DOE/WIPP 97-2278

EXHAUST SHAFT: PHASE 2 HYDRAULIC ASSESSMENT DATA REPORT INVOLVING DRILLING, INSTALLATION, WATER-QUALITY SAMPLING, AND TESTING OF PIEZOMETERS 1-12

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APPENDIX 1:

Geology of Piezometer Holes to Investigate Shallow Water Sources Under the Waste Isolation Pilot Plant

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ABSTRACT

Twelve holes (PZ 1-12) were drilled around the area of the WIPP surface facilities to determine the lateral and stratigraphic extent of shallow water known to exist in the lower Santa Rosa Formation around the exhaust shaft. All of the drillholes encountered surficial eolian sand (and fill), the Mescalero caliche, the Gatuña Formation, the Santa Rosa Formation, and the upper Dewey Lake Formation. Eleven drillholes produced water from the lower Santa Rosa.

All units were geologically consistent with previous studies. Across the facility area, units from Mescalero to Dewey Lake are continuous, exhibit gentle slopes (structure contours), and reflect broader trends in thickness and structure. Except for drillhole PZ-8, which was dry, moist zones and water were encountered in the Santa Rosa. The uppermost Dewey Lake in several of these holes was proven dry; dry dust was blown from this interval while drilling.

Drilling for design work (1978-79) and mapping in the exhaust shaft (1984) show that this shallow water did not exist through at least 1984. The air intake shaft (AIS) in 1988 flowed enough water (with dissolved salt) from the Santa Rosa and upper Dewey Lake to be moist and develop salt efflorescences. Solutes in waters from PZ drillholes and AIS indicate infiltrating waters contacted WIPP surface salt piles or another near-surface source of salt from WIPP activities.

The lower Santa Rosa revealed zones that were much harder drilling due to silicification. These indurated zones combined with reduced permeability of fine grained rocks of the uppermost Dewey Lake to perch the water.

Several lines of evidence have been synthesized as possible indicators of site-wide trends to probable changes in vertical permeability of the Dewey Lake and Santa Rosa. Data on fluid levels during logging, uppermost reported gypsum, lost circulation zones, reports of water or moist zones, and site-wide resistivity surveys were gathered from WIPP sources. These data are less precise than is information from PZ drillholes. Trends in these data are interpreted as indicators of permeability and are related to different perching zones.

As hypothesized, these perching zones are effective at different depths across the site because of the more recent geological history of the area. There is a strong

relationship between encounters of water in the Dewey Lake and indicators of perching zones. At the WIPP site facilities location, the uppermost two effective perching zones are the lower Santa Rosa (investigated here) and the upper Dewey Lake (as indicated in the air intake shaft). Southwest across the site, the Santa Rosa is absent because of erosion, and the uppermost effective perching zone is created by cementation changes (sulfate) in the Dewey Lake.

If the shallow water found in this study under the WIPP facilities has migrated laterally to the south and west well beyond the present area of investigation, it will involve Dewey Lake perching zones, as the Santa Rosa pinches out in that direction.

INTRODUCTION

Project Background

For several years, water has flowed in small volumes into the WIPP exhaust shaft at shallow depths. The water is clearly not from deeper ground water sources such as the Rustler Formation, but the extent of the water, its chemistry, and likely sources were undetermined. Three drillholes very close to the exhaust shaft were drilled during 1996 and prepared for water sampling and water level measurements (Intera, 1996). These drillholes demonstrated that the water was not restricted to the immediate shaft area and that the water occurred in the Santa Rosa Formation (or possibly the uppermost Dewey Lake Formation). Nevertheless, the areal extent of the water was undetermined, and the origin(s) poorly bounded.

During June and July, 1997, 12 additional holes were drilled and prepared for water sampling and water level measurements. The main objectives during this preliminary phase were to determine the extent of shallow water, obtain head and chemical data to indicate possible sources of the water, to determine the stratigraphic units in which water is present, and to provide the basis for any further programs to explore the extent of water or place dewatering drillholes, if desired. Overall program objectives, drilling and completion methods, and hydrological data and analysis are included in the main report by Intera.

Geological descriptions of cores and cuttings, and the interpretation of the geological data, were the responsibility of Dennis Powers. Field log descriptions are attached to this report (Appendix A).

Geological Units and Background for PZ Drillholes

Seven identifiable formal and informal artificial and natural units (Figure 1) have been encountered during drilling for this program, though not all are identifiable or present in each drillhole. From the surface down, these are: 1) fill - local units disturbed by construction or material brought in for construction, 2) Holocene(?) dune sand, 3) Pleistocene Berino soil, 4) Pleistocene Mescalero caliche, 5) Miocene - Pleistocene Gatuña Formation, 6) Triassic Santa Rosa Formation, and 7) Permian Dewey Lake Formation. All formations were encountered during the drilling generally as expected.

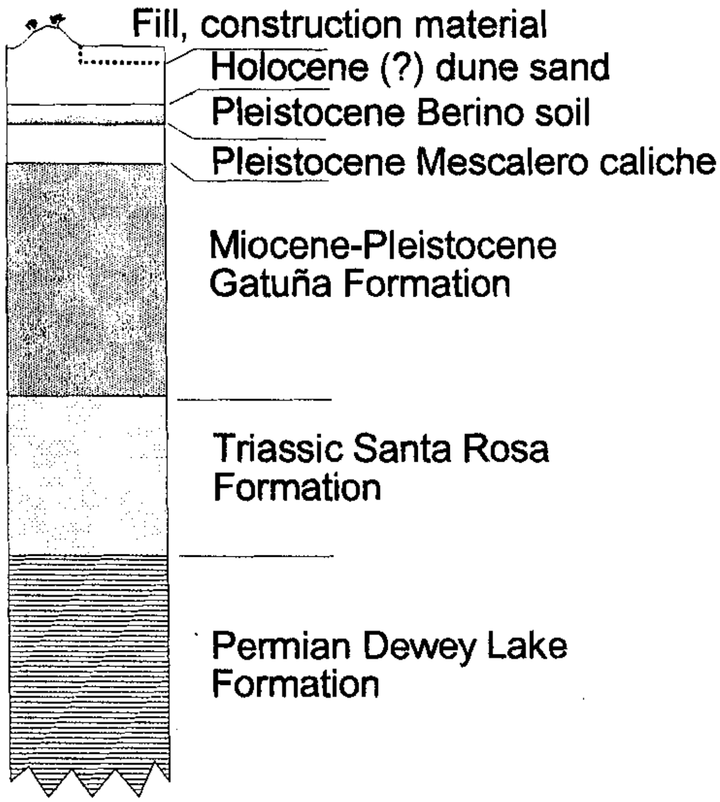


Figure 1
Units Commonly Encountered During Shallow Drilling at WIPP

The geology of these drillholes could be forecast on the basis of the mapping of the exhaust and air intake shafts (Holt and Powers, 1986, 1990) as well as nearby drillholes such as B-25 (Bechtel National, Inc., 1979) and WIPP 21 (Sandia [National] Laboratories and US Geological Survey, 1980). Drilling to investigate potash resources revealed the broader stratigraphic relationships and presence of the Santa Rosa over the site (Jones, 1978). Numerous shallow holes (B series) were drilled in 1979 for design of surface facilities, and these drillholes demonstrated the lack of very shallow groundwater as well as the distribution of near surface rock units (Sergent, Hauskins & Beckwith, 1979).

Fill, Construction Materials. Around the facilities, significant areas have been modified by construction activities. Much of the dune sand has simply been levelled in place, though some of the upper part has been removed as "soil" for later rehabilitation following decommissioning of the WIPP facility. Gravel from nearby caliche pits has been imported to stabilize the surface, and one hole (PZ-1) was drilled through asphalt surfacing. Another drillhole (PZ-7) was located on top of a small berm, constructed of dune sand with caliche surfacing, around an evaporation pond.

Holocene(?) Sand Dunes. The Holocene sand dunes in this area have been little studied as geological units. While most are stabilized, small areas remain active around the site. These dunes may be older than Holocene and may represent more than one episode of dune formation, based on limited examination of aerial photographs.

Berino Soil. The Berino soil, originally designated by Chugg and others (1971) during the soil survey of Eddy County, is a dark reddish brown siltstone to argillaceous sandstone that is partially lithified, mainly by accumulation of clay minerals. It is a fossil soil or paleosol. It was examined by Bachman (1980) briefly, who noted its occurrence overlying the Mescalero caliche and under dune sand. Bachman interpreted the Berino as probably a remnant B horizon relative to the underlying Mescalero caliche, and Powers (1993) agreed with that assessment. Powers and others (1997) reassessed the relationship based on trenches west of WIPP and concluded that the Berino was distinct from the Mescalero in origin.

In a study of the ages of near-surface units, Rosholt and McKinney (1980) interpreted the age of formation of the Berino as 330,000 ± 75,000 years.

Mescalero Caliche. The Mescalero caliche in the area of WIPP is best known from the work of George Bachman (e.g., Bachman, 1974, 1976; Bachman and Machette, 1977). The Mescalero is an informal stratigraphic unit originally designated by Bachman (1976) for the pedogenic carbonate deposits across the Mescalero plains. The drillhole data for design studies for WIPP was used to prepare a map of the elevation of the top of the caliche in the area where surface facilities now exist (Sergent, Hauskins & Beckwith, 1979, figure 3). Further away, Powers (1993) studied the Mescalero in pipeline trenches, finding a range of development from about stage 2 through stage 5 (Bachman and Machette, 1977) across topographic changes. Powers and others (1997) examined outcrops of the Mescalero exposed in the El Paso Energy pipeline trench just west of the WIPP boundaries and found that the caliche is stratigraphically continuous across the area. The unit is locally variable and was disrupted by erosion/solution prior to formation of the Berino soil (about 330,000 years ago). In general, the Mescalero caliche is continuous across the general site area and provides broad evidence of geomorphic stability.

Rosholt and McKinney (1980) dated carbonate from the Mescalero using uranium-trend methods. The lower part yielded an age of about 570,000 ± 110,000 years, and the upper part was 420,000 ± 60,000 years.

Miocene-Pleistocene Gatuña Formation. The Gatuña Formation is relatively thin across most of the WIPP site (Bachman, 1985). In the eastern half of the WIPP withdrawal area, no Gatuña is reported; caliche is developed on the Santa Rosa. Several caliche quarries at topographic highs east of the WIPP withdrawal area expose well-lithified Santa Rosa under caliche. The Gatuña thickens considerably to the west, especially along Nash Draw and nearer the present day Pecos River (Powers and Holt, 1993, 1995a). It was deposited predominantly in a fluvial environment. The base of the formation is regionally unconformable, and it can fill localized channels caused by erosion. The thickness of the unit can vary considerably over short distances. The formation has filled in some areas along the general Pecos River trend where dissolution caused subsidence (Powers and Holt, 1995a).

Triassic Santa Rosa Formation. The Santa Rosa is thin near the center of the WIPP site (e.g., Powers and Holt, 1995b). It thickens rapidly to the east (Jones, 1978) as a consequence of eastward dip and eastward rise in the surface topography. The formation was deposited in dominantly fluvial environments (McGowen et al., 1979). It lies unconformably on the Dewey Lake.

Permian Dewey Lake Formation. The Dewey Lake thickens from west to east across the site to a regional maximum of about 600 ft east of the WIPP site (Schiel, 1988). It was deposited during ephemeral flooding of shallow streams and rivers. The unit is characteristically fine-grained, ranging from interbedded fine sandstone to mudstone. It has a distinctive reddish-brown color with small spots and thin zones that are greenish-gray.

Unit Distinctions

During this study, some cores were taken using flight augers and retrievable core barrels. Most holes were drilled using a tricone bit and compressed air to remove cuttings. The stratigraphy of these drillholes was determined by monitoring the cuttings for composition and color. Because the return time (to the surface) for cuttings at these shallow depths is very short, distinct changes in composition can commonly be determined quickly and accurately. Depths to most units are considered accurate to the nearest foot; a few unit distinctions are taken to the nearest half foot. Over intervals where cores were not retrieved or cuttings did not return to the surface, boundaries may be placed on the basis of changes in drilling rates. Most of the following discussion is based on distinctions made on the basis of cuttings.

The fill material/graded material is mainly orange to brownish, unconsolidated sand from the stabilized dunes that covered the site prior to construction. Some caliche gravel or other coarse material is mixed with the upper surface in some locations. There is little to distinguish the base of graded material at most locations from the undisturbed dune sand. In some drillholes, the basal dune sand included additional silt and clay, is more lithified, and is a darker reddish brown. This corresponds to the Berino soil (e.g., Chugg et al., 1971; Bachman, 1980; Powers and others, 1997) that overlies the Mescalero across most of the site.

The top of the Mescalero is reliably determined because of the abrupt change in cuttings to white carbonate and reduced drilling rates. Sergent, Hauskins & Beckwith (1979) prepared a contour map of the elevations of the top of Mescalero from the B series holes, and the data correspond closely to our findings.

The top of Gatuña for this study is placed where brownish to reddish-brown Gatuña sandstone is observable as part of the cuttings. This corresponds to the contact as it is observed in outcrops and other cores (Powers and Holt, 1993, 1995; Powers, 1993). Mescalero caliche infiltrated the upper Gatuña, forming nodules and carbonate crusts. The alteration decreases with depth. In outcrops, the Mescalero dominates over an interval that is generally about 3 ft thick (see Powers, 1993; Powers and others, 1997; Kennedy, 1997). Gatuña character is distinguishable below that and increases with depth. Cuttings begin to change color from white to slightly brownish white and are accompanied by increasing proportions of Gatuña sandstone. The sand grains are generally fine to coarse, poorly sorted, and chips show small pores from bioturbation as well as bluish-black MnO_2 stains.

The Sergent, Hauskins & Beckwith (1979) study consistently places the Mescalero-Gatuña boundary much deeper, implying that the Mescalero is 10-15 ft thick across the WIPP site center. The upper Mescalero, as described in the Sergent, Hauskins & Beckwith report, corresponds to the differentiation of the Mescalero in this report; they included much more of the carbonate-cemented sandstone in Mescalero, while I attribute it to Gatuña that has been altered by Mescalero pedogenic processes.

