7
06-08-84					2150				5339 a/	7.79	7954	8464	21	
07-19-84	127	5.28	20	2.4	54.8	175.0	209.84	1.2	536	8.42	628			55
08-14-84					200				291	7.57	617	568	24	
MEAN	333	45	64	6.5	327	476	256	1.1	1508	8.2	2275	2572	17.7	9.13

a. Note on table says "concentration in pool?"

Water Quality Analyses, USBR (1984)

Site 4 – 15' Piezometer: Table 15.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	3640				4320				10955	7.87		16500	
05-23-83	3536	147.7	302.7	15.5	5200	960	516.1	0	10452	7.65		16500	
06-07-83					3850 *				7973	8.04	11700 *		12
06-22-83					3000				7150 *	8.46	10000	9500	14
07-07-83	1676	3.6	8.4	4.8	1204	515	505	1.8	3454	8.16	5250	5250	14
07-26-83					500				4000 *	8.09	4300	5000	15
08-24-83					320				1532	8.03	2600	2750	16
09-28-83					360				1580	8.23	2600	2750	17
10-26-83	369.6	17.6	27.2	3.9	306.8	475	319.64	0	1482	7.91	2310	2550	17
11-21-83					215				1256	7.87	2200	2500	15
12-13-83					240				1276	8.2	2200	2800	14.4
01-19-84	692	36.8	51.2	4.08	398.8	485	306.22	0	1504	7.85	2560	2750	12
02-13-84					435				1717	7.75	2700	3000	11
03-14-84					425				1735	8.08	2700	2750	11
04-18-84	516	31.2	72	5.6	511	350	284.26	0	1795	7.78	3250	2964	11
05-16-84					500				3766	7.78	2874	3132	11
06-08-84					650				1999	8.37	3220	2800	13
07-19-84	555	40.3	89.6	5.2	580	512.5	303.78	0.6	2754		3080	2892	14
08-14-84													
MEAN	1569	46	92	6.5	1279	550	373	0.4	3688	8.0	3972	5082	13.6

Water Quality Analyses, USBR (1984)

Site 4 – 20.5' Piezometer: Table 16.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	4760				5480				13378			21000	
05-23-83	4980	129.2	203.4	19.9	6300 *	1200	564.86	0	13787	8.03		21000	
06-07-83					6550				14921	7.68	20250	20600	12
06-22-83					4000				9000 *	8.14	13200	13000	14
07-07-83	2364	4.32	12	6.89	2156	615	653.9	1.2	5291	8.41	8000	8000	14
07-26-83					1000				4400 *	8.18	7000	7000	14
08-24-83					700				2483	7.96	4000	4400	15
09-28-83					510				1964	8.06	3100	3500	15
10-26-83	1044	7.2	12	3.1	592 *	462.5	374.54	0	1736	8.30	2720	3000	15
11-21-83					517 *				1601	8.04	2650	2800	15
12-13-83					570				2029	7.99	3300	3300	16.7
01-19-84	726	10.6	25.6	3.52	645	492	305.0	0.9	1736	8.35	2610	2800	14
02-13-84					700				2208	7.95	3550	3800	13
03-14-84					600				2040	7.89	2800	3700	12
04-18-84	1075	36	88	7.8	1150	375	283.04	0	3349	8.01	5940	5532	12
05-16-84					1550				3753	7.79	5982	6452	11
06-08-84					2550				6250 *	7.69	8694	7464	13
07-19-84	972	42	112	6.1	1274	612.5	322.08	0	3101	8.30	4510	4280	14
08-14-84													
MEAN	2274	.38	75.5	7.9	2046.9	626	417	0.4	5168	8.0	6144	7868	13.7

Water Quality Analyses, USBR (1984)

SITE 6 River (Mile 9.9): Table 17.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbona mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.	Flow (cfs)
05-13-83	1370				1536				4459			7500		
05-23-83	756	37	93	8.6	900	395	280.6	0	2383	8.30		4235		32.0
06-07-83					2050				2038	7.95	7600	7250	18.5	11
06-22-83					2500				5970	8.06	10000	10000	27	5.5
07-07-83	2196	62.4	116	11.6	3244	514	305	0	5696	8.15	9100	9100	22	4.5
07-26-83					6500				11025	7.87	17000	17000	24	1.0
08-24-83					1800				3882	8.12	6200	7200	25	6
09-28-83					1150				2685	8.05	4250	4750	17	10
10-26-83	1100	88	76.8	8.35	996	387.5	273.3	2.4	2549	8.37	3650	4600	11	17.5
11-21-83					2050				4475	7.98	9000	7800	10	10
12-13-83					4150				8243	8.0	12175	13800	3.3	5.0
01-19-84	5480	220.8	310.4	19.9	6400	875	662.46	0	13209	7.80	18880	22000	0	0
02-15-84					5550				10711	7.70	15200	16800	4.0	3
03-14-84					6000				11889	7.72	15000	18000	14	2.5
04-18-84	2034	81.6	148	16.3	2900	550	364.78	0	6321	8.11	10820	11555	12	6
05-16-84					1500				3431	8.05	5536	5228	16	13.0
06-08-84					6500				11630	7.64	17020		20	1.5
07-19-84	296	9.6	32	3.8	297.6	150	231.8	0	1121	8.32	1586	1758	23	60
08-14-84					250				460	7.57	951	908	24	201
MEAN	1890	83	129	11.4	2962	479	353	0.4	5904	8.0	9645	9416	15.9	21.6

Water Quality Analyses, USBR (1984)

Site 6 – 21' Piezometer: Table 18.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	2792				4000 *				7752			13000	
05-23-83	2792	49.5	91.3	13.8	3720	560	666.1	0	7694	8.16		12800	
06-07-83					3850				8900 *	7.65	13000	13000	14
06-22-83					3500				7197	8.06	11250	12000	14
07-07-83	2828	48	100	13.3	3640	564	528.3	0	7246	8.07	11800	11800	14
07-26-83					3500				7116	7.86	11200	13000	15
08-24-83					4000				6366	7.7	9250	11000	15
09-28-83					3250				6483	7.78	9700	4000	15
10-26-83	3244	101.6	97.6	13.8	3400 *	687.5	484.34	0	6669	8.10	9370	10800	16
11-21-83					3700				7470	7.74	11200	12000	12
12-13-83					4200				8296	7.49	12000	11900	17.7
01-19-84	4120	376	244.8	19.5	4840	810	513.62	0	9637	8.0	16500	13500	16
02-13-84					4950				9807	7.74	14000	15000	14
03-14-84					5500				10454	7.56	13900	15100	16
04-18-84	3505	230	312	25.1	5200	635	472.14	0	10876	7.78	18500	15200 *	14
05-16-84					5500				10706	7.58	16782	17660	14
06-08-84					5500				11842	7.42	17048	17852	15
07-19-84	3784	142.1	337.6	19.4	5300 *	887.5	447.74	0	11397	7.9	18000	15260	15
08-14-84									11598	7.53	18916	16200	17
MEAN	3295	158	197	17.5	4308	691	519	0	8816	7.8	13672	13214	14.9

Water Quality Analyses, USBR (1984)

Site 6 – 31' Piezometer: Table 19.

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	LAB Conduct. umhos	Field Conductivity umhos	Field Water Temp.
05-13-83	4920				6040				14160			22000	
05-23-83	5260	148.6	254.7	28.2	5920	970	588.0	0	15048	7.93		23000	
06-07-83					7750				15200 *	7.58	22500	24000	14
06-22-83					8500				14719	7.73	22250	22000	15
07-07-83	4360	151.2	260	24	7280	935	530.7	0	14356	7.92	21500	21500	15
07-26-83					8000				14020	7.62	20100	22700	15
08-24-83					8000				14056	7.74	20050	21800	15
09-28-83					7050				13770	7.64	19200	21500	15
10-26-83	6160	67.2	266.4	25.6	6600 *	1280	679.54	0	13545	7.87	20400	19500	15
11-21-83					6900				13511	7.51	19500	22900	10
12-13-83					6950				13618	7.70	19950	21500	10
01-19-84	5800	216	292.8	24.7	6840	1170	707.6	0	13740	8.01	22200	19000	15
02-13-84					6600				13226	7.65	18300	18500	14
03-14-84					6600 *				13035	7.74	18000	20000	16
04-18-84	4519	212.2	276	27.1	6400	765	684.42	0	13201	7.69	22400	20584	15
05-16-84					6500 *				12659	7.58	19204	20100	16
06-08-84					6500				13300 *	7.63	19376	21004	15
07-19-84	4365	128.6	187.2	19.3	6864	1100	583.16	0	12173	7.76	19350	19420 *	15
08-14-84					6500 *				12035	7.63	20800		15
MEAN	5055	154	256	24.8	6937	1037	629	0	13651	7.72	20299	21167	14.4

Water Quality Analyses, USBR (1984)

SITE 6 – 50' Piezometer: Table 20

Date	Sodium mg/l	Magnesium mg/l	Calcium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Bicarbonate mg/l	Carbonate mg/l	Total Dissolved Solids mg/l	LAB pH pH Units	Field Conduct. umhos	Field Conductivity umhos
05–13–83	5920											
05–23–83	7720	163.2	456.5	43.2	10750 *	1285	555.1	0	20432	7.73		30100
06–07–83					10150				20800 *	7.24	30000	32000
06–22–83					11300 *				20224	7.49	29500	31500
07–07–83	8160	43.2	75.2	39.2	10400	1365	570.0	0	20846	7.89	30000	30000
07–26–83					11100 *				20426	7.47	29200	31000
08–24–83					11500				20275	7.18	27500	30000
09–28–83					10550				20418	7.42	27200	30000
10–26–83	8360	383.2	426.4	44.2	10700 *	1625	786	0	20825	7.76	30300	30000
11–21–83					10700				20590	7.21	28500	31800
12–13–83					10450				20077	7.28	28100	28000
01–19–84	8280	353.6	496	43.5	10280	1612	812.52	0	18600 *	7.89	32000	28000
02–15–84												
03–14–84												
04–18–84												
05–16–84												
06–08–84												
07–19–84												
MEAN	7688	235.8	363.5	42.5	10716	1472	681	0	20319	7.5	29230	30218

AGRICULTURE
...ICAL ANALYSIS
PETROLEUM

BC LABORATORIES INC

J. J. EGLIN, REG. CHEM. ENGR.

3016 UNION AVE BAKERSFIELD, CALIFORNIA 93305
MAIN OFFICE 4100 PIERCE ROAD, BAKERSFIELD CA 93308 PHONE 327-4911

HGC, 1984a

Hydro Geo Chem, Inc.
744 N. Country Club
Tucson, Arizona 85716

Date Reported: 12/2/83
Date Received: 11/7/83
Laboratory No.: 12517

Attention: Mr. John Ward

WATER ANALYSIS

Sample Description: #3

Constituents	Parts/million
Calcium	580.
Magnesium	145.
Sodium	6,900.
Potassium	35.
Carbonate	0.
Bicarbonate	849.
Chloride	10,832.
Sulfate	1,440.
Nitrate	(<) 0.4
Total Dissolved Solids, By Summation	20,783.
Boron	1.5

(<) refers to "less than"

B C LABORATORIES, INC.

BY J. J. Eglin
J. J. Eglin

kc

Field Parameters

Well: Piezometer site 6:50' (Channel deposits)
Location: 13.34.5.12
Date: 10-18-83
Time: 1000
Temp: 18.0°C
pH: 6.60
Alkalinity: 803 mg/l

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HGC, 1984 a

Hydro Geo Chem, Inc.
744 N. Country Club
Tucson, Arizona 85716

Date Reported: 12/2/83
Date Received: 11/7/83
Laboratory No.: 12519

Attention: Mr. John Ward

WATER ANALYSIS

Sample Description: #5B

Constituents	Parts/million
Calcium	360.
Magnesium	130.
Sodium	4,800.
Potassium	19.
Carbonate	0.
Bicarbonate	255.
Chloride	7,788.
Sulfate	920.
Nitrate	(<) 0.4
Total Dissolved Solids, By Summation	14,273.
Boron	1.0

(<) refers to "less than"

B C LABORATORIES, INC.

BY J. J. Eglin
J. J. Eglin

kc

Field Parameters

Well: Piezometer site 2:55' (Channel deposits)
Location: 13.33.14.24
Date: 10-18-83
Time: 1400
Temp: 17.0°C
pH: 6.95
Alkalinity: 325 mg/l
Spec. cond. (25°) = 25,000 μmhos

AGRICULTURE
CHEMICAL ANALYSIS
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HGC, 1984a

Hydro Geo Chem, Inc.
744 N. Country Club
Tucson, Arizona 85716

Date Reported: 12/2/83
Date Received: 11/7/83
Laboratory No.: 12518

Attention: Mr. John Ward

WATER ANALYSIS

Sample Description: #4B

Constituents	Parts/million
Calcium	420.
Magnesium	170.
Sodium	8,700.
Potassium	28.
Carbonate	0.
Bicarbonate	520.
Chloride	13,275.
Sulfate	1,600.
Nitrate	(<) 0.4
Total Dissolved Solids, By Summation	24,714.
Boron	1.0

(<) refers to "less than"

B C LABORATORIES, INC.

BY J. J. Eglin
J. J. Eglin

kc

Field Parameters

Well:	Piezometer site 3:35' (Channel deposit)
Location:	13.33.12.23
Date:	10-18-83
Time:	1130
Temp:	18.0°C
pH:	6.90
Alkalinity:	452 mg/l
Spec. cond.	(25°) = 44,500 μmhos

Extracts of soil samples from tributaries collected by Ashby Lewis Canadian River Survey, 01/29/73 and 03/01/73

SAMPLE IDENTIFICATION	N–9	S–11	S–12	S–13	S–15	S–17	S–8	N–8	S–7	N–7	S–6	N–6	S–5	S–3	N–3	N–4	S–2
PHOTO	1	3	4	5	6	10?	10	18	19	22	23	23?	25	27	27	27	30
RIVER MILE	1.65	9.0	11.6	15.6	18.4	24.8	24.8	40	42.5	46.5	48	50	54	55.4	55.8	56.5	59
NAME				Tusco–coillo Canyon				Horse Creek	Truj–illo Creek	Minne–osa Creek	Los Arches Creek				Pedriza Creek		
PARAMETERS																	
Chloride, mg/l	50	400	350	150	1025	350	425	125	75	75	150	100	550	100	50	75	50
Sodium, mg/l	10	275	275	89	616	230	400	70	107	73	67	119	400	167	45	13	41
Sodium chloride, mg/l	82.5	660.0	577.5	247.5	1691.2	577.5	701.2	206.2	123.7	123.7	247.5	165.0	907.5	165.0	82.5	123.7	82.5
Sulfate, mg/l	25	125	172.5	107.5	330	240	515	185	1225	375	87.5	185	335	310	30	45	15

NOTES

Sampling points listed in downstream order from Ute Lake. Samples with N prefix collected in a tributary entering river from the north; those with a S prefix collected in a tributary entering river from south.

Some river mile designations are approximate, based on large–scale maps; they may be changed as small–scale maps become available.

There were two S–17 stations marked on photos and only one S–17 analysis. Ashby Lewis indicated Ocotober 15, 1991 that "S–17" marked on photo 9 probably is the location where a surface water sample reported as S–16 was taken, and that the soil sample extract reported as S–17 probably was collected at the "S–17" marked on photo 10. The location of the soil sample extract reported as N–6 was not marked on any photo; Ashby Lewis indicated that it was probably collected from a tributary on photo 23.

Sand   Sample

TEXAS WATER QUALITY BOARD
DOMESTIC SAMPLE INFORMATION

District I County ~~New~~ State New Mexico Basin Canadian Date 11-25-69

Pertaining to Canadian River Permit —— Page

Time Noon Weather Clear Flow 1500 GPM

Method of Flow Measurement Estimate

Material Sampled: Raw, Primary, Partially Treated, Final Effluent, Stream (Sand)

PHOTO #1 RIVER MILES Grab R-21 - R22 AREA Composite ______ hr.

Point of Collection River Bed 1/4 mile Below Ute dam in

Observations: New Mexico, Salt Deposits in Sand
Flow rather low due to water not being discharged
from Ute. Flow seepage water from springs
and dam.

FIELD ANALYSIS

Water Temp. ______ °F pH ______ Dissolved O_2 ______ Turbidity ______

Chlorine Residual ______

Date Shipped 11-26-69 Iced ______ Signature [signature]

CENTRAL LABORATORY ANALYSIS

Date Received 11-28-69 Lab. No. 139588 Date Completed DEC 22 1969

pH ______ NH_3-N ______ T. S. Solids ______

Conductivity ______ NO_2-N ______ F. S. Solids ______

O-PO_4 ______ NO_3-N ______ V. S. Solids ______

B.O.D.$_5$ ______

Chloride — 1.4 mg/g

Please Analyze For soluble salts

FORM NO. G-152 (WGB 34)

Chlorides

Analyses of samples from piezometers drilled as part of USBR early work, from CRMWA files

PARAMETERS

	Alkalinity, mg/l	Calcium, mg/l	Chloride, mg/l	pH, pH units	Sodium, mg/l	Sodium chloride, mg/l	Specific conductance, umhos/cm	Sulfate, mg/l	TDS, calculated, mg/l
3–07–74									
Canadian River at Highway 54									
10 ft. well			3800			6270.0	12000		
20 ft. well			4250			7012.5	14100		
30 ft. well			5650			9322.5	18200		
40 ft. well			4700			7755.0	15500		
50 ft. well			4000			6600	14500		
4–23–74									
Canadian River at Highway 54									
10 ft. well			3750			6187	11700		
20 ft. well			7300			12045	20000		
30 ft. well			7850			12952	21000		
40 ft. well			8400			13860	21500		
50 ft. well			7300			12045	21800		
1–21–75									
1 mile +/– below Ute Dam									
20 ft. well	398	528	4150	7.6	2697		11500	438	7813
1–27–75									
1 mile +/– below Ute Dam									
20 ft. well	406	552	4400	7.7	2860		12000	550	8360
3–06–75									
Canadian River at Highway 54									
10 ft. well			8600			14520	22800		
20 ft. well			9400			15510	22100		
30 ft. well			8650			14272	21000		
40 ft. well			9050			14932	21000		
50 ft. well			8800			14520	21500		
3–06–75									
Canadian River near TX–NM state line									
20 ft. well			1450			2392	4750		

TAB 13 Part B.2 Triassic aquifers

HGC, 1984a

Table 6: Summary of chemical characteristics of 23 samples of Triassic groundwater in the study area

Ion	Range mg/l	Average mg/l	Average meq/l
Ca	2 - 210	54	2.7
Mg	0 - 190	35	2.9
Na	4 - 1370	366	15.9
K	3.2 - 7.1	4.7	0.12
HCO_3	88 - 852	449	7.4
CO_3	0 - 75	14	0.46
SO_4	56 - 1760	416	8.7
Cl	4 - 1130	152	4.3
Br	0.15 - 0.50	0.29	0.004
pH	6.9 - 9.3	7.7	—
TDS	527 - 5520	1261	—

AGRICULTURE
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MAIN OFFICE 4100 PIERCE ROAD, BAKERSFIELD CA 93308 PHONE 327-4911

HGC, 1984a

Hydro Geo Chem, Inc.
744 North Country Club Road
Tucson, Arizona 85716

Date Reported: 10/18/83
Date Received: 10/3/83
Laboratory No.: 10730

WATER ANALYSIS

Sample Description: 6. 9/22/83 1600

Constituents	Parts/million
Calcium	210.
Magnesium	85.
Sodium	49.
Potassium	4.9
Carbonate	0.
Bicarbonate	355.
Chloride	42.5
Sulfate	600.
Nitrate	1.3
Total Dissolved Solids	1,375.
Boron	0.08
Silica	27.
Hardness as $CaCO_3$	875. (51.1 gr/gal)
Electrical Conductivity, Micromhos	1,610.
pH	7.3

B C LABORATORIES, INC.

BY J. J. Eglin
J. J. Eglin

ad

Field Parameters

Well:	"Logan Cemetary Windmill" (Triassic)
Location:	13.33.1.43
Date:	9-22-83
Time:	1600
Temp:	18.0°C
pH:	6.96
Alkalinity:	300 mg/l

HGC, 1984a

AGRICULTURE
CHEMICAL ANALYSIS
PETROLEUM

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Hydro Geo Chem, Inc.
744 North Country Club Road
Tucson, Arizona 85716

Date Reported: 10/18/83
Date Received: 10/3/83
Laboratory No.: 10728

WATER ANALYSIS

Sample Description: 4. 9/22/83 1030

Constituents	Parts/million
Calcium	140.
Magnesium	190.
Sodium	205.
Potassium	7.1
Carbonate	0.
Bicarbonate	761.
Chloride	255.
Sulfate	548.
Nitrate	(<) 0.4
Total Dissolved Solids	2,122.
Boron	0.10
Silica	16.
Hardness as $CaCO_3$	1,132. (66.1 gr/gal)
Electrical Conductivity, Micromhos	2,800.
pH	7.5

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J. J. Eglin

ad

Field Parameters

Well:	"Revuelto Creek Windmill: (Triassic)
Location:	13.33.24
Date:	9-22-83
Time:	1000
Temp:	18.0°C
pH:	6.93
Alkalinity:	580 mg/l

TAB 13 Part B.3 Brine aquifer

Summary of brine aquifer water quality data

DH-1

Parameter	Date 6/75	6/75	6/75	6/75	6/75	6/75	6/75	6/75	6/75	6/75
Chloride, mg/l	11800	11800	12950	2350	16450	18500	16100	15950	17400	16250
Iron, total, mg/l	0.80	0.24	0.43	0.08	0.48	0.80	0.27	0.10	0.48	0.29
Sodium chloride, mg/l	19470	19470	21368	3878	27142	30525	26565	26318	28875	26812
Specific conductance, umhos/cm	34000	37000	36000	8600	45000	52000	51000	50000	49000	49000
Sulfate, mg/l	1650	1450	2150	500	2000	1950	1900	500	missing	1750
Notes	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	1,10	1,11

DH–2

Date	7/75	7/75	5/12/83	7/19/83
Parameter				
Bicarbonate, mg/l			1280.18	1076.57
Calcium, mg/l			448.5	384.0
Carbonate, mg/l	4800	4950	5760	6580
Chloride, mg/l	4800	4950	5760	6580
Fluoride, mg/l			0.6	0.5
Iron, total, mg/l	0.24	1.08	1.34	0.19
Magnesium, mg/l			89.0	96.0
NaCl, mg/l	7920	8168		
Nitrate, mg/l			2.8	
pH, lab, pH units			7.84	7.62
Potassium, mg/l			54.8	36.8
Sodium, mg/l			4240	7880
Specific conductance, umhos/cm	16300	16900		
Specific conductance, field, 25°C, umhos/cm			17500	17800
Sulfate, mg/l	1015	1013	1450	1710
Temperature, field, °C				18
Total dissolved solids, mg/l			11985	12138
Notes	1, 12	1, 13	14	14

DH-3

Date	7/19/84	7/19/84
Parameter		
Bicarbonate, mg/l	762.5	784.5
Calcium, mg/l	235.2	344.0
Carbonate, mg/l	0	0
Chloride, mg/l	15920	15200
Magnesium, mg/l	200.0	249.6
pH, lab, pH units	7.92	7.90
Potassium, mg/l	37.1	37.3
Sodium, mg/l	9335.0	9125.0
Specific conductance, field, 25°C, umhos/cm	36000	36000
Sulfate, mg/l	2175.0	2175.0
Temperature, field, °C	18.0	18.0
Total dissolved solids, mg/l	27892	26434
Notes	15	15

TW-1

Parameter	3/07/78	3/12/78	4/07/78	6/01/87	6/07/87
Alkalinity, P., mg/l as $CaCO_3$			0		
Alkalinity, M., mg/l as $CaCO_3$			1194		
Aluminum, mg/l			4.25		
Bicarbonate, mg/l				88.5	1030
Calcium, mg/l				128	696
Calcium, mg/l			2000		
Carbonate, mg/l				0.00	0.00
Chloride, mg/l	22000	22000	18600	13800	18900
Copper, mg/l			<0.5		
Fluoride, mg/l			1.43		
Hardness, total, mg/l as $CaCO_3$			2300		
Iron, mg/l			90		
Magnesium, mg/l				200	254
Magnesium, mg/l as $CaCO_3$			300		
Maganese, mg/l			0.030		
Nitrate, mg/l					
Nitrate, mg/l as NO_3			<0.5	0.00	
pH, pH units	7.10	7.56	7.31	8.20	7.78
Potassium, mg/l				206	239
Sodium, mg/l	14300	14300	12900	9050	12100
Specific Conductance, umhos/cm				40500	43200
Sulfate, mg/l	9700	8600	2800	1420	2120
Total dissolved soilds, mg/l			36649		
Total dissolved solids, 180°C, mg/l				35300	36600
Anions + cations, mg/l				24900	35400
Notes	16	16	17, 18	17	17

OW–1

Date	5/28/87	6/08/87
Parameter		
Bicarbonate, mg/l	161	1050
Calcium, mg/l	400	696
Carbonate, mg/l	0.00	0.00
Chloride, mg/l	12100	19400
Magnesium, mg/l	146	224
Nitrate, mg/l	0.00	0.00
pH, pH units	7.80	7.70
Potassium, mg/l	253	231
Sodium, mg/l	8200	12500
Specific Conductance, umhos/cm	38300	43200
Sulfate, mg/l	2820	2180
TDS, 180°C, mg/l	33000	37500
Anions + cations, mg/l	24000	36300
Notes	17	17

OW-3

Parameter	Date 1/24/78	4/25/78	7/19/83	10/17/83	10/17/83	1/19/84	5/28/87	6/01/87	6/03/87	6/08/87
Alkalinity, field, mg/l				836					679	
Alkalinity, total, mg/l as $CaCO_3$										
Bicarbonate, mg/l	753		877.83	159		731.53	1210	1080		989
Boron, mg/l				3.2						
Bromine, mg/l					5.5					
Calcium, mg/l	768		792	800		1576	880	864		832
Carbonate, mg/l	0.00		0	0		0	0.00	0.00		0.00
Chloride, mg/l	27000	31500	26800	27435	26600	23760	13500	18100	28000	23700
del Carbon-13, per mil, PDB				-4.65						
del Oxygen-18, per mil, wrt SMOW				-9.84						
del Deuterium, per mil, wrt SMOW				-71.2 -71.7						
Fluoride, mg/l			0.7							
Iodine, ug/l					70					
Iron, mg/l			0.47							
Magnesium, mg/l	273		244.8	220		552.0	390	268		293
Nitrate, mg/l				<0.4			0.00	0.00		0.00
Percent modern carbon				5.72 +/-0.58						
pH, pH units	7.3	6.42					7.40	7.30	7.1	7.58
pH, field, pH units				6.36						

OW-3

Parameter / Date	1/24/78	4/25/78	7/19/83	10/17/83	10/17/83	1/19/84	5/28/87	6/01/87	6/03/87	6/08/87
pH, lab, pH units			7.61			7.78				
Phosphorus, −T, mg/l as P									<0.01	
Phosphorus, −0, mg/l as P									<0.01	
Potassium, mg/l	94.6		62.9	75		65.4	253	250		282
Sodium, mg/l	17800	20475	19640	17500		22400	9050	12100		15800
Specific conductance, umhos/cm	67800	50000		69000			53600	50100	53760	53200
Specific conductance, field, 25°C, umhos/cm			65800	78400		>60000				
Sulfate, mg/l	2600	2725	2810	2880		2770	3400	2480	2255	2600
Temperature, field, °C			18.5	19.0		18.5				
Total dissolved solids, mg/l			49180			51005				
Total dissolved solids, 105°C, mg/l	49000									
Total dissolved solids, 180°C, mg/l							48000	48600		49300
Total dissolved solids, calculated, mg/l		54700								
Total dissolved solids, by summation, mg/l				49072						
Total suspended solids, mg/l									47	
Tritium activity, TU				−2.3+/−0.5						
Volatile suspended solids, mg/l									17	
Anions + cations, mg/l	49300						28700	35100		44400
Notes	17	17	19	20	21	22	17	17	17	17

OW-4

Parameter	1/31/78	4/25/78	7/19/83
Bicarbonate, mg/l	803		1011.95
Calcium, mg/l	576		624
Carbonate, mg/l	0.00		0
Chloride, mg/l	16400	29000	19700
Iron, mg/l			0.83
Magnesium, mg/l	322		182.4
pH, pH units	7.30	6.61	
pH, lab, pH units			7.55
Potassium, mg/l	68.4		51.7
Sodium, mg/l	10600	18850	17940
Specific Conductance, umhos/cm	46500	48000	
Specific conductance, field, 25°C umhos/cm			57000
Sulfate, mg/l	2200	2650	2660
Temperature, field, °C			17.5
Total dissolved solids, mg/l			36406
Total dissolved solids, 105°C, mg/l	31900		
Total dissolved solids, calculated, mg/l		50500	
Anions + cations, mg/l	30900		
Notes	17	17	23

NOTES

1 From well log in USBR, 1979, Appendix D.

2 Sample #11, flowing open hole at 296 ft.

3 Sample #12, flowing open hole at 296 ft.

4 Sample #13, flowing open hole at 296 ft.

5 Sample #14, flowing open hole at 296 ft., after circulating.

6 Sample #15, flowing open hole at 316 ft.

7 Sample #16, flowing open hole at 336 ft.

8 Sample #17, flowing open hole at 356 ft.

9 Sample #18, flowing open hole at 356 ft.

10 Sample #19, flowing open hole at 356 ft.

11 Sample #23, flowing open hole at 356 ft.

12 Sample #5, flowing open hole at 516 ft.

13 Sample #6, flowing through casing set at about 40 ft.

14 Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21, and HGC, 1984a, Appendix B, Table B.1. Values are from USBR, 1984, except for fluoride, iron and nitrate, which are from HGC, 1984a. Note that samples from DH−2 may not be representative of the brine aquifer, because the well is only cased to about 40 feet (USBR, 1984, Hydrology/Hydrogeology Appendix, p. IV−53 and 56.)

