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GEOLOGIC REPORT
ON THE
LOGAN, NEW MEXICO AREA
LAKE MEREDITH SALINITY STUDY - TEXAS AND NEW MEXICO

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INTRODUCTION

The Lake Meredith Salinity Control Project was initiated to locate brine inflows into the Canadian River and develop a method of controlling these flows to prevent additional degradation of the water quality in Lake Meredith. The project covers an area along the Canadian River between Ute Dam near Logan, New Mexico, and Sanford Dam near Borger, Texas, (figure 1). It is a joint study that is funded by the U.S. Bureau of Reclamation (Reclamation), the Canadian River Municipal Water Authority (CRMWA), and the State of Texas.

Ute Dam is an earthfill structure roughly 5,300 feet long with a crest elevation of about 3812. The feature was constructed by the State of New Mexico in 1962 and was modified in 1984. It forms the first impoundment (Ute Lake) upstream of Lake Meredith on the Canadian River.

Sanford Dam is a zoned earthfill structure that is 6,300 feet long and has a structural height of 220 feet. It is located on the Canadian River about 37 miles northeast of Amarillo, Texas. The dam was constructed by Reclamation and was completed in 1965 as part of the Canadian River Project. The dam impounds a reservoir (Lake Meredith) that has a flood control capacity at elevation 2965 of 1,407,572 acre-feet of water. The maximum reservoir storage has never approached this elevation since the dam was constructed. Water impounded by the lake is pumped through 322 miles of pipeline for use by 11 cities in Texas that are located south of the dam at higher elevations. Ute and Sanford Dams are roughly 150 miles apart.

Since impoundment began in 1965, Lake Meredith has experienced a gradual decline in water quality that is partly associated with reduced reservoir levels. Concentration of sodium, chloride, sulfate and total dissolved solids often exceed the recommended standards for municipal water supplies. A gradual increase of these contaminants is expected to continue unless some corrective action is undertaken.

In response to these concerns, CRMWA requested Federal assistance in seeking a means to alleviate, or at least control, the salinity problem developing in Lake Meredith. In March 1983, Reclamation initiated the Lake Meredith Salinity Control Project to determine a course of action to solve the problem. Since that time a number of studies have been conducted by Reclamation, CRMWA, the State of Texas, and others to (a) identify the sources of saline contamination in the Canadian River between Ute Lake in New Mexico and Lake Meredith in Texas, (b) determine the magnitude and extent of saline water inflows into reaches of the Canadian River, (c) evaluate alternatives for reducing or controlling the salinity inflow, and (d) evaluate the effectiveness of implementing a plan for reducing or controlling the salinity levels of Lake Meredith. Studies that have been completed since 1983 were done intermittently and were controlled by the availability of funds and other factors.

Hydrogeologic investigations have determined that a significant source of sodium chloride brine of natural origin produced by the dissolution of Permian halite beds flows into the Canadian River near Logan, New Mexico. This brine producing area is restricted to a reach about 5.5 miles long extending from Ute Dam to the point where Revuelto Creek enters the Canadian River. The Logan area accounts for a large part of the chloride and some of the sulfate reaching Lake Meredith. Another large brine producing area appears to be concentrated in the "Dunes" area which is located between Revuelto Creek and the Texas state line. Figure 2, located in the appendix, shows the chloride loading that has been measured in the Canadian River between Ute Dam and the Texas state line.

Based on the above finds and other studies that have been undertaken, the plan that is most acceptable to CRMWA for improving the water quality of Lake Meredith is to intercept the brine at the Logan source by well pumping. Disposal of this brine would be accomplished by deep well injection into underlying permeable geologic units.

PURPOSE OF REPORT

The purpose of this report is to document the geologic investigations that have been conducted in the Logan, New Mexico, area between December 1993 and August 1994 and supplement this with information that was collected earlier. Groundwater modeling and seismic (shallow and deep) investigations have been or are being completed for the study at this time. Data from these investigations will be presented in separate reports.

INVESTIGATIONS

Previous

Numerous studies have been undertaken and various documents have been prepared for the Lake Meredith Salinity Control Project. These range from drilling holes and preparing geologic logs to completing detailed geologic, groundwater, and surface water reports. The most significant studies that are related to the geologic conditions of the site are listed below.

1. During June and July 1975, drill holes DH1 and 2 were completed by Reclamation. These holes ranged from 356 to 556 feet in depth. A natural gamma log was run in DH2 to a depth of 160 feet, and geologic logs of both holes were prepared based on drill cutting data.

2. A limited geophysical investigations program was completed north and south of the Canadian River near Logan by Reclamation. This is described in the "Report on Electrical Resistivity and Seismic Refraction Surveys, Canadian River, Lake Meredith Salinity Study," dated 1976.

3. Between September 1977 and March 1978, Test Well TW 1 was drilled to a depth of 358 feet. Additional drilling was also completed on Observation Wells POW1, OW2, OW3 and OW4. These holes were drilled to depths ranging from 318 to 382 feet and were used to gather information on the pump test that was conducted in TW1 during March 1979. All of this work was completed by

Reclamation. Natural gamma logs were also run in all of the wells (OW4 log could not be located) and a geologic log for each well was prepared using information obtained from drill cuttings.

4. During August and September 1983, Reclamation cored DH3 to a depth of 569.5 feet. A natural gamma log was also completed in this hole, and a geologic log was prepared using data collected from drill core samples.

5. Under a Reclamation contract, Hydro Geo Chem, Incorporated, from Tucson, Arizona, prepared a pictorial report that displayed geologic and groundwater conditions in the salinity project area. This information is documented in the January 9, 1984, report titled "Geologic Study Related to Salt Pollution - Lake Meredith Salinity Study, Texas-New Mexico."

6. A report prepared by Reclamation titled, "Lake Meredith Salinity Control Project - Hydrology/Hydrogeology Appendix, Canadian River - New Mexico-Texas" was completed in December 1984. This report documents the drilling (12 shallow holes from 14.5 to 59.3 feet) that was completed in alluvial deposits at Water Quality and Flow Monitoring sites 1 through 4 and 6. It also covers, in detail, additional data on geology, surface and subsurface water quality, seismic and miscellaneous studies.

7. Hydro Geo Chem, Incorporated, completed a report on December 19, 1984, titled, "Analysis of Geophysical Data to Examine the Feasibility of Deep-Well Injection of Brine Near Logan, New Mexico." This report presents the data

collected from two deep seismic lines (one near north-south and one near east-west) that were completed south and east of the brine producing area near Logan.

8. Another Hydro Geo Chem, Incorporated, report that was also prepared under Reclamation contract was finalized on May 1, 1985. This report is titled, "Study and Analysis of Regional and Site Geology Related to Subsurface Salt Dissolution Source of Brine Contamination in Canadian River and Lake Meredith, New Mexico - Texas and Feasibility of Alleviation or Control." This document presents data on the geology, hydrology, geochemistry, and feasibility of saline control for the project.

9. In June 1985, Reclamation published the "Technical Report on the Lake Meredith Salinity Control Project, Canadian River, Texas-New Mexico." This summarized much of the earlier investigations and developed preliminary cost estimates and plans for constructing a salinity control project.

10. In July 1992, the Bureau of Economic Geology in Austin, Texas, prepared a report titled, "Canadian River Salinity Sources, Ute Reservoir, New Mexico to Lake Meredith, Texas: Evaporite Dissolution Patterns and Results of February 1992 Water Quality Survey." This document was prepared under contract for CRMWA. It provides background information on geologic conditions, evaporite dissolution patterns, water chemistry, river conductivities, flows, and other miscellaneous items along the Canadian River downstream from Ute Dam.

11. The Texas Bureau of Economic Geology also conducted an electromagnetic study along a section of the Canadian River for CRMWA. This is documented in the April 1993 report titled, "Electromagnetic Delineation of Saline Groundwater Plumes in Alluvium and Bedrock Along the Canadian River Between Ute Reservoir and Rana Canyon, New Mexico."

12. Two documents with an executive summary were prepared in July 1992 and revised in May 1993 by Parker, Smith and Cooper, Incorporated in association with Lee Wilson and Associates for CRMWA. These are the "Surface Water Notebook" and the "Groundwater Notebook" for the "Lake Meredith Salinity Control Project." The two publications and executive summary reference a significant portion of available geologic, groundwater, and surface water information that exists in the area. The publications also expand on this information and provide additional insight to the salinity control program.

1993 and 1994

Recent geologic and groundwater investigations that were completed by Reclamation or CRMWA include drilling and logging test and observation wells, performing pump tests, mapping the area geology, conducting shallow and deep seismic studies, and collecting information on previously drilled oil and water wells near the city of Logan.

Two test wells, TW2 and 3, were drilled to depths of 348.4 and 369.7 feet, respectively. Drilling was initiated in December of 1993 and was completed in March of 1994. A total of four observation wells OW5A, 5B, 6A, and 6B were also completed to depths ranging from 125 to 510 feet. These wells were drilled in March 1994 to assist in monitoring groundwater conditions during the pump tests that were conducted at TW2 and 3 in April. Observation Well OW6C was added during June because of questions that developed regarding the geology at OW6A and B. This hole was drilled to 440 feet. Selected exploratory holes were geophysically logged using self potential 16-64 normal resistivity, neutron, sonic, density, caliper, temperature, and natural gamma log probes. A televiewer log was also completed in OW6C and natural gamma, caliper, and temperature logs were run in TW1 which was drilled in 1978. Geophysical logs for selected drill holes completed for the recent investigations program (TW1 through 3, and OW5A and 6C) and natural gamma logs for most of the drill holes completed prior to 1979 (DH2 and 3, POW1, and OW2 and 3) are included in this report. Also, included are geologic logs for DH1 through 3, TW1 through 3, POW1, OW2 through 4, OW5A, 5B, 6A, 6B, and 6C and completion records (figure 9 through 15) for the holes drilled in late 1993 and early 1994. Locations of the drill holes are shown on drawing 1253-600-22. Selected information on ground surface and water level elevations, formation thicknesses, well and observation well characteristics, and other pertinent information are tabulated on table 1 (sheets 1 and 2 of 2).

One additional test well (TW4) and three observation wells (OW7, 8, and 9) were drilled and a pump test performed in TW4 during November and December 1994. Data collected from these investigations will be included in reports that will be prepared at a later date.

added

Geologic mapping was completed in the area during mid-1994 and was concentrated along the Canadian River and Revuelto Creek. This information is shown on drawing 1253-600-22. A number of geologic drawings (1253-600-21 through -33) were also produced using information obtained from all previous investigations.

added

Two seismic surveys were completed recently by Reclamation. One was concentrated between Observation Well OW6C and Test Well TW3. Part of this survey was conducted along the valley floor of the Canadian River and part was directed at an area above the Canadian River trench. This survey collected information on shallow lithologic units, the brine aquifer, fractures and faults, and other data for the project. The seismic profile only penetrated to a relatively shallow depth of about 800 feet.

A second much deeper seismic investigations program has also been completed. This study used older information that (a) was purchased from a geophysical investigations company, and (b) was documented in the Hydro Geo Chem, Incorporated, report dated December 19, 1994. These surveys were modified by modern computer enhancement and correlated with deep oil test wells in the surrounding area. The purpose of the deep seismic study was to gather information on the deep brine injection zones near Logan.

Results of the shallow and deep seismic studies are documented in the October 1994 report titled, Geophysical Investigations-Lake Meredith Salinity Study, New Mexico. Another study by Reclamation that examines existing oil well logs in the area is in progress and will be completed in the near future.

Reclamation is also presently finalizing a model that investigates the characteristics of the groundwater regime in the study area. The modeling, along with a groundwater report discussing the pump tests and other data, and the shallow and deep seismic investigations will not be part of this geology report.

Geologic, groundwater, chemical, and miscellaneous data were gathered from various sources for Reclamation drill holes and other water wells in the area of Logan. These data have been tabulated on tables 5 through 26, and they are included in the appendix of this report. Location of all holes, except for wells BYW and WPN, are shown on drawing 1258-600-22.

REGIONAL GEOLOGY

Physiography

The Logan area lies in the Canadian River Valley within the Great Plains Physiographic Province. In this area the Canadian River is entrenched up to several hundred feet below the general land surface and is flanked on both sides by the Canadian River "breaks." The breaks consist of a strip of land 15 to 30 miles wide that has been dissected by the Canadian River and its tributaries. The resulting topography varies from gently rolling hills and flat terraces to rough and broken topography that has a badland-type appearance.

Stratigraphy and History

Sedimentary rocks that occur in this portion of New Mexico range from Upper Pennsylvanian to Holocene in age. Only rocks younger than the Permian crop out in the area. Further south in the Palo Duro Basin, pre-Pennsylvanian sediments are known to exist as they have been penetrated by petroleum exploration holes.

Precambrian rocks lie deeply buried beneath the area. These rocks were extensively eroded, and the surface varies widely in topographic relief. Either the area remained above sea level during the early part of the Paleozoic or older sediments that existed were removed by erosion prior to upper Pennsylvanian deposition.

The upper Pennsylvanian unit that unconformably overlies the Precambrian has been named the Sangre de Cristo Formation. This formation may also be Permian age, in part, and it interfingers laterally or conformably underlies the Permian Abo Formation. Both units contain red arkosic sandstones and brownish red shales and siltstones that were largely derived from highlands northwest of Quay County, New Mexico. The Sangre de Cristo arkosic sandstones are well graded with angular to subangular particles. The Abo contains more fine-grained clastic materials and less arkosic sandstones and the sandstones that are present are more uniform in grain size. The Abo and Sangre de Cristo are continental deposits that accumulated adjacent to the highlands that existed in northeastern New Mexico, and both appear to grade into marine limestones, dolomites, and shales to the south. Because of the interfingering, lenticular nature, and similarities of these units, it is difficult to differentiate between them. It is also difficult to determine the location of the Permian-Pennsylvanian boundary within these strata. The combined thickness of both formations ranges from 350 to over 2,000 feet in northeastern New Mexico.

The Yeso Formation of Permian age conformably overlies the Abo Formation. It consists of a series of interbedded fine-grained yellowish sandstones, pale red siltstones and shales, and a number of halite and anhydrite horizons. Much of the unit was deposited in a marine environment and was laid down along the flanks of the highlands that existed when the Abo and Sangre de Cristo Formations were formed. Marine conditions were more restricted near the close of Yeso deposition, and there is a collection of sandstones in the upper section. The Yeso has been divided, from oldest to youngest, into the Red Cave, Lower Clear Fork, Tubb, Upper Clear Fork, and Glorieta Formations in the Palo Duro Basin. All of these formations will be referred to as the Yeso in this report. Thickness of the Yeso in the vicinity of Logan appears to be about 1,100 feet. It thins to the north and becomes much thicker to the south and southeast.

The San Andres Formation conformably overlies the Yeso and was deposited in expanded Permian seas. The unit contains interbedded sandstone, limestone, dolomite, halite, gypsum, and anhydrite. Many sandstones that were deposited northwest of Quay County change to carbonates to the east and south. After deposition, the salt beds in this unit extended far into northeastern New Mexico. Because of the dissolutioning that has taken place, however, the northern limits of these halite intervals now terminate near or south of the Canadian River. Up to 250 feet of salt has been reported in the San Andres in an oil well located several miles east of the city of Logan. The San Andres is about 700 feet thick near Logan. The formation thins to the north and thickens to the southeast into the Palo Duro Basin.

Overlying the San Andres is the Permian marine Bernal Formation of the Artesia Group. The Artesia Group is separated into a number of formations in the Palo Duro Basin. These include, from oldest to youngest, the Queen/Grayburg, Seven Rivers, and Solado/Tonsill Formations. Only the Bernal Formation or Artesia Group names will be used in this report. The Bernal consists of red- to salmon-colored shale, siltstone and fine-grained sandstone with interbedded anhydrite, salt, dolomite, and limestone. Like the San Andres and the Yeso, salt beds were deposited far north into east-central New Mexico in the Bernal, but dissolution of these evaporites has removed them to points south of the Canadian River. The Bernal thickens to the southeast and changes into a more complex clastic, carbonate, and evaporite sequence. Overlying the Bernal in parts of northern New Mexico are the Alibates Dolomite and Dewey Lake (Quartermaster) Formation of Permian age. There is general disagreement as to whether these formations are or are not present beneath the study area. Recent seismic studies indicate that they may be present. For the purpose of this report, all material below the Tecovas and above the San Andres will be considered as part of the Bernal Formation. The Bernal appears to be at least 350 feet thick and possibly up to 1,000 feet thick beneath the Logan area.

The Permian Bernal and the overlying Triassic Dockum Group are separated by an erosional unconformity. The unconformity also marks a change from marine to continental deposition.

The Dockum Group has been divided into the upper Chinle Formation and a lower Santa Rosa Sandstone. The Santa Rosa has also been separated into the upper Trujillo and lower Tecovas Formations. In this report, the Chinle, Trujillo, and Tecovas names will be used.

The Tecovas and Trujillo are clastic rocks that accumulated under flood-plain and deltaic conditions. Both formations are similar and consist of cross-bedded and lenticular sandstone with discontinuous and lenticular shale units. The Tecovas and Trujillo Formations range from 140 to 235 and 175 to 240 feet thick, respectively, in the area of Logan. Exposures of the Trujillo Formation are common along the Canadian River downstream of Ute Dam. The Tecovas only crops out sparingly along the river channel. West of Quay County, it is evident that the Tecovas Sandstone was deposited on an irregular sinkhole or karst topographic surface which developed because of the dissolution of Permian salt and the collapse of overlying sediments.

The Chinle Formation conformably overlies the Trujillo. The Chinle is about 1,200 feet thick and is composed of brown to red and variegated shales and siltstones with one or more thick sandstone beds near the center of the deposit. Like the Tecovas and Trujillo, the Chinle was deposited in a continental-type environment. The Triassic Dockum Group is about 1,600 feet thick near Logan and thins to the north.

The Jurassic Wingate (?) Sandstone rests with local disconformity and local unconformity on the Chinle sediments. This interruption in deposition was caused by the gentle folding that occurred in the area at the close of the Triassic period. The Wingate (?) appears to have been deposited by eolian and subaqueous processes. Local deposits of thin-bedded limestones suggest that lacustrine accumulation may have also periodically occurred.

The succeeding Morrison Formation, also of Jurassic age, is an accumulation of clastic debris that was laid down on vast lowlands and flood plains. The stratigraphic sequence between the Wingate and the Morrison Formations is incomplete and appears to have been interrupted either by nondeposition or erosion. Jurassic sediments do not exist near Logan, as they have been eroded away. These formations, however, appear to have been in excess of 300 feet thick in the area, and they were likely much thicker to the north.

Lower Cretaceous sediments in northeastern New Mexico rest unconformably on Jurassic and even Triassic rocks in places. These sediments include shale and sandstone beds of the Purgatorie Formation. Lying directly above the Purgatorie is the Dakota Sandstone which is considered to be of Upper Cretaceous age. At least part of these units may have been deposited in a marine environment, but they grade into continental deposits to the west and northwest. The Purgatorie and Dakota Formations that cap isolated buttes and benches are about 200 feet thick near the city of Tucumcari, New Mexico.

The Colorado Group of Upper Cretaceous age includes, in ascending order, the Graneros Shale, Greenhorn Limestone, Carlisle Shale and Niobrara Formation. These marine deposits have been completely removed by erosion in the Logan area. Outcrops in surrounding areas indicate that up to 800 feet of these sediments had accumulated in east-central New Mexico.

During late Cretaceous and much of Cenozoic time (especially in areas west of Quay County) there were periods of widespread and repeated uplifting, although it appears that eastern New Mexico was not greatly effected by this. There was, however, slight folding in localized areas, and the general area was tilted so that the regional dip was changed to the southeast. After the mountain building developed in the west and streams were rejuvenated, large quantities of clastic debris were deposited throughout eastern New Mexico in Tertiary time. Remnants of this accumulation (Ogallala Formation) are now exposed along higher benches north and south of the Canadian River. Because the Ogallala was deposited on an unevenly eroded surface, it ranges in thickness from tens of feet over preexisting highs to 550 feet thick in buried valleys.

Recent history shows that erosion dominated the geologic process, and much of the Ogallala and older sediments were removed to varying depths. Solutioning of Permian salts, which may have been intermittently continuous since at least the Triassic, continued in a more active environment with the development of an extensive sinkhole and karst topographic surface. Terrace deposits that exist along the rivers and major tributaries indicate that there was intermittent entrenchment through these channels during the Pleistocene period. Following the excavation of the Canadian River trench, Holocene silts, sands and gravels have partially filled these channels. Aeolian deposits that include loess silts and clays and dune sands partially mantle Pleistocene terraces and older geologic units, especially in areas north of the Canadian River.

Figure 3, located in the appendix, is a stratigraphic column showing the relationships of the formations in the study area. The column is only partially complete for the strata younger than Triassic in age.

A generalized geologic section that extends north-south through the Logan area is shown on figure 4. This section also shows the geologic units that are rich in salt deposits.

Structure

The major subsurface tectonic features in east-central New Mexico include the Sierra Grand Uplift and the Palo Duro Basin (figure 5). The Sierra Grande Uplift is a buried structure that is linear in shape and trends in a north-northeastern direction. It is located northwest of Quay County. Associated with this structure is the Oldham Nose (includes the Bravo Dome), which is also a positive area that trends from the Sierra Grande Uplift towards the southeast and may be an extension of the Amarillo Uplift in the panhandle of

Texas. All of these elevated structures appear to have been active during the Mississippian, Pennsylvanian, and Permian times. There is also some evidence that they may have developed over features that were present in the basement complex in Precambrian time.

The Palo Duro Basin is a large west-northwest trending basin that formed in conjunction with the adjacent structural highs. This basin lies to the south of Logan. Two smaller and deeper sections of this depression are the Tucumari and Cuervo Basins. The Tucumcari and Cuervo Basins appear to have been best developed during late Pennsylvanian and early Permian times, as they have been filled with a very thick accumulation of Abo and Sangre de Cristo deposits.

Limited information suggests that there are a series of block mountain-type faults in the east-central section of New Mexico, and that these faults may be the controlling features for the uplifts and basins described above. The faults appear to have been activated in late Paleozoic time, and they were likely rounded off by erosion and covered by Permian and possibly upper Pennsylvanian sediments. Major trends of this faulting appear to be oriented in a northwest direction, and there is information supporting truncation of these features by less extensive northeast trending faults. Evidence suggests that at least one of the major faults lies near Tucumcari and that the south side of the fault has dropped up to several thousand feet to form the Tucumcari Basin. Recent seismic investigations also suggest that a similar-type fault may exist directly north of Logan.

Groundwater

The regional groundwater system has been divided into a deep brine aquifer, an evaporite aquitard, and an upper aquifer that in places can contain saline or fresh water. The deep brine aquifer consists of the Abo and Sangre de Cristo Formations, which have a relatively high permeability value. Brines in this deep aquifer are dominated by sodium and chloride and have typical TDS contents of 150,000 to 170,000 mg/L. The hydraulic head in the brine aquifer is generally lower than the ground surface and the hydraulic gradient is generally downward in the area. Information gathered by others indicates that the piezometric surface in the deep brine aquifer slopes eastward at a rate exceeding 6 feet per mile.

The evaporite aquitard unit is composed of the Yeso, San Andres, and Bernal (Artesia) Formations. These units, on average, have lower permeabilities and porosities and act as a barrier over the deep brine aquifer. The aquitard is dominated by siltstone, shale, fine-grained sandstone, carbonate, and evaporite deposits, and it also contains brine solutions as the result of the breakdown of salt by dissolutioning. Water levels in these units appear to be above the Canadian River in New Mexico, but they slope eastward and lie generally below the river in Texas. Thus, the water level gradient in the aquitard is steeper than the ground surface (river floor) in eastern New Mexico.

Although the aquitard has a rather low primary permeability, the upper part has been extensively fractured in areas where salt dissolutioning and resultant formation collapse have taken place. Because of the hydraulic head in the aquitard, brines from this unit can move upward into the overlying Tecovas and Trujillo Formations mainly along the discontinuities that now cross these formations.

The upper aquifer includes the Tecovas, Trujillo, and Ogallala Formations. The Ogallala is much younger and is separated stratigraphically from the Trujillo. Both the Tecovas and the Trujillo are composed largely of permeable sandstone, and they are generally under artesian conditions near Logan, with heads being slightly higher in the Tecovas. Groundwater in these units moves towards the Canadian River from both the north and south.

Immediately south of the river, the Tecovas and often the Trujillo contain salt water. Deeper petroleum explorations farther south of the river indicate that the Tecovas and Trujillo often have a sodium- and chloride-rich brine that has moved upwards from the Permian. North of the Canadian river, the Trujillo and possibly Tecovas Formations contain better water, as these units are being flushed by fresh water working from the surface towards discharge points in the river.

Baseline flows along the Canadian River and its major tributaries originate from the Permian and Triassic rocks. Water from the Permian sediments is typically highly mineralized and that from the Triassic units is of fair to poor quality.

Salt Dissolution

Dissolution of bedded halite and anhydrite/gypsum from the Permian strata has occurred in large areas of New Mexico and Texas (figure 6). Salt was originally known to extend nearly to the Texas-Oklahoma border, but it has been removed in much of the area north of the Canadian River. This removal has taken place along the up-dip sections of the Permian strata where it butts up on the South flank of the Oldham Nose and Amarillo uplifts. The salt has been progressively removed from this area since Triassic time and the removal appears to have been more active since deposition of the Ogallala Formation.

Major streams that existed at the time of the Ogallala deposition are known to have flowed in a southeasterly direction along the dip of the Ogallala surface. As dissolutioning took place, subsidence along the northern margin of the Palo Duro Basin developed, and a series of lakes and basins formed along a front that extended in a general east-west direction. River systems that predated the Canadian River were diverted into these collapse features, and subsequent integration of this system eventually formed the present easterly flowing Canadian River. Existing information shows that sediments, behind or up dip of the dissolution fronts have collapsed at least 250 feet and may have locally settled up to depths of 500 feet.

Salt dissolutioning apparently takes place along joints and faults cutting evaporite deposits and along the margins of the existing salt beds. Along the front of the evaporite margin, groundwater removes the salt, and the overlying and adjacent beds settle into the void that is formed. Fractures develop in the collapsing rock, and this in turn provides easy access for groundwater to continue the salt dissolutioning process. Although salt beds appear to be thinned by dissolutioning, dissolutioning of a salt bed usually takes place along a steeply dipping front that gradually advances towards the center of structural lows. As the process takes place, the highest beds are removed first, and each older underlying halite bed is then taken out in a receding step-like sequence.

As sections of the salt beds are eliminated and settlement occurs, several types of structural features are formed. Collapsing rock is broken and cut by new joints and faults, and preexisting fractures are opened. The dominant fracture system that develops probably follows the direction of the salt front. Collapse breccias form along bedding where salt beds have been removed, and breccia-filled pipes often develop vertically at the intersection of crossing fractures. The pipes are often circular in shape and can extend from a salt bed to the ground surface. Similar features are common at Sanford Dam in Texas. Large undrained depressions and folded, rolling terrain also typically develop over dissolutioned areas. Folds that develop generally do not have consistent trends and, therefore, can easily be distinguished from structures developed by mountain building processes.

The Permian sequence contains salt beds in the Bernal (Artesia), San Andres, and Yeso Formations. Halite within the Bernal has been removed along an east-northeasterly trending front that extends from about Tucumcari to a point possibly 10± miles south of the city of Logan. Interpretations on the location of this front vary widely, and some investigators place the northern limit of the salt only several miles south of the river.

Salt in the underlying San Andres Formation occurs in several beds. Like the Bernal, the salt beds thicken in a southerly direction. The dissolution fronts of all the salt units within the San Andres probably lie along or just slightly south of and parallel to the Canadian River near the city of Logan.

The Yeso Formation salts appear to be thinner than those in the San Andres, and they extend north of the Canadian River. Existing information suggests that the Yeso salt fronts lie in an east-west direction near Logan. A thick siliciclastic-halite bed in the Glorieta Unit (upper Yeso) may have been partially affected by dissolutioning beneath the Canadian River. However, this bed also appears to extend a considerable distance to the north. The approximate locations of the salt beds and areas where they have been removed are shown in sections (figures 7 and 8) that were produced by T.C. Gustavson, et al. in 1992.

SITE GEOLOGY

General

The Lake Meredith Salinity Control Project encompasses an area along the Canadian River between Ute Dam in New Mexico and Lake Meredith in Texas. Geologic investigations that were recently completed for this report are located in the reach of the Canadian River between Ute Dam and the mouth of Revuelto Creek, a distance of about 5.5 miles. This section appears to be the most significant brine producing source on the project. Drawing 1258-600-22 shows the location of exploration holes, and drawing 1258-600-33 shows the topography and general location of the study area. Photographs 1 through 16 show various features in the project area.

The topography between Ute Dam and Revuelto Creek is relatively flat except in the Canadian River and Revuelto Creek trenches. In the trench areas, near vertical cliffs are common with some walls exceeding 100 feet in height. The maximum topographic relief in the study areas is about 200 feet, ranging between elevations of 3650 to 3850.

Stratigraphy

Geologic units that are exposed or were penetrated by drill holes vary from Holocene to Permian in age. A brief description of each unit, from oldest to youngest, is listed below:

Bernal Formation (Artesia Group) - Permian

This formation consists of orange-red to salmon colored marine deposits of siltstone and shale with some fine-grained sandstone and thin beds of limestone and dolomite. Zones of bedded anhydrite occur in areas, and secondary deposits of gypsum fill in some fractures. Salt (halite) deposits are interbedded in the Bernal farther south, but these units have been removed by dissolutioning beneath the Canadian River. The top of this formation is an unconformity, and there is considerable relief on this surface. West of Quay County, sinkholes and a karst surface are reported to have developed on the top of the Bernal as the result of dissolutioning of salt deposits in the Permian. This formation does not crop out in the study area, but it was penetrated in many of the drill holes that were completed. As described earlier under the stratigraphy and history section of this report, the Alibates Dolomite and Dewey Lake (Quartermaster) Formations may be present beneath the study area. If so, they have not been separated, and for the purpose of this report, are included within the Bernal. These sediments appear to be at least 350 feet thick and possibly up to 1,000 feet thick beneath the Logan area.

Tecovas Formation (Dockum Group) - Triassic

The Tecovas Formation can be separated into three units, an upper and lower shale and a middle sandstone section. The upper shale unit ranges from 28.0 to 65.0 feet thick in the study area. Drill Holes 1 and 3 penetrated 65 and 64 feet of this unit, respectively. In both holes, the entire sequence was red to gray shale and sandy shale. Progressing to the east, the unit thins and contains more light gray, moderately cemented, fine-grained sandstone partings. Test Well 3 penetrated 28 feet of the upper unit, and this drill hole contained six shale beds that had a combined thickness of 18.5 feet. East of TW3, the unit appears to thicken, and in outcrops along the river downstream of Revuelto Creek, it contains less sandstone.

Groundwater in the Tecovas and Trujillo formations usually have artesian heads higher than the Canadian River, with the hydraulic head in the Tecovas being slightly higher near the river. The upper shale horizon appears to be a limited barrier for upward groundwater movement. The barrier is least effective where the unit thins, contains more sandstone, or is fractured and faulted.

The middle part of the Tecovas is made up mostly of light gray, micaceous, weakly to moderately cemented, fine-grained (100± sieve), rather permeable quartzitic sandstone. The sandstone contains clay and silt binder, locally. The unit is cross bedded and lenticular and has moderately cemented thin lentils of conglomerate in the upper part and discontinuous thin red, maroon or gray clayshale, sandy shale, and shaley sandstone units throughout. Two thin shaley units that are located about one-third and two-thirds of the way through this middle section appear to be fairly continuous in the Logan area. At least 90 percent of the middle unit is sandstone. Scattered thin carbonaceous seams occur in the central part of the sandstone and large petrified logs are known to exist locally. The Tecovas Sandstone is a good aquifer, but it contains generally saline water, especially south of the

Canadian River. The upper 50 to 60 feet of the upper and middle units crop out downstream of the study area along the lower part of the Canadian River trench in sec. 7, T. 13 N., R. 34 E. The sandstone is about 80 feet thick in the area of TW 1 and 2. It thickens upstream to about 145 feet at DH1 and downstream to over 170 feet at TW3.

The lower shale lies immediately above the Bernal Formation. It varies from 15 to 45 feet in thickness and consists of gray shale and sandy shale with some thin beds of sandstone. Where it is thickest, the lower shale unit appears to contain large amounts of sandstone.

Thickness of the Tecovas Formation changes rapidly. It ranges from 163 feet in TW2 to 222 feet thick in DH3 and averages about 190 feet thick.

Trujillo Formation (Dockum Group) - Triassic

The Trujillo Formation conformably overlies the Tecovas Formation. Like the Tecovas, it is composed of continental fluvial and deltaic deposits. The upper half of the Trujillo is yellow-brown to light gray, micaceous, generally fine-grained, silty, to clayey, weakly to moderately cemented, quartzitic sandstone with red, maroon, and gray lenticular and discontinuous clayshale and sandy shale beds. The lower part contains similar shales and sandy shales, but the sandstones are coarser and conglomeritic with slightly more cement. Conglomerates contain fragments of limestone, sandstone, chert, and petrified wood. Sandstones and conglomerates range from thin bedded to massive and are cross bedded and lenticular. On outcrop, the Trujillo forms extensive tan to brown, blocky cliffs that exceed 100 feet in height along the walls of the Canadian River trench. The Trujillo Formation is also a good aquifer, and it provides domestic water supplies for wells located north of the river. Wells south of the trench within several miles of the river will produce fair to poor (saline) quality water. It appears that the quality of water in the Trujillo also improves east of Revuelto Creek . Deeper wells south in the Tucumcari Basin often encounter saline brines in the Trujillo.

At the Highway 469 crossing of Revuelto Creek there is evidence that dissolutioning of salt was taking place in the Permian sediments when the Trujillo Formation was being deposited. At this location, the main sandstone section has settled into a synclinal feature that is filled with red and maroon shales and sandy shales and capped by a flat lying upper sandstone that forms the top of the Trujillo. The shale unit thins to the south and west, and the upper sandstone converges with the lower sandstone unit in these areas.

The complete section of the Trujillo was only penetrated in drill holes DH3 and OW5A. At DH3 the Trujillo is 174 feet thick, and it thickens to 230 feet in OW5A.

Chinle Formation (Dockum Group) - Triassic

The upper member of the Dockum Group is the Chinle Formation. This unit conformably overlies the Trujillo, and it forms a less resistant slope above the Trujillo cliff. It is composed of brown to red and variegated shales and siltstones with one or more thick sandstone beds in the center of the section that have characteristics similar to the Trujillo sandstone. The Chinle also contains some calcareous horizons that may represent lacustrine deposits. Only two drill holes penetrated the lower part of the Chinle. They were DH3 which encountered about 100 feet of the deposit and OW5A which penetrated the bottom 5 feet of the formation. The Chinle often caps the topographic highs in the area and is exposed extensively south of the Canadian River. Total thickness of this deposit is about 1,200 feet where it has not been disturbed by erosion.

Terrace Deposits - Pleistocene

Three terrace levels occur within the immediate vicinity of the Canadian River near Logan. These deposits are gray to brown, generally unconsolidated, and contain subrounded hard sand and gravel with some silt, clay, and cobbles. Gravels are chiefly of igneous or metamorphic origin, but hard fragments of sedimentary rocks such as sandstones and carbonates are present. The upper 1 to 2 feet of all terraces contain caliche or caliche coated gravels. Lenticular zones of highly cemented ($CaCO_3$) and generally highly oxidized conglomerate occur throughout, and these appear to be most common in the lower levels of the Qt_2 terrace. The terraces mark preexisting levels of the Canadian River, and they are much more extensive north of the trench. This may indicate that the river was being forced southward into depressions as salt dissolutioning was taking place in the underlying Permian sediments. The Qt_3 terrace is the oldest, and it lies about 160 to 180 feet above the existing channel. The youngest is the Qt_1 terrace, and it is 60 to 80 feet above the river. Located between is the Qt_2 terrace which is about 100 to 120 feet higher than the floor of the Canadian River trench. All terraces are mantled by a soil cover of silt, clay, sand, and scattered pebbles that varies from 1 to 20 feet in thickness. This soil cover is partly wind (loess and dune sand) and water (colluvium) deposited and was mapped with the terraces on the geologic map (drawing 1253-600-22). Total thickness of the soil cap and terrace gravel may exceed 60 feet.

Colluvium Deposits - Holocene

The colluvium consists of gray to tan unconsolidated clay, silt, sand, and gravel that was deposited on upland slopes. Included and mapped with this debris are deposits of low density loess and dune sand. Only the more extensive soil covered areas are shown on the geologic map (drawing 1253-600-22).

Alluvium Deposits - Holocene

Alluvium consists of unconsolidated clay, silt, sand, and gravel with some cobbles and was deposited beneath the flood plains of the Canadian River and Revuelto Creek. Drilling investigations at Ute Dam and several drill holes completed along the channel for this study show that the alluvium is up to 60 feet thick in the area. Shallow seismic studies that were recently conducted along the trench floor, however, indicate that the deposits may be up to 100 feet thick in the area of TW3.

The lateral extent of the geologic units in the area is shown on drawing 1253-600-22. Geologic sections A-A through F-F (drawings 1253-600-23 through -26) show the vertical relationships of these units along selected alignments. Locations of the sections are shown on drawing 1253-600-22.

Structure

Folding

The principle structure in the immediate area is an anticline that is located east of Revuelto Creek. The axis of this anticline lies near the center of sec. 8, T. 13 N., R. 34 E. Early investigations indicated that it could be traced for a distance of at least 40 miles, plunging to the southwest about 20 miles south of Tucumcari. Recent evidence suggests that this structure may trend to the northwest. To simplify nomenclature in this report, the anticline will be referred to as the Revuelto Creek Anticline.

Bedding at the surface along the west flank of the Revuelto Creek Anticline has a very gentle dip of about 1 degree towards the west. Oil exploration holes show that the structural relief on this fold at the top of the San Andres Formation is at least 1,000 feet, and it may exceed 1,400 feet over an east-west distance of about 30 miles.

Other folds occur in east-central New Mexico trending in a similar direction. These structures and the Revuelto Creek Anticline may be the result of compressive forces that developed during several stages of time over topographic features in the Precambrian. It is likely that the anticlines were present at least since the Pennsylvanian period. Additional deformation may have also developed in some of these structures after Chinle deposition and in Late Cretaceous and at several times during the Cenozoic.

The structural basin lying west of the anticline is an irregular-shaped depression. It is locally interrupted by several small anticlines that appear to have east-west trends. The syncline opens southward into the Tucumcari/Palo Duro Basins.

Salt dissolutioning that occurred after Permian time has created irregularities in the anticlinal and synclinal structures described above. In the area of Logan, a number of minor anticlines and synclines have developed on the west flank of the Revuelto Creek Anticline as the result of collapse over dissolutioned salt beds. Location of these features are shown on the geologic map (drawing 1253-600-22) and the structure contour maps (drawing 1253-600-27, through -29). Structural relief on these flexures exceed at least 100 feet in places. Although none of these extend over great distances, they appear to have significant control over the courses of the Canadian River and Revuelto Creek.

At least four minor anticlines caused by salt dissolutioning were mapped immediately south and east of Logan. Other smaller anticlines and domes likely exist as the Triassic sediments are extensively deformed by settlement. One anticlinal structure trends in an east northeasterly direction and subparallels the Canadian River south of Observation Well OW6C. This structure plunges towards the river where it ends in a shallow depression. Immediately east of this flexure, another anticline begins and it also follows in a north-northeasterly direction but diverts to the north between Revuelto Creek and the Canadian River. This structure appears to fade out in the area of TW3. Another small flexure trends and plunges northeastward in the river bend south of the city of Logan. The fourth small structure mapped trends east-west and lies about 2 1/2 miles south of where Revuelto Creek enters the Canadian River.

For the purpose of simplification, only the two most important synclines that are associated with the anticlines described above are plotted on the geologic map (drawing 1253-600-22). These are also features caused by salt dissolutionment. One of the synclines follows roughly the course of Revuelto Creek along the west flank of the Revuelto Creek Anticline and plunges in a southerly direction. Dips on both sides of this feature are very low and seldom exceed 2 degrees. The second syncline probably lies near the southern limits of the city of Logan and likely subparallels the Canadian River. The exact location of the axis on this feature is inferred on drawing 1253-600-22 as all bedrock outcrops are covered by Pleistocene or Holocene deposits, and the flexure cannot be mapped. Triassic sediments are, however, known to be at higher elevations north of the city. A third synclinal structure is located off (south) of the geologic map on Revuelto Creek. It trends in an east-west direction, and it is mentioned here because it also is a feature that causes a major direction change in Revuelto Creek.