The Santa Rosa is a common source of the sediment that forms the Gatuña, making this boundary the most difficult to place in either core or cuttings. The Santa Rosa includes fine to coarse, highly micaceous sandstones interbedded variably with claystones or siltstones. Santa Rosa sandstones are generally dark brown, while claystones and siltstones can include green. Some beds display whitish reduction spots. Outcrops of the Santa Rosa commonly strike the eye as having a purplish cast. The distinction at the base of Gatuña was commonly made on the basis of higher mica concentrations, more intense hues (browns, greens), and induration (slower drilling rates). Some beds near the base of the Santa Rosa are highly indurated. Cuttings from these beds are limited, but tests with acid show little carbonate cement. The beds are probably partially cemented by silica.

The Dewey Lake is most commonly differentiated from the Santa Rosa on the basis of color (more of a brick red color and chips with greenish-gray reduction spots) and composition (no coarser sands, decreased mica content). Drilling rates for the Dewey Lake also increased over the basal Santa Rosa and became more constant.

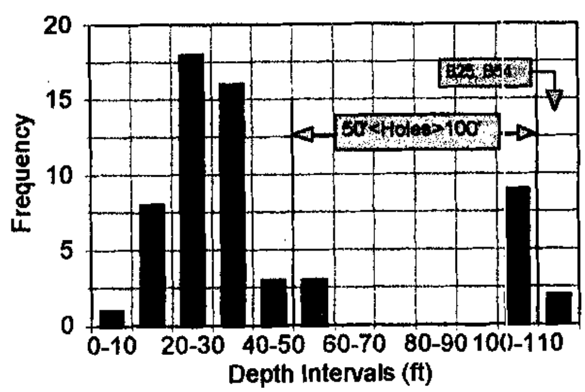
Origin of Water

To understand the origin of this water, we consider both the likely sources as well as how long the water has been in place. While the current study is designed to understand the sources of the water in some detail, previous geological studies greatly constrain the possibilities of how long this zone has been saturated.

Design studies included drilling holes at 54 locations from late 1978 through part of 1979 at the location of proposed WIPP facilities. There were 54 principal drillholes and 6 supplemental or offset drillholes. The drillholes ranged in depth from about 6 to about 902 ft in depth. At 52 locations, the drillholes had total depths of 100 ft or less and were drilled with air (Bechtel, 1979, p. 10). Two drillholes (B25 and B54) were 901.8 and 210 ft deep, respectively. Drilling mud was used for B25 (Bechtel, 1979b); I assume drilling fluid was used for B54, but I found no specific information in the original reports. Twelve of the drillholes were drilled with air and were between 50 and 100 ft deep (Figure 2) and should have been deep

Figure 2

Depth of B Series Holes



enough to intercept the water at its current depth. These drillholes cross the area where water has currently been found as well as some areas beyond the area of the PZ wells; they demonstrate that the water was not present below the site in 1979.

In 1984, the exhaust shaft was constructed and mapped (Holt and Powers, 1986). No water was found through this shallow interval during the mapping. The water was not present at the exhaust shaft in 1984.

During the mapping of the air intake shaft (AIS) late in 1988, Holt and Powers (1990) noted that the shaft walls were wet in the basal sandy siltstones of the Santa Rosa Formation at a depth of 51.5 ft (33 ft below plenum + 18.5 ft of plenum) (elevation of 3358.5 ft msl). Holt and Powers suggested that water was accumulating in Santa Rosa sandstones overlying the siltstones. Salt efflorescence accumulated on the surface of the shaft to a depth of about 63 ft as air flowing into the shaft evaporated the water. Holt and Powers also found moist zones and salt efflorescence above a cementation change in the Dewey Lake at a depth of about 182.5 ft (164 + 18.5 ft). They concluded that the source was infiltration of meteoric water that had come in contact with the halite muck pile immediately north of the facilities. By 1988, water had infiltrated in the vicinity of the AIS and charged units at 51.5 ft and 183 ft depth.

These geological investigations show that the shallow water found during this study (PZ drillholes) did not exist generally across the site in 1979, and was not observable at the exhaust shaft in 1984. It is reasonable to conclude that it did not exist at all at least as late as 1984. By 1988, the AIS mapping showed that water with dissolved halite had infiltrated to the Santa Rosa and Dewey Lake at this location. The solutes in the water in the AIS and also indicated in preliminary testing of water from PZ holes show that the water flow path has to involve a surface source of halite such as tailings piles from WIPP or brine pits for drilling and is not due, for example, to leaks from pipes carrying water of drinking quality. Further solute analyses will be significant in determining what were the sources and flow path of the water.

SUMMARY STRATIGRAPHIC DATA FROM PZ DRILLING

Basic stratigraphic data for each drillhole in the PZ series is included in a table for convenience (Table 1).

TABLE 1

Depth (ft) Interval for Stratigraphic Units					
Drillhole	**Fill, Dune Sand**	**Mescalero caliche**	**Gatuña Formation**	**Santa Rosa Formation**	**Dewey Lake Fm**
PZ-1	nd[§]	nd	nd-40	40-~56	~56-67.5 (TD)
PZ-2	0-9	9-12	12-39	39-~57	~57-65 (TD)
PZ-3	0-8	8-10	10-38	38-63	63-70 (TD)
PZ-4	0-9	9-12	12-31	31-57	57-65 (TD)
PZ-5	0-7	7-9	9-36	36-62.5	62.5-71.5 (TD)
PZ-6	0-7	7-9	9-32	32-55	55-66 (TD)
PZ-7	0-7.5	7.5-9.5	9.5-30	30-69	69-71.5 (TD)
PZ-8	0-6.5	6.5-9	9-31	31-60	60-67 (TD)
PZ-9	0-8	8-11	11-36	36-75	75-82.5 (TD)
PZ-10	0-6	6-9	9-28	28-46	46-57 (TD)
PZ-11	0-10	10-12.5	12.5-34	34-71	71-82 (TD)
PZ-12	0-6	6-8	8-39	39-62	62-77 (TD)

[§]ND = not determined. Depths are approximate (about ± 1 ft). Some contacts to nearest 0.5 ft due to marked contrast. Gatuña-Santa Rosa contact is difficult; the Gatuña incorporated Santa Rosa sediment.

In part because of grading, the fill and dune sand over caliche shows a relatively uniform depth across the area of investigation. This is also consistent with the findings of the pre-construction surveys.

The Mescalero is consistently 2 to 3 ft thick in this investigation. This is consistent with outcrop and trench data in the area, though it contrasts with pre-construction surveys because of different concepts of the Mescalero-Gatuña contact.

The Gatuña averages 24 ft thick in the 11 drillholes in which both top and base were picked. Most of the cores and cuttings of the Gatuña display evidence of bioturbation, Mn staining, and possible mineral precipitation along likely ped [a soil structure] surfaces that are consistent with pedogenic alteration of the upper part of the formation as it was accumulating in this area prior to development of the Mescalero. Most of the formation would be similar to the part called informally the "McDonald Ranch member" by Powers and Holt (1993, 1995a).

The Santa Rosa averages about 39 ft thick in the PZ series holes. This is consistent with the broader site relationships, where the site center is near the western limit of Santa Rosa following erosion prior to Gatuña deposition. The Santa Rosa thins rapidly to the south and west of this area.

COMPARISON WITH STRATIGRAPHIC DATA FROM PREVIOUS STUDIES

The main sources of comparable data within the WIPP fenced area and out to a radius of about 3 miles are drillholes for the design studies (Figure 3) (Sergent, Hauskins, Beckwith, 1979; Bechtel, 1979), potash exploration for WIPP (Jones, 1978), and various exploratory and hydrologic drillholes for WIPP (Figure 4) (see, for example, data summaries of relevant units in Powers and Holt, 1995b). Units down to the upper Dewey Lake can be compared for the area of the facilities; the thickness of the Dewey Lake for a broader area is based on deeper drillholes that were not a part of this study.

Figure 3

Basemap of Drillhole Locations Near WIPP Site

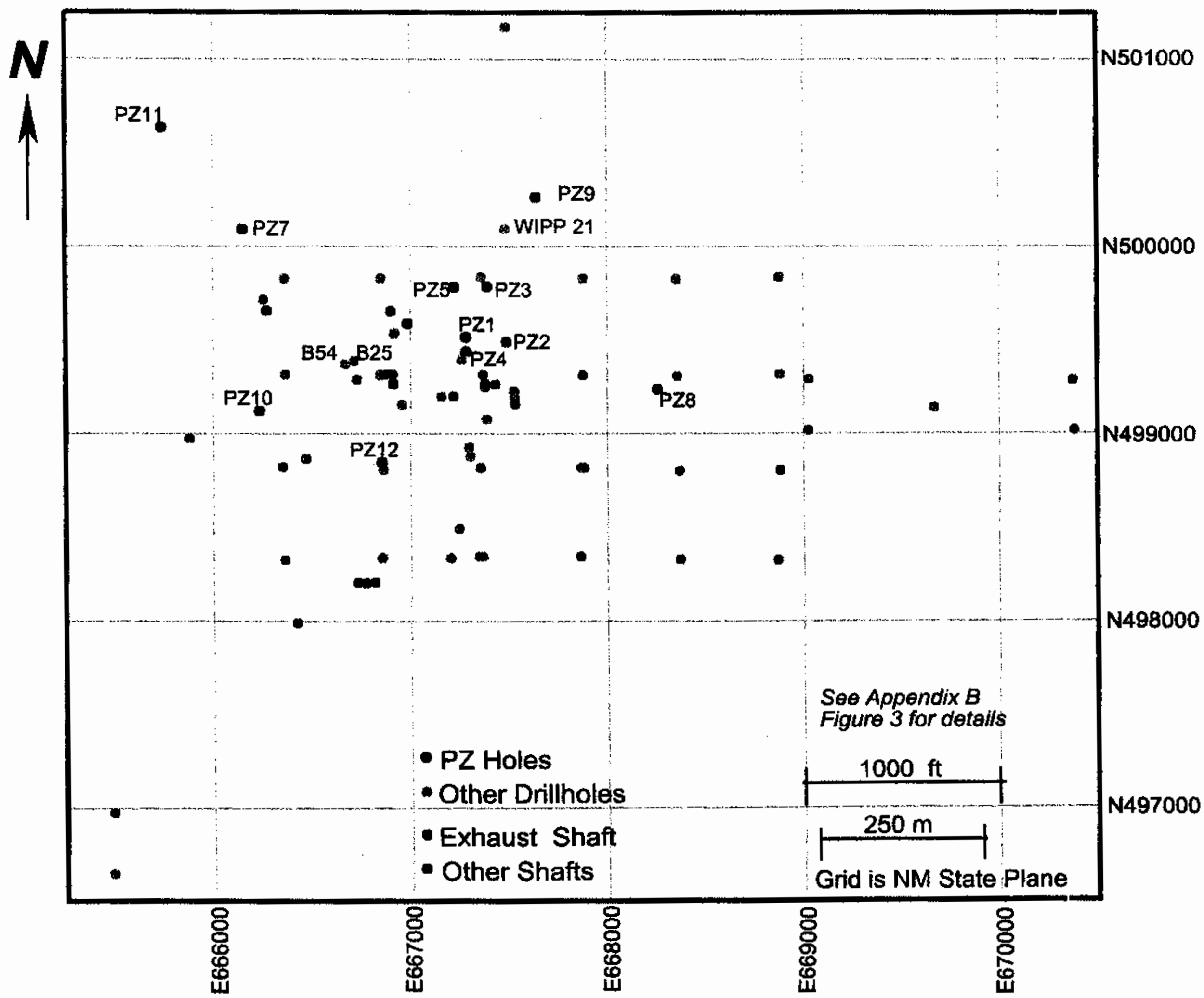
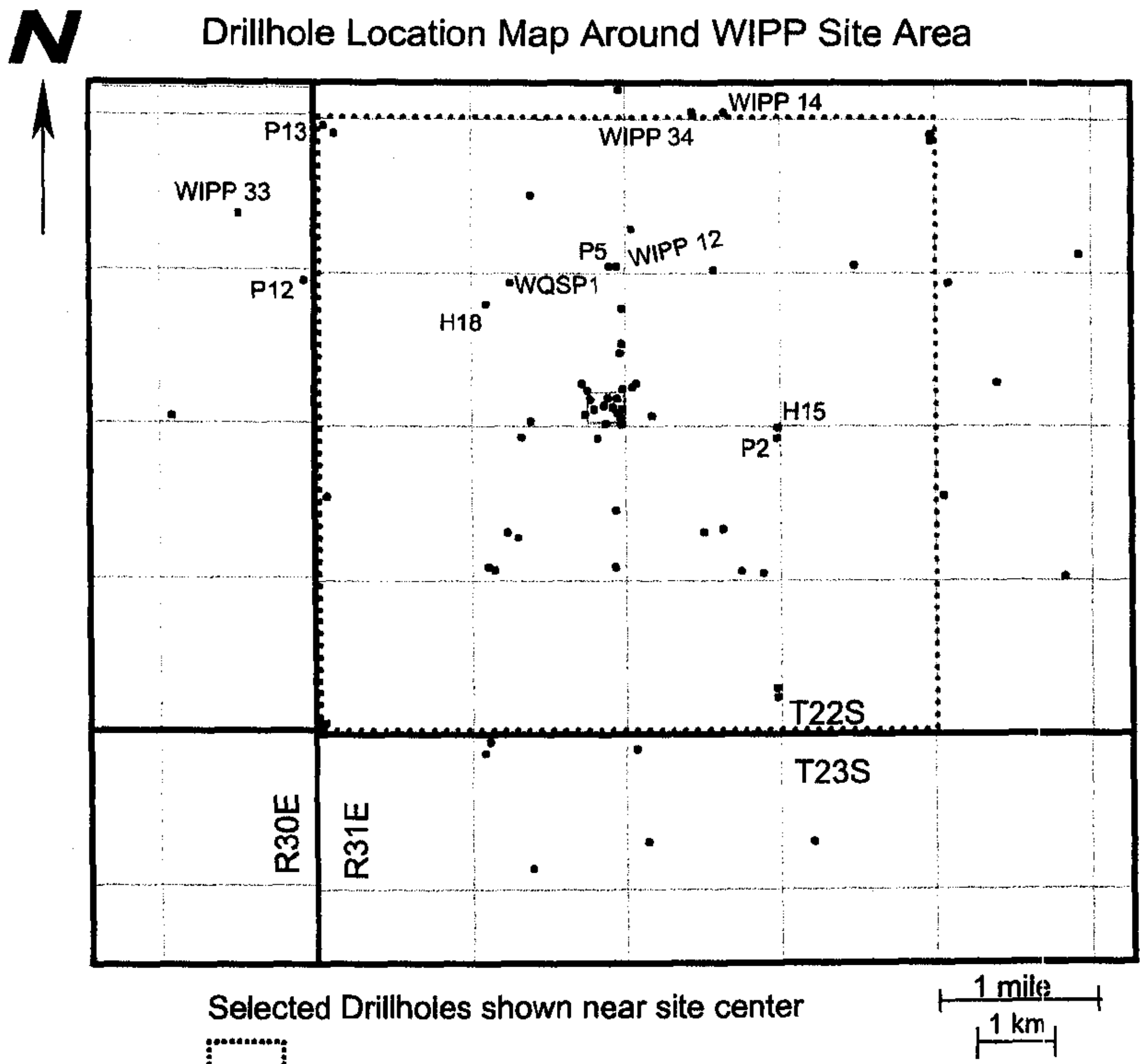