15 Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21. Note that samples from DH−3 were obtained after air−lifting for about 1 hour; the specific conductance had not stabilized at the time of sample collection (USBR, 1984, Hydrology/Hydrogeology Appendix, p. IV − 53 and 56.)

16 Reported in USBR, 1979, p. 19.

17 From CRMWA files.

18 Iron in suspension.

19 Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21 and HGC, 1984a, Appendix B, Table B.1. Note that outgassing of CO_2 rapidly changed pH of water samples collected from well OW−3, and probably, other brine aquifer wells (USBR, 1984, Hydrology/Hydrogeology Appendix, p. IV−53). Values are from USBR, 1984, except for fluoride and iron, which are from HGC, 1984a.

20 Reported in HGC, 1984a, p. 156,157,161, and Appendix B, Table B.1. Appendix B, Table B.1 includes a different value (69000) for specific conductance than p. 161. Del Carbon−13 and Percent modern carbon (PMC) values reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Attachment C.

21 Reported in HGC, 1984a, p. 172.

22 Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21.

23 Reported in USBR, 1984 (Hydrology/Hydrogeology Appendix), Table 21, and HGC, 1984a, Appendix B, Table B.1. Values are from USBR, 1984, except for iron, which is from HGC, 1984a.

TAB 13 Part B.4 Permian aquifers

AGRICULTURE
CHEMICAL ANALYSIS
PETROLEUM

BC LABORATORIES INC
J. J. EGLIN, REG. CHEM. ENGR.
3016 UNION AVE BAKERSFIELD, CALIFORNIA 93305
MAIN OFFICE 4100 PIERCE ROAD, BAKERSFIELD CA 93308 PHONE 327-4911

Hydro Geo Chem, Inc.
744 North Country Club Road
Tucson, Arizona 85716

Date Reported: 10/18/83
Date Received: 10/3/83
Laboratory No.: 10729

WATER ANALYSIS

Sample Description: 5A 9/22/83 1400

Constituents	Parts/million
Calcium	1,360.
Magnesium	610.
Sodium	29,000.
Potassium	64.
Carbonate	0.
Bicarbonate	904.
Chloride	43,719.
Sulfate	5,250.
Nitrate	(<) 0.4
Total Dissolved Solids	80,948.
Boron	3.5
Silica	37.
Hardness as $CaCO_3$	5,913. (345 gr/gal)
Electrical Conductivity, Micromhos	70,650.
pH	6.6

B C LABORATORIES, INC.

BY J. J. Eglin
J. J. Eglin

ad

Field Parameters

Well:	"Dripping Springs" (Permian-Yeso?)
Location:	13.31.25.12
Date:	9-22-83
Time:	1400
Temp:	22.8°C
pH:	6.02
Alkalinity:	765 mg/l

Index to **TAB 14**: Maps, charts and graphs related to water quality

A. Figures related to several aquifers

HGC, 1984a, Figure 43

HGC, 1984a, Figure 44

HGC, 1984a, Figure 45

HGC, 1984c, two unnumbered figures

USBR, 1979, Figure 3

B. Figures related to aquifers in single geologic unit

1. Alluvium

HGC, 1984a, Figure 34

HGC, 1984a, Figure 35

HGC, 1984a, Figure 36, 20 and 21

USBR, 1984, Figures 7-14

USBR, 1984, Figures 25-42

USBR, 1979, Figure 2

2. Triassic aquifers

HGC, 1984a, Figure 32

USBR, 1984, Figure 61

3. Brine aquifer

HGC, 1984a, Figure 33

USBR, 1984, Figure 62

4. Permian aquifers

HGC, 1984a, Figure 30

HGC, 1984a, Figure 31

5. Figures related to pre-Leonardian aquifer(s)

Bassett and Bentley, 1983, Figure 11

TAB 14 Part A. Figures related to several aquifers

HGC, 1984a

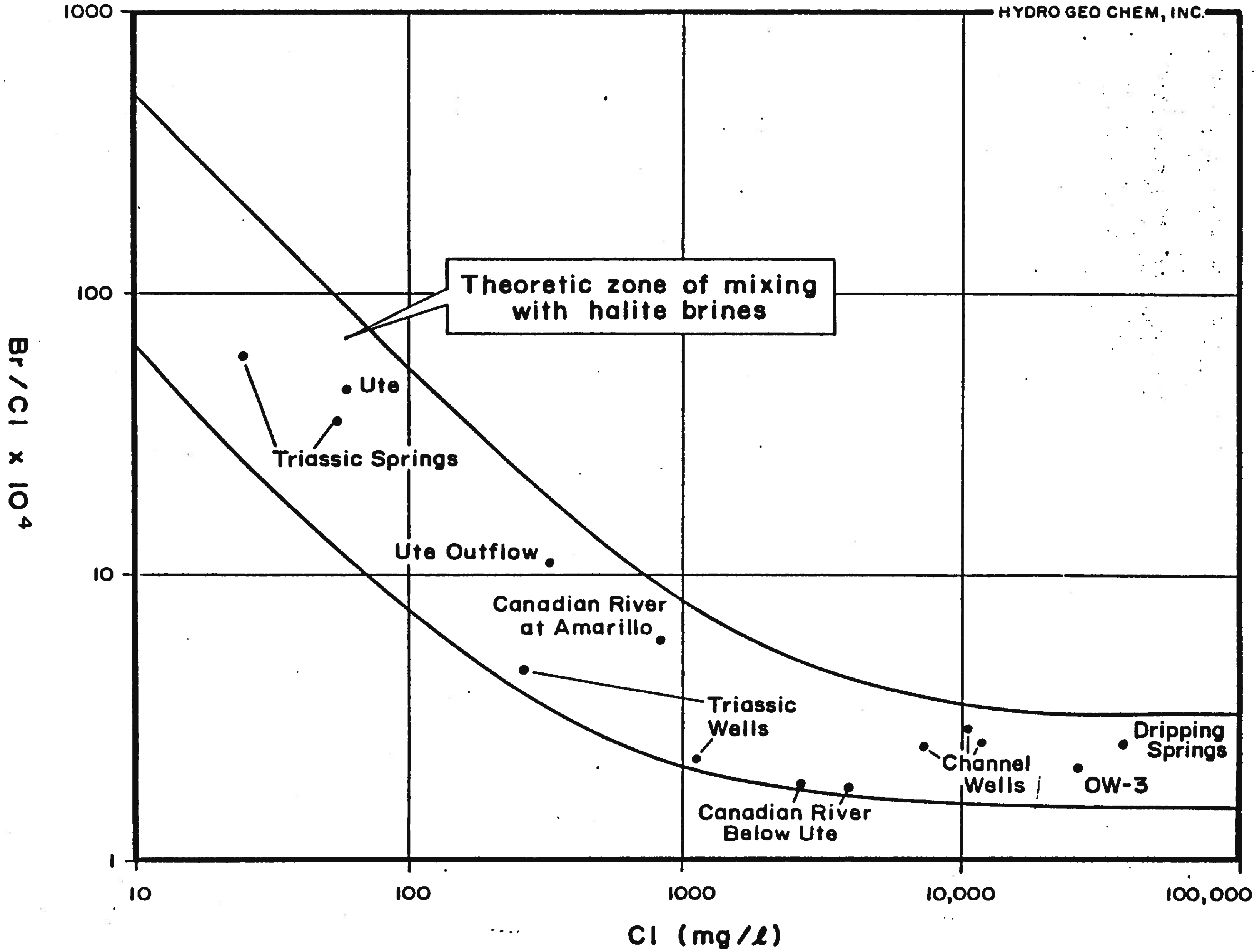


Figure 43. Bromide/chloride ratios of surface and groundwater

HGC, 1984a

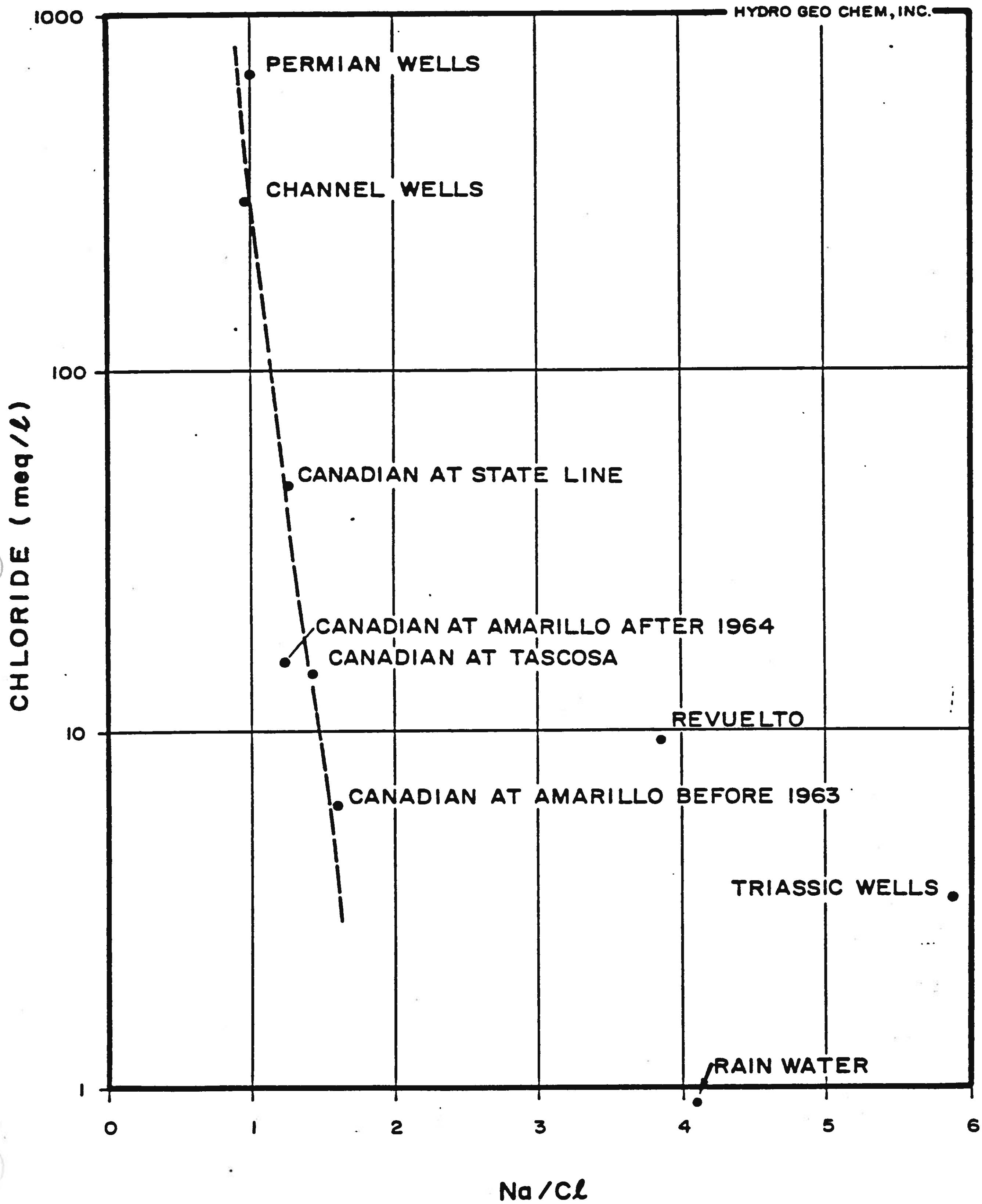


Figure 44. Sodium/chloride ratios of surface and groundwater

HGC, 1984a

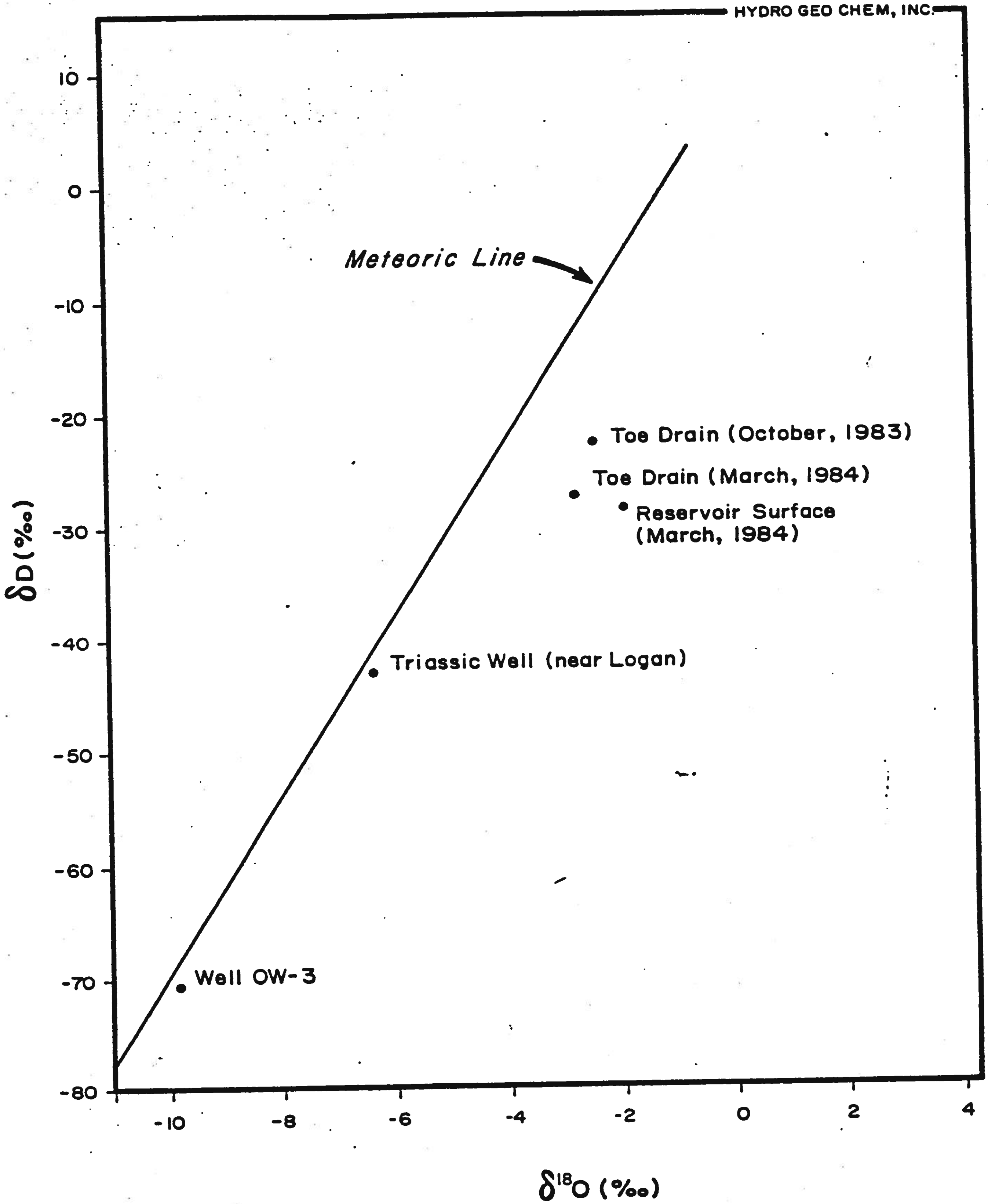
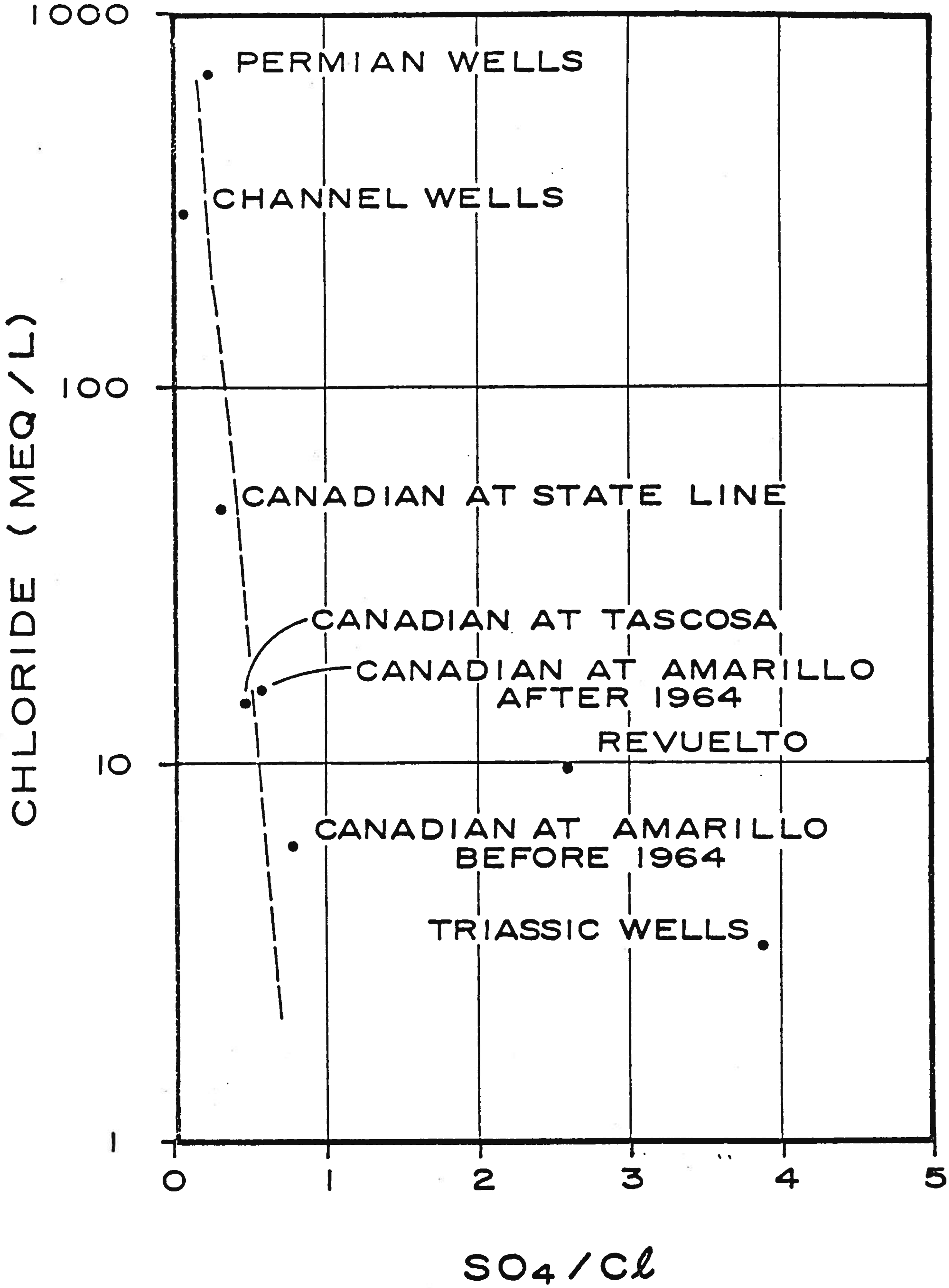


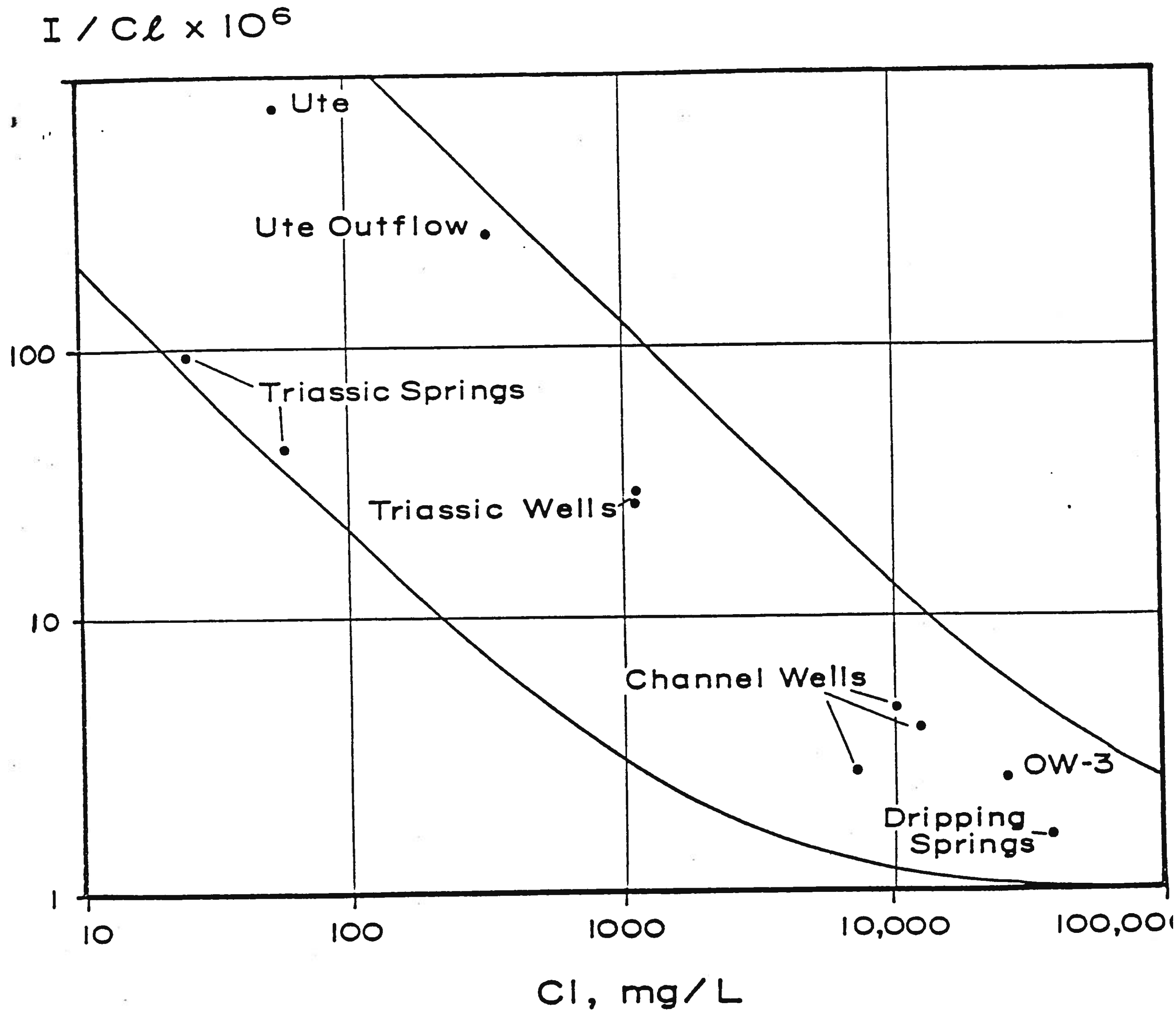
Figure 45. Stable isotopic distributions

HGC, 1984c



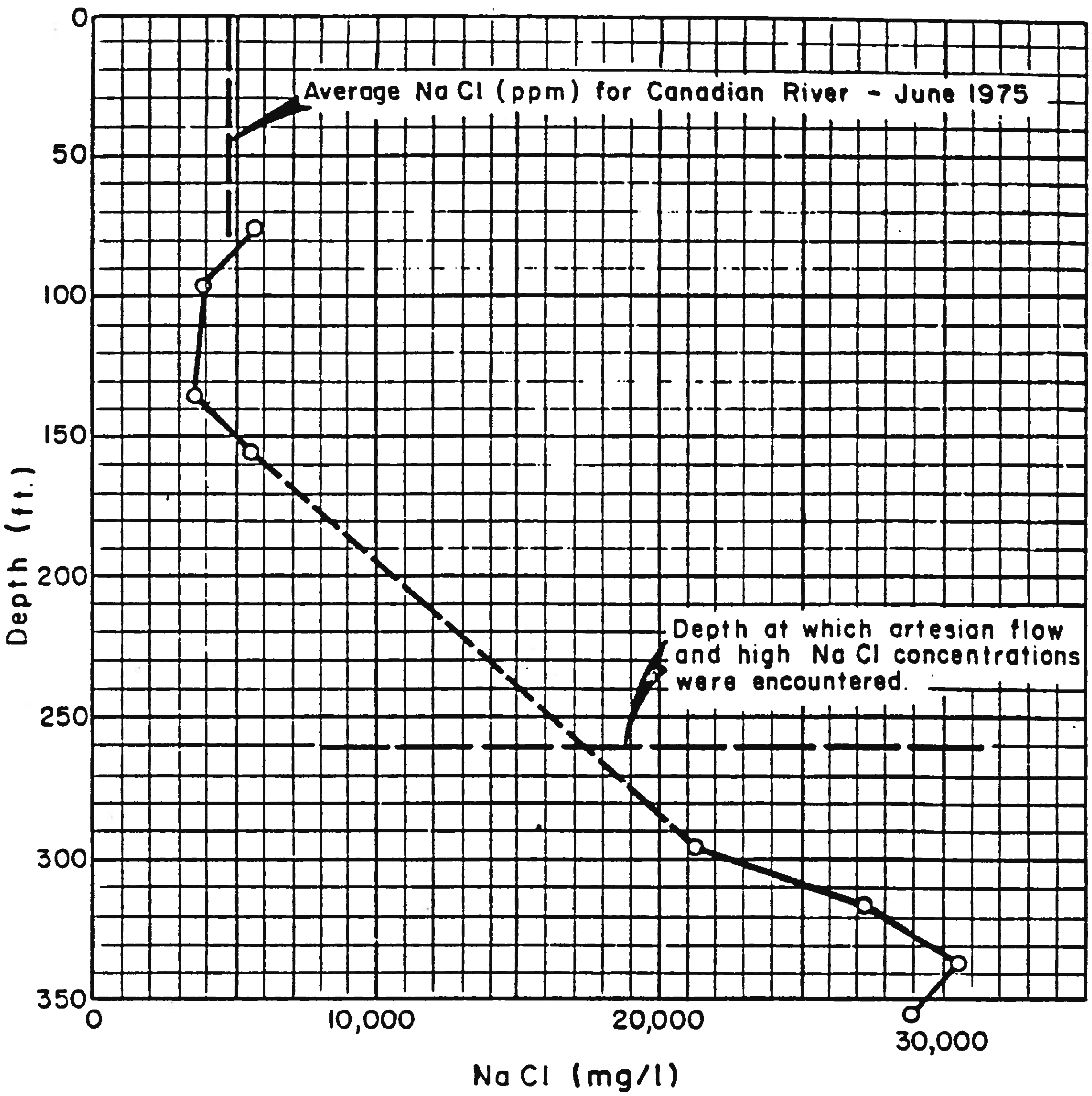
SULFATE - CHLORIDE RATIOS OF SURFACE AND GROUNDWATERS

HGC, 1984c



IODIDE - CHLORIDE RATIOS, THIS STUDY

USBR, 1979



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LAKE MEREDITH SALINITY STUDY, TEX.-N. MEX.

