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# Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM

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SITE SELECTION AND EVALUATION STUDIES OF THE WASTE ISOLATION  
PILOT PLANT (WIPP), LOS MEDANOS, EDDY COUNTY, NM

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ABSTRACT

Bedded-salt deposits of the Salado Formation have been selected for evaluation for a proposed Waste Isolation Pilot Plant (WIPP) to be located in Eddy County, NM, ~26 mi east of Carlsbad. Site selection and evaluation studies that included geologic mapping, geophysical surveys, drilling, and resource appraisal were conducted over and under the prospective location. The lower portion of the Salado meets essential criteria for waste isolation. Beds chosen for waste storage lie 2074-2730 ft below the surface. High-purity salt exists at these depths, and the geologic structure revealed by geophysical surveys indicates that these beds are essentially flat. Additional geophysical surveys are now under way. The initial interpretation of the new data indicates that more structure may exist in the salt beds in the northern portion of the site area. Full evaluation of potentially commercial deposits of potash and natural gas within the WIPP site will be reported by separate studies, as will be the hydrologic details of the region.

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Special mention is due a working panel that periodically reviewed the progress of the site study. Members of this panel were: Roger Y. Anderson, Charles L. Elliot, Gebhard J. Long, Edward L. Reed, Sherman A. White, and Roy C. Williamson, Jr.

Charles L. Jones of the U.S. Geological Survey has been associated with the WIPP since its inception. His works and thoughts provide the basis for parts of this report. Jerry W. Mercer and Brennon R. Orr, also of USGS, conducted the hydrologic studies at Los Médanos.

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SITE SELECTION AND EVALUATION STUDIES OF THE WASTE ISOLATION  
PILOT PLANT (WIPP), LOS MEDANOS, EDDY COUNTY, NM

Introduction

Sandia Laboratories has investigated the feasibility of constructing an underground facility for the terminal isolation of radioactive waste (radwaste) in southeastern New Mexico salt beds. The project is known as the Waste Isolation Pilot Plant (WIPP). One objective of the project is to establish the suitability of halite (salt) as the surrounding medium for radwaste. This report addresses the initial site selection and evaluation of an area believed to be suitable.

The scope of this report is limited to geologic investigation of the immediate area proposed for the site. Other studies that relate to site characterization, such as hydrology and ecology, will not be discussed in this report but will be reported separately. Site investigations are continuing, with new knowledge being gained almost daily. This report considers only studies completed before June 1, 1977.

Much previous geologic work preceded Sandia's entrance into the WIPP program. It is assumed that the reader is knowledgeable about published reports of the U.S. Geological Survey (USGS) on their work from 1972-1975. In addition, familiarity with the regional geologic setting of the New Mexico portion of the Delaware Basin is assumed. A regional geologic summary is being prepared by Dennis Powers and Sue-Ellen Shaffer (SAND77-0448).

This report is supported with 37 illustrations (Figures 1-37). The first 18 are maps that commence with the surface and progress downward through the geologic section. They will not necessarily be introduced in that order in the text. Figures 19-27 deal with drilling, geophysics, and resources. The last five illustrations (Figures 33-37) contain photographic scenes of the general area and the activities conducted during site evaluation. A reader not acquainted with the physiography of southeast New Mexico or not knowledgeable in the techniques of geologic exploration may find it desirable to review these photographs before attempting to digest the text that follows.

Engineering studies have indicated that ~3 sq mi will be needed for the underground facilities. Additional area will be required beyond the excavated area to ensure the long-term integrity of the repository. A 1-mi-wide zone around the repository will be established in which no underground excavation or deep drilling is allowed, with an additional 1-mi-wide zone established in which some underground mining and deep drilling will be allowed. On the surface, only the plant site (an area limited to ~60 acres) will require restricted access. The eventual design led to the designation of four zones:

Zone	Zone Use	Acres
I	Surface Facilities	58
II	Underground storage	1,889
III	1-mi-wide zone surrounding Zone II. No mining or drilling.	6,201
IV	1-mi-wide zone surrounding Zone III. Mining and drilling in conformance with ERDA specifications are allowed.	10,812
		18,960

**Location of Los Medaños Study Area and Geographic Definition of the Proposed WIPP Site**

This report focuses on a 10 x 10-mi square area centered on the proposed WIPP site. The center of the area is 26 mi east of Carlsbad, NM, in east-central Eddy County (Figure 1). Access from Carlsbad is southwest on U.S. 285 towards Loving; then east on State 31 to the junction with State 128 to Milepost 11. A gravel road leads north into a network of roads constructed in the site area.

Figure 3 is a topographic map of the Los Medaños study area scaled at 1 in. = 4000 ft, a standard scale used for most of the maps presented. This 10 x 10-mi area will hereafter be referred to as "Los Medaños," the Spanish word for sand dunes. The name appears on the U.S. Coast and Geodetic 15-min Nash Draw quadrangle for an active dune field near the James Ranch in the southern part of the map area.

The WIPP site area, divided by the previously described zones, is also shown in Figure 3. The irregular pattern of the outer boundary of Zone IV originated from a desire to conform to the Bureau of Land Management's (BLM) land subdivision system. The WIPP program plan calls for the entire area within this boundary to be brought under control of the Department of Energy (DOE). The inner boundaries that define Zones II and III are polygonal, designed to minimize the area to be withdrawn and still conform with the requirement to avoid deep drill holes.

In this report, "Los Medaños site" or "area" refers to the 10 x 10-mi basic map, whereas the "WIPP site" is the composite of Zones I-IV centered within the larger area.

**History of Site Selection and Evaluation at Los Medaños**

Oak Ridge National Laboratory (ORNL) and the USGS jointly selected the northern portion of the Delaware Basin as a general location for waste disposal in early 1972. The USGS immediately began regional geologic investigations resulting in the selection of a 3-sq-mi area at the Lea-Eddy County boundary and designated as the "Old Site" on Figure 1. Field investigations began in March 1974 under the direction of ORNL. Two holes were drilled, AEC No. 7 to 3,918 ft and AEC No. 8 to

3,028 ft, with the latter hole completed on May 19, 1974 (see Figure 2). The site area then lay dormant until Sandia assumed responsibility for the WIPP program. Drilling activities recommenced in June 1975 with the objective of drilling two more holes, one on each of the remaining site corners. Only the ERDA No. 6 hole, located near the northwest corner, was actually drilled. An artesian flow of brine was encountered at 2,709 ft. This phenomenon, coupled with complex structure as evidenced by the core, resulted in rejection of that site.

The USGS recommended other alternate site areas on November 14, 1975. After further refining site selection criteria, the site now known as Los Medaños, located in T22S, R31E, was selected as the best. Site evaluation activities expanded to include geophysical surveys for mapping geologic structure and drilling to test stratigraphy. ERDA No. 9, a stratigraphic test hole, was drilled in the geographic center of Los Medaños during the summer of 1976. The hole was drilled 2,887 ft just into the top of the Castile Formation. AEC No. 8, originally drilled to 3,028 ft, was deepened in 1976 through the Castile and into the Delaware to 4,910 ft. Resource assessment of potash required drilling 21 core holes through the McNutt to intermediate depths. Three hydrologic test locations have been drilled to the top of the Salado. Records from these and other preexisting holes thus provide details of the stratigraphic conditions. Extensive open-hole formation testing was done in ERDA No. 9 and during the deepening of AEC No. 8.

Seismic exploration surveys commenced in the summer of 1976. Twenty-six line miles of 24-fold CDP-type profiling were run along crossing lines through the site. In addition, some 200 line miles of older seismic data were purchased through a brokerage firm from Shell Oil Co. These data were fully reduced and interpreted by August 1976. During the fall and winter of 1976 other seismic profiles were obtained from several oil companies. An updated interpretation using this additional information was completed in early March 1977.

Shallow geophysical survey techniques have also been used at the site. A weight-drop technique was used for high-resolution seismic prospecting in the hope that shallow structures (i. e., those above the Salado) could be mapped. Results were inconclusive. Electrical resistivity surveys were tested in the site area during the summer of 1976. Results have indicated it is not a successful method for detecting regional suberosion of salt from the Rustler and Salado Formations.

Electrical and detailed gravity surveys have been conducted over known breccia pipes near but outside the site. The electrical surveys were successful in detecting the pipes, but the gravity work was only partially successful. This work commenced in the summer of 1976, with data reduction and interpretation completed in early 1977.

Regional gravimetric and airborne magnetic surveys were purchased in mid-1976 from private sources. The magnetic surveys defined more precisely the course of the long dike that passes along the western edge of Nash Draw, and the magnetic profiles were also searched for evidence of other dike trends. The gravity surveys were reviewed for indications of breccia pipes as well as deep structure. Interpretative reports of both surveys were completed by year-end.

Aerial photos over the site and buffer areas were made on February 19, 1976, before any field activities began, to give a record of the land surface conditions in a pristine condition. A larger area was flown in early October 1976. These photos were used for photogeologic interpretative studies in and around the site.

Oil and gas resources were evaluated by using existing production and exploratory drilling information, along with structural interpretations obtained from the seismic studies.

#### Large-Scale Screening Criteria Used to Select the Los Medaños Site

The criteria used by ORNL and USGS in selecting the original site along the Lea-Eddy County boundary were:

- A 2-mi radius from any boring through the Ochoan evaporites down into the Delaware, or deeper formations
- Salt of high purity at < 3,000 ft
- A minimum depth to suitable salt of 1,000 ft
- Avoidance of obvious mineral resources

The cores from AEC Nos. 7 and 8 intercepted commercial grades of potash. At ERDA No. 6, the complex structure and brine flow were sufficient evidence that more selective criteria were needed in selecting future sites.

Selection criteria for the Los Medaños site were expanded to include:

- Avoidance of known oil and gas trends
- Avoidance of the known potash enclave for the site proper, and minimizing the area affected by the buffer zone
- Allowance for a probable salt deformation belt 6 mi wide out into the basin and away from the Capitan Reef
- Establishing a distance of 1 mi or more from suberosion of the top of the Salado Formation
- Minimizing State and private land in Zones I and II
- Avoidance of existing potash lease rights in Zone I and II
- Avoidance of known anticlinal structures

One important criterion was relaxed. The 2-mi radius from deep borings was reduced to 1 mi. This change, which resulted from studies performed for ORNL on the dissolution effects in boreholes, was made desirable by the extensive deep gas-exploration drilling in the Delaware Basin. Results of borehole plugging and dissolution studies indicate that a 1-mi buffer is very conservative.

These criteria were applied to all areas in the New Mexico portion of the Delaware Basin where the Salado was known to be both free of dissolution, at an acceptable mining depth, and free of deep drill holes. Figure 1 illustrates areas that in the judgment of USGS met these three criteria. Figure 2 illustrates how the expanded criteria were applied at Los Medaños. Only the current site and an area designated as Alternate II withstood the test of the additional criteria. The Los Medaños site was preferred because Alternate II was restricted in size, was deeper, and the high-purity salt lying between the Cowden and Castile was thought to be absent. The top of the Salado was at ~800 ft at Los Medaños versus 1500 ft at Alternate II. Other factors favored the selection:

- Structural interpretation of what seismic data was then available to Sandia indicated the Los Medaños site would be in a synclinal area unfavorable for oil and gas accumulation.
- If the site were in a syncline, geopressured brine reservoirs would be less likely.
- Alternate II area lay adjacent to the Double X and Triple X shallow oil fields where water flooding for secondary recovery could occur.

No seismic exploration data whatsoever was available to Sandia on the Alternate II area, and only partial coverage at Los Medaños.

Sandia Laboratories selected Los Medaños as the best candidate area in early December 1975.