The courses of the Canadian River and Revuelto Creek in the area of Logan appear to be controlled mostly by structures (anticlines and synclines) that developed as the result of underlying salt dissolutionment in Permian sediments. The halite beds in the Bernal Formation have been removed north of the Canadian River, and the salt fronts for these units now lie several miles to the south. The underlying San Andres Formation contains a number of thick salt beds, and geologic information shows that the fronts for the lower salt beds roughly underlie the Canadian River. Evidence suggests that the Canadian River trench may have developed over these dissolution fronts in the San Andres, and that the anticlines subparalleling the river on the south are surface features that formed as the result of strata draping over one or more San Andres salt fronts at depth.

The regional dip of sediments in this area of New Mexico is to the southeast. Bedding in the area of Logan, however, only rarely follows this trend because of the structural features that have developed. Surface mapping and drill hole information show that Triassic sediments dip generally from 1 to 2 degrees, but locally dips can be up to 6 or 8 degrees. In most instances, especially in the Trujillo Formation, it is impossible to obtain accurate measurements at the surface because of cross bedding. Cross bedding locally exceeds 45 degrees in places.

Jointing

Three separate joint surveys have been completed within the study area. The initial survey was conducted by Hydro Geo Chem, Incorporated, before May 1985. A second survey was completed by the Texas Bureau of Economic Geology (BEG) in April 1993. The third and last joint study was conducted by Reclamation in OW6C using geophysical (televiewer) equipment.

Hydro Geo Chem, Incorporated, mapped jointing at a number of locations along the Canadian River. Four of these sites are located between Ute Dam and Revuelto Creek. The location of the sites along with dominant joint trends are shown on drawing 1253-600-22. Four major joint trends were recognized. These had strikes ranging from N. 50°W., to N. 70°W., N. 10°W. to N. 30°W., N. 30°E. to N. 50 °E and N. 70°E. to N. 90°E. The N. 10°W. to N. 30°W. trend appears to subparellel the Revuelto Creak Anticlinal axis. The N. 30°E. to N. 50°E. and N. 70°E. to N. 90°E. trends lie roughly normal to the Revuelto Creek Anticlinal axis, and it is theorized by the writer that they probably developed with the N. 10°W. to N. 30°W. fractures when the anticline was formed. The N. 70°E to N. 90°E. fracture trend also roughly follows the salt dissolution fronts that are located deep in the Permian sediments. Reclamation has found that jointing typically develops in two major systems on anticlinal structures. The dominant set usually trends normal to the anticlinal axis and the second most prominent fracture system(s) lies roughly along the axis of the structure or at about right angles to the major joint group.

The joints that developed in conjunction with the formation of Revuelto Creek Anticline were features that contributed to the destruction of the salt beds north of the river. These fractures enabled groundwater to move into the deposits and begin the dissolutioning process. As the salt receded and the overlying strata collapsed, existing joints were opened and new ones formed to accelerate the breakdown.

Hydro Geo Chem, Incorporated, reported that all of the fracture systems were near vertical and were spaced from 6 to 36 inches apart. There was no evidence of displacement on any of the features at ground surface. Many of the joints were opened up to 1/4 inch and generally filled with calcium carbonate. Occasional fractures contained fine sand filling. It was also noted by Reclamation during the 1994 investigations that the calcium carbonate filling in the joints was salty near the level of the Canadian River. This was not apparent in joints located higher on the canyon walls.

Studies conducted by BEG found similar patterns in the discontinuities. The BEG determined that the primary joint system varied from N. 50°E. to S. 50°E. (averaged N. 82°W.) at nine sites between Ute Dam and Revuelto Creek and that they are roughly parallel to and formed in a similar time frame as the Palo Duro Basin. They concluded that the joints may have also been influenced by later subsidence resulting from dissolution of underlying Permian salts. BEG also recognized that the subsidence following salt dissolution may have been responsible for opening some of these fractures. At all nine locations, one or more secondary or crossing joint sets formed at high angles to the primary system.

BEG reported that most joints are near vertical and spaced less than 36 inches apart. The dominant system often appeared in groups and had more continuity than the secondary fractures. Secondary breaks often terminated along the east-west fractures.

BEG studies indicated that the primary joints were often open up to 1 millimeter in width with calcite filling and/or manganese and iron staining. In places, the joints were sealed with fine clastic sediments. Secondary joints had little evidence of separation or mineralized filling.

As drilling progressed during 1993 and 1994, it was noted that almost all exploratory holes encountered large water losses in selected locations. These loss areas were also the zones that appeared to produce most of the brine inflows into the drill holes. Because of this, Reclamation ran a televiewer log in OW6C to gather information on subsurface fracturing. This was analyzed by the geophysics department at Stanford University in California.

Fracture characteristics were determined for the three most critical horizons that were penetrated in OW6C. These included the Trujillo Formation (mostly sandstone) from 1 to 229 feet, the upper shale unit in the Tecovas from 229 to 278 feet, and the remaining portion of the Tecovas Formation (mostly sandstone) from 278 to 410 feet. Because the upper 87± feet of the hole was dry, the televiewer could not be used in this interval. Caving conditions below 378 feet also prevented the use of this instrument at the bottom of the hole.

After reviewing the color televiewer display, fractures were separated into natural joints and bedding plane breaks. These were grouped and tabulated for the three geologic horizons in the drill hole. Stereo net plots and joint rose diagrams were then produced for each of these units to determine typical and dominant fracture trends. Fracture frequencies and apertures were also plotted for the entire surveyed interval, and a pictorial display was generated that shows the fracture dip, depth of break, and grouping of joints that weigh the frequency and openness of these features. These data are shown on figures 16 through 23 in the appendix of the report. Tables 2 through 4 also list each fracture encountered in the drill hole and indicate the direction, dip, aperture (openness), and classification of each break. The actual televiewer plot is not included in this report.

Figures 17, 19, and 21 show joint rose and stereo net diagrams for bedding plane fractures in the Trujillo, upper shale unit of the Tecovas, and the sandstone unit of the Tecovas in OW6C, respectively. The dominant trends of the bedding plane fractures strike to the south and southwest in the Trujillo and upper shale unit of the Tecovas. Those in the Tecovas sandstone appear to vary more with dominant orientations being towards the northwest, west, and south (based on limited data points). Most of the fractures have dips less than 45 degrees and slope towards the northwest; however, one major set in the Trujillo dips to the southeast. The Trujillo and Tecovas sandstones are often cross bedded and orientations and dips of bedding vary considerably. Therefore, bedding fractures indicated on figures 17 and 21 can be very misleading. Bedding in the upper shale unit of the Tecovas is likely not cross bedded, and the orientations of bedding fractures indicated on figure 19 are probably more representative of the actual orientation of the strata at depth.

The dominant natural fractures in the Trujillo Formation (figure 16) trend to the southwest with the dip being mostly from 45 to 80 degrees to the northwest in OW6C. Natural fractures in the upper shale unit of the Tecovas also support this trend, but dips tend to be less than 50 degrees. The dominant trend of natural fractures in the Tecovas sandstone unit appears to be in an eastward direction, with dips being fairly steep (80 degrees) to the south (figure 21).

Fractures in OW6C occurred with less frequency below a depth of 300 feet. They also appeared to be most concentrated and most open between depths of 140 and 220 feet. Fractures located in this interval generally dipped to the north or northwest at between 50 and 70 degrees (figure 23).

Drilling information indicates that open fractures were being encountered in most of the exploratory holes as they were being advanced. While drilling OW6C below a depth of 350 feet, brine water (10 gal/min±) was blown out of OW6A to heights of 8 feet above the casing. OW6C was advanced using air to remove cuttings. OW6A was drilled to a depth of 230.6 feet with slotted screen installed between 143.0 and 193.0 feet. Communications between both holes had to be along open fractures. The unusually high permeabilities encountered in the TW1 pump test and the water level surge in TW2 during the pump test can only be attributed to similar open water producing discontinuities.

The three fracture studies conducted by Hydro Geo Chem, Incorporated, BEG, and Reclamation all indicate that the dominant natural fracture system is oriented roughly east-west or within 40± degrees of this direction. The first two studies show that fractures measured at the surface are more steeply dipping than those measured by Reclamation in OW6C. Fracture dips recorded by the televiewer log probably are not indicative of actual conditions as the vertical drill hole probably penetrated very few high angle (near 90 degrees) joints as drilling paralleled these features.

Faulting

Faulting does not cut any of the Triassic sediments exposed along the walls of the Canadian River between Ute Dam and Revuelto Creek. However, shallow buried faults likely exist because of the collapse that has occurred along fractures over dissolutioned salt beds in the Permian sediments. Deep faults are known to occur along the north flank of the Tucumcari Basin in rocks as young as Permian in age.

Investigations completed for Ute Dam by the State of New Mexico indicated that there is a fault zone cutting the left abutment of the structure. The location of this feature is shown on drawing 1253-600-22. The fault is covered by Pleistocene debris, but it apparently trends in an east-west direction. It appears to be a normal fault with the north block being dropped an estimated 190 feet. This feature may be related to the dissolutioning of salt beds.

Drilling in the area of TW1 also shows unusually rapid changes in geologic horizons (drawings 1253-600-24 and -25). This may be due to irregularities caused by collapse or to small displacement faulting.

Shallow seismic studies recently completed between OW6C and TW3 indicate that there are a series of small faults or very prominent fractures with displacements of up to 50 feet along the survey alignments. The study shows that these features terminate upwards in the Tecovas, but a few penetrate into the Trujillo. It appears that these structures continue downward to depths in excess of 800 feet (maximum seismic penetration) into the Bernal Formation and possibly into the underlying San Andres. Trends of these faults could not be determined; however, they may strike east-west following the direction of the most prominent joint system and parallel to the fault in the left abutment of Ute Dam. Evidence suggests that they either originate where the salt has been removed in the Bernal or in the salt fronts in the San Andres beneath the Canadian River.

Petroleum investigations show that there are a number of major northwest trending fault zones that cut through east-central New Mexico. One of these faults lies near Tucumcari. Offset on this structure may be up to several thousand feet with the south side being dropped. Evidence suggests that the primary movement on this fracture and the other similar ones may have occurred in the Pennsylvanian or very early Permian time as sediments younger than the Abo Formation do not appear to be offset. This structure may form the northern boundary of the Tucumcari Basin. Recent deep seismic studies completed by Reclamation also indicate that a similar trending fault, with the south side being down, passes north of Logan. As of this time, displacement has not been determined along this feature.

Seismic Hazard

The Logan area is located in Zone 1 on the Seismic Risk Map of the Conterminous United States that was prepared by S.T. Algermissen of the U.S. Coast and Geodedic Survey in 1969. Zone 1 is an area that has a 90 percent probability of not having ground shaking with a horizontal acceleration exceeding 0.04 g (gravity) in a 50-year period. This probability for maximum horizontal ground acceleration is equivalent to a source earthquake having a return period of 475 years. Zone 1 is also an area where distant earthquakes may cause minor damage to structures with fundamental periods greater than 1.0 second and corresponds to intensities V or VI on the Modified Mercalli Intensity Scale.

The largest earthquake ever recorded near Logan occurred in 1970 about 40 miles to the north-northeast and registered VI intensity on the Modified Mercalli Intensity Scale. The intensity VI earthquake was noticeable to all people in the area and caused slight damage to some structures.

Data from other areas indicate that minor seismic events can be produced by injecting fluids into deeply buried geologic units. Injecting fluids into wells at the Rocky Mountain Arsenal near Denver, Colorado, produced earthquakes that had magnitudes greater than 4 on the Richter scale. These events could be felt at the ground surface by residents living in the area.

Reclamation is now injecting brine into the Mississippian Leadville Limestone at Paradox Basin in western Colorado. This injection is taking place below a depth of 15,000 feet under pressures of 5,000 lb/in^2 at ground surface. Seismic monitoring of the area has shown that numerous small earthquakes are occurring at depth, but none have been felt at the ground surface. The largest event that has been recorded to date had a magnitude of about 2.7. Slightly stronger quakes are anticipated as additional fluids are injected. Data gathered at Paradox shows that the seismic events are occurring along existing faults and at distances of up to several kilometers from the injection well.

added

There are numerous injection wells scattered throughout New Mexico and Texas. None, however, are located near the city of Logan and, therefore, there is no information that can be gathered from local sources. Contractors that are familiar with well injections in southern New Mexico and western Texas state that little, if any, seismic monitoring is being done in conjunction with the injections. It is also confirmed that earthquakes have not been felt at the ground surface that could be attributed to these wells.

It is likely that brine injection will create seismic events, but these will probably be so small that they will never be felt by local residents. Seismic stations that are selectively placed in the surrounding area would, however, be sensitive enough to record these events.

Groundwater

Investigations

Reclamation has completed a number of deep drill holes in the study area to collect geologic and groundwater information. These include three pump test wells (TW1, 2 and 3), three exploratory holes (DH1, 2, and 3), and eight groundwater observation wells (POW1, OW2 through 4, 5A, 5B, 6A, 6B, and 6C). Test Well 1, DH1 and 2, POW1, and OW2 through 4 were drilled between 1975 and 1978. Drill Hole 3 was completed in 1983. The remaining exploration holes were finished during the first half of 1994. Locations of these holes are shown on drawing 1253-600-22. Geologic logs for all of the holes, except TW1, are included in the appendix of this report. Also, included in the appendix are natural gamma logs for TW1, DH2, DH3, POW1, OW2, and OW3; gamma, temperature, caliper, neutron, density, resistivity, self potential, and sonic velocity logs for OW5A and OW6C; and results of the televiewer survey in OW6C (figures 16 through 23).

Reclamation conducted three pump tests in the study area prior to May 1994. One pump test was completed during March 1979 in TW1, and one pump test each was conducted in TW2 and TW3 during March and April 1994. All of the wells were screened in the Tecovas Formation, which has been identified as the source of highly saline water that spreads upward into the alluvium below the Canadian River.

One additional test well (TW4) and three observation wells (OW7, 8, and 9) were drilled and a pump test performed in TW4 during November and December of 1994. Data collected from these investigations will be included in reports that will be prepared at a later date.

Added

Drawdown characteristics were monitored in several nearby observation wells (POW1, OW2 through 4, and DH1) when the pump test at TW1 was conducted. Pump tests in TW2 and 3 were completed without closely spaced observation wells. The object of the test in TW1 was to determine the transmissivity and storage coefficient of the Tecovas aquifer. In TW2 and 3, the objectives of the tests were to obtain the transmissivity and possible storativity for the same aquifer. Storativity data for TW2 and 3, however, were not obtained. Critical data recovered from the 3 pump tests are listed below:

	TW1	TW2	TW3
Rate of pumping (gal/min)	475	87-88	105
Pumping time (hrs)	97	74.75	74.75
Recovery time (hrs)	68	44.60	101.67
Drawdown (ft)	-	36.5	7.0
Transmissivity (ft^2/day)	2500	678	1308
Storage Coefficient	0.00015	-	-

Saturated thickness (ft)	69.4	119	138
Hydraulic Conductivity (ft/day)	36	5.69	9.47

Information has also been gathered on water chemistry for samples collected at nine Reclamation drill holes (TW1 through 3, DH1 through 3, POW1, OW3, and OW4) and 13 other wells (CW1 through 6, LCW, LF, DTW, NMW, RCW, BYW, and BPW) that penetrated Triassic or Permian sediments in the area of Logan. Locations of these holes (except for BYW and BPW) are shown on drawing 1253-600-22. Explanations of the symbols for non Reclamation drill holes are given on drawing 1253-600-21. Information sheets listing the water chemistry test results and other pertinent items for all wells are included on tables 5 through 26 in the appendix. Other similar water chemistry tests were completed at other times for samples collected in the Reclamation drill holes, but results of these tests are not included in this report. The data, however, shown on tables 5 through 13 are indicative of the other tests.

During the early stages of the project investigations, a number of shallow wells were drilled into the alluvium deposits beneath the Canadian River and Revuelto Creek. These wells were screened for sampling and monitoring purposes and they varied from 14.5 to 54.5 feet in depth. The wells were placed at Water Quality and Flow Monitoring Sites 1 through 4 and 6. Locations of these sites are shown on drawing 1253-600-22. Geologic section G-G, drawing 1253-600-32, shows the depths and relationships of these wells in the alluvial section. Numerous water quality samples from these sites were tested, and the results of these tests are listed in other publications. Selected data, however, on ranges in sodium, chloride, and total dissolved solid concentrations and electrical conductivities from water samples collected in the alluvium wells, the Canadian River and Revuelto Creek are graphically shown on figures 24 through 27 in the appendix.

Detailed discussions on water quality and groundwater conditions in the area will not be included in this report as these data have been documented in other reports, and a new and separate report is in the process of being prepared for the groundwater model. Data that is supplied in this groundwater section only provides a brief summary of the general conditions in the study area. Water quality data for wells drilled in the area have been gathered from a number of sources. This information is listed on tables 5 through 26 for easy reference. Additional water quality data for the river and the alluvial wells at Water Quality and Flow Monitoring Sites 1 through 4 and 6 are presented graphically on figures 24 through 27.

Triassic Brine Aquifer

Base flows on the main stem of the Canadian River originate from Triassic or Permian sediments, water from several reservoirs, and irrigation return flows from Revuelto Creek. Water from the Triassic is typically of fair to poor quality. Permian water is generally highly mineralized. The Permian groundwater flows to the east at a gradient between 15 and 20 feet per mile from the Sangre de Cristo Mountains in New Mexico to Texas. Heads are usually above the Canadian River in New Mexico, but because the hydraulic gradient is much steeper than the river gradient, heads fall below the river in Texas.

The permeability of the Permian rocks is generally low, but it can be high locally due to fractures and dissolution.

Most of the Triassic groundwater flow is toward the Canadian River in New Mexico. Like the Permian, the water level gradient in the Triassic rocks decreases to the east.

Wells drilled by Reclamation into the Tecovas Formation encountered saline water that was under artesian head in the vicinity of the Canadian River. The Tecovas Formation has a shale cap that probably limits upward migration of the saline water, except where it thins or is crossed by fractures. Recent explorations at OW6C, located south of the river, also penetrated brine water above the Tecovas high in the overlying Trujillo Formation. This condition was also reported to have been encountered by a local driller in a well completed for a housing complex that is located about 2,500 feet southeast of the right abutment of Ute Dam. Because of the poor water quality, the well was abandoned.

Wells completed in the Trujillo Formation north of the Canadian River and east of Revuelto Creek (within a few miles of the river) contain fair to good quality water that is used for domestic and stock watering purposes. Very few water supply wells appear to penetrate into the Tecovas Formation on the north side of the river as adequate water supplies can be obtained from the Trujillo. However, City Well 6 (CW6) located about 4,000 feet northwest of Logan probably bottoms in the Tecovas Formation. This well was low in chloride concentrations (55± mg/L) and had a low electrical conductivity of

0.71 millisiemens/cm @ 25 °C (mS/cm). DH3 located about 4,000 feet southwest of Logan and north of the river also penetrated the Tecovas, but it had much higher chloride concentrations (15,920 mg/L). The chloride concentrations and conductivities of water in this hole, however, are significantly less than that encountered in wells near the river in the areas of TW1, TW2, OW5A, and OW6C (figures 5 and 6 and drawings 1253-600-23 and -24). Oil explorations point out that brine waters are common in deep wells that penetrate the Trujillo and Tecovas Formations south of Tucumcari. Reclamation investigations also show that brine concentrations in groundwater drop off significantly north or downstream of OW5A in the vicinities of TW3 and DH2 (gravel pit area). Drawing 1253-600-31 is a contour plot for conductivities measured in selected water samples that were collected from the Tecovas Formation in Reclamation drill holes. As discussed above, these contours show that conductivities decrease rapidly north of the river in the Tecovas Formation in the area of Logan and that the highest conductivity concentrations in the Tecovas are located in an area beginning from a point upstream from TW1 and extending to a point between TW3 and OW5A. Unless other evidence is generated by the groundwater model that is presently being produced, this is the reach of the Canadian River where the brine producing wells should be located.

Available information suggests that brine water enters the Tecovas and possibly Trujillo Formations at depth from salt dissolution fronts located in the Bernal and possibly older formations south and southwest of the study area. Because of hydraulic heads, this water moves upslope and discharges into the Canadian River through the alluvium underlying the river. Much of the movement in the formational material appears to be through fractures. Saline water may also be working vertically along faults and fractures that penetrate to the salt fronts in the San Andres Formation that directly underlie the Canadian River at depths exceeding 1,000 feet. Both the Bernal and San Andres salt units are, therefore, considered to be the main contributors of salt to the Canadian River in the area of Logan.

Relatively, fresh water from the Chinle and precipitation falling on the Trujillo appear to move downward and mix with the Permian water in the brine aquifer (Tecovas Formation). It was postulated by Hydro Geo Chemical, Incorporated, that the Tecovas water (based on carbon content from several locations) in the area is composed of 57 percent Permian water and 43 percent Triassic water. They also calculated that the total brine flow from the Tecovas to the river in the Logan area was 0.90 ft^3/s and that 0.57 ft^3/s of this was derived from the Permian sediments. The Tecovas brine is diluted by fresh water as it works through the Trujillo and alluvium on its path to the river. The groundwater model that is presently being produced will likely modify the estimated brine inflow quantity figures.

The river serves as a discharge point for the brine and fresh water working from the south and the fresh water coming from the north. Because of this, it forms a general boundary between the two water types in the Logan area.

Alluvium Brine Aquifer

The Canadian River below Ute Dam has cut a channel up to several hundred feet deep into Triassic sediments. This channel has been partly filled by about 60 feet of sand, gravel, silt, and clay near Logan. The buried channel is deeper downstream, and at the Texas state line the alluvium deposits are up to 100 feet thick. The channel fill is 400 to 600 feet wide in New Mexico, but it widens to as much as 2 miles in Texas. The stream gradient is fairly uniform and averages about 5.3 feet per mile.

Water levels in piezometers at Water Quality and Flow Monitoring Sites 1 through 4 and 6 are generally within a foot or two of land surface, and they range from slightly below to slightly above river levels. There are no significant differences in water levels between piezometers at different depths at the same site; however, water levels in the deeper piezometers are generally slightly higher.

Brine concentrations in the alluvial aquifer are lower than those in the Tecovas Formation. The salt water from the Tecovas is apparently diluted by fresh water entering the system from the higher Triassic units, especially those sources located on the north side of the river.

Sodium, chloride, and TDS concentrations and electrical conductivities for the alluvial groundwater are similar for the shallow and deep piezometers at Water Quality and Flow Monitoring Sites 1 and 2. Downstream from this reach of river at Site 3, these constituents and the conductivities are higher in the water samples collected from deeper piezometers in the alluvium indicating that there may be a density stratification of the brines. There is a drop in values downstream at Site 6, but the water in the lower piezometer remains higher in sodium, chloride, TDS, and electrical conductivity values than the upper well. Concentrations of sodium, chloride, and TDS, and values of electrical conductivities generally are lower in the river than the groundwater in the underlying alluvial deposits (figures 24 through 27).

Observation Wells 7 and 8 (OW7 and 8) and Test Well 4 (TW4) were completed during November 1994. These holes are located on the Canadian River floodplain immediately north of TW2. TW4 and OW7 and 8 all penetrated clean sand and gravel deposits overlying fine, uniform sand. Another lower sand and gravel unit occurs beneath the fine sand and overlies bedrock in most of the wells. Conductivities of the groundwater in the upper sand and gravel unit were considerably lower than those in the fine sand horizon and the older units below. It appears that upward migration of the brine is hindered in the less permeable fine sand unit and that Canadian River flows are readily flushing out the brine in the more permeable upper sand and gravel unit. As described earlier in this report, additional information on TW4 and OW7 and 8 will be provided in a supplement to this report.

added

Canadian River

The surface water quality has been measured periodically at a number of points along the Canadian River downstream from the Ute Dam. Salinity appears to increase fairly rapidly from Ute Dam to Revuelto Creek. From Revuelto Creek to the state line, there is a very gradual increase in brine inflows with a significant increase occurring near the Dunes Dam site. Chloride concentrations drop between the state line and Tascosa, Texas, because of an influx of fresh water to the system. Between Tascosa and Amarillo, the chloride load again increases slightly along the river. The transport of salt down the river is not constant, but it varies with flow rate. Figure 2 shows the chloride loading in tons per year for the reach of river between Ute Dam and the Texas state line.

Geophysics

Borehole

Borehole geophysical logging was performed in five wells (TW1 through 3, OW5A, and OW6C) that were completed in the study area in 1994. The purposes of the survey were (a) to determine lithologies in each well, (b) correlate stratigraphic units, and (c) aid in determining screen intervals for well completions. The geophysical logging suite performed in wells TW2, TW3, OW5A, and OW6C included natural gamma, neutron, density, caliper, 16-64 normal resistivity, temperature, SP and sonic velocity. In addition, a borehole televiewer log was run in OW6C. Natural gamma, temperature, and caliper logs were also completed in TW1 which was drilled in 1978. The overall quality of the geophysical logs was good with the exception of the electric logs which provided no resolution of geologic boundaries. The reason for the lack of sensitivity on the electric logs is unknown, but it may be the result of the extremely high salinity of the borehole fluid. Except for TW1, each well was generally logged within hours of completion and immediately after the well had been flushed. The wells were then allowed to recover to the static level prior to logging. This timeframe did not allow for stratification of water temperatures.

The geophysical logs were analyzed using a commercially available log analysis package. Shale volumes were calculated using the standard gamma ray index method. This method estimates the shale volume by a ratio method comparing measured gamma counts/second to the gamma ray counts/second for 100 percent shale and 100 percent sand. Porosity estimates were calculated using a standard density porosity method. This method estimates porosity by comparing measured densities with formation matrix and pore fluid densities. The average porosity values that were obtained for the three sandy zones that produce the brine in the Tecovas Formation (figure 28) are listed below:

Well	Depth (ft.)	Average Porosity (%)
TW2	175-222	10.9
TW2	224-264	17.7
TW2	271-290	3.1
TW3	125-195	17.9
TW3	200-261	19.6
TW3	268-299	21.3
OW5A	306-352	9.8
OW5A	358-402	8.9
OW5A	411-441	11.8
OW6C	278-323	18.7
OW6C	334-362	19.2
OW6C	382-395	9.5

In general, the percentage of shale (clay) is the controlling factor in variations of porosity, with higher shale contents reducing overall porosity.

Correlations of the geologic units, based on geophysical data, are shown on figure 28 which is included in the appendix. These contacts vary slightly from those shown on drawings 1253-600-23 and -24. The correlation of specific units between each well was complicated by the interbedded and sometimes lenticular nature of the Triassic sediments. As can be seen on figure 28, the upper shale unit in the Tecovas Formation is much thicker and more consistent to the west. This horizon thins and breaks into sandstone and shale units eastward. The middle sandstone section in the Tecovas can also be divided into three distinct sandstone horizons that are separated by two rather continuous shale beds that divide the unit into nearly equal sections. A continuous but varying thickness of shale with sandstone forms a lower section (lower shale unit) in the Tecovas that immediately overlies the Permian sediments.

TW1, which was drilled about 16 years earlier, was also logged with geophysical equipment in 1994. The full suite of logs could not be run in this hole because of the casing that is installed. Surveys did show that the 12-inch-diameter casing had separated between depths of 242 and 248 feet.

Data collected on fracturing in OW6C by the televiewer log were analyzed and processed. This information was presented earlier in the jointing section of this report. Basic data are portrayed on tables 2 through 4 and figures 16 through 21.

Geophysical logs for TW1 through 3 and OW5A and 6C that were completed in 1994 and the natural gamma logs for TW1, DH2, DH3, POW1, OW2, and OW3 are included in the appendix of this report.

Shallow Seismic

Field work has been completed on a shallow seismic survey that was conducted south of Logan in 1994. These data have been analyzed, and the results of this study are included in a report titled, "Geophysical Investigations, Lake Meredith Salinity Study, New Mexico."

Six short lines were completed. Lines 1 through 4 follow the Canadian River valley floor from a location northwest of TW2 to a point near TW3. Line 5 extends from a point north of OW6C to the intersection of Highways 54 and 469. Line 6 begins at the highway intersection and heads northeastward for about 3,000 feet. Lines 5 and 6 were completed on the bench overlooking the Canadian River trench. The shallow seismic surveys were initiated to gather (a) additional geologic data between selected drill holes, (b) information on the brine aquifer, (c) fracture characteristics in the Triassic and Permian sediments, and (d) other pertinent information that might be useable in locating the brine production wells for the salinity control system.

Deep Seismic

A series of deep seismic profiles have been evaluated to determine where to place the brine injection wells for the salinity project. Two lines were completed prior to 1984 and were reported on by Hydro Geo Chemical, Incorporated, in their December 19, 1984, report titled "Analyses of Geophysical Data to Examine the Feasibility of Deep-Well Injection of Brine Near Logan, New Mexico." One of these lines extends from near the west edge of sec. 22, T. 13 N., R. 33 E., eastward for a distance of 6 miles. The second line lies normal to this alignment and extends in a north-south direction for 4.5 miles. Both lines cross at a point 3.5 miles east of the Highway 54 and 469 intersection.

Additional existing seismic profiles were purchased from a geophysical exploration company during 1994. These lines form a U-shape and extend from a point 4 miles north of Logan southward for 20 miles, then turn west for 6 miles before trending north an additional 9 miles. This line ties to at least one existing oil well (Ute Anticline) that has been geophysically logged in the past.

All of the seismic lines have been analyzed and some have been enhanced using modern computer applications. Portions of these data are included in the report titled, "Geophysical Investigations, Lake Meredith Salinity Study, New

Mexico." Because of legal problems, not all of the purchased data can be published. Most of this information, however, can be reviewed in the Geophysics Section in Reclamation's Denver Office.

Based on the deep seismic data and information from area oil wells, it appears that the best injection zones will be in (a) dolomite beds in the upper part of the San Andres Formation between depths of about 1,000 to 1,200 feet, (b) Glorieta sandstone between depths of approximately 1,700 to 1,800 feet, and (c) arkosic sandstones in the lower part of the Abo and upper part of the Sangre de Cristo Formations at depths of about 3,000 to 3,600 feet. These depths are inferred from seismic data collected at a location where Highways 54 and 469 join in sec. 22, T. 13 N., R. 33 E. Other potential injection zones may be encountered in pilot well borings, and these should be tested to determine their possible use for this project.

Foundation Considerations

Added

Various construction problems may be encountered in excavations that will be required for engineering features (pipelines, buildings, etc.) built in the area. These could include stability of trench excavations, difficulties in excavating cemented materials, and high groundwater in some cuts.

Any excavation below a depth of several feet in the Canadian River floodplain will encounter groundwater. The alluvial materials in the floodplain will vary from fine, uniform sand to sand and gravel with cobbles. Both types of materials are highly permeable and will be difficult to unwater.

Excavations in the alluvial materials will be very unstable. Fine sands, if submerged, will tend to flow in excavations. Walls of shallow trenches (less than 10 feet deep) will likely have to be cut on slopes that range from 1:1 to 1 1/2:1.

Equipment can also become bogged down in areas along the Canadian River floodplain. Dune sand deposits and soft saturated alluvial materials can seriously retard vehicle traffic in selected areas.

Excavations above the Canadian River trench will be in unsaturated materials. However, heavy precipitation can contribute to construction problems if runoff is allowed to flow in open, undrained cuts.

Excavation slopes will vary depending on the type of material that is encountered. Shallow temporary cuts in rock (competent sandstone and shale) can be made with vertical walls. Excavations in cohesive soils such as clay, silty clay, and sandy clay (loess and colluvial deposits) should be made on 3/4:1 slopes while cuts in dry granular sand and gravel (terrace deposits) should be made on 1:1 slopes.

Excavations in all overburden deposits (alluvium, terrace, colluvium, loess, dune sand, etc.) can be accomplished easily with a backhoe or dozer, except in areas where terrace deposits may be cemented with calcium carbonate. The cemented areas may be rippable if they are thin. More massive cemented gravel units may have to be drilled and blasted.

Cuts in the Trujillo sandstone can generally be ripped with difficulty to depths of 5 feet using modern dozer (D-8) equipment. Deeper excavations and highly cemented zones may have to be blasted.

The Chinle Formation consists of alternating sandstone and shale. Shallow cuts (5 feet deep) can generally be made with a backhoe or dozer and ripper. Occasional massive, cemented sandstones may have to be removed by blasting.

Care should be taken so that buildings, pumps, etc., are not founded on low density soils such as loess. These materials will consolidate and settle upon being wetted and loaded.

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APPENDIX

Photographs

Photograph 1 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking northwest (right) to west (left) towards the right (west) valley wall along the Canadian River. Highway 54 bridge crossing at right. Resistant ledge is Trujillo Sandstone (near top of unit). Qt_2 Terrace caps the Trujillo Sandstone. Photo taken from area west of rodeo grounds in SW 1/4 sec. 14, T. 13 N., R. 33 E. Downstream is to left.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 2 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking west (right) to southwest (left) towards the right (west) valley wall along the Canadian River. Photograph shows area slightly downstream of photograph 1. Sandstone ledges on Canadian River trench wall are in the Trujillo Formation. Qt_2 Terrace caps sandstone at right and is shown in the foreground. Photo taken from area west of rodeo grounds in SW 1/4 sec. 14, T. 13 N., R. 33 E. Downstream is to left.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 3 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking southwest (right) to southeast (left) towards the right (south) wall of the Canadian River trench. Photograph shows area downstream of photograph 2. Railroad bridge on left is in S 1/2 sec. 14, T. 13 N., R. 33 E. Sandstone ledges are part of the Trujillo Formation. A thin Chinle Formation section caps the high on the right side of the picture. Photo taken from area south of rodeo grounds.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 4 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking southwest (right) to southeast (left) at right (south) wall of the Canadian River trench. Photograph shows area slightly downstream of photograph 3. Railroad bridge on right is in S 1/2 sec. 14, T. 13 N., R .33 E. Sandstone ledges are part of the Trujillo Formation. The Chinle Formation crops out along the skyline. TW 2 is located near road at center of picture. Downstream is to left.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 5 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking southwest (right) to east (left) at right (south and east) wall of the Canadian River trench. Photograph shows area slightly downstream of photograph 3. Area shown is in SE 1/4 sec. 14 and SW 1/4 sec. 13, T. 13 N., R .33 E. OW5A is located on top of ridge. Cliff is Trujillo Sandstone. This is capped by a thin mantle of Chinle Formation that is overlain by a Qt_3Terrace remnant. Downstream is to the left.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 3 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking northeast along the right (east) wall of the Canadian River trench. Rock exposed is the Trujillo Sandstone. The lowest bench at left is the Qt_1Terrace. The right side of photograph 6 matches to the left side of photograph 5. Area shown is in the NW 1/4 sec. 13, T. 13 N., R. 33 E.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Photograph 7 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking west to southwest from Highway 54 bridge (NW 1/4 sec. 14, T. 13 N., R. 33 E.) upstream into Candian River channel. Trujillo Sandstone ledge on right center of picture. Chinle Formation lies above. Qt_1 and Qt_2 Terraces on left side of picture.

Photograph 8 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking northwest at canyon wall along Canadian River (NW 1/4 sec. 14, T. 13 N., R. 33 E.). Highway 54 bridge crossing on left. Resistant ledge is Trujillo Sandstone. Slope above is the Chinle Formation which is capped by the Qt_2 Terrace. Qt_2 Terrace also in foreground.

U.S. Bureau of Reclamation photo by G. Taucher 4–26–94

Photograph 9 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking southeast towards the wall of the Canadian River trench. Taken from Highway 54 bridge in NW 1/4 sec. 14, T. 13 N., R. 33 E. Resistant ledge is Trujillo Sandstone. Thin section of Chinle Formation above sandstone at left. Qt_2 Terrace caps bench.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

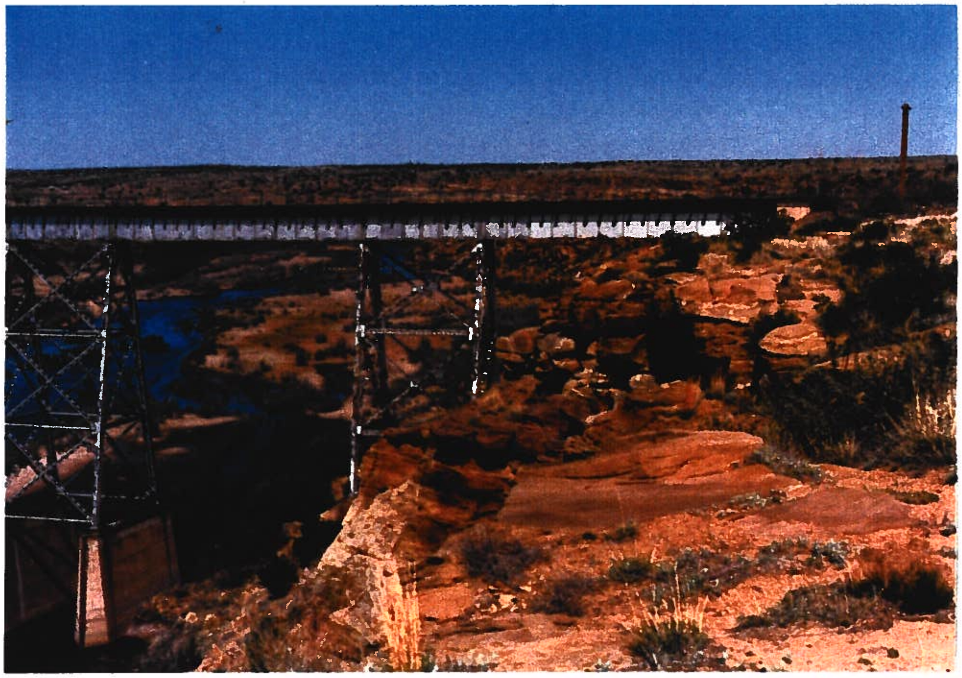
Photograph 10 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking west southwest (upstream) towards the Canadian River trench from OW5A (SW 1/4 sec. 13, T. 13 N., R. 33 E.). Sandstone ledges on both sides of the river are in the Trujillo Formation. Qt_2Terrace caps bench on right.

U.S. Bureau of Reclamation photo by G. Taucher 4–26–94

Photograph 11 – Lake Meredith Salinity Study – Logan, New Mexico Area – Panoramic view looking east northeast (downstream) towards the Canadian River (left). The Revuelto Creek trench is located on the right. Most of the sandstone is part of the Trujillo Formation. The Tecovas Formation crops out along the river on the left side of the picture. Taken from gravel pit area (SE 1/4 sec. 12, T. 13 N., R. 33 E.).

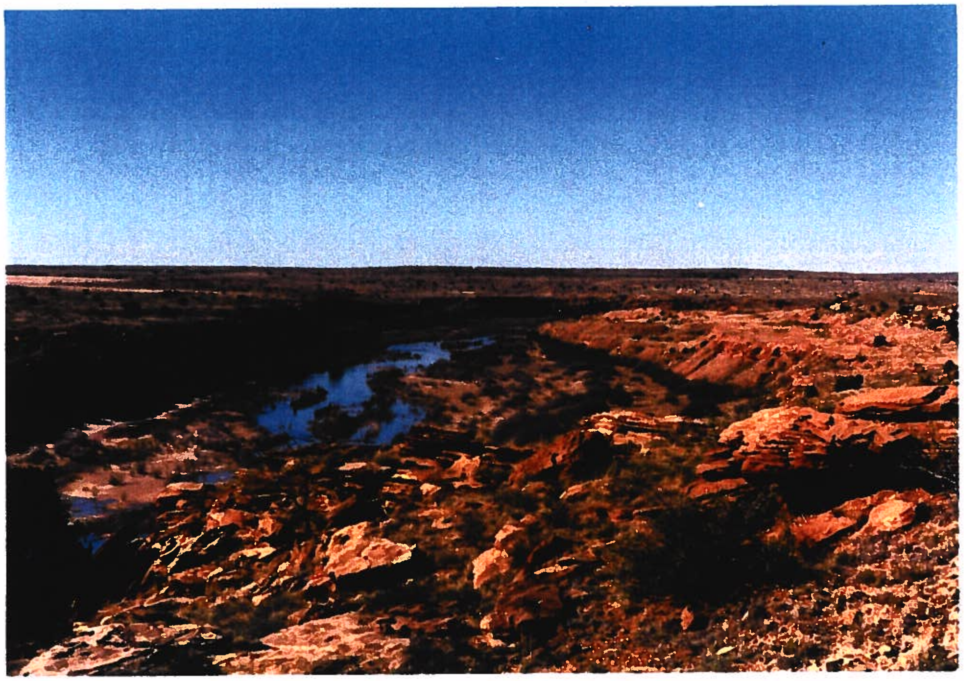
Photograph 12 – Lake Meredith Salinity Study – Logan, New Mexico Area – View looking north northeast at Chinle Formation exposure in Highway 54 cut located about 1400 south of the city of Logan, New Mexico (NW 1/4 sec. 14, T. 13 N., R. 33 E.). The Chinle is capped by the Qt Terrace in this area.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94



Photograph 13 – Lake Meredith Salinity Study – Logan, New Mexico Area – View looking east (downstream) along the Canadian River trench. South abutment of railroad bridge shown anchored to Trujillo Sandstone (SW 1/4 sec. 14, T. 13 N., R. 33 E.).