Na Cl vs. Depth

DH-1

JUNE 1975

FIGURE 3

TAB 14 Part B.1 Figures related to channel alluvium

HGC, 1984 a

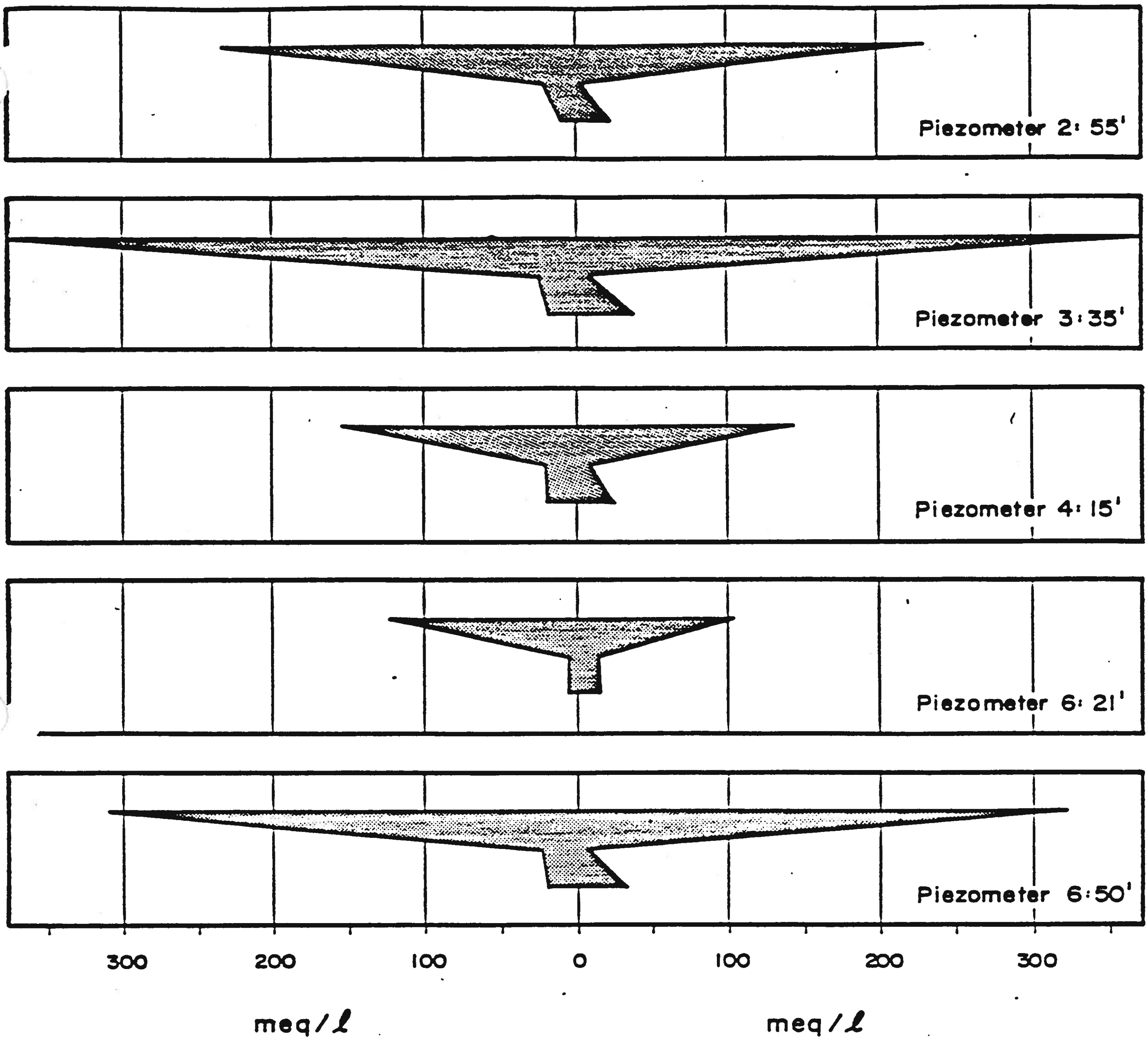


Figure 34. Stiff diagrams of water from wells in channel deposits

HGC, 1984a

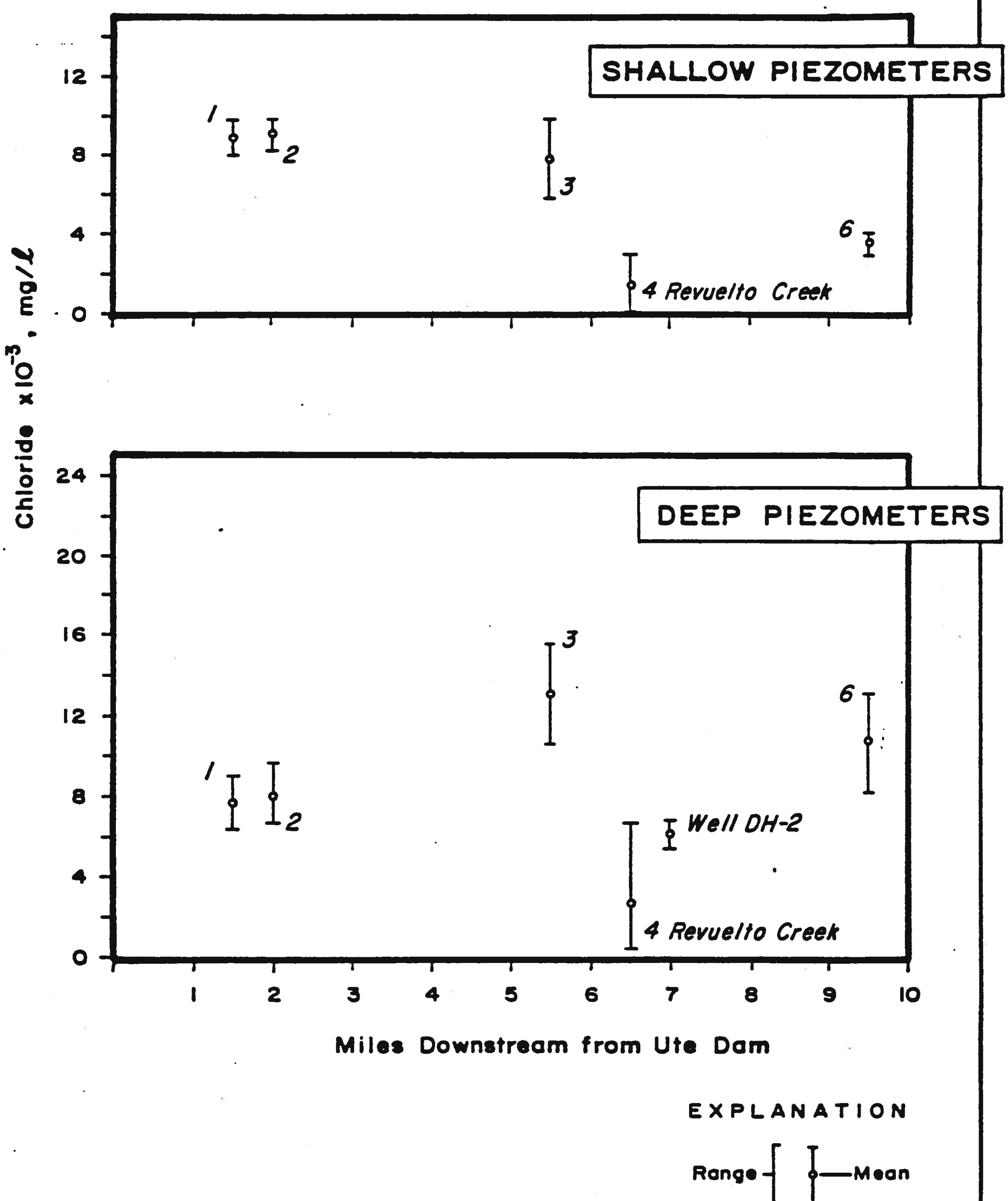


Figure 35. Ranges of chloride concentrations in water from wells in channel deposits

HGC, 1984a

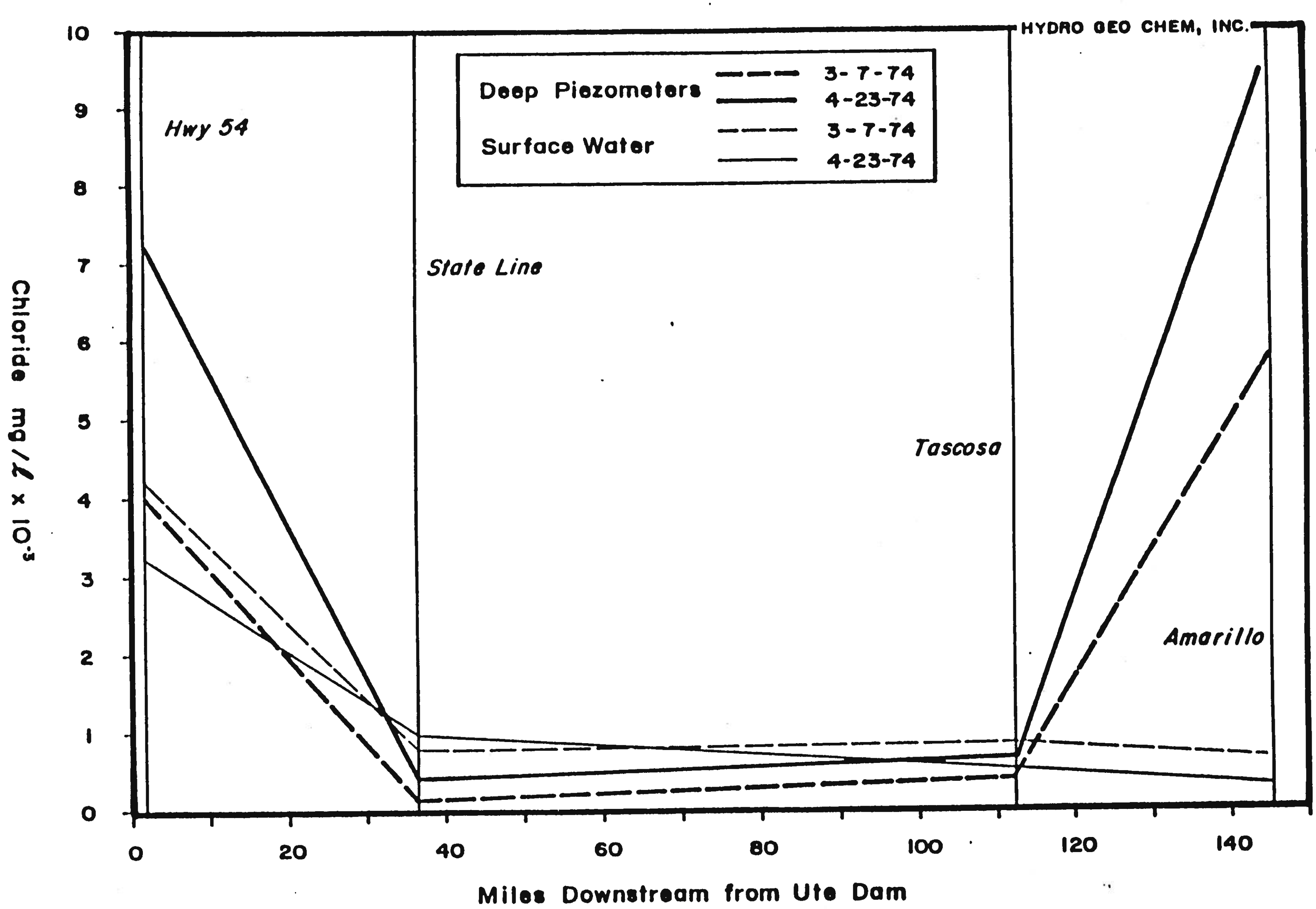


Figure 36: Ranges in chloride concentrations in CRMWA piezometers

HGC, 1984a

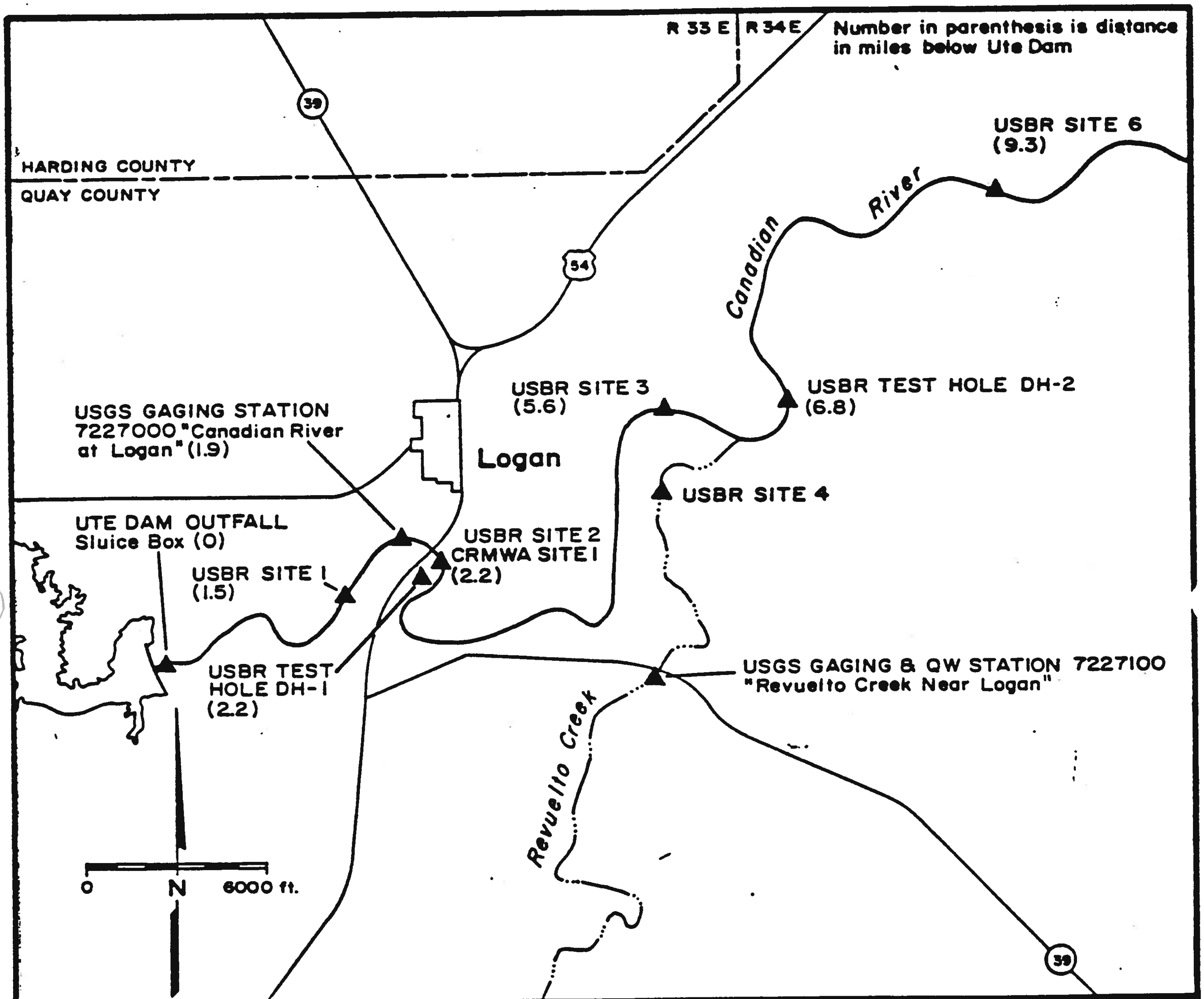


Figure 20. Location map of wells and measuring points in detailed study area

HYDRO GEO CHEM, INC.

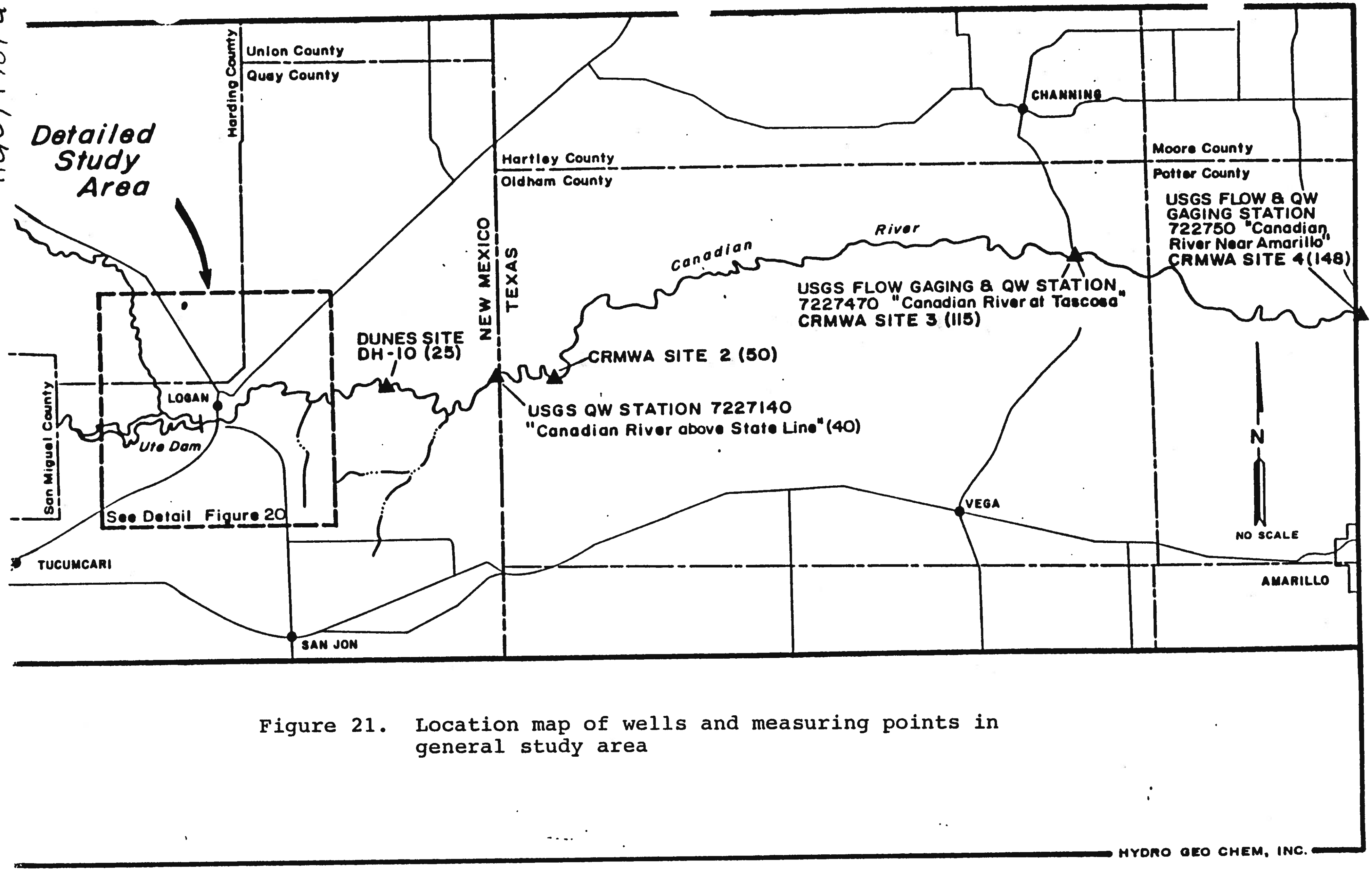


Figure 21. Location map of wells and measuring points in general study area

USBR, 1984

K+E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO.

46 1513

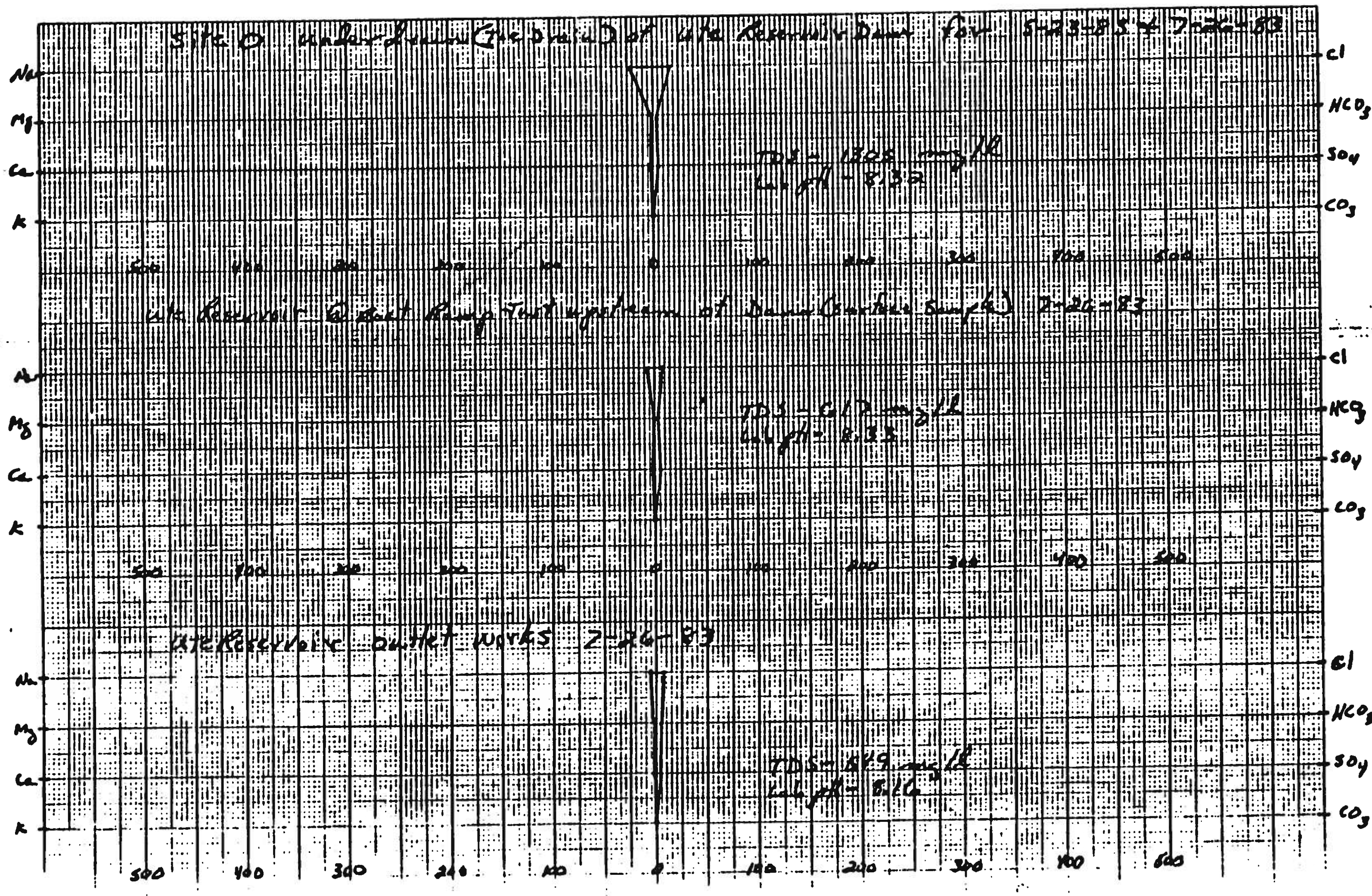


Figure 7 - Stiff Diagrams of Water Samples Collected at Site O and Ute Reservoir Near Logan, NM

· USBR, 1984

K+E 10 X 10 TO THE CENTIMETER · KEUFFEL & ESSER CO. · 46 1513

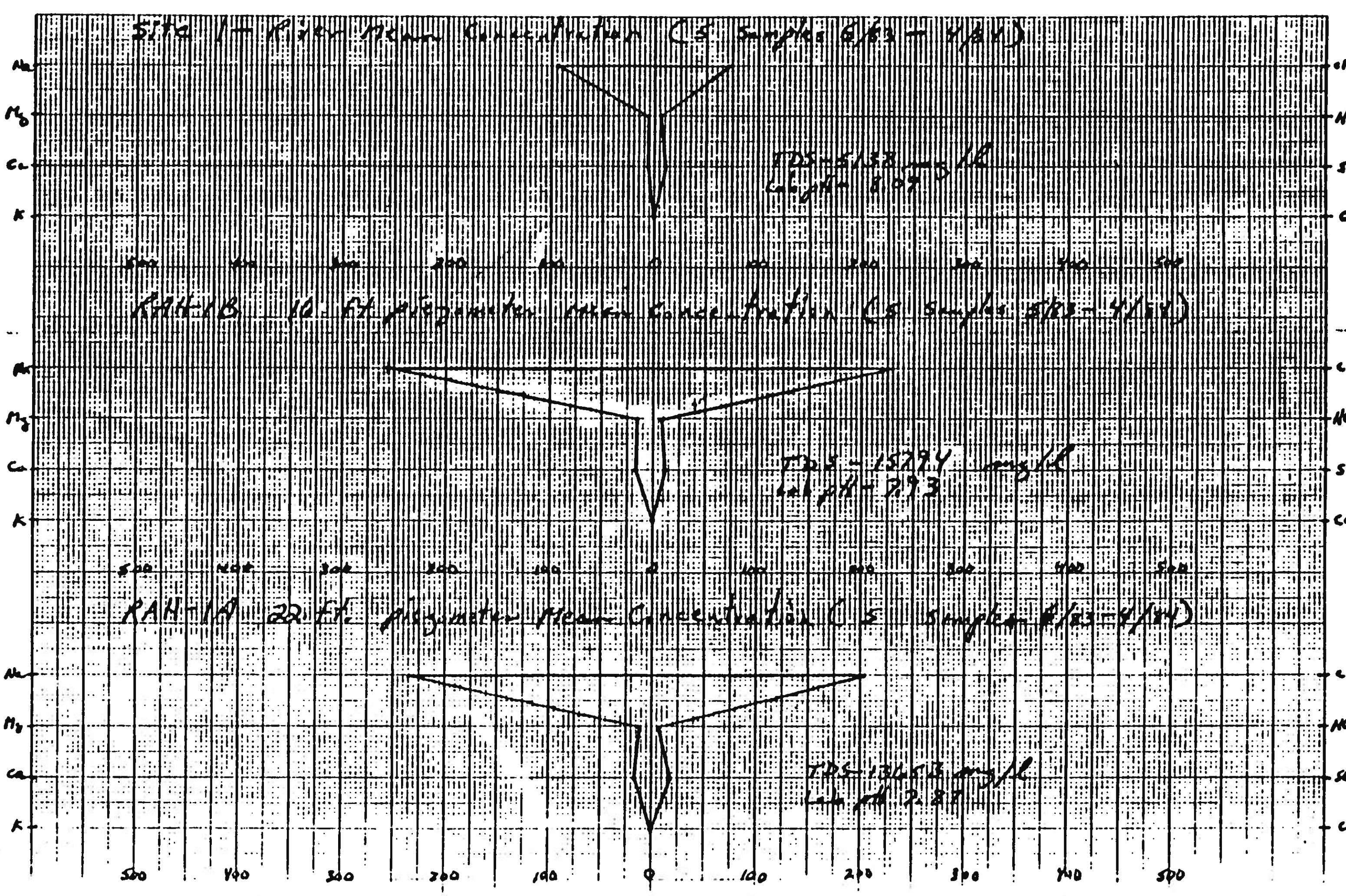


Figure 8 - Stiff Diagrams for Water Samples Collected at Site 1 Near Logan, NM

USBR, 1984

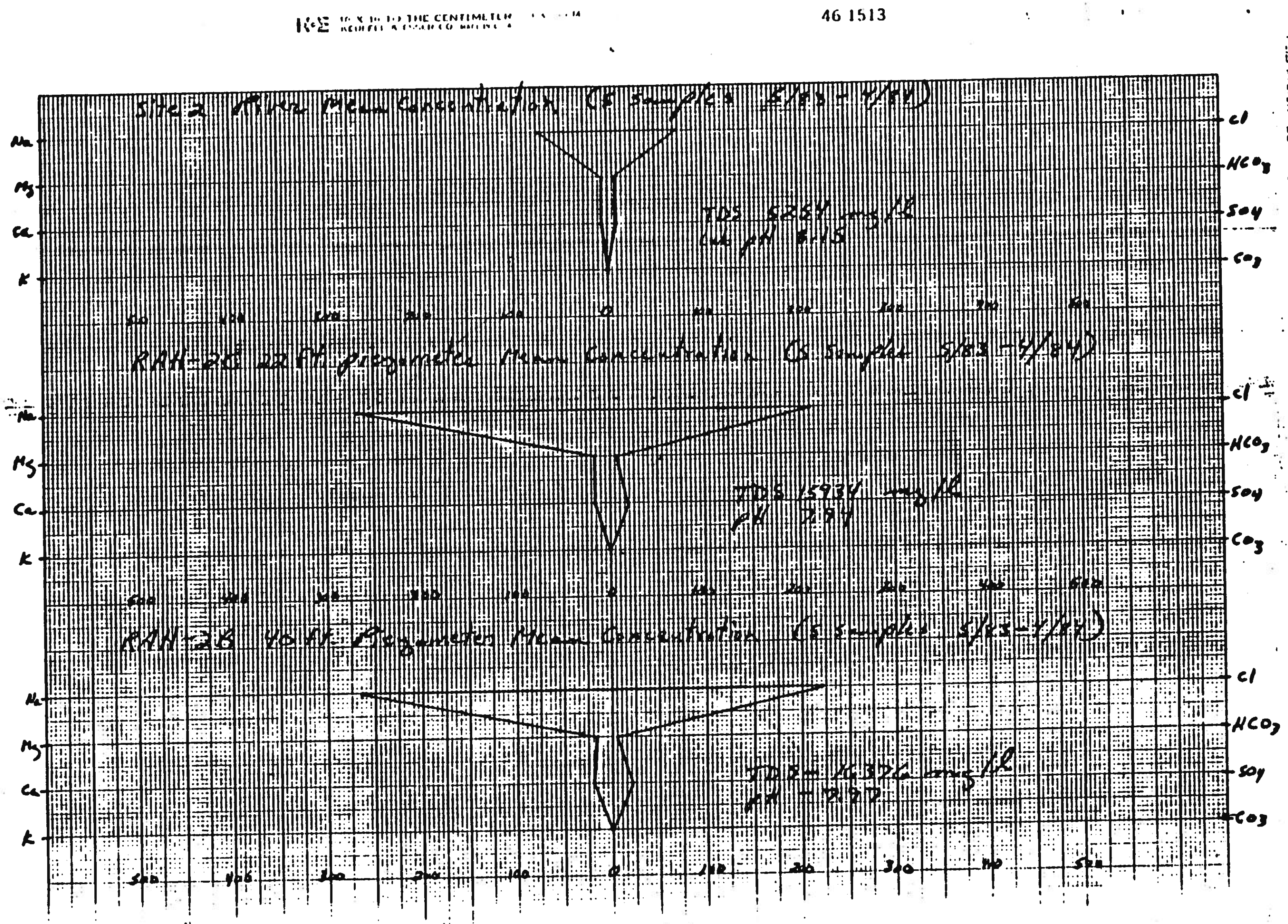


Figure 9. - Stiff Diagrams For Water Samples Collected at Site 2 Near Logan, NM

USBR, 1984a

K-E KEUFFEL & ESSER CO.