#### Topography and Surface Features

The land surface at Los Medaños, an essentially gentle west-to-southwest dipping plane, is devoid of sharp physiographic features. Elevations range from 3,570 ft in the east to 3,250 ft in the west, with the average slope gradient 50 ft/mi. The steepest local gradients are on the leeward side of active sand dunes that reach the angle of repose for such sand. The most prominent topographic feature is Livingston Ridge, a mild escarpment 75 ft high. A small sinkhole 30 ft deep and ~1,000 ft in diameter exists in the north part of the site. Partially stabilized sand dunes cover most of the land surface, particularly to the north, east, and southeast. Active dunes are present in the south. The flattest terrain is on the west where the land surface consists of outcroppings of Mescalero caliche.

#### Surficial Geology

Outcroppings in the site area consist of Rustler and Dewey Lake of Permian age, the Gatuna of Pleistocene age (all extensively covered by caliche), and then sand dunes of recent but not accurately dated age. Surficial geology is shown in Figure 3. Because this map was compiled from aerial photos, small outcroppings may have gone undetected.

Outcroppings conform to the known subsurface geology, which is a north-striking and gently east-dipping monocline, with the oldest rocks exposed on the escarpment at Livingston Ridge. The Dewey Lake and Gatuna are present sparingly on the ridge face and immediately pass under the caliche eastward. Scattered outcrops of Rustler lie to the east. The caliche surface has been breached along a shallow drainage extending across Livingston Ridge in the northwest part of the area. Outcroppings are lost after entering the dune field and seldom reappear eastward in the site area.

#### Subsurface Structure From Surface Down to the Top of the Castile

It is desirable to describe the sediments and their structure from the surface to the top of the Castile separately from sediments in deeper beds. The sediments above the Castile represent an interval where standard seismic exploration records do not resolve the units, and drilling provides the only realistic exploration tool. This is true in spite of electrical resistivity surveys capable of giving some insight into the top evaporites; e. g., base of the Dewey Lake to the first salt or anhydrite, whether in the Rustler or Salado. Near the site described as the area shown in Figure 4, there are 158 drill holes from which information can be gleaned in drilling records. This information is summarized in Table I.

TABLE I  
Drill Hole Information Available

Type Boring	Mean Depth (ft)	Complete Record to	Partial Record to
21 Potash Holes (Sandia)	1,500	Base of McNutt	
5 ERDA Hydro Holes	850	Top of Salado	
102 Potash Holes (Industry)	1,500		Top Salado, base of 124
5 Petroleum Development/ Exploratory	>4,000		Dewey Lake, Rustler, Salado, Castile, and deeper
21 Petroleum Development/ Exploratory	>4,000		Base of Castile down to total depth
AEC No. 7	3,918	Lower part of Castile	
AEC No. 8	4,910	Upper part of Delaware	
ERDA No. 6	2,775	Cowden Anhydrite	
ERDA No. 9	2,887	Top of Castile	

Wireline geophysical logs were run in the 21 potash exploratory holes drilled by Sandia. These logs allowed picking of all significant formation changes down to the depth drilled. For other potash holes drilled by private industry, the procedure was much simpler. These holes were rotary-drilled with no core down into the upper part of the Salado and then cored to depths slightly below the base of the 124 Bed. No wireline logs were run. The depth to the 124 Bed is considered to be reliable, but the depth to the top of the Salado had to be inferred from examination of the rotary-drill cuttings. Moreover, unless care was taken to use a salt-saturated circulating medium, the cuttings were leached of halite, which resulted in picking the top of the Salado deeper than the actual formation. Therefore, the contours on the base of the 124 Bed are more accurate than those for the top of Salado.

These drill records are interpreted in Figures 5-13. The immediate subcrop geology (i.e., what is present immediately beneath the sand and caliche) is shown in Figure 5. The Santa Rosa Formation covers the east side of the mapped area. Note that the younger Gatuna is absent on top of the Santa Rosa but covers an extensive portion of the west side, where it rests directly on the Dewey Lake. Farther west, the Dewey Lake is exposed in a belt that follows the Livingston Ridge escarpment. The Rustler is exposed in the extreme west on the plain below Livingston Ridge. The setting described conforms to an outcrop pattern expected from nearly flat-lying beds that have been truncated by erosion to conform with existing topography. There is the suggestion that the thin Gatuna Formation (never more than 30 ft thick) represents outwash alluvial deposition as the Santa Rosa was eroded from west to east. A tongue of exposed Dewey Lake that may represent a shallow postcaliche erosional channel extends southeast from Livingston Ridge.

Figures 8 and 9 present smooth structural contouring of eight shallow stratigraphic horizons. These maps cover a smaller area than the standard site-area maps. This smaller area is that in which extensive well logs were obtained from the 21 potash exploration holes. As previously explained, detailed records are not available for the industry-drilled potash and oil/gas holes in the surrounding area.

The top of the Gatuna structure map (Figure 8) is somewhat misleading in that it represents not only that top but the top of the Santa Rosa or Dewey Lake where the Gatuna is absent. The other seven maps are normal structure maps. The form of the top of the Santa Rosa Formation appears to be that of a flat-lying bed that has suffered erosion encroachment from the west. On the other hand, the top of the Dewey Lake has had little erosion and presents itself as a flat-lying, undulating surface. The top of the Rustler Formation is the first horizon to reveal a southeast-plunging synclinal structure. This structure persists in the deeper horizons in this sequence of maps; e.g., the Vaca Triste that marks the top of the McNutt Member of the Salado.

The four maps in Figure 10 and the top two in Figure 11 are isopachous contours for the intervals between the surfaces just described. The erosional wedge shape of the Santa Rosa is quite evident, as is the rapid thinning of the Dewey Lake towards Livingston Ridge and Nash Draw that is also caused by erosion.

The Rustler rapidly thickens from 300 ft in the center of the area to 500 ft in the extreme southeast due to decreasing suberosion of salt from within this formation. A suberosion front is postulated along the steepest gradient of these contours. About 200 ft of salt has been removed over all except the extreme southeast part of the area. This suberosion is believed to have preceded the suberosion in the underlying Salado.

The isopach of the interval from the top of the Salado to the base of the 103 Marker Bed (Figure 11, upper left map) reveals that the suberosion wedge extends down to the top of Salado salt in the extreme west. (Note the rapid thinning west of Hole P-12.) Indeed, Holes P-12, -13, and -14 exhibit solution residue at the top of the Salado, and in Hole P-14 evidence exists indicating a thin brine aquifer located at the very top of the first salt bed penetrated. The approximate position of these suberosion fronts, Salado and Rustler, is shown in Figure 5. The position is approximate but the best that can be given. The front in the Salado Formation is somewhat farther east than what USGS had postulated (refer to Figure 2).

The lower two maps shown in Figure 11 concern thicknesses related to the 124 Marker Bed. The structure of that horizon will be discussed later. Suffice it to state now that both maps are featureless and reveal only that the intervals gradually thicken southward.

Figure 12 presents the smoothed contour results for the top of the Salado in the study area. The humped contours on the west reflect the removal of salt by suberosion. The same southeast-plunging syncline open to the southeast that was observable in the Rustler Formation is in evidence. A cluster of three depressions lies at the upper (northwest) end of this trend. The deepest of these is centered on Hole F-91 in the southwest corner of Section 10, T21S, R31E. No detailed record is available on this industry-drilled hole, and it is not known if the overlying Rustler, Dewey Lake, and Santa Rosa Formations are actually depressed as one would suspect, or if the top of the Salado was erroneously reported. The low is near a shallow surface sink located in the extreme southeast part of Section 9.

Anticlinal structures are shown over ERDA No. 6 in the extreme northeast and Hole B-1, a deep gas well properly known as Belco Hudson Federal No. 1 and located to the southwest in Section 1, T23S, R30E. Both structures are known to possess geopressured brine reservoirs in the underlying Castile Formation.

Structural contours for the base of the 124 Marker Bed are given in Figure 13. The 124 Marker Bed is the deepest and most consistently reported bed cored in all of the potash drill holes. In addition, the depths reported in the industry-drilled holes are considered valid because they are based on cored sections.

The surface of the base of the 124 Marker Bed is similar to that described for the top of the Salado. The two anticlines centered on ERDA No. 6 and the Belco Hudson Federal No. 1 well persist. Note the centers of two depressions along the axis of the syncline. The one to the extreme

east may not be closed since drill records are sparse in that area. The other roughly coincides with the cluster of three lows described for the top of the Salado. The center has shifted slightly to the west, centered on Hole F-92.

In Zones I and II the surface of the 124 Marker Bed is relatively uniform, with a gentle eastward dip that varies from 80-100 ft/mi. This horizon is 470 and 1,020 ft, respectively, above the low-level transuranic (TRU) and intermediate-level (RH) mining horizons selected for waste disposal in the WIPP facility; therefore, it is the best estimate of structural conditions in those levels. No faulting is discernible from the drilling information. High-resolution geophysical surveys to be conducted over the site area are expected to confirm that significant faults do not exist.

#### Subsurface Structure from the Precambrian Basement Up to the Castile

Deep drilling at Los Medaños is limited to the cluster of five holes in the James Ranch gas field and to 21 other tests in a widely spaced pattern. The spacing is such that only regional deep structural trends can be projected. Seismic exploration surveys, consisting of 26 line miles of new data obtained by Sandia plus ~500 line miles of proprietary data from industry, were used to refine the structural setting. Results are shown in Figures 14-17, which are for the surfaces indicated in Table II.

TABLE II  
Seismic Structure Mapping Horizons

Bed	Stratigraphic Position	Mean Depth (ft)	Mean Elevation (ft)
Castile Horizon	~700 ft above Base. Ochoan Age	3,400	Sea Level
Delaware Sandstone	Top of Delaware Mountain Group. Guadalupian Age	4,200	-800
Morrow Limestone	Principal gas-producing horizon at Los Medaños. Lower Pennsylvanian Age	13,400	-10,000
Devonian Marker	Limestone Unit	15,900	-12,500

Two seismic profiles are exhibited in Figure 24 to illustrate the quality of the data obtained by the Sandia surveys. On these profiles the position of the beds listed in Table II is superimposed to illustrate the interpretation technique. The approximate Precambrian surface is indicated. Even though some consistent horizons in the Precambrian appear on the records, they are not interpretable, and no attempt has been made to do any quantitative structural interpretation below the Devonian marker.

The seismic interpretation agrees with the regional structural setting. These data illustrate that on a small scale warping and faults exist, these structures becoming more pronounced with depth. Seismic interpretation is largely an art form even though the field surveys use sophisticated electronics, and the raw data is digitally processed with elaborate programs to condition and then "stack" the seismic response signals. No two geophysicists fully agree; this is particularly true in analyzing fault traces. The interpretation presented here is the more complex of two studies performed by independent geophysicists. From the standpoint of defending the geologic stability of the repository, it is more conservative to use the complex interpretation. The structure will be described from the deepest (Devonian) back up to the Castile.

Referring to Figure 17, the fault trends are north to northeast with a subsidiary trend to the northwest. The maximum fault displacement seen on the Devonian is 300 ft, and the most common mode is a downdropping on the west side. Anticlines and synclines having amplitudes of 500 ft from the troughs to ridges are prevalent in the Devonian. Coming up to the Morrow Limestone, some 2,500 ft higher stratigraphically, the structure is less complex (Figure 16). The strong north-to-northeast trending faults have died away. Structural relief from syncline to anticline is reduced to a 200-500 ft range. At the Delaware sandstone horizon, about 10,000 ft above the Morrow Limestone, warping reduces to 300 ft maximum (Figure 15). The faults shown are not continuous extensions of faults shown in the Morrow to Devonian but represent two periods of faulting. The older terminates in the Pennsylvanian and is related to basement-type movements, and a younger post-Permian set formed due to compaction during diagenesis after deposition of the Delaware Mountain and perhaps the Ochoan evaporites.