Figure 4

Drillhole Location Map Around WIPP Site Area



Selected Drillholes shown near site center

WIPP Withdrawal Area

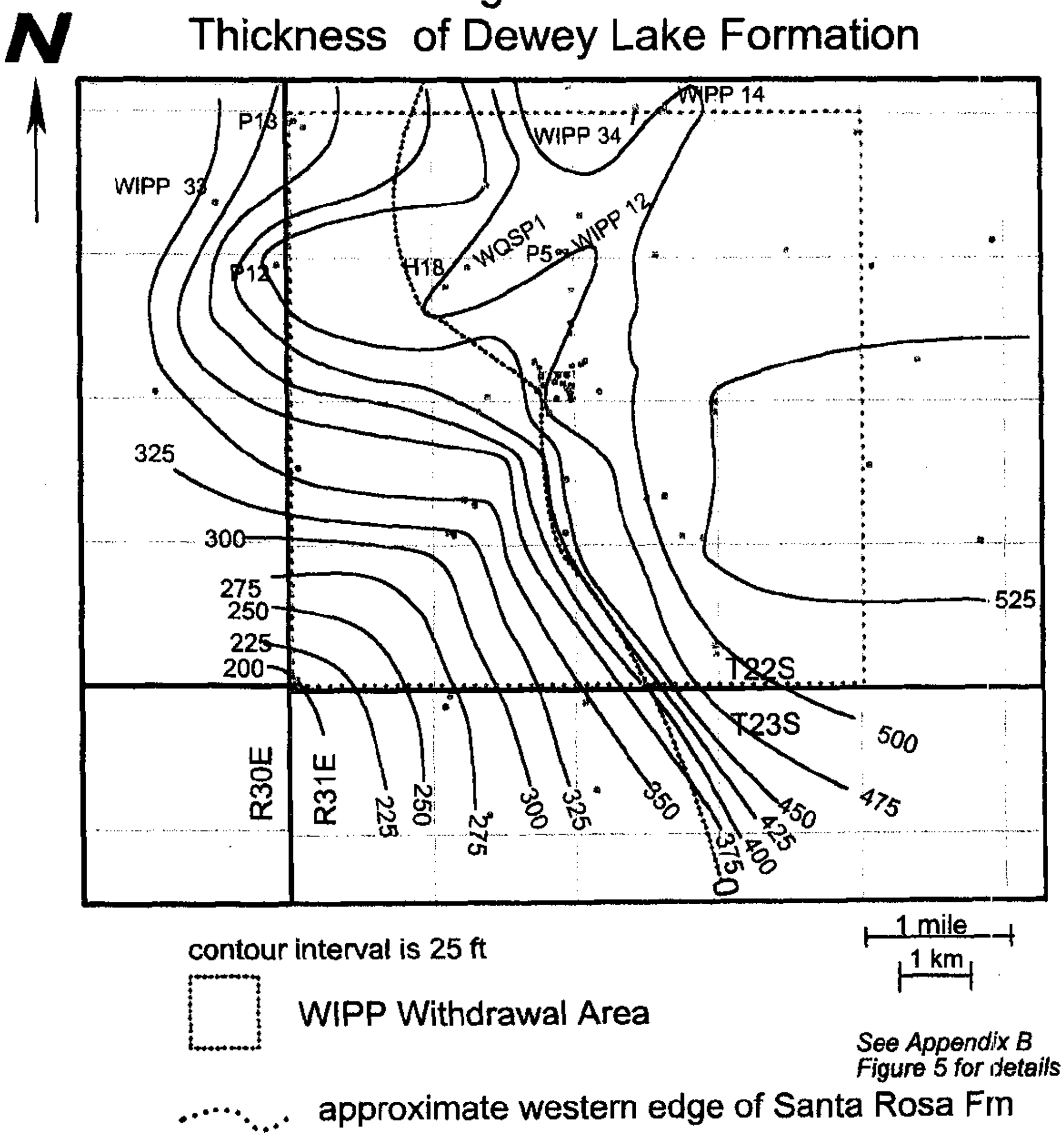
Hole Location, selected holes identified

See Appendix B Figure 4 for details

Dewey Lake Data

From the larger area (Figure 5), Dewey Lake thicknesses reveal three main features. In the eastern part of the map area, the Dewey Lake is more than 525 ft thick; this is similar to much of the Dewey Lake to the east, where it thickens to about 600 ft

Figure 5
Thickness of Dewey Lake Formation



See Appendix B Figure 5 for details

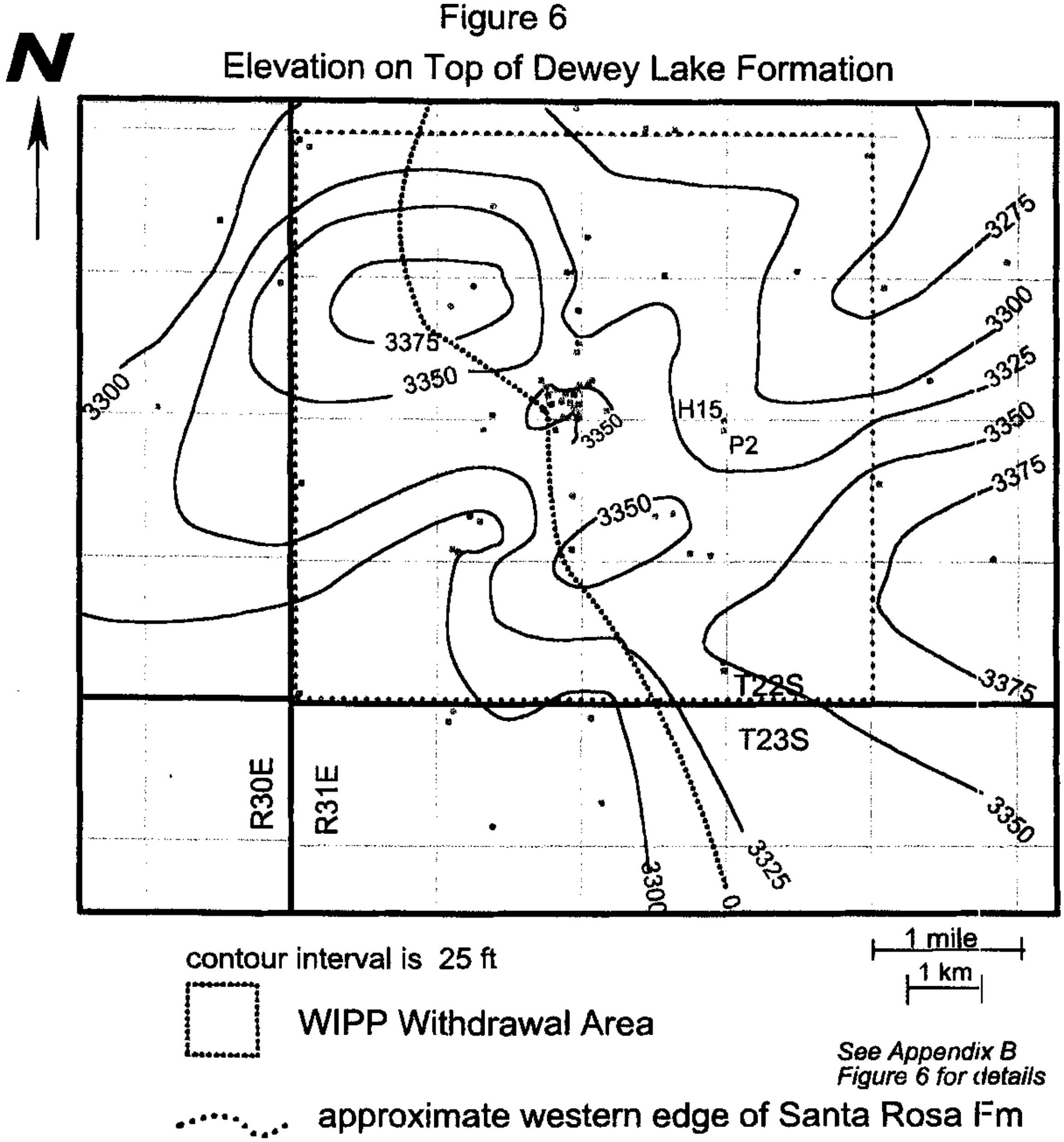
(e.g., Schiel, 1988). The southwestern half of the map shows thinning with a persistent gradient to the southwest. The isopach contours generally parallel the estimated edge of the Santa Rosa. The northeastern quarter of the map has somewhat thinner Dewey Lake, about 500 ft thick.

The thickness map also shows two minor features. In the center of the northwest quadrant, the Dewey Lake appears to be thicker toward the west along a "nose" defined by drillholes P12, H18, and WQSP1 (Figure 4). This nose does not differ in thickness greatly from the northwest-southeast trend defined through the site center. The nose is accentuated by drillholes P13 and WIPP 33, where the Dewey Lake is significantly thinner. The second minor feature is a narrow thinner zone near the north center area of the map defined by WIPP12, P5, and WIPP14. This zone trends north-northeast. It is not a significant feature, as it is defined by differences as little as 5 ft between drillholes WIPP34 and WIPP14, which is generally about the normal interpretive limits for precision on geophysical logs (e.g., Holt and Powers, 1988).

A map of the elevation of the top of the Dewey Lake (Figure 6) does not reflect regional structure for these units. The structure of units of the underlying Rustler Formation show that the regional dip is eastward and is of the order of 100 ft/mile. The general trend of elevation on top of the Dewey Lake is for a relative high or ridge along a zone from southeast to northwest with a saddle near the WIPP surface facilities. The Dewey Lake tends to be slightly higher under the WIPP site. The top of the Dewey Lake slopes off both to the southwest and northeast from this ridge.

The slope to the southwest corresponds mainly to broader erosional thinning of the Dewey Lake prior to deposition of the Gatuña. The Santa Rosa is missing over most of this area, having also been eroded prior to Gatuña deposition.

Figure 6
Elevation on Top of Dewey Lake Formation

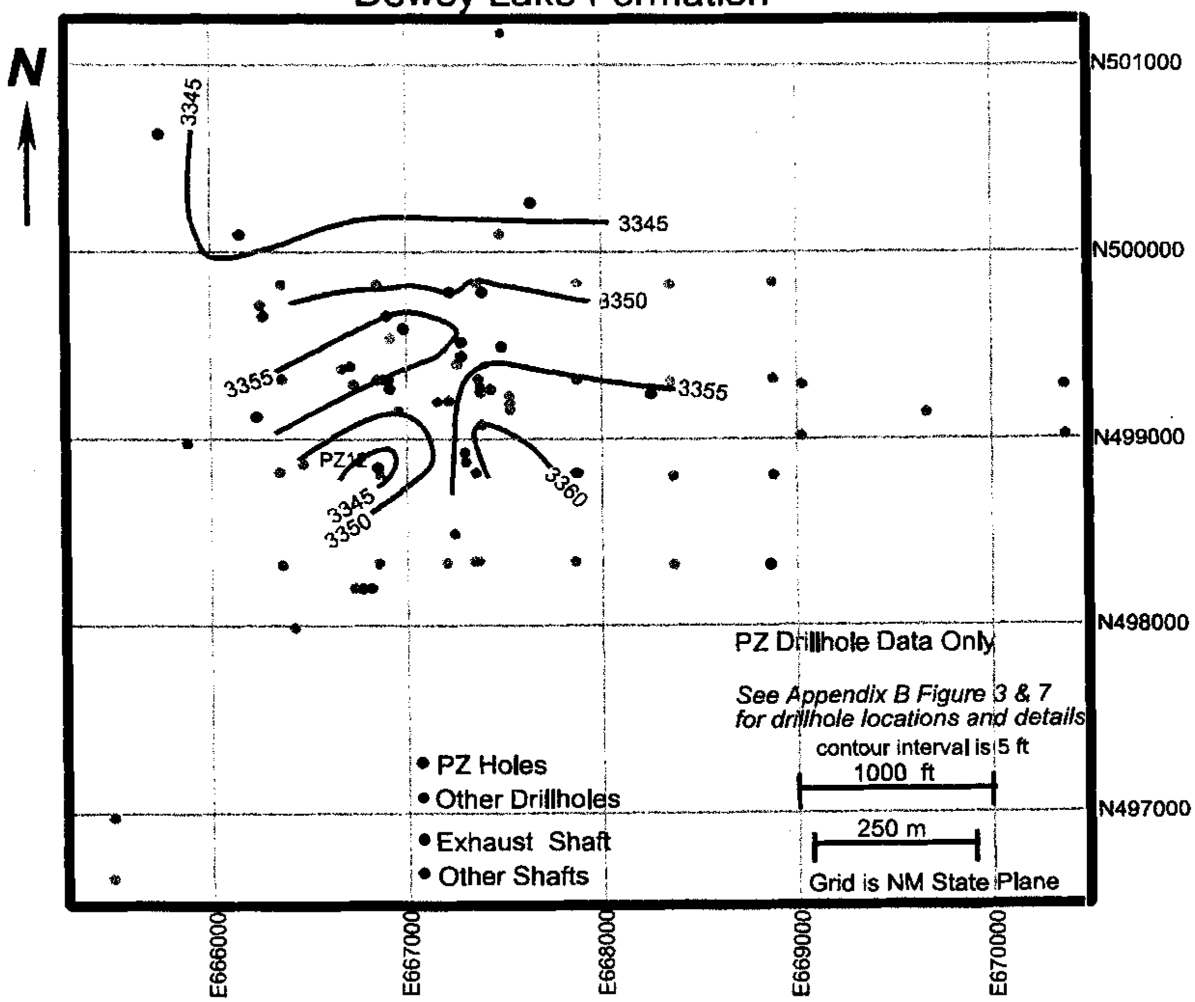


The slope to the northeast corresponds to thicker Santa Rosa and slightly thinner Dewey Lake. I interpret this as due mainly to more localized erosion of the Dewey Lake prior to Santa Rosa deposition.