U.S. Bureau of Reclamation photo by G. Taucher 4–26–94

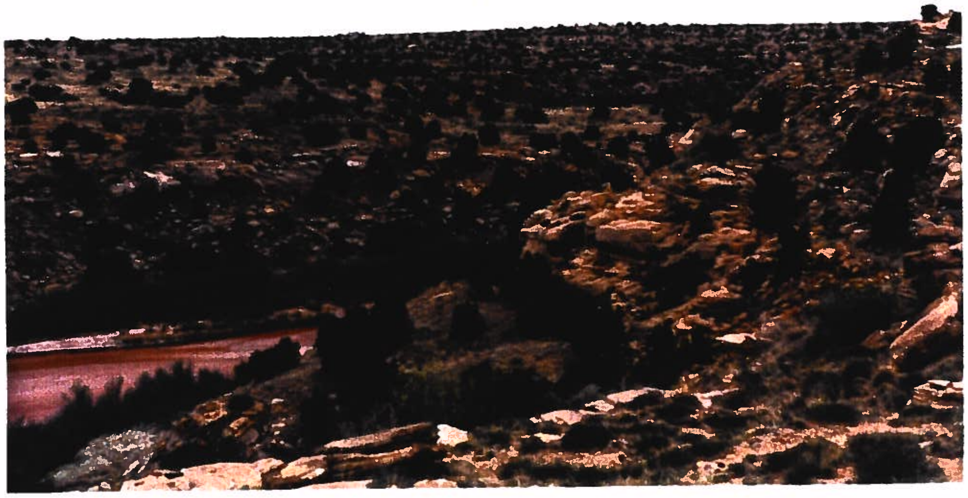


Photograph 14 – Lake Meredith Salinity Study – Logan, New Mexico Area – View looking north (downstream) along the Canadian River trench towards the gravel pit area. Photograph shows trench in SW 1/4 sec. 12 and NW 1/4 sec. 13, T. 13 N., R. 33 W. Picture taken from OW5A area. Trujillo Sandstone in foreground. Qt_2 Terrace shown on both sides of river. Qt_1 Terrace is lowest bench right side of river.

U.S. Bureau of Reclamation photo by G. Taucher 4–26–94

Photograph 15 – Lake Meredith Salinity Study – Logan, New Mexico Area – View looking southeast (upstream) towards the east wall of the Revuelto Creek canyon near the Highway 469 bridge crossing in the N 1/2 sec. 24, T. 13 N., R. 33 E. Note the two sandstone ledges in the Trujillo Formation separated by a red shale unit that has characteristics of the Chinle Formation. The shale thins, and the sandstone beds come together to the south and west of this area. The upper ledge is at the top of the Trujillo. The sandstone is capped by the Qt_2 Terrace.

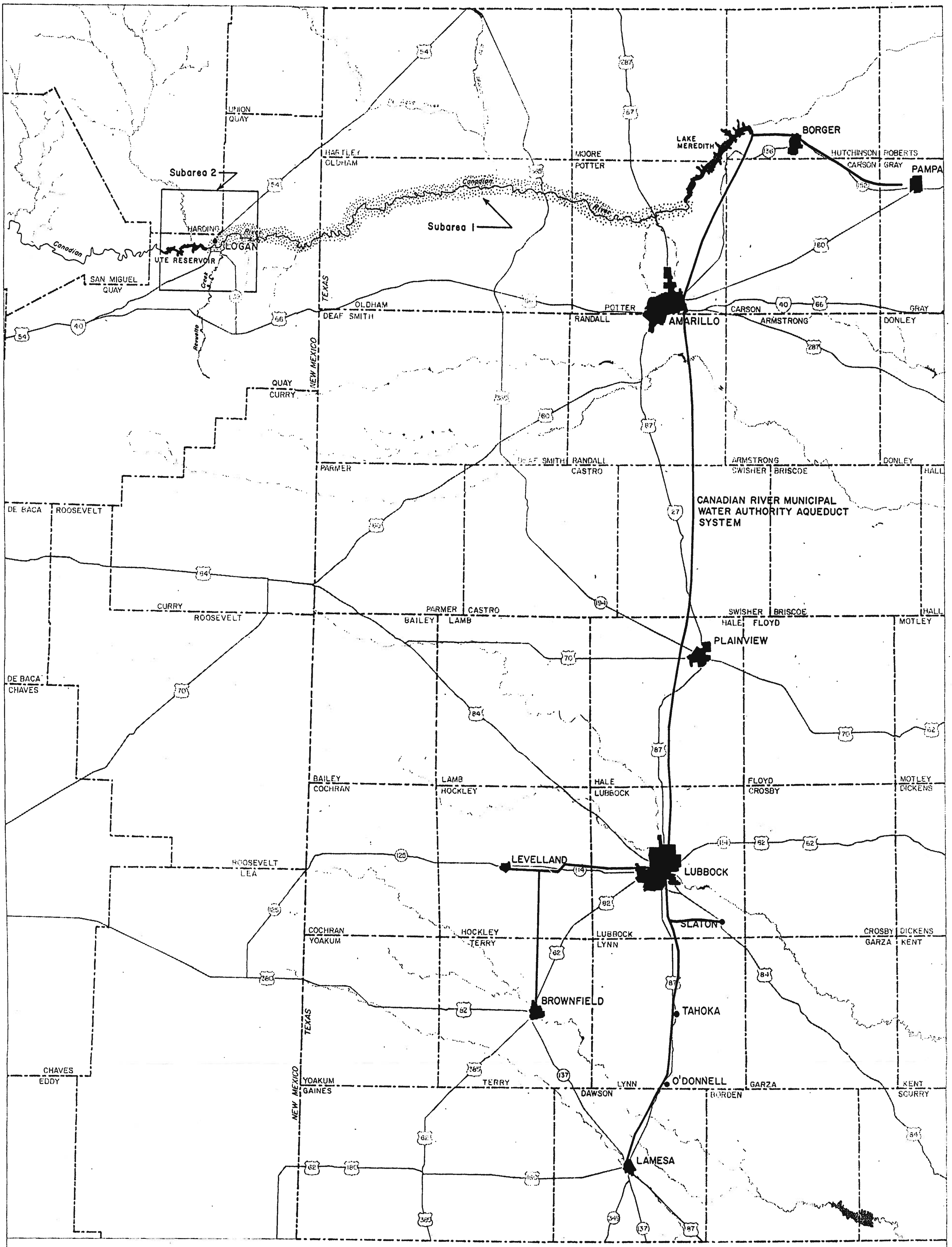
U.S. Bureau of Reclamation photo by G. Taucher 6–15–94



Photograph 16 – Lake Meredith Salinity Study – Logan, New Mexico Area – View looking east southeast from a point just north of the center of sec. 13, T. 13 N., R. 33 E. across the Reveulto Creek canyon. The sandstone beds on both sides of the creek are part of the Trujillo Formation. The Chinle Formation crops out in areas near the skyline. Bedding dips from the skyline towards Reveulto Creek along the west flank of an anticline. Dips of these units are under several degrees.

U.S. Bureau of Reclamation photo by G. Taucher 6–15–94

Figures



▨ SUBAREA I -- INCLUDES THE CANADIAN RIVER REACH BETWEEN UTE DAM AND LAKE MEREDITH

☐ SUBAREA 2 -- INCLUDES THE REGION OF MAJOR BRINE INFLOW TO THE CANADIAN RIVER

N

10 0 10 20 30 40
SCALE of MILES

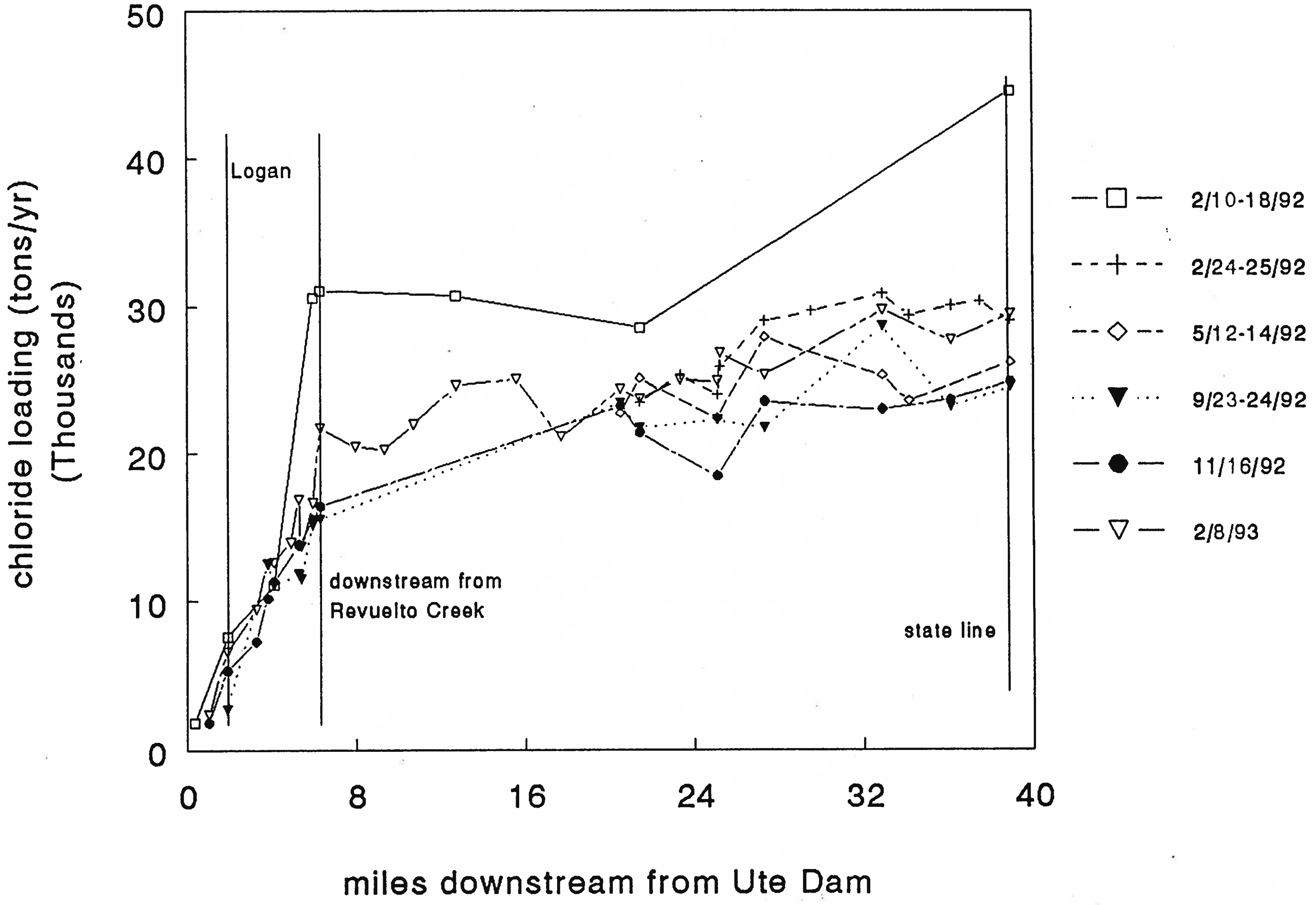
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LAKE MEREDITH SALINITY CONTROL PROJECT

LOCATION MAP

DECEMBER 1984

Figure 1

Canadian River, Ute to State Line:
Chloride Loading



LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO

Figure 2

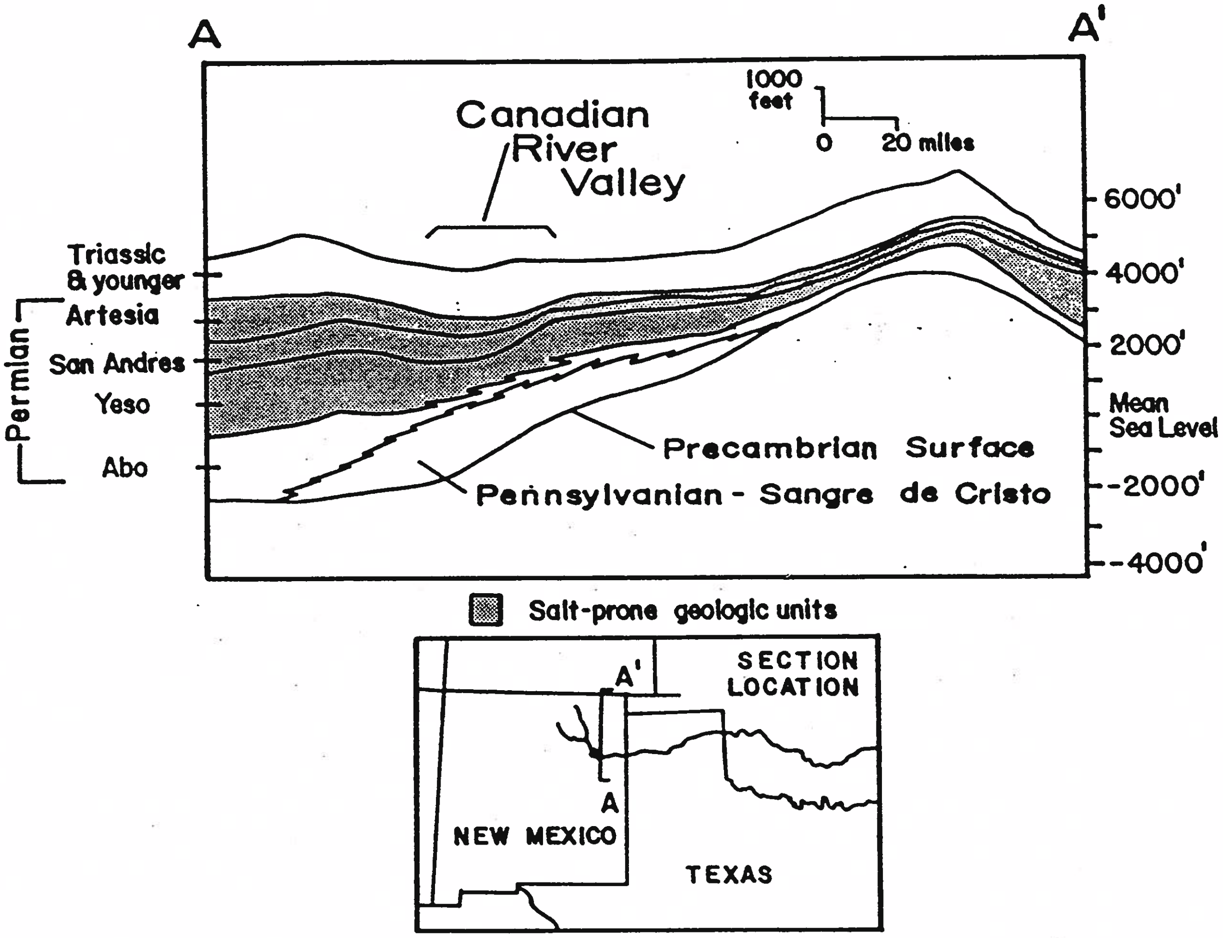
		NE NEW MEXICO STUDY AREA			PALO DURO BASIN	
SYSTEM	**SERIES**	**GROUP**	**FORMATION**	**GROUP**	**FORMATION**	**General Lithology & Depositional setting**
QUATERNARY	HOLOCENE				*alluvium, dune sand* *Playa*	
	PLEISTOCENE				*Tahoka* *cover sands* *Tule / "Playa"* *Blanco*	Lacustrine clastics & windblown 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 (Qudrtermaster)*	Sabkha salt, anhydrite, red beds, & peritidal dolomite
					Alibates	
	GUADALUPE	ARTESIA	*Bernal* *	ARTESIA	*Salado/Tonsill* *	
					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

HYDRO GEO CHEM, INC.

LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
STRATIGRAPHIC COLUMN

Figure 3

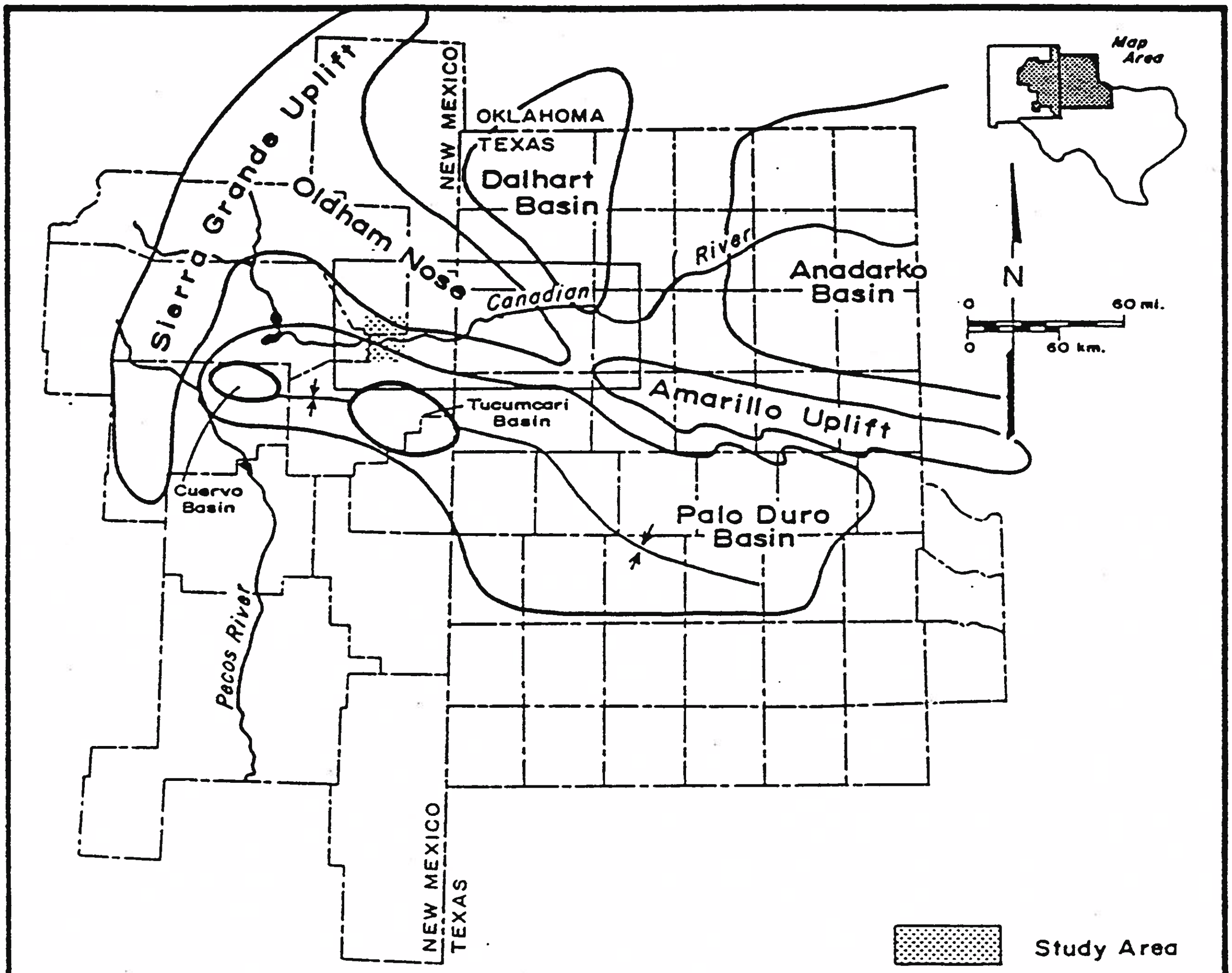


SUBSURFACE GEOLOGIC FORMATIONS
Logan, New Mexico Area

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

LAKE MEREDITY SALINITY STUDY-TEXAS, N. MEXICO
GENERALIZED NORTH-SOUTH GEOLOGIC SECTION
THROUGH LOGAN, N. MEXICO AREA

Figure 4

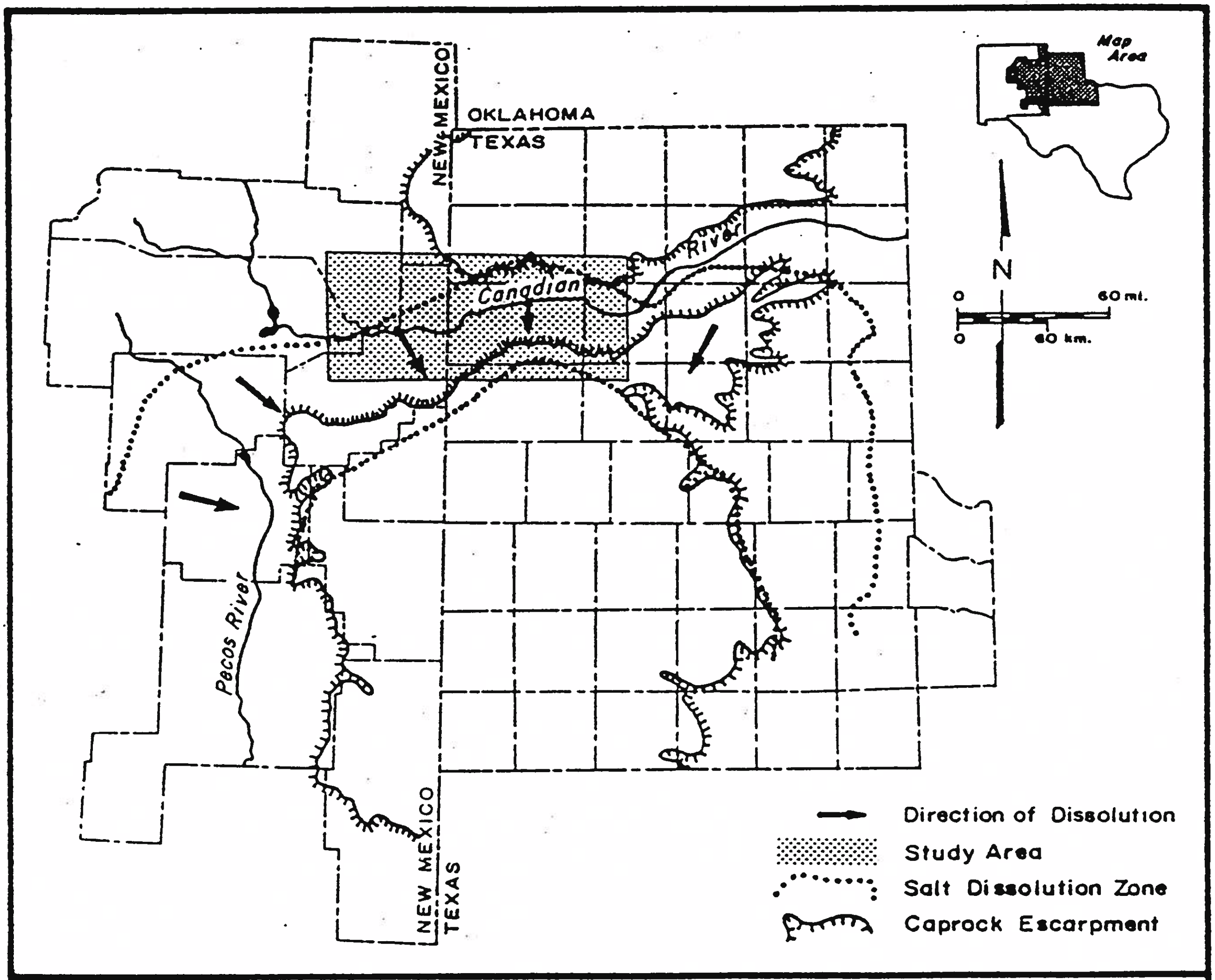


Adapted from Nicholson, 1960; Gustavson and others, 1982

HYDRO GEO CHEM, INC.

LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
MAJOR GEOLOGIC STRUCTURES IN EASTERN
NEW MEXICO AND NORTHWESTERN TEXAS

Figure 5

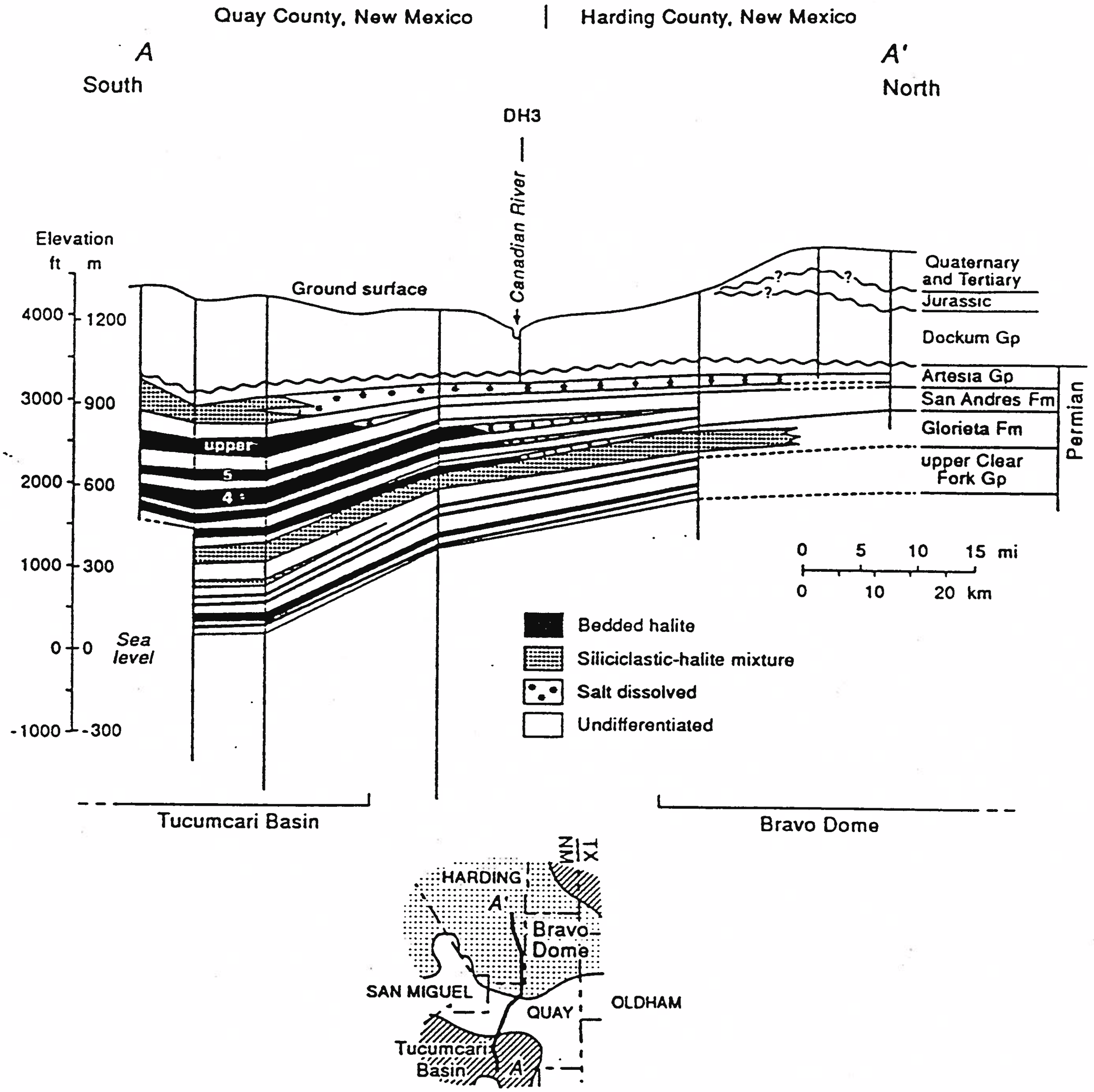


Adapted from Simpkins and others, 1981

HYDRO GEO CHEM, INC.

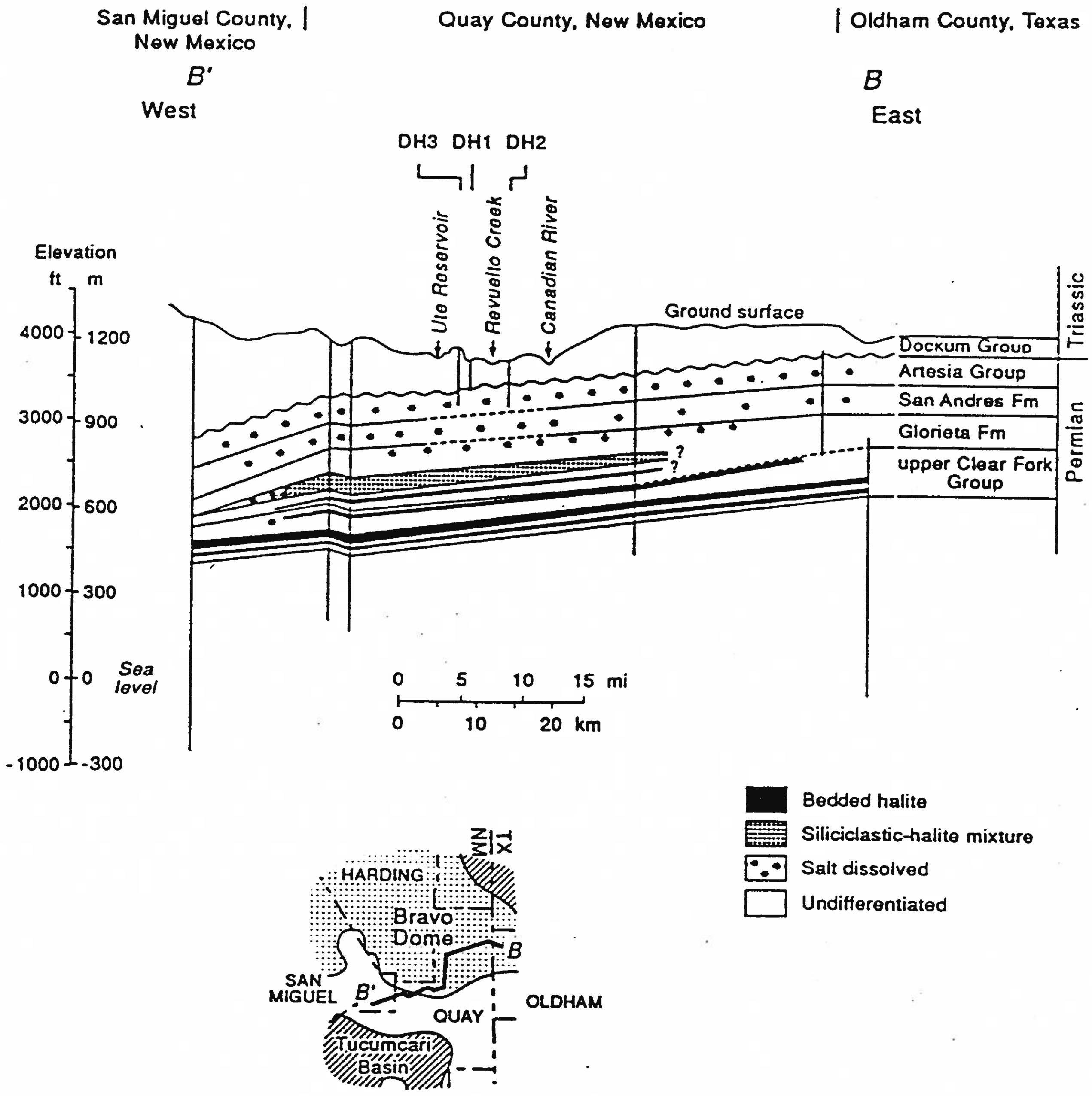
LAKE MEREDITY SALINITY STUDY-TEXAS, N. MEXICO
SALT DISSOLUTION ZONE IN EASTERN
NEW MEXICO AND NORTHERWESTERN TEXAS

Figure 6



North-South structural cross section through the Ute Dam area
Source: T.C. Gustavson, et. al., 1992