The Castile horizon, shown in Figure 14, is the shallowest structure map that can be gleaned from existing seismic surveys. The mapping horizon is the middle, not the top, of the Castile Formation. This horizon lies 850-1300 ft, respectively, below the low-level transuranic (TRU) and intermediate-level remote-handled (RH) mining horizons for the WIPP project. It is, therefore, the best representation of structural conditions immediately below the planned repository mining levels just as the base of the 124 Marker Bed was for the conditions above.

Possible faults are shown. Minor faulting with displacements of less than 10 ft has been witnessed in the potash mines. Faults shown in the Castile should be considered tentative pending more-detailed and higher-resolution seismic profiling. The northeast-trending fault may be partially substantiated by surface outcroppings (refer to Figure 3). The fault trace follows the approximate trend of Livingston Ridge. The Dewey Lake Formation outcrops along the west face of the ridge, and the local dips are 10-20° to the west. This steep local attitude, which is reverse to the regional dip, is attributed to slumping due to salt dissolution at the top of the Salado in Nash Draw. However, the Rustler Formation outcrops immediately to the west in Section 15, T22S, R30E. The thickness of the Dewey Lake is thought to be 250 ft or more, whereas the topographic relief is only 100 ft. Hence, a fault may exist between the Rustler outcrops and the ridge face. Such a fault would coincide with the trend and displacement mode of the one shown on the Castile surface. The vertical displacement could be as great as 150 ft with the downthrown block on the

east. No fault trace is observable on the air photos, and the veneer of caliche that caps Livingston Ridge is not disturbed. If the speculated fault exists, then its last period of movement preceded the formation of the caliche. Another possibility is that the Rustler and upper part of the Salado may rapidly thicken as they pass westward out from under Livingston Ridge; a thickening that can be attributed to swelling of anhydrite being converted to gypsum.

The structure of the Castile horizon is in general agreement with that exhibited by the 124 Marker Bed. The anticlines around the Belco Hudson Federal No. 1 well in Section 1, T23S, R30E at both horizons are congruent. An anticline is expected under the ERDA No. 6 location in the Castile; however, the seismic data available to use was not of sufficient quality to allow valid interpretation in that particular area. The main difference in the shapes of the 124 Marker Bed and Castile horizon surfaces is that the southeast-plunging syncline on the former has been subdued on the latter. Indeed, a closed anticline is postulated in the Castile centered in the northeast corner of Section 21, T22S, R31E. The low northwest of this anticline is roughly in the same position as the sharp low revealed in the 124 Marker Bed.

#### Geologic Cross Sections and Composite Structure Map

The results of the previously described geologic structure maps were used to compile two geologic cross sections along crossing lines through the site area. Figure 6 is a cross section looking northwest, and Figure 7 is a cross section looking northeast. The vertical scale is exaggerated three and one-third over the horizontal; hence, the structure is amplified. Key potash exploration and oil/gas wells that were used to assist compilation of the cross sections are shown. Interpolation between holes made use of the plan structure maps.

A composite plan map of structural trends is presented as Figure 18. This map attempts to correlate known structural trends in the "shallow" and "deep," defined as the Delaware and Devonian, respectively. These trends were established by a synthesis of the seismic and gravity data available. This particular map was more useful in estimating hydrocarbon potential of the site area than in revealing features in the Ochoan evaporites.

#### Stratigraphic Test Drilling at Los Medaños

The reader may find it helpful to review the pictorial displays in Figures 36 and 37 to understand the text that immediately follows.

Four deep core holes have been drilled for stratigraphic and physical testing of salt beds believed to be suitable for waste disposal. Essential stratigraphic data are summarized in Table III.

TABLE III  
Stratigraphic Summary of Four Holes

	Drill Hole Number			
	ERDA 9	ERDA 6	AEC 8	AEC 7
Location (section/twp/range)	20/22S/31E	35/21S/31E	11/22S/31E	31/21S/32E
Date Completed	6/26/76	9/24/75	8/5/76*	4/18/74
Surface (Kelly Bushing)	(3415)	3536	(3542)	(3662)
Formation Tops	Depth	Elev.	Depth	Elev.
Gatuna	27	3,388	12	3,524
Santa Rosa	54	3,361	22	3,514
Dewey Lake	63	3,352	71	3,465
Rustler	550	2,865	536	3,000
Magenta	610	2,805	595	2,941
Culebra	720	2,695	710	2,826
Salado	860	2,555	815	2,721
103 Marker (base)	1,050	2,365	984	2,552
Vaca Triste (base)	1,370	2,045	1,282	2,254
124 Marker (base)	1,670	1,745	1,537	1,999
126 Marker (base)	1,744	1,671	1,613	1,923
136 Marker (base)	2,058	1,357	1,913	1,623
139 Marker (base)	2,180	1,235	2,024	1,512
Cowden (top)	2,540	875	2,270	1,266
Cowden (bottom)	2,562	853	2,290	1,246
Castile	2,836	579	2,555	981
Delaware	-----	-----	4,315	-773
Total Depth	2,887	528	2,775	761
			4,910	-1,368
			3,918	-256

\* AEC No. 8 was drilled to 3028 ft on 5/19/74. The hole was reentered and deepened to 4910 ft during July and early August 1976.

Of the four holes, three (ERDA No. 6 and AEC Nos. 7 and 8) were drilled at the old site on the Lee-Eddy County Line. ERDA No. 9 was drilled in the exact center of the Los Medanos site and is of greatest significance to this discussion; however, there was generally excellent lateral correlation between all four holes. The deeper part of ERDA No. 6 is the single exception, where complex structure was revealed by the steep dips in the core along with brine flow encountered immediately below the Cowden. That good lateral correlation exists between holes spaced several miles apart is the traditional experience in the Ochoan evaporites of the Delaware Basin.

Figure 19 is a diagrammatic section of drilling results from ERDA No. 9. The drilling schedule was as follows:

1. Cement 16-in. surface casing to 40 ft in 20-in. hole.
2. Rotary drill into top of Salado (1049 ft).
3. Run wire line geophysical logs.
4. Set 10-3/4-in. casing and cement to 1056 ft in a 15-in. hole. Run bond logs.
5. Convert to an inverted oil-emulsion drilling fluid.
6. Pass circulating system through gas separator (continuous mud analysis and gas sampling).
7. Drill continuous core to depth of 2,887 ft: hole 7-3/4 in.; core 4-1/4 in.
8. Conduct three drill-stem tests at selected intervals while drilling.
9. Ream hole to 9-7/8 in. to 2886 ft.
10. Run wireline geophysical logs.
11. Conduct six additional tests by straddle-packer testing after logging.
12. Stand 7-in. casing. Cement back to 2540 ft. Run bond logs.
13. Run directional survey.
14. Cap well.

The purpose of the extensive formation testing and drilling-fluid monitoring was to detect any evidence of geopressured brine flow such as that found at the ERDA No. 6 hole. No unusual conditions were observed. Table IV summarizes the results of the drill-stem testing. The slight pressure buildups reflect nitrogen-brine accumulations similar to those that are frequently observed in nearby potash mines. These are to be expected throughout the Salado Formation, particularly in or near clay seams. A trace of  $H_2S$  was detected by the drilling fluid monitors at 1409 ft. The concentration was 0.5 ppm, well below the limit of hazard to health. Drill-stem Test No. 1 tested this zone, with no further recorded evidence of  $H_2S$ . Trace amounts of  $H_2S$  may be present in the evaporites, but that  $H_2S$  was detected at all in this hole testifies more to the sophistication of the gas monitors rather than to an anomalous geologic condition.

TABLE IV

## Results of Drill-Stem Testing

DST #	Date Tested	Interval Tested (ft)	Gross Thickness (ft)	Type Test	Fluid Recovered	Hydrostatic Pressure, Psig	Flow Period (Minutes)	Bottom Hole Flowing Pressure, Psig	Shut-in Time (Minutes)	Bottom Hole Shut-in Pressure, Psig	Gradient Between Top & Bottom	Calculated Flow Rate, BPD	Calculated Permeability, md						
													Initial	Final	Bomb (psi)	Horner Method K	Ramey Method K	McKinley Method K	
1	5/14/76	1,440 - 1,496	56	Bottom Set	25' Drilling Fluid. (12.7' due to expansion)	584 581	30 60	41 48 43	38 60	38 43 43	50 0.3919 0.4054	2.97 0.3592	NA						
Remarks: Open tool with fair blow. Reopened tool with no blow. No measurable flow. No analysis possible due to short shut-in period & continuance of afterflow during the buildup period. During drilling, this interval had minor H <sub>2</sub> S entry recorded.																# *	# *	# *	
2	5/19/76	2,026 - 2,106	80	Bottom Set	2' Drilling Fluid. (14.17' possible due to expansion)	838 838	30 120 240	42 47 68	42 46 46	270 480 720	42 46 46	131 0.3918) 0.4227) 0.4124)	0.01194	NA		none	0.0032	none	0.00655
Remarks: Reportedly potential zone of storage. No fluid or gas entry observed during drilling. Opened tool with very weak blow. Dead in 13". Reopened tool for 2nd & 3rd flows and dead. All fluid entry on DST accounted for by drilling fluid expansion. Static BHP per Horner plot indeterminate due to afterflow, but second shut-in reflects some flattening indicative of depletion.																*	*	*	
* Average permeability per core analysis 2,037 to 2,055.3' ranged from 0.0003 to 0.17 md with an average 0.019624 md.																			
3	5/24/76	2,524 - 2,630	106	Bottom Set	2' Drilling Fluid. (About 15' possible due to expansion)	1,034 1,034	70 60 120	55 61 61	56 57 58	180 480 120	56 57 58	243 0.4016) 0.4016) 0.4016)	0.1926	NA		none	0.00157	none	0.00216
Remarks: No fluid or gas entry noted during drilling. DST run to evaluate potential storage interval. Opened tool with a very weak blow. Dead in 10". No blow on second and third flow. All fluid entry during DST accounted for by drilling fluid expansion. Static BHP per Horner plot indeterminate due to afterflow.																			
4	6/10/76	2,635 - 2,886	251	Bottom Set	33' Drilling Fluid. (39.4' possible due to expansion)	1,097 1,088	30 120 180	125 136 138	129 133 135	360 720 1,440	129 133 135	377 312 312 0.408 ) 0.412 ) 0.4106)	0.297	NA		none	0.0004	none	0.00654
Remarks: No fluid or gas entry noted during drilling. Interval tested as major clean salt section and to test bottom of hole (total depth). Tool opened with very weak blow. Dead in 13". Tool reopened with a very, very weak blow. Dead in 6". Reopened tool and had a very, very weak blow with blow decreasing throughout flow period and dead in 2' 10". (Had slight blow at start of 3rd flow period that could be indicative of slight drill pipe leak). All fluid entry during DST accounted for by drilling fluid expansion. Ramey method of estimating permeability subject to question due to indications of wellbore fracturing or some type of wellbore stimulation. Cored interval 2,653 to 2,684.7', had permeability to air ranging from 0.0004 to 16.0 md with an average of 1.536 md. The average is distorted by the sample (2,682-84.7') with k = 16.0 md. High permeability is believed associated with hairline fractures that could be due to mechanical torque. Porosity throughout cored interval is extremely low at less than 0.7%.																			