46 1513

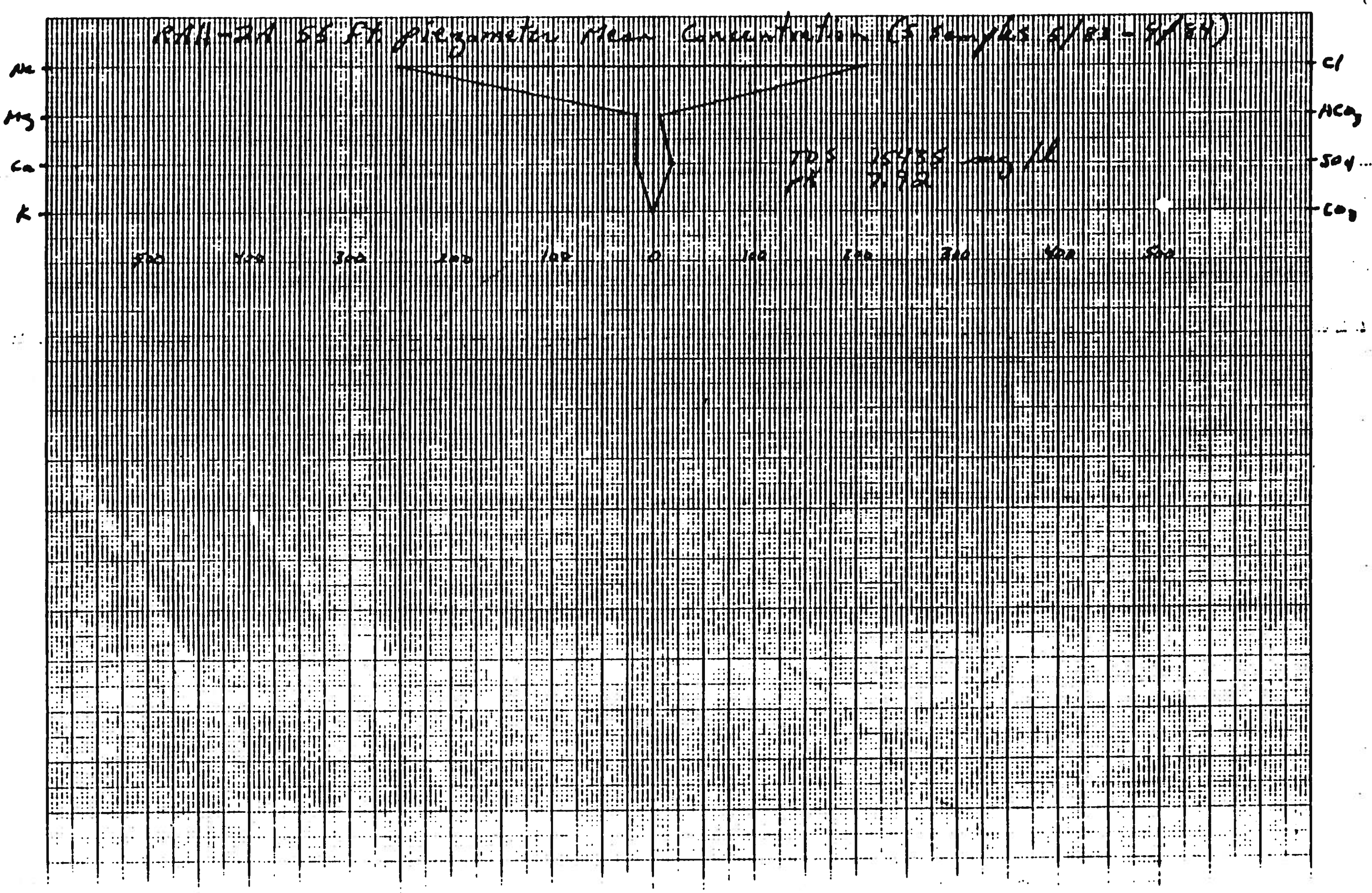


Figure 9 (continued)

USBR, 1984

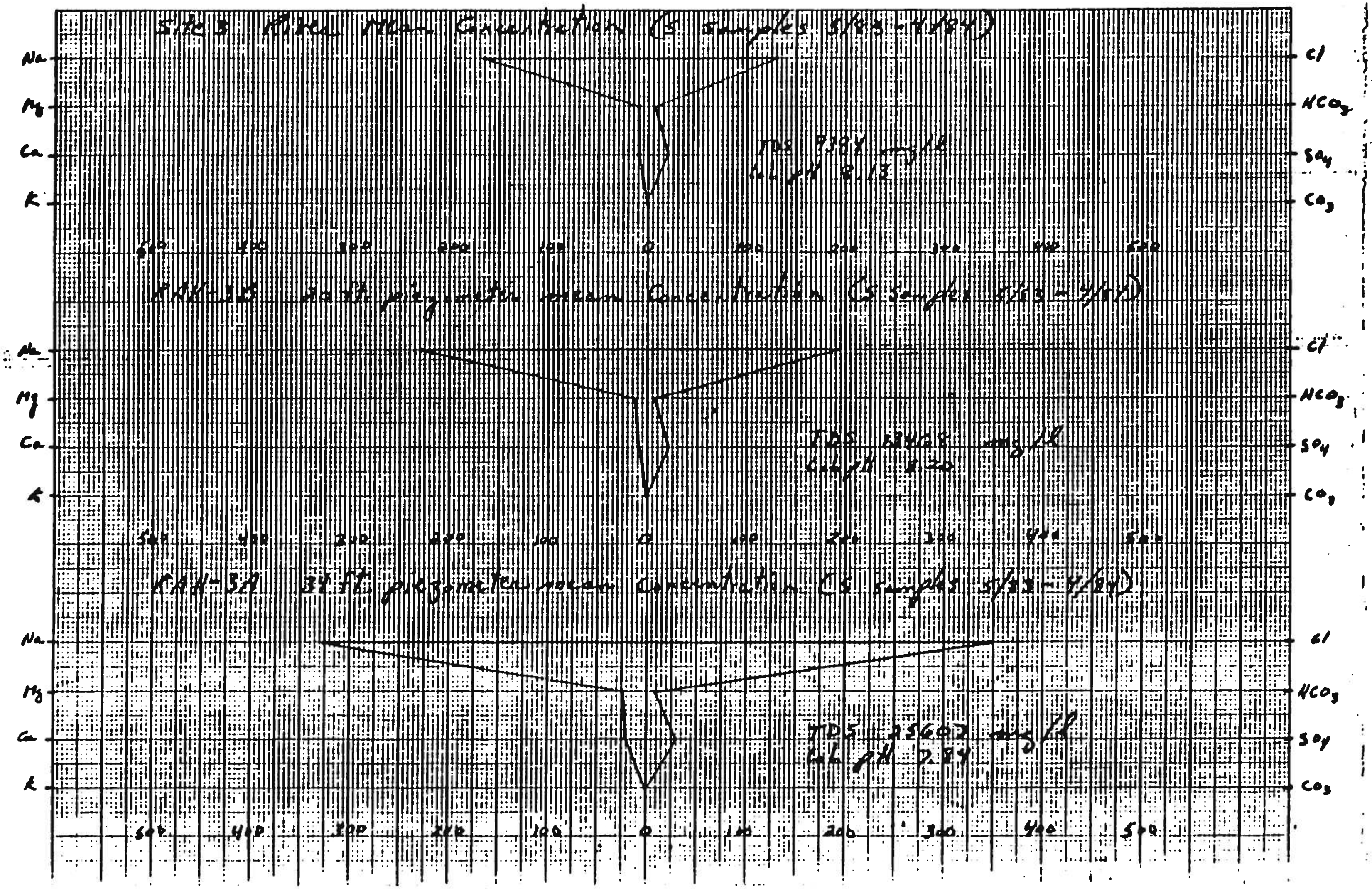


Figure 10 - Stiff Diagrams for Water Samples Collected at Site 3 Near Logan, NM

USBR, 1984

K&E 10 X 10 TO THE CENTIMETER 46 1513

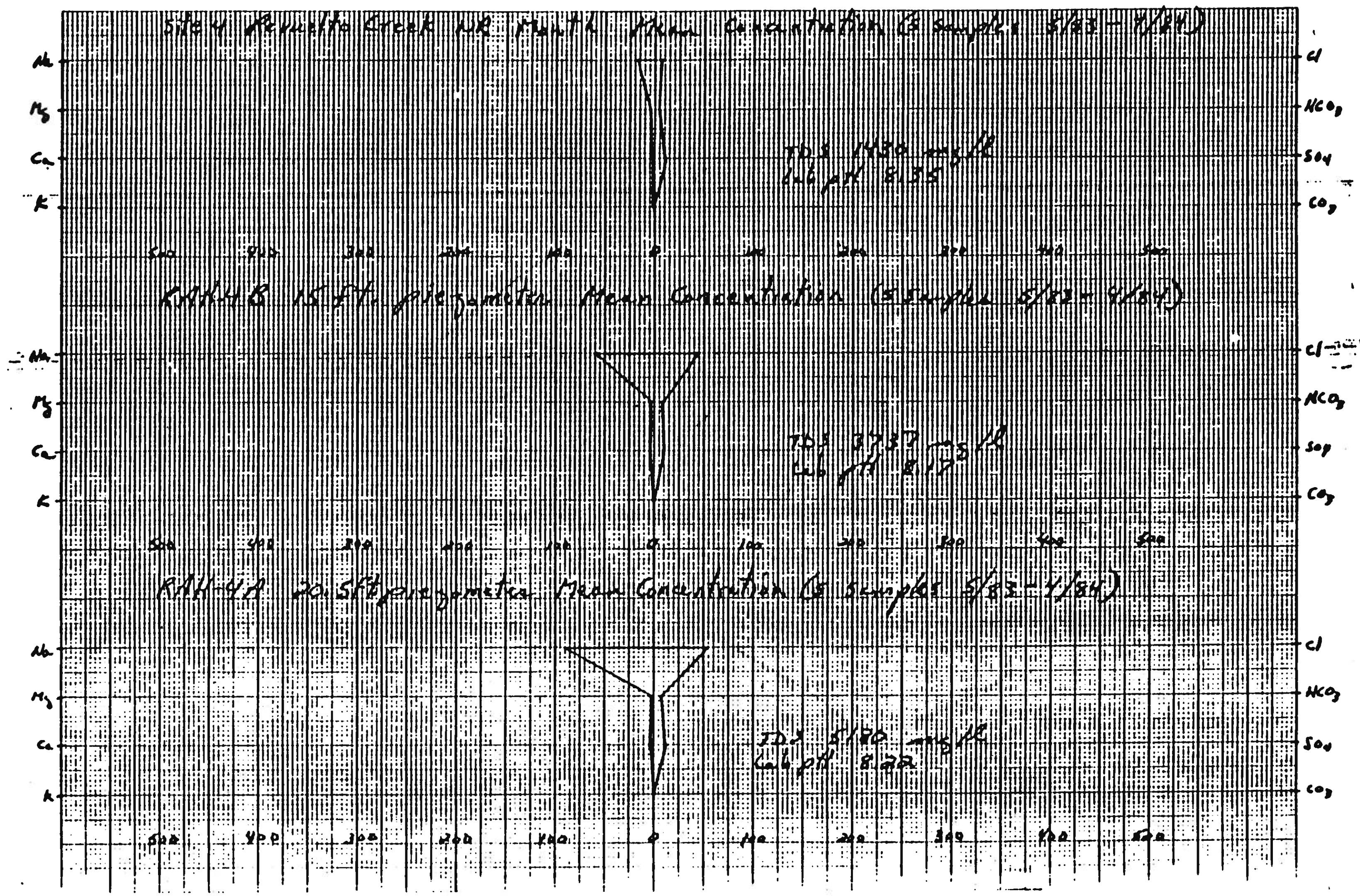


Figure 11 - Stiff Diagrams for Water Samples Collected at Site 4 Near Logan, NM

USBR, 1984

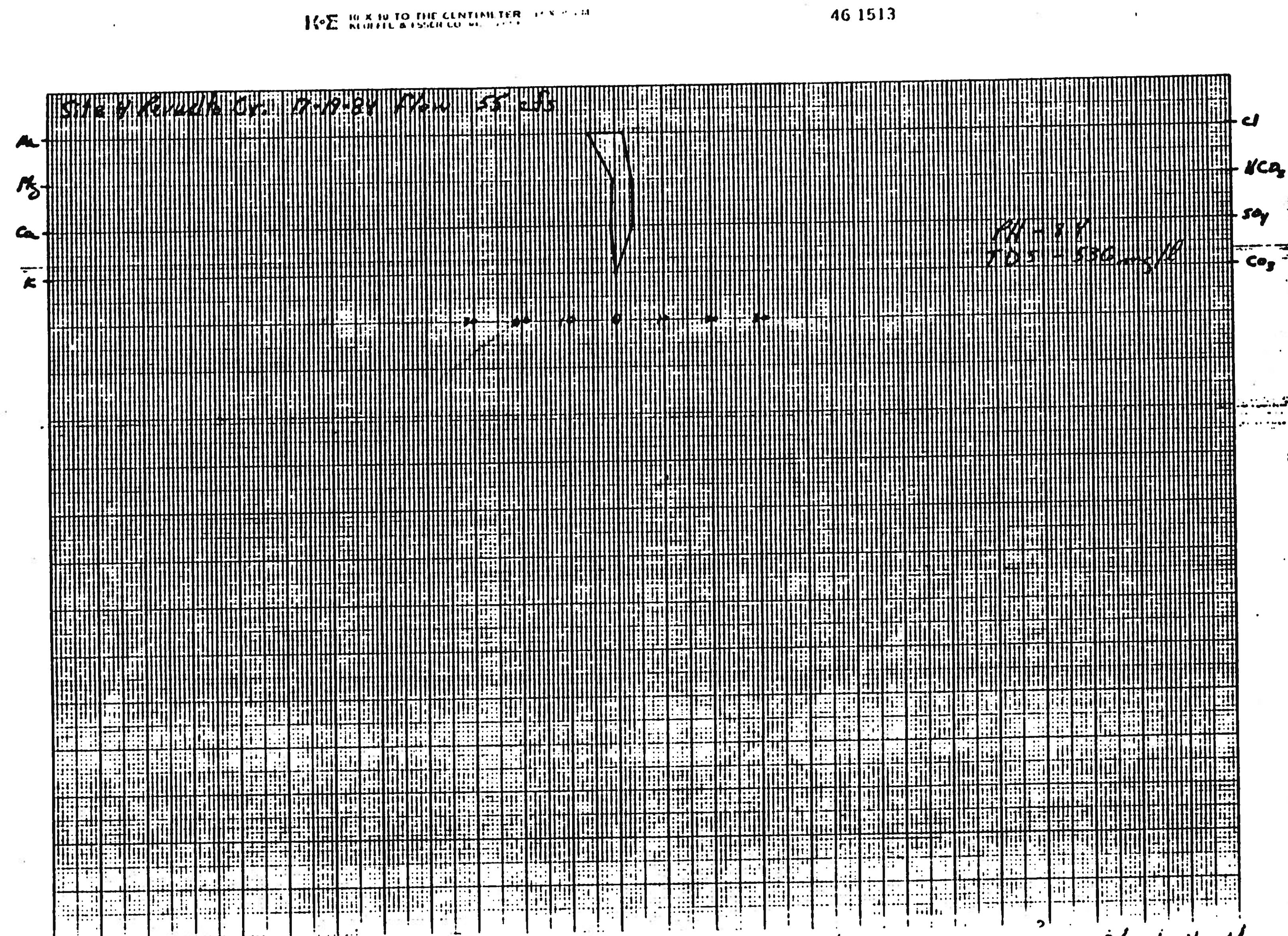
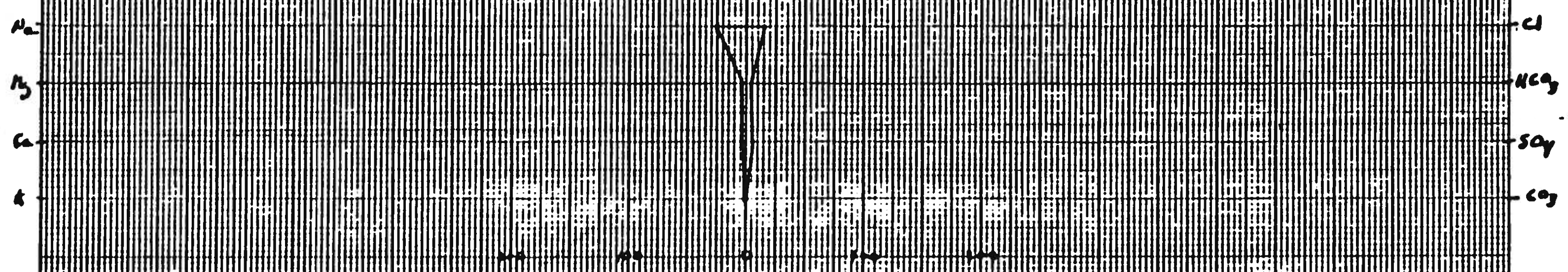


Figure 12 - Stiff Diagram for Water Sample When Creek Flow Was 55 ft³/s at Site 4 Near Logan, NM

USBK, 1984

USGS Revuelto Creek nr Logan, NM 07227100 WY 1981 and WY 1982



Mean of 7 Samples in meq/l

	Flow (cfs)	Na	Ca	Mg	K	Cl	HCO3	Sample Alk (as CaCO3)	CO3 (est)	SO4	Sample TDS (mg/l)	pH
Min	.01	160	28	17	1.5	8.3	—	180	—	64	638	8.5
Max	5870	1100	65	80	8.0	1500	—	320	—	570	3520	8.7
Mean	—	578	42.9	34.5	4.5	567	~246	217	~0	336	1903	8.5
meq/l	—	25	2.5	2.8	0.12	16	~4.3 est.	—	~0 est.	7.0	—	—

only Total Alk reported

Figure 13 – Stiff Diagram For Water Samples Collected by USGS at Revuelto Creek Gage Near Logan NM

·USGK, 1984

K·E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO. 46 1513

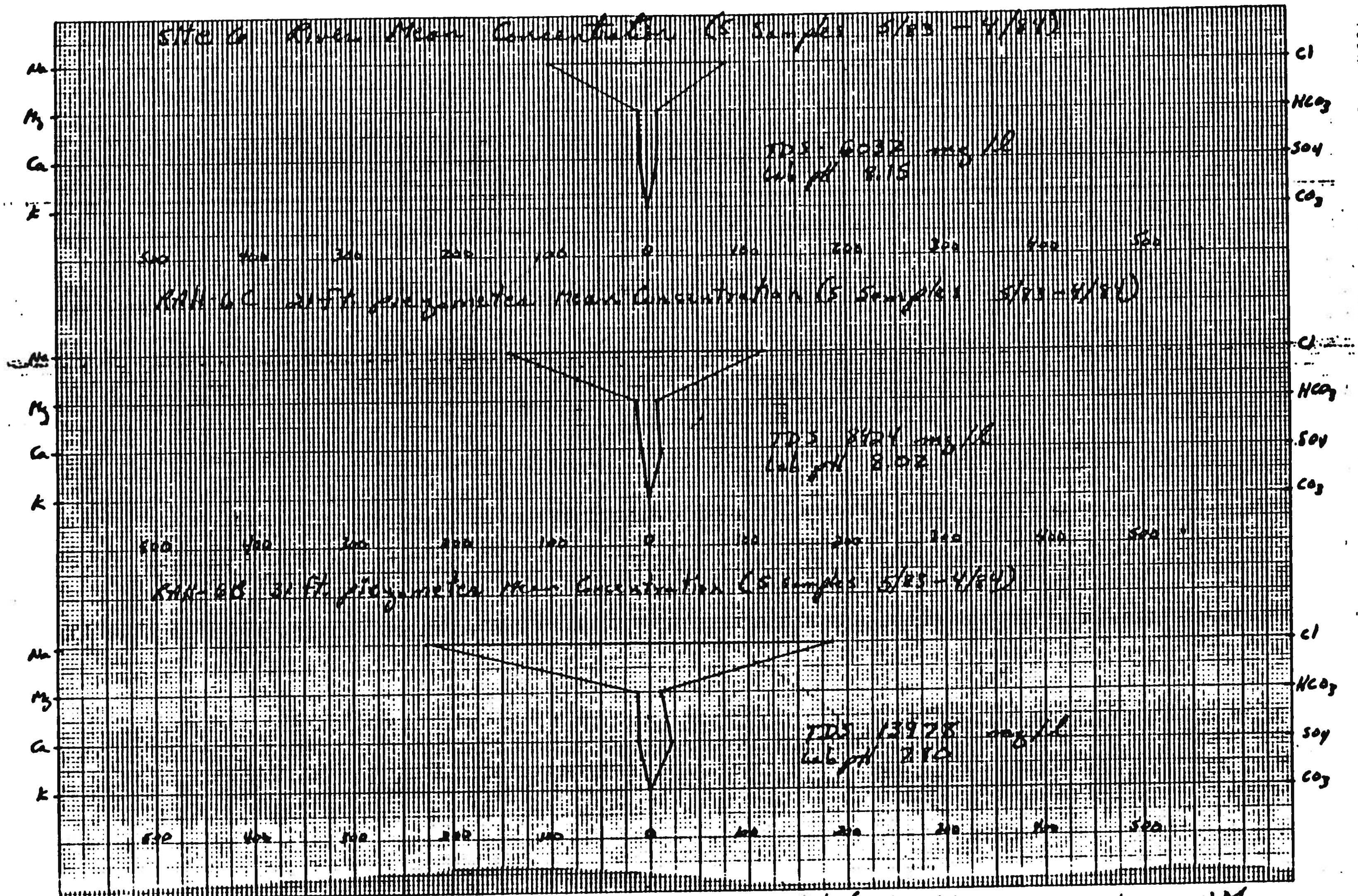


Figure 14 – Stiff Diagrams for Water Samples Collected at Site 6 Near Logan, NM

USBR, 1984

46 1513

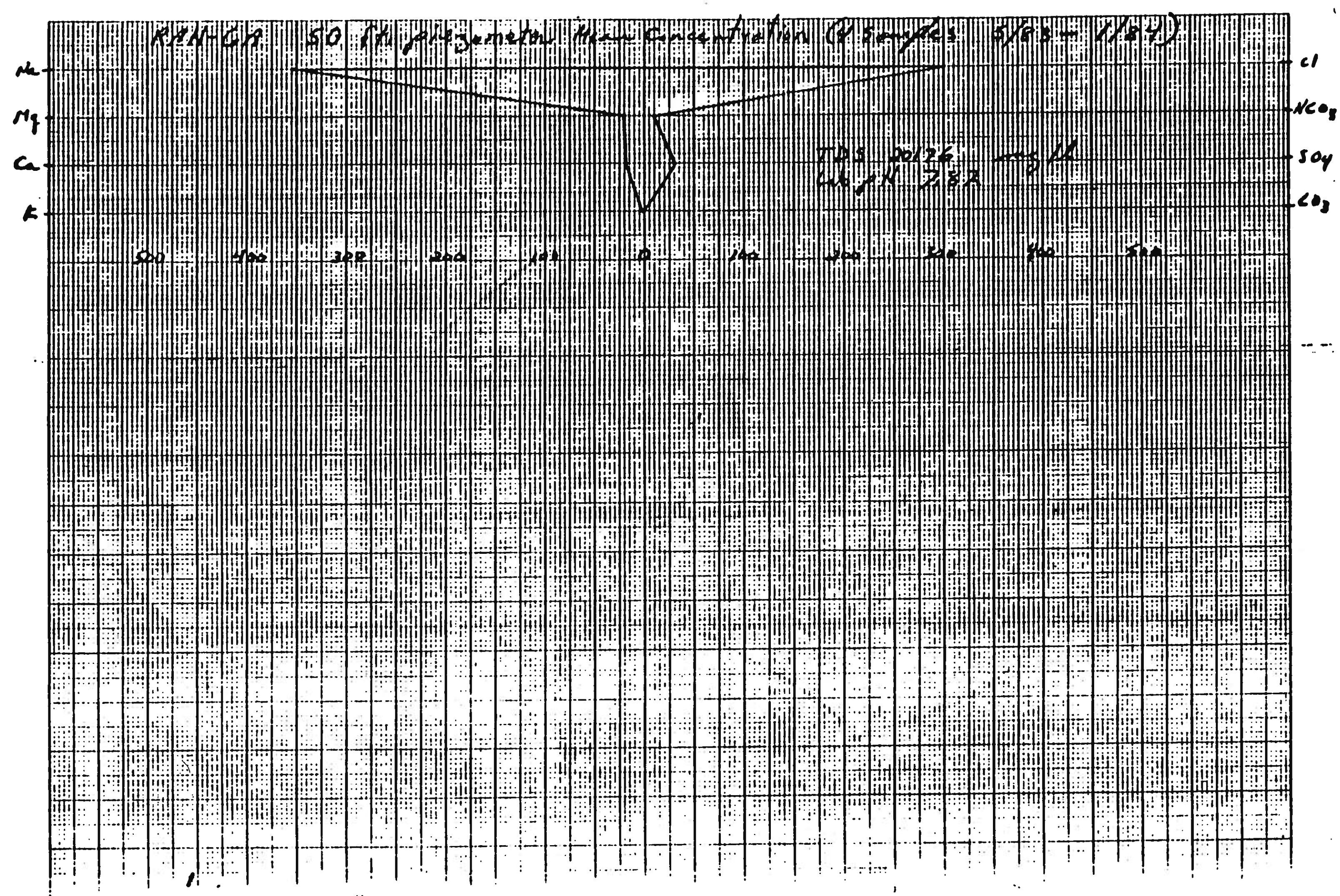


Figure 14 (Continued)

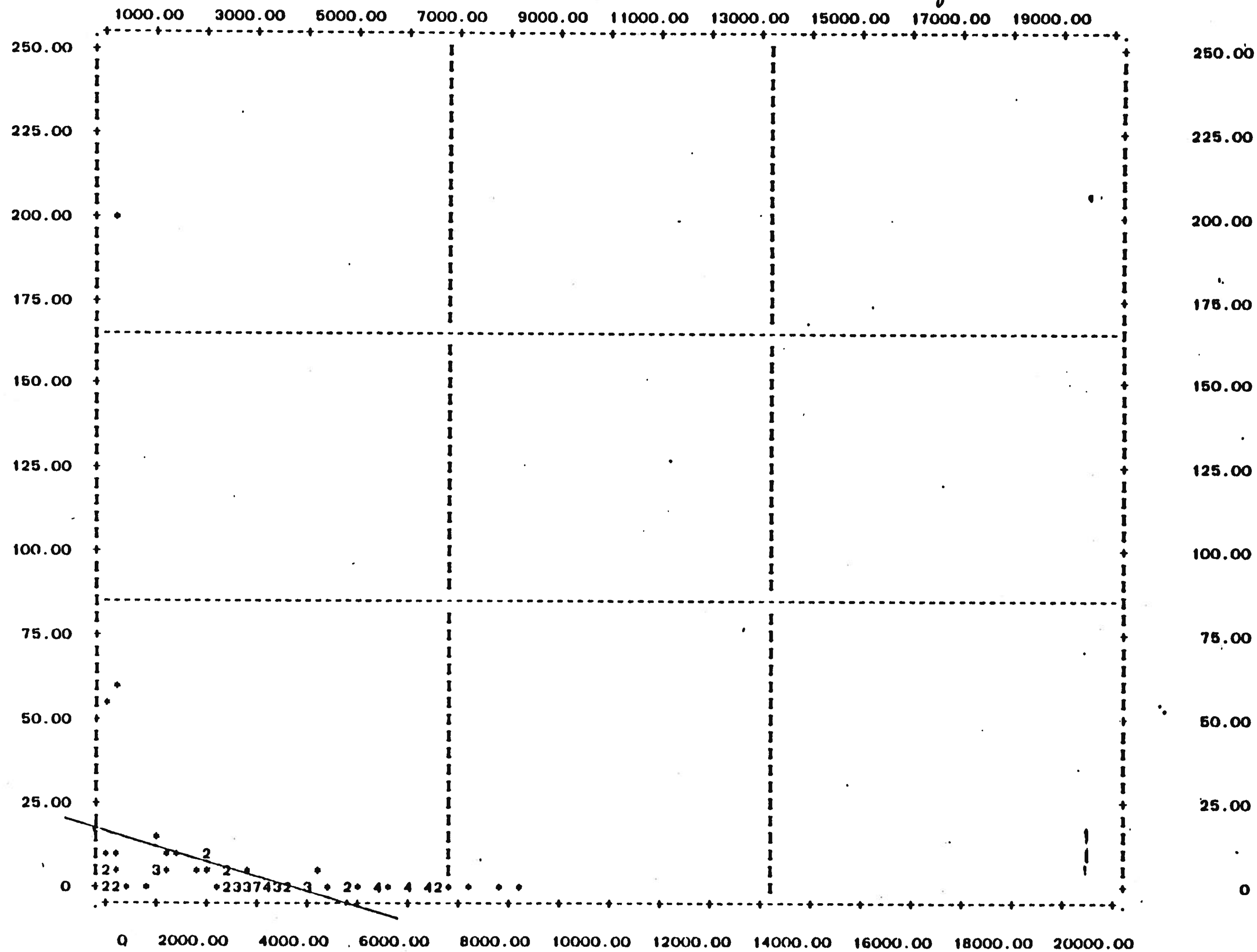
USBR, 1984

CANADIAN RIVER NR LOGAN,NM
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S01 S04 S08 S13 S17