Figure 7

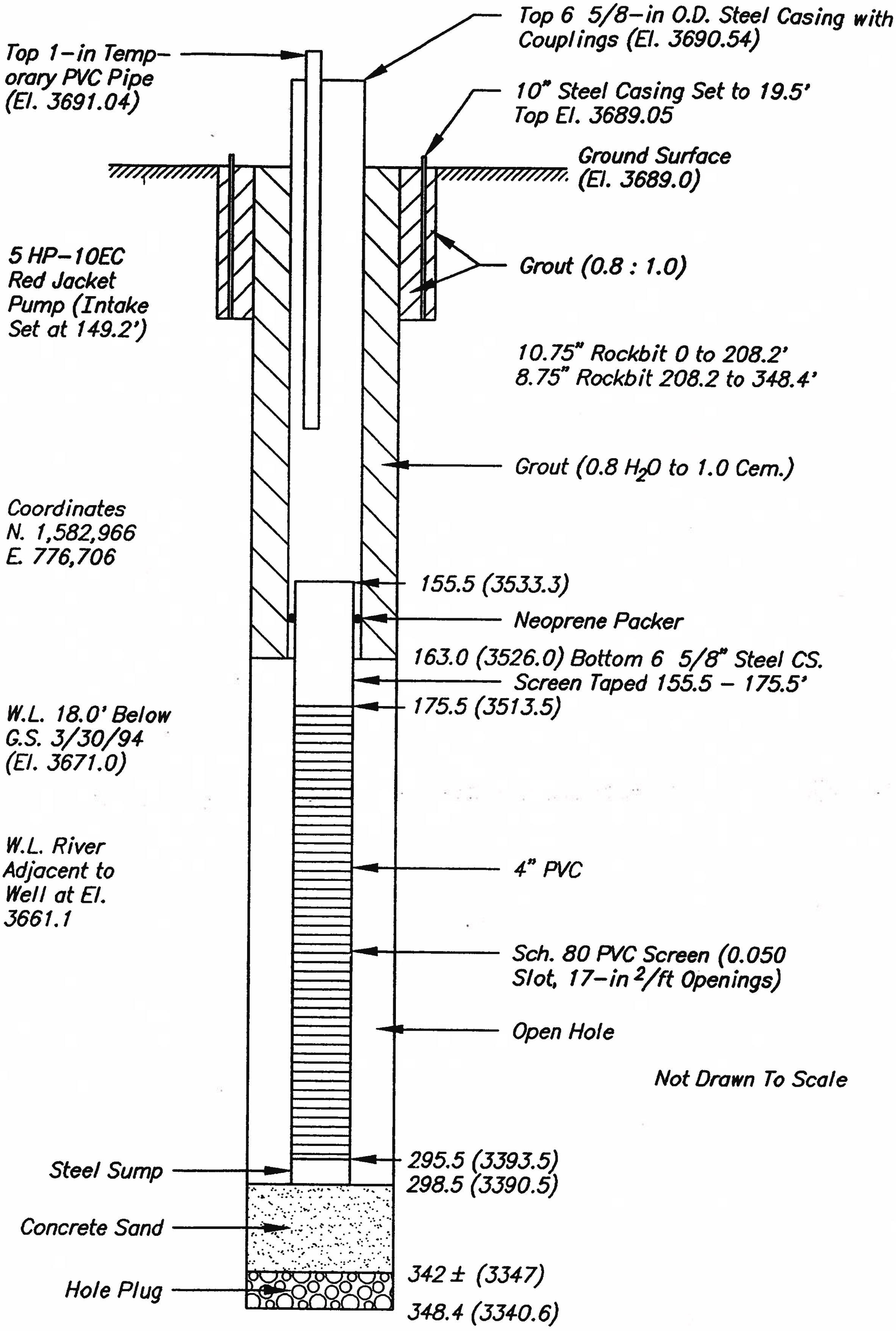


East-West structural cross section through the Ute Dam area

Source: T.C. Gustavson, et al., 1992

LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO

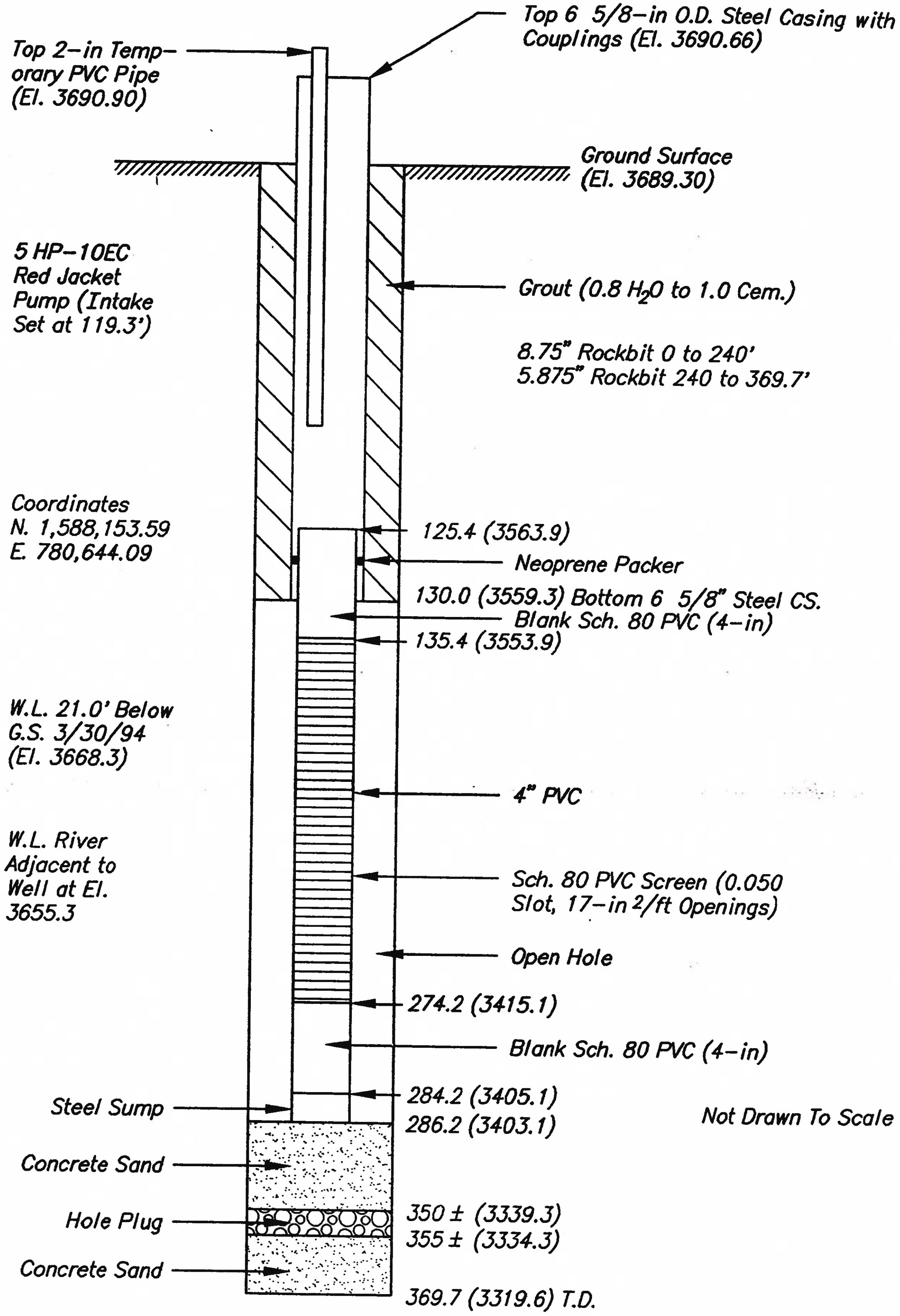
Figure 8



LAKE MEREDITH SALINITY STUDY

TW2 COMPLETION

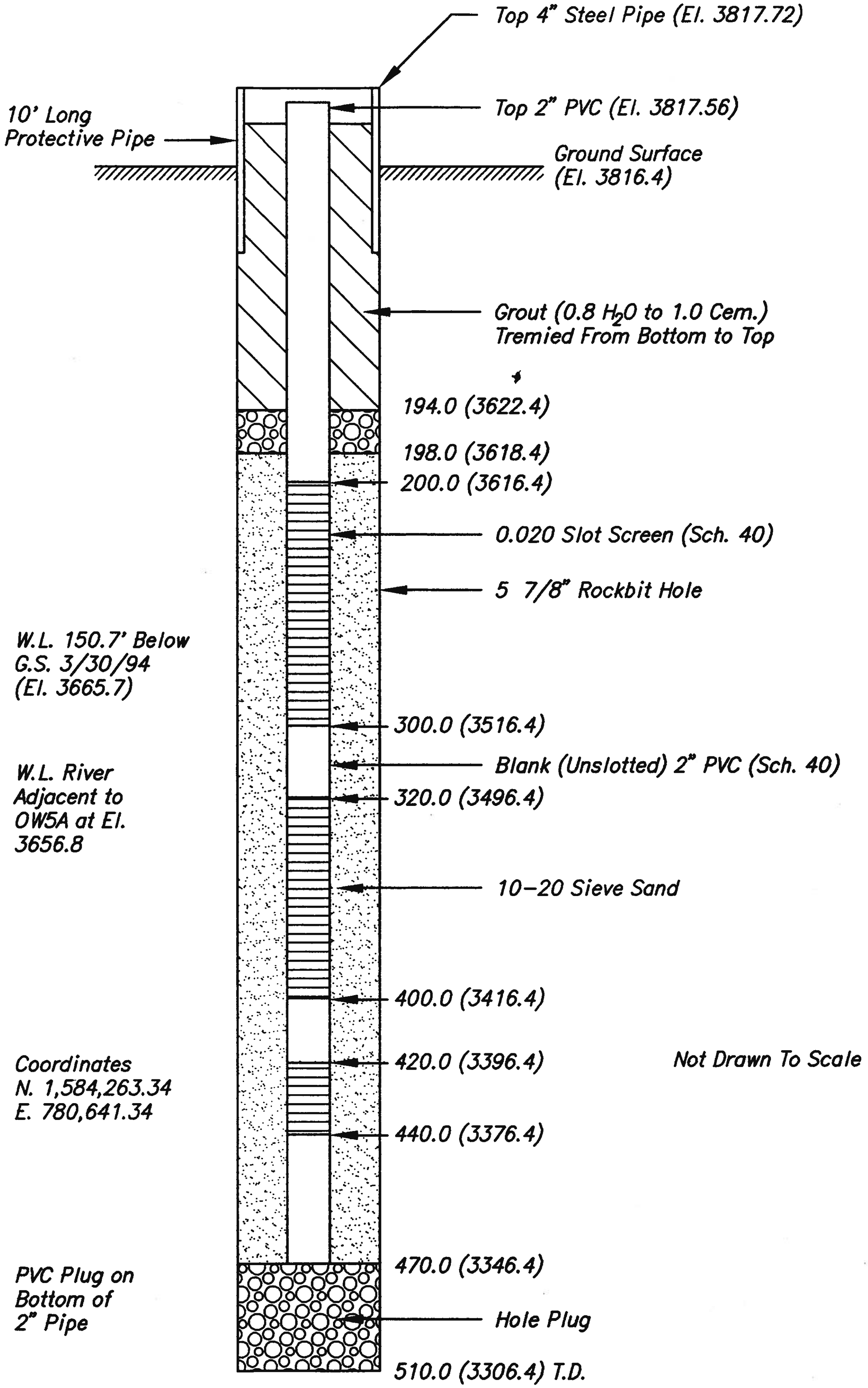
FIGURE 9



LAKE MEREDITH SALINITY STUDY

TW3 COMPLETION

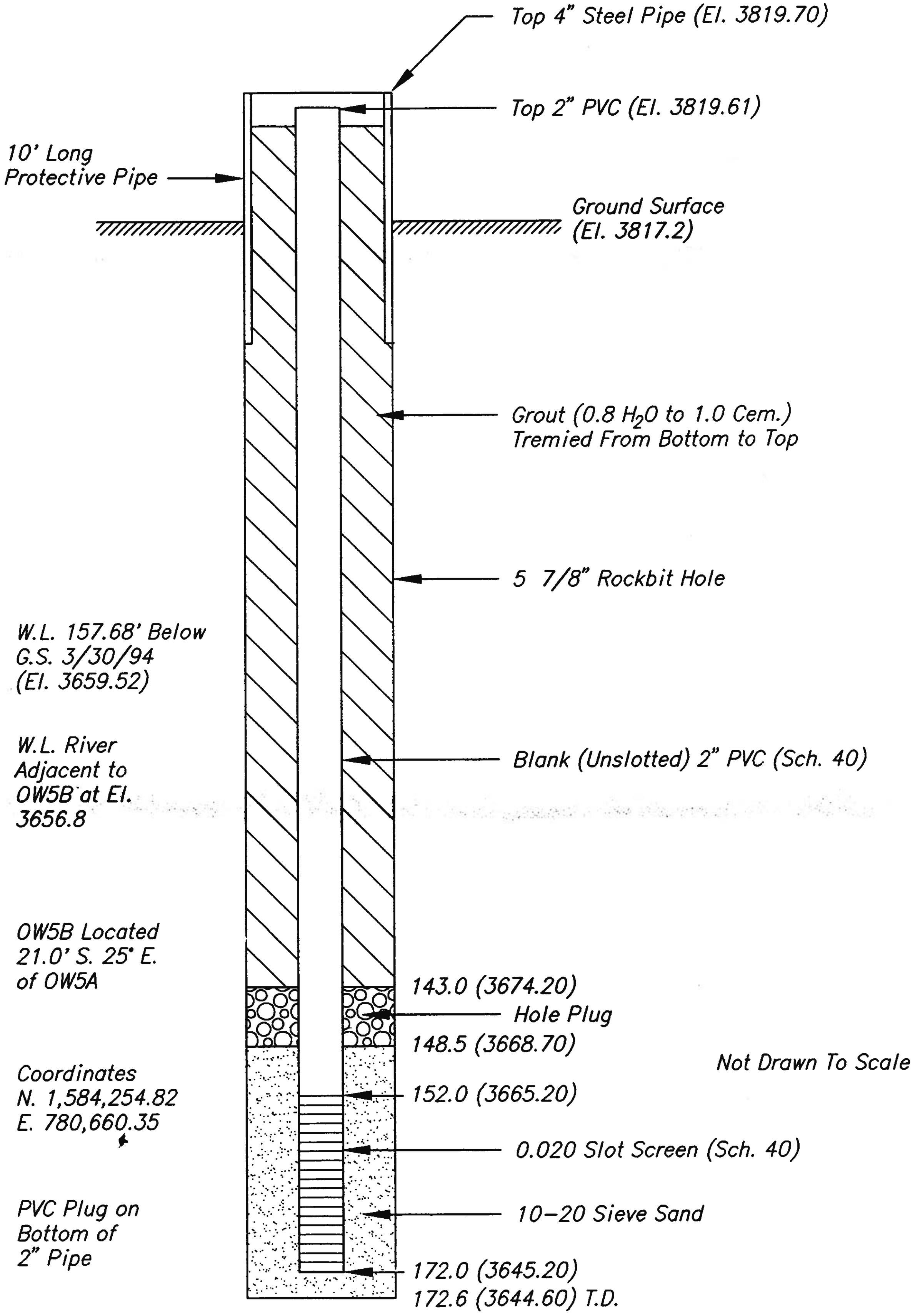
FIGURE 10



LAKE MEREDITH SALINITY STUDY

OW5A COMPLETION

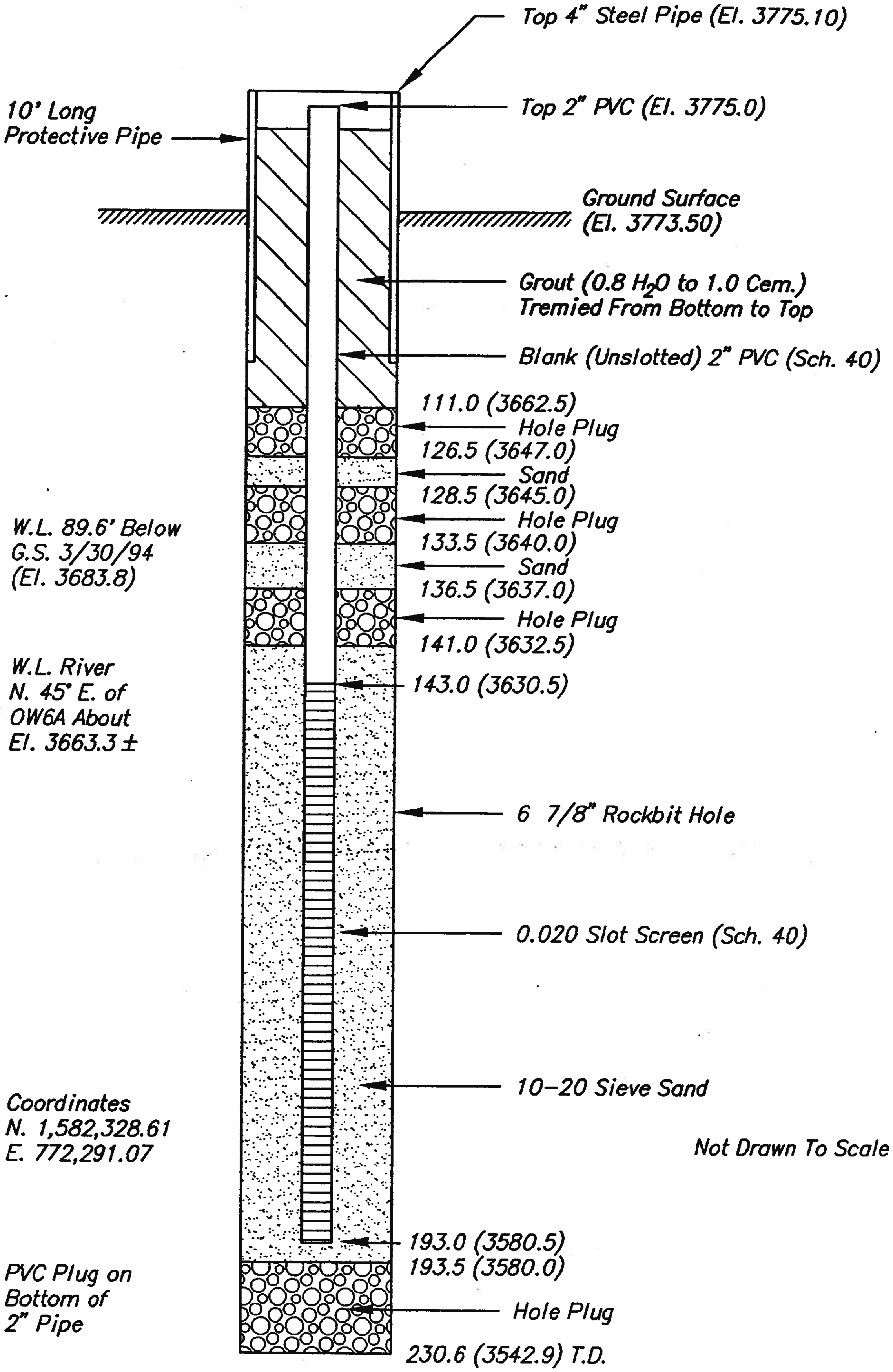
FIGURE 11



LAKE MEREDITH SALINITY STUDY

OW5B COMPLETION

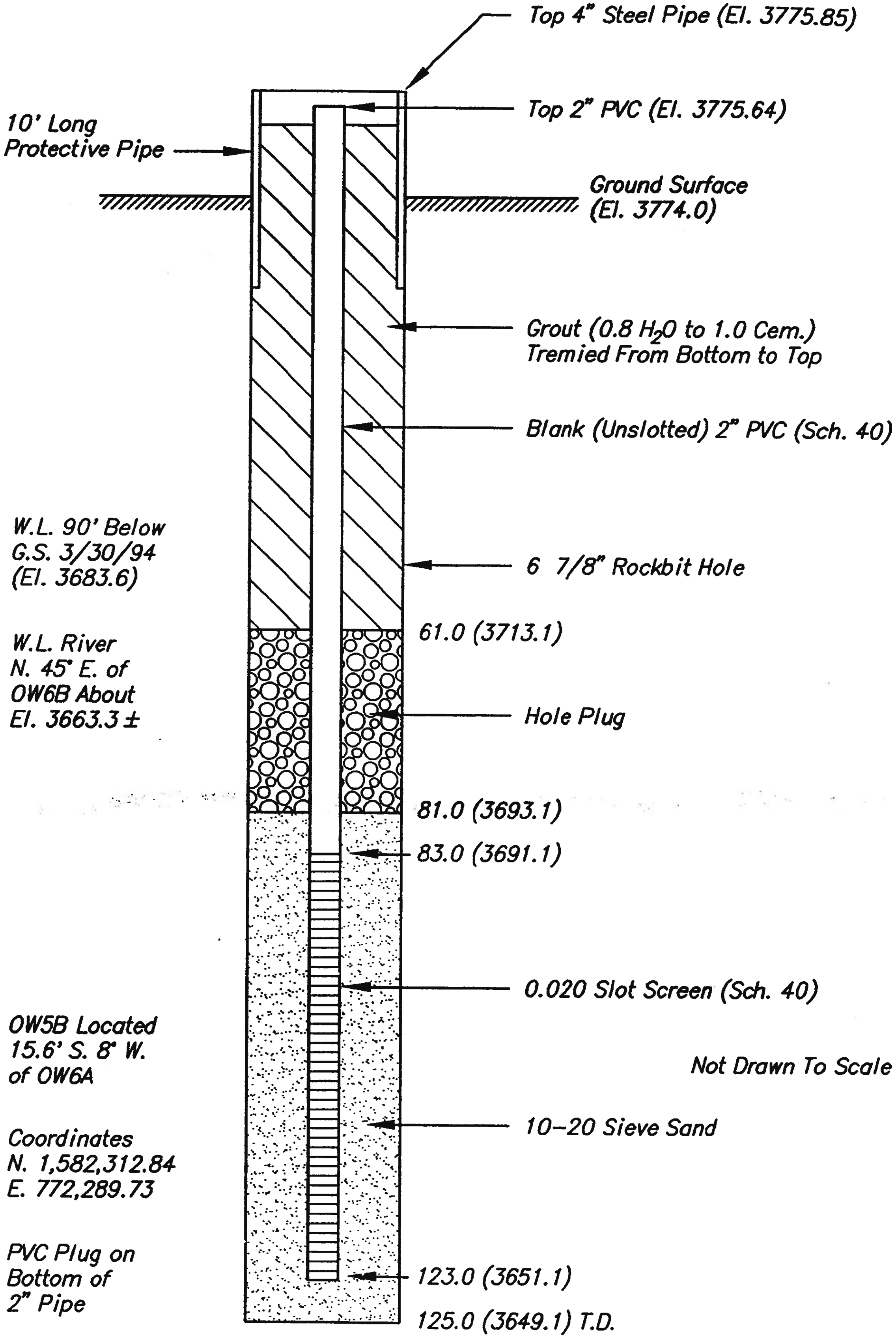
FIGURE 12



LAKE MEREDITH SALINITY STUDY

OW6A COMPLETION

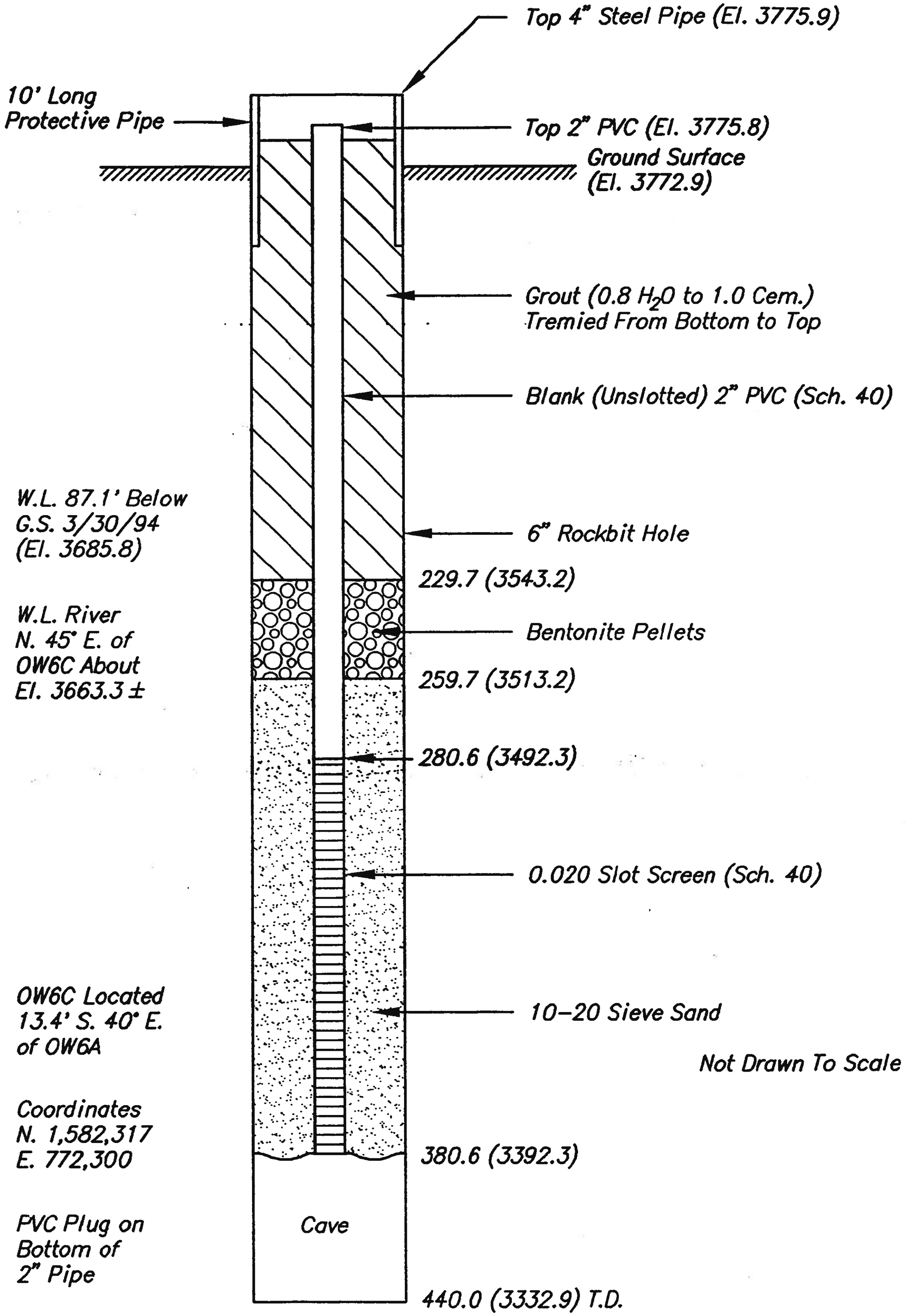
FIGURE 13



LAKE MEREDITH SALINITY STUDY

OW6B COMPLETION

FIGURE 14



LAKE MEREDITH SALINITY STUDY

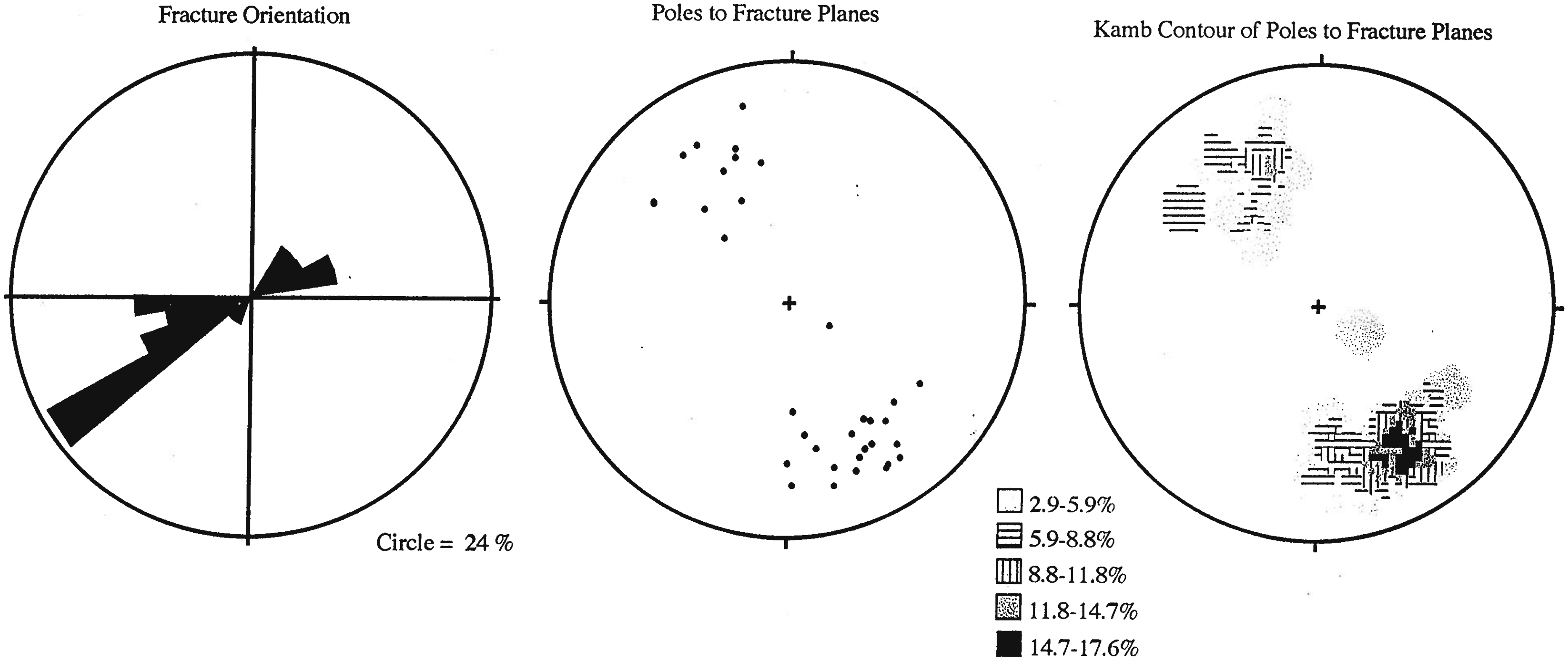
OW6C COMPLETION

FIGURE 15

LAKE MEREDITH FRACTURE ANALYSIS

Natural Fractures in Trujillo Formation

N = 34



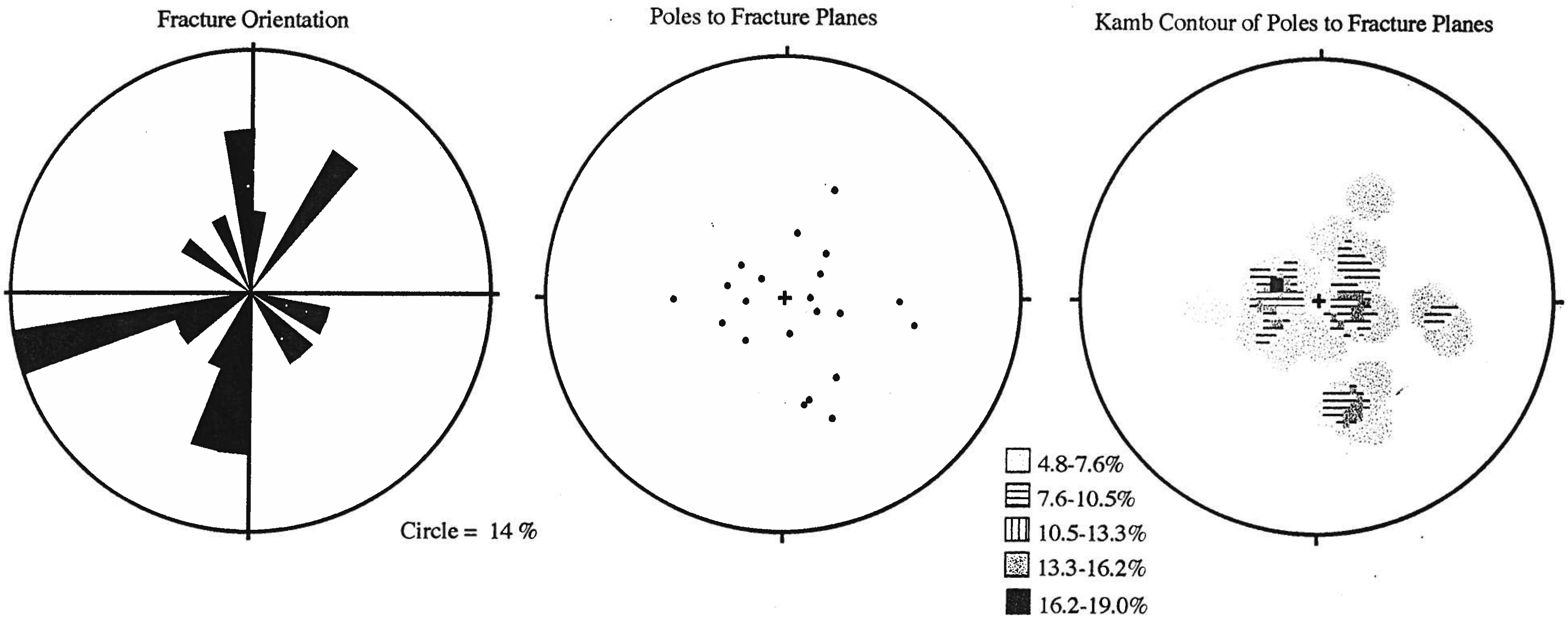
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL FRACTURES IN TRUJILLO FORMATION
OBSERVATION WELL OW6C

Figure 16

LAKE MEREDITH FRACTURE ANALYSIS

Bedding Plane Fractures in Trujillo Formation

N = 21



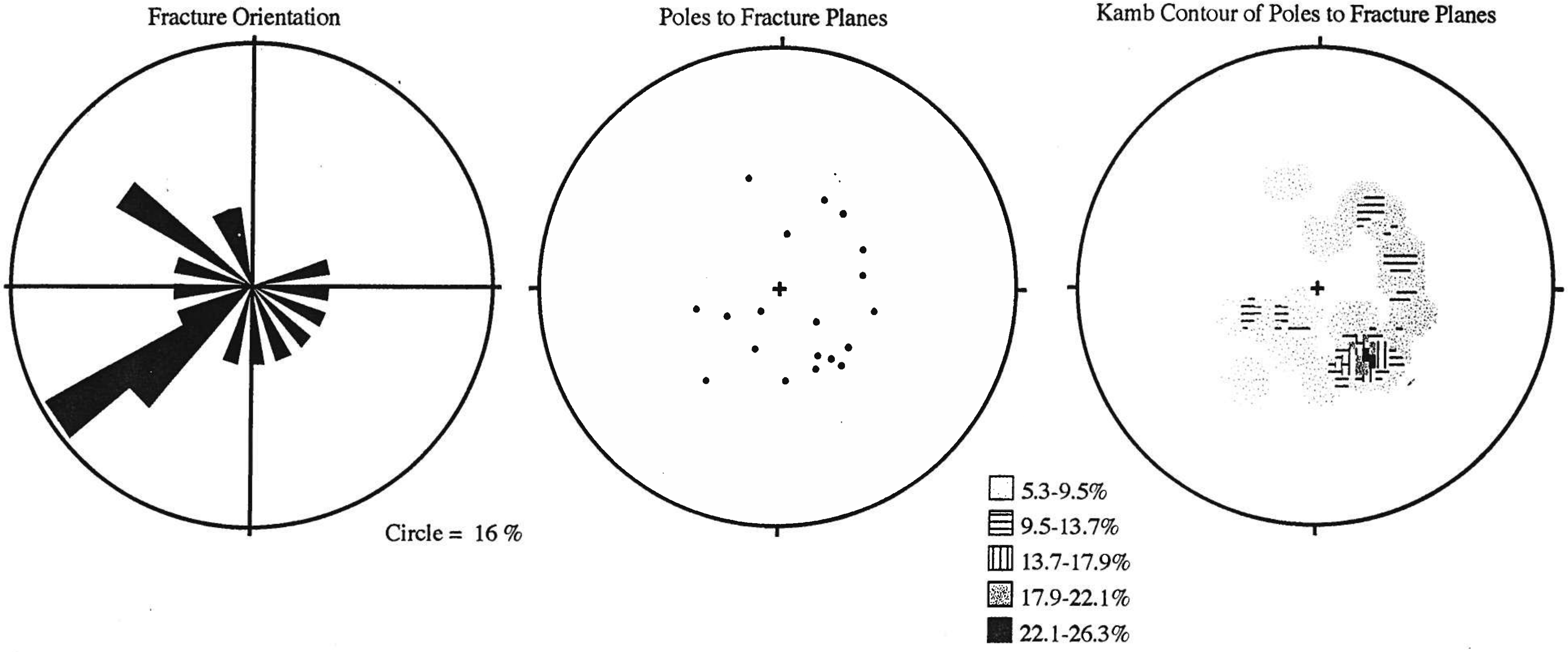
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
BEDDING PLANE FRACTURES IN TRUJILLO FORMATION
OBSERVATION WELL OW6C

Figure 17

LAKE MEREDITH FRACTURE ANALYSIS

Natural Fractures in Upper Shale Unit of the Tecovas Formation

N = 19



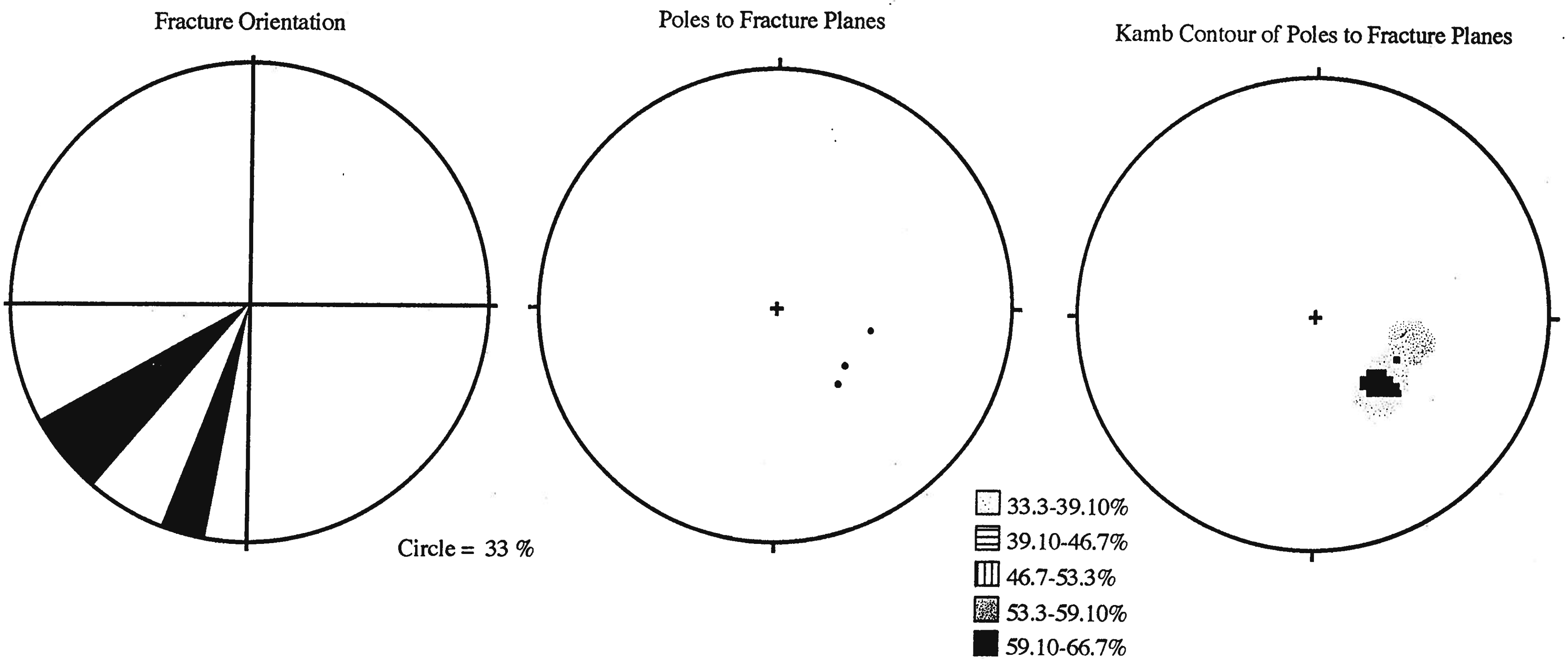
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL FRACTURES IN UPPER SHALE UNIT OF TECOVAS FORMATION
OBSERVATION WELL OW6C

Figure 18

LAKE MEREDITH FRACTURE ANALYSIS

Bedding Plane Fractures in Upper Shale Unit of the Tecovas Formation

N = 3



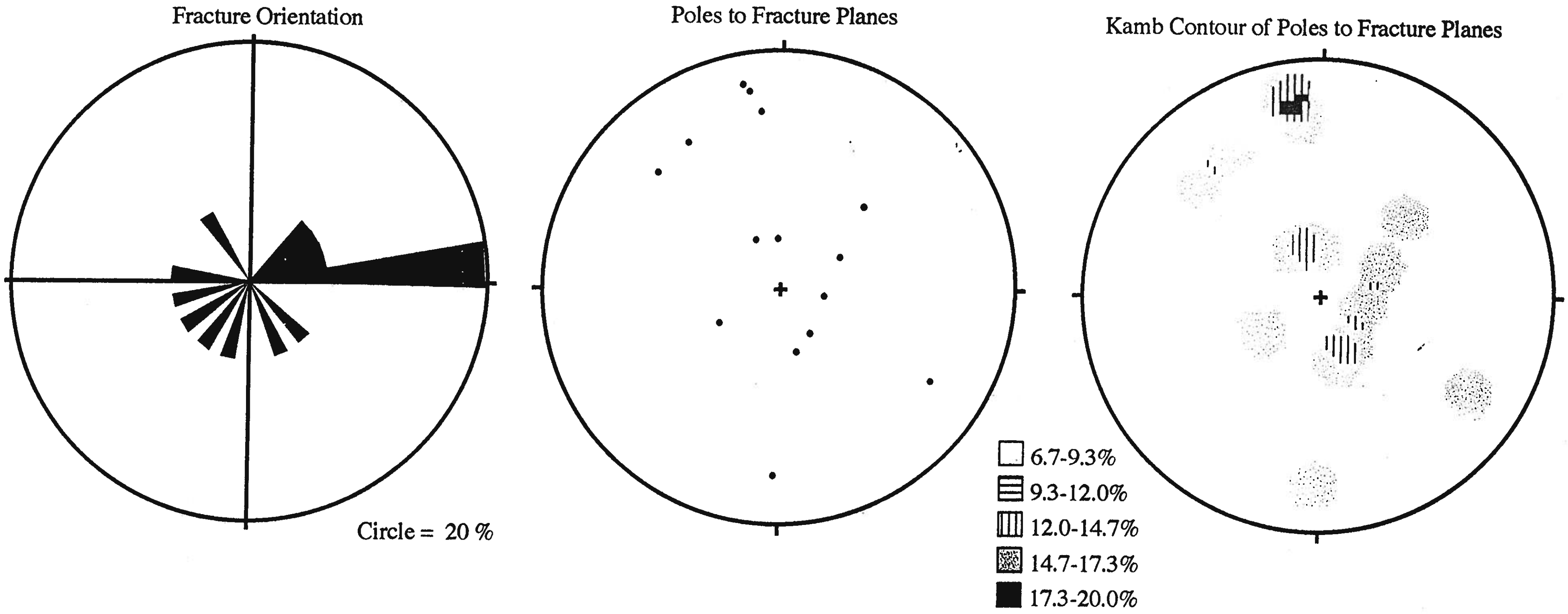
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
BEDDING PLANE FRACTURES IN UPPER SHALE UNIT IN TECOVAS FORMATION
OBSERVATION WELL OW6C

Figure 19

LAKE MEREDITH FRACTURE ANALYSIS

Natural Fractures in Lower Tecovas Formation

N = 15



LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL FRACTURES IN SANDSTONE UNIT OF TECOVAS FORMATION
OBSERVATION WELL OW6C

Figure 20

LAKE MEREDITH FRACTURE ANALYSIS

Bedding Plane Fractures in Lower Tecovas Formation

N = 4

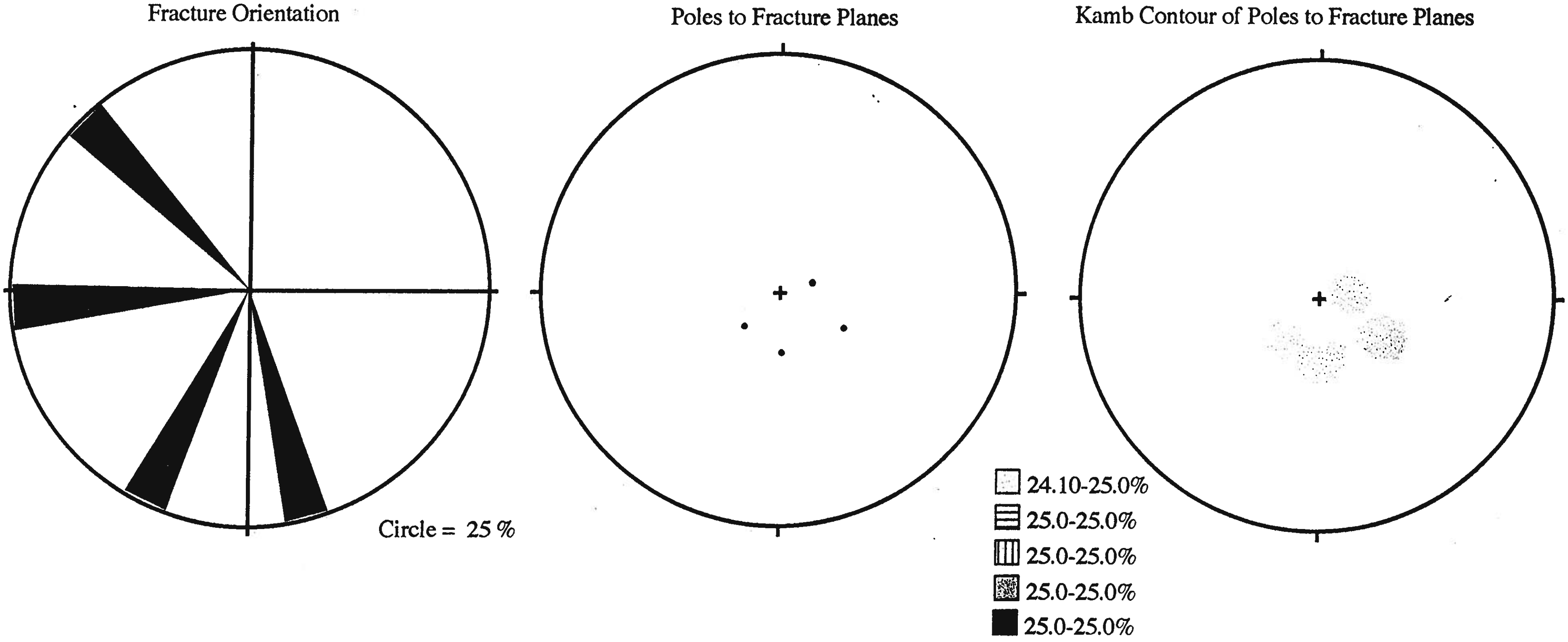
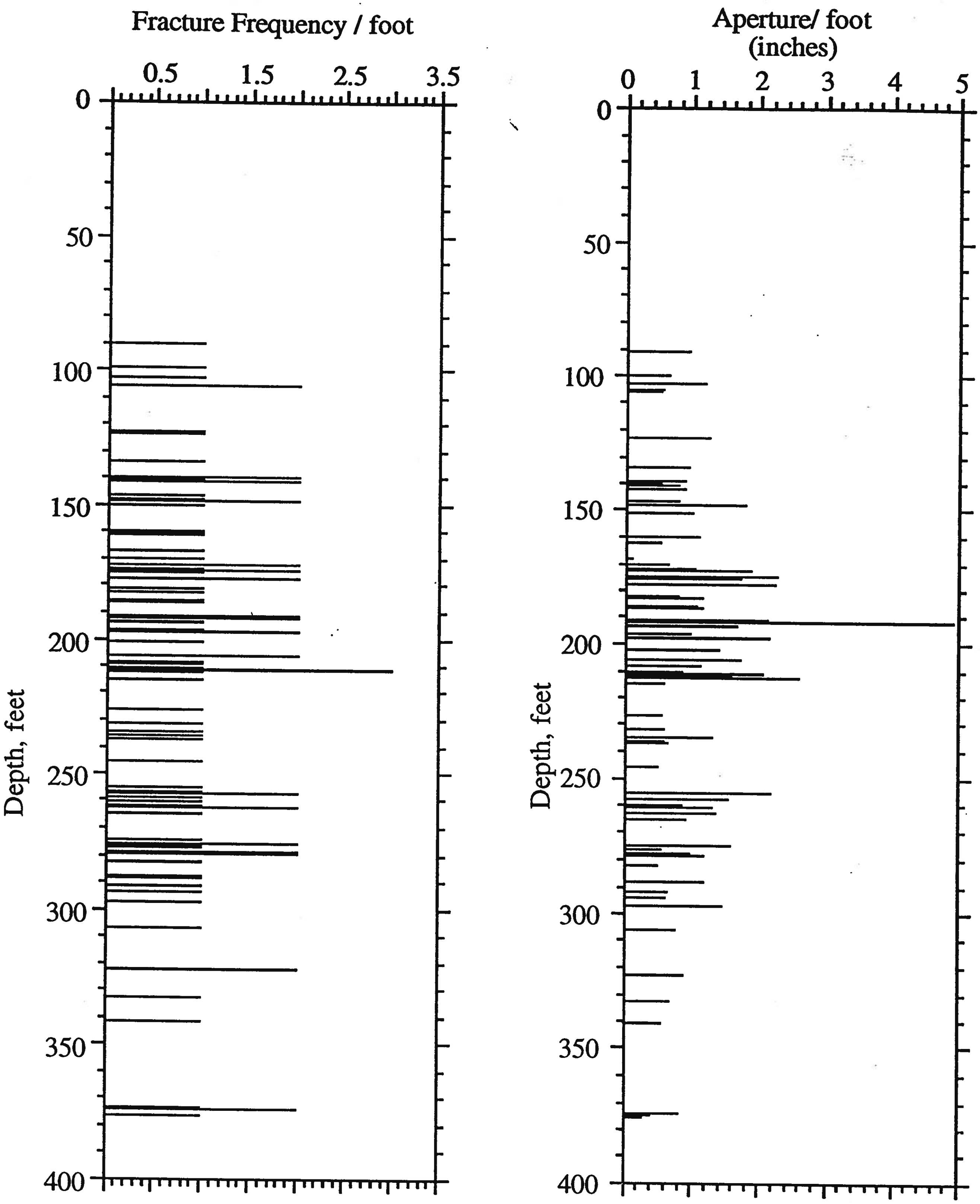