Footnotes: Pressure readings normally taken from bottom gauge unless gauge was inoperative.

Attempts to meter surface flow rates with Halliburton and Cone &amp; Kerley low pressure diaphragm flow meters were unsuccessful. Flow rates were too small to measure in all cases.

# Based on Halliburton Report by Mr. James E. Sigman dated August 9, 1976.

TABLE IV (contd)

## Results of Drill-Stem Testing

DST #	Date Tested	Interval Tested (ft)	Gross Thickness (ft)	Type Test	Fluid Recovered	Hydrostatic Pressure, Psig	Flow Period (Minutes)	Bottom Hole Flowing Pressure, Psig	Shut-in Time (Minutes)	Bottom Hole Shut-in Pressure, Psig	Top & Bottom Bomb (psi)	Gradient Between Bottom & Top (Psig)	Calculated Flow Rate, BPD	Calculated Permeability, md				
														Horner Method Damage	Ramsey Method Damage	McKinley Method Damage		
						Initial	Final	Initial	Final	Initial	Final	Initial	Final	Psig				
5	6/13/76	2,524 - 2,635	111	Straddle	15' Drilling Fluid. (12' due to expansion)	1,098	1,113	60	30	30	720	30	256	0.426)	0.0099	NA	NA	none 0.0035 <sup>#</sup> none 0.0025 <sup>#</sup>
Remarks: Retest of clean salt zone tested previously by DST #3. Opened tool with a very weak blow and dead at end of 1st flow. Reopened with a slight blow and dead in 4 minutes. Horner plot indeterminate due to continued afterflow conditions.																		
6	6/15/76	2,310 - 2,376 & 1,432 - 1,498	66	Straddle	..... Misrun..... Misrun.....													
Remarks: Misrun - could not obtain packer seat at either interval.																		
7	6/16/76	2,310 - 2,348	38	Straddle	..... Misrun.....													
Remarks: Misrun - packer held for first flow but lost packer seat when tool opened for second flow.																		
8	6/17/76	2,635 - 2,725	90	Straddle	3' Drilling Fluid (9.7' possible due to expansion)	1,140	1,120	60	29	25	720	26	166	0.429)	0.0396	272	none 0.00007	none 0.0017
Remarks: Interval tested is 100 foot clean salt section and possible storage site. Interval is the upper third of DST #4. Opened tool with very weak blow and dead in 1 minute. No blow on second and third flow. Horner plot indicates possible pressure depletion.																	none 0.00141	
9	6/20/76	2,310 - 2,348	38	Straddle	..... Misrun.....												none 0.00235 <sup>#</sup> none 0.025 <sup>#</sup>	
Remarks: Misrun - attempt to retest interval attempted by DST #7. Packers would not hold. Move tool to 1,455 - 1,498'.																		
10	6/20/76	1,455 - 1,498	43	Straddle	120' Drilling Fluid	1,001	667	60	92	91	720	91	199	0.36	NA	NA	none 0.000655 <sup>#</sup> none 0.000694 <sup>#</sup>	
Remarks: Packer did not hold per DST #9 at 2,310-2,348'. Moved tool to 1,455-98' to attempt retest of DST #1 interval which was zone that indicated slight H <sub>2</sub> S influx during drilling. 120 feet fluid recovery probably due to fluid entry during packer failure on attempted test 2,310-48'; therefore, not representative of this zone. Opened tool with very weak blow. Dead in 3 minutes. No blow on 2nd and 3rd flow. Horner plots reflect possible depletion from 225 to 175 psig P <sub>s</sub> on 2nd and 3rd shut-ins but not definite due to continued afterflow. Loss of hydrostatic pressure not detected on bombs and probably leaked into formation above packer.																		

Footnotes: Pressure readings normally taken from bottom gauge unless gauge was inoperative.

Attempts to meter surface flow rates with Halliburton and Cone &amp; Kerley low pressure diaphragm flow meters were unsuccessful. Flow rates were too small to measure in all cases.

# Based on Halliburton Report by Mr. James E. Sigmund dated August 9, 1976.

The nitrogen-brine accumulations should be at pressures either equal to or greater than the equivalent pressure of a saturated brine column extending from the depth of measurement to the top of the salt beds. The reason is that the brine is completely salt-saturated; if minor amounts of interstitial water are present in the salt, they should reflect a normal salt-brine hydrostatic gradient. On the other hand, if the brine-gas is contained within small confined lenses, then pressures should be equivalent to normal gravity loading of the overlying salt and other rocks. Plastic flowage of the salt should ensure this condition if the brine gases are isolated pockets.

The highest pressure buildup was in Test No. 4 where the test interval was 2635-2886 ft. If the fluids were confined by an equivalent brine column, then the pressure would be in the order of 800 psi. Since the final shut-in pressure was only 312 psi after 24 hr, we must conclude that the drill-stem test did not adequately test the formation. This is not an operational fault of the technique we used, but rather an indication that extremely long shut-in times (perhaps a month or more) will be required. Such times are not realistic for conducting active drilling operations. Therefore, the only conclusion that can be drawn from the 10 drill-stem tests is that no significant amount of fluid is present in the Salado. Definitive tests as to what trace amounts are present and under what pressures must be determined by other means, preferably by perforations through a well cased hole.

The core-handling procedures were routine in that as each run was removed, it was cleaned, marked as to footage, examined megascopically for geologic detail, photographed, and then wrapped and sealed in polyethylene plastic. This suite of core was and continues to be tested for physical and chemical properties. The test results will be reported by others.

Cutting samples were collected routinely every 10 ft during core-section drilling. These samples were examined chemically and by X-ray diffraction to determine the quality of the salt and to detect any mineral assemblage extraneous to that expected for the Salado. These analyses are complete, and no anomalous minerals were identified.

A detailed descriptive log of the lithology of ERDA No. 9 is given in Figure 20. The log was compiled from examination of rotary cuttings collected every 10 ft from the surface to 1090 ft, and from core examination from there down to the total depth of 2886 ft. Core recovery was excellent, exceeding 95 percent. The log has indicated that the stratigraphy is quite normal for the Salado Formation in this part of the Delaware Basin. Bedding planes were flat, never exceeding a 5° dip. While minor amounts of potassium ore minerals occurred in several of the traditional ore-bed horizons, none of the intercepts could be considered as economic.

#### Horizon Selection for Waste Disposal

The USGS advised that the two best potential zones for waste disposal were the infra-Cowden halite (i. e., salt beds beneath the Cowden anhydrite and the top of the Castile) and a second zone lying between the 134 and 140 Marker Beds. These selections were based on USGS knowledge gained

from drilling records and logs from holes drilled throughout the Delaware Basin, and on examination of the core from the three holes drilled at the old site location. A complex suite of wire line geophysical logs was run under open-hole, fluid-filled conditions at ERDA No. 9 to increase the understanding of the entire Salado section, and to verify and refine horizon selection. The following logs were run (Table V):

TABLE V  
Wireline Geophysical Logs Run In ERDA No. 9

Type	Purpose
Acoustic	Elastic velocity, P wave
Acoustic, VDL	Elastic velocity, S wave
Density	Formation density
Neutron	Hydrogen detection
Spectral gamma	Uranium, thorium, potassium
Temperature	Formation temperature
Caliper	Hole size
Induction	Formation resistivity
Microlaterolog	Formation resistivity
Neutron lifetime	Calcium, oxygen, silicon, hydrogen
Cyclic activation	
Inelastic neutron	
Silicon-calcium	
"Sonan"	Fluid entry
Diplog	Dip of bedding planes
Fluid density	Drilling mud density
Sidewall acoustic	Elastic velocity, P wave
Sidewall VDL	Elastic velocity, S wave
"Seisviewer"	Hole damage, fractures
Uphole seismic	Formation velocities

Rarely has such a comprehensive set of borehole geophysical measurements been made in a single hole. To some extent the measurements were redundant, but measuring the same parameters by different sensors has enhanced the credibility of the interpretations.

Figures 21-23 illustrate the wireline geophysical logs for six parameters: density, gamma radiation, caliper, sonic velocity, electrical resistivity, and two neutron activation logs. The combination of natural gamma and sonic velocity was the most useful in picking the traditional marker beds. Normally these beds have polyhalite and anhydrite mixtures that reveal themselves as increases in both natural radiation and seismic velocity. The neutron activation logs consistently

confirmed our interpretations. The Cowden anhydrite bed and the Castile are best shown by the density, velocity, and neutron activation logs. Little natural gamma radiation is present in these anhydrites.

A detailed study of each of the various logs was made. In that the objective of the WIPP program is to demonstrate the utility of salt as a medium for waste isolation, then the horizons selected should be those of the highest purity and with fewest nonhalite interbeds. Any zone exceeding 50 ft thick that indicated uniform salt was considered to be a candidate horizon. The logs were then cross-correlated to determine which horizons were the most consistent; i. e., absent of anomalous response. It was in this manner that the two mining levels were selected.

The logs confirmed that the purer and thicker halite beds were in the lower portion of the Salado. The Upper Member is clay- and anhydrite-bearing. The McNutt (Middle Member) contains appropriate polyhalite and other hydrous minerals. Within the Lower Member, the infra-Cowden halite was by far the purest and most uniform, as inferred from elastic properties, density, lack of gamma activity, and uniform electrical resistivity. Next in quality was a halite zone between the 136 and 140 Marker Beds. Further refinement led to selection of an intermediate-level TRU (remote-handled) zone within the infra-Cowden and low-level TRU (contact-handled) waste zones (Table VI):

TABLE VI  
Horizon Selection, ERDA No. 9

	Depth (ft)	Elev. (ft)	Thickness (ft)	Stratigraphic Position
<b>Contact Waste Zone:</b>				
top	2,074	1,352	102	Base of 137 Bed
base	2,176	1,250		Top of 139 Bed
<b>Remote-Handled Waste Zone:</b>				
top	2,620	806	110	Below anhydrite lense
base	2,730	696		Above anhydrite lense

Tentative mining plans call for excavation of rooms ~20 ft high; these thicknesses are more than adequate. Ideally, mine openings should be placed in the middle of the zones selected so as to give uniform conditions above and below the repository levels.

A similar suite of logs was run in AEC No. 8 (Table VII) once that hole was deepened into the Delaware. The caliper log indicated some hole enlargement in the salt sections; hence, the logs were not considered as reliable as those from ERDA No. 9. However, they offered a good comparison of conditions 4 mi away. The same horizons appear to be the best for waste disposal and differ only in thickness.

TABLE VII  
Horizon Selection, AEC No. 8

	Depth (ft)	Elevation (ft)	Thickness (ft)	Stratigraphic Position
<b>Contact Waste Zone:</b>				
top	2,128	1,414	118	Base of 136
base	2,246	1,296		Top of 139
<b>Remote-Handled Waste Zone:</b>				
top	2,616	926	104	Below anhydrite lense
base	2,720	822		Above anhydrite lense

A summary of significant physical properties for the proposed horizons to be used is given in Table VIII. The elastic data presented are based on the constitutive equations where, if density, P-wave, and S-wave velocities are known, then all elastic properties can be calculated. The table illustrates that the halite horizons are quite uniform.

#### Geophysical Surveys

The seismic surveys have been partially described in the section dealing with the structure beneath the Salado Formation. However, a fuller description of both those surveys and other geophysical exploration surveys needs to be presented to demonstrate how remote sensing from the surface has assisted in site evaluation. Both shallow and deep seismic surveys have been conducted that rely on two properties of the rock layers, P-wave velocity and density. Electrical surveys have also been conducted that measure earth resistivity. Finally, magnetics and gravimetric surveys that are potentiometric measurements of the total earth fields were used.