84/09/23. 16.52.12. PAGE 3

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR003 CHLORIDES

Figure 25 – Scattergram, Flow vs Chlorides
Group I Data



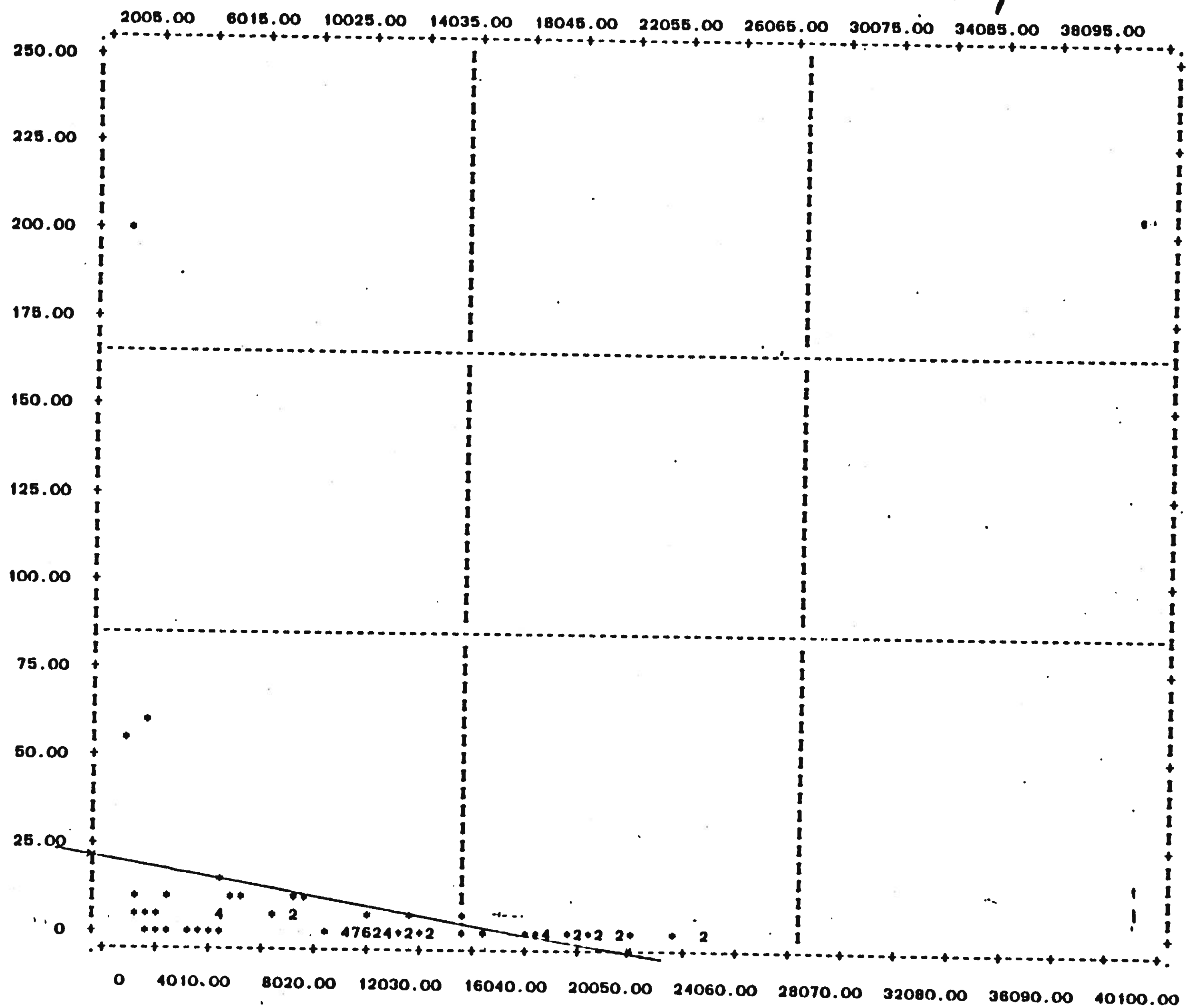
USBR, 1984

CANADIAN RIVER NR LOGAN,NM
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S01 S04 S08 S13 S17

84/09/23. 16.52.12. PAGE 5

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 26 - Scattergram, Flow VS Field Conductance
Group I Data

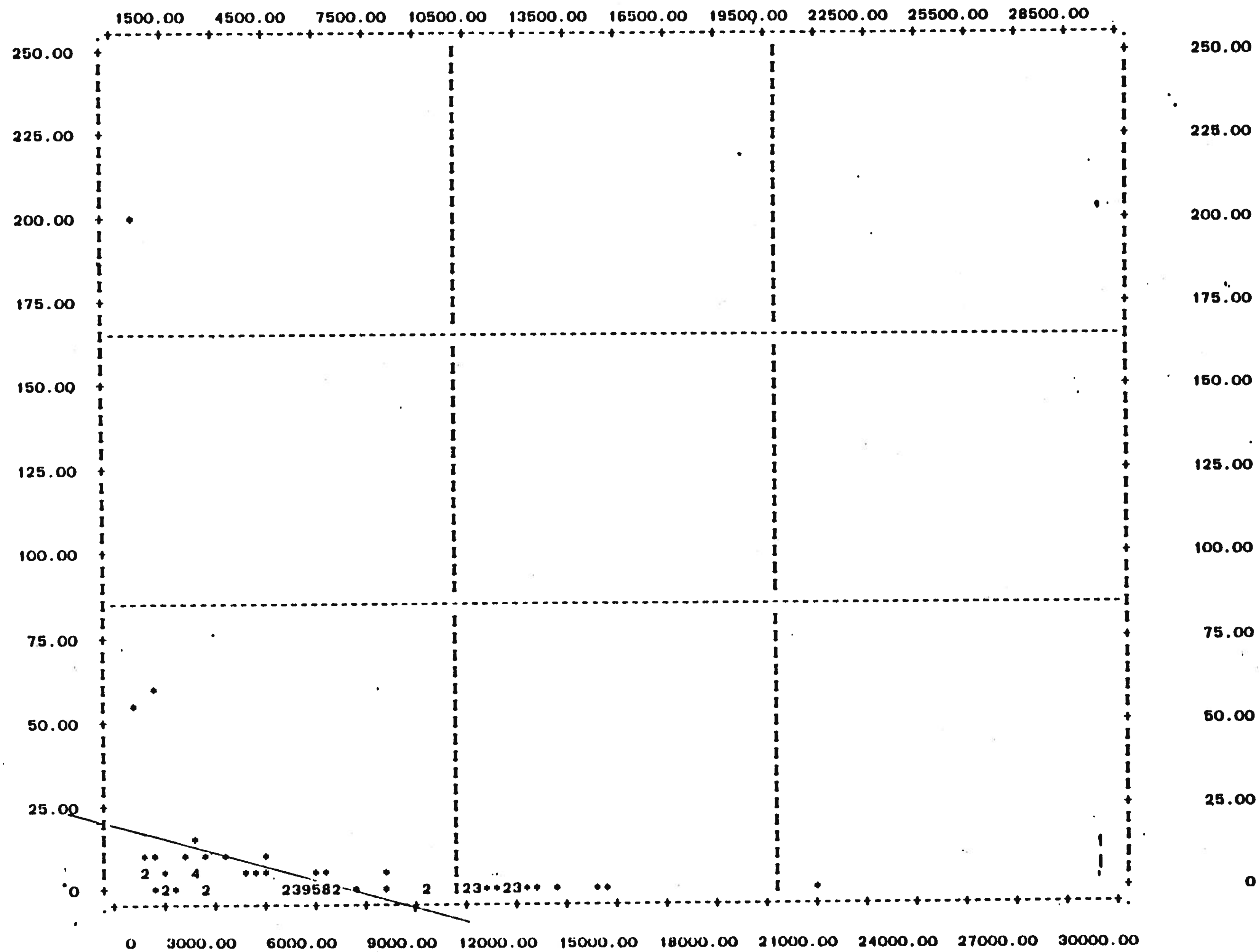


— USBR, 1984

CANADIAN RIVER NR LOGAN,NM   84/09/23.   16.52.12.   PAGE   7
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE   NONAME   (CREATION DATE = 84/09/23.)
SUBFILE   S01   S04   S08   S13   S17

Figure 27 – Scattergram, Flow vs TDS
Group I Data

SCATTERGRAM OF   (DOWN) VAR002   FLOW
(ACROSS) VAR006   TDS

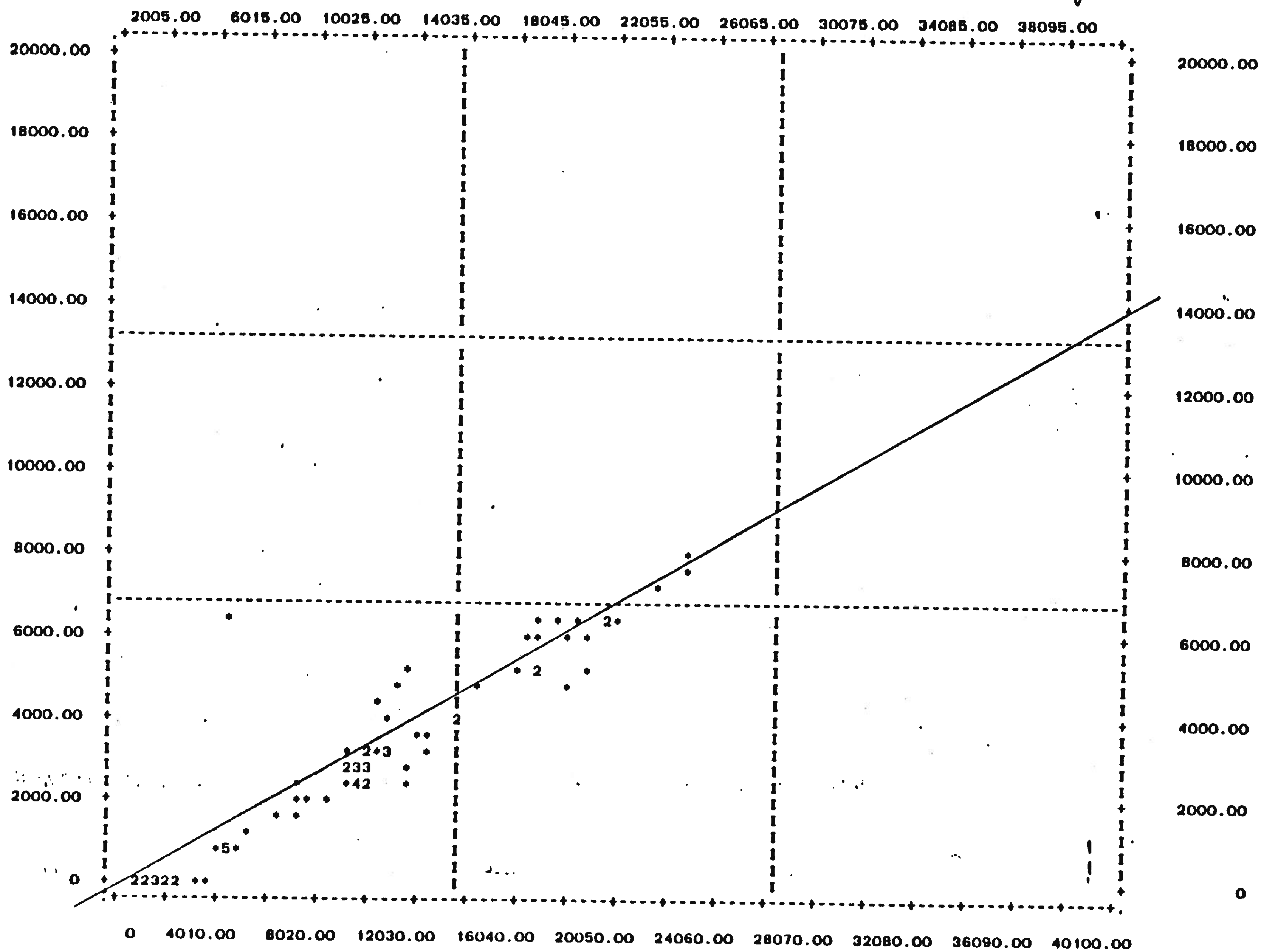


USBR, 1984

CANADIAN RIVER NR LOGAN,NM 84/09/23. 16.52.12. PAGE 9
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S01 S04 S08 S13 S17

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 28 - Scattergram, Chlorides VS Field Conductance Group I Data

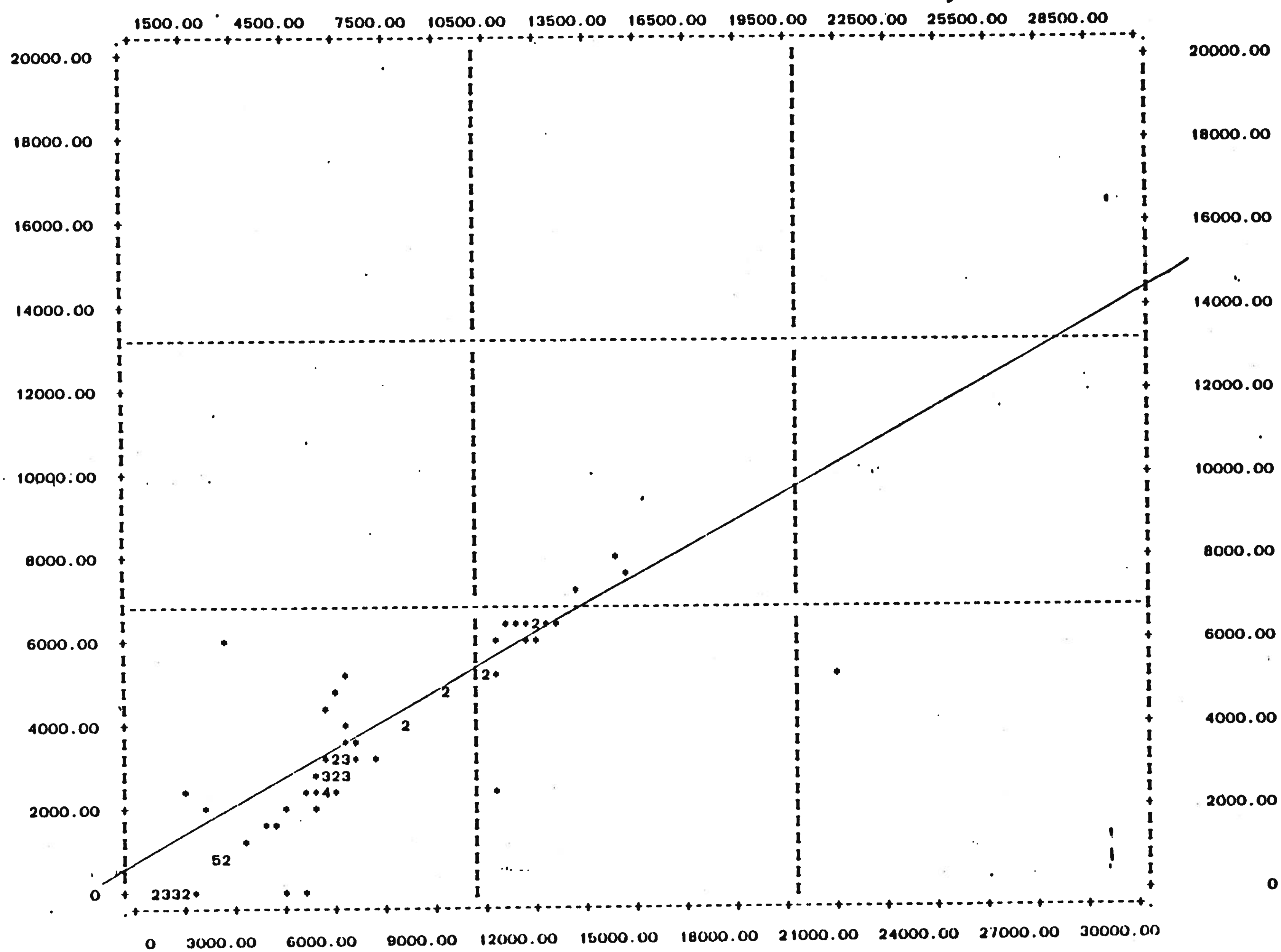


USBR, 1984

CANADIAN RIVER NR LOGAN,NM
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S01 S04 S08 S13 S17

Figure 29 - Scattergram, Chlorides vs TDS
Group I Data

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR006 TDS

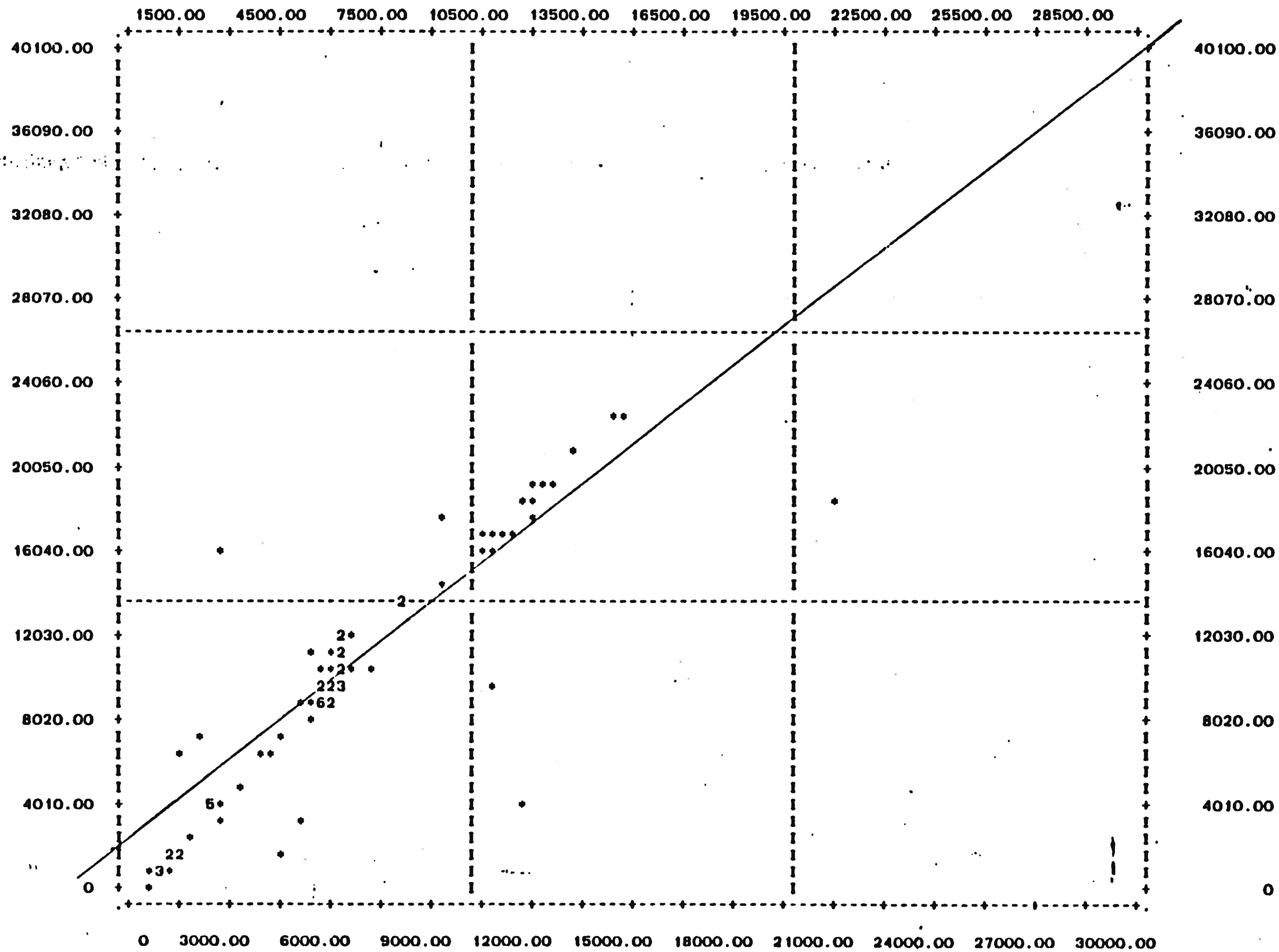


USBR, 1984

CANADIAN RIVER NR LOGAN,NM 84/09/23. 16.52.12. PAGE 21
SCATTERGRAM-ALL SURFACE WATER-CANADIAN RIVER NR LOGAN,NM
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S01 S04 S08 S13 S17

SCATTERGRAM OF (DOWN) VAR005 FIELD CONDUCTANCE
(ACROSS) VAR006 TDS

Figure 30 - Scattergram, Field Conductance VS TDS
Group I Data

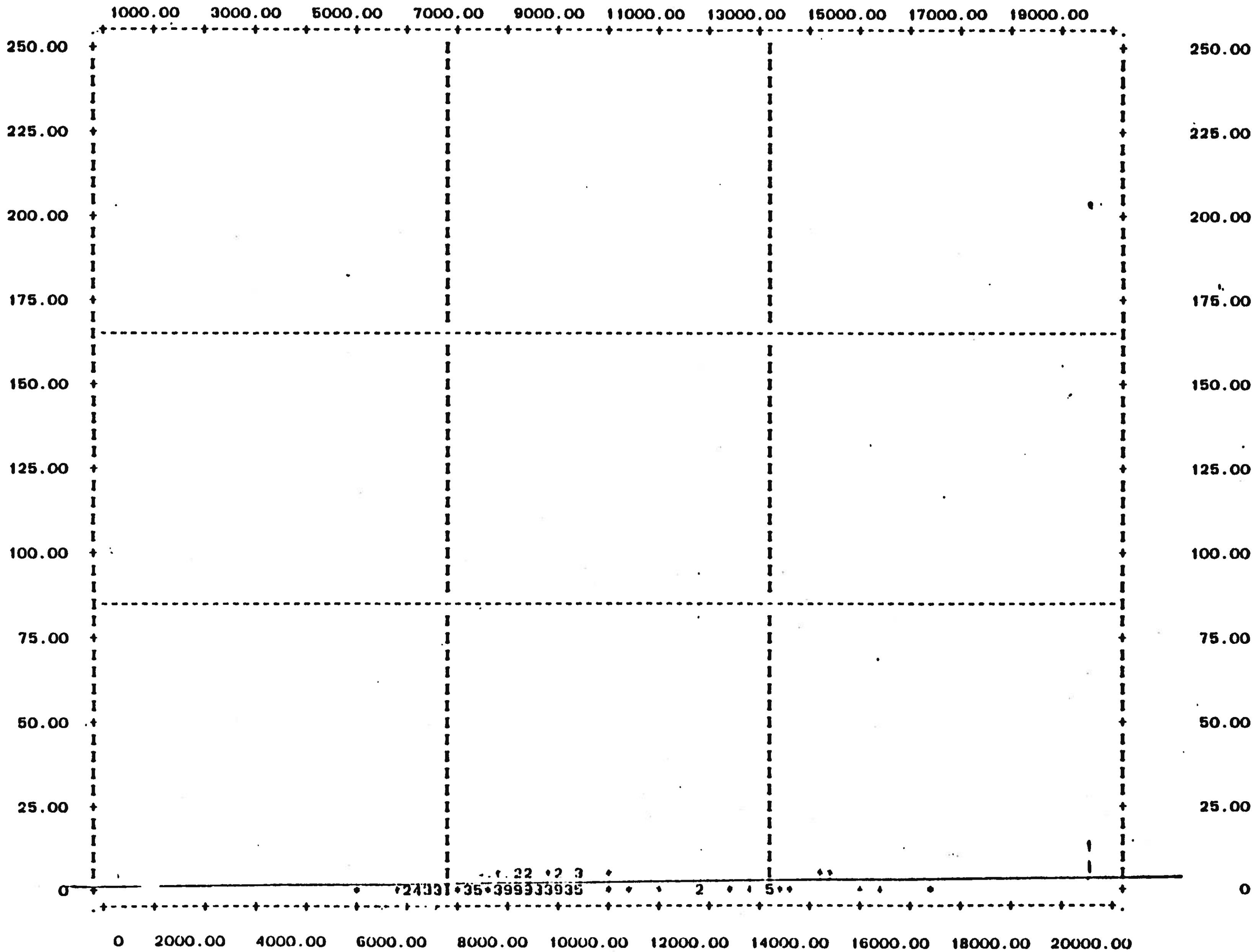


USBR, 1984

SCATERGRAM-PIEZOMETERS AB REVUELTO CREEK
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S02 S03 S05 S06 S07 S09 S10

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR003 CHLORIDES

Figure 31 - Scattergram, Flow vs Chlorides Group II Data

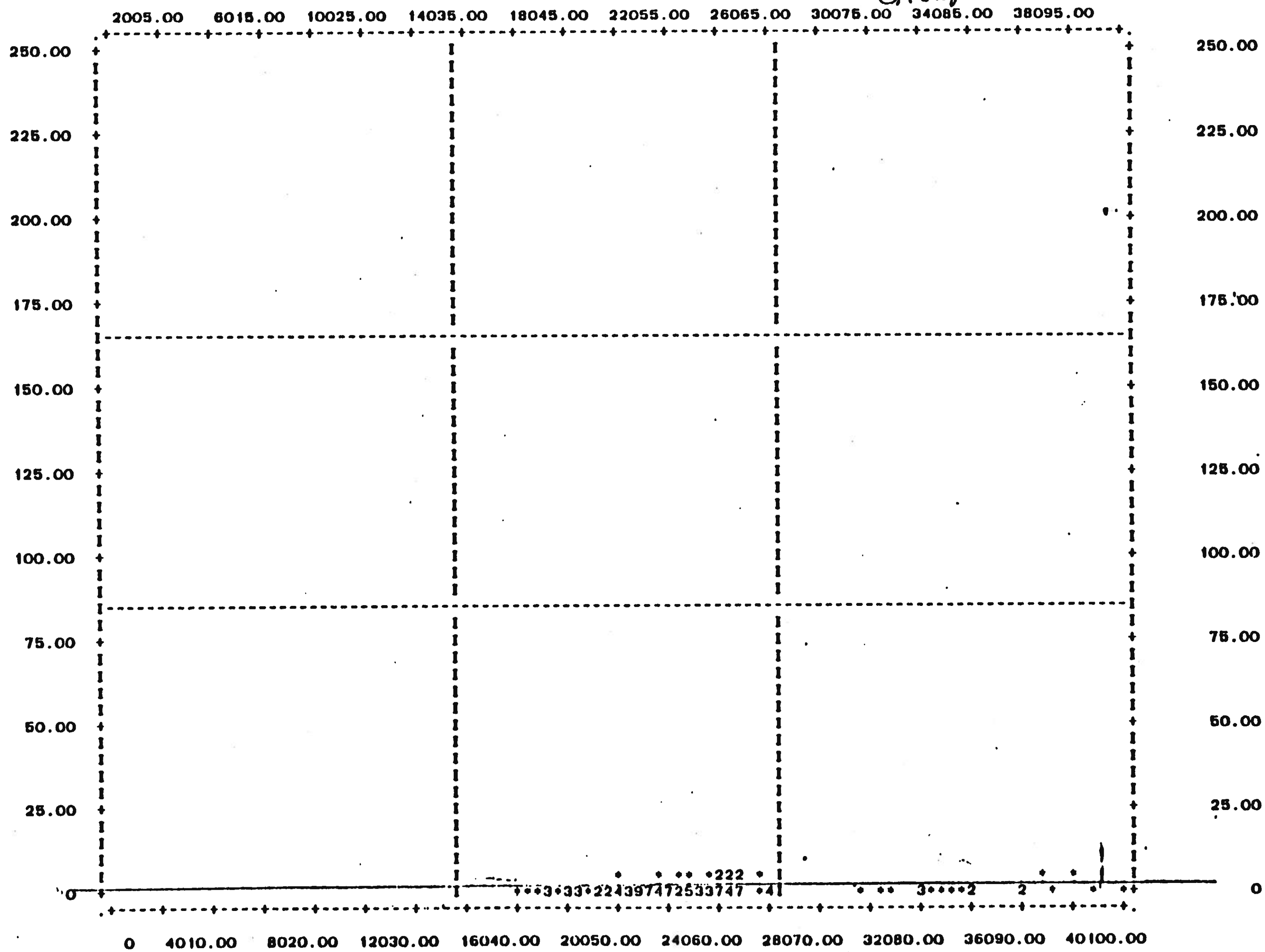


USGK, 1984

CANADIAN RIVER NR LOGAN,NM
SCATERGRAM-PIEZOMETERS AB REVUELTO CREEK
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S02 S03 S05 S06 S07 S09 S10

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 32 – Scattergram, Flow vs Field Conductance Group II Data