Figure 21

LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
BEDDING PLANE FRACTURES IN SANDSTONE UNIT OF TECOVAS FORMATION
OBSERVATION WELL OW6C

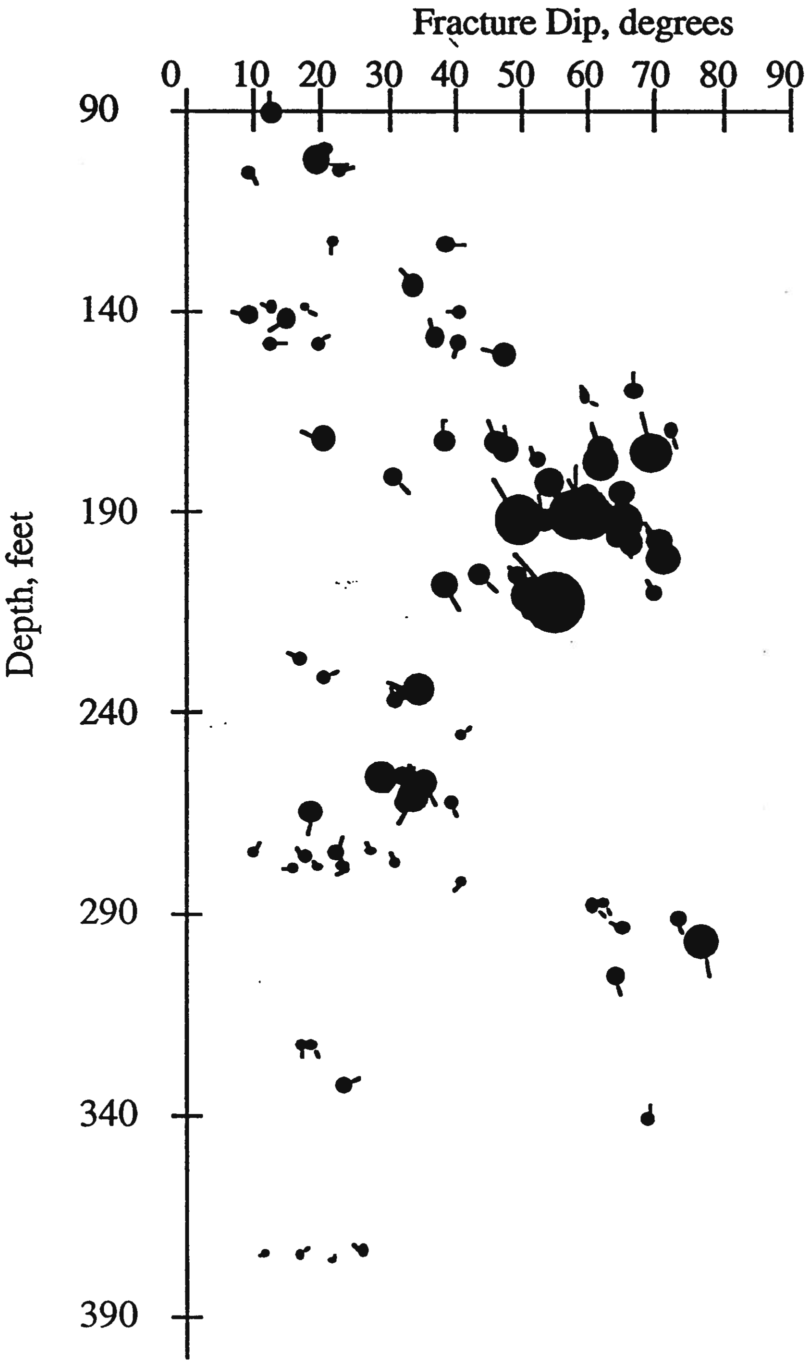
LAKE MEREDITH FRACTURE ANALYSIS



LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
FRACTURE FREQUENCY & APERTURE/FOOT
OBSERVATION WELL OW6C

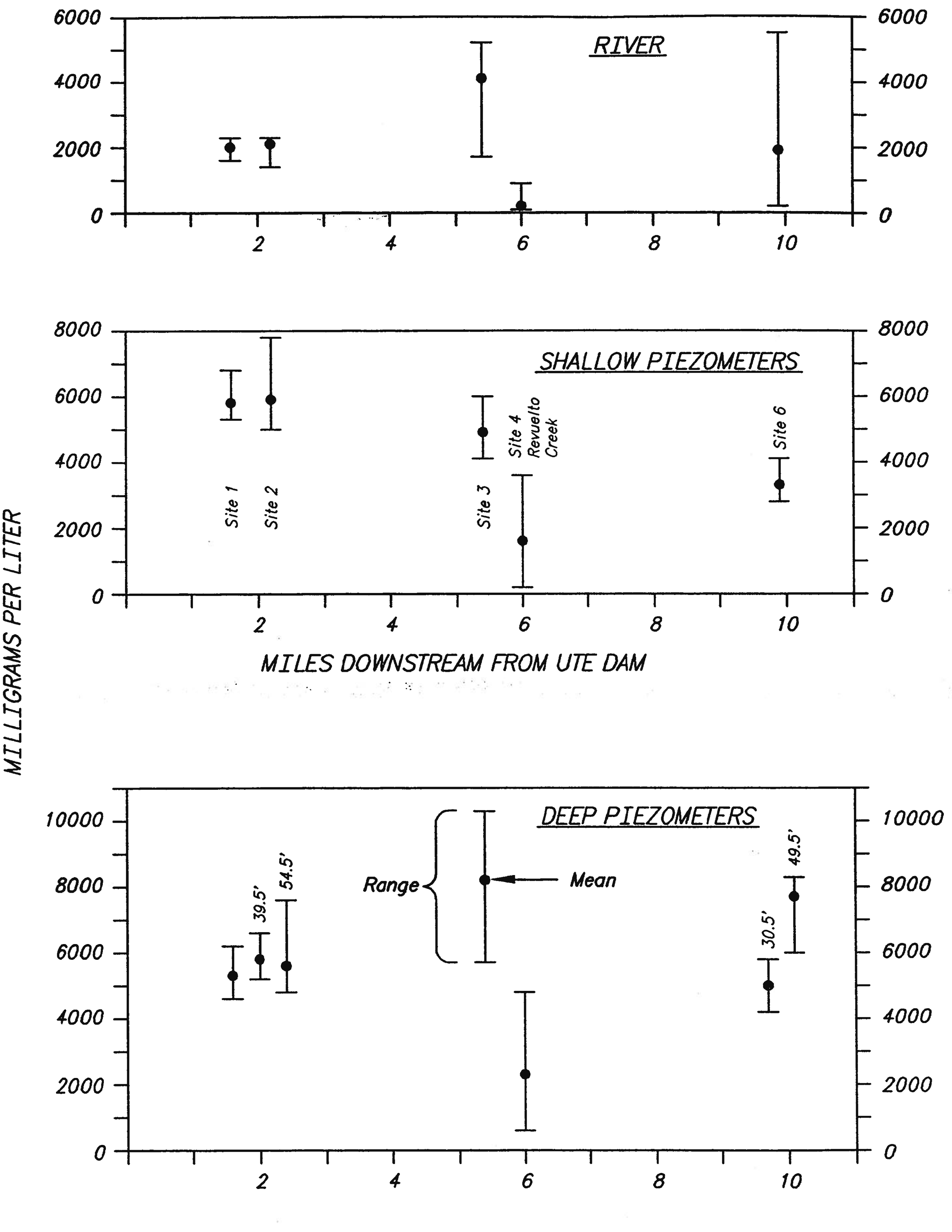
Figure 22

LAKE MEREDITH FRACTURE ANALYSIS



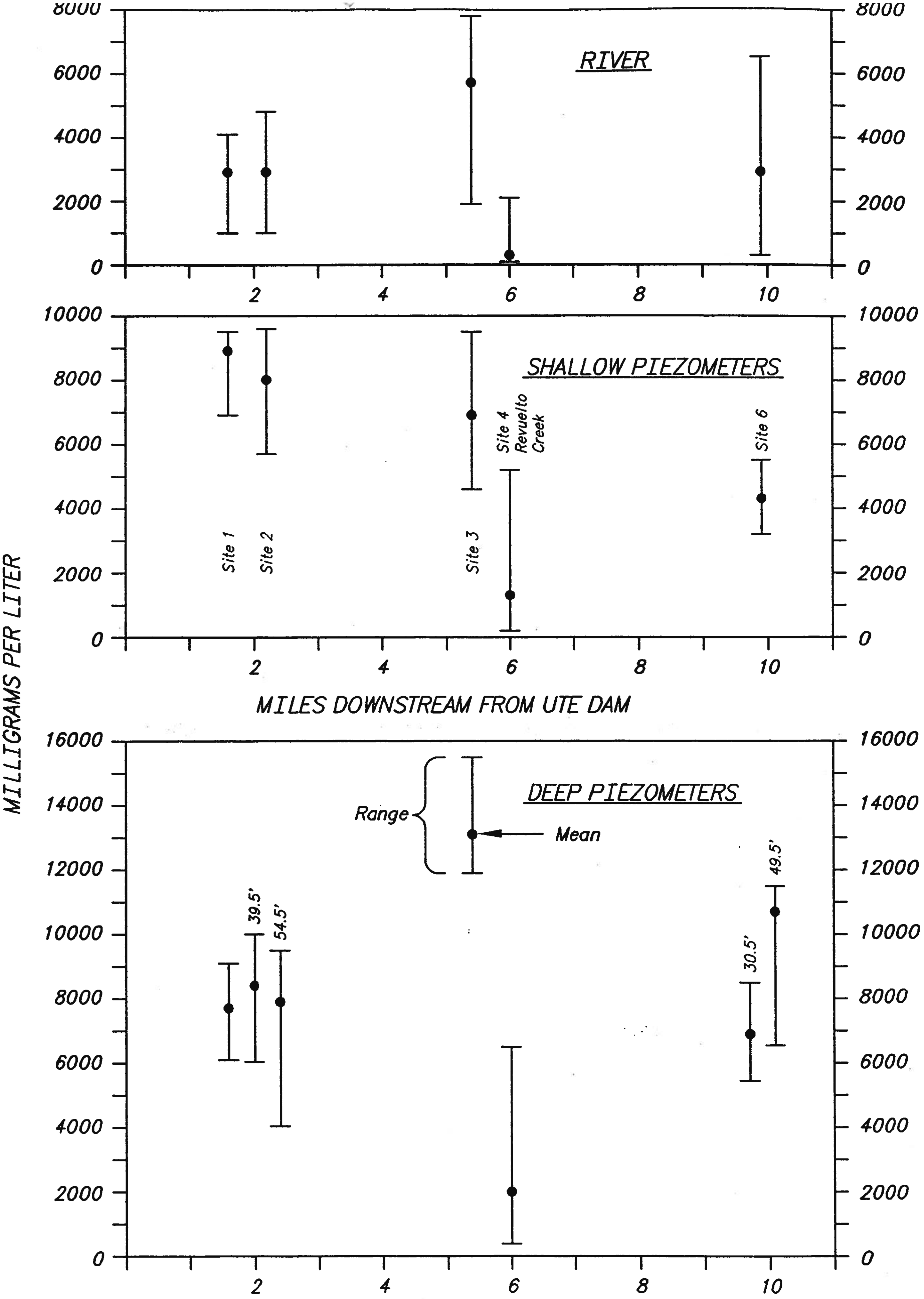
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
PICTORIAL REPRESENTATION OF FRACTURE CHARACTERISTICS
OBSERVATION WELL OW6C

Figure 23



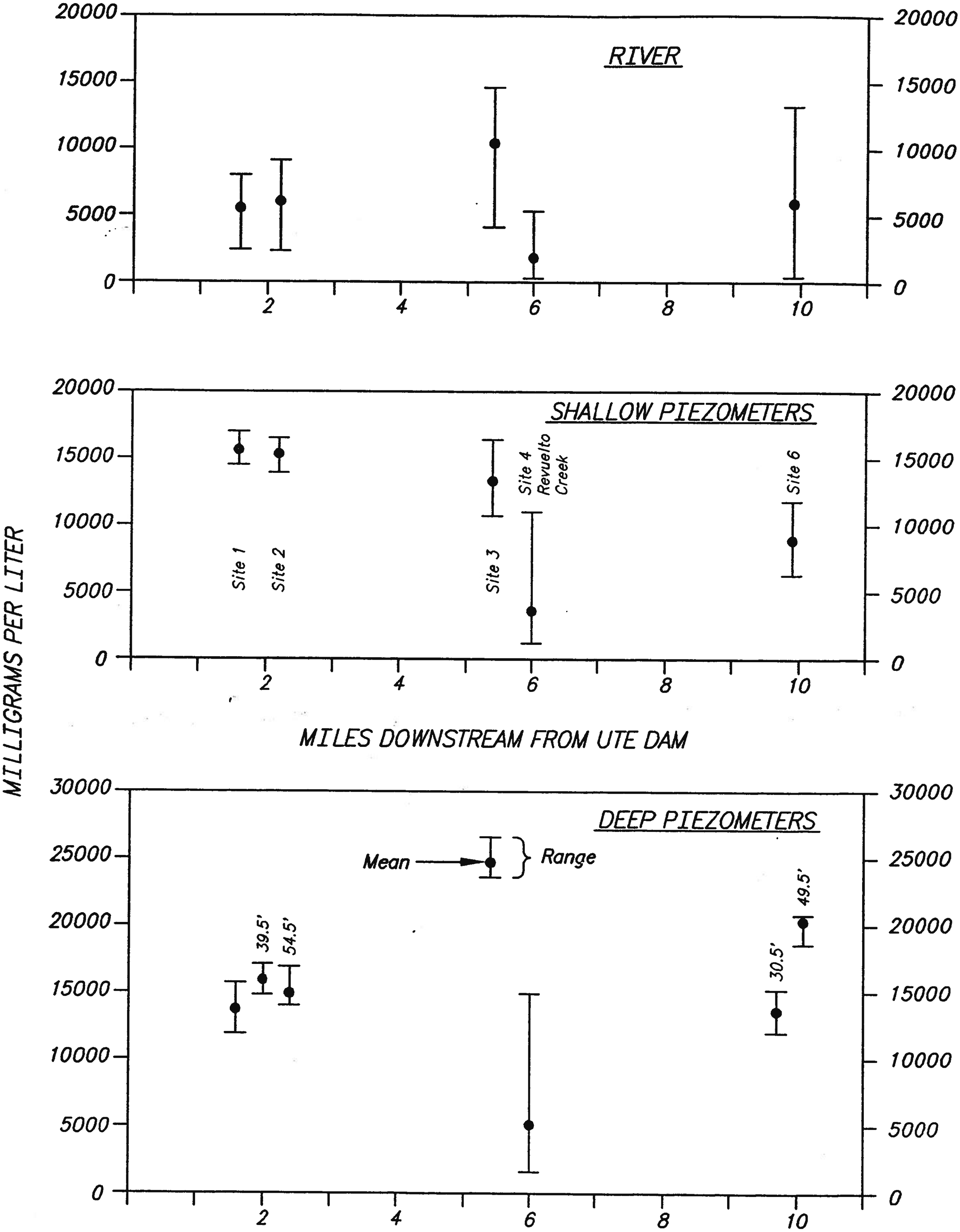
Lake Meredith Salinity Study — Texas, N. Mexico
Ranges of sodium concentrations at Water Quality and Flow Measuring Sites.

FIGURE 24



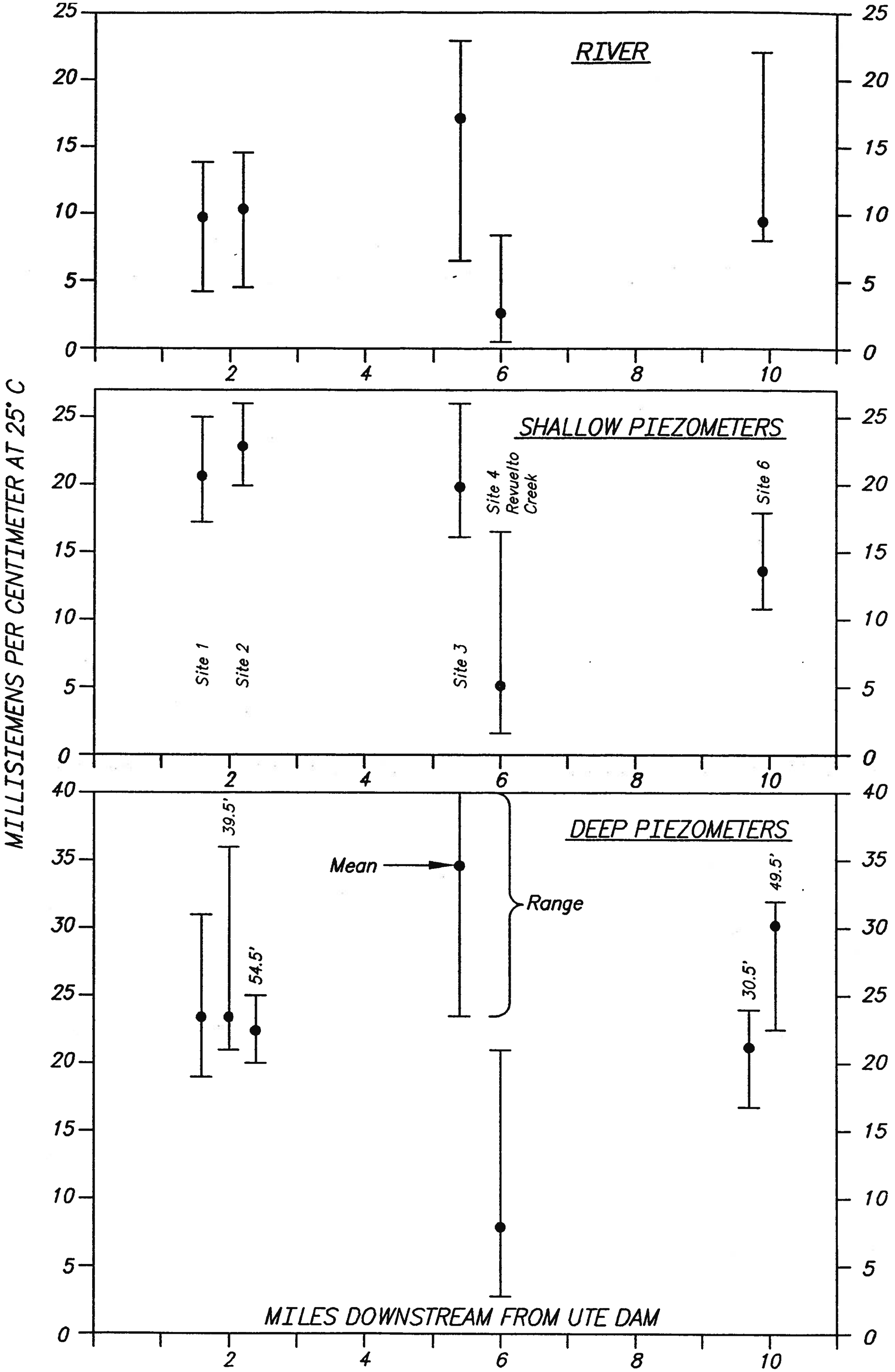
Lake Meredith Salinity Study — Texas, N. Mexico
Ranges of chloride concentrations at Water Quality and Flow Measuring Sites.

FIGURE 25



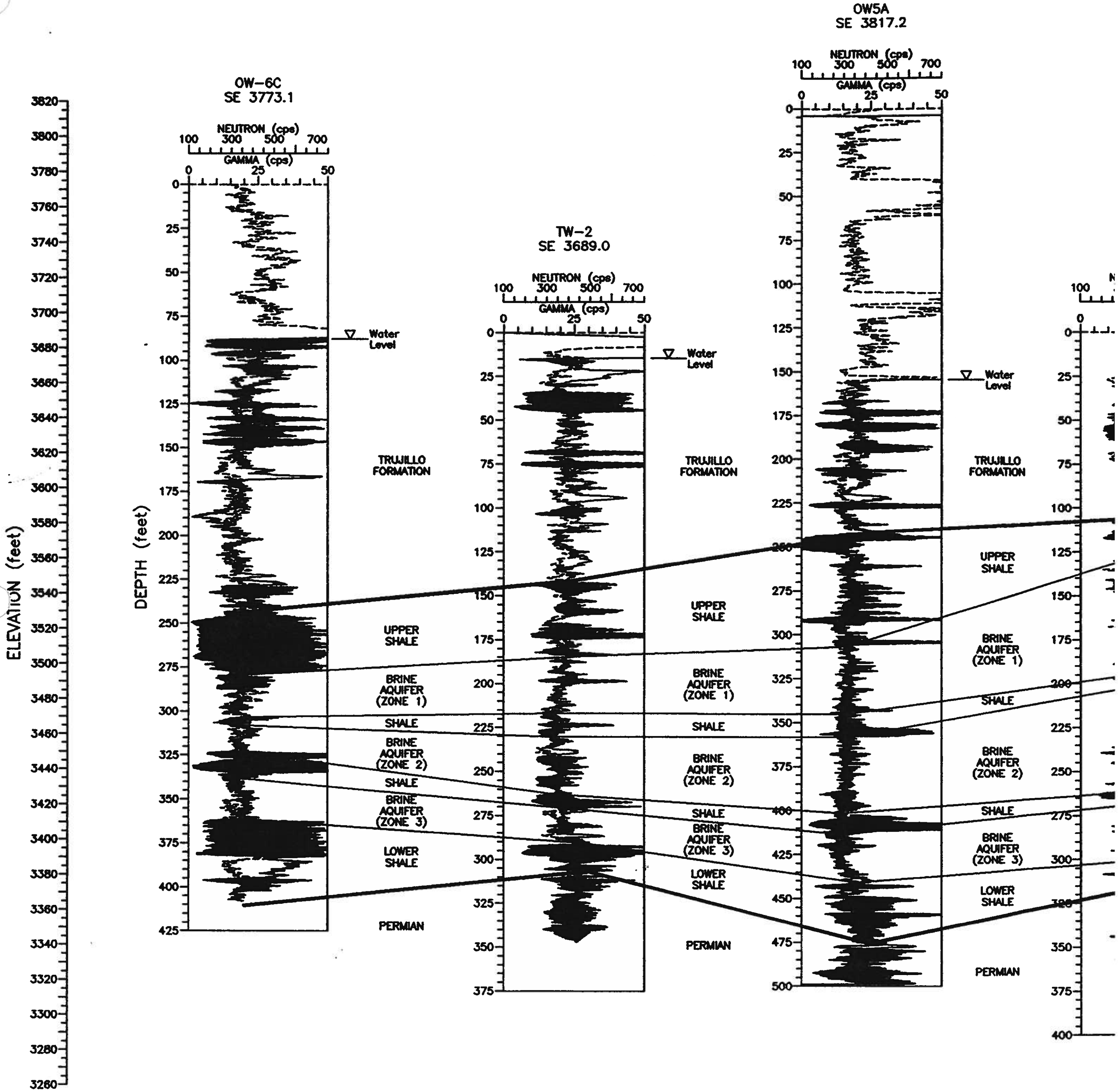
Lake Meredith Salinity Study – Texas, N. Mexico
Ranges of total dissolved solid concentrations
at Water Quality and Flow Measuring Sites.

FIGURE 26



Lake Meredith Salinity Study — Texas, N. Mexico
Ranges of electrical conductivities at Water Quality and Flow Measuring Sites.

FIGURE 27



OW-6C
SE 3773.1
TW-2
SE 3689.0
OW5A
SE 3817.2
NEUTRON (cps)
100 300 500 700
GAMMA (cps)
0 25 50
ELEVATION (feet)
DEPTH (feet)
3820
3800
3780
3760
3740
3720
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3500
3480
3460
3440
3420
3400
3380
3360
3340
3320
3300
3280
3260
Water Level
TRUJILLO FORMATION
UPPER SHALE
BRINE AQUIFER (ZONE 1)
SHALE
BRINE AQUIFER (ZONE 2)
SHALE
BRINE AQUIFER (ZONE 3)
LOWER SHALE
PERMIAN

Tables

LAKE MEREDITH SALINITY STUDY
DRILL HOLE DATA

DRILL HOLE	GROUND SURFACE ELEV.	TOP OF CASING ELEV.	CASING STICKUP	DEPTH TO TECOVAS FORMATION	ELEVATION TOP OF TECOVAS	THICKNESS OF TECOVAS	THICKNESS UPPER TECOVAS UNIT - TOTAL SHALE IN PARENTHESIS	NUMBER OF SHALE BEDS IN UPPER TECOVAS	DEPTH TO BERNAL FORMATION	ELEVATION TOP OF BERNAL
DH 1	3674.50	(?)	(?)	196.0 (?) 1/	3478.50 (?)	160.0 (?)	65.0 (65.0')?	1 (?)	Not Reached	Below 3318.5
DH 2	3655.72	3660.92	5.20	37.0 (?) 2/	3618.72 (?)	167.0 (?) 3/	41.0 (22.0')	5 (?)	204 ± (?)	3451.72 (?)
DH 3	3781.00	3782.80	1.80	288.0	3493.00	218.0 4/	64.0 (64.0')	1	506 ± (?)	3275.0
POW 1	3674.73	3675.90	1.17	251.0	3423.73	67.0 PLUS	20.0 (18.5')	2	Not Reached	Below 3356.73
OW 2	3676.88	3682.80	5.92	232.0	3444.88	116.0 PLUS	29.0 (25.0')	3	Not Reached	Below 3328.88
OW 3	3672.81	3673.71	0.90	160.0	3512.81	166.0	52.0 (35.0')	3	326.0	3346.81
OW 4	3676.50	3677.45	0.95	204.0 (?)	3472.50 (?)	178.0 PLUS	86.0 (86.0') ?	1	Not Reached	Below 3294.50
OW 5A Deep	3816.40	3817.72	1.32	241.5	3574.9	220.5	64.0 (22.0')	8	462.0	3354.4
OW 5B Shallow	3817.20	3819.70	2.5	-	-	-	-	-	-	-
OW 6A Middle	3773.20	3775.11	1.91	-	-	-	-	-	-	-
OW 6B Shallow	3773.80	3775.86	2.06	-	-	-	-	-	-	-
OW 6C Deep	3773.1	3775.89	2.79	229.0	3544.1	181.0	49.0 (42.5)	3	410.0	3363.1
TW 1	3674.01	3680.36	6.35	232.0	3442.01	110.0 PLUS	54.0 (44.0)	2	Not Reached	Below 3316.01
TW 2	3689.00	3690.54	1.54	141.0	3548.00	165.0	44.0 (27.5)	4	306.0	3383.00
TW 3	3689.30	3690.66	1.36	98.0	3591.30	214.0	28.0 (18.5)	6	312.0	3377.30

Table 1
Sheet 1 of 2

DRILL HOLE	*CASING AND SCREEN INTERVALS	HOLE DEPTH	WATER LEVEL ELEVATION AND (DATE)	REMARKS
DH 1	CS 0-31.5' OH 31.5 - 356.0'	356.0	-	Artesian flow at 261: 1/ No Geophysical Log. Data based on written log.
DH 2	CS 0-42.0' OH 42.0 - 556.0'	556.0	3657.8 (3/30/94)	Artesian flow at 456: 2/ U. Tecovas could be higher and eroded away. 3/ Top Permian at 204± (written log). U. Tecovas determined from Gamma Log.
DH 3	CS 0-368.0' SC 368.0 - 417.5'	569.5	3697.3 (3/30/94)	4/ Bottom Tecovas estimated at 506'±. Used Gamma Log to 460' to develop data.
POW 1	CS 0-233± SC 233.0 - 318.0'	318.0	-	Artesian flow at 294'. Used Gamma Log for data.
OW 2	CS 0-260.0 (?) SC 260.0 - 340.0	348.0	-	Hole may have bottomed near top of Permian. Used Gamma Log for data. Reported artesian flows.
OW 3	CS 0-270.0' SC 270.0 - 350.0	362.0	3673.7 (3/30/94)	Reported artesian flows. Used Gamma Log to develop data.
OW 4	CS 0-293.0' SC 293.0 - 377.0	382.0	-	Reported artesian flow. Resistivity but no Gamma Log. Data Based on written log. Reported artesian flows.
OW 5A Deep	CS 0-200.0, 300.0 - 320.0, 400.0 - 420.0 and 440.0 - 470.0 SC 200.0 - 300.0, 320.0 - 400.0 and 420 - 440.0'	510.0	3665.7 (3/30/94)	Data based on Geophysical and cuttings information.
OW 5B Shallow	CS 0-152.0' SC 152.0 - 172.0'	172.6	3659.52 (3/30/94)	Hole 21.0' S.25°E. of OW 5A. Data based on Geophysical and cuttings information.
OW 6A Middle	CS 0-143.0' SC 143.0 - 193.0'	230.6	3683.5 (3/30/94)	Data based on Geophysical and cuttings information.
OW 6B Shallow	CS 0-83.0' SC 83.0 - 123.0'	125.0	3683.4 (3/30/94)	Hole 15.6' S.8°W. of OW 6A. Data based on Geophysical and cuttings information.
OW6C Deep	CS 0-280.6' SC 280.6 - 380.6'	440.0	3686.0 (6/19/94)	Data based on Geophysical and cuttings information. Hole is 13.4' S. 40° E. of OW6A.
TW 1	CS 0-242.0 BL 248.0 - 268± SC 268± - 346±	358.0	3676.5 (3/30/94)	Casing and screen separated 242.0 - 248.0'. It appears that there is communication between Trujillo and Tecovas. Data based on Geophysical Log. Unsure of blank and screen sections.
TW 2	CS 0-175.5' and 295.5-298.5 SC 175.5 - 295.5'	348.4	3671.0 (3/30/94)	Top 12.5' of screen taped. Data based on Geophysical and cuttings information. Top temporary PVC pipe at 3691.04.
TW 3	CS 0-135.4 and 274.2 - 286.2' SC 135.4 - 274.2'	369.7	3668.3 (3/30/94)	Data based on Geophysical and cuttings information. Top temporary PVC pipe at 3690.90. See log for additional casing information.

* OH = Open hole CS = Casing or blank PVC BL = Blank PVC SC = Screen

Table 1
Sheet 2 of 2

LAKE MEREDITH SALINITY STUDY
OBSERVATION WELL OW6C

Fractures Measured in Trujillo Formation

Depth	Dip	Dip Direction	Aperture	Classification
226.68	16.700	298.30	0.550	Natural Fracture
215.31	51.000	153.00	0.590	Natural Fracture
212.77	54.900	320.10	2.60	Natural Fracture
211.53	51.200	324.60	1.56	Natural Fracture
211.32	52.100	312.90	0.450	Natural Fracture
211.17	55.400	301.10	0.940	Natural Fracture
210.75	70.000	327.40	0.650	Natural Fracture
209.55	56.900	160.40	0.850	Natural Fracture
208.36	38.600	154.50	1.13	Natural Fracture
206.17	43.700	137.50	0.910	Natural Fracture
206.07	49.500	168.10	0.800	Natural Fracture
201.94	71.300	328.60	1.38	Natural Fracture
197.98	66.500	337.50	1.07	Natural Fracture
197.66	70.600	323.40	1.08	Natural Fracture
196.29	64.300	143.40	0.970	Natural Fracture
193.25	65.200	321.60	1.67	Natural Fracture
192.18	49.600	326.30	2.05	Natural Fracture
192.01	53.300	348.10	1.00	Natural Fracture
191.71	60.100	331.60	1.87	Natural Fracture
191.14	57.900	359.20	2.12	Natural Fracture
186.91	60.000	125.70	1.14	Natural Fracture
185.74	65.000	148.60	1.05	Natural Fracture
182.90	54.100	159.20	1.16	Natural Fracture
181.80	30.900	134.50	0.790	Natural Fracture
177.87	61.900	343.40	1.58	Natural Fracture
177.60	52.200	333.40	0.660	Natural Fracture
175.61	69.500	345.10	1.72	Natural Fracture
174.96	47.800	352.20	1.11	Natural Fracture
174.54	61.900	334.50	1.15	Natural Fracture
173.19	46.200	337.50	1.00	Bedding Plane Fracture
172.72	38.600	348.10	0.870	Bedding Plane Fracture
172.10	20.500	286.90	1.03	Bedding Plane Fracture
170.06	72.400	166.30	0.630	Natural Fracture
167.72	38.600	356.30	0.0800	Natural Fracture
161.80	59.500	125.70	0.510	Natural Fracture
160.48	59.400	328.60	0.400	Natural Fracture
159.83	66.900	358.10	0.690	Natural Fracture
150.85	47.500	282.20	0.990	Bedding Plane Fracture
148.31	19.600	39.800	0.550	Bedding Plane Fracture
148.26	12.600	82.200	0.590	Bedding Plane Fracture
147.91	40.500	205.70	0.640	Bedding Plane Fracture
146.76	37.000	345.10	0.780	Bedding Plane Fracture

Table 2
Sheet 1 of 2

141.96	14.900	238.60	0.870	Bedding Plane Fracture
141.12	9.4000	273.00	0.78	Bedding Plane Fracture
140.44	40.700	272.20	0.520	Bedding Plane Fracture
139.15	12.800	293.90	0.460	Bedding Plane Fracture
139.10	17.700	125.70	0.400	Bedding Plane Fracture
133.95	33.800	326.30	0.940	Bedding Plane Fracture
123.47	38.600	88.100	0.740	Bedding Plane Fracture
122.75	21.800	192.20	0.490	Bedding Plane Fracture
105.30	22.700	66.300	0.550	Bedding Plane Fracture
105.78	9.2000	127.00	0.52	Bedding Plane Fracture
102.62	19.500	99.800	1.18	Bedding Plane Fracture
99.900	20.600	225.70	0.620	Bedding Plane Fracture
90.800	12.800	349.20	0.930	Bedding Plane Fracture

LAKE MEREDITY SALINITY STUDY
OBSERVATION WELL OW6C

Fractures Measured in Upper Shale Unit of the Tecovas Formation

Depth	Dip	Dip Direction	Aperture	Classification
277.54	31.000	322.90	0.47	Natural Fracture
276.22	17.600	311.70	0.55	Natural Fracture
275.19	22.300	19.900	0.690	Natural Fracture
275.01	9.9000	34.500	0.480	Natural Fracture
274.67	27.300	329.10	0.390	Natural Fracture
264.88	18.400	189.30	0.920	Natural Fracture
262.60	39.400	164.70	0.590	Natural Fracture
262.73	32.500	354.80	0.760	Natural Fracture
261.12	33.700	208.30	1.31	Natural Fracture
260.48	33.700	221.70	0.830	Natural Fracture
258.33	29.500	262.00	0.600	Natural Fracture
257.63	35.200	320.10	0.930	Bedding Plane Fracture
256.20	29.100	74.700	1.34	Natural Fracture
255.94	32.100	246.30	0.830	Natural Fracture
245.87	41.000	37.300	0.480	Natural Fracture
237.27	31.000	334.70	0.620	Natural Fracture
235.61	32.300	310.10	0.580	Bedding Plane Fracture
234.58	34.500	283.80	1.31	Bedding Plane Fracture
231.60	20.400	60.200	0.570	Natural Fracture

Table 3

LAKE MEREDITY SALINITY STUDY
OBSERVATION WELL OW6C

Fractures Measured in Lower Units of the Tecovas Formation

Depth	Dip	Dip Direction	Aperture	Classification
376.03	21.700	356.40	0.270	Bedding Plane Fracture
374.54	16.800	44.300	0.400	Bedding Plane Fracture
374.44	11.800	254.70	0.330	Bedding Plane Fracture
373.81	26.300	299.70	0.490	Bedding Plane Fracture
341.01	68.900	1.1000	0.55	Natural Fracture
332.71	23.500	58.900	0.650	Natural Fracture
322.89	17.100	178.10	0.40	Natural Fracture
322.77	18.500	153.00	0.48	Natural Fracture
306.04	64.200	173.50	0.76	Natural Fracture
297.30	76.900	169.40	1.45	Natural Fracture
293.91	65.000	301.10	0.61	Natural Fracture
291.58	73.400	170.90	0.63	Natural Fracture
288.06	60.500	132.90	0.65	Natural Fracture
287.77	62.200	147.40	0.52	Natural Fracture
282.18	41.000	225.70	0.48	Natural Fracture
279.31	15.900	281.00	0.43	Natural Fracture
279.20	23.600	243.00	0.38	Natural Fracture
278.71	19.500	324.60	0.37	Natural Fracture
278.30	23.200	343.60	0.50	Natural Fracture

Table 4

INFORMATION SHEET

TEST WELL 1 (TW1)

Location: N. 1,585,252.5, E. 774,291.3
Ground Surface: 3674.01
Depth: 358.0-ft.
Bottom of Hole: Tecovas Formation (Triassic)
Screen in Tecovas
Water Level: 3676.5 (3-30-94) Artesian

Water Analyses

Sample Date 9-16-93
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	630.0
Magnesium	212.0
Sodium	12,500.0
Potassium	54.9
Carbonate	0.0
Bicarbonate	1,070.0
Sulfate	2,160.0
Chloride	18,600.0
Sum (Cations+ Anions)	35,300.0
Aluminum	<0.150
Boron	2.070
Beryllium	<0.0025
Cadmium	<0.010
Chromium	<0.010
Cobalt	<0.030
Copper	<0.020
Iron	12.85
Manganese	0.661
Nickel	<0.020
Lead	<0.150
Silver	<0.010
Vanadium	<0.010
Zinc	<0.020
Electrical Conductivity (milliSiemens/cm @ 25°C)	31.0
pH	6.26
Suspended Solids	46.8 mg/L
Total Dissolved Solids	35,100.0 mg/L

Note: Locations of all wells, except for wells BYW and WPW, are shown on drawing 1253-600-23

INFORMATION SHEET

TEST WELL 2 (TW2)

Location: N. 1,582,966, E. 776,706
Ground Surface: 3689.0
Depth: 348.0-ft.
Bottom of Hole: Bernal Formation (Permian)
Screen in Tecovas Formation (Triassic)
Water Level: 3676.5 (3-30-94)

Water Analyses

Sample Date: 3-31-94
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	1038.0
Magnesium	327.0
Sodium	68.9
Potassium	22,400.0
Alkalinity (as $CaCO_3$)	524.7
Alkalinity (as HCO_3)	640.1
Chloride	35,470.0
Sulfate	3,170.0
Sum	63,114.0
Aluminum	<0.150
Boron	1.799
Beryllium	<0.0025
Cadmium	<0.010
Chromium	<0.010
Cobalt	<0.010
Copper	0.054
Iron	5.40
Manganese	0.281
Nickel	<0.010
Lead	<0.050
Silver	<0.010
Vanadium	0.034
Zinc	0.620
Arsenic	<0.080
Selenium	<0.050
Strontium	15.76
Mercury	<0.20 (ug/L)

Electrical Conductivity (milliSiemens/cm @ 25°C)	105.0
Total Dissolved Solids	62,789.0 mg/L
SAR	155.31
Hardness as mg $CaCO_3$/L	3,939.5

Table 6

INFORMATION SHEET

TEST WELL 3 (TW3)

Location: N. 1,588,153.59, E. 780,644.09
Ground Surface: 3689.3
Depth: 369.7-ft.
Bottom of Hole: Bernal Formation (Permian)
Screen in Tecovas Formation (Triassic)
Water Level: 3668.3 (3-30-94)

Water Analyses:
Sample Date: 4-05-94
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	397.0
Magnesium	130.0
Sodium	6,744.0
Potassium	34.9
Alkalinity (as $CaCO_3$)	813.9
Alkalinity (as HCO_3)	993.0
Chloride	10,470.0
Sulfate	1,580.0
Sum	20,349.0
Aluminum	<0.150
Boron	1.770
Beryllium	<0.0025
Cadmium	<0.010
Chromium	<0.010
Cobalt	<0.010
Copper	<0.010
Iron	4.66
Manganese	0.774
Nickel	<0.010
Lead	<0.050
Silver	<0.010
Vanadium	0.022
Zinc	0.498
Arsenic	<0.080
Selenium	<0.050
Strontium	7.21
Mercury	<0.2

Electrical Conductivity (milliSiemens/cm @ 25°C)	29.5
Total Dissolved Solids	19,844.0 mg/L
SAR	75.17
Hardness as mg $CaCO_3$/L	1,524.6

Table 7

INFORMATION SHEET

DRILL HOLE 1 (DH1)

Location: N. 1,585,226.9, E. 774,266.3
Ground Surface: 3674.5
Depth: 356.0-ft.
Bottom of Hole: Tecovas Formation (Triassic)
Water Level: Artesian
Water Analyses:
Sample Date: June 1975
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Chloride	16,100.0
Iron, Total	0.27
Sodium Chloride	26,565.0
Sulfate	1,900.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	51.0

Table 8

INFORMATION SHEET

DRILL HOLE 2 (DH2)

Location: N. 1,591,010±, E. 785,440±
Ground Surface: 3655.72
Depth: 556.0-ft.
Bottom of Hole: Bernal Formation (Permian)
Open hole in Tecovas (Triassic) and Bernal Formations
Water Level: 3657.8 (3-30-94)

Water Analyses:
Sample Date: 7-19-83
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	384.0
Magnesium	96.0
Sodium	7,880.0
Potassium	36.8
Bicarbonate	1,076.57
Chloride	6,580.0
Sulfate	1,710.0
Fluoride	0.5
Iron, total	0.19
Total Dissolved Solids	12,138.0
pH (lab)	7.62
Electrical Conductivity (field) (milliSiemens/cm @ 25°C)	17.8
Temperature (field)	18.0°C

INFORMATION SHEET

DRILL HOLE 3 (DH3)

Location: N. 1,585,902, E. 770,028
Ground Surface: 3781.0
Depth: 569.5-ft.
Bottom of Hole: Bernal Formation (Permian)
Screen in Tecovas Formation (Triassic)
Water Level: 3697.3 (3-30-94)

Water Analyses

Sample Date: 7/19/83
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	235.2
Magnesium	200.0
Sodium	9,335.0
Potassium	37.1
Bicarbonate	784.5
Chloride	15,920.0
Sulfate	2,175.0
Total Dissolved Solids	26,434.0
pH (lab)	7.90
Electrical Conductivity (field) (milliSiemens/cm @ 25°C)	36.0
Temperature (field)	18.0°C

Table 10

INFORMATION SHEET

OBSERVATION WELL 1 (POW1)

Location: N. 1,585,178.6, E. 774,245.7
Ground Surface: 3674.73
Depth: 318.0-ft.
Bottom of Hole: Tecovas Formation (Triassic)
Screen in Tecovas
Water Level: Artesian flow

Water Analyses

Sample Date: 6-3-87
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	696.0
Magnesium	224.0
Sodium	12,500.0
Potassium	231.0
Carbonate	0.0
Bicarbonate	1,050.0
Sulfate	2,180.0
Chloride	19,400.0
Sum (Cations + Anions)	36,300.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	43.2
pH	7.7
Total Dissolved Solids	37,500.0 mg/L

Table 11

INFORMATION SHEET

OBSERVATION WELL 3 (OW3)

Location: N. 1,584,830.4, E. 773,931.6
Ground Surface: 3672.81
Depth: 362.0-ft.
Bottom of Hole: Bernal Formation (Permian)
Well screen in Tecovas (Triassic) and Bernal (Permian)
Water Level: 3673.7 (3-30-94)

Water Analyses

Sample Date: 10-17-83
Sampled By: Hydro Geo Chem, Inc.