#### Shallow Seismic Surveys

A rectangular grid of 1/2-mi survey lines was run at Los Medaños. A total of 43 line miles were surveyed. The system utilized close-spaced clusters of geophones implanted into the soil. Seismic energy was imparted into the earth by hoisting and then dropping a 1,000-lb weight under freefall. Signals were recorded and timed in relation to the moment of impact of the weight onto the land surface. Wave trains reflected from deep horizons were observed and, by using known velocities for the immediately underlying sedimentary beds, the depths to significant acoustic impedance interfaces were calculated.

The results of this survey are ambiguous because high frequencies are necessary to resolve shallow bodies, and the weight-dropping technique failed to provide sufficient amplitude of high-frequency signals. The results of the shallow work have been discarded because many anomalies thought to exist, based on that survey, were disproven after the 21 potash core holes were drilled. If future shallow seismic surveys are conducted, considerably more sophistication will be required of the instrumentation system along with stronger energy input.

TABLE VIII  
Physical Properties of Disposal Horizons

TRU Level					
Depth	Density	Young's Modulus (psi)	Bulk Modulus (psi)	Shear Modulus (psi)	Poisson's Ratio (psi)
2071.0	2.17	.50333E+07	.34681E+07	.20026E+07	.25671E+00
2072.0	2.17	.51467E+07	.35271E+07	.21475E+07	.25680E+00
2073.0	2.14	.49948E+07	.35434E+07	.19641E+07	.27151E+00
2074.0	2.16	.49958E+07	.36294E+07	.19679E+07	.26931E+00
2075.0	2.11	.49931E+07	.34505E+07	.19833E+07	.25882E+00
2076.0	2.12	.48727E+07	.32789E+07	.19454E+07	.25232E+00
2077.0	2.12	.49171E+07	.32258E+07	.19731E+07	.24603E+00
2078.0	2.12	.48691E+07	.31978E+07	.19535E+07	.24623E+00
2079.0	2.13	.48990E+07	.32135E+07	.19673E+07	.24512E+00
2080.0	2.12	.49621E+07	.32365E+07	.19937E+07	.24448E+00
2081.0	2.12	.50124E+07	.33778E+07	.20037E+07	.25268E+00
2082.0	2.12	.48969E+07	.33007E+07	.19545E+07	.25274E+00
2083.0	2.12	.48938E+07	.32447E+07	.19537E+07	.24863E+00
2084.0	2.11	.47847E+07	.32667E+07	.19049E+07	.25589E+00
2085.0	2.12	.47434E+07	.32693E+07	.18851E+07	.25816E+00
2086.0	2.11	.48029E+07	.32847E+07	.19115E+07	.25630E+00
2087.0	2.11	.47450E+07	.33646E+07	.18756E+07	.26495E+00
2088.0	2.11	.47861E+07	.33189E+07	.19009E+07	.25893E+00
2089.0	2.11	.47659E+07	.31197E+07	.19134E+07	.24539E+00
2090.0	2.12	.47672E+07	.29935E+07	.19307E+07	.23457E+00
2091.0	2.11	.45342E+07	.31738E+07	.18058E+07	.25436E+00
2092.0	2.12	.44382E+07	.31324E+07	.17525E+07	.25772E+00
2093.0	2.12	.44312E+07	.30999E+07	.17555E+07	.26181E+00
2094.0	2.13	.44996E+07	.33448E+07	.17633E+07	.27576E+00
2095.0	2.13	.46598E+07	.34148E+07	.18314E+07	.27195E+00
2096.0	2.14	.47744E+07	.34339E+07	.18822E+07	.26827E+00
2097.0	2.13	.48031E+07	.33279E+07	.19092E+07	.25920E+00
2098.0	2.13	.46230E+07	.32561E+07	.18296E+07	.26337E+00
2099.0	2.14	.48635E+07	.29248E+07	.19911E+07	.22258E+00
2100.0	2.15	.46452E+07	.31842E+07	.18596E+07	.24898E+00
2101.0	2.16	.48697E+07	.29101E+07	.18943E+07	.23256E+00
2102.0	2.15	.46369E+07	.30933E+07	.20034E+07	.23466E+00
2103.0	2.12	.49912E+07	.32551E+07	.20054E+07	.24444E+00
2104.0	2.12	.52460E+07	.31910E+07	.21395E+07	.22602E+00
2105.0	2.12	.49413E+07	.33113E+07	.19744E+07	.25133E+00
2106.0	2.12	.47238E+07	.29590E+07	.18171E+07	.23359E+00
2107.0	2.12	.46385E+07	.31755E+07	.18574E+07	.24864E+00
2108.0	2.12	.43495E+07	.33940E+07	.16906E+07	.28641E+00
2109.0	2.12	.43785E+07	.34139E+07	.15678E+07	.30072E+00
2110.0	2.11	.45134E+07	.32111E+07	.17829E+07	.26574E+00
2111.0	2.12	.49239E+07	.33730E+07	.19587E+07	.25692E+00
2112.0	2.12	.48491E+07	.32926E+07	.19326E+07	.25454E+00
2113.0	2.12	.48915E+07	.31864E+07	.19656E+07	.24431E+00
2114.0	2.11	.47980E+07	.32864E+07	.19299E+07	.25667E+00
2115.0	2.13	.49677E+07	.32739E+07	.19917E+07	.24713E+00
2116.0	2.17	.49852E+07	.33437E+07	.19917E+07	.25151E+00
2117.0	2.19	.51560E+07	.34244E+07	.20540E+07	.24905E+00
2118.0	2.38	.56015E+07	.38610E+07	.23214E+07	.24957E+00
2119.0	2.23	.56624E+07	.37327E+07	.22701E+07	.24717E+00
2120.0	2.11	.57080E+07	.31637E+07	.23793E+07	.19949E+00
2121.0	2.12	.51990E+07	.28435E+07	.21748E+07	.19527E+00
2122.0	2.12	.42164E+07	.31299E+07	.16529E+07	.27543E+00
2123.0	2.13	.44993E+07	.32278E+07	.17746E+07	.26768E+00
2124.0	2.13	.46515E+07	.32165E+07	.18473E+07	.25898E+00
2125.0	2.13	.48152E+07	.32282E+07	.19239E+07	.25140E+00
2126.0	2.12	.49418E+07	.32564E+07	.19814E+07	.24707E+00
2127.0	2.12	.51757E+07	.32853E+07	.20913E+07	.23743E+00

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TRUE LEVEL

TABLE VIII (cont'd)

## Physical Properties of Disposal Horizons

TRU Level					
Depth	Density	Young's Modulus (psi)	Bulk Modulus (psi)	Shear Modulus (psi)	Poisson's Ratio
2128.0	2.13	.49364E+07	.34319E+07	.19618E+07	.25816E+00
2129.0	2.13	.47866E+07	.32630E+07	.19132E+07	.25093E+00
2130.0	2.13	.49914E+07	.32110E+07	.19930E+07	.24219E+00
2131.0	2.14	.51411E+07	.32989E+07	.20721E+07	.24031E+00
2132.0	2.15	.52516E+07	.33825E+07	.21154E+07	.24124E+00
2133.0	2.13	.52313E+07	.33417E+07	.21109E+07	.23909E+00
2134.0	2.12	.53142E+07	.31464E+07	.21756E+07	.21903E+00
2135.0	2.13	.51777E+07	.31733E+07	.21080E+07	.22810E+00
2136.0	2.13	.53043E+07	.31883E+07	.21851E+07	.21376E+00
2137.0	2.13	.54372E+07	.29465E+07	.22799E+07	.19245E+00
2138.0	2.12	.50827E+07	.31553E+07	.21636E+07	.23152E+00
2139.0	2.13	.53747E+07	.29151E+07	.22532E+07	.19270E+00
2140.0	2.14	.53216E+07	.31813E+07	.21945E+07	.21221E+00
2141.0	2.13	.52171E+07	.34883E+07	.22856E+07	.25071E+00
2142.0	2.37	.57075E+07	.38397E+07	.22789E+07	.25226E+00
2143.0	2.38	.58142E+07	.38570E+07	.23279E+07	.24881E+00
2144.0	2.13	.53163E+07	.36654E+07	.21135E+07	.25613E+00
2145.0	2.11	.48819E+07	.36393E+07	.19118E+07	.27651E+00
2146.0	2.11	.49417E+07	.34165E+07	.19622E+07	.25638E+00
2147.0	2.13	.52315E+07	.33773E+07	.21059E+07	.24189E+00
2148.0	2.17	.53112E+07	.34679E+07	.21311E+07	.24619E+00
2149.0	2.21	.54212E+07	.35217E+07	.21799E+07	.24344E+00
2150.0	2.18	.53463E+07	.34231E+07	.21551E+07	.23981E+00
2151.0	2.11	.49971E+07	.34134E+07	.19430E+07	.26019E+00
2152.0	2.11	.48569E+07	.33799E+07	.18338E+07	.27627E+00
2153.0	2.10	.48461E+07	.31957E+07	.18471E+07	.25769E+00
2154.0	2.11	.48867E+07	.31277E+07	.19740E+07	.23221E+00
2155.0	2.12	.49113E+07	.31693E+07	.19774E+07	.24175E+00
2156.0	2.12	.48112E+07	.34263E+07	.19302E+07	.26597E+00
2157.0	2.12	.50613E+07	.33128E+07	.21323E+07	.24534E+00
2158.0	2.11	.51632E+07	.31693E+07	.21045E+07	.22814E+00
2159.0	2.10	.49693E+07	.31803E+07	.21043E+07	.23961E+00
2160.0	2.11	.48217E+07	.31479E+07	.19364E+07	.24477E+00
2161.0	2.10	.43254E+07	.33823E+07	.16886E+07	.28688E+00
2162.0	2.11	.43655E+07	.52503E+07	.17104E+07	.27613E+00
2163.0	2.11	.47339E+07	.50261E+07	.19699E+07	.23927E+00
2164.0	2.10	.51179E+07	.29304E+07	.21167E+07	.21892E+00
2165.0	2.08	.51923E+07	.30853E+07	.20785E+07	.22500E+00
2166.0	2.10	.52193E+07	.31633E+07	.21422E+07	.21816E+00
2167.0	2.10	.46013E+07	.29432E+07	.18557E+07	.23972E+00
2168.0	2.11	.44618E+07	.29257E+07	.17912E+07	.24577E+00
2169.0	2.11	.47920E+07	.23133E+07	.19545E+07	.22591E+00
2170.0	2.10	.44934E+07	.33615E+07	.17591E+07	.27721E+00
2171.0	2.09	.44953E+07	.33616E+07	.20339E+07	.22284E+00
2172.0	2.09	.49344E+07	.30317E+07	.20079E+07	.22873E+00
2173.0	2.09	.48616E+07	.30300E+07	.18436E+07	.26451E+00
2174.0	2.09	.49986E+07	.31698E+07	.20141E+07	.23783E+00
2175.0	2.19	.49883E+07	.35736E+07	.19655E+07	.26760E+00
2176.0	2.43	.52213E+07	.41435E+07	.20238E+07	.28998E+00
2177.0	2.62	.56532E+07	.47845E+07	.21736E+07	.30272E+00
2178.0	2.48	.64164E+07	.53943E+07	.24654E+07	.30169E+00
2179.0	2.29	.62581E+07	.54462E+07	.23900E+07	.30853E+00

TRU LEVEL (cont'd)

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TABLE VIII (cont'd)