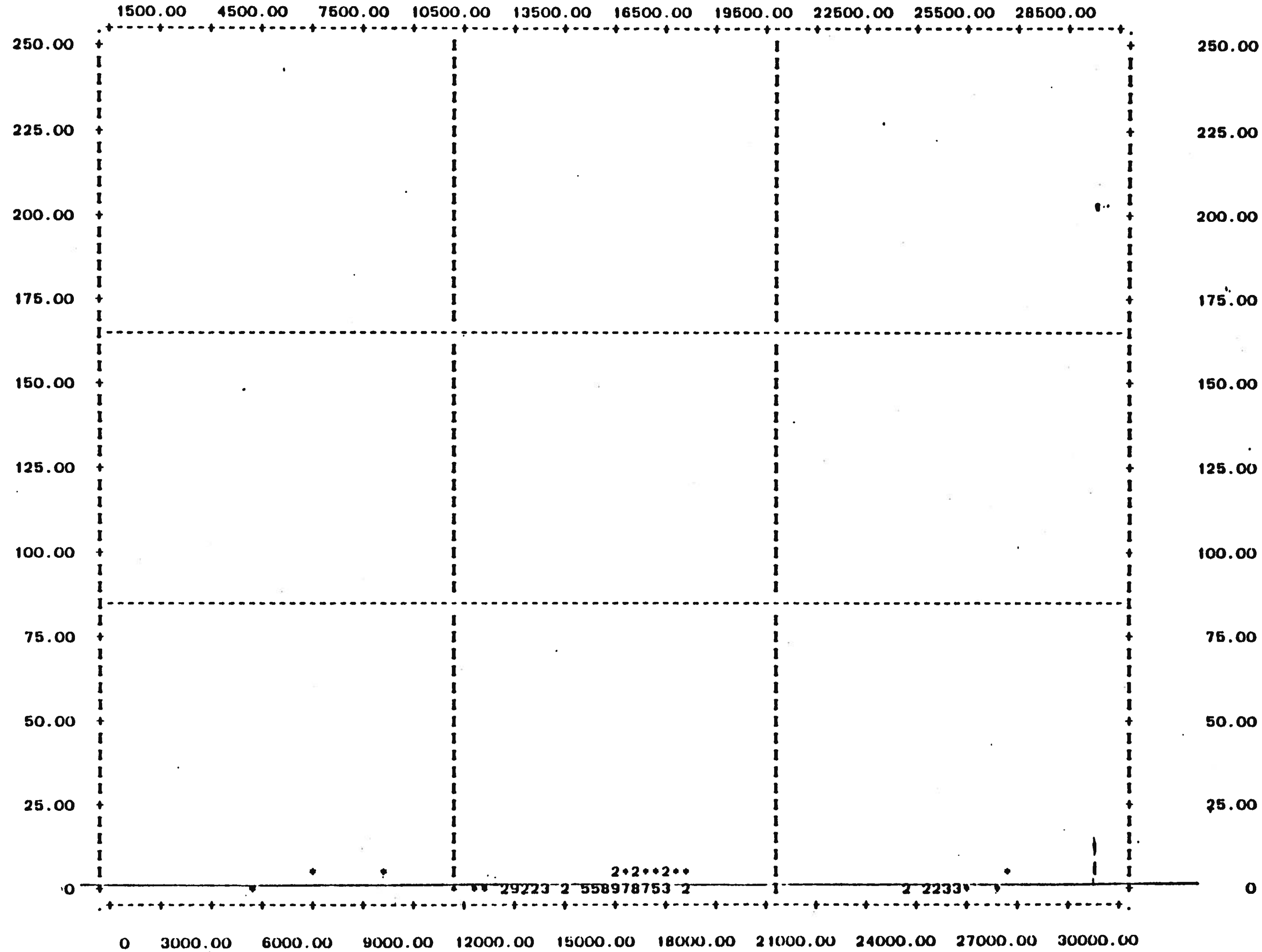


USBR, 1984

SCATERGRAM-PIEZOMETERS AH REVUELTO CREEK
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S02 S03 S05 S06 S07 S09 S10

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR006 TDS

Figure 33 - Scattergram, Flow vs TDS Group II Data

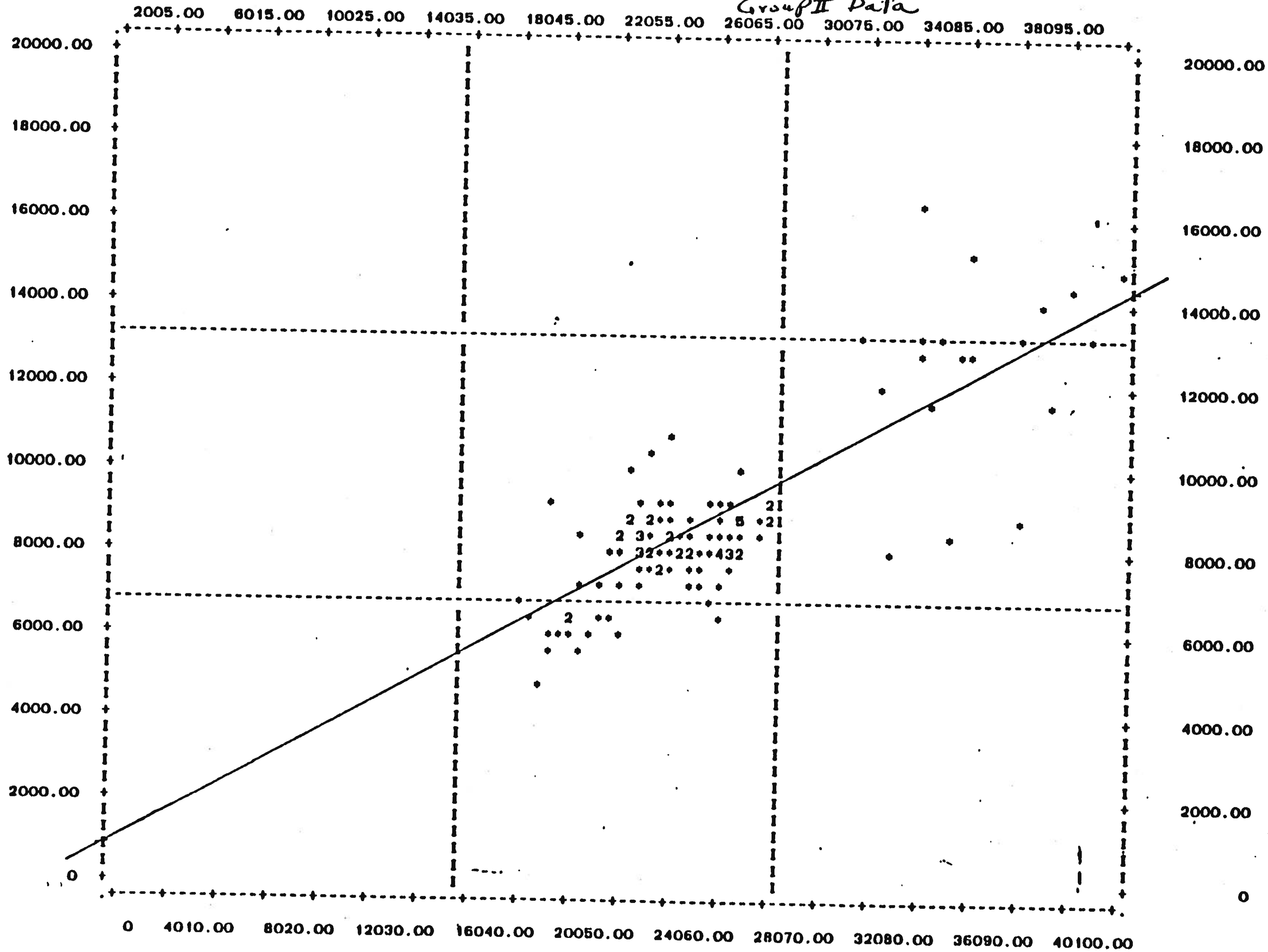


USBR, 1984

SCATERGRAM-PIEZOMETERS AB REVUELTO CREEK 84/09/23. 16.52.12. PAGE 43
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S02 S03 S05 S06 S07 S09 S10

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 34 - Scattergram, Chlorides vs Field Conductance
Group II Data

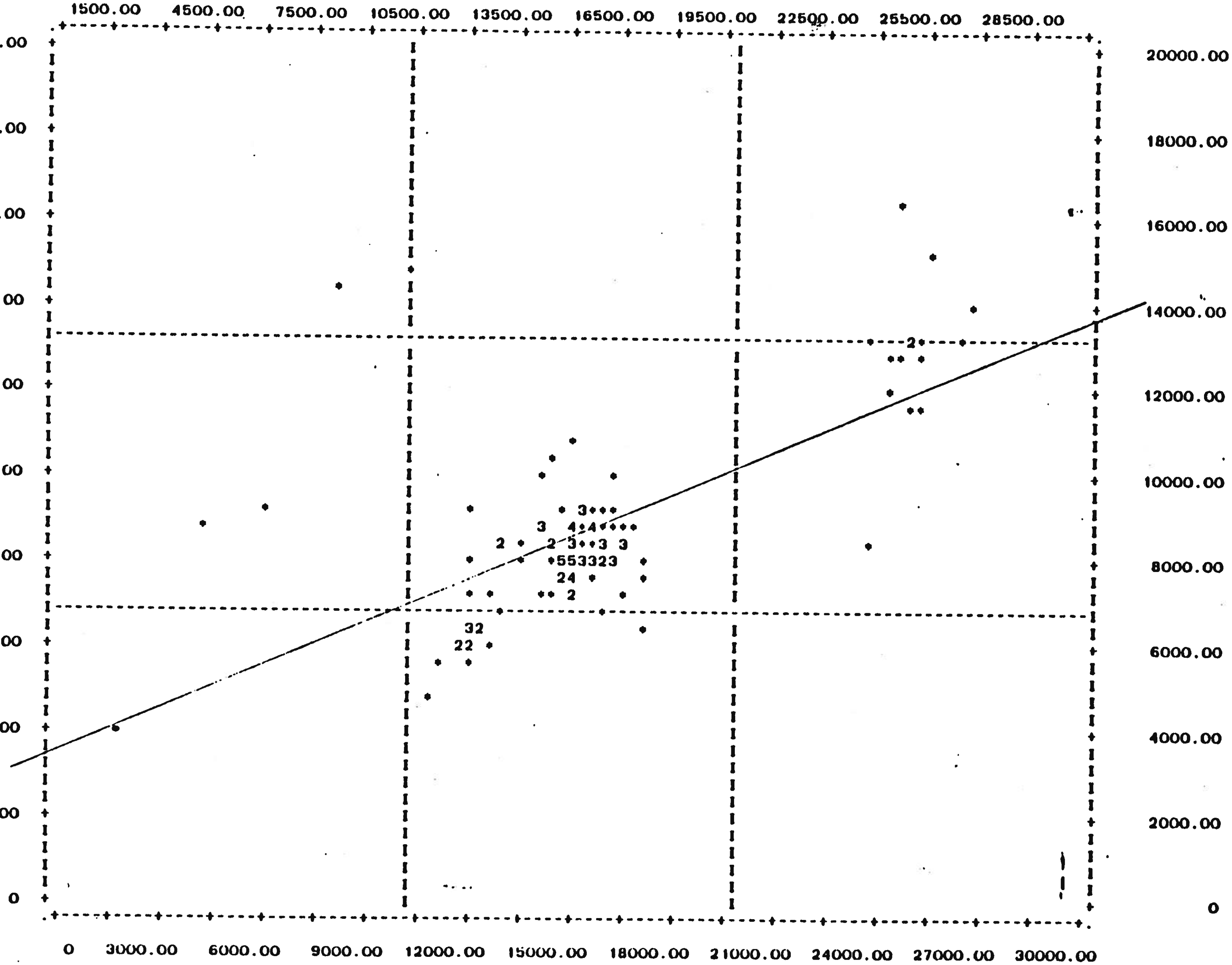


USBR, 1984

SCATERGRAM-PIEZOMETERS AB REVUELTO CREEK
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S02 S03 S05 S06 S07 S09 S10

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR006 TDS

Figure 35 — Scattergram, chlorides vs TDS Group II Data



USBR, 1984

CANADIAN RIVER NR LOGAN,NM

SCATERGRAM-PIEZOMETERS AB REVUELTO CREEK

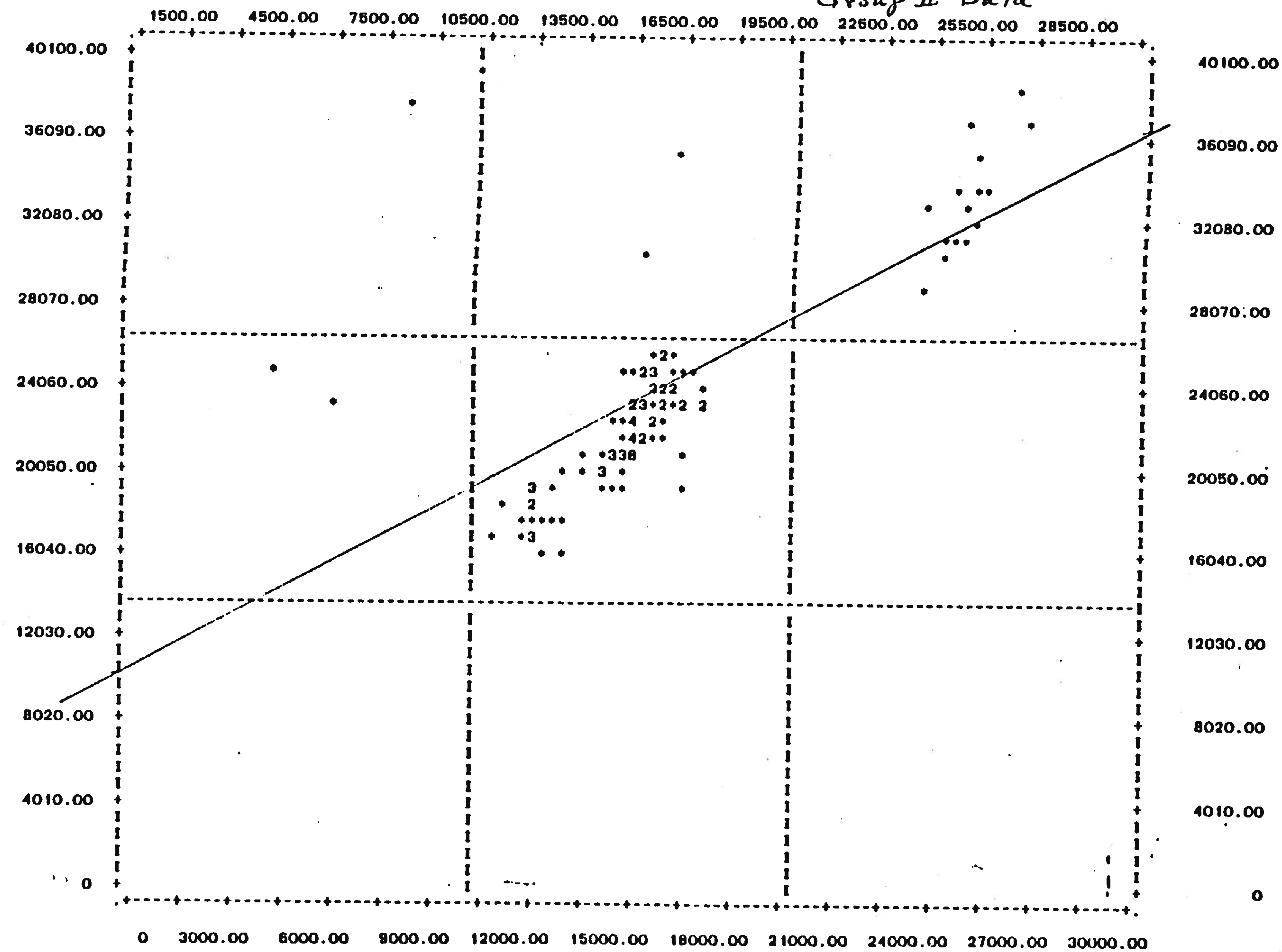
FILE NONAME (CREATION DATE = 84/09/23.)

SUBFILE S02 S03 S05 S06 S07 S09 S10

84/09/23. 16.52.12. PAGE 55

SCATTERGRAM OF (DOWN) VAR005 FIELD CONDUCTANCE (ACROSS) VAR006 TDS

Figure 36 - Scattergram, Field Conductance VS TDS Group II Data

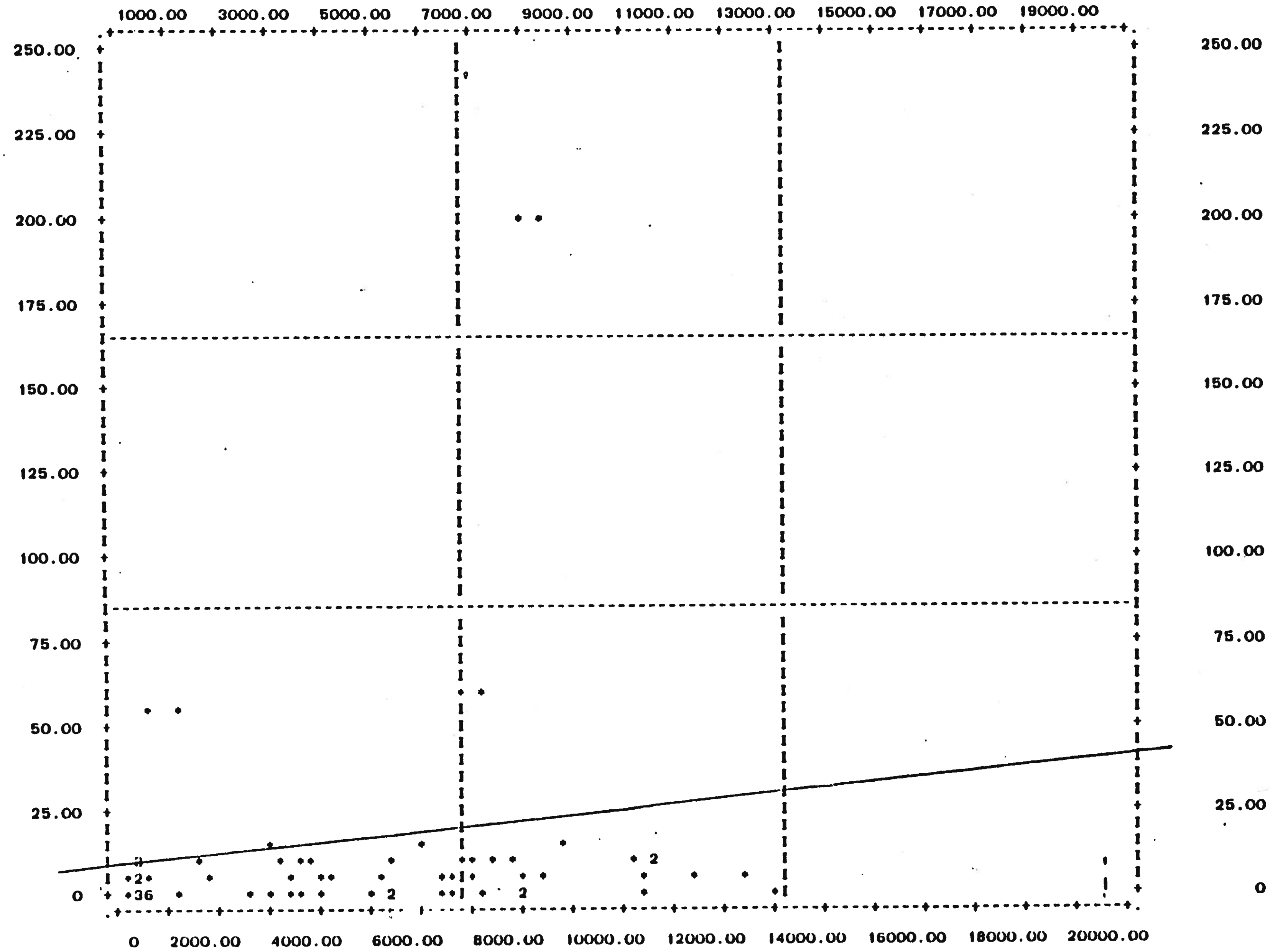


USBR, 1984

SCATTERGRAM-PIEZOMETERS,REVUELTO CR AND CANAD. R BELOW REV CR
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S11 S12 S14 S15 S16

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR003 CHLORIDES

Figure 37 - Scattergram, Flow vs Chlorides Group III Data

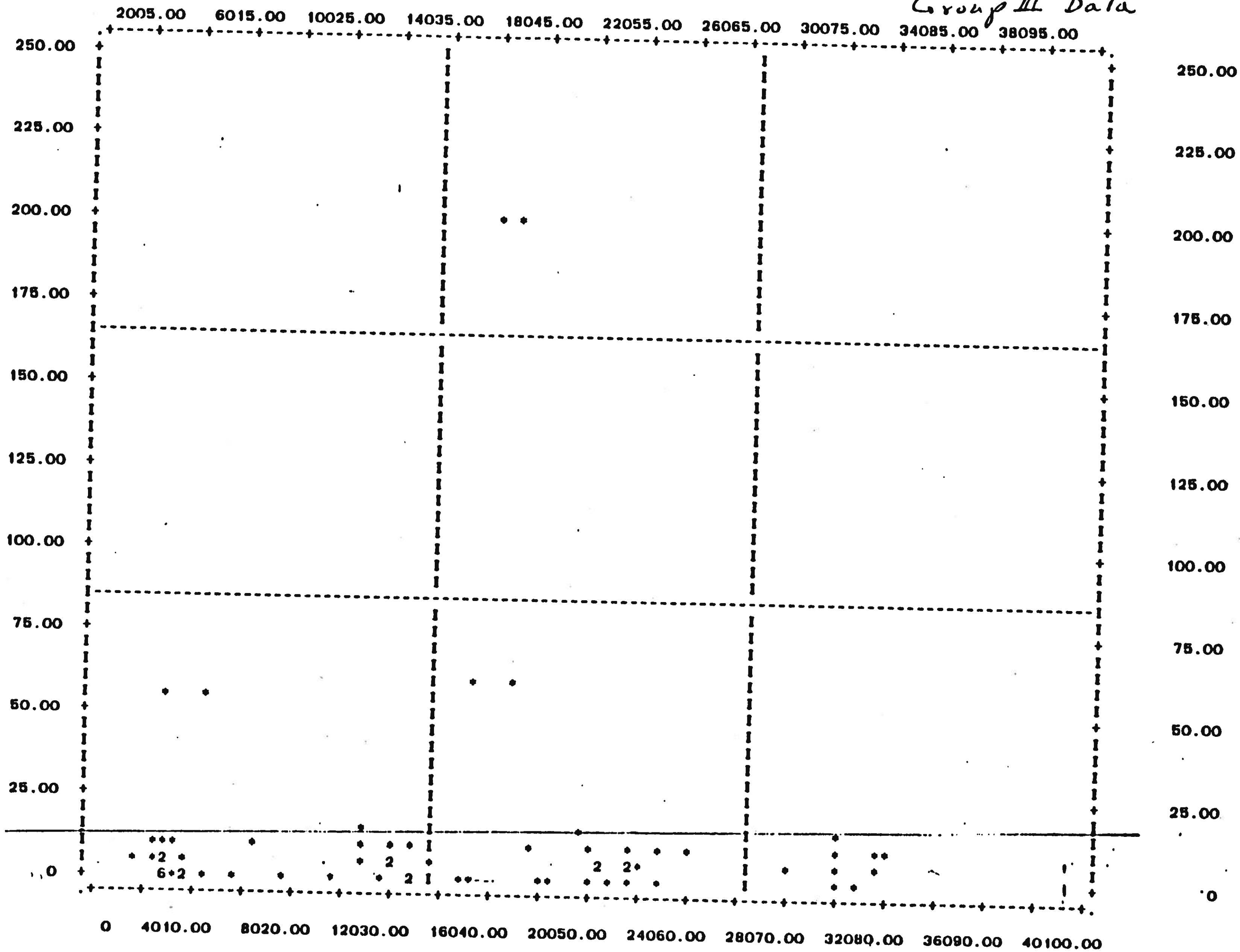


USBR, 1984

FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S11 S12 S14 S15 S16

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 38 – Scattergram, Flow vs Field Conductance
Group III Data

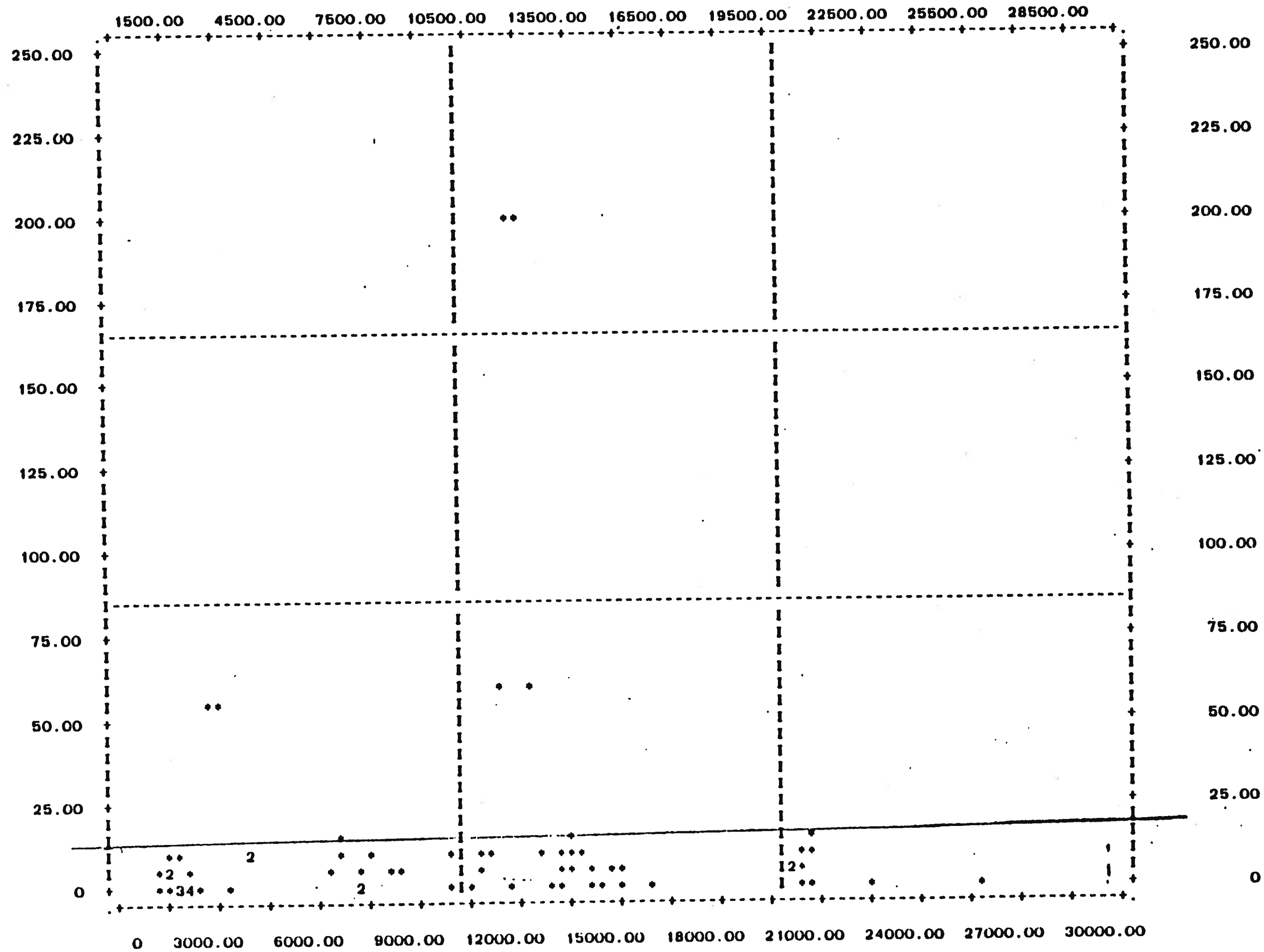


USBR, 1984

CANADIAN RIVER NR LOGAN,NM
SCATTERGRAM-PIEZOMETERS,REVUELTO CR AND CANAD. R BELOW REV CR
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S11 S12 S14 S15 S16