Constituents	Milligrams/Liter (mg/L)
Calcium	800.0
Magnesium	220.0
Sodium	17,500.0
Potassium	75.0
Carbonate	0.0
Bicarbonate	159.0
Chloride	27,435.0
Sulfate	2,880.0
Nitrate	<0.4
Total Dissolved Solids	49,072.0 (by summation)
Boron	3.2

Field Parameters	
Temperature	19.0°C
pH	6.36
Alkalinity	836 mg/L
Electrical Conductivity (milliSiemens/cm @ 25°C)*	78.4

* Other electrical conductivity measurements ranged from 50.0 to 69.0 milliSiemens at 25°C.

Table 12

INFORMATION SHEET

OBSERVATION WELL 4 (OW4)

Location: N. 1,585,300±, E. 773,470±
Ground Surface: 3676.5
Depth: 382.0-ft.
Bottom of Hole: Tecovas Formation (Triassic)
Well screen in Tecovas
Water Level: Near ground surface

Water Analyses

Sample Date: 7-19-83
Sampled By: U.S. Bureau of Reclamation

Constituents	Milligrams/Liter (mg/L)
Calcium	624.0
Magnesium	182.4
Sodium	17,940.0
Potassium	51.7
Bicarbonate	1,011.95
Chloride	19,700.0
Sulfate	2,660.0

Table 13

INFORMATION SHEET

CITY WELL 1 (CW1)

Location: N. 1,599,293, E. 770,971
Ground Surface: 3914.1
Depth: 340.0-ft.
Log of Hole: Interpreted from driller's log
0 - 145 (3769.1) Chinle Formation (Triassic)
145 - 340 (3574.1) Trujillo Formation (Triassic)
Bottom of Hole: Trujillo Formation
Screen in Trujillo
Water Level: Unknown
Capacity: 145 gpm

Water Analyses

Sample Date: 2-22-78
Sampled By: City of Logan ?

Constituents	Milligrams/Liter (mg/L)
Chloride	61.0
Nitrate	3.82
Arsenic	<0.005
Barium	<0.10
Cadmium	<0.001
Chromium	0.010
Lead	0.019
Mercury	0.0015
Selenium	0.002
Silver	<0.001

Electrical Conductivity (milliSiemens/cm @ 25°C)	0.75
Electrical Conductivity (July 1994) (milliSiemens/cm @ 25°C)	0.65

Table 14

INFORMATION SHEET

CITY WELL 2 (CW2)

Location: N. 1,590,213, E. 774,708
Ground Surface: 3818.0
Depth: 254.0-ft.
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: 3714.0 (Date unknown); 3720.44 (July 1994)
Capacity: 80 gpm
Drawdown: 55-ft. after 1.5 hrs. pumping
Water Analyses
Sample Date: Unknown
Sampled By: City of Logan ?

Constituents	Milligrams/Liter (mg/L)
Chloride	54.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	0.88
Electrical Conductivity (July 1994) (milliSiemens/cm @ 25°C)	0.85

Table 15

INFORMATION SHEET

CITY WELL 3 (CW3)

Location: N. 1,588,585, E. 761,737
Ground Surface: 3857.6
Depth: 255-ft. ?
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: 3750.6 (Date unknown)
Capacity: 97 gpm
Drawdown: 18-ft. after 30 minutes pumping

Water Analyses

Sample Date: Unknown
Sampled By: City of Logan ?

Constituents	Milligrams/Liter (mg/L)
Chloride	62.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	0.96
Electrical Conductivity (July 1994) (milliSiemens/cm @ 25°C)	0.82

Table 16

INFORMATION SHEET

CITY WELL 4 (CW4)

Location: N. 1,588,083, E. 763,081
Ground Surface: 3834.6
Depth: 205-ft.
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: 3758.6 (Date unknown) which is 24-ft. lower than in 1966;
3760.67 (July 1994)
Capacity: 349 gpm
Drawdown: Unknown

Water Analyses

Sample Date: 5-27-87
Sampled By: City of Logan ?

Constituents	Milligrams/Liter (mg/L)
Calcium	108.0
Magnesium	117.0
Sodium	64.4
Potassium	4.29
Carbonate	0.0
Bicarbonate	378.0
Sulfate	347.2
Nitrate	0.86
Chloride	84.4
Fluoride	<0.31
Arsenic	<0.005
Barium	<0.10
Cadmium	<0.001
Chromium	<0.005
Iron	<0.05
Lead	<0.01
Manganese	<0.05
Mercury	<0.005
Selenium	<0.021
Silver	<0.001

Total Hardness	750.0 mg/L
Alkalinity	309.0 mg/L
Total Dissolved Solids	1026.0 mg/L
pH	7.49
Electrical Conductivity (milliSiemens/cm @ 25°C)	1.42

Table 17

INFORMATION SHEET

CITY WELL 5 (CW5)

Location: N. 1,587,458, E. 754,770
Ground Surface: 3852.5
Depth: 335-ft. (Caved back to 197-ft.)
Log of Hole: Interpreted from driller's log.
0 - 30 (3822.2) Sand and gravel with Caliche
30 - 141 (3711.5) Chinle Formation (Triassic)
141 - 332 (3520.5) Trujillo Formation (Triassic)
332 - 335 (3517.5) Tecovas Formation (Triassic)
Bottom of Hole: Appears to be in Tecovas Formation (Triassic)
casing to 190-ft. which is probably in the Trujillo Formation (Triassic)
Water Level: 3782.5 ? (Also reported at 3722.5)
Capacity: 64 gpm
Drawdown: Unknown

Water Analyses

Sample Date: 2-13-87
Sampled By: City of Logan ?

Constituents	Milligrams/Liter (mg/L)
Calcium	44.0
Magnesium	24.4
Sodium	112.7
Potassium	3.12
Carbonate	0.0
Bicarbonate	264.0
Sulfate	132.0
Chloride	46.9
Nitrate	<0.04
Fluoride	0.43
Arsenic	<0.005
Barium	0.11
Cadmium	0.002
Chromium	<0.005
Iron	0.16
Lead	<0.01
Mercury	<0.0005
Solenium	<0.005
Silver	<0.001

Total Hardness	210.0 mg/L
Alkalinity	216.0 mg/L
Total Dissolved Solids	482.0 mg/L
pH	7.89
Electrical Conductivity (milliSiemens/cm @ 25°C)	0.80

Table 18

INFORMATION SHEET

LOGAN CEMETERY WELL (LCW)

Location: N. 1,593,150±, E. 781,800±
Ground Surface: 3816±
Depth: Unknown
Bottom of Hole: Unknown but probably in Trujillo Formation (Triassic)
Water Level: Unknown

Water Analyses

Sample Date: 9-22-83
Sampled By: Hydro Geo Chem, Inc.

Constituents	Milligrams/Liter (mg/L)
Calcium	210.0
Magnesium	85.0
Sodium	49.0
Potassium	4.9
Carbonate	0.0
Bicarbonate	355.0
Chloride	42.5
Sulfate	600.0
Nitrate	1.3
Total Dissolved Solids	1,375.0
Boron	0.08
Silica	27.0
Hardness as $CaCO_3$	875.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	1.6
pH	7.3

Field Parameters

Temperature	18.0°C
pH	6.96
Alkalinity	300.0 mg/L

Table 20

INFORMATION SHEET

LAND FILL WELL (LF)

Location: N. 1,583,855.59, E. 775,225.80
Top 6-in Casing: 3761.91
Depth: 160-ft±
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: 3668.4 (3-31-94)

Water Analyses

No tests available
Used for groundwater quality monitoring

INFORMATION SHEET

DAM TENDER WELL (DTW)

Location: N. 1,587,477, E. 765,523
Ground Surface: 3822.9
Depth: 199-ft
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: 3739.9 (1992±); 3742.8 (July 1994)

Water Analyses

Used for domestic water supply

Electrical Conductivity (July 1994) (milliSiemens/cm @ 25°C)	1.0

No other water tests available

INFORMATION SHEET

NEW MEXICO INTERSTATE STREAM WELL (NMW)

Location: N. 1,585,127, E. 765,615
Ground Surface: 3795.8
Depth: Unknown
Bottom of Hole: Unknown but likely in Trujillo Formation (Triassic)
Water Level: 3748.96 (July 1994)

Water Analyses

No tests available
Used for potable water supply

INFORMATION SHEET

REVUELTO CREEK WELL (RCW)

Location: N. 1,581,023, E. 783,165
Ground Surface: 3796.9
Depth: 160-ft
Bottom of Hole: Trujillo Formation
Water Level:

Water Analyses

Sample Date: 9-22-83
Sampled By: Hydro Geo Chem, Inc.

Constituents	Milligrams/Liter (mg/L)
Calcium	140.0
Magnesium	190.0
Sodium	205.0
Potassium	7.1
Carbonate	0.0
Bicarbonate	761.0
Chloride	255.0
Sulfate	548.0
Nitrate	< 0.4
Total Dissolved Solids	2,122.0 (By summation)
Boron	0.10
Silica	16.0
Hardness as $CaCO_3$	1,132.0
Electrical Conductivity (milliSiemens/cm @ 25°C)	2.8
pH	7.5

Field Parameters

Temperature	18.0°C
pH	6.93
Alkalinity	580.0 mg/L

Table 24

INFORMATION SHEET

BOB YOUNG WELL (BYW)

Location: Section 24,T.13N.,R.33E. (Not located on drawing 1253-600-23)
Ground Surface: Unknown
Depth: 160-ft
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: Unknown

Water Analyses

Sample Date: 8-20-83 (?)
Sampled By: U.S. Bureau of Reclamation

Sodium	9.0± Milliequivelents/Liter (meq/L)
Magnesium	3.0±
Calcium	6.0±
Chloride	3.0±
Bicarbonate	7.0±
Sulfate	3.0±
Total Dissolved Solids	2073.0 mg/L
pH	8.22

INFORMATION SHEET

COX-WOODS PLACE WELL (WPW)

Location: Section 8, T.13N.,R.34E. (Not located on drawing 1253-600-23)
Ground Surface: Unknown
Depth: 250-ft.
Bottom of Hole: Probably in Trujillo Formation (Triassic)
Water Level: Unknown

Water Analyses

Sample Date: 7-20-84 (?)
Sampled By: U.S. Bureau of Reclamation

Sodium	17.0±	Milliequivelents/Liter (meg/L)
Magnesium	26.0±	
Calcium	1.0±	
Chloride	6.0±	
Bicarbonate	7.0±	
Sulfate	36.0±	
Total Dissolved Solids	3260.0	mg/l
pH	8.72	

Sample from stock tank

Table 26

Geologic Logs
1975 to 1983

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 (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 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 irregualr 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

CS-
4-3/4" Drag Bit

1994 GEOLOGIC INTERPRETATION
0-30' HOLOCENE ALLUVIUM
30-196' TRIASSIC TRUJILLO FM.
196-356' TRIASSIC TECOVAS FM.

NOTE: CONTACTS ADJUSTED BECAUSE OF GAMMA LOG

3.0
10.0
14.0
30.0
56.0
60.0
72.0
76.0

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 (9-60)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 5

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					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
			FROM (P, Cs, or Cm)	TO								
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" 10								10			72' - 76' Sandy Shale, some medium to coarse sand, and silt with high argillaceous content. Fair HCL reaction; fairly well indurated. Mottled gray color. 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.
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/1 NaCl 3,663 " Sulfate 500 " Total Fe 0.10 " Conductance 6,750	20 30								20 30			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.
6. Same as 5, taken 30 minutes later. Chloride 2,100 mg/1 NaCl 3,465 " Sulfate 500 " Total Fe 0.02 " Conductance 6,750	40 50								40 146.0 50			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.
7. Packered hole 131'-156', blew hole, hole dry; hole took water 24 gal/min; again blew hole and sampled. Chloride 3,200 mg/1 NaCl 5,280 " Sulfate 700 " Total Fe 0.13 " Conductance 10,000	60 70								156.0 60 70			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)
8. Same as 7, pumped in water, blew hole, and took sample. Chloride 3,300 mg/1 NaCl 5,445 " Sulfate 200 " Total Fe 0.13 " Conductance 10,100	80								80			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.
	90								90 196.0			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

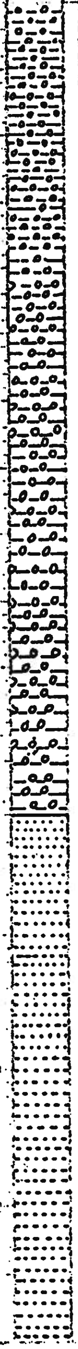
Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside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

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 5

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-1 LOCATION .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
COORDS. N. .... E. ....
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
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	4-3/4" Drag Bit 10 20 30 40 50 60 70 80 90								10 20 30 40 50 60 261 70 80 90			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 = Hawthorne, 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 .... PROJECT .... STATE .... SHEET 3 OF 5 HOLE NO. DH-1

7-1337 (9-69)
Bureau of Reclamation

GPO 854-401

GEOLOGIC LOG OF DRILL HOLE

SHEET 4 OF 5

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

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

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

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

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

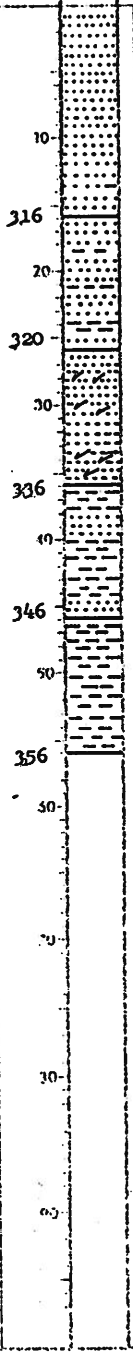
18. At 356' after flowing 30 minutes.
Chloride 15,950 mg/l
NaCl 26,318 "
Sulfate 500 "
Total Fe 0.10 "
Conductance 50,000

19. At 356' after flowing all night.'
Chloride 17,500
NaCl 28,875
Sulfate missing
Total Fe 0.48
Conductance 49,080

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 6/30/75.
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
GPO 854-401

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					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
			FROM (P, Cs, or Cm)	TO								
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 7/1/75. Chloride 3,000 mg/1 NaCl 4,950 " Sulfate 500 " Total Fe 0.10 " Conductance 11,900 Note: Codductance in micromhos /cm @ 25° C	10 20 30 40 50 60 70 80 90								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"

FEATURE .... PROJECT .... STATE .... SHEET 5 OF 5 HOLE NO. DH-1 ....

7-1337 (8-69)
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 GROUND ELEV. 3665' A.M.S.L DIP (ANGLE FROM HORIZ.) 90
COORDS. N 35° 22' 10" E 103° 22' 35"
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	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

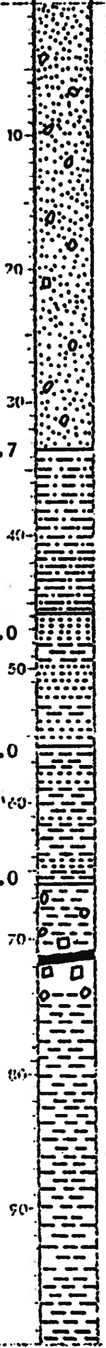
4. River water 7/5/75.
Chloride 5,700 mg/l
NaCl 9,045 "

Type and size of hole:
7-7/8" Rock Bit
4-3/4" Drag Bit CS

1994 GEOLOGIC INTERPRETATION
0-33.7' HOLOCENE ALLUVIUM
33.7-203± TRIASSIC TECOVAS FM.
203±-556 PERMIAN BERNAL FM.

NOTE:
- CONTACTS ADJUSTED BECAUSE OF GAMMA LOG

Depth (feet): 33.7, 46.0, 56.0, 66.0



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' - 106' 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"

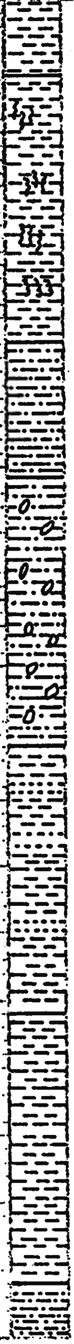
FEATURE Canadian River Below Ute Dam PROJECT Salinity Study STATE SHEET 1 OF 6 HOLE NO. DH-2

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 6

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-2 LOCATION .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
COORDS. N. .... E. .... TOTAL DEPTH .... BEARING ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN ....
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/1 Total Fe 0.06 " Conductance 17,600 5. From 516', artesian encountered at 466', 3gpm. Chloride 4,800 mg/1 NaCl 7,920 " Sulfate 1,015 " Total Fe 0.24 " Conductance 16,300 6. From 534', flowing from casing. Chloride 4,950 mg/1 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/1 NaCl 9,900 " Sulfate 650 " Total Fe 0.10 " Conductance 17,600 Note: Conductance in micromhos /cm @ 25° C.	4-3/4" Drag Bit 10 20 30 40 50 60 70 80 90								106.0 10 70 126.0 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-re 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"

FEATURE .... PROJECT .... STATE .... SHEET 2 OF 6 HOLE NO. DH-2

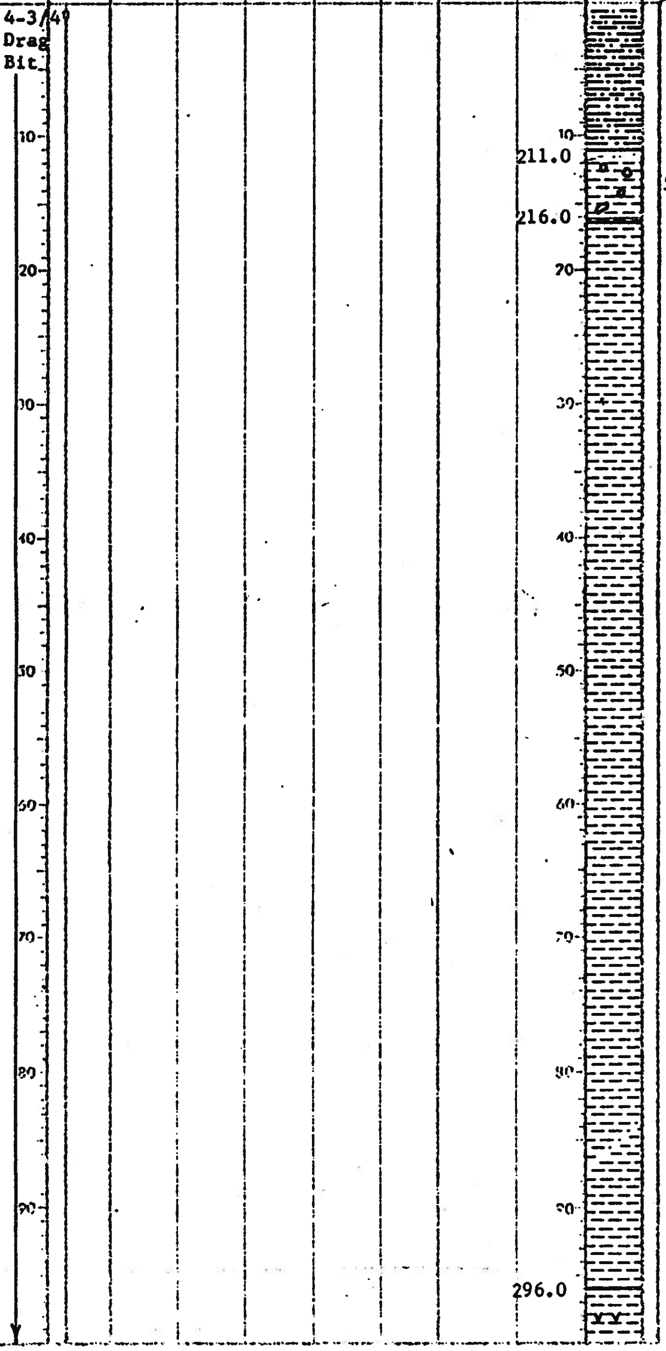
7-1337 (9-69)
Bureau of Reclamation
GPO 854-451

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 6

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



456' - 516' <u>Ferruginous Sandy Shale</u>. 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' <u>Ferruginous Siltstone</u>, fairly sandy, fine to very fine sand. Argillacous 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
- V Mica
- ▬ Coal

EXPLANATION

☐ CORE LOSS
■ CORE RECOVERY

Type of hole .... D = Diamond, H = Heystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cc = 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"

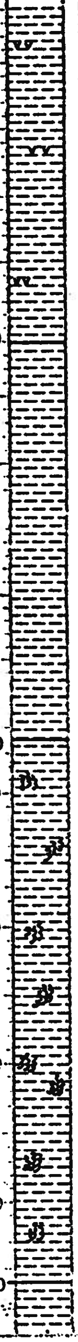
7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET. . 4 . . . OF .6. . . .

FEATURE . . . . PROJECT . . . . STATE . . . .
HOLE NO. . . DH-2. . . LOCATION . . . . GROUND ELEV. . . . . DIP (ANGLE FROM HORIZ.) . . . .
COORDS. N. . . . . E. . . . .
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					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET) FROM (P, Cs, or Cm)	DEPTH (FEET) TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
	$4^3/4$" Drag Bit 10 20 30 40 50 60 70 80 90								10 20 326.0 30 40 50 356.0 60 70 80 90 396.0			



EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Hoystallite, 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 . . . . PROJECT . . . . STATE . . . . SHEET .4. . OF 6. . HOLE NO. DH-2. . . . .

7-1337 (9-69)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

SHEET . . 5 . . . OF . . 6 . . . .

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

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

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

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					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
			FROM (P, Cs, or Cm)	TO								
	4 3/4" Drag Bit											
	10								10			
	20								20			
	30								30			
									436.0			
	40								40			
	50								50			
									456.0			
	60								60			
	70								70			
	80								80			
	90								90			

EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Heystellite, 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 (9-63)
Bureau of Reclamation

GPO 834-421

GEOLOGIC LOG OF DRILL HOLE

SHEET . . 6 . . . . OF . . 6 . .

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

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

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

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					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
			FROM (P, Cs, or Cm)	TO								
	43/4" Drag Bit											
	10								10			
									516.0			
	20								20			
	30								30			
									536.0			
	40								40			
	50								50			
	60								60			
	70								70			
	80								80			
	90								90			

EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Haystallite, 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 HOLE NO DH-3

SHEET 1 OF 6

PROJECT: LAKE MEREDITH SALINITY STUDY FEATURE: DEEP CORE HOLE AREA: LOGAN AREA STATE: NEW MEXICO
COORDS. N. 1585902 E. 770028 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 569.5 BEARING
DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES | PERCENT CORE RECOVERY | DEPTH SCALE (FEET) | CLASSIFICATION INTERVALS: GRAPHIC DEPTHS | ELEVATIONS (FEET) | SAMPLES FOR TESTING | CLASSIFICATION AND PHYSICAL CONDITION

NOTES

DRILLED USING S+H 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
6 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 297.0-350.0 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.

<u>1994 GEOLOGIC INTERPRETATION</u>

0-11' PLEISTOCENE TERRACE
11-118' TRIASSIC CHINLE FM.
118-288 TRIASSIC TRUJILLO FM.
288-508 TRIASSIC TECOVAS FM.
508-569.5 PERMIAN BERNAL FM.

NOTE: CONTACTS ADJUSTED BECAUSE OF GAMMA LOG

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
3697.8
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, EXCEPT 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 MOTLING.

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.

86.0-90.1 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 145.0-148.0 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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 2 OF 6

PROJECT: LAKE MEREDITH SALINITY STUDY FEATURE: DEEP CORE HOLE AREA: LOGAN AREA STATE: NEW MEXICO
COORDS. N. 1585902 E. 770028 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 569.5 BEARING
DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

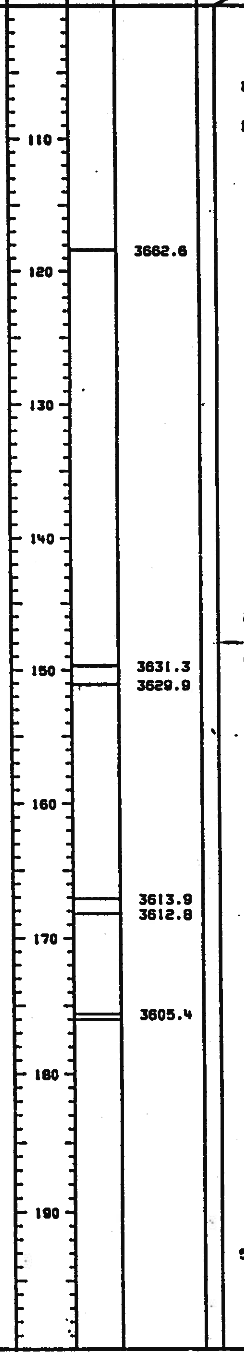
NOTES

PERCENT CORE RECOVERY

DEPTH SCALE (FEET)

CLASSIFICATION INTERVALS: GRAPHIC DEPTHS / ELEVATIONS (FEET)

SAMPLES FOR TESTING



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.

149.7-151.1 FT.: CLAYSTONE.
BLOCKY. BLUISH GRAY.

151.1-298.0 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 MODERIATE REACTION WITH HCL. 75 DEGREES FRACTURE AT 177.3 FT., VERTICAL FRACTURE AT 223.4 FT. VUGS UP TO 1/8 INCH DIAMETER AND 1/2 INCH DEEP IN WELL CONMENTED CONGLOMERATIC SANDSTONE AT 234.1-238.3 FT. AND 246.9-258.7 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.

205.9-206.1 FT.: SHALE.
CLAYEY. GRAY.

223.8-224.9 FT.: SHALE.
CLAYEY. BLACK LAMINATIONNS 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.

350.0-496.7 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 449.3-450.5 FT. VERTICAL FRACTURE AT 360.0 FT. AND 415.0 FT., 70 DEGREES FRACTURE AT 386.0 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.C-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.

496.7-514.0 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 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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 3 OF 6

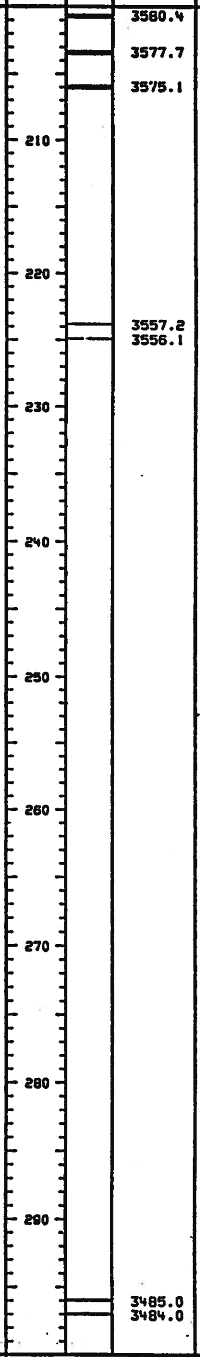
PROJECT LAKE MEREDITH SALINITY STUDY FEATURE DEEP CORE HOLE AREA LOGAN AREA STATE NEW MEXICO

COORDS. N. 1585902 E. 770028 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 569.5 BEARING

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

NOTES	PERCENT CORE RECOVERY		DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS GRAPHIC DEPTHS	CLASSIFICATION INTERVALS ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



518.0-535.5 FT.: SILTSTONE.
SANDY. GREENISH REDUCTION SPOTS. 3-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.

535.5-541.1 FT.: SANDSTONE.
GREENISH REDUCTION SPOTS. FINE-GRAINED. MOSTLY ROUNDED GRAINS. HARD. STRONG REACTION WITH HCL. SALMON-RED.

541.1-544.4 FT.: SHALE.
SANDY. FEW FRAGMENTS LIMESTONE (-3/4"). WELL CONSOLIDATED. GREENISH TO SALMON-RED.

544.4-569.1 FT.: SILTSTONE.
SANDY. GREENISH REDUCTION SPOTS. INTERCALALATED WITH LIGHT RED SHALE AND DARK GREENNISH GRAY SHALE. FEW CACITE-FILLED FRACTURES. MODERATE REACTION WITH HCL. HARD. WELL CONSOLIDATED. ONE HAMMER BLOW FRAGMENTS SMALL PIECE. LIGHT-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 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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 4 OF 6

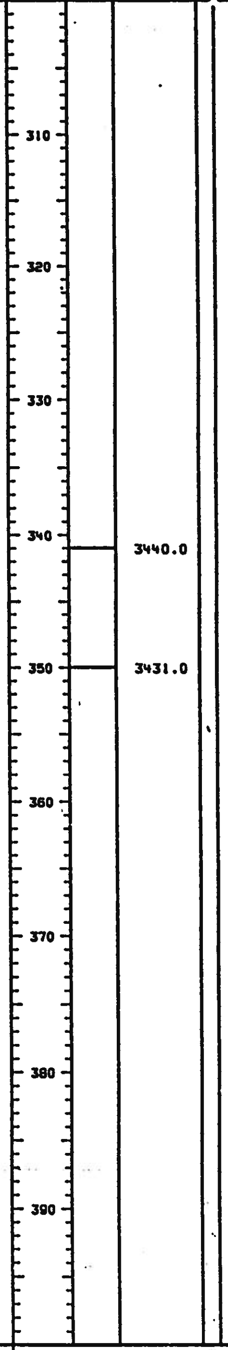
PROJECT LAKE MEREDITH SALINITY STUDY FEATURE DEEP CORE HOLE AREA LOGAN AREA STATE NEW MEXICO

COORDS. N. 1585902 E. 770028 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 569.5 BEARING

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

NOTES	PERCENT CORE RECOVERY		DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS		SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
				GRAPHIC DEPTHS	ELEVATIONS (FEET)		



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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 5 OF 6

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

COORDS. N. 1585902 E. 770028 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 569.5 BEARING

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

NOTES	PERCENT CORE RECOVERY		DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS GRAPHIC DEPTHS	CLASSIFICATION INTERVALS ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
					3378.8		
					3376.6		
			410				
			420				
			430				
					3347.0		
					3345.7		
			440				
			450		3330.5		
			460				
			470				
					3308.1		
					3306.0		
			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 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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

GEOLOGIC LOG OF HOLE NO DH-3

SHEET 6 OF 6

PROJECT LAKE MEREDITH SALINITY STUDY FEATURE DEEP CORE HOLE AREA LOGAN AREA STATE NEW MEXICO
COORDS. N. 1565902 E. 770028 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 569.5 BEARING
DEPTH TO WATER 84.9 FT. 9/9/83 LOGGED BY SHIRLEY SHADIX REVIEWED BY JOE JACKSON

NOTES	PERCENT CORE RECOVERY		DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS		SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
				GRAPHIC DEPTHS	ELEVATIONS (FEET)		
			510				
					3267.0		
					3263.0		
			520				
			530				
					3245.5		
			540				
					3239.9		
					3236.6		
			550				
			560				
					3211.9		
			570				
			580				
			590				

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 361.5 FT. PLACED 3.0 FT. BENTONITE 358.5-361.5 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:

7-1337 (6-74)
Bureau of Reclamation

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 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

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

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-~~[illegible]~~	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'.

1994 GEOLOGIC INTERPRETATION

0-26.5' HOLOCENE ALLUVIUM
26.5-251' TRIASSIC TRUJILLO FM.
251-318' TRIASSIC TECOVAS FM.

NOTE: CONTACTS ADJUSTED BECAUSE OF GAMMA LOG

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

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 cure 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"

* GPO 778-404

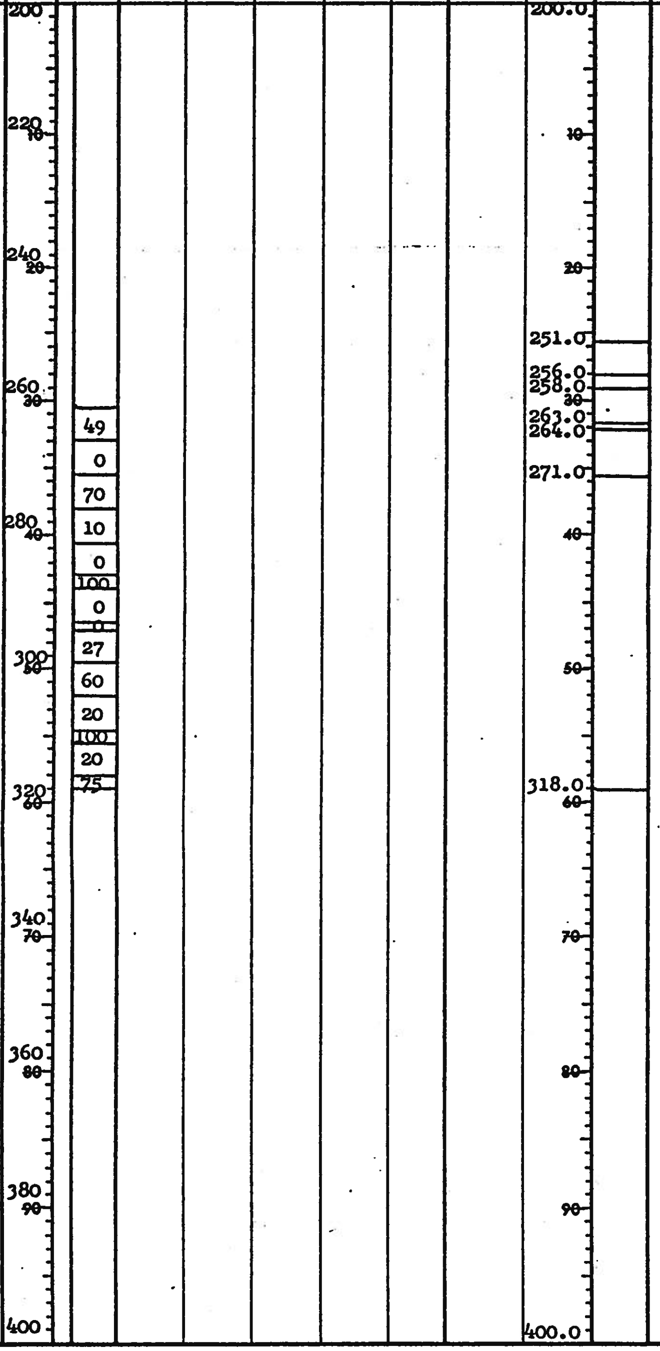
7-1887 (6-74)
Bureau of Reclamation

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 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 I. 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



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"

GPO 778-404

7-1337 (6-74)
Bureau of Reclamation

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 GROUND ELEV. 3,676.88' DIP (ANGLE FROM HORIZ.) 90.0°
COORDS. N. .... E. ....
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	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 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.

1994 GEOLOGIC INTERPRETATION

0-22' HOLOCENE ALLUVIUM
22-232' TRIASSIC TRUJILLO FM.
232-348' TRIASSIC TECOVAS FM.

NOTE:
CONTACTS ADJUSTED
BECAUSE OF GAMMA LOG

CORE RECOVERY (%)
55
18
51
95
0

DEPTH (FEET): 20.0, 91.0, 232.0, 261.0, 333.0, 348.0, 400.0

CLASSIFICATION AND PHYSICAL CONDITION

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.

EXPLANATION

□ CORE LOSS
■ CORE RECOVERY

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.

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 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' o[illegible] 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 scale: 40 ~~10~~, 80 ~~20~~, 120 ~~30~~, 160 ~~40~~, 200 ~~50~~, 240 ~~60~~, 280 ~~70~~, 320 ~~80~~, 360 ~~90~~, 400

1994 GEOLOGIC INTERPRETATION

0-48.1' HOLOCENE ALLUVIUM
48.1-159' TRIASSIC TRUJILLO FM.
159-326' TRIASSIC TECOVAS FM.
326-362 PERMIAN BERNAL FM.