At the facilities location, concentrated data from the PZ drillholes and B series permits more detailed reconstruction of the surface of the Dewey Lake that can be compared to the broader site area information.

The PZ data alone (Figure 7) indicates a northward slope across this limited area. The exception is the point at drillhole PZ 12 at the south central part of the map with an elevation of 3344. While a re-examination of the drillhole log data indicates the original

Figure 7
Elevation of Top of
Dewey Lake Formation

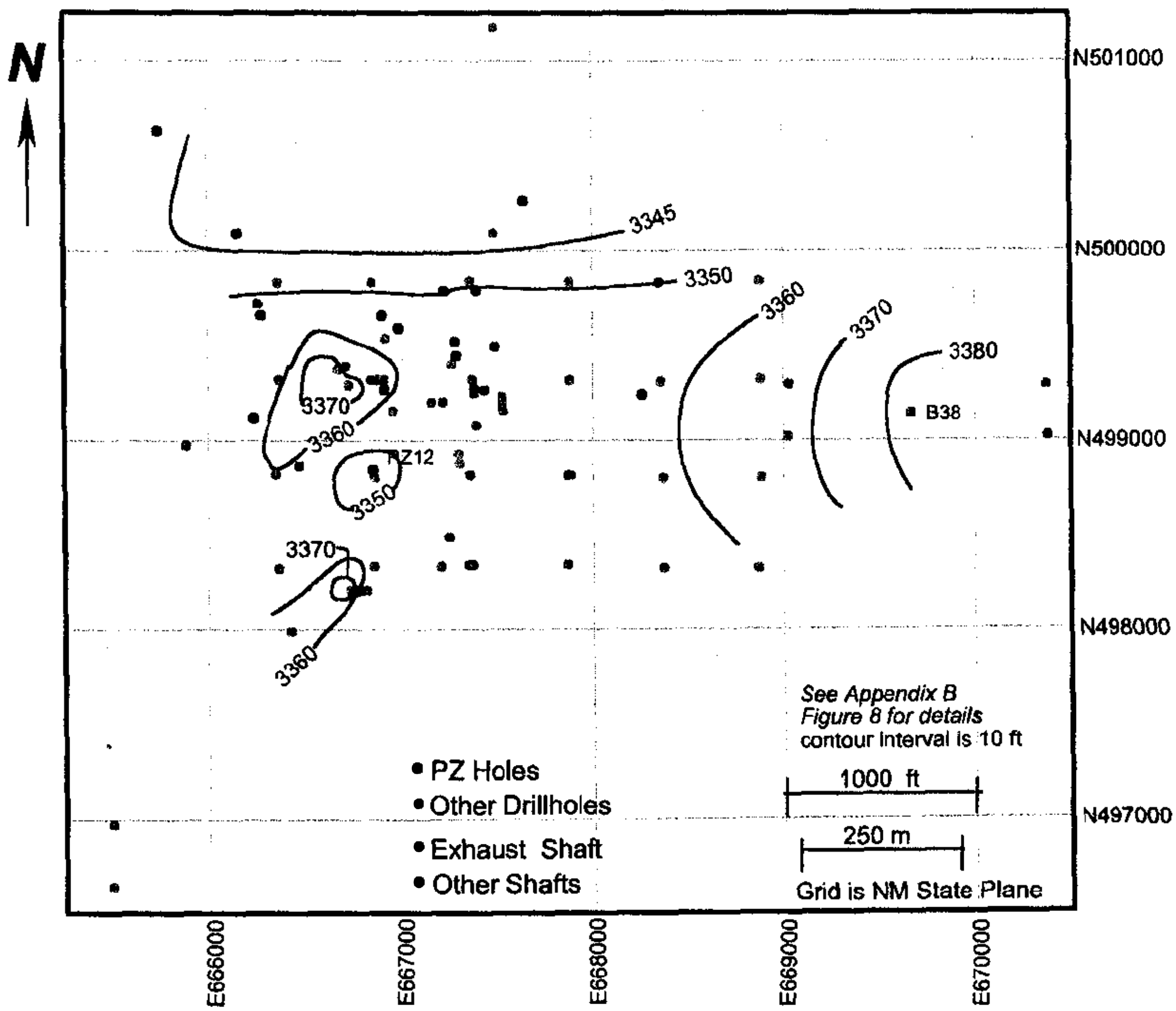


"pick" is consistent with the data, it is also very possible that the contact could be as high as 3359 ft (depth of 47 ft). Cuttings and core from the claystones and siltstones of this zone are not always clearly diagnostic (see, for example, AIS mapping; Holt and Powers, 1990). This datum is not being modified here; no conclusions of this report have been based on this single point.

Combining the PZ and B series data (Figure 8) reveals the same pattern across the facilities areas. In addition to the apparent anomalously low value at PZ 12, B 38

Figure 8

Elevation of Top of Dewey Lake Formation



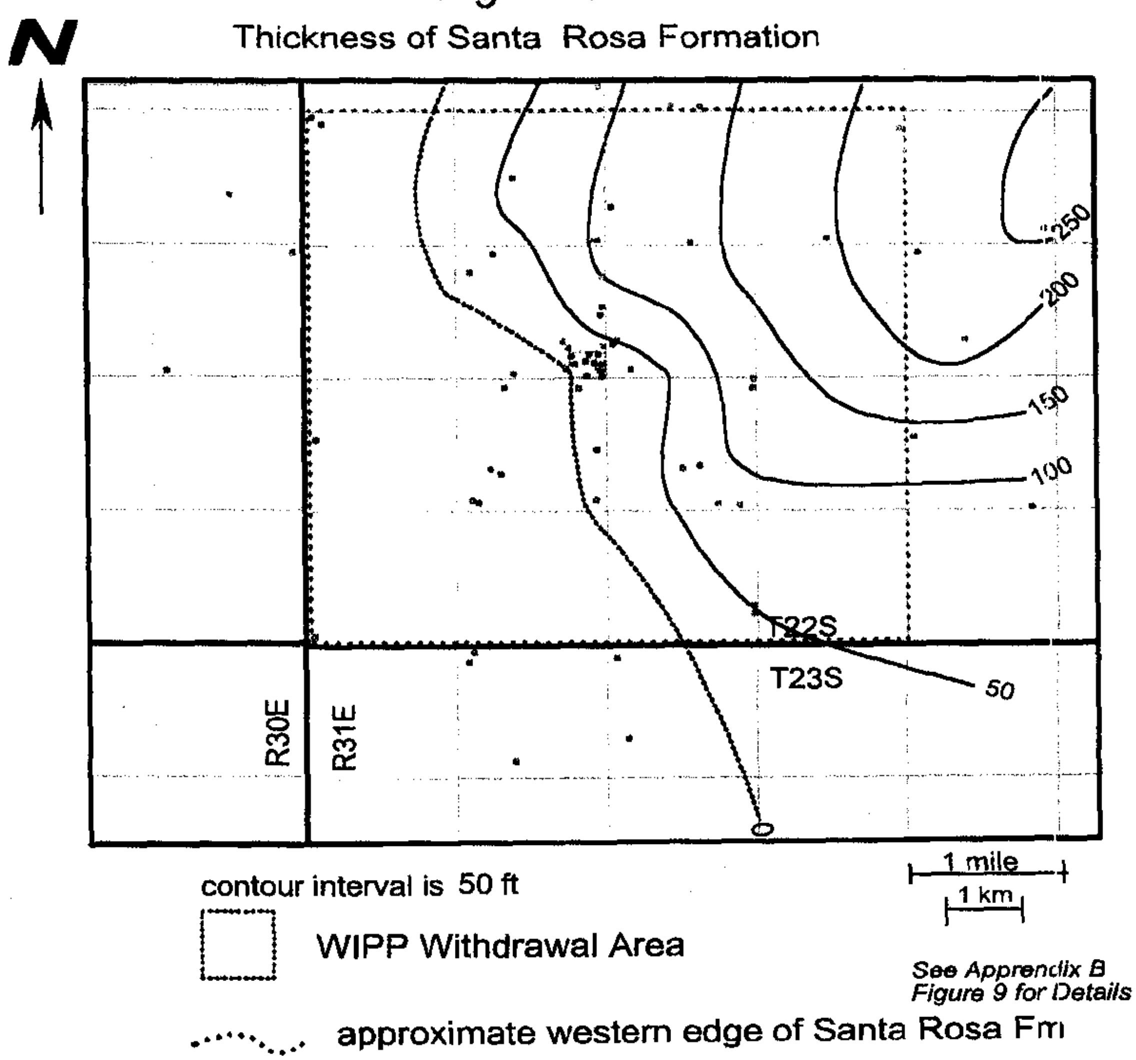
appears to have an anomalously high value of 3386 ft. The broader pattern (Figure 6) is that the surface of the Dewey Lake is becoming deeper to the east, toward P 2 and H15. The drill log of B 38 doesn't permit another interpretation of the data.

Santa Rosa Data

A map of the thickness of the Santa Rosa (Figure 9) displays a single trend of thickening to the northeast. The west-southwest half of the map is not known to have

Figure 9

Thickness of Santa Rosa Formation

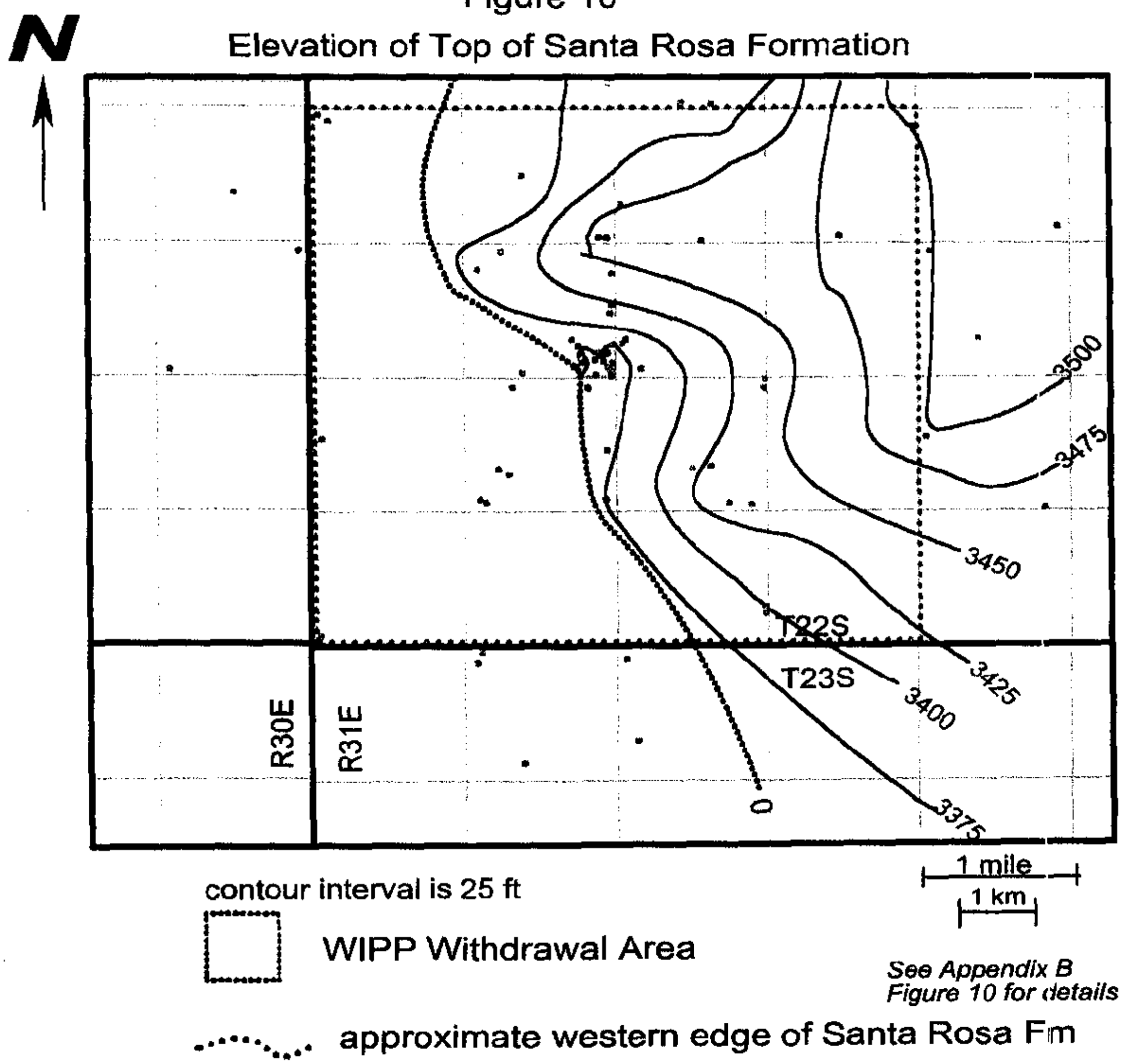


Santa Rosa, and an erosional edge of the Santa Rosa has been inferred based on drillhole locations and approximate gradient of thickness changes in the Santa Rosa.

Combined with the elevation map on top of the Dewey Lake, the Santa Rosa thickness indicates modest localized erosion and fill of the deepened area.

Elevations on top of the Santa Rosa (Figure 10) do not reflect regional structure trends. The elevations slope downward to the southwest toward the erosional edge of

Figure 10
Elevation of Top of Santa Rosa Formation



the formation from a high area near the northeast corner of the map. Across the northern edge of the map, the top of the Santa Rosa drops off more sharply.

Across much of the map area, Gatuña erosion of the Santa Rosa was fairly uniform across a planar surface. At the facilities location in the center of the map, a concentration of data causes some more abrupt contour changes. A modest valley trends approximately east from the facility areas, mirroring modern surface topography.

Within the facility area, the top of the Santa Rosa can be interpreted in more detail by considering the PZ and B series data. Two maps have been constructed, and they show very similar patterns. One map (Figure 11) uses the PZ and B data that are explicit; for the second map (Figure 12), I have inferred some Santa Rosa values where the original report (Sergent, Hauskins & Beckwith, 1979) did not include an interpretation of the top of Santa Rosa.