## Physical Properties of Disposal Horizons

RH Level					
Depth	Density	Young's Modulus (psi)	Bulk Modulus (psi)	Shear Modulus (psi)	Poisson's Ratio (psi)
2616.0	2.18	.50675E+07	.36081E+07	.20015E+07	.26592E+00
2617.0	2.61	.60151E+07	.46217E+07	.23440E+07	.28308E+00
2618.0	2.35	.54971E+07	.51846E+07	.20770E+07	.32329E+00
2619.0	2.12	.49717E+07	.49793E+07	.18641E+07	.33359E+00
2620.0	2.12	.51656E+07	.38143E+07	.19817E+07	.27811E+00
2621.0	2.12	.51565E+07	.31139E+07	.20566E+07	.22936E+00
2622.0	2.12	.50257E+07	.32323E+07	.20251E+07	.24386E+00
2623.0	2.12	.49546E+07	.33417E+07	.19774E+07	.25281E+00
2624.0	2.13	.49245E+07	.34333E+07	.19527E+07	.26095E+00
2625.0	2.12	.49557E+07	.33887E+07	.19715E+07	.25636E+00
2626.0	2.12	.47134E+07	.35320E+07	.18470E+07	.27735E+00
2627.0	2.12	.49453E+07	.36050E+07	.17611E+07	.23995E+00
2628.0	2.12	.49486E+07	.34131E+07	.19203E+07	.26253E+00
2629.0	2.12	.47556E+07	.35281E+07	.18656E+07	.27523E+00
2630.0	2.12	.49517E+07	.33729E+07	.19723E+07	.25527E+00
2631.0	2.12	.50339E+07	.32640E+07	.20291E+07	.24425E+00
2632.0	2.11	.49856E+07	.33132E+07	.19859E+07	.25021E+00
2633.0	2.11	.49106E+07	.33792E+07	.19521E+07	.25780E+00
2634.0	2.11	.50252E+07	.32674E+07	.24213E+07	.24367E+00
2635.0	2.11	.49516E+07	.32615E+07	.19855E+07	.24697E+00
2636.0	2.11	.50334E+07	.31886E+07	.20213E+07	.23837E+00
2637.0	2.11	.49613E+07	.32262E+07	.19946E+07	.24373E+00
2638.0	2.11	.49614E+07	.32219E+07	.19663E+07	.24637E+00
2639.0	2.11	.48766E+07	.32540E+07	.19503E+07	.25023E+00
2640.0	2.11	.48650E+07	.32751E+07	.19383E+07	.25284E+00
2641.0	2.11	.50118E+07	.32501E+07	.20136E+07	.24140E+00
2642.0	2.12	.49317E+07	.33456E+07	.19655E+07	.25432E+00
2643.0	2.13	.49639E+07	.33773E+07	.19785E+07	.25498E+00
2644.0	2.12	.49621E+07	.33515E+07	.19797E+07	.25324E+00
2645.0	2.12	.49990E+07	.33318E+07	.19997E+07	.24994E+00
2646.0	2.12	.50354E+07	.32652E+07	.20254E+07	.24306E+00
2647.0	2.12	.50412E+07	.32417E+07	.20309E+07	.24187E+00
2648.0	2.11	.49765E+07	.32237E+07	.20023E+07	.24272E+00
2649.0	2.11	.49539E+07	.32683E+07	.19842E+07	.24733E+00
2650.0	2.12	.49656E+07	.33131E+07	.19953E+07	.25157E+00
2651.0	2.12	.49133E+07	.33777E+07	.19535E+07	.25756E+00
2652.0	2.12	.48188E+07	.34865E+07	.18915E+07	.27028E+00
2653.0	2.12	.51419E+07	.33039E+07	.20230E+07	.24587E+00
2654.0	2.12	.49757E+07	.33474E+07	.19867E+07	.25227E+00
2655.0	2.11	.49390E+07	.33311E+07	.19710E+07	.25290E+00
2656.0	2.10	.49426E+07	.32484E+07	.19828E+07	.24637E+00
2657.0	2.10	.48779E+07	.32642E+07	.19454E+07	.25266E+00
2658.0	2.11	.49341E+07	.33148E+07	.19553E+07	.25342E+00
2659.0	2.12	.49153E+07	.33743E+07	.19548E+07	.25722E+00
2660.0	2.12	.49364E+07	.33763E+07	.19646E+07	.25635E+00
2661.0	2.13	.49962E+07	.33883E+07	.19917E+07	.25425E+00
2662.0	2.13	.51463E+07	.33803E+07	.20176E+07	.25109E+00
2663.0	2.13	.51112E+07	.33364E+07	.20530E+07	.24483E+00
2664.0	2.14	.51239E+07	.34693E+07	.20054E+07	.25409E+00
2665.0	2.14	.49343E+07	.34756E+07	.19528E+07	.26339E+00
2666.0	2.14	.51448E+07	.33746E+07	.20165E+07	.25086E+00
2667.0	2.12	.49717E+07	.33388E+07	.19853E+07	.25187E+00
2668.0	2.11	.49959E+07	.33372E+07	.19498E+07	.25549E+00
2669.0	2.11	.49450E+07	.32733E+07	.19823E+07	.24807E+00
2670.0	2.11	.49431E+07	.32712E+07	.19826E+07	.24789E+00
2671.0	2.11	.49549E+07	.33355E+07	.19305E+07	.25741E+00
2672.0	2.13	.49472E+07	.33132E+07	.19765E+07	.25151E+00
2673.0	2.13	.49928E+07	.32771E+07	.20034E+07	.24608E+00

RH LEVEL

TABLE VIII (cont'd)

## Physical Properties of Disposal Horizons

RH Level					
Depth	Density	Young's Modulus (psi)	Bulk Modulus (psi)	Shear Modulus (psi)	Poisson's Ratio (psi)
2674.0	2.13	.49773E+07	.32952E+07	.19937E+07	.24826E+00
2675.0	2.12	.51356E+07	.32306E+07	.20302E+07	.24020E+00
2676.0	2.11	.48836E+07	.33282E+07	.19450E+07	.25545E+00
2677.0	2.12	.48926E+07	.33707E+07	.19445E+07	.25808E+00
2678.0	2.13	.49683E+07	.33596E+07	.19818E+07	.25352E+00
2679.0	2.12	.49817E+07	.33851E+07	.19467E+07	.25871E+00
2680.0	2.14	.48945E+07	.34534E+07	.19365E+07	.26379E+00
2681.0	2.14	.49982E+07	.33766E+07	.19940E+07	.25329E+00
2682.0	2.14	.50018E+07	.33748E+07	.19950E+07	.25292E+00
2683.0	2.13	.49714E+07	.33635E+07	.19827E+07	.25366E+00
2684.0	2.12	.49194E+07	.33721E+07	.19531E+07	.25705E+00
2685.0	2.12	.48436E+07	.34253E+07	.19152E+07	.26435E+00
2686.0	2.13	.47397E+07	.35222E+07	.18808E+07	.27335E+00
2687.0	2.12	.47215E+07	.35576E+07	.18461E+07	.27881E+00
2688.0	2.12	.47254E+07	.35414E+07	.18433E+07	.27759E+00
2689.0	2.15	.46448E+07	.35915E+07	.19043E+07	.26940E+00
2690.0	2.16	.47984E+07	.35928E+07	.18782E+07	.27741E+00
2691.0	2.17	.49775E+07	.35703E+07	.19633E+07	.26764E+00
2692.0	2.15	.48844E+07	.36143E+07	.19158E+07	.27477E+00
2693.0	2.14	.48746E+07	.36214E+07	.19106E+07	.27566E+00
2694.0	2.13	.48361E+07	.35691E+07	.19255E+07	.27137E+00
2695.0	2.13	.47748E+07	.35991E+07	.18668E+07	.27889E+00
2696.0	2.13	.48057E+07	.35129E+07	.18890E+07	.27200E+00
2697.0	2.15	.49515E+07	.34243E+07	.19665E+07	.25893E+00
2698.0	2.16	.49997E+07	.33715E+07	.19953E+07	.25285E+00
2699.0	2.15	.49486E+07	.33485E+07	.19736E+07	.25369E+00
2700.0	2.14	.49348E+07	.33259E+07	.19697E+07	.25271E+00
2701.0	2.12	.49338E+07	.32729E+07	.19754E+07	.24875E+00
2702.0	2.12	.48906E+07	.33282E+07	.19483E+07	.25512E+00
2703.0	2.12	.47716E+07	.34555E+07	.18763E+07	.26990E+00
2704.0	2.13	.49032E+07	.34063E+07	.19456E+07	.26307E+00
2705.0	2.15	.49267E+07	.34531E+07	.19525E+07	.26211E+00
2706.0	2.18	.49637E+07	.35259E+07	.19614E+07	.26537E+00
2707.0	2.21	.49737E+07	.36245E+07	.19562E+07	.27129E+00
2708.0	2.23	.49775E+07	.37115E+07	.19497E+07	.27648E+00
2709.0	2.25	.51578E+07	.36675E+07	.20377E+07	.26561E+00
2710.0	2.23	.52019E+07	.35885E+07	.20669E+07	.25849E+00
2711.0	2.17	.50693E+07	.35210E+07	.20133E+07	.25867E+00
2712.0	2.14	.49299E+07	.35113E+07	.19470E+07	.26603E+00
2713.0	2.12	.48205E+07	.35487E+07	.18925E+07	.27360E+00
2714.0	2.11	.47623E+07	.35830E+07	.18625E+07	.27848E+00
2715.0	2.10	.48110E+07	.35282E+07	.18900E+07	.27274E+00
2716.0	2.10	.48456E+07	.35136E+07	.19075E+07	.27816E+00
2717.0	2.10	.47764E+07	.35222E+07	.18746E+07	.27399E+00
2718.0	2.11	.47481E+07	.35661E+07	.18630E+07	.27429E+00
2719.0	2.10	.48193E+07	.34352E+07	.19031E+07	.26618E+00
2720.0	2.10	.48101E+07	.34413E+07	.18951E+07	.26708E+00
2721.0	2.10	.47769E+07	.34857E+07	.18783E+07	.27160E+00
2722.0	2.11	.48110E+07	.35233E+07	.18900E+07	.27247E+00
2723.0	2.14	.48638E+07	.36145E+07	.19063E+07	.27573E+00
2724.0	2.19	.51132E+07	.36907E+07	.19681E+07	.27361E+00
2725.0	2.12	.47566E+07	.35142E+07	.18580E+07	.26055E+00
2726.0	2.08	.45698E+07	.35124E+07	.17807E+07	.28316E+00
2727.0	2.06	.48255E+07	.32409E+07	.19279E+07	.25179E+00
2728.0	2.07	.51837E+07	.36156E+07	.21358E+07	.21351E+00
2729.0	2.36	.53882E+07	.43463E+07	.21080E+07	.27804E+00
2730.0	2.73	.56432E+07	.49170E+07	.25604E+07	.27776E+00
2731.0	2.59	.59586E+07	.55285E+07	.22564E+07	.32337E+00

RH LEVEL (cont'd)

Anhydrite Bed

### Deep Seismic Exploration Surveys

Sandia conducted 26 line miles of vibratory-type seismic surveys in the site area. In addition, 500 line miles of other deep-sounding seismic surveys have been obtained either by purchase or loan from private industry. Figure 26 presents the various surveys that were used to compile structural maps of the Castile and deeper horizons. Some difficulty was experienced in synthesis of the surveys because they involved different crews, instrumentation, and data processing. However, the interpretation is considered adequate for initial site evaluation.

Several structural anomalies were noted on the seismic profiles, but fortunately none were discovered in the area proposed for actual mining. The more significant of these anomalies will now be described.