NOTE:
CONTACTS ADJUSTED
BECAUSE OF GAMMA LOG

DEPTH (FEET): ~~10~~, 48.1, 60.0, 72.0, ~~20~~, ~~30~~, 162.0, ~~40~~, 170.0, 191.0, ~~50~~, 212.0, ~~60~~, ~~70~~, 302.0, ~~80~~, 326.0, 350.0, ~~90~~, 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"

* GPO 778-404

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	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

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.

40 80 120 160 200 240 280 320 360 400

10 20 30 40 50 60 70 80 90

1994 GEOLOGIC INTERPRETATION

0-11' HOLOCENE ALLUVIUM
11-204' TRIASSIC TRUJILLO FM.
204-382' TRIASSIC TECOVAS FM.

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.

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-4

Geologic Logs
1993 and 1994

GEOLOGIC LOG OF DRILL HOLE NO. TW-2

SHEET 1 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 12-03-93 **FINISHED:** 01-15-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 18.2 (3670.80) 02-9-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582966 E 776706
TOTAL DEPTH: 348.4
DEPTH TO BEDROCK: 2.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.0
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHIRLEY J. SHADIX
REVIEWED BY:

NOTES

NOTE:
All measurements are from ground surface and in feet unless noted otherwise.

Logging was done by Shirley Shadix from sample bags 0.0 to 208.2 feet and mud logging on site from 208.2 to total depth with exception of core runs. Logs were adjusted by G. Taucher and Gerald Wright based on geophysical interpretations.

PURPOSE OF HOLE:
For use as pump test hole to determine aquifer characteristics.

DRILL:
SIMCO 5000.

DRILLER:
Bureau of Reclamation crew from Loveland, Colorado (Mike Kocian)

DRILLING METHOD:
Drilled with 10.75-inch rockbit to 208.2 ft. Drilled with 8.75 inch rockbit 208.2-348.4 ft., except cored with HWD4 face discharge carbide bit from 208.2-213.2 ft. and from 225.0-230.0 ft.

DRILLING FLUID:
EZ-Mud 0.0-348.4 ft. Mud pump is Gardner-Denver 5 X 8-inch powered by Cat Diesel engine.

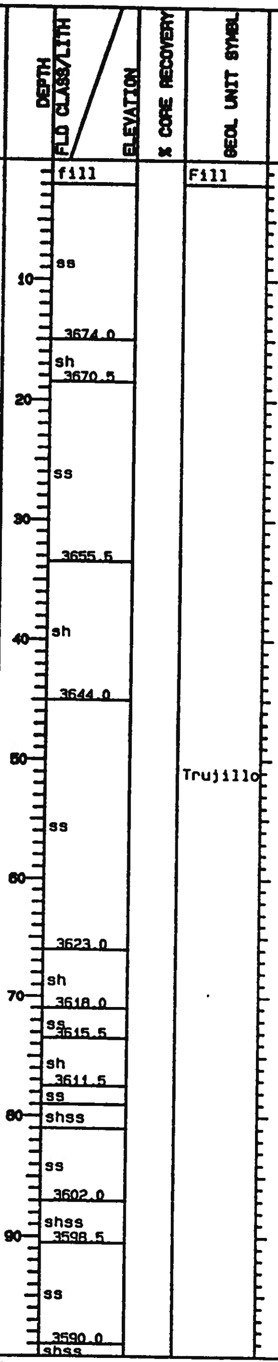
CASING RECORD:
Set 19.5 ft. of 10 inch casing on 12-6-93. Set 163.0 ft 6 5/8-inch OD steel casing 12-20-93.

CAVING RECORD:
(Amount of caved material above bottom depth.)

Bottom of Hole	Amount of Cave
55.0'	1.0'
125.0'	6.4'
338.4'	3.0'

WATER LOSSES:
Geologist noted 100% water loss at 25.0 ft. 12/6/93.

HOLE COMPLETION:
(From Driller's Report)
Placed hole plug 348.4 to 342+ ft. Placed sand from 342'+ to 171.0 ft. Placed bentonite balls as seal from 171.0 to 166.6 ft. Grouted 163.0 ft of 6 5/8-inch OD steel casing in place by pumping into steel casing. Grout moved upward in annulus from 166.6 feet to ground surface. Drilled out cement, bentonite and sand from 163.0 to 298.5 ft. Placed 3 ft long 4-inch steel sump at



CLASSIFICATION AND PHYSICAL CONDITION

0.0-2.0 ft: BACKFILL FOR DRILL PAD

2.0-306.0 ft: TRIASSIC DOCKUM GROUP

2.0-141.0 ft: TRIASSIC TRUJILLO FORMATION
Sandstone, Shaley Sandstone, Sandy Shale and Shale.
Sandstones are fine to coarse grained, gray to tan with few yellowish horizons; conglomeritic in places; contains varying amounts of clay or silt.
Shales are gray to tan with some red; varying amounts of sand.

2.0 - 15.0	Sandstone
15.0 - 18.5	Shale
18.5 - 33.5	Sandstone
33.5 - 45.0	Shale
45.0 - 66.0	Sandstone
66.0 - 71.0	Shale
71.0 - 73.5	Sandstone
73.5 - 77.5	Shale
77.5 - 79.0	Sandstone
79.0 - 81.0	Shaley Sandstone
81.0 - 87.0	Sandstone
87.0 - 90.5	Shaley Sandstone
90.5 - 99.0	Sandstone
99.0 - 105.5	Shaley Sandstone
105.5 - 111.0	Sandstone
111.0 - 114.0	Shaley Sandstone
114.0 - 141.0	Sandstone

141.0 - 306.0 ft: TRIASSIC TECOVAS FORMATION
Sandstone, Shaley Sandstone, Sandy Shale and Shale.
Sandstones are predominantly fine to very fine grained with occasional medium grained zones; scattered silty and clayey layers; white; occasional carbonaceous materials.
Shales are red to gray with varying amounts of fine sand.

141.0 - 150.0	Sandy Shale
150.0 - 152.0	Sandstone
152.0 - 160.5	Sandy Shale
160.5 - 165.5	Sandstone
165.5 - 175.0	Shale
175.0 - 180.5	Sandstone
180.5 - 185.0	Sandy Shale
185.0 - 197.5	Sandstone
197.5 - 200.0	Shale
200.0 - 222.5	Sandstone
222.5 - 225.0	Sandy Shale
225.0 - 266.0	Sandstone
266.0 - 271.0	Sandy Shale
271.0 - 280.0	Sandstone
280.0 - 282.0	Shaley Sandstone
282.0 - 292.0	Sandstone
292.0 - 302.5	Sandy Shale
302.5 - 306.0	Sandstone

306.0 - 348.4 ft: PERMIAN BERNAL FORMATION

306.0 - 308.0 Dolomite. Hard, white

308.0 - 348.4 Siltstone with Sandstone and Shale/Claystone. Siltstones are red, sandy and contain claystone layers. Shales/claystones vary from red, salmon, gray and greenish gray

COMMENTS:

ss = Sandstone
shss = Shaley Sandstone
sysh = Sandy Shale
sh = Shale
clst = Claystone
slst = Siltstone
dol = Dolomite

GEOLOGIC LOG OF DRILL HOLE NO. TW-2

SHEET 2 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 12-03-93 **FINISHED:** 01-15-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 18.2 (3670.80) 02-9-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582966 E 776706
TOTAL DEPTH: 348.4
DEPTH TO BEDROCK: 2.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.0
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHIRLEY J. SHADIX
REVIEWED BY:

NOTES

bottom to 298.5 ft. Placed 120 ft. 4-inch Schedule 80 PVC screen (0.050 inch slots, 17 square inches openings per foot of screen) and 20 ft taped screen at top to 295.5 ft. Steel casing has 1.54 ft. stickup. Neoprene packer set between steel casing and PVC pipe.

CONDUCTIVITIES:
River Water 12/2/93 at 7.5 degrees Centigrade 11.4 millisiemens/cm*
River Water 12/7/93 was 9.11.
City of Logan water supply tested 0.793 millisiemens/cm* 12/7/93.

CONDUCTIVITIES MEASURED FROM RETURN WATER SAMPLES:

Depth (ft)	Millisiemens/cm*
70.0'	1.95
100.0'	3.02
125.0'	3.93
150.0'	4.19
176.0'	4.49
200.0'	5.28
208.2'	10.91
213.2'	10.86
218.2'	9.29
223.2'	11.03
230.0'	11.14
248.4'	8.92
268.4'	9.49
288.4'	20.00+
308.4'	12.73
328.4'	14.95
348.4'	14.94

Note - Millisiemens/cm* readings not accurate as weight of drill mud prevented formation water from entering hole.

CONDUCTIVITY MEASURED BY GEOPHYSICAL TEAM:
(After blowing out hole with air)

Depth (ft)	Millisiemens/cm*
348.4'	68.4**

**68.4 x 640 = 43,776 mg/L (approximate total dissolved solids)

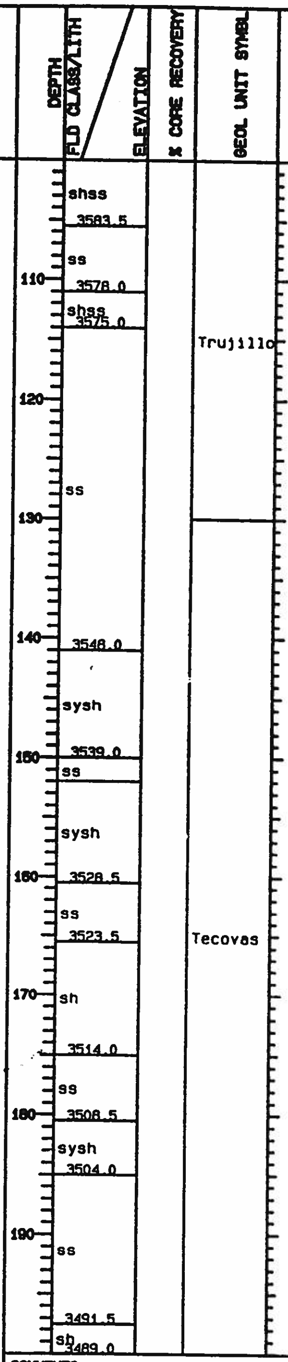
CONDUCTIVITIES OF WATER TAKEN DURING PUMP TEST:

Date	Time	Millisiemens/cm*
3-30-94	12PM	78.5
3-30-94	3PM	101.6
3-30-94	5PM	105.6
3-31-94	10AM	107.7
3-31-94	3PM	105.0
4-1-94	9AM	103.5
4-2-94	1PM	107.9

*Temperature corrected to 25C.

WATER LEVEL ELEVATIONS DURING DRILLING:
(Recorded at the beginning each shift)

Depth of hole	Elevation of water



CLASSIFICATION AND PHYSICAL CONDITION

in color; silty to sandy zones.
308.0 - 311.0 Sandstone
311.0 - 318.0 Sandy Shale
318.0 - 340.0 Siltstone
340.0 - 348.4 Claystone

NOTE:
Above information obtained from logging drill cuttings, geophysical data and limited core samples.

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. TW-2

SHEET 3 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 12-03-93 FINISHED: 01-15-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 18.2 (3670.80) 02-9-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582966 E 776706
TOTAL DEPTH: 348.4
DEPTH TO BEDROCK: 2.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.0
ANGLE FROM HORIZONTAL: 90.0 AZIMUTH:
HOLE LOGGED BY: SHIRLEY J. SHADIX
REVIEWED BY:

NOTES

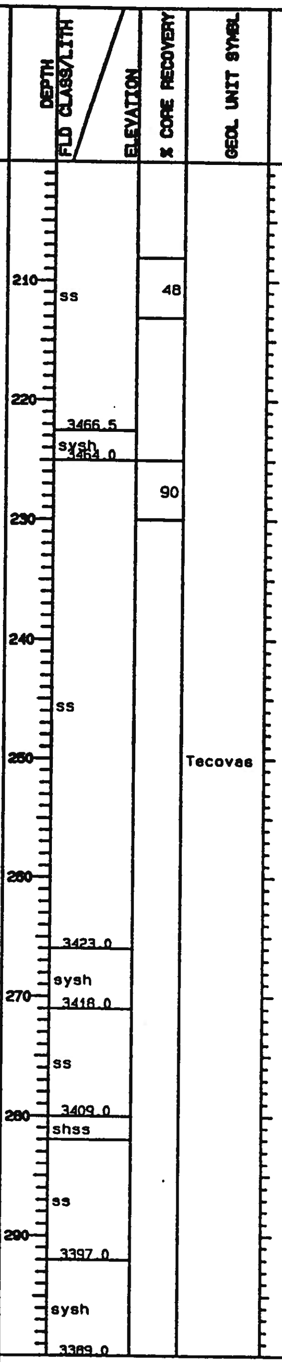
55.0'	3667.0
125.0'	3667.5
208.1'	3673.3
225.1'	3673.2
278.4'	3674.3
338.4'	3677.4
348.4'	3671.7
348.4'	3671.5
348.4'	3671.3

WATER LEVEL ELEVATIONS AFTER COMPLETION:

Date	Elevation
12-20-93	3671.5
12-21-93	3671.3
02-09-94	3670.8
03-11-94	3671.2
03-27-94	3671.5
03-28-94	3671.4

SURVEY DATA:

Elevation	Feature
3689.0	Ground surface
3689.05	Top of Surface Casing
3690.54	Top of 6-inch casing
3691.04	Top 1-inch temporary PVC pipe
3661.1	Flowline of river 90 degrees to well



CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. TW-2

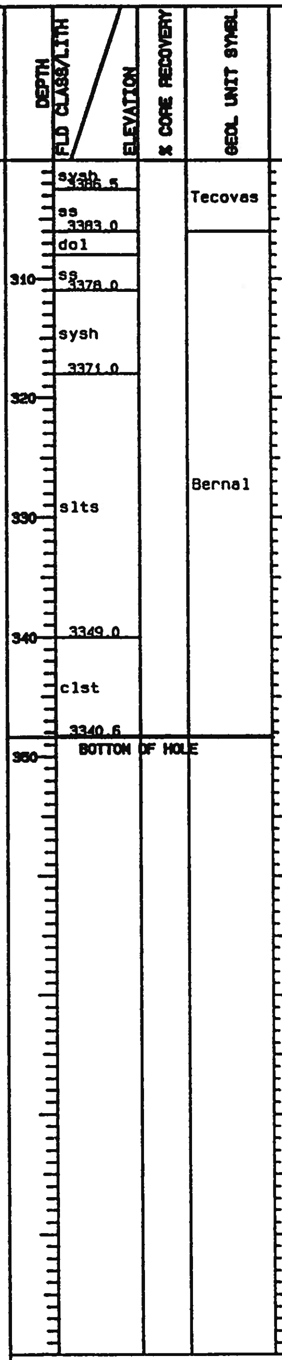
SHEET 4 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 12-03-93 FINISHED: 01-15-94
DEPTH AND ELEV. OF WATER
LEVEL AND DATE MEASURED: 18.2 (3670.80) 02-9-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582966 E 776706
TOTAL DEPTH: 348.4
DEPTH TO BEDROCK: 2.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.0
ANGLE FROM HORIZONTAL: 90.0 AZIMUTH:
HOLE LOGGED BY: SHIRLEY J. SHADIX
REVIEWED BY:

NOTES



CLASSIFICATION AND
PHYSICAL CONDITION

COMMENTS:

SHEET 4 OF 4	DRILL HOLE TW-2

GEOLOGIC LOG OF DRILL HOLE NO. TW-3

SHEET 1 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 01-16-94 **FINISHED:** 03-02-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 22.3 (3667.00) 03-11-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1588153.59 E 780644.09
TOTAL DEPTH: 369.7
DEPTH TO BEDROCK: 0.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.3
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: S.SHADIX, G.TAUCHER, G.WRIGHT
REVIEWED BY:

NOTES

NOTE:
All measurements are from ground surface and in feet unless noted otherwise.

This log was prepared from data gathered in mud and core (240.0-245.0 ft.) logging by Joe Jackson and Shirley Shadix, and interpretation of geophysical logs by Glenn Taucher and Gerald Wright.

PURPOSE OF HOLE:
For use as pump test hole to determine aquifer characteristics.

DRILL:
SIMCO 5000.

DRILLER:
Bureau of Reclamation crew from Loveland, Colorado (Mike Kocian)

DRILLING METHOD:
Drilled with 8.75-inch rockbit 0.0-240.0 ft. Cored with HWD4 face discharge carbide bit 240.0-245.0 ft. Drilled with 5.875-inch rock bit 245.0-369.7 ft.

DRILLING FLUID:
EZ-Mud 0.0-240.0 ft. and bentonite mud 240.0-258.0 ft. Used verafoam and air 258.0-263.0 ft. Used air and formation water only 263.0-369.7 ft. Mud pump is Gardner-Denver 5 X 8" powered by Cat diesel engine.

CASING RECORD:
6 5/8-inch steel casing cemented to 130.0 ft.

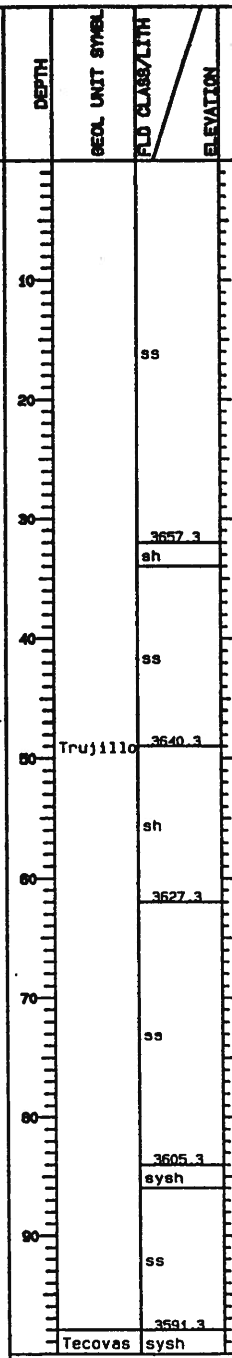
CAVING RECORD:
(Amount of caved material above bottom depth.)

Bottom of Hole Interval	Amount of Cave
220.0'	19.0'
330.0'	10.0'
370.0'	5.0'

WATER LOSSES:

Depth	% Loss
214.0'	30
245.0'	100

HOLE COMPLETION:
(From Driller's Report)
Placed 10 pails of sand in bottom of hole, followed by 3 pails bentonite pellets. Filled hole with sand up to 133.0 feet and added bentonite pellets to 131.7 feet. Grouted 6 5/8th O.D. steel casing to 130.0 ft. by forcing grout through center of casing to ground surface. After grout set for 72+ hours, sand



CLASSIFICATION AND PHYSICAL CONDITION

0.0-312.0 ft: TRIASSIC DOCKUM GROUP

0.0 - 98.0 ft: TRIASSIC TRUJILLO FORMATION:
Sandstone, Shaley Sandstone, Sandy Shale and Shale.
Sandstones are fine to coarse grained; gray to tan with some yellowish brown horizons; conglomeritic in places. Contains varying amounts of clay or silt.

Shales are blue gray and contain varying amounts of sand.

0.0 - 32.0	Sandstone
32.0 - 34.0	Shale
34.0 - 49.0	Sandstone
49.0 - 62.0	Shale
62.0 - 84.0	Sandstone
84.0 - 86.0	Sandy Shale
86.0 - 98.0	Sandstone

98.0 - 312.0 ft: TRIASSIC TECOVAS FORMATION
Sandstone, Shaley Sandstone, Sandy Shale and Shale/Claystone.
Sandstones are predominantly fine to very fine grained with occasional medium grained zones; scattered silty to clayey layers; white to gray and blue gray; micaceous; minus 1/4-inch vugs noted in core samples; fragments of carbon and wood 160 to 170 ft.
Shales/claystones vary from yellow-brown, gray, blue, red to black; and contain varying amounts of fine sand.

98.0 - 100.0	Sandy Shale
100.0 - 103.0	Sandstone
103.0 - 104.0	Sandy Shale
104.0 - 105.0	Sandstone
105.0 - 110.0	Shale
110.0 - 112.0	Sandstone
112.0 - 120.0	Shale
120.0 - 123.5	Sandstone
123.5 - 126.0	Shale
126.0 - 172.0	Sandstone
172.0 - 174.5	Shaley Sandstone
174.5 - 182.0	Sandstone
182.0 - 183.0	Shaley Sandstone
183.0 - 195.0	Sandstone
195.0 - 201.0	Shale
201.0 - 206.0	Sandstone
206.0 - 206.5	Sandy Shale
206.5 - 227.0	Sandstone
227.0 - 231.0	Shaley Sandstone
231.0 - 261.5	Sandstone
261.5 - 267.5	Shale
267.5 - 271.0	Sandstone
271.0 - 274.0	Sandy Shale
274.0 - 299.5	Sandstone
299.5 - 304.0	Sandy Shale
304.5 - 307.5	Sandstone
307.5 - 312.0	Shale

312.0 - 369.7 ft: PERMIAN BERNAL FORMATION

312.0 - 314.0 Dolomite. Hard, white

314.0 - 369.7 Sandstone, Sandy Shale and Siltstone.
Sandstones are fine to coarse grained, silty and contain grains

COMMENTS:

ss = Sandstone
shss = Shaley Sandstone
sysh = Sandy Shale
sh = Shale
clst = Claystone
slst = Siltstone
dol = Dolomite

GEOLOGIC LOG OF DRILL HOLE NO. TW-3

SHEET 2 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 01-18-94 **FINISHED:** 03-02-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 22.3 (3667.00) 03-11-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1888153.89 E 780644.09
TOTAL DEPTH: 369.7
DEPTH TO BEDROCK: 0.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.3
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: S.SHADIX, G.TAUCHER, G.WRIGHT
REVIEWED BY:

NOTES

was washed out of hole to a depth of 286.2 ft. Set 4-in diameter steel sump 284.2 to 286.2. 4-in diameter PVC sch. 80 blank 274.2 to 284.2. 4-in diameter sch. 80 screen (0.50 slot. 17 square inches of openings per foot of screen) 274.2 to 135.4 and 4-in PVC blank (sch. 80) 135.4 to 125.4 feet. Neophrene packer set between steel casing and PVC pipe.

CONDUCTIVITIES MEASURED FROM RETURN WATER SAMPLES:

Depth (ft)	Millisiemens/cm*
245.0'	21.0
249.7'	21.5
369.7'	24.8

CONDUCTIVITIES MEASURED BY GEOPHYSICAL TEAM:
(After jetting)

Depth (ft)	Temp (deg F)	Millisiemens/cm*
150.0	60.0	21.0
190.0	60.5	20.5
250.0	61.5	20.8
295.0	63.0	23.7
337.0	64.0	33.3**

**33.3 x 640 = 21,120 mg/L (approximate total dissolved solids in mg/L)

WATER LEVEL ELEVATIONS DURING DRILLING:
(Recorded at the beginning each shift)

Depth of hole	Elevation of water
20.0'	3687.8'
120.0'	3682.8'
220.0'	3664.2'
240.0'	3669.3'
258.0'	3665.2'
330.0'	3665.2'
369.7'	3655.3'

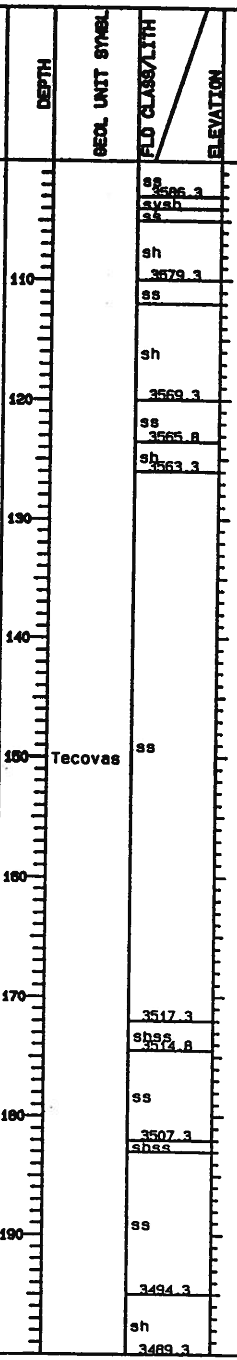
WATER LEVEL ELEVATIONS AFTER COMPLETION:

Date	Elevation
03-11-94	3667.0

SURVEY DATA:

Elevation	Feature
3689.3	Ground surface
3690.66	Top of 6-inch casing
3690.90	Top 2-inch temporary PVC pipe
3655.3	Flowline of river 90 degrees to well

*Temperature corrected to 25C



CLASSIFICATION AND PHYSICAL CONDITION

of various colors, grayish-red. Sandy Shales are sandy and red to gray. Siltstones are salmon to red.

314.0 - 315.5 Sandstone
315.5 - 322.5 Sandy Shale
322.6 - 324.0 Sandstone
324.0 - 330.0 Sandy Shale
330.0 - 332.0 Sandstone
332.0 - 336.5 Sandy Shale
336.5 - 339.0 Sandstone
339.0 - 369.7 Siltstone

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. TW-3

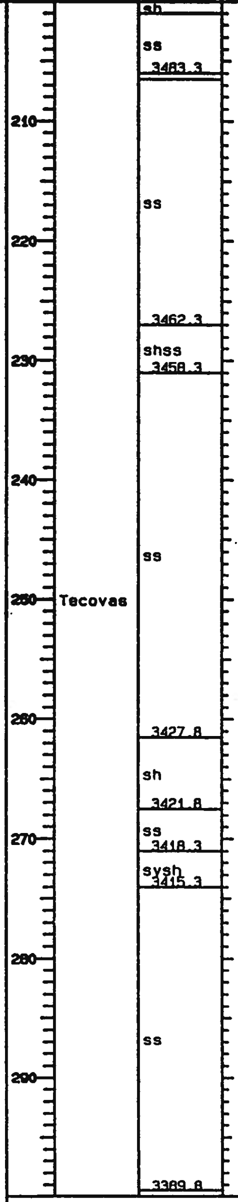
SHEET 3 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 01-18-94 FINISHED: 03-02-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 22.3 (3667.00) 03-11-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1588158.50 E 780644.08
TOTAL DEPTH: 369.7
DEPTH TO BEDROCK: 0.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.3
ANGLE FROM HORIZONTAL: 90.0 AZIMUTH:
HOLE LOGGED BY: S.SHADIX, G.TAUCHER, G.WRIGHT
REVIEWED BY:

NOTES	DEPTH	GEOL UNIT SYMBL	FLD CLASS/LITH / ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION



COMMENTS:

SHEET 3 OF 4 | DRILL HOLE TW-3

GEOLOGIC LOG OF DRILL HOLE NO. TW-3

SHEET 4 OF 4

FEATURE: TEST WELL
LOCATION: SOUTH BANK CANADIAN RIVER
BEGUN: 01-16-94 FINISHED: 03-02-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 22.3 (3667.00) 03-11-94

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1586153.80 E 780644.09
TOTAL DEPTH: 369.7
DEPTH TO BEDROCK: 0.0

STATE: NEW MEXICO
GROUND ELEVATION: 3689.3
ANGLE FROM HORIZONTAL: 90.0 AZIMUTH:
HOLE LOGGED BY: S.SHADIX, G.TAUCHER, G.WRIGHT
REVIEWED BY:

NOTES	DEPTH	GEOL UNIT SYMBL	FLD CLASS/LITH	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
		Tecovas	sysh	3385.3	
			ss	3381.8	
	310		sh	3377.3	
		Bernal	dol		
			ss		
	320		sysh	3366.8	
			ss		
			sysh	3359.3	
	330		ss		
			sysh	3352.8	
			ss	3350.3	
	340 350 360		slts	3319.6	
	370	BOTTOM OF HOLE			

COMMENTS:

SHEET 4 OF 4 DRILL HOLE TW-3

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

SHEET 1 OF 6

FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

NOTE:
All measurements are from ground surface and in feet unless noted otherwise. This log was prepared using mud logging data (J. Jackson and S. Shadix) and geophysical log interpretations (Gerald Wright and G. Taucher).

DEPTH & ELEVATION OF WATER LEVELS & DATA MEASURED:
OW5A-152.73' (3665.13) 3-28-94
OW5B-160.0' (3659.55) 3-20-94

COORDINATES:
OW5A - N. 1,584,263.34;
E. 780,641.34
OW5B - 21.0' S.25E. of OW5A
N. 1,584,254.82; E. 780,660.35

TOTAL DEPTH:
OW5A - 510.0 ft.
OW5B - 172.6 ft.

GROUND ELEVATION:
OW5A - 3816.40
OW5B - 3817.20

ELEVATION TOP 4-IN. PIPE:
OW5A - 3817.72
OW5B - 3819.70

PURPOSE OF HOLE:
Observation holes for groundwater measurements.

DRILL:
SIMCO 5000.

DRILLER:
Bureau of Reclamation crews from Loveland, Colorado (Mike Kocian) and Billings, Montana (James McLaughlin)

DRILLING METHOD:

OW 5A:
10-inch rockbit 0 to 3.0 ft.;
5 7/8-inch rockbit 3.0 to 510.0 ft.

OW 5B:
5 7/8-inch rockbit 0 to 172.6 ft.

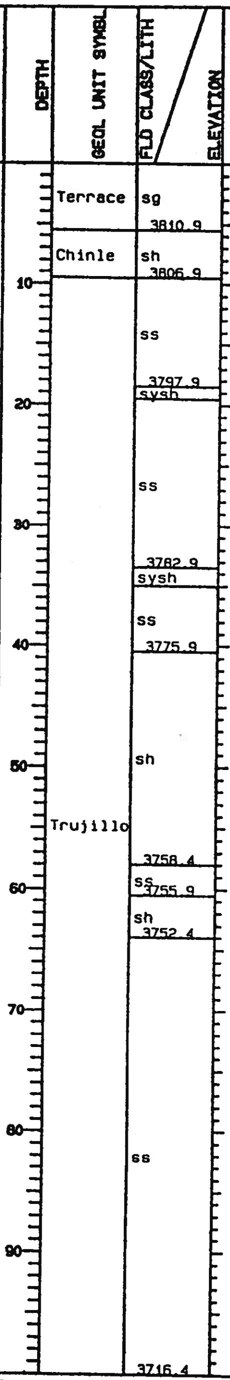
DRILLING FLUID:
Used air to blow out cuttings in both holes.

CASING RECORD:
Set 10-inch casing 0 to 3.0 ft. in OW 5A (casing pulled).
No casing set in OW 5B.

ESTIMATED WATER FLOWS IN HOLES:

OW5A:
10 - 25 gpm 213.0 to 290.0'
75 - 100 gpm 310.0 to 320.0'
150 - 160 gpm at 380'
175 gpm at 430'

OW5B:
No estimate made.



CLASSIFICATION AND PHYSICAL CONDITION

0.0-5.5 PLEISTOCENE TERRACE:
Sand and Gravel with some silt.

5.5-462.0 TRIASSIC DOCKUM GROUP:

5.5-9.5 TRIASSIC CHINLE FORMATION:
Shale, red, contains some fine sand.

9.5-241.5 ft: TRIASSIC TRUJILLO FORMATION:
Sandstone, Shaley Sandstone, Sandy Shale and Shale. Sandstones are fine to coarse grained; gray to tan with reddish-brown horizons; conglomeritic in places; contains varying amounts of clay and silt.
Shales are gray, blue-gray and red and contain varying amounts of sand.

9.5 - 18.5	Sandstone
18.5 - 19.5	Sandy Shale
19.5 - 33.5	Sandstone
33.5 - 35.0	Sandy Shale
35.0 - 40.5	Sandstone
40.5 - 58.0	Shale
58.0 - 60.0	Sandstone
60.0 - 64.0	Shale
64.0 - 105.0	Sandstone
105.0 - 112.0	Shale
112.0 - 113.5	Sandstone
113.5 - 119.0	Shale
119.0 - 121.0	Sandstone
121.0 - 147.5	Shaley Sandstone
147.5 - 152.5	Sandstone
152.5 - 155.0	Shale
155.0 - 166.5	Sandstone
166.5 - 168.0	Sandy Shale
168.0 - 172.0	Sandstone
172.0 - 177.0	Shale
177.0 - 179.0	Sandstone
179.0 - 184.5	Shale
184.5 - 190.0	Sandstone
190.0 - 196.5	Shale
196.5 - 205.0	Sandstone
205.0 - 207.0	Sandy Shale
207.0 - 210.0	Shaley Sandstone
210.0 - 224.5	Sandstone
224.5 - 228.5	Shale
228.5 - 237.0	Sandstone
237.0 - 237.5	Sandy Shale
237.5 - 241.5	Sandstone

241.5 - 462.0 ft: TRIASSIC TECOVAS FORMATION
Sandstone, Shaley Sandstone, Sandy Shale and Shale. Sandstones are predominantly fine to very fine grained with occasional medium grained zones; scattered silty and clayey layers; white to light gray and brown; micaceous. Shales vary from green to gray and black; contains varying amounts of fine sand.

241.5 - 246.5	Shale
246.5 - 260.0	Sandstone
260.0 - 263.5	Shale
263.5 - 272.0	Sandstone

COMMENTS:

ss = Sandstone
shss = Shaley Sandstone
sysh = Sandy Shale
sh = Shale
slst = Siltstone
dol = Dolomite
sg = Sand and Gravel

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

HOLE COMPLETION:

OW 5A:
Set hole plug 470.0 to 510.0 ft. Installed 2-inch dia. PVC from point 1.32 ft. above ground surface to 470 ft. (screen 200.0 to 300.0, 320.0 to 400.0 and 420.0 to 440.0 ft.; Blank 1.32 above G.S. to 200.0, 300.0 to 320.0, 400.0 to 420.0 and 440.0 to 470.0 ft.; PVC plug on bottom of pipes). Sand packed (bagged sand) hole 470.0 to 198.0 ft. Hole plug 198.0 to 194.0. Tremied in 0.8 to 1 (water-cement) grout from 194.0 to ground surface. Hole accepted 8 cu. yd. of grout. Set 10-ft. of 4-inch steel protective pipe at surface with locking cap.

OW 5B:
Set 2-inch dia. PVC pipe from point 2.25 ft. above ground surface to 172.0 ft. (screen 152.0 to 172.0 ft.; blank 2.25 ft. from point above ground surface to 152.0 ft. PVC plug at bottom of pipe). Sand packed (bagged sand) hole 172.6 to 148.5 ft. Hole plug 148.5 to 143.0 ft. Tremied in 0.8 to 1 (water-cement) grout from 143.0 to ground surface. Set 10-ft. of 4-inch steel protective pipe at surface with locking cap.

CONDUCTIVITIES MEASURED FROM OW5A DRILL WATER SAMPLES:

Hole Depth	Millisiemens/cm*
213'	Greater than 20
290'	42.7
330'	64.8
510'	92.2**

CONDUCTIVITIES MEASURED IN WATER SAMPLES:

(Collected in OW5A)
(After hole drilled)

Hole Depth	Millisiemens/cm*
160'	88.2
300'	77.4

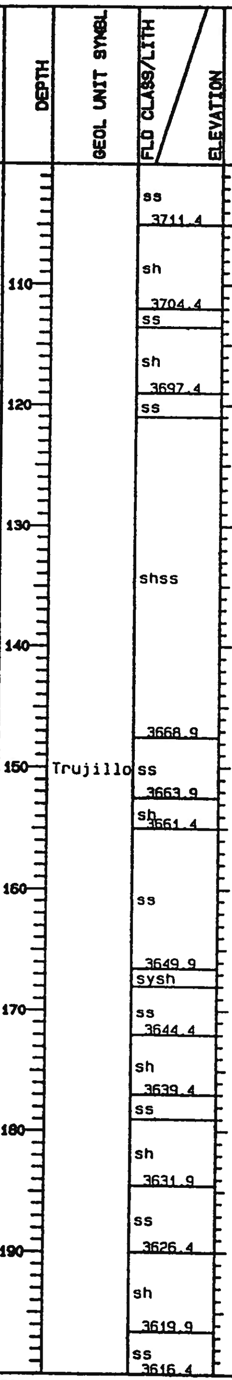
CONDUCTIVITIES OF WATER COLLECTED IN BAILER 4/26/94:

Hole	Millisiemens/cm*
OW 5A	98.00
OW 5B	7.64

**92.2 x 640 = 59,008 mg/L (approximate total dissolved solids)

*Temperature corrected to 25C.

WATER LEVEL ELEVATIONS DURING DRILLING:



CLASSIFICATION AND PHYSICAL CONDITION

272.0 - 274.0 Sandy Shale
274.0 - 275.0 Sandstone
275.0 - 277.0 Sandy Shale
277.0 - 278.5 Sandstone
278.5 - 281.0 Shaley Sandstone
281.0 - 282.0 Sandstone
282.0 - 285.0 Sandy Shale
285.0 - 287.0 Sandstone
287.0 - 288.5 Sandy Shale
288.5 - 290.0 Sandstone
290.0 - 292.5 Shale
292.5 - 303.0 Sandstone
303.0 - 305.5 Shale
305.5 - 343.0 Sandstone
343.0 - 344.0 Sandy Shale
344.0 - 351.5 Sandstone
351.5 - 358.0 Shale
358.0 - 403.0 Sandstone
403.0 - 412.0 Shale
412.0 - 441.5 Sandstone
441.5 - 444.5 Sandy Shale
444.5 - 449.5 Sandstone
449.5 - 457.0 Sandy Shale
457.0 - 458.5 Sandstone
458.5 - 462.0 Sandy Shale

462.0 - 510.0 ft: PERMIAN BERNAL FORMATION
462.0 - 477.0 Siltstone - Salmon to red
477.0 - 479.0 Dolomite - White, hard
479.0 - 510.0 Siltstone - Salmon to red

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

(Recorded at the beginning each shift)

OW 5A:

Hole Depth	Elevation of Water
70.0'	dry at 3746.3
290.0' (noon)	3663.90
410.0'	3664.40
510.0'	3663.90

OW 5B:
Hole completed in one day. No water levels obtained.

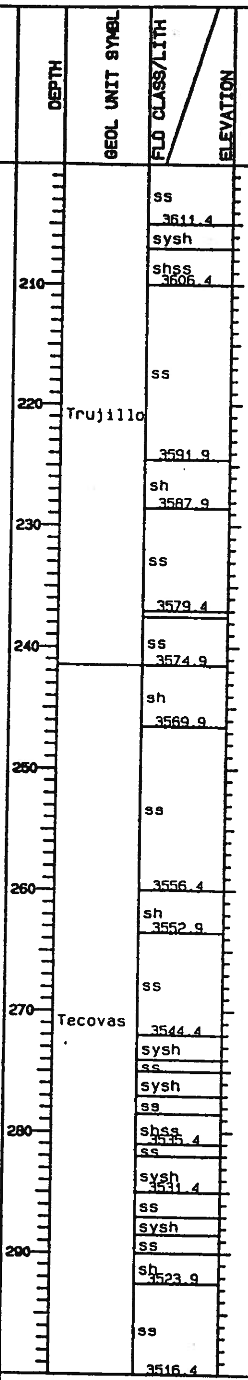
WATER LEVEL ELEVATIONS AFTER COMPLETION:

OW 5A:

Date	Elevation
03-27-94	3663.81
03-28-94	3663.67

OW 5B:

Date	Elevation
03-27-94	3654.99
03-28-94	3656.09



CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

SHEET 4 OF 6

FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

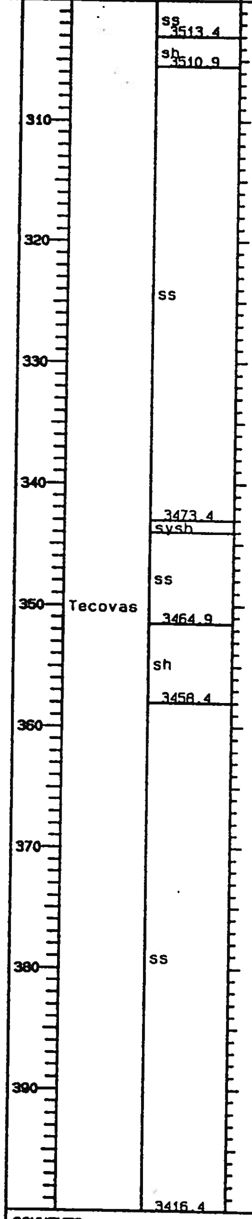
DEPTH

GEOL UNIT SYMBL

FLD CLASS/LITH

ELEVATION

CLASSIFICATION AND PHYSICAL CONDITION



COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

SHEET 5 OF 6

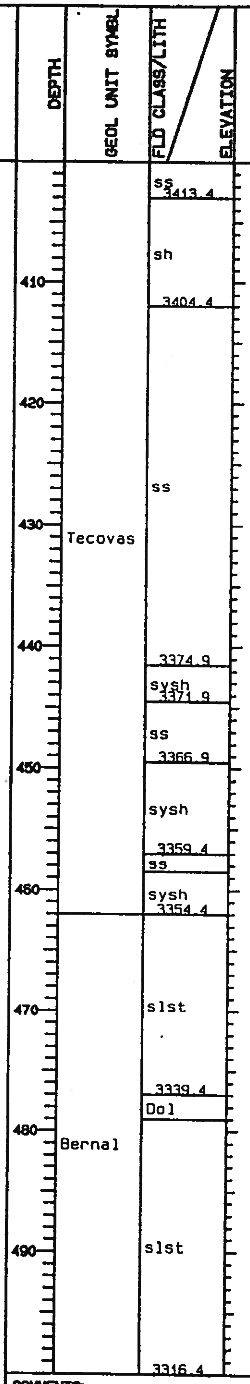
FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

CLASSIFICATION AND PHYSICAL CONDITION



COMMENTS:

SHEET 5 OF 6 DRILL HOLE OW-5A & 5

GEOLOGIC LOG OF DRILL HOLE NO. OW-5A & 5B

SHEET 6 OF 6

FEATURE: OBSERVATION WELLS
LOCATION: TOP SOUTH WALL CANADIAN RIVER
BEGUN: 03-12-94 **FINISHED:** 03-25-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 510.0
DEPTH TO BEDROCK: 5.5

STATE: NEW MEXICO
GROUND ELEVATION: 3816.40
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: SHADIX, JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES	DEPTH	GEOL UNIT SYMBL	FLD CLASS/LITH	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
		Bernal	slst		
	510			3306.4	
		BOTTOM OF HOLE			
	520				

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW-6A & 6B

SHEET 1 OF 3

FEATURE: OBSERVATION WELLS
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 03-24-94 **FINISHED:** 03-28-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 230.6
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.2
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

NOTE:
All measurements are from ground surface and in feet unless noted otherwise. This log was prepared using mud logging data (J. Jackson & S. Shadix) and geophysical log interpretations (Gerald Wright & G. Taucher).