These two maps generally show that the top of the Santa Rosa declines to the southwest. Several drillholes from the area of the exhaust shaft to the southwest outline a narrow, deeper area of the contact between the Santa Rosa and overlying Gatuña. This is interpreted as an erosional channel on top of the Santa Rosa.

The Santa Rosa showed some characteristics that were common to most of the PZ drillholes. Medium to coarse grained greenish gray sandstones were observed in most drillholes in the lower part of the Santa Rosa. In addition, a zone of hard drilling was encountered near the base of the Santa Rosa. Chips from this zone effervesced very little and retained integrity even when treated with strong (muriatic) acid for at least 24 hours. This zone is likely partially silicified.

Gatuña Formation Data

The Gatuña in general thickens to the south and southwest of the site facility area (Figure 13). North and northeast of the facility area, the Gatuña is not present, and the Santa Rosa forms the subcrop under surficial sand and the Mescalero caliche.

Figure 11

Elevation of Top of Santa Rosa Formation (PZ & B Series Data)

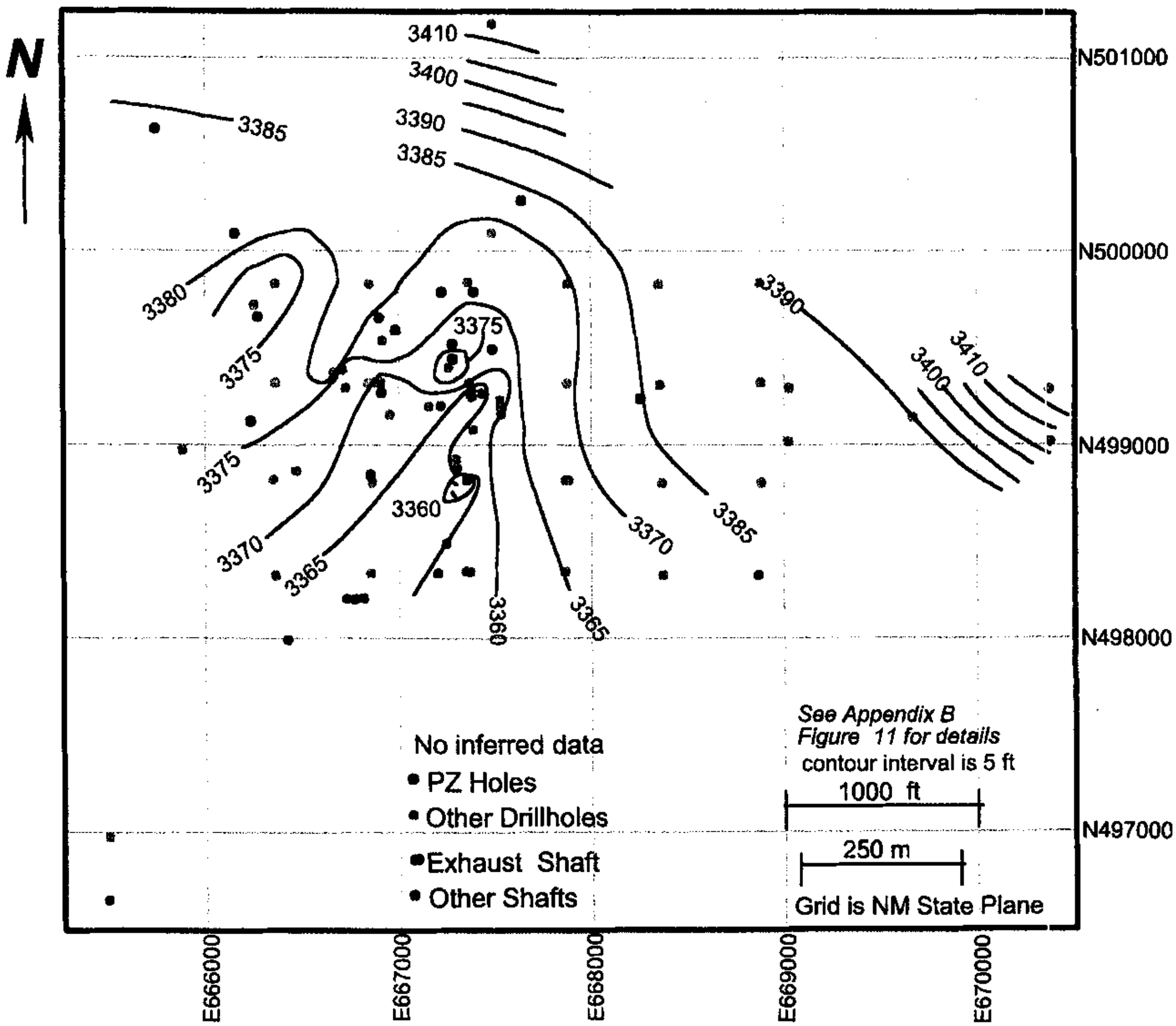


Figure 12

Elevation of Top of Santa Rosa Formation (PZ and Inferred B Series Data)

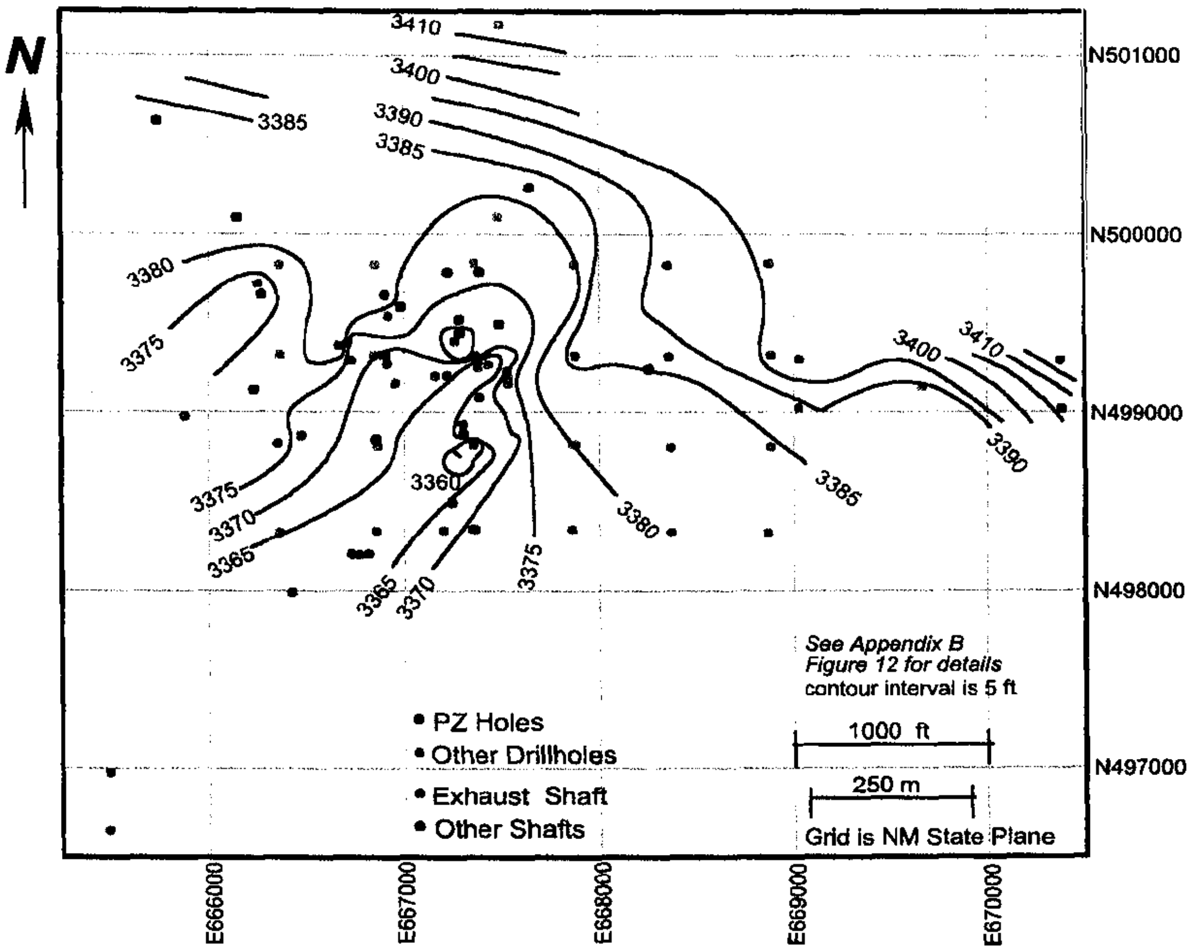
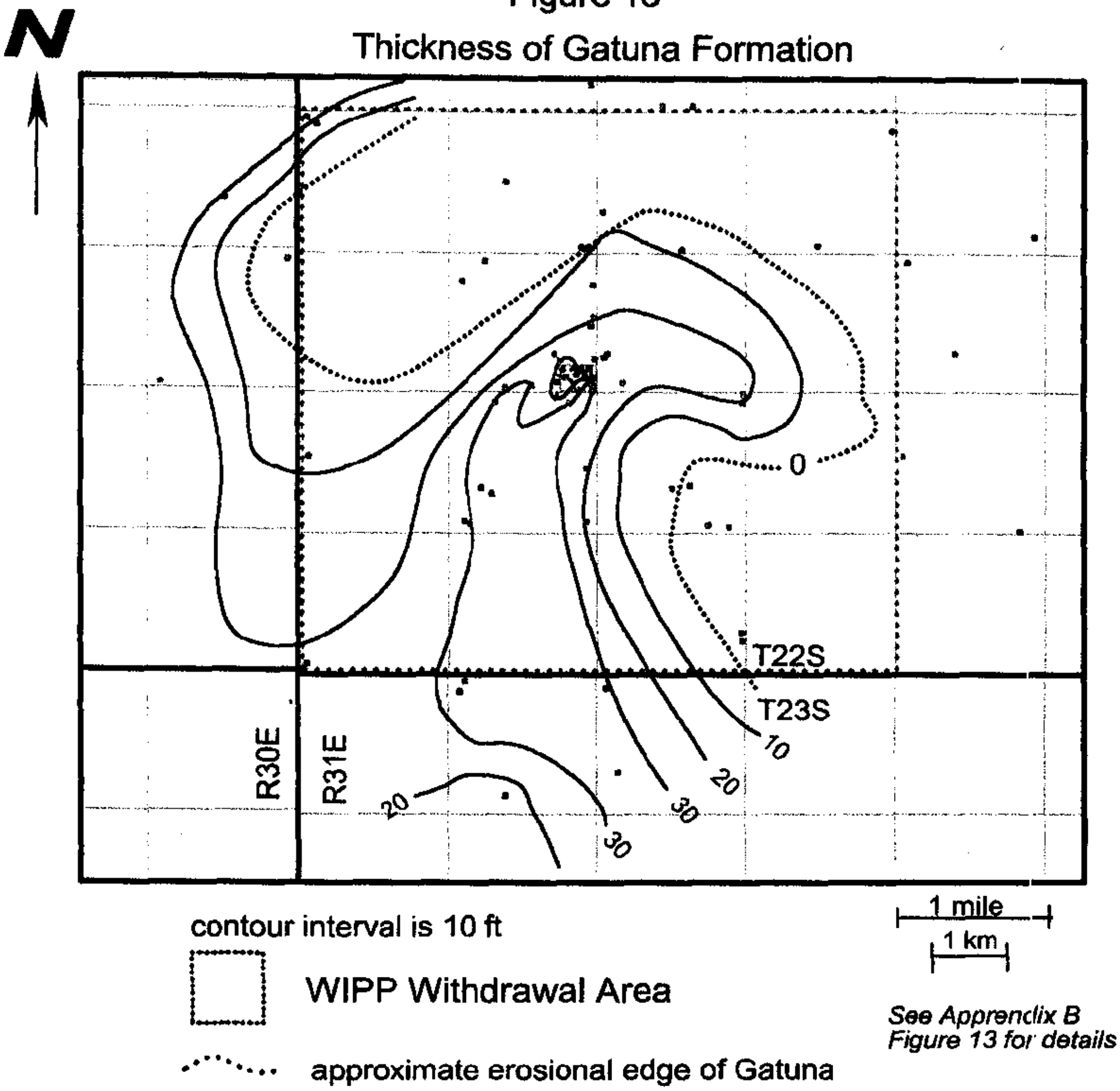


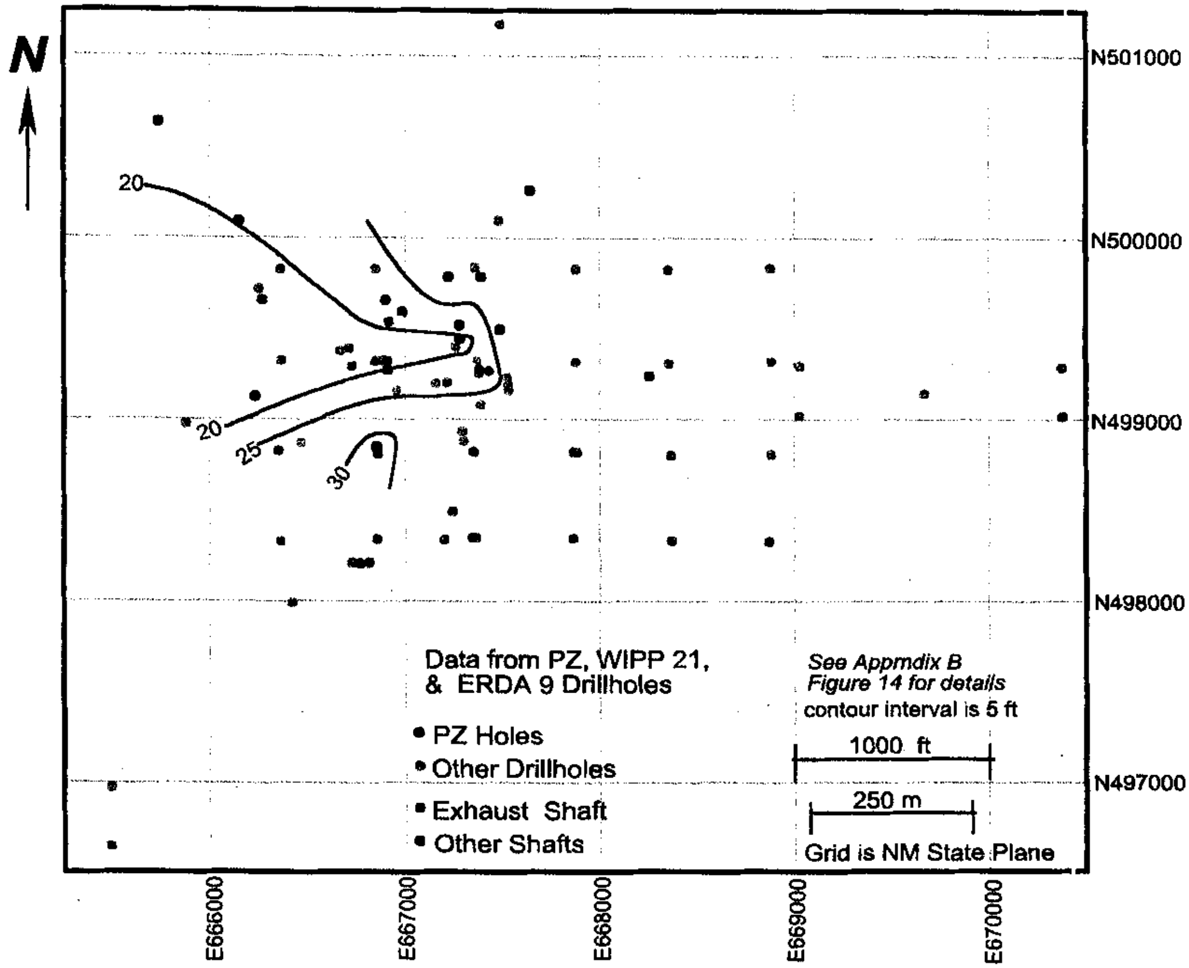
Figure 13
Thickness of Gatuna Formation



The Gatuña ranges from 19 to 31 ft thick in drillholes at the location of the surface facilities (Figure 14). The surface of the Santa Rosa was eroded by drainage to the south and southwest before the Gatuña began to accumulate in this area. Thinner Gatuña under the western area of the surface facilities is likely due to more recent erosion and erosion before the Mescalero began to form.