Anticlinal Feature Near Belco Hudson Federal No. 1 Well, Section 1, T23S, R30E -- An anticlinal feature exists that persists from the top of Salado down to the Devonian Marker. Sandia Line 2 passed over this structure from northeast to southwest. The details of portions of that line are shown in Figure 25. The surface trace of the profile is shown on Figure 26. Only the shallow portion (Delaware upwards) of the profiles is shown. The anticline just described appears in the lower half of the diagram at Station 143. The Belco Hudson Federal No. 1 Well is ~1000 ft in front of this vertical profile. Note that the anticline gives way to a syncline at Station 155. Complex structure is still evident to the southwest as far as Station 177. Structure along the Delaware sandstone horizon is rather mild, revealing only a gentle anticline centered under Station 155. The complex structure in the Castile may represent salt flowage or deep removal of salt by groundwater.

Anticline in the Castile, Northwest Part, Section 21, T22S, R31E -- An anticline was shown on the structure map of the Castile, Figure 14. The details of the seismic profile over the feature are shown in the upper part of Figure 25. The crest of the anticline is at Station 35. Note that the two reflectors just above the Castile horizon marker appear to merge on the crest of the anticline (recall that the 124 Marker Bed structure map, Figure 13, reveals a synclinal structure for the Salado in this area).

Complex Feature, Northwest Part, Section 8, T22S, R31E -- Note the position of a seismic profile line labeled "Cabin Lake 5" on Figure 26. It is an east-west line about 8 mi long with its center point on the northern boundary of Section 8, T22S, R31E. This line was run by an oil company, but permission had been granted to inspect but not copy the shallow portions of the data.

Normally the Delaware and Castile reflections are easily traceable on the section. However, the Castile reflections completely disappear for about 1/2 mi, even though the Delaware horizon continues in a normal fashion. The center of the Castile anomaly is in the northwest part of Section 8. This position is roughly congruent with a depression of the 124 Marker Bed, although the center of the latter is the southeast center of the same section (Figure 13). Lack of tight drill-hole control and wide spacing of seismic profiles could account for this discrepancy in position. The structure could be interpreted as a breccia pipe formed by deep-salt dissolution that has caused downward displacement of the anhydrite beds within the Castile.

New seismic profiling recommenced in the site area under Sandia's direction during the fall of 1977. Full data reduction and interpretation of these new surveys will not be in hand until 1978. However, the initial interpretation of the records has verified the presence of this structure. In addition, a new feature of similar but less pronounced character has been recognized in the seismic data centered on the common corner of Sections 16, 17, 20, and 21, T22S, R31E. This location is at the northern boundary of Zone II.

While other structures were discovered during the study of seismic profiles available from several oil companies, the above three anomalies were the only significant ones found in the WIPP site area. Seismic data from oil company records were not of sufficient quality to make a reliable interpretation of the complex Castile structure known to exist near ERDA No. 6. The profiles do reveal that the Castile is disturbed, but no definitive interpretation is possible.

#### Magnetic Surveys

Sandia purchased from private sources a 1-gamma-resolution airborne magnetic survey over the entire New Mexico portion of the Delaware Basin. In addition, a 10-gamma resolution was available from the USGS for much the same area. These two surveys have been reinterpreted to establish the strike trend of the lamprophyre dike that outcrops south of White City, NM, and that has been observed in two potash mines and in several deep oil tests. The course of the dike, shown in Figure 1, passes no closer than 7 mi to Zone II of the proposed site, a distance considered to be far enough so as not to present a hazard. If other dike trends exist, the surveys were not of sufficient resolution to detect them.

The magnetic surveys do not reveal any sharp contrasts in the site area. Hence, no major basement structure is postulated under the site.

#### Gravimetric Surveys

Complete coverage of the New Mexico portion of the Delaware Basin was purchased from private sources. The station density is approximately 6.8/sq mi and has been contoured on an interval of 0.2 milligal. Deep structural trends are evident. These features have been correlated with seismic interpretations to provide a structural trend map (Figure 14). The results indicate an east-west-trending belt of structural highs passing beneath the site area. North-trending highs are present to the east and west. The lows are sinuous and farther out. These structural trends are considered to be normal for a major depositional basin such as the Delaware.

#### Schlumberger Expansion Arrays

A total of 40 Schlumberger expansion array surveys were conducted in the site area. The location of these surveys is shown in Figure 27. Even though line lengths are long, each expander yields valid resistivity only in the central part of the line. The objective is to determine lithologic changes with depth, as shown by changes in electrical resistivity. The salt is highly resistive in relation to the siltstones and sandstones of the Dewey Lake and Santa Rosa Formations. If salt and

anhydrite are present in the Rustler, they should show a corresponding increase in resistivity and can be detected. If the salt has been removed and the anhydrite converted to gypsum, then the surveys might reflect the top of the first salt in the Salado Formation. Unfortunately, the results of the field work do not support this hypothesis. Apparently, the varying thicknesses of the Santa Rosa and Dewey Lake beds overwhelm the electrical response of the underlying salt beds.

#### Detailed Electrical and Gravity Surveys Conducted Over Breccia Pipes Outside the Site Area

Breccia pipes are known to exist in the Delaware Basin. While several specific hypotheses have been ventured for their origin, there is general agreement that dissolution of salt followed by collapse of the overlying strata is the essential process by which they are formed. All known pipes are in areas that have experienced major salt dissolutioning. That at least one penetrates as deep as the McNutt member of the Salado has been confirmed by underground exposures in the Mississippi Chemical Co. potash mine. Aerial views of this particular pipe and several others are shown in Figure 28. The surface topographic exposure of these particular pipes may be due to the fact that they are located within Nash Draw. It is conceivable that breccia pipes exist that do not express themselves topographically; and indeed, one having very little surface relief was accidentally encountered in the 1950s during the drilling of a potash exploratory hole in Section 12, T20S, R29E. Even though that particular pipe is 20 mi northwest of the proposed site at Los Medaños, it was sufficient warning to us that we should devise a method for detecting these special structures. The Los Medaños area is relatively flat, and outcrops are covered with dune sand.

Detailed electrical resistivity and gravimetric surveys have been run over two known and three suspected pipes. The known pipes are the two previously described, the one encountered in the potash mine and the one discovered by an exploratory hole. The three suspected pipes were distinctive topographic features near the one exposed in the mine (refer to Figure 28). All of these locations are outside the area of investigation at Los Medaños, but they serve as case studies to determine the feasibility of detecting breccia pipes under shallow cover.

The electrical resistivity surveys employed an in-line pole-dipole technique. Both the dipole length and separation from the input pole were varied so as to determine experimentally the best configuration to reach below the surface weathering effects. This technique of geophysical surveying has proved successful in detecting the two known pipes. The surveys reveal that the breccia core has a much lower resistivity than the surrounding undisturbed strata. Results of profiling across the three suspected structures revealed that two are accompanied by prominent lows and are therefore thought to be breccia pipes (Hill A and B in Figure 28). The third (Hill D in Figure 28) had no such low and is thought not to be a pipe. An example of the data derived over Hill A and B is presented in Figure 29.

The same technique of measuring earth resistivity was applied in the shallow sink structure in the southeast part of Section 9, T22S, R31E. The results of that work are shown in Figure 30. The data clearly show that it is a shallow feature that does not persist with depth.

Gravimetric surveys were conducted over the same five known and suspected breccia pipes across which electrical surveys were conducted. The surveys were detailed and used the best available instrumentation and techniques. Station density was every 100 ft over the suspected structures, plus a surrounding grid of 200-ft stations out at least two diameters from the pipes. All field measurements were reduced following conventional procedures for gravity data analysis. The detailed areas were contoured at 0.05-milligal intensities. These were then compared with a regional gravity map that was contoured on 0.20-milligal intervals.

The conclusion from the gravity work is that it was not a reliable indicator of the presence of breccia pipes. No abnormal high or low over the regional field was discernible.

#### Mineral Resource Evaluation

At the onset of the evaluation for the WIPP site location, we realized that some conflict with mineral resource was inevitable. The site was chosen in an attempt to minimize this conflict, but no details were available to quantify the extent of this conflict. Some potash drilling had been done in the area, but the data were not initially available to Sandia because such information is held in confidence by the USGS on behalf of the various mining companies who had done the drilling. Oil and gas production rates were known for proven reservoirs, but full exploration had not been conducted in the site area. In addition, the sudden advent of the energy crisis escalated the price of natural gas four-to fivefold in just the last 2 yr, causing interest in previously unattractive areas. The Morrow Formation is the principal gas-producing horizon in this portion of the Delaware Basin, but it was not considered to be an attractive exploration target before the price escalation. This is no longer true; deep exploratory drilling is now under way throughout the basin. Indeed, applications for drilling permits have been filed by three different companies in the Los Medaños site area in recent months.

#### Oil and Gas

The oil and gas potential now has been evaluated for the Los Medaños site and environs. The evaluator used the Delaware to Devonian structural maps that resulted from the seismic surveys to plan step-out wells to fully develop known fields as well as to plan wildcat tests to prospect likely structures. Production histories of surrounding wells were tabulated to predict total recoveries and decline rates associated with the withdrawal. Risk factors were assigned based on experience within the Delaware Basin. Conventional discounted cash-flow analyses were then used to calculate the present value of these resources. The potentially recoverable hydrocarbons, principally natural gas, were estimated assuming full and prudent development under current economics and technology.

The essential results of the oil and gas study are shown in Figure 32. The position of known and postulated reservoirs are shown superimposed on the Morrow Limestone structure. Known production in the area ranges from Delaware down to the Morrow Formation. However, the Delaware and Bone Springs are thought to be of only minor importance. Natural gas occurring in the Atoka and Morrow sandstones, both of Pennsylvanian age, hold the best promise for commercial production.

There are two principal producing fields in the Los Medaños area. Five wells produce gas from the Morrow in a field known as Cabin Lake in the northwest. Another five-well field, called the Los Medaños Field, produces gas from both the Atoka and Morrow in the southwest part of the map area. Four other single-well fields produce from the Delaware, Bone Springs, Atoka, and Morrow Formations. Fourteen dry holes have been drilled. Of these, only two were deep enough to penetrate the Pennsylvania; the other 12 tested only the Delaware Formation.

From the structure contours on Figure 32, it appears that a faulted anticline controls the Morrow reservoir in the Los Medanos field to the southwest of the site region. This same structure probably persists up into the Atoka. Therefore, the best opportunity for extension of both these reservoirs exists to the northeast.

Within the boundaries of the actual WIPP site, a pattern of faulted anticlines is shown. These structures are believed to hold promise for discovery of gas in the Morrow. Experience in other parts of the Delaware Basin has indicated a tendency for Morrow gas reservoirs to occur on the flanks of quaquaversal structures and noses.

To evaluate the hydrocarbon resources within the boundaries of the WIPP site, potential drilling sites were picked based on the structure contours of the Morrow. Depending on structure and offset distance from producing wells, these potential drilling sites were ranked as either proven undeveloped, probable, or possible. These locations are shown in Figure 32. Two locations are considered proven undeveloped, and both are immediate offsets to a prolific Atoka gas well in the southern part of Section 36, T22S, R30E. This particular well, known as the Shell James Ranch No. 1, has been partially surrounded by an arc of four other wells on the south and west that failed to tap the Atoka reservoir even though all four made successful completions in the Morrow. The production decline for the Atoka well indicates that the well is probably draining several square miles. This fact, coupled with favorable structure, indicates that immediate offsets to the northeast have a high chance of success. These wells will only enhance the rate of recovery of the Atoka reservoir now being drained by one well. Ultimate recovery will remain about the same. Four other prospective drilling sites were selected to fully develop the Morrow reservoir in the Los Medaños Field. Two of these locations were ranked as "probable," and two were ranked as "possible."