DEPTH & ELEVATION OF WATER LEVEL & DATE MEASURED:

OW6A-90.99 (3683.81) 3-28-94
OW6B-91.56 (3683.64) 3-28-94

COORDINATES:

OW6A - N. 1,582,328.61
E. 772,291.07
OW6B - 15.6' S. 8W.' of OW6A
N. 1,582,312.84 E. 772,289.73

TOTAL DEPTH:

OW6A - 230.6
OW6B - 125.0

GROUND ELEVATION:

OW6A - 3773.2
OW6B - 3773.8

ELEVATION TOP 4-IN. PIPE:

OW6A - 3775.11
OW6B - 3775.86

PURPOSE OF HOLES:
Observation holes for groundwater measurements.

DRILL:
SIMCO 5000.

DRILLER:
Bureau of Reclamation crews from Loveland, Colorado (Mike Kocian) and Billings, Montana (James McLaughlin).

DRILLING METHOD:

OW 6A:

6 7/8-inch rockbit 0 to 230.6 ft.

OW 6B:
6 7/8-inch rockbit 0 to 125.0 ft.

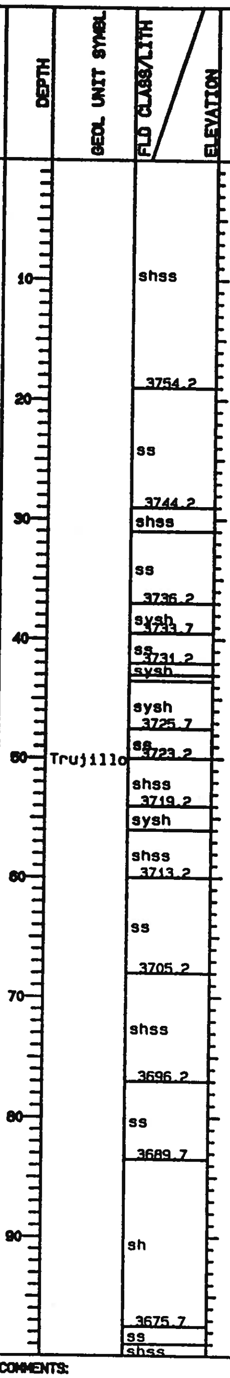
DRILLING FLUID:
Used air to blow out cuttings in both holes.

CASING RECORD:
No casing used in either hole.

ESTIMATED WATER FLOWS IN HOLE:

Encountered water flows (no estimated volume) in soft zone (or void) 110.6 to 114.7 ft. in OW 6A.

No large flows reported in OW



CLASSIFICATION AND PHYSICAL CONDITION

0.0-190.0 ft: TRIASSIC DOCKUM GROUP

0.0-230.6 ft: TRIASSIC TRUJILLO FORMATION
Sandstone, Shaley Sandstone, Sandy Shale and Shale. Sandstones are fine to coarse grained, gray to tan with reddish-brown horizons; conglomeritic in places; contains varying amounts of clay or silt.
Shales are gray to blue-gray and red and contain varying amounts of sand.

0.0 - 19.0 Shaley Sandstone
19.0 - 29.0 Sandstone
29.0 - 31.0 Shaley Sandstone
31.0 - 37.0 Sandstone
37.0 - 39.5 Sandy Shale
39.5 - 42.0 Sandstone
42.0 - 43.0 Sandy Shale
43.0 - 43.5 Sandstone
43.5 - 47.5 Sandy Shale
47.5 - 50.0 Sandstone
50.0 - 54.0 Shaley Sandstone
54.0 - 56.0 Sandy Shale
56.0 - 60.0 Shaley Sandstone
60.0 - 68.0 Sandstone
68.0 - 77.0 Shaley Sandstone
77.0 - 83.5 Sandstone
83.5 - 97.5 Shale
97.5 - 99.0 Sandstone
99.0 - 101.0 Shaley Sandstone
101.0 - 102.0 Sandstone
102.0 - 108.5 Sandy Shale
108.5 - 114.5 Sandstone
114.5 - 117.0 Sandy Shale
117.0 - 123.5 Sandstone
123.5 - 126.0 Sandy Shale
126.0 - 132.5 Sandstone
132.5 - 136.0 Shale
136.0 - 140.5 Sandstone
140.5 - 149.5 Shale
149.5 - 230.6 Sandstone

COMMENTS:

ss = Sandstone
shss = Shaley Sandstone
sysh = Sandy Shale
sh = Shale
slst = Siltstone

GEOLOGIC LOG OF DRILL HOLE NO. OW-6A & 6B

SHEET 2 OF 3

FEATURE: OBSERVATION WELLS
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 03-24-94 **FINISHED:** 03-28-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 230.6
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.2
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

6B.

HOLE COMPLETION:

OW 6A:
Set hole plug 230.6 to 193.5 ft. Installed 2-inch dia. PVC from point 1.50 ft. above ground surface to 193.0 ft. (screen 143.0 to 193.0 ft. blank from point 1.50 ft. above ground surface to 143.0 ft. PVC cap on bottom of pipe). Sand packed (bagged sand) hole 193.5 to 141.0. Hole plug 141.0 to 136.5, 133.5 to 128.5 and 126.5 to 111.0 ft. Sand pack 136.5 to 133.5, and 128.5 to 126.5 ft. Tremied in 0.8 to 1 (water-cement) grout from 111.0 to ground surface. Set 10 ft. of 4-inch steel protective pipe at surface with locking cap.

OW 6B:

Installed 2-inch dia. PVC from point 1.19 ft. above ground surface to 123.0 ft. (screen 83.0 to 123.0 ft; blank from point 1.19 ft. above ground surface to 83.0 ft; PVC cap on bottom of pipe). Sand packed (bagged sand) hole 125.0 to 81.0 ft. Hole plug 81.0 ft. to 61.0 ft. Tremied in 0.8 to 1 (water-cement) grout from 61.0 ft. to ground surface. Set 10 ft. of 4-inch steel protective pipe at surface with locking cap.

CONDUCTIVITIES MEASURED IN WATER SAMPLES COLLECTED:

OW6A:

Hole Depth	Millisiemens/cm*
100.0	53.7
160.0	72.8
190.0	74.8
215.0	77.4

CONDUCTIVITIES OF WATER COLLECTED IN BAILER:
(04/26/94)

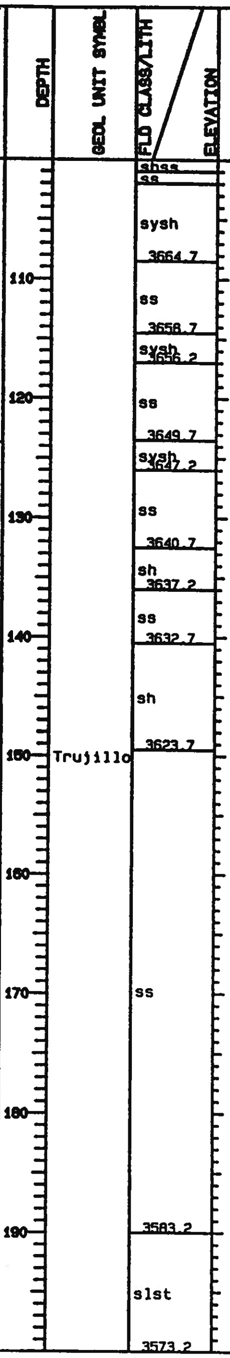
Hole	Millisiemens/cm*
OW 6A	74.24**
OW 6B	1.29

**74.24 x 640 = 47,514 mg/L (approximate total dissolved solids)

(Driller reported encountering salty water at 130.6 ft. and indicated that salt content was increasing in hole with depth.)

*Temperature corrected to 25C.

WATER LEVEL ELEVATIONS DURING DRILLING:



CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW-6A & 6B

SHEET 3 OF 3

FEATURE: OBSERVATION WELLS
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 03-24-94 **FINISHED:** 03-28-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N E See Notes
TOTAL DEPTH: 230.6
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.2
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: JACKSON, TAUCHER, WRIGHT
REVIEWED BY:

NOTES

(Recorded at the beginning of each shift)

OW 6A:

Hole Depth	Elevation of water
230.6'	3682.7

OW 6B:

Hole Depth	Elevation of water
125.0'	3681.71

WATER LEVEL ELEVATIONS AFTER COMPLETION:

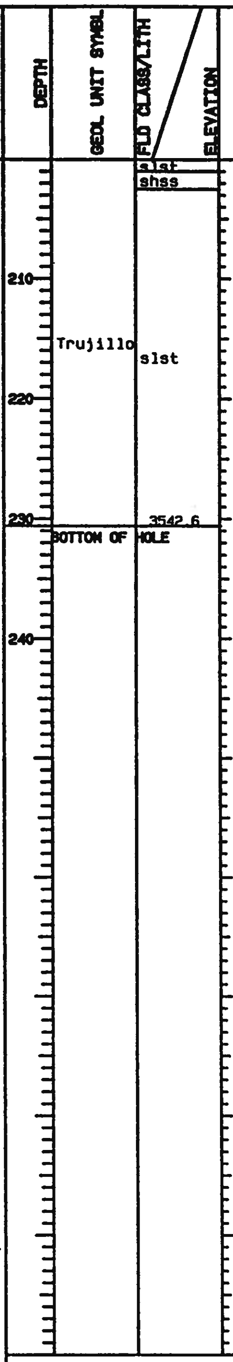
OW 6A:

Date	Elevation of water
03-27-94	3682.29
03-28-94	3682.21
06-17-94	3683.2
06-19-94	3683.6

OW 6B:

Date	Elevation of water
03-28-94	3681.64
06-17-94	3684.4
06-19-94	3682.5

06-17 and 06-19 water levels probably effected by drilling at OW6C.



CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW6C

SHEET 1 OF 5

FEATURE: OBSERVATION WELL
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 06-14-94 **FINISHED:** 06-19-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582317.67 E 772300.26
TOTAL DEPTH: 440.0
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.1
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: GLENN TAUCHER
REVIEWED BY:

NOTES

NOTE:
All measurements are from ground surface and in feet unless noted otherwise. This log was prepared using data obtained from drill cuttings and geophysical logs.

DEPTH & ELEVATION OF WATER LEVEL & DATE MEASURED:

89.3 (3683.8) 06/17/94
87.1 (3686.0) 06/19/94

06/17 and 06/19/94 water levels may not have stabilized after drilling (hole at 440 ft.)

LOCATION:
OW6C - 13.4' S 40 E of OW6A

TOTAL DEPTH:
440.0'

GROUND ELEVATION:
3772.9

ELEVATION TOP 4-IN. PIPE:
3775.89

ELEVATION TOP 2-IN. PVC:
3775.81

PURPOSE OF HOLE:
To gather information on geology and to monitor groundwater.

DRILL:
SIMCO 5000.

DRILLER:
Rick Allison (Drill Foreman - Loveland, Colorado)

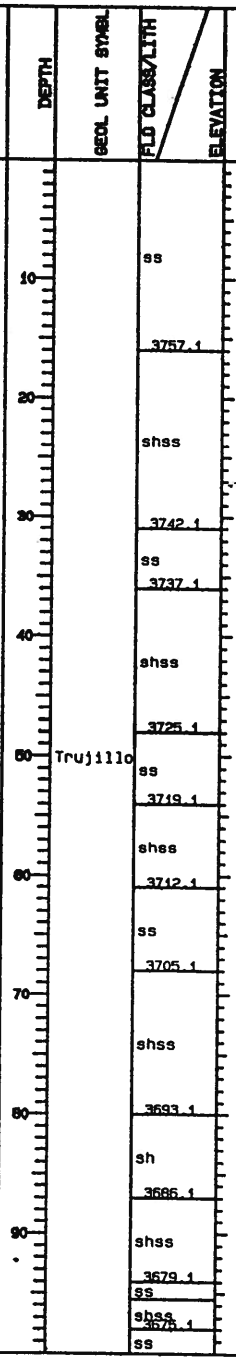
DRILLING METHOD:
6-inch rockbit 0 to 440.0 ft.

DRILLING FLUID:
Used air to blow out cuttings and water.

CASING RECORD:
6-inch I.D. temporary casing set to 9.0 ft on 06/14/94. Casing pulled after grouting on 06/19/94.

ESTIMATED WATER FLOW IN HOLE:
Encountered some free water at about 110 feet and significant water flow at about 135 feet. Estimated 50-75 gpm water flow from hole at 161.4 feet. Estimated 80-100 gpm water flow from hole at 227 feet. Estimated 100 gpm water flow from hole at 440 feet (water forced out by air).

At about 350 feet, water (up to 10 gpm) began flowing from OW6A (depth of OW6A is 230.6 feet). At times, air pressure in OW6C would shoot water in OW6A to heights of 6-8 feet



CLASSIFICATION AND PHYSICAL CONDITION

0.0-410.0 ft: TRIASSIC DOCKUM GROUP

0.0-229.0 ft: TRIASSIC TRUJILLO FORMATION

Alternating Sandstone, Shaley Sandstone, Sandy Shale and Shale.

Sandstones and Shaley Sandstones from 0.0 to 103.0 feet are fine grained, yellow-brown, compact, weakly to moderately cemented and contain varying amounts of silt and clay binder.

Sandstones and Shaley Sandstones from 103.0 to 229.0 feet are light brown near top but soon change to light to medium gray, range from fine and uniform (100 sieve) grained to conglomeritic (100 sieve to plus 1/4 inch pebbles), compact, weakly to moderately cemented and contain varying amounts of silt and clay binder. Cuttings range from SP to SC and SM (unified soil classification system).

Shales and Sandy Shales from 0.0 to 229.0 feet are yellow-brown above 80.0 feet and medium gray to red below 80.0 feet, slightly brittle, contain varying amounts of fine sand (200 sieve). Breaks down to CH (unified soil classification system) when worked.

0.0 - 16.0 Sandstone
16.0 - 31.0 Shaley Sandstone
31.0 - 36.0 Sandstone
36.0 - 48.0 Shaley Sandstone
48.0 - 54.0 Sandstone
54.0 - 61.0 Shaley Sandstone
61.0 - 68.0 Sandstone
68.0 - 80.0 Shaley Sandstone
80.0 - 87.0 Shale
87.0 - 94.0 Shaley Sandstone
94.0 - 95.5 Sandstone
95.5 - 98.0 Shaley Sandstone
98.0 - 103.0 Sandstone
103.0 - 109.0 Shaley Sandstone
109.0 - 116.0 Sandstone
116.0 - 119.0 Shaley Sandstone
119.0 - 124.5 Sandstone
124.5 - 127.0 Sandy Shale
127.0 - 132.5 Sandstone
132.5 - 135.5 Sandy Shale
135.5 - 138.0 Sandstone
138.0 - 140.5 Sandy Shale
140.5 - 145.0 Sandstone
145.0 - 148.5 Sandy Shale
148.5 - 229.0 Sandstone

229.0 - 410.0 ft: TRIASSIC TECOVAS FORMATION

Alternating Sandstone, Sandy Shale, and Shale.

Sandstones are mostly light gray but are tan in zones, mostly fine and uniform grained (100 sieve) but contain coarser units higher in the formation, micaceous with carbonaceous streaks between 325 and 345 feet, compact, weakly to moderately cemented and contain some silt and clay binder in places.

Shales and Sandy Shales are red to gray, slightly brittle, contain varying amounts of fine sand (200 sieve) and break down to CH (unified soil classification system) when worked.

229.0 - 234.0 Sandy Shale
234.0 - 239.0 Sandstone
239.0 - 241.5 Sandy Shale
241.5 - 243.0 Sandstone

COMMENTS:

ss = Sandstone
shss = Shaley Sandstone
sysh = Sandy Shale
sh = Shale
ssss = Zones of Siltstone, Shale and Sandstone

GEOLOGIC LOG OF DRILL HOLE NO. OW6C

FEATURE: OBSERVATION WELL
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 06-14-94 **FINISHED:** 06-19-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1682317.67 E 772300.26
TOTAL DEPTH: 440.0
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.1
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: GLENN TAUCHER
REVIEWED BY:

NOTES

above ground surface. This continued to bottom of hole (440 feet) except when OW6A was temporarily capped. OW6A is 13.4 feet from OW6C.

GEOPHYSICAL LOGS:
Geophysical logs (caliper, resistivity, self potential, gamma, neutron, sonic, density, temperature and televiewer) were completed in hole on 06/17/94.

DRILLING RECORD:
Drove 6-inch temporary casing to 9.0 feet on 06/14/94. Lodged tools in casing hammer. Spent remainder of day taking apart casing hammer.

Six-inch rockbit 9.0 to 201.4 feet on 06/15/94.

Six-inch rockbit 201.4 to 440.0 feet on 06/16/94. Water level start of shift on 06/16/94 was at 68.6 feet (3704.3). Hole caving at 380 feet.

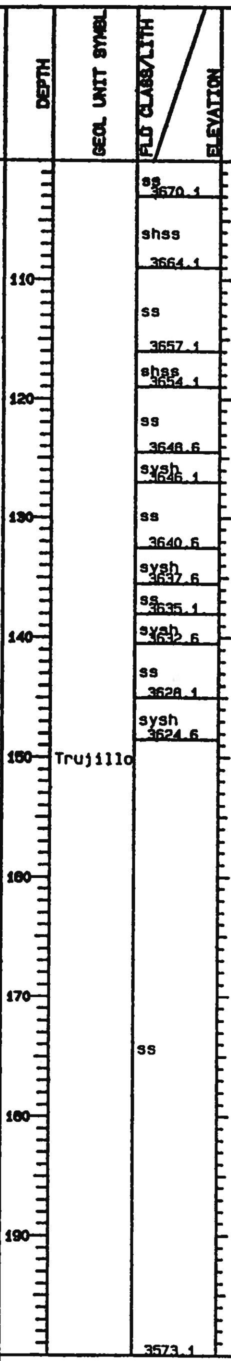
Hole caved back to about 410 feet on 06/17/94 and to 380.6 feet on 06/18/94.

Driller reported hard drilling 160 to 180, and 204 to 232.4 feet in Trujillo Formation. Tecovas sandstone is moderately hard drilling but not as hard as lower part of Trujillo Formation. Very hard zone at 386 to 392 feet.

HOLE COMPLETION:
Installed 2-inch dia. PVC from point 2.9 feet above ground surface to 280.6 feet. 2-inch dia. screen (0.020 slot) set 280.6 to 380.6 feet. PVC cap on bottom of screen. Sand packed (bagged sand) hole 380.6 to 259.7 feet. Bentonite pellets 259.7 to 229.7 feet. Tremied in 0.8 to 1 (water-cement) grout from 229.7 to ground surface. Set 10 feet of 4-inch steel protective pipe at surface with locking cap (top of 4-inch pipe is 3.0 feet above ground surface). PVC pipe, sandpack and bentonite pellets installed on 06/18/94. Hole grouted and protective pipe set on 06/19/94.

CONDUCTIVITIES MEASURED IN WATER SAMPLES COLLECTED:

Hole Depth	Millisiemens/cm Temp. corrected to 25C.
121.4	1.84 taken in thin mud
141.4	12.5
161.4	65.2



CLASSIFICATION AND PHYSICAL CONDITION

243.0 - 278.0	Shale
278.0 - 323.0	Sandstone
323.0 - 326.5	Shale
326.5 - 328.0	Sandy Shale
328.0 - 335.0	Shale
335.0 - 362.0	Sandstone
362.0 - 383.0	Shale
383.0 - 395.0	Sandstone
395.0 - 397.0	Sandy Shale
397.0 - 410.0	Sandstone

410.0 - 440.0 ft: PERMIAN BERNAL FORMATION
Alternating zones of Siltstone, Shale, and Sandstone. Most of cuttings were carried away as silt and clay. Some fine sand was recovered. Material is red to reddish-brown, firm but softer than the overlying material.

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW6C

SHEET 3 OF 5

FEATURE: OBSERVATION WELL
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 06-14-94 **FINISHED:** 06-19-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

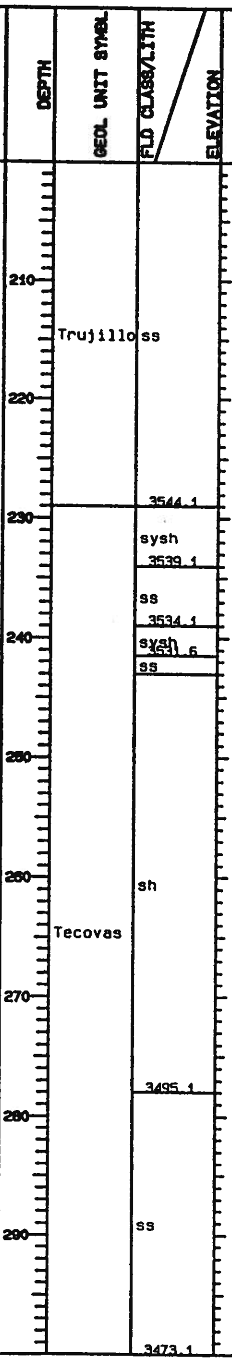
PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582317.67 E 772300.26
TOTAL DEPTH: 440.0
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.1
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: GLENN TAUCHER
REVIEWED BY:

NOTES

181.4	68.8
201.4	71.7
221.4	72.2
243.4	73.7
262.4	74.0
276.0	73.3
292.4	73.0
312.4	74.3
326.0	71.0
342.4	71.6
362.4	72.6
382.4	72.6
402.4	72.0
422.4	74.0
432.4	73.3

Note - Conductivity measurements made in water blown from drill hole using air to advance hole.



CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW6C

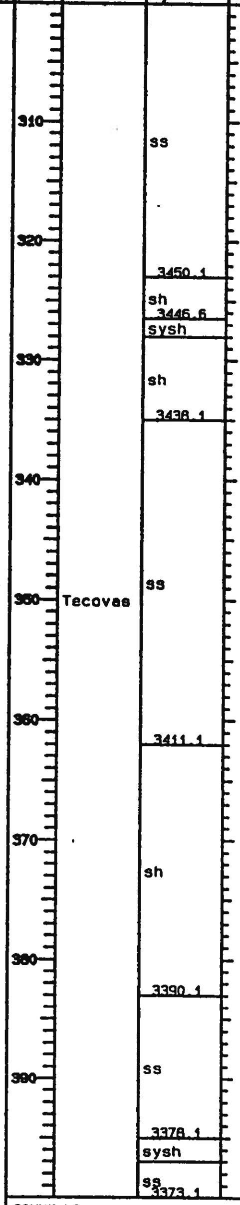
SHEET 4 OF 5

FEATURE: OBSERVATION WELL
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 06-14-94 **FINISHED:** 06-19-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582317.67 E 772300.26
TOTAL DEPTH: 440.0
DEPTH TO BEDROCK: 0

STATE: NEW MEXICO
GROUND ELEVATION: 3773.1
ANGLE FROM HORIZONTAL: 90.0 **AZIMUTH:**
HOLE LOGGED BY: GLENN TAUCHER
REVIEWED BY:

NOTES	DEPTH	GEOL UNIT SYMBL	FLD CLASS/LITH / ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION



COMMENTS:

GEOLOGIC LOG OF DRILL HOLE NO. OW6C

SHEET 5 OF 5

FEATURE: OBSERVATION WELL
LOCATION: SOUTH WALL CANADIAN RIVER
BEGUN: 06-14-94 FINISHED: 06-19-94
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: LAKE MEREDITH SALINITY
COORDINATES: N 1582317.67 E 772300.26
TOTAL DEPTH: 440.0
DEPTH TO BEDROCK: 0

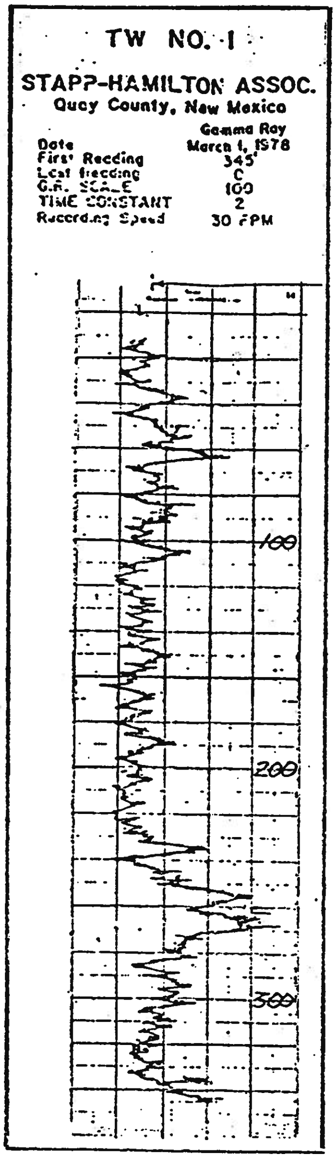
STATE: NEW MEXICO
GROUND ELEVATION: 3773.1
ANGLE FROM HORIZONTAL: 90.0 AZIMUTH:
HOLE LOGGED BY: GLENN TAUCHER
REVIEWED BY:

NOTES	DEPTH	GEOL UNIT SYMBL	FLD CLASS/LITH	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
		Tecovas	ss		
	410			3363.1	
	420				
		Bernal	ssss		
	430				
	440			3333.1	
		BOTTOM OF HOLE			
	450				

COMMENTS:

SHEET 5 OF 5 DRILL HOLE OW6C

Geophysical Logs
1975 to 1983

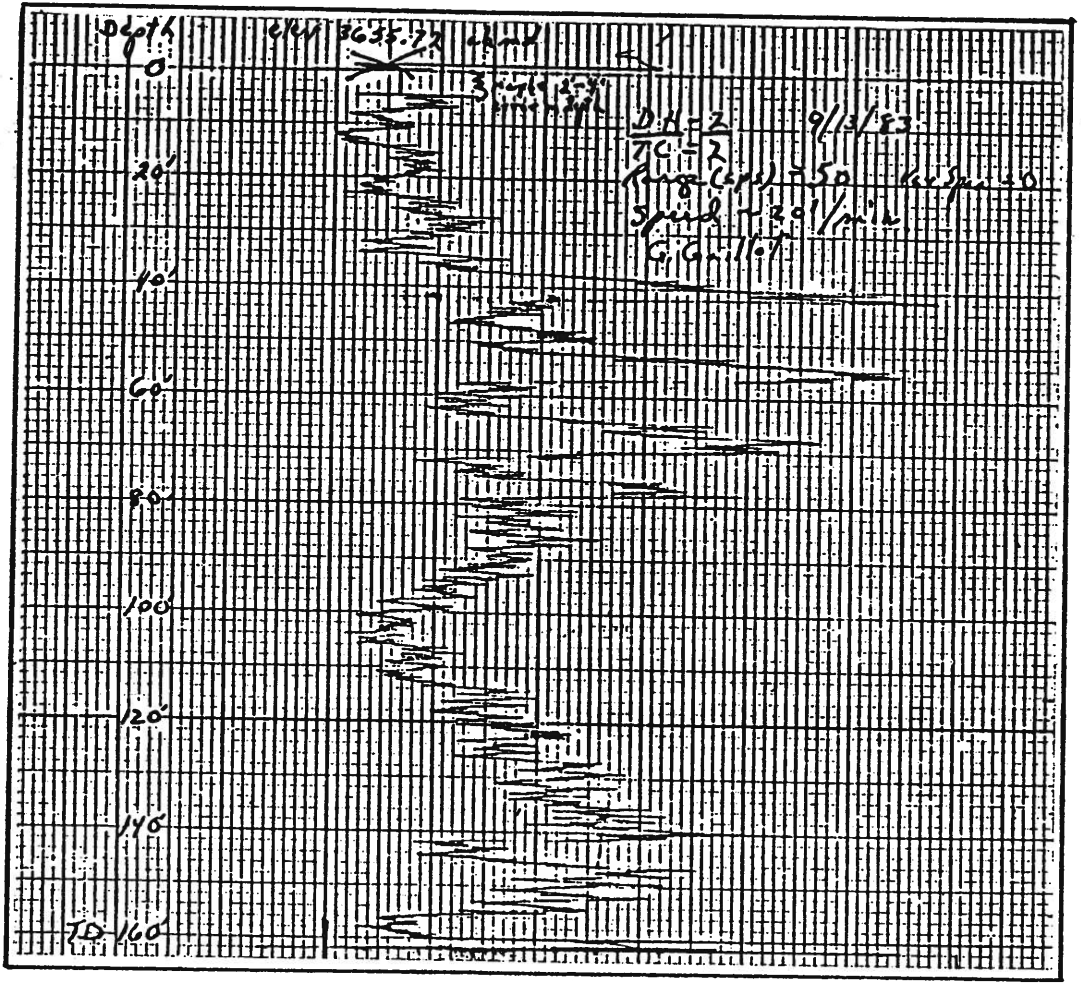


TW NO. 1

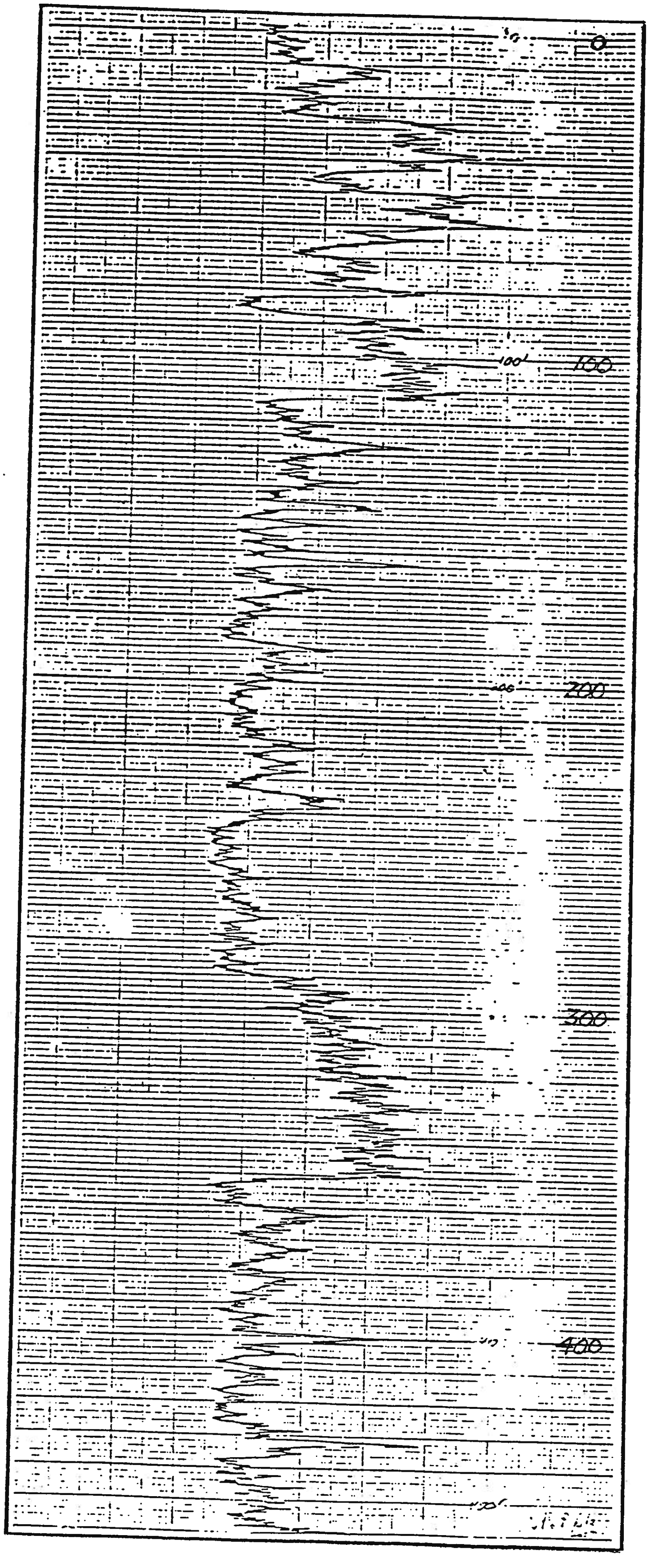
STAPP-HAMILTON ASSOC.
Quay County, New Mexico

	Gamma Ray
Date	March 1, 1978
First Reading	345'
Last Reading	0
G.R. SCALE	100
TIME CONSTANT	2
Recording Speed	30 FPM

LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL GAMMA LOG FOR TW1

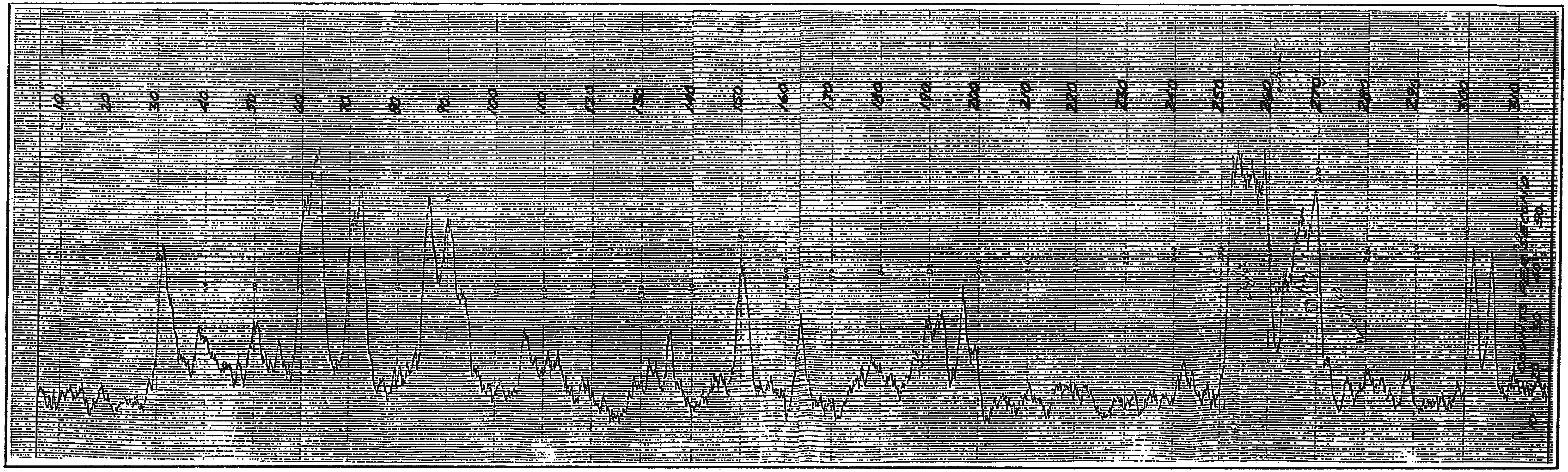


LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL GAMMA LOG FOR DH2



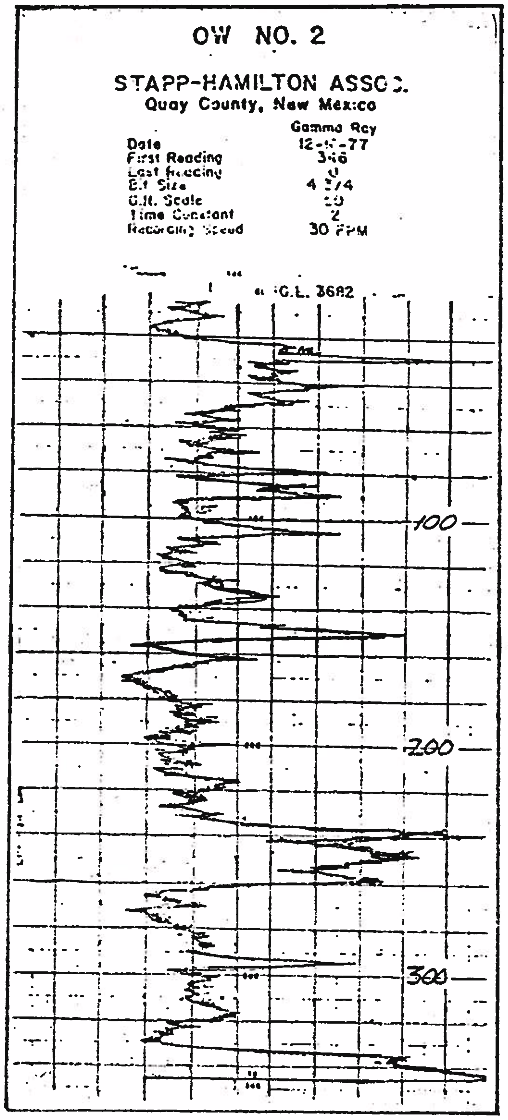
LAKE MEREDITH SALINITY STUDY-TEXAS, N. MEXICO
NATURAL GAMMA LOG FOR DH3

Geophysical Log DH3



LAKE MEREDITH SALINITY STUDY-TEXAS, NEW MEXICO
NATURAL GAMMA LOG FOR POW1

Geophysical Log POW1



OW NO. 2

STAPP-HAMILTON ASSOC.
Quay County, New Mexico

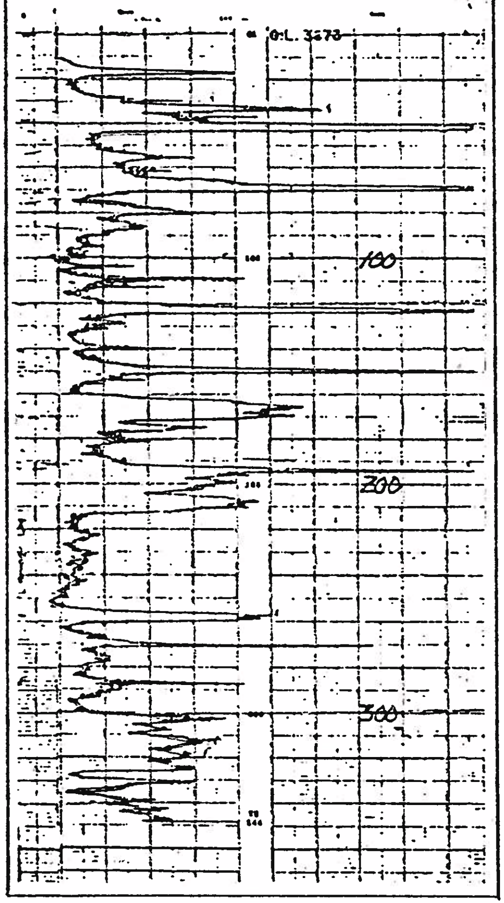
	Gamma Ray
Date	12-[illegible]-77
First Reading	346
Last Reading	0
Bit Size	4 3/4
G.R. Scale	[illegible]
Time Constant	2
Recording Speed	30 FPM

LAKE MEREDITY SALINITY STUDY-TEXAS, N. MEXICO
NATURAL GAMMA LOG FOR OW2

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



LAKE MEREDITH SALINITY CONTROL STUDY-TEXAS, N. MEXICO
NATURAL GAMMA LOG FOR OW3

Geophysical Logs
1993 and 1994