Figure 14

Thickness of Gatuna Formation



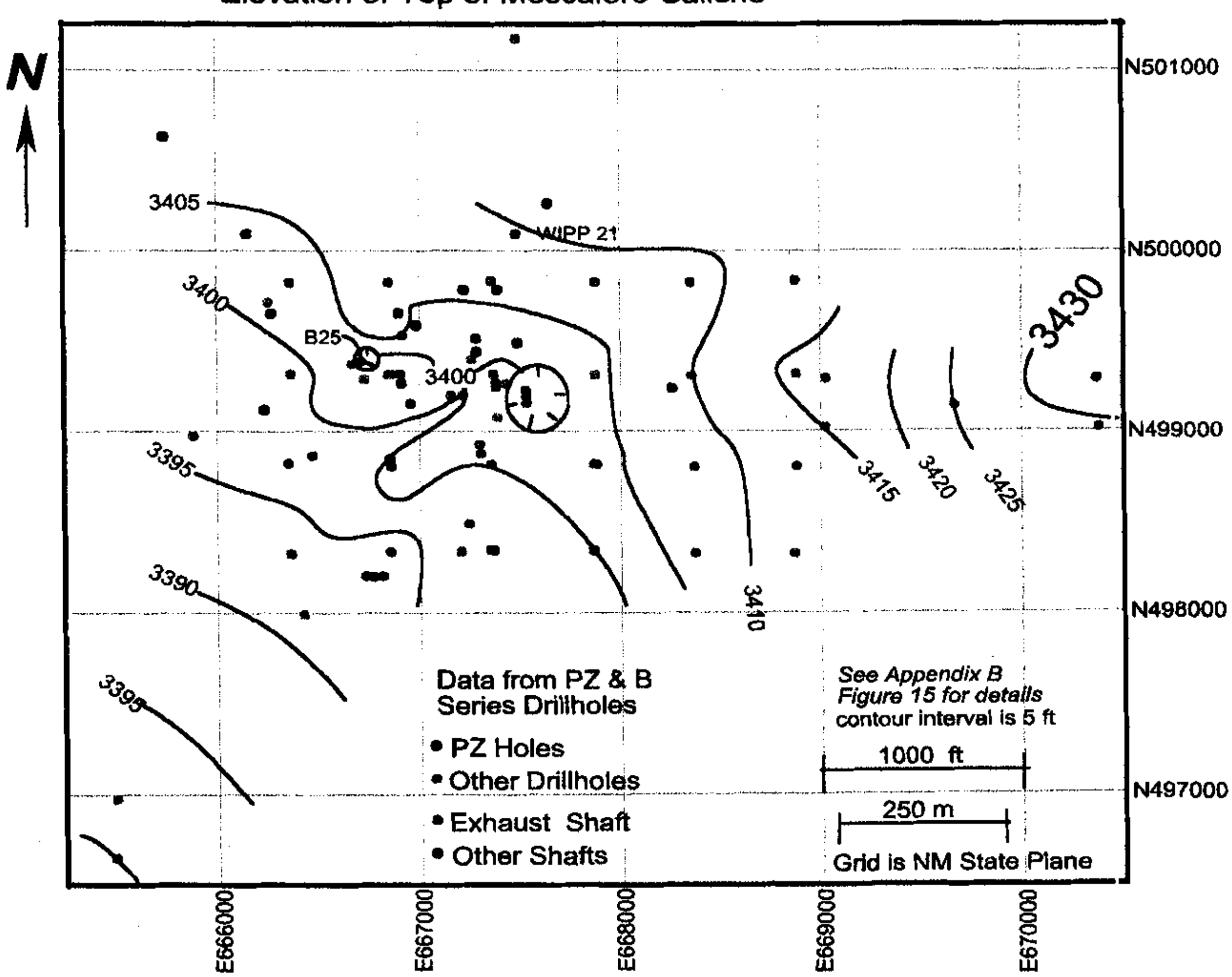
It is clear from drilling logs of the B series holes that the contact between Gatuña and Mescalero caliche for that work was distinguished differently from the current study and from most of the other site drillhole logs. In the B series drillholes, the Mescalero was continued downward through the zone where carbonate dominated or was at least quite significant. The Mescalero is commonly between 10 and 20 ft thick, as differentiated by this criterion in the B holes. The Mescalero is about 3 ft thick in other studies as well as for the PZ holes because the Gatuña is "picked" at about the first identifiable Gatuña sandstone. The B hole data are not equivalent to PZ data, they were not used to construct the map.

Mescalero Caliche Data

The Mescalero is generally present across the site and is noted in basic data reports for various drillholes. Only the elevation map of the top of Mescalero for the vicinity of the site facilities was constructed (Figure 15). Data from the B holes as well as current drilling are comparable.

Figure 15

Elevation of Top of Mescalero Caliche



As expected, Mescalero data generally conform to the topography of the area at the site, rising to the east and north. The most dramatic feature is an elevation low around 3 drillholes of the B series about 200 ft southeast of the exhaust shaft. This corresponds to a topographic low with more dense vegetation observable on aerial photos (Figure 16) taken before development of the surface facilities at WIPP.

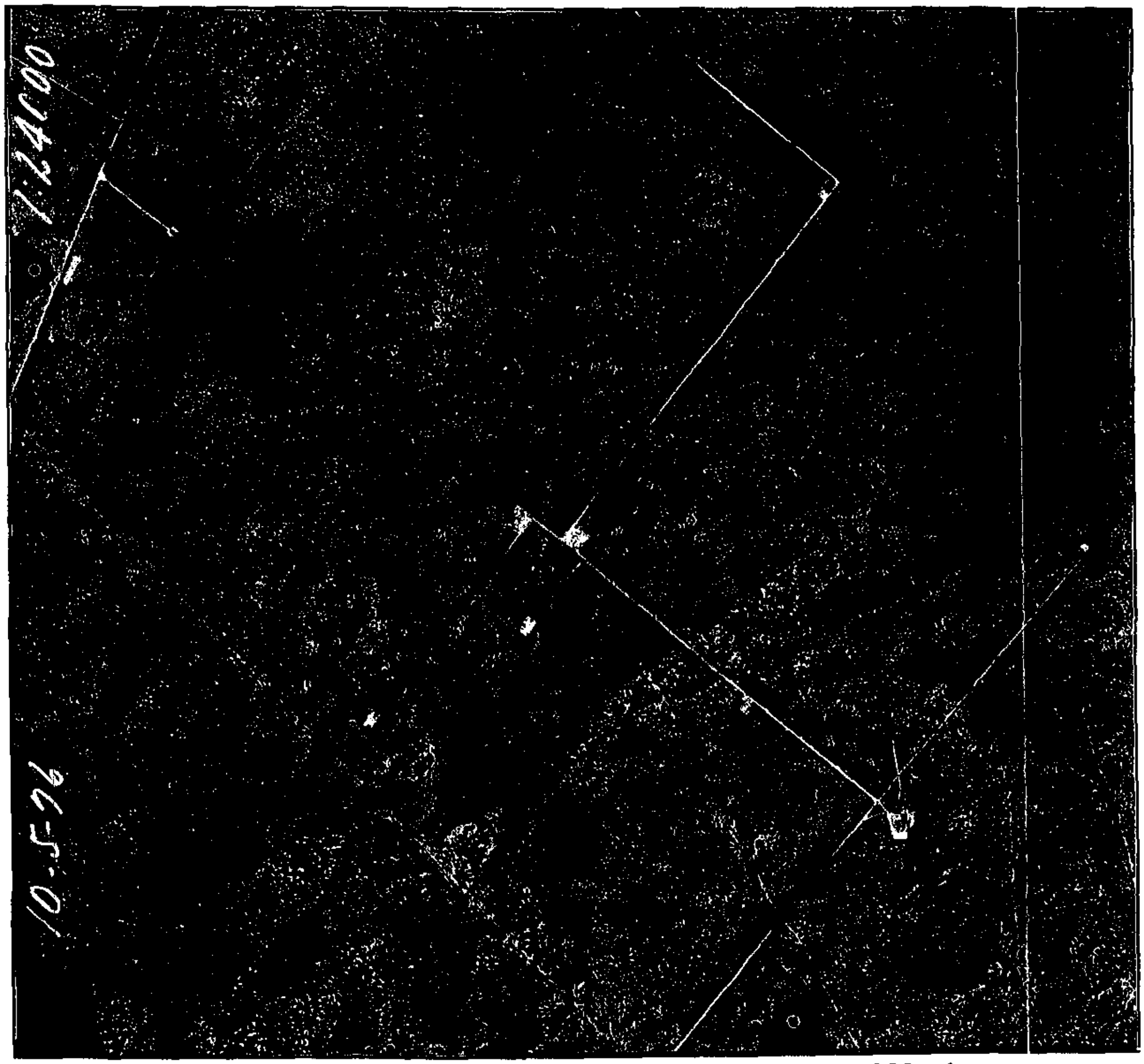


Figure 16. Aerial photo (10/5/76) of central WIPP site. Scale 1:24000. Arrow near center points to dense vegetation at location of topographic low and low on Mescalero caliche (see Figure 16). ERDA 9 drilling pad to left of central arrow.

Surface Sand and Berino Soil

The surficial sediments above the Mescalero were mapped for the design studies prior to construction. The main features of a map of thickness of this sand (Bechtel, 1979, figure 2) is a thick area that corresponds to the low on the Mescalero caliche and thinner sands to the west and southwest. Because there are very local differences associated with dune and interdune areas, no conclusions are based on these sand distributions.

OTHER DATA RELATED TO PERCHED WATER

In order to better understand the various geological factors that may affect location and distribution of the water at shallow depths under the facility, I examined records for other information that may bear on this problem. While these data are neither as precise nor as directly relevant as some of the recent drilling data, they are helpful in understanding broader patterns. The drilling for the potash tests (Jones, 1978) is used as the data base because it provides a reasonably consistent data set with respect to drillhole logging techniques, drilling methods, and descriptions. Some of the other WIPP drillholes near the WIPP site supplement the data from the potash drilling.

Long study of the WIPP site consistently demonstrates that the rocks above the Rustler are not saturated, though apparentlyirregular zones of perched water have been encountered. As porosity is a necessary factor for perched water, I examined phenomena that may signify porosity zones in the shallow subsurface. Examples are reports of cementing minerals, levels of drilling fluids during geophysical logging, loss of circulation, and resistivity changes.

Presence of Sulfate in Dewey Lake

Sulfate occurs in the Dewey Lake most visibly as fillings of fractures (e.g., Holt and Powers, 1990). In addition, Holt and Powers (1990) reported a cementation change in the AIS at a map depth of 164.5 ft (183 ft below surface) that coincided with the uppermost detectable gypsum fracture fillings. Though not analyzed further, Holt and Powers (1990) suggested that the cement was probably anhydrite. The Dewey Lake just above this cementation change was moist in the AIS, suggesting that the cementation change can perch available water if it infiltrates to that depth. For this analysis, I used reported gypsum, which is almost certainly from fracture fillings, as a proxy for this cementation change because of the relationship in the AIS.

I plotted the elevation of the uppermost reported sulfate (Figure 17) as an estimate of trend of the cementation/fracture filling across the WIPP site. The map includes an area along the eastern part of the map where the top of first reported sulfate is high, above 3200 ft. There are also high areas in the north and western parts. A low area trends from near the site center to the south-southwest, and there is a low based on one drillhole at the south central edge of the map.