SCATTERGRAM OF (DOWN) VAR002 FLOW
(ACROSS) VAR006 TDS

Figure 39 - Scattergram, Flow vs TDS Group III Data

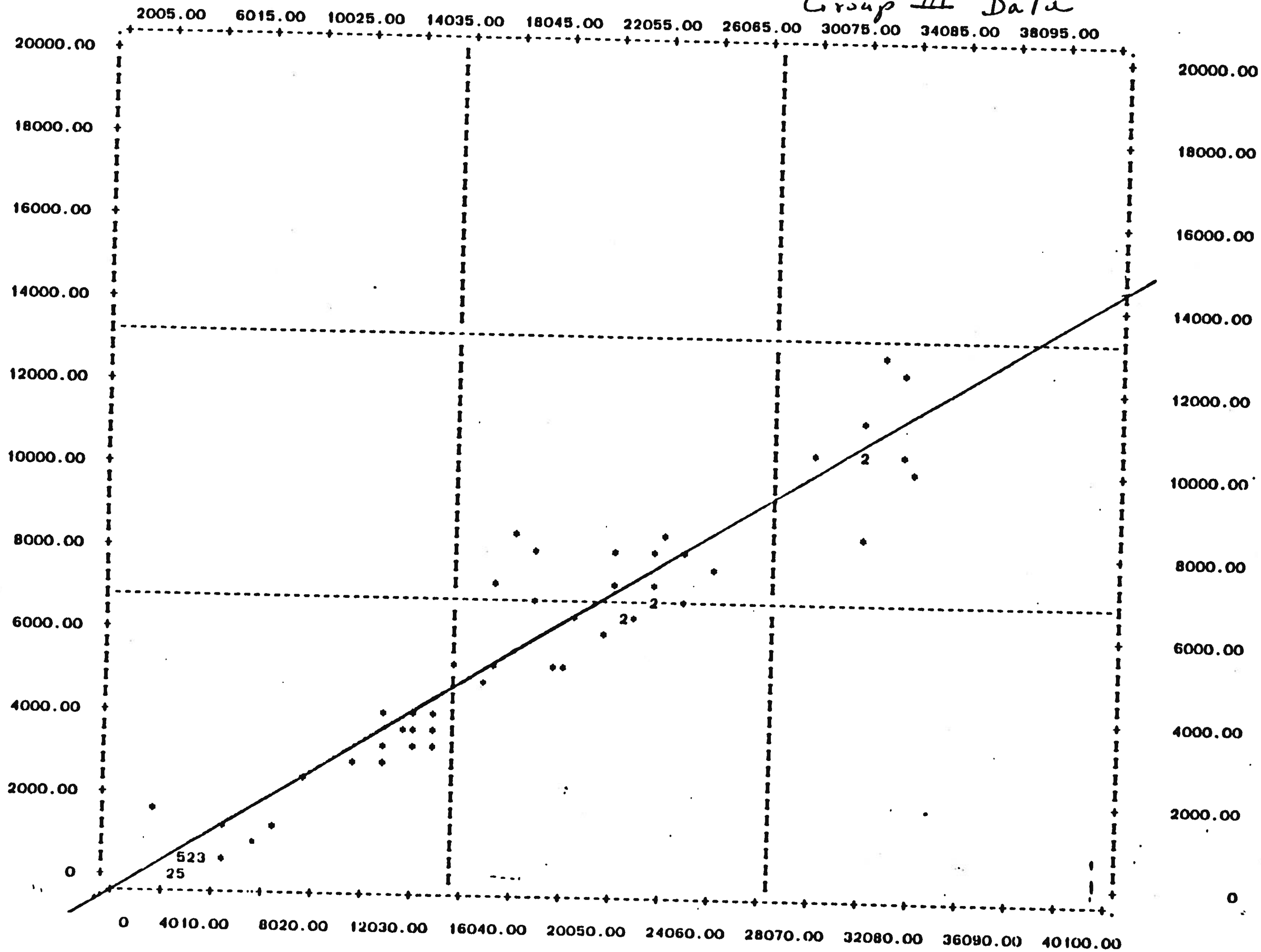


USBR, 1984

FILE NONAME (CREATION DATE = 84/09/23.) ...CH AND CANAD. R BELOW REV CR
SUBFILE S11 S12 S14 S15 S16

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR005 FIELD CONDUCTANCE

Figure 40 - Scattergram, Chlorides vs Field Conductance
Group III Data

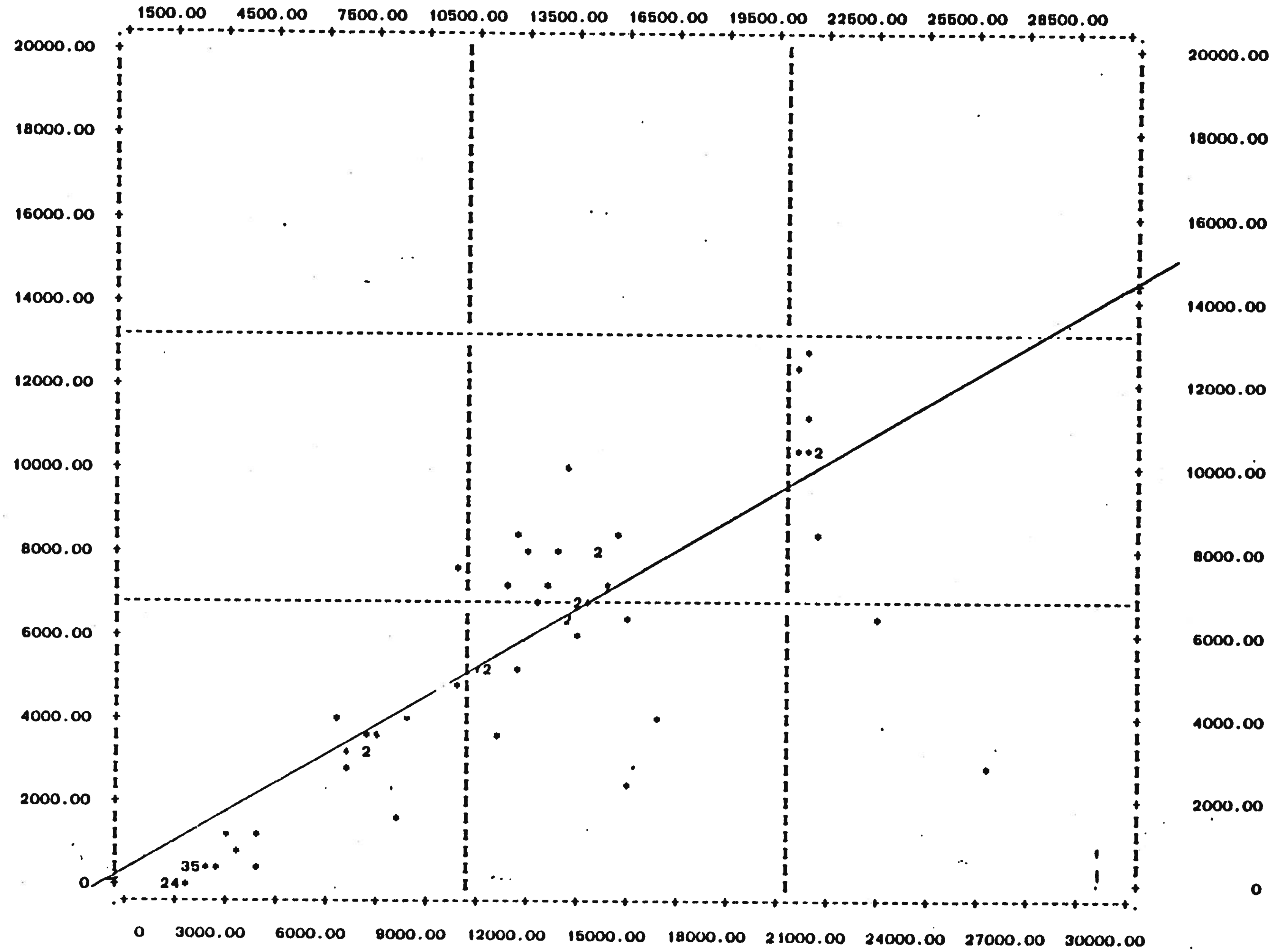


USBR, 1984

CANADIAN RIVER NR LOGAN,NM 84/09/23. 16.52.12. PAGE 79
SCATTERGRAM-PIEZOMETERS,REVUELTO CR AND CANAD. R BELOW REV CR
FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S11 S12 S14 S16 S18

SCATTERGRAM OF (DOWN) VAR003 CHLORIDES
(ACROSS) VAR006 TDS

Figure 41 - Scattergram, Chlorides VS TDS Group III Data

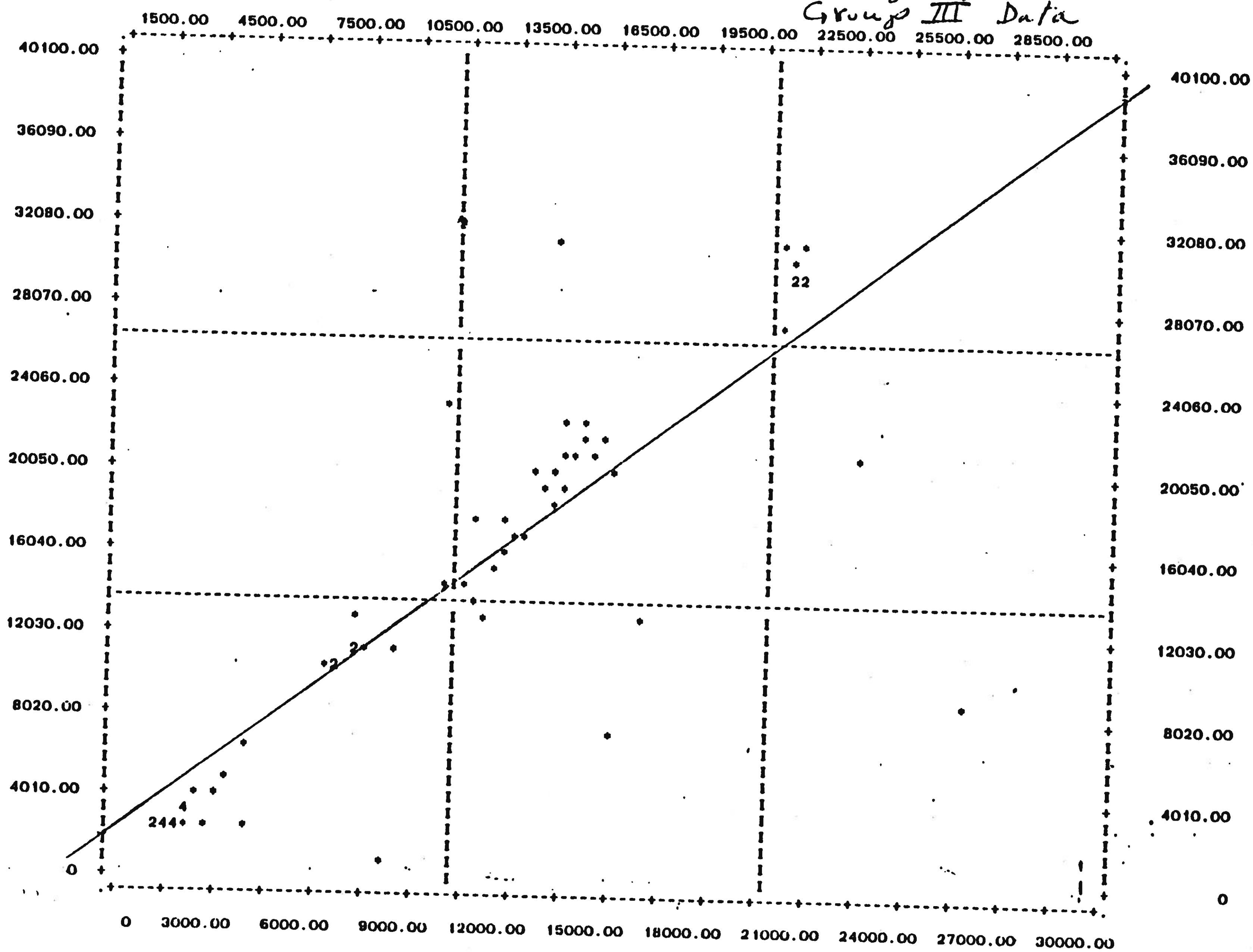


FILE NONAME (CREATION DATE = 84/09/23.)
SUBFILE S11 S12 S14 S15 S16

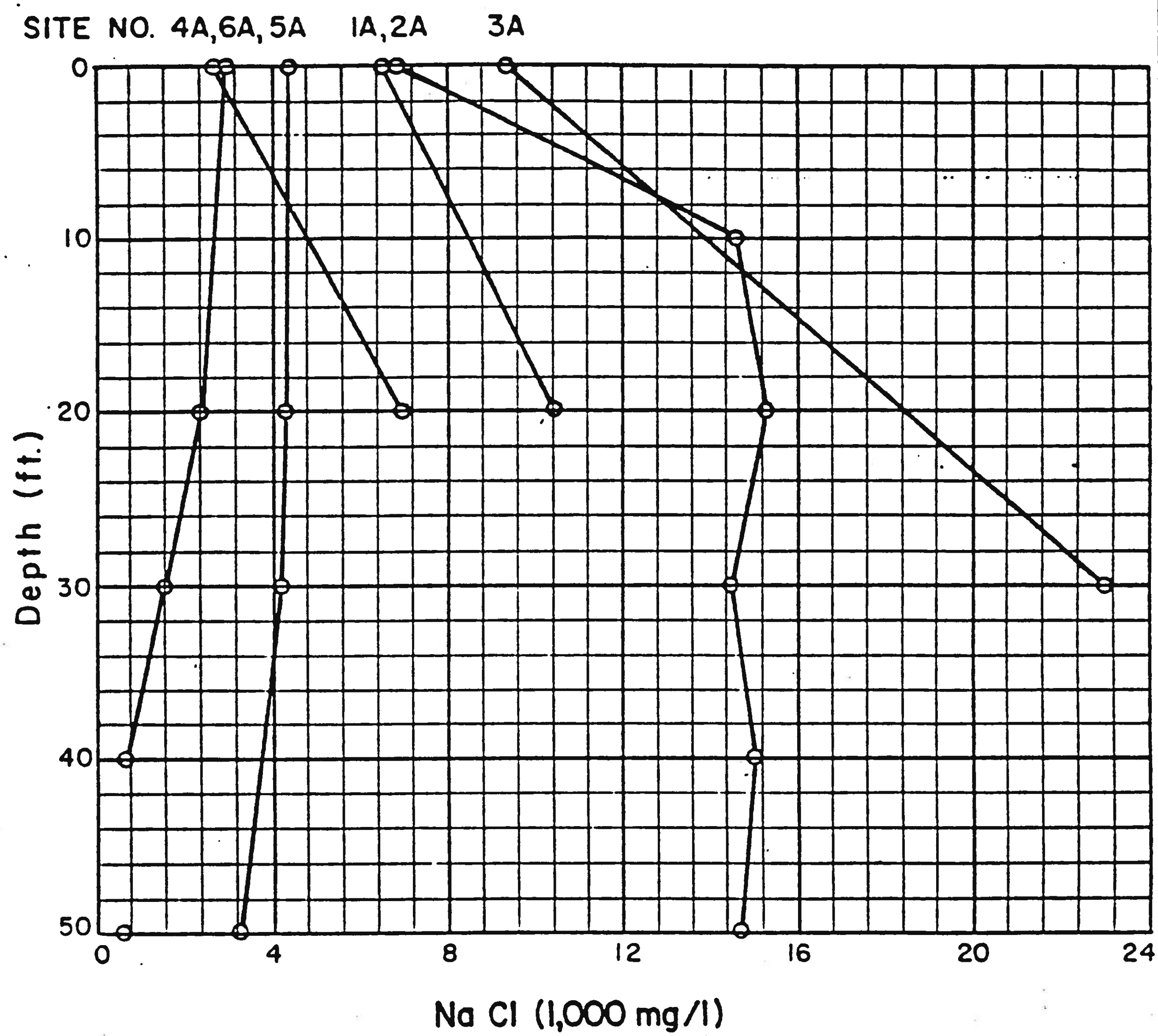
SCATTERGRAM OF (DOWN) VAR005 FIELD CONDUCTANCE
(ACROSS) VAR006 TDS

USBR, 1984

Figure 42 - Scattergram, Field Conductance vs TDS
Group III Data



USBR, 1979



Na Cl (mg/l) vs. Depth for water samples from drill holes in channel alluvium. Sampled 3/6/75

Site 1A - 1 Mi. D/S from Ute Dam
Site 2A - 2 Mi. D/S from Ute Dam
Site 3A - 5 Mi D/S from Ute Dam
Site 4A - 6 Mi D/S from Ute Dam
Site 5A - 11 Mi D/S from Ute Dam
Site 6A - 29 Mi D/S from Ute Dam

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LAKE MEREDITH SALINITY STUDY, TEX.-N. MEX.

Na Cl vs. Depth

FIGURE 2

TAB 14 Part B.2 Figures related to Triassic aquifers

HGC, 1984a

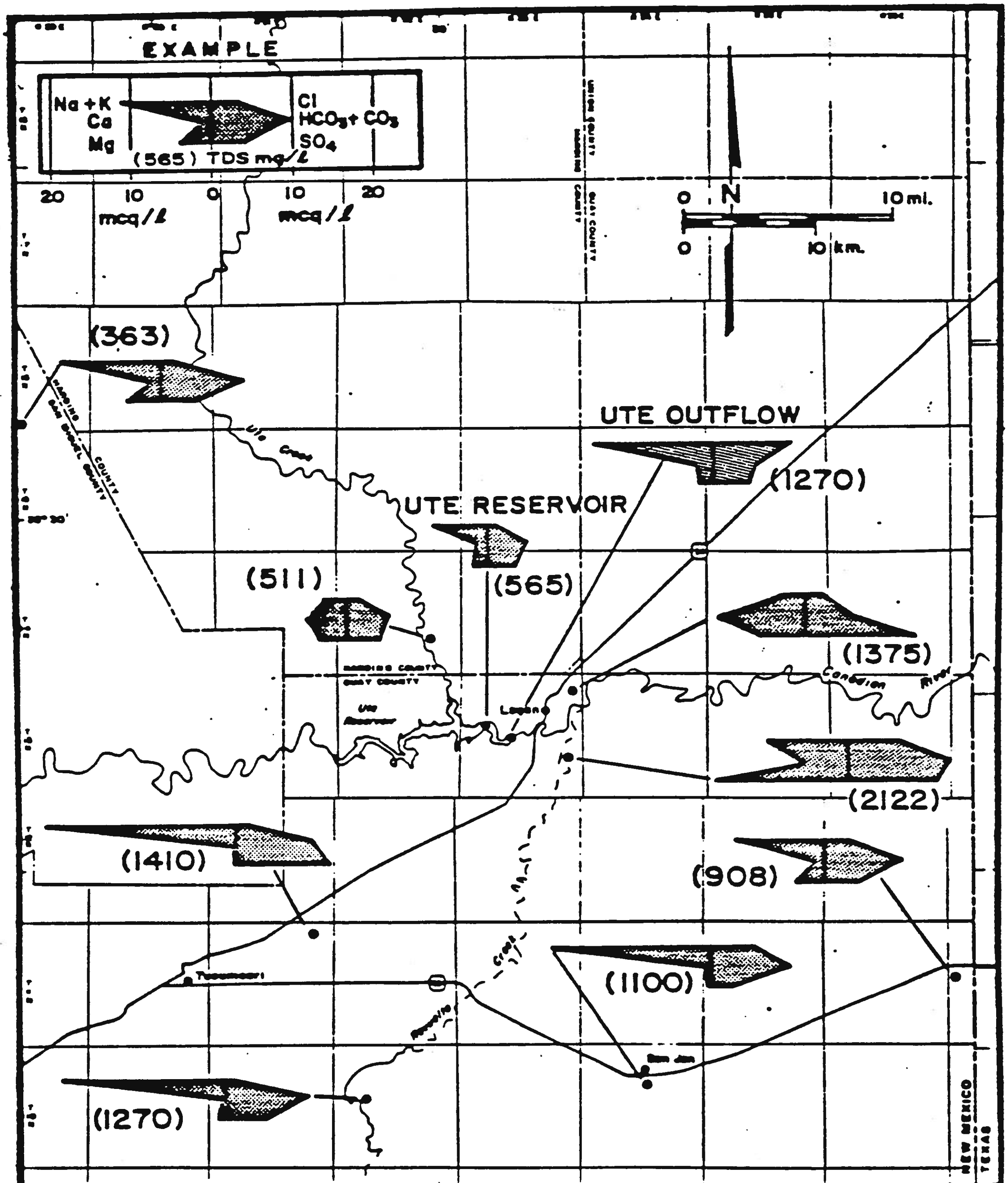


Figure 32. Stiff diagrams of Triassic water

USBR, 1984

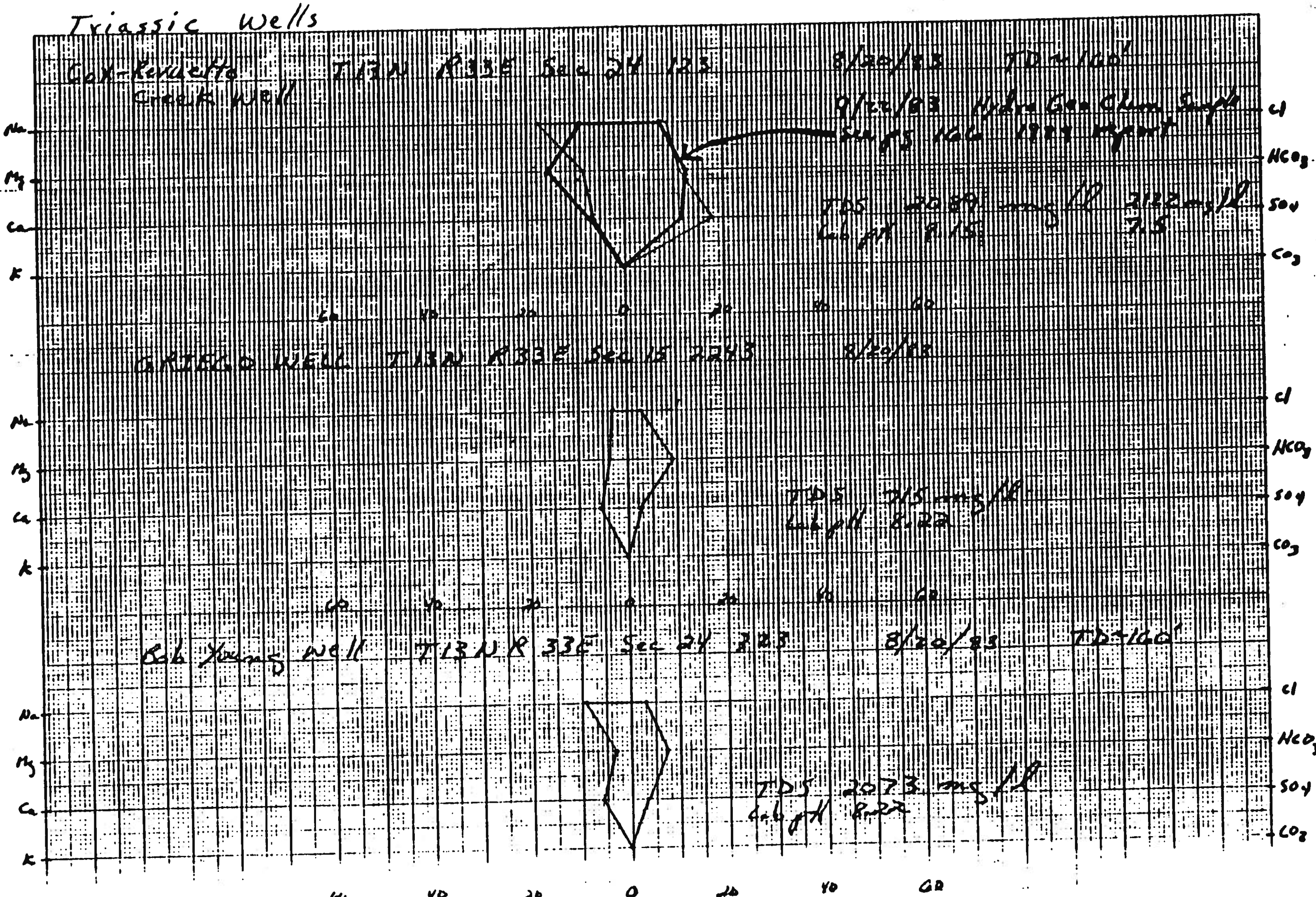


Figure 61-Stiff Diagrams for Chemical Analyses of Water Samples, Triassic Wells Near Logan, NM

USBK, 1984

K•E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN USA

46 1513

Figure 61 (continued)

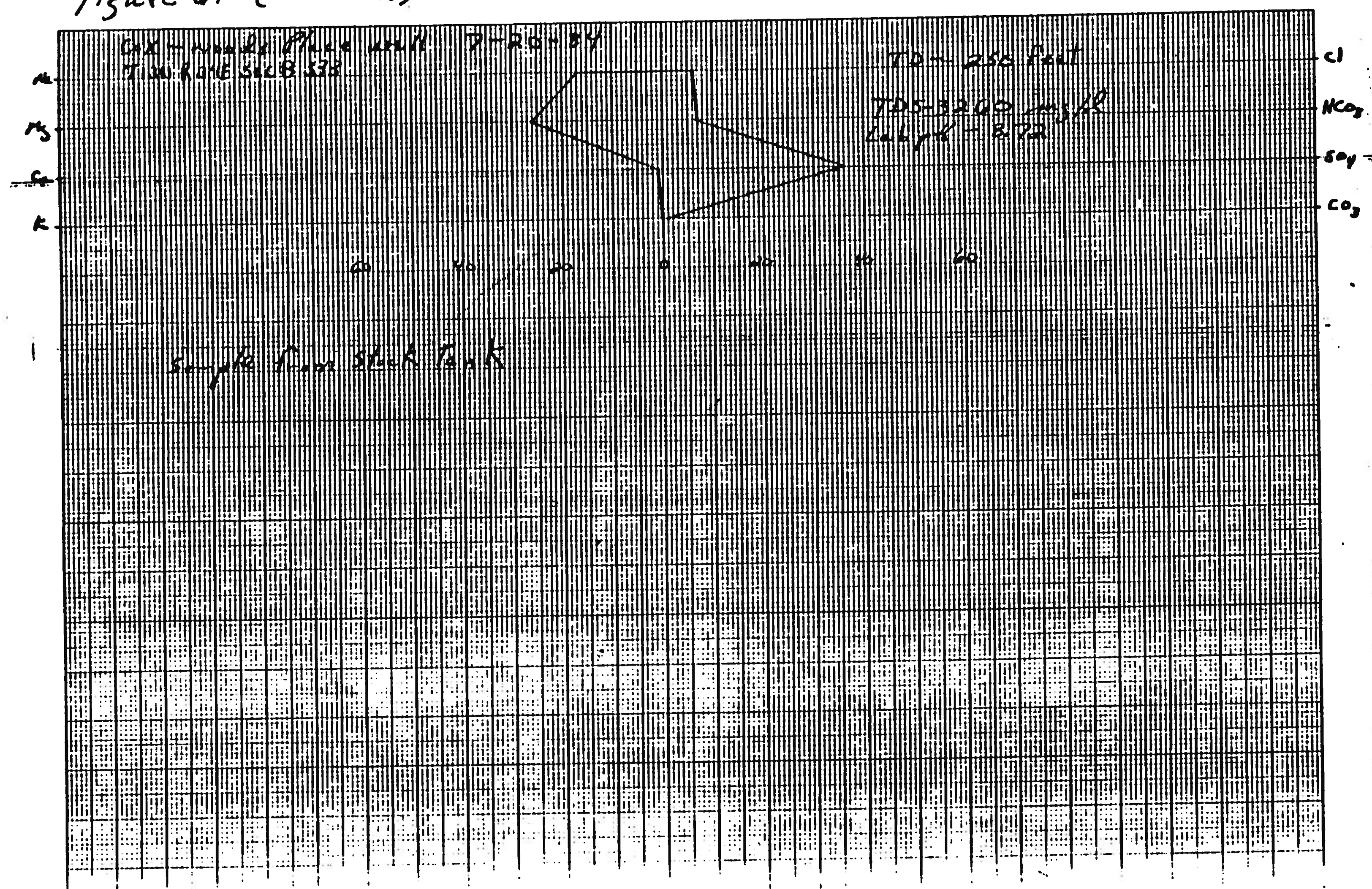


Figure 61 Continued

TAB 14 Part B.3 Figures related to brine aquifers

HGC, 1984a

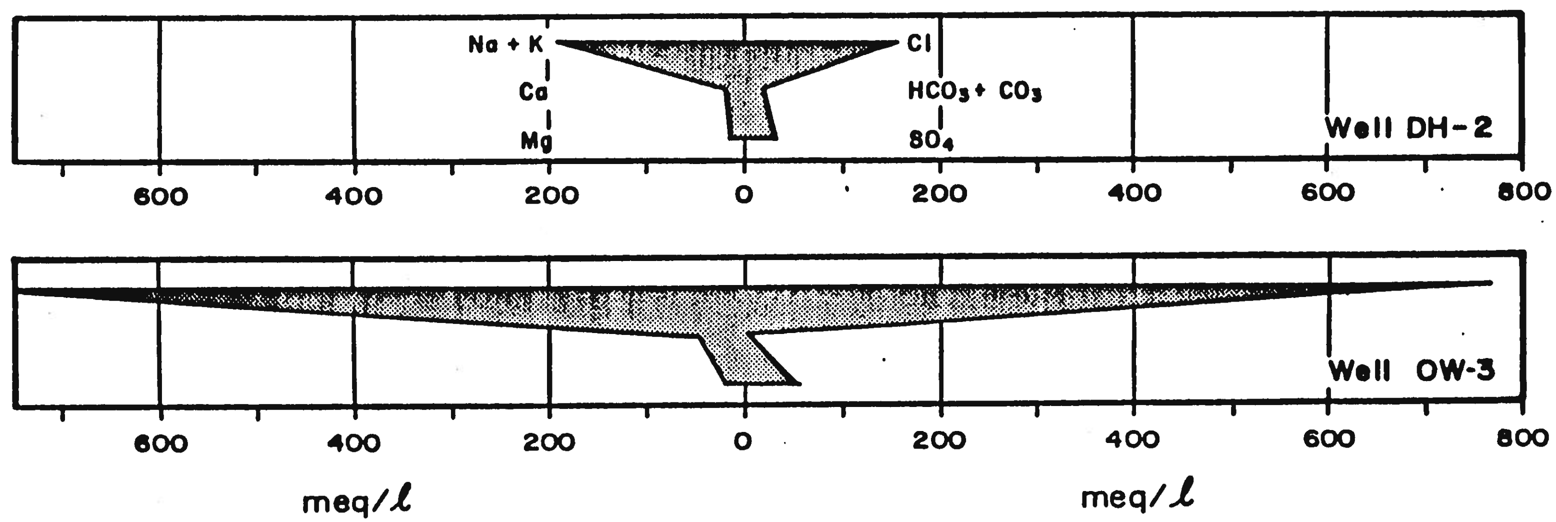


Figure 33. Stiff diagrams of shallow brine aquifer water

USBR, 1984

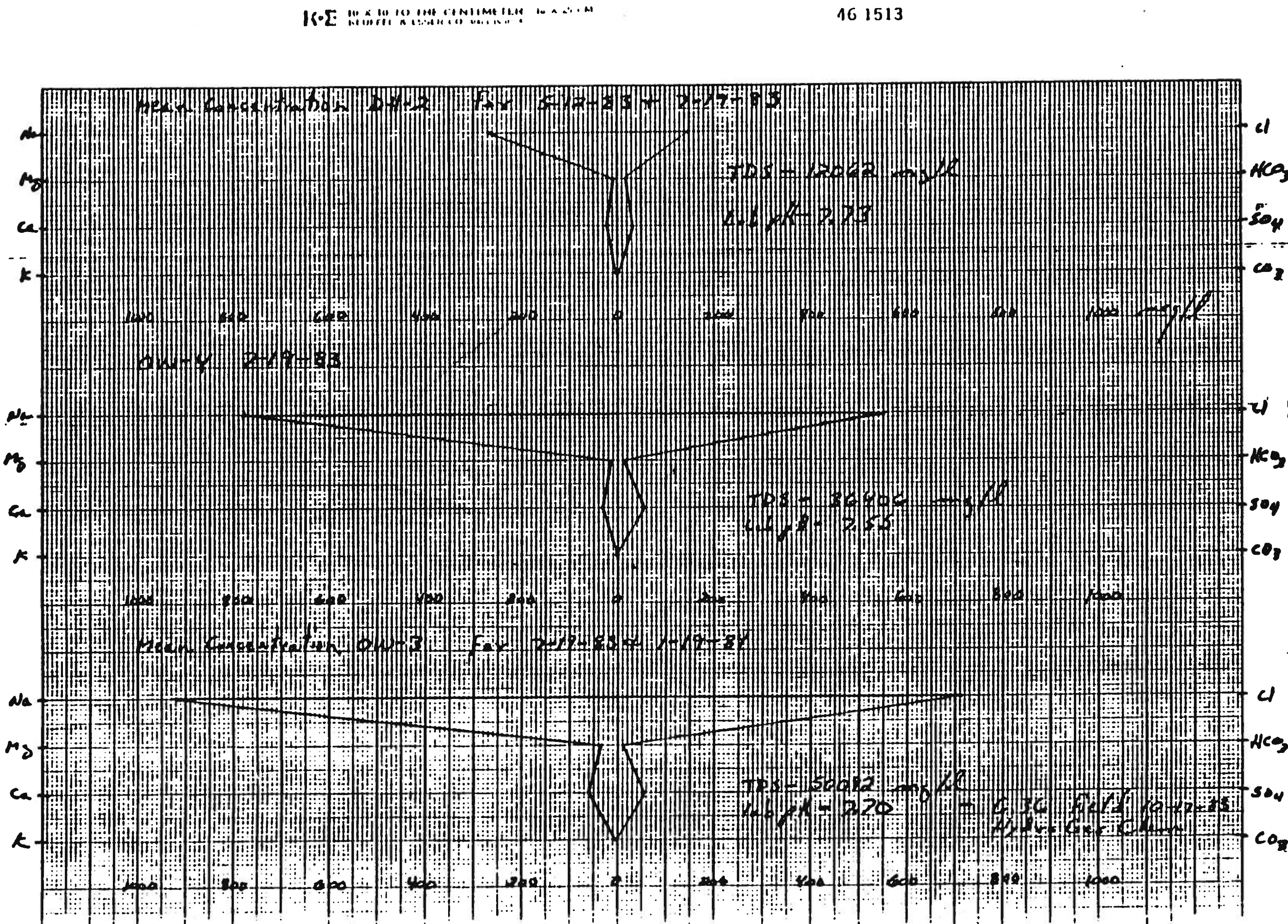


Figure 62 - Stiff Diagrams for Chemical Analyses of Water Samples From Exploratory Drill Holes Near Logan, NM