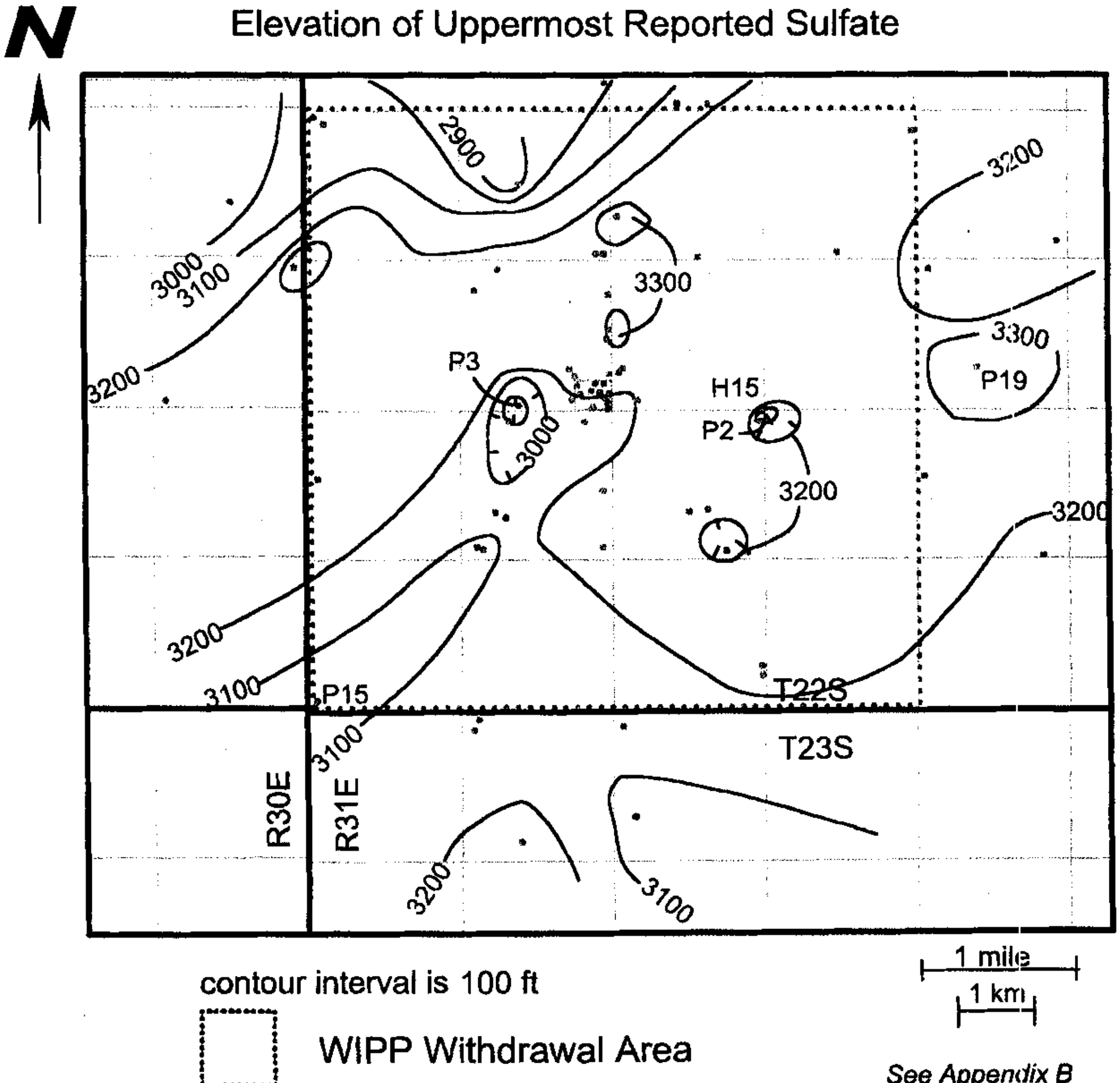
This map should not be overinterpreted. There is a difference of about 140 ft in the first reports of gypsum in two adjacent drillholes (P2, H15; Figure 4) in the east-central part of the map. This is most likely a consequence of a factor such as how the drilling was returning cuttings to the surface at any particular time. The main features are the broad high areas and the lows along the northwest corner and south of the facilities, and they are indicated by several drillholes rather than a single data point.

The top of the Dewey Lake is somewhat irregular compared to the general eastward dip on underlying units. To the east and northeast, gypsum is stratigraphically higher in the Dewey Lake. At P19, gypsum was reported in the lower Santa Rosa. West of the site center, there are also some drillholes in which the gypsum is stratigraphically high. To the northwest and in the south central part of the map, gypsum is progressively lower in the Dewey Lake; at P15, in the southwestern corner of T22S, R31E, the Dewey Lake does not appear to have gypsum at all.

As a first approximation, gypsum in the Dewey Lake is believed to signal a vertical change in porosity due to cementation that can retard further infiltration and result in perched water. This change corresponds generally to a position close to but below reports of water in the Dewey Lake in the southern part of the site area.

Figure 17

Elevation of Uppermost Reported Sulfate



See Appendix B Figure 17 for details

Fluid Level During Logging

The fluid level during logging is a function of factors such as rock permeability, drilling techniques (including adding material to reduce loss of drilling fluids), and adding fluid to the drillhole before logging. While there is no information about the potash drilling that allows reconstruction of all of these factors, the methods of drilling were the same, and the logging target was the Salado. It is less likely that, for example, additional fluid was added to the hole during logging to maintain the level to near the surface. As in the review of data about gypsum, trends are more likely to be real, while a single drillhole might be atypical because of a variety of events preceding and during geophysical logging.

The fluid level was reported explicitly for a few of the potash drillholes (Jones, 1978). The neutron and density log responses for the drillholes indicate depth of water during logging; the only ambiguous drillhole was P19.

The map pattern of fluid levels during logging (Figure 18) shows high areas to the east and along the west, with a low trough trending northwest-southeast across the southern part of the site.

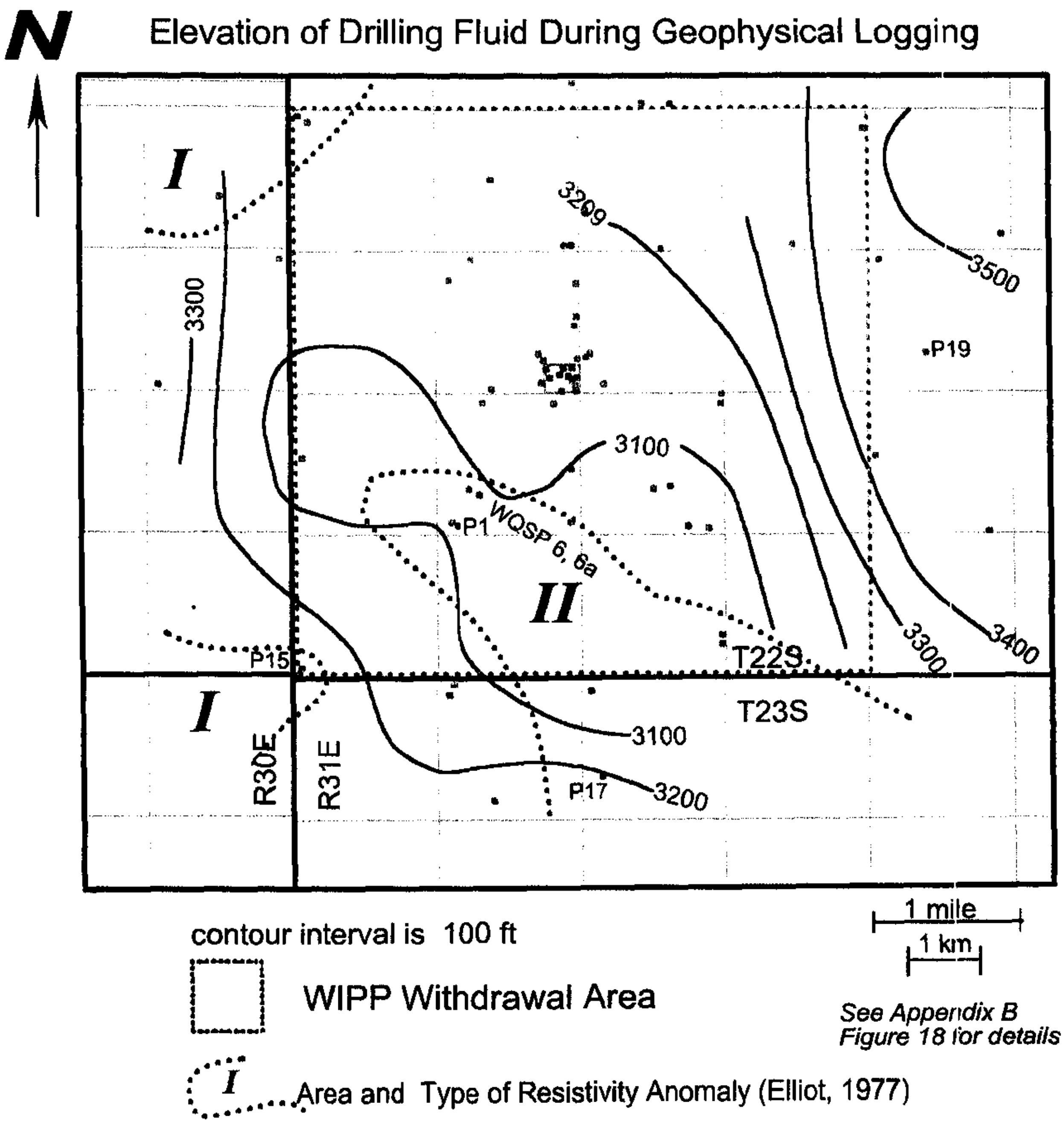
Along the eastern side of the map, the logging water remained close to the surface in a position stratigraphically equivalent to the upper Santa Rosa. The high elevation of logging water along the western side and southwestern corner of the map is the top of the Dewey Lake, also near the ground surface. Along the low trough, the top of the logging water was commonly 200 to 300 ft below the top of the Dewey Lake.

Loss of Circulation/Reported Water/Resistivity Data

Along with information from the potash drilling, basic data reports for most other drillholes in the map area were examined, and loss of circulation was indicated at relatively shallow depths in several drillholes (Table 2). While loss of circulation indicates zones of relatively greater permeability, it is again only useful as an indicator of trends. Drilling techniques varied for many holes, and air drilling doesn't respond in the same manner as drilling with water or brine.

Figure 18

Elevation of Drilling Fluid During Geophysical Logging



As a number of the potash holes were drilled with air through the upper section, encounters of water were more likely to be observed and reported. Water was reported in the Dewey Lake from three drillholes (P1, P15, P17, noted on Figure 17) during potash exploration, but none of the drillholes was completed as an observation or test hole for this water. These drillholes are all in the southwestern part of the map. More recently, WQSP6 (noted on Figure 18) encountered water in the lower part of the Dewey Lake as well at a location less than a mile from P1.

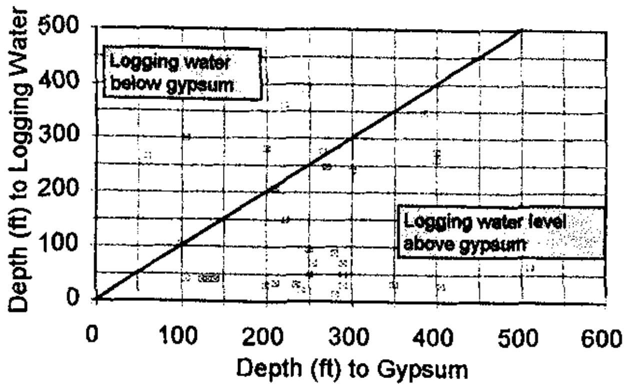
A major resistivity survey of the WIPP site was conducted in 1976 and 1977 (Elliot, 1977) as part of site characterization. Three larger areas with anomalously low resistivity were identified; they were classified as type I and II anomalies (Figure 18). Elliot (1977) inferred that the type I anomalies, located in the northwest and southwest corners of the studied area, were associated with a dissolution front and water. The lobate type II anomaly is oriented northwest to southeast and was believed to reflect an area of greater porosity. Elliot suggested that this anomaly reflects "an increase in porosity or water-bearing properties of perhaps the upper Salado, definitely the Rustler Formation and maybe even the lower part of the Dewey Lake Formation." All four of the drillholes (P1, P15, P17, WQSP6) that encountered water in the Dewey Lake are in the type I and II resistivity anomalies. [Note that the main differences between "type I and II" anomalies is in the interpretation, not in the geophysical response.]

Discussion of "Other Data"

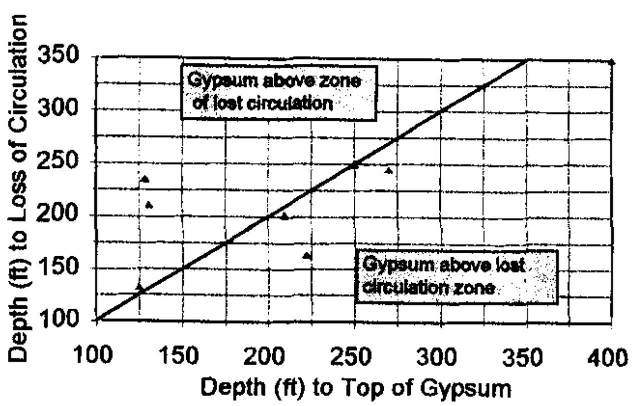
In principle, the change in cementation of the Dewey Lake, fluid levels during logging, loss of circulation, and occurrences of water in the shallow subsurface should show some relationship. The three features of cementation, fluid levels, and loss of circulation (Figure 19a,b,c) (Table 2) show little relationship among these variables. The maps (Figures 17, 18) are a better indicator of some trends.

Figure 19

A. Logging Water vs Gypsum



B. Gypsum vs Circulation Loss



C. Log Water vs Loss of Circulation

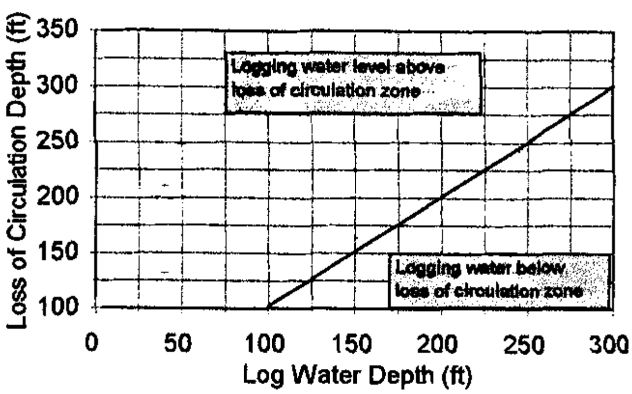


Table 2

Data for Figure 19A,B,C

Drillhole Name	Top of Gypsum	Top of Log Water	Lost Circulation Zone
P1	270	245	245
P2	385	345	
P3	400	260	
P4	245	382	
P5	265	276	
P6	105	306	
P7	210	208	
P8	200	280	
P9	250	395	
P10	255	70	
P11	350	32	
P12	60	266	
P13	300	240	
P14	105	40	
P15	235	32	
P16	100	104	
P17	280	88	
P18	290	30	
P20	405	30	
P21	280	14	
e9	222	150	164
w12	199	30	
w13	510	65	
w18	250	50	249
w19	131	40	211
w21	210	35	
w22	210	35	202
w33	400	274	350
w34	290	70	
h11b3	122	458	
h11b4	240	20	
h12	129		235
h14	220	360	
h15	250	95	
h16	140	40	
h17	290	50	
h18	125	40	132

Note: All data in feet below ground.