USBR, 1984

K•E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1512

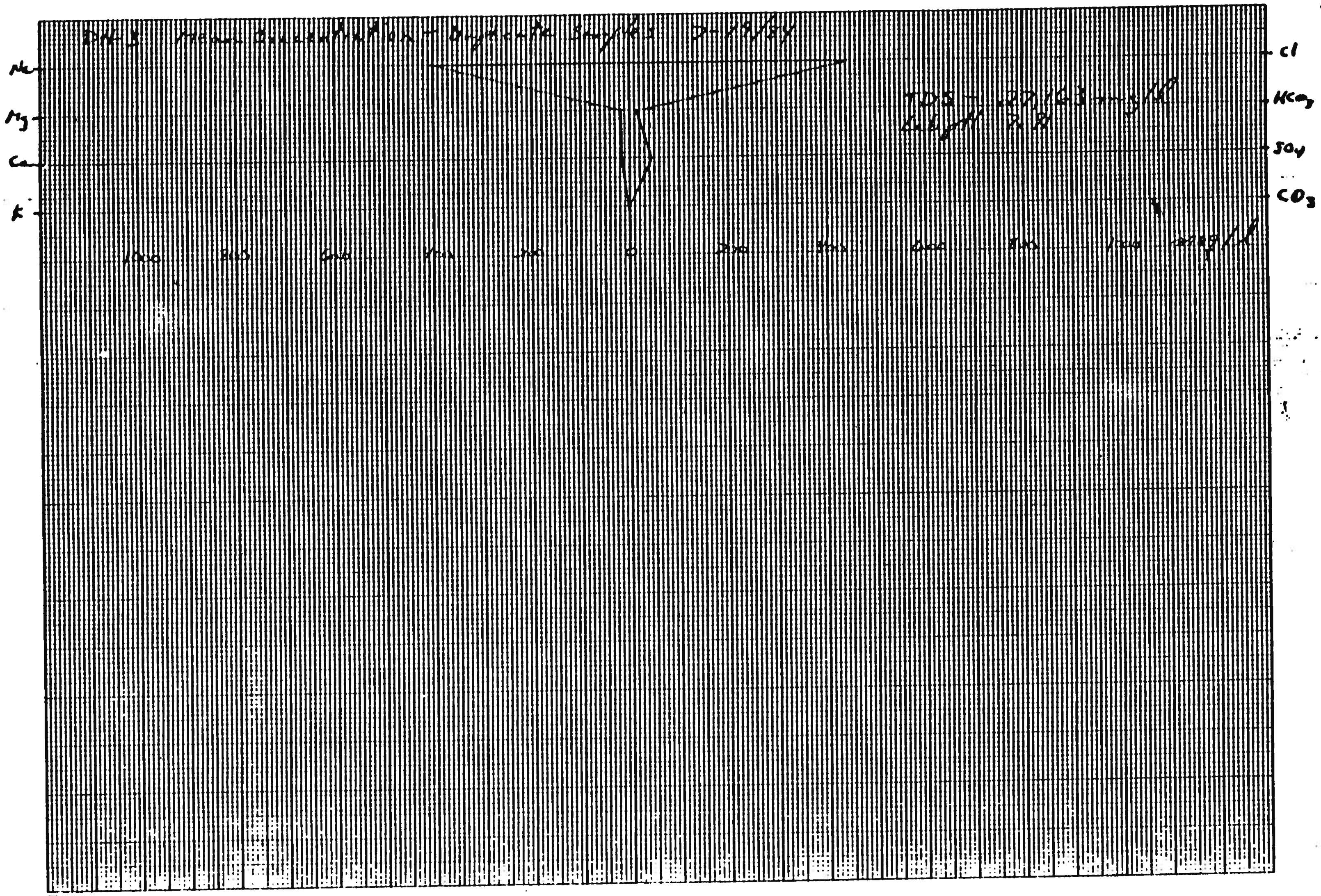


Figure 62 (continued)

TAB 14 Part B.4 Figures related to Permian aquifers

HGC, 1707a

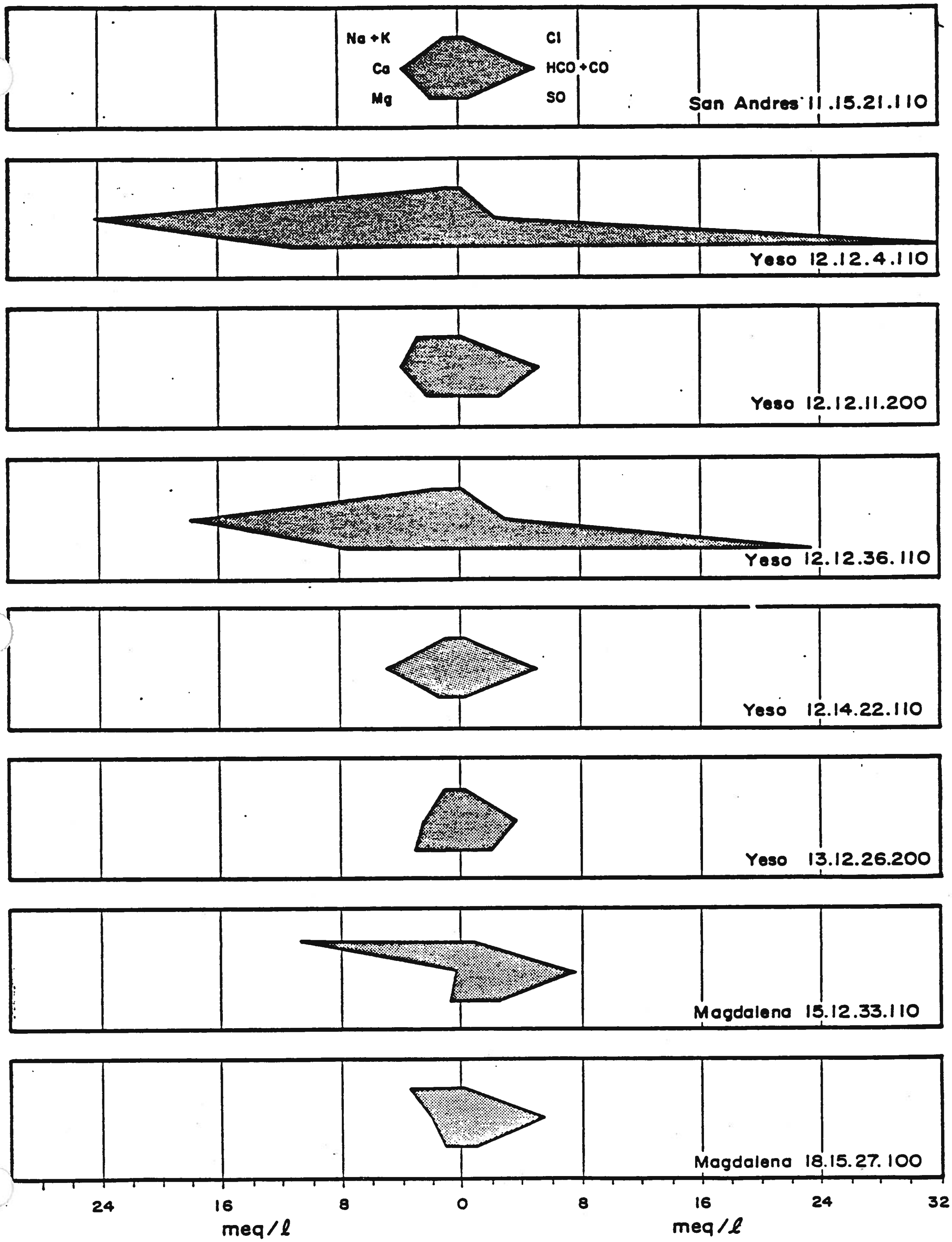


Figure 30. Stiff diagrams of Permian water near recharge area

HGC, 1984a

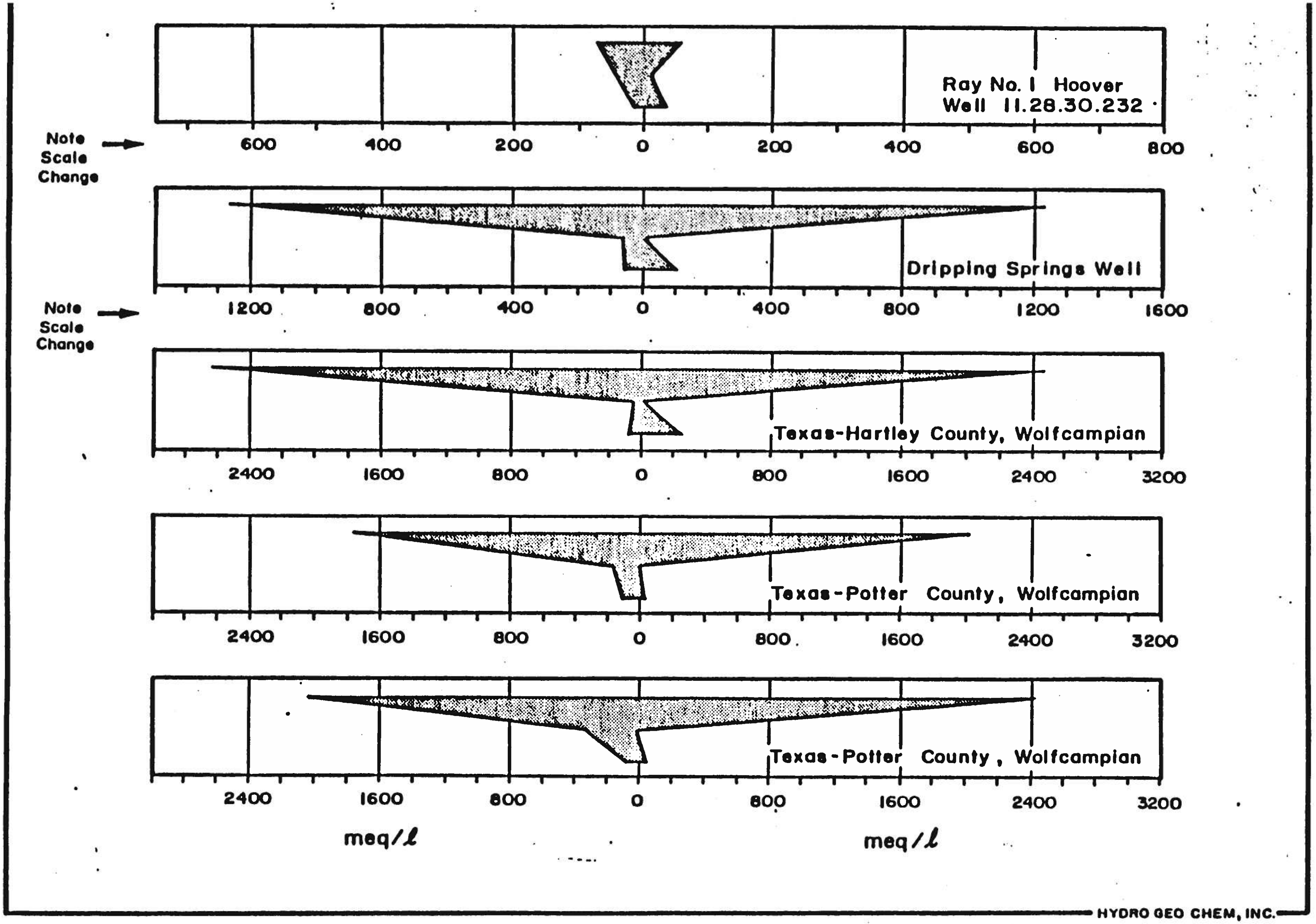


Figure 31. Stiff diagrams of Permian water near study area

TAB 14 Part B.5 Figures related to pre-Leonardian aquifer(s)

Bassett and Bentley, 1983

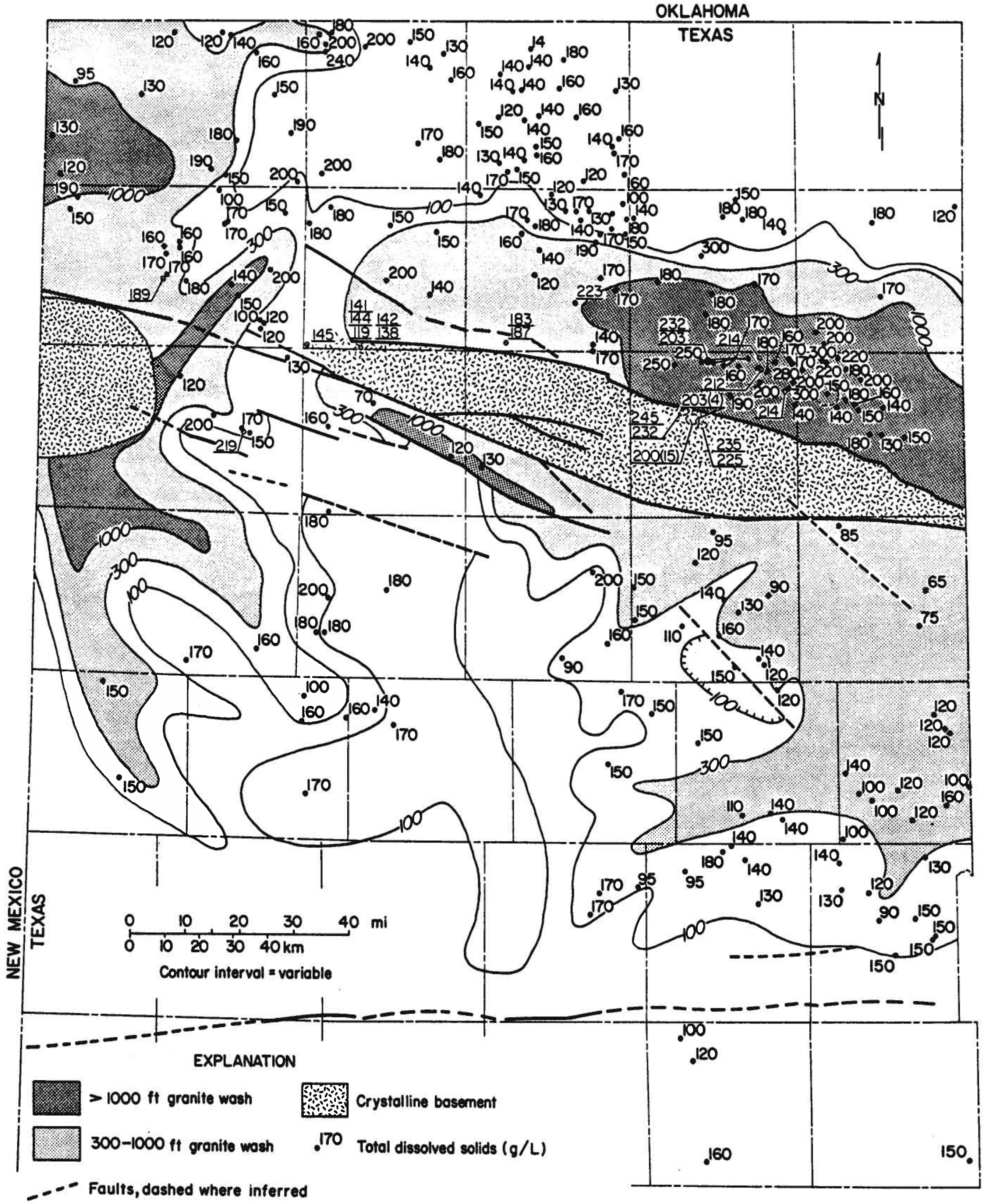


Figure 11. *Contour lines showing isopachous map of granite wash in the deep-basin brine aquifer (from Dutton, 1982). Data points indicate total dissolved solids (g/L) from chemical analyses of the brines (see underlined data, this figure, which are from appendix B, table B-1) or computed from spontaneous potential logs (see appendix C, table C-2). Structure data are from A. Goldstein (written communication, 1981).*

Gustavson, et al., 1980a

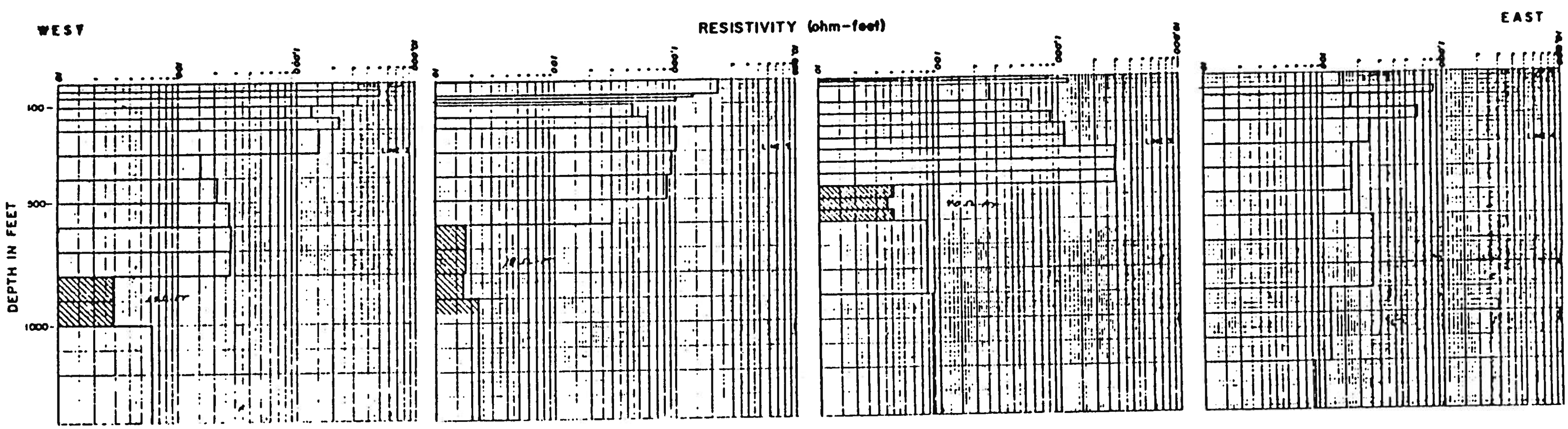
Table 1. Salt dissolution expressed as rates of horizontal and vertical dissolution. (Solute load data from U.S. Geological Survey, 1968-1977)*

Basin	Mean annual solute load	Annual rates of horizontal dissolution				Annual rates of vertical dissolution			
		Mean		Max	Min	Mean		Max	Min
	$\times 10^5 ft^3$	ft/yr	cm/yr	ft/yr	ft/yr	$\times 10^{-5}$ ft/yr	$\times 10^{-3}$ cm/yr	$\times 10^{-5}$ ft/yr	$\times 10^{-5}$ ft/yr
1A Canadian River (Tascosa)	(5 years)** 4.460	0.00189	0.0576	0.00246	0.00132	1.0499	3.2001	1.367	0.735
1B Canadian River (Amarillo)	(5 years) 6.9542	0.00188	0.0575	0.00239	0.00081	1.0312	3.1431	1.306	0.452
1C Canadian River (Canadian)	(3 years) 7.9221	0.00186	0.0568	0.00261	0.00118	0.7665	2.3362	1.072	0.484
3 Salt Fork of the Red River (Wellington)	(9 years) 2.119	0.00621	0.1893	0.01265	0.00154	0.7405	2.2571	1.509	0.183
4A Prairie Dog Town Fork of the Red River (Lakeview)	(9 years) 24.1188	0.00963	0.2935	0.02337	0.00376	5.6674	17.2742	11.926	2.637
4C Little Red River (Turkey)	(9 years) 12.851	0.25353	7.7276	0.47850	0.13238	27.1130	82.6404	51.172	14.157
4D Prairie Dog Town Fork of the Red River (Childress)	(9 years) 119.5366	0.08485	2.5862	0.01925	0.00564	17.7560	54.1203	29.142	11.816
5A North Pease River (Childress)	(5 years) 4.3677	0.01077	0.3283	0.01607	0.00758	1.7911	5.4593	2.672	1.261
5B Middle Pease River (Paducah)	(5 years) 0.5515	0.00100	0.0305	0.00248	0.00018	0.2027	0.6177	0.500	0.037
5C Pease River (Childress)	(8 years) 32.5842	0.02408	0.7339	0.03318	0.01737	5.8465	17.8200	8.056	4.216
6-10 Area includes basins 6-10	(5-9 years) 115.5136	0.1249	3.8070	0.1735	0.0846	30.8860	94.1405	42.910	20.926
6 North Fork Wichita River (Paducah)	(8 years) 19.8165	2.6808	81.7108	3.2283	2.1093				
8A South Fork Wichita River (Guthrie)	(6 years) 13.6156	0.2686	8.1870	0.3115	0.2229				
10B Salt Fork Brazos River (Peacock)	(9 years) 25.0487	0.0327	0.9967	0.0672	0.0087				
10C Croton Creek (Jayton)	(9 years) 6.3678	0.0635	1.9355	0.1352	0.0218				
10D Salt Fork Brazos River (Aspermont)	(9 years) 70.1657	0.07216	2.1994	0.1061	0.0447				

*Preliminary horizontal rates in Gustavson and others (1979c) are lower due to a difference in procedure. All dissolution zones beneath a basin were considered to contribute to solute load for the basin.

**Number of years of data.

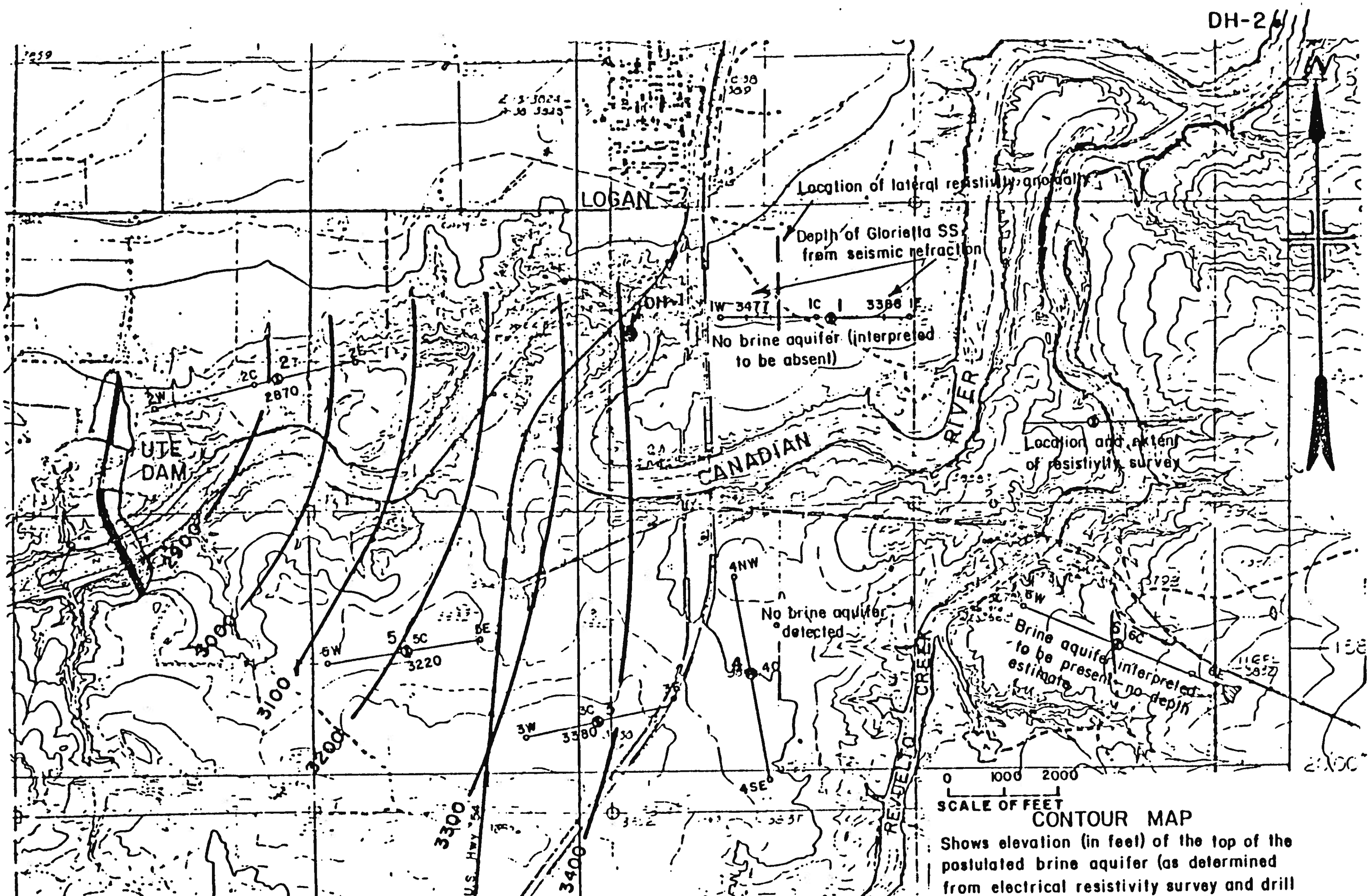
USBR, 1979



Cross-section of resistivity soundings, lines 2, 3, 4, 5, the brine aquifer has been cross-hatched.

FIGURE 4

USBR, 1979



CONTOUR MAP

Shows elevation (in feet) of the top of the postulated brine aquifer (as determined from electrical resistivity survey and drill hole information).

Lake Meredith Salinity Study

Drill Hole - DH

FIGURE 5