Logging fluid levels indicate that in the east and northeast of the map area, there are few porous zones for the fluid to leak into in the shallow subsurface.

The most striking relationship (Figure 18) is between the 3 factors of logging fluid elevations, areas with anomalously low resistivities for the area (Elliot, 1977), and occurrences of water within the Dewey Lake. All of the WIPP holes that encountered Dewey Lake water in the southern area are clearly associated with the resistivity anomaly. And the outline of anomaly II is very similar to the low area on drilling fluids. The resistivity anomalies also correspond well with low elevations of uppermost sulfate in a southeasterly trend as well as at the southwestern corner of the WIPP site. The very low elevation of sulfate in P3 near the center of the site doesn't correspond to resistivity anomalies. That point is anomalous with respect to other sulfate data, and the uppermost sulfate may have been missed.

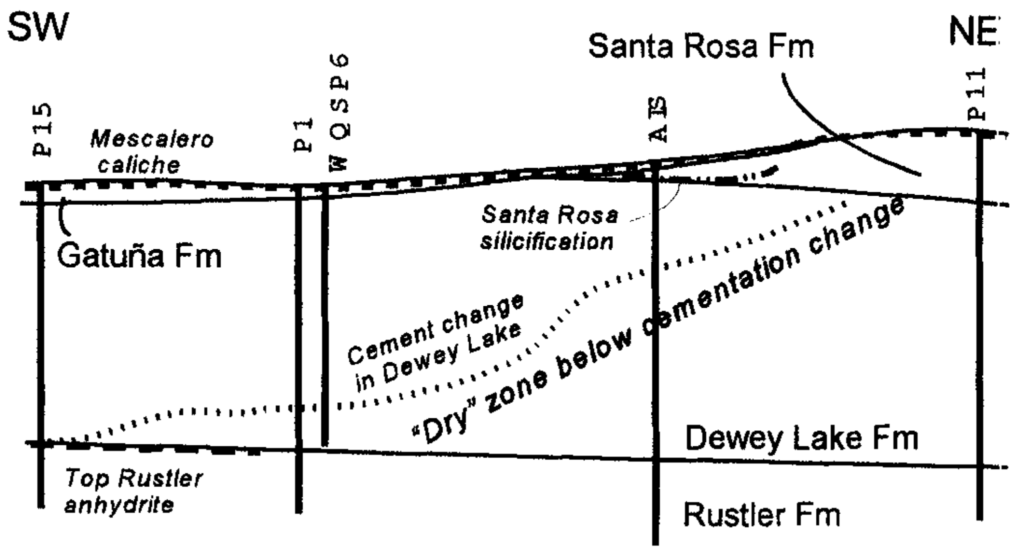
HYPOTHESIZED PERCHING ZONES ACROSS WIPP

The combination of rock types and observed moisture suggests that there are four zones (Figure 20) from the top of Rustler that may serve as perching horizons if water infiltrates to the zones.

The lowermost perching zone (Figure 20) exists across the site because of the relative impermeability of the uppermost anhydrite of the Rustler. It is likely only effective around the southern and western margins of the WIPP site (e.g., P15) where stratigraphically higher horizons are not impeding infiltration.

The next higher perching zone is hypothesized to be a cementation change within the Dewey Lake, such as Holt and Powers (1990b) observed at the AIS. I took the uppermost sulfate as an approximation for this cementation change based on the AIS data. Sulfate is observed progressively higher stratigraphically across the site from southwest to northeast, with an area corresponding generally to the resistivity anomaly and water occurrences that roughly parallels dip. From the

Figure 20
Diagrammatic Representation of Perching Zones Hypothesized Across the WIPP Site



middle of the site to the east, this perching zone may be less involved as overlying zones reduce infiltration. At the site center, this perching zone appears also to have affected water infiltrating from surface halite tailings piles, considering the report of a second wet zone in the AIS.

Around the WIPP surface facilities, we encountered a hard drilling zone or zones in the lower Santa Rosa in association with the shallow water. As the uppermost Dewey Lake was clearly dry in several PZ drillholes, the finer grained siltstones and claystones of the Dewey Lake likely combined with indurated lower Santa Rosa to create a perched zone.

The surface sands above the Mescalero caliche are very commonly damp, as was noted both during our drilling program for the PZ holes and for the design studies (B series drillholes). This moisture from surface precipitation ordinarily only infiltrates to about the level of the Mescalero; this is the source of this particular unit. Well formed Mescalero will impede infiltration locally, but it is unlikely to form a strong perching zone. If water ponds frequently in a area, the eventual result will be to dissolve the carbonate and move it deeper through infiltration. Though I list the Mescalero as a potential perching zone, it would only be a short term barrier from a geological perspective.

CONCLUSIONS

Water encountered during drilling of the PZ holes appears to be restricted to the lower Santa Rosa. Sandstones in this zone are commonly fine to coarse grained and quite porous. While some drillholes show thicker greenish-gray sandstone at about this level, the saturated sandstone in other drillholes is generally brown. One characteristic of the lower Santa Rosa is hard drilling zones, and chips from these units have little carbonate. There is likely some silicification. The greenish-gray reduction and silicification are undoubtedly ancient features and are unrelated to the water currently at this level. The water is perched on the upper Dewey Lake, which was clearly dry in several of the drillholes.

The Santa Rosa also includes interbedded siltstones and claystones that appear variable in thickness and distribution, though rotary drilling through the Santa Rosa in most drillholes limits estimates of the thickness and extent of these less permeable intervals of the Santa Rosa. Cores from some of the drillholes show relationships and variation consistent with fluvial depositional environments interpreted for the Santa Rosa. These zones will affect estimates of the saturated thickness and fluid volume in the saturated zone.

Review of shaft data and facility design drillholes demonstrates that the Santa Rosa under the site facilities area was not saturated through 1984. The water encountered here postdates 1984, and the sodium chloride content shows that at least some infiltrating water contacted surface salt piles or other sources of salt at

WIPP. By 1988, the AIS had wet zones with salt efflorescence in the Santa Rosa and also the Dewey Lake.

Less precise data about sulfate cements, fluid levels during logging, loss of circulation zones, and resistivity anomalies were reviewed as guides to broader site characteristics to explain the shallow water at the site facilities. There are likely several perching zones (uppermost Rustler anhydrite, cement change in Dewey Lake, silicification/induration of lower Santa Rosa, and, temporarily, the Mescalero caliche) that are involved at different locations and to differing degrees across the site, depending on the geologic history of erosion and exposure.

To the south and west of the area investigated during this study, the Santa Rosa pinches out due to erosion prior to Gatuña deposition. If the shallow water in the Santa Rosa moves in that direction, the Santa Rosa will cease to be a perching horizon, and the water will seek the next perching horizon, which is most likely the cementation change in the Dewey Lake.

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APPENDIX A

Field Geological Logs
for PZ Series Drillholes

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1 | LOCATION: North of Exhaust Shaft - WIPP

DRILLING DATE: 6/23/97 | EXCAVATION DATE: | NORTHING:

DRILLING DIRECTION: Down | DRILL METHOD: | EASTING:

DRILL MAKE/MODEL: | COLLAR ELEVATION:

HOLE DIAMETER: 3¼ ID 6.00 OD (IN) | HOLE DEPTH: 67.5 (FT) | DRILLING CREW: Geoprojects

LOGGED BY: DW Powers | DATE: 6/23/97 | SCALE: 1 inch = 2 ft | SHEET 1 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
augered			13–29 (15, 17, 19, 21, 23, 25, 27, 29)		Probable fill of eolian sand, some pebbles, pieces of caliche to 11 ft depth. All moist, some calcareous clay @ about 9 ft. Top of undisturbed Gatuña Fm @ 11 ft. Siltst, argillaceous, sandy zones. Very calc. at top, mod calc. downward with some non-calc. zones. Gen. 2.5YR 6/6 light red. 11-34.	Begin about 3pm. Augered to 15 ft down location augered by hand. Augering to estimated 34' before coring.

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: Nol exhaust shaft		
DRILLING DATE: 6/23-24/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: down	DRILL METHOD:	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¼" ID (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/23/97 & 6/24/97	SCALE: 1" = 2ft	SHEET 2 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
augered			29		Gatuña Fm., cont	
			31			
			33			begin coring 4:10 p
1	~1'	34.5			included plug from augers. rootcasts, <<1 mm dia, MnO_2 staining.	
2	~4'	NA	35		Ss, silty, argill, and siltstone, sandy, argill. 2.5YR3/6 dark red. Gen poor to mod induration, core doesn't hold together well. Porous, some scattered bioturbation and MnO_2. Sand is fine to very fine, generally subround, mod. sorting.	
			37	MnO_2	Calc. zone, hard, pebbles from Santa Rosa - black chert. Small pores, root casts.	
		39.0			Hard, calc. ss. @ ~38.7, w/crystalline cement and 1 mm. claystone clasts	
3	~2.0		39	no recovery	Gatuña Fm (possible that Santa Rosa begins @ 37.5 ft; matrix appears ≈ Gatuña to ~40').	
					Santa Rosa Fm	
			41			
					gg moist 42.1-42.4 5YR8/1 white	
			43		Arg. sltst., slightly sandy, calc 10R4/6 red.	end drilling at 44.0 @ 5 pm
		44.0				water @ 41.82 ft bgs @ ~8 am 6/24/97
			45			

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: N. of Exhaust Shaft	
DRILLING DATE: 6/24/97	EXCAVATION DATE: 6/24/97	NORTHING:
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:
DRILL MAKE/MODEL:		COLLAR ELEVATION:
HOLE DIAMETER: (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects
LOGGED BY: DW Powers	DATE: 6/24/97	SCALE: 1" = 2 ft. SHEET 3 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
4	52"	NA	45–49		Ss. w/thin zones siltstone. Sand is v.f.-med, subround, mod. sorting, ~1% mica (mainly biotite). Poor to mod induration, mild effervescence. Thin bedding (2-4mm) with variable cementation. (44'-49.5)	Core 4 moist.
5	~4	49.0–49.5	49			
no core			51		Ss, silty, dark brown, poor recovery - strat position probable.	recovered soupy mud on top of core
6	3'	52.0–54.0	53		7.5YR 6/4 light brown; brownish gray to gg zone; 5YR 7/2. Ss, generally light brown to greenish-gray from about 51.5-54.3 Sand gen. fine. to fine, some med, subround to round, mod. sorting, slight fining upward. Bed effervesces slowly. Well cemented. Breaks horiz. into ¼ to 10" pieces	slow drilling
7	6"	54.0–54.5			SS, dk brown w/ white cemented pores, gen. med sand, subround. Calcareous, brittle - discs ~1/8";	
cement			55			slow drilling - clean hole out - did not log material recovered.
8	2'	NA	57		Dewey Lake Fm 2.5YR 4/4. Interbedded dark brown siltstone and silty claystone w/ greenish gray reduction spots. Calcareous - slow eff. Core recovered in pieces. Some thin layering observed, v.f. ss. layers	
9	5'	NA	59–61		-88	

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: N. of Exhaust Shaft		
DRILLING DATE: 6/24/97	EXCAVATION DATE:		NORTHING:
DRILLING DIRECTION: Down	DRILL METHOD:		EASTING:
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¼" ID (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/24/97	SCALE: 1" = 2ft	SHEET 4 OF 4

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
			61		V. thin laminae (fissile) silty claystone 61-63.5	
9	5'				fissile; D.L. shows some slight fining upwards cycles from sandy siltst. or siltstone to silty claystone.	dry
			63			
10	4'		65		diagrammatic rep. of fining upward cycle thicknesses	
			67			
		67.5				TD 67.5 @ 12:08 pm

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-2	LOCATION: East of Exhaust Shaft Bldg.		
DRILLING DATE: 6/24/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¾" ID (IN)	HOLE DEPTH: 65 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: D.W. Powers	DATE: 6/24/97	SCALE: 1" = 4 ft	SHEET 1 OF 3

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
auger only			0		light brown eolian sand/fill to 6'; slightly reddish brown from ~6' - ~9'	spud 4:55 pm
			4			
					Berino?	
			8		Mescalero caliche	
			12		Gatuña - highly calcareous sand, ss, f to coarse, poorly sorted	
			16		light reddish brown	
			20		med reddish brown	5:25 pm.
			24			
			28			
			32			

GEOLOGIC ROCK CORING LOG

HOLE ID: Pz-2	LOCATION: East of Exhaust shaft		
DRILLING DATE: 6/24/97-6/25/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: Down	DRILL METHOD: Auger/Auger with split spoon	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¼" ID (IN)	HOLE DEPTH: 65 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/24/97-6/25/97	SCALE: 1" = 2ft	SHEET 2 OF 3

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
			32			
end augering						end augering @ 5:45p. lightning
1	6"		34		Ss, pebbly (to 1"). Sand mainly f-c, poorly sorted, subang to subround, <1% opaques, little biotite. Pebbles of ss (intraclasts, some prob Santa Rosa), small chert granules. Friable to poor induration, porous, gen non-calc. to ~37.5'. Calcareous, MnO_2 staining 37.5 to 39.0	begin 8:20am 6/25/97
2	3½ ft	NA	36		~2.5YR 4/6	
					non calc.	
			38		calc. Slight MnO_2 ~2.5YR 5/6-4/6	
					Gatuña	
		39.0			Santa Rosa Sandstone, dark reddish brown, well indurated, slightly calc, grains show prob. silica overgrowth for slight add. cementation. Sand gen f, mod well sorted, well rounded to subround, ~1% opaques, includes biotite. Laminae ~2-3mm thick, parallel bedding 39-42; 2-4mm from 46.5-48; 3-5mm from 48.5-52.	
3	3'	1 piece 1' long	40		2.5YR 3/4 Dark reddish Brown	possible more/less of core
		42	42		Zone from ~42-44 shows intra clasts of SR ss in reddish brown sandy siltstone.	
4	2'	friable to pieces <2"			2.5YR 4/6 mottled 6/6	
		44.0	44			
5					2.5YR 3/6 dark red - non-calc	core moist top core ~45-46.5
	4'	gen. mainly	46			
					2.5YR 4/4 slightly calc. thin lam. 2-4mm 48	harder drilling
			48			