The faulted anticlinal structure in the northwest part of the proposed land withdrawal area is considered more speculative than the northeast extension of the Los Medaños field. The Delaware, Bone Springs, and Atoka beds would be tested by any well going on down to the Morrow Sandstone, but experience elsewhere in this part of the Delaware Basin indicates a low probability of striking commercial reservoirs. On the other hand, the chances of encountering gas in the Morrow are considered to be fairly good. Eleven drilling targets were selected for this area; 8 are considered probable and 3 as possible. Finally, four other locations were chosen to explore a structural nose located farther east. These four locations were assigned possible rankings for Morrow gas discoveries.

The potential gas that could be discovered and produced if the above hypothetical drilling program was executed is given in Table IX. The two Atoka wells will tap a reservoir that is now being efficiently drained by the Shell James Ranch No. 1. Therefore, little loss in resource is expected if the WIPP land withdrawal prevents drilling these two particular wells. However, these two drilling prospects have a good probability of extending the known Morrow reservoir in the Los Medanos Field, and prevention of drilling at those locations must be considered as a loss of those resources.

TABLE IX  
Potential Economic Gas Resources Under WIPP Site

Location (Section/Township/Range)	Expected Reservoir	Expected Reserve (Billion Cu Ft)		
		Proven	Probable	Possible
N 1/2 36, 22S, 30E	Atoka	-----Being Drained-----		
	Morrow	2.07	--	--
W 1/2 1, 22S, 30E	-----Outside WIPP Boundary-----			
SW 1/4 31, 22S, 31E	Atoka	-----Being Drained-----		
	Morrow	2.07	--	--
NW 1/4 31, 22S, 31E	Morrow	--	1.64	--
S 1/2 25, 22S, 30E	Morrow	--	--	1.33
SW 1/4 30, 22S, 31E	Morrow	--	--	1.33
SE 1/4 7, 22S, 31E	Morrow	--	2.09	--
SE 1/4 13, 22S, 30E	Morrow	--	2.09	--
NW 1/4 17, 22S, 31E	Morrow	--	2.09	--
NE 1/4 17, 22S, 31E	Morrow	--	2.09	--
SE 1/4 16, 22S, 31E	Morrow	--	--	1.67
W 1/4 24, 22S, 30E	Morrow	--	2.09	--
SW 1/4 19, 22S, 31E	Morrow	--	--	1.67
NW 1/4 19, 22S, 31E	Morrow	--	2.09	--
NE 1/4 20, 22S, 31E	Morrow	--	2.09	--
SE 1/4 20, 22S, 31E	Morrow	--	--	1.67
NE 1/4 21, 21S, 31E	Morrow	--	2.09	--
NE 1/4 28, 21S, 31E	Morrow	--	--	1.67
SE 1/4 33, 21S, 31E	Morrow	--	--	1.67
NE 1/4 34, 31S, 31E	Morrow	--	--	1.67
	Totals	4.14	18.36	12.68
	Grand Total			35.18

Potash

Potash resource evaluation was more difficult and is not yet complete. This evaluation is being performed jointly by the USGS and the U. S. Bureau of Mines (USBM). The procedure was to in-fill drill between previously existing potash exploration holes (those that had been drilled by industry) at

a minimum spacing of 1 hole/sq mi, or 21 new holes. Cores were taken continuously across the potential potash-bearing zones, selectively split, and then assayed. The results of these holes, along with information from the older privately drilled holes, allowed potential ore zones to be defined in plan, thickness, and grade. This phase of the evaluation was conducted by the USGS, but economic evaluation of this resource is the responsibility of the USBM. Mining methods and cost data have been accumulated from the existing mining operations in the immediate area. Beneficiation testing on core samples has been done to determine what refining will be required and what percent recovery can be expected for the deposits under the Los Medanos site area. Discounted cash-flow analysis will be used to determine the present value of the resources.

The initial findings of the USGS indicate that potentially economic quantities of potash exist within the proposed site. The lateral extent of these deposits is presented in Figure 31. It has been established policy within the USGS to consider as potential ore any deposit of potash mineralization that meets or exceeds these requirements: 4 ft of 10-percent  $K_2O$  as sylvite, or 4 ft of 4-percent  $K_2O$  as langbeinite or the equivalent combination of the two minerals. A "measured" reserve classification is given to those individual ore zones that have at least three sampled intercepts no farther than 1.5 mi apart. Reserves are classed as "indicated" when the sample density is less, but where at least one intercept and reasonable geologic projection can be made. These standards are used by the USGS to determine if potash mineralization under federal lands qualifies for competitive bidding. All potash mineral lands in the Carlsbad district that meet these qualifications have been placed in an enclave called the Known Potash Area (KPA).

The position of the enclave as officially described by the USGS as of April 17, 1975, is posted on Figure 31. Our drilling of the 21 potash exploratory holes has demonstrated that much of the WIPP site area, originally mostly outside the KPA, would now fall within the minimum requirements set by USGS.

A more complete description of the data presented in Figure 31 will now be attempted. Langbeinite and sylvite ores are being currently mined in the extreme west part of the map area. The langbeinite is being extracted from the 4th ore zone, and the sylvite is being mined from the 10th ore zone. These are two of the traditional mining horizons known in the Carlsbad Potash District. Past mining and planned future extensions are shown. Plans are very tentative and are projected only for a few decades in advance of mining. Additional drilling or a change in market conditions could alter these plans. In addition, the plans are only of the existing Nash Draw mine now being operated by the Duval Corporation. Other mining leases exist in the area, but no plans have been submitted by the owners.

The USGS refined their estimates of ore to include a class higher than that required for land classification for competitive bidding. They set the higher criteria as 14%  $K_2O$  for sylvite or 8%  $K_2O$  for langbeinite while retaining the thickness and number of drill intercepts. A belt of higher-grade potash is shown that extends from Duval's Nash Draw mine on the west around the northern portion of the proposed WIPP site area. Four circular areas of indicated ore with these higher grades are also shown.

The USGS has released their initial findings. Measured ore meeting the minimum criteria was found in the 2nd, 3rd, 4th, 5th, 8th, 9th, and 10th ore zones. Deposits with the most economic potential occur in the 10th and 4th ore zones. The same conditions prevail under the higher grade requirements, but the potential tonnage decreases. Preliminary estimates for the WIPP site are given in Table X.

TABLE X  
Potential Potash Reserves Under the WIPP Site

Ore Zone	Minimum Grade		Higher Grade	
	Measured	Indicated	Measured	Indicated
4	108.3	5.2	58.5	0.3
10	101.6	5.9	47.7	3.3
All Others	<u>112.8</u>	<u>24.1</u>	<u>24.6</u>	<u>1.1</u>
Totals	322.7	35.2	130.8	4.7

The USBM has not completed their economic evaluation to determine to what extent these measured and indicated reserves can be considered as actually mineable under today's market conditions and existing technology.

#### Potential Geologic Hazards

Investigations conducted at Los Medaños and reported here have found geologic conditions to be favorable to the proposed repository. Full confirmation of the site must await completion of detailed studies now under way. The work reported here is considered to be adequate to establish that the major selection criteria have been met. What follows is a discussion of some potential geologic hazards recognized in the surrounding areas that, if present in Zone II, might present a risk to terminal radioactive waste isolation. Additional geologic and geophysical investigations now under way at Los Medaños will determine additional geologic information relative to these potential hazards.

#### Salt Flowage

Highly deformed salt was revealed in the cores of halite beds from the Castile Formation in AEC No. 7. More intense deformation was observed in ERDA No. 6 and extended up in the section to the Cowden anhydrite. Examination of seismic profiles near the Capitan Reef has further substantiated the existence of a salt-deformation belt in front of that geologic feature. The selection of the Los Medaños site took this deformation belt into consideration. However, we assigned an arbitrary width of 6 mi for the belt. Local deformation could extend farther out into the basin, particularly over or near any anticline or fault in the Delaware Mountain Group immediately underlying the

Castile. Possible faults in the Delaware were observed on several seismic profiles, and their tentative positions are shown on Figure 15. Note that a shallow graben is shown between two of the northwest-trending faults. This minor structure could be the cause for the more complex structures seen in approximate juxtaposition in the 124 Marker Bed and in the Castile. (Figures 13 and 14).

The deformation belt in front of the reef is considered to have been formed by a décollement process initiated during the Tertiary Period when the entire Delaware Basin was tilted to the east. If correct, then all of the evaporite section should have had translation even though the intense deformation would be limited to near the Capitan Reef, which acted as an abutment. Some crinkling of halite beds sandwiched between anhydrite beds should be anticipated during such movement. In ERDA No. 9 the anhydrite lenses in the zone from the Cowden to the top of the Castile were essentially flat-lying, but at the contacts with halite there was some evidence of mixing that could be attributed to deformation. Salt recrystallization was also visible. A few thin anhydrite lenses were present in the thicker sections of infra-Cowden halite; frequently they exhibited contortion.

#### Brine and Gas Accumulations in the Salado

Brine and gas pockets are hit on an almost routine basis in the course of mining potash from the McNutt member of the Salado. The largest pocket reported contained an estimated 100,000 gal of brine, but the average pocket is much smaller (10-100 gal). No quantitative measurements have been made on the gas volume or its in-situ pressure. The gas is mostly nitrogen; the brine is saturated in Na, Mg, K, and Ca chlorides and sulfates. The presence of these pockets has presented no major obstacle to potash mining, and the inference is that they will not present a hazard to WIPP mining operations. However, the presence of these fluid accumulations needs to be cited to correct the impression that salt beds are completely dry. The simpler geology (i.e., thick pure salt beds) selected for the repository mining levels is suggestive of a lesser frequency of occurrence of fluid-bearing lenses.

Table XI lists the known nitrogen gas "kicks" we witnessed in our exploratory drilling program: ERDA 9, ERDA 6, AEC 8, and AEC 7.

TABLE XI  
Nitrogen Gas "Kicks"

<u>Hole</u>	<u>Depth (ft)</u>	<u>Comments</u>
ERDA 9	1409	Trace H <sub>2</sub> S
ERDA 6	1841	Blew for 30 min
	2021	Blew for 45 min
AEC 8	1100-1282	Produced N <sub>2</sub> gas for several mos
AEC 7	1610	N <sub>2</sub> gas. Blew for 1 hr
P-7	780-1234	Numerous kicks
P-12	unknown	Hole unloaded drill fluid over a weekend shutdown. Depth thought to be 1300 ft.
P-20	unknown	Slight blow when hole reached final depth

Perhaps the highest pressured zone encountered was in AEC No. 7, which was drilled by ORNL. It occurred after the planned total depth was reached and while the drill pipe was being removed before demobilization of the rig. The gas entry point was believed to be at a depth of 1610 ft. Some drilling fluid was ejected from the hole, but the blowout was exhausted in about 1 hr.

A nitrogen gas kick was initiated in AEC No. 8 on June 26, 1975. The hole had been left in a temporary abandoned condition by ORNL a little over a year; we were attempting to set a packer below the Culebra aquifer zone so as to complete the hole as an observation well. The tubing and packer assembly were ejected from the hole, and nitrogen gas continued to be emitted from the hole. The well was allowed to flow under open hole conditions for 2 mos with no noticeable depletion in flow rate. Subsequent flow tests were done in June 1976. The calculated open flow was 35,000 cu ft/day.

Suberosion of Salt at the Base of the Evaporites and Relationship to Breccia Pipes and Geopressured Brine Reservoirs

Breccia pipes are known to exist in Nash Draw. They are a potential hazard that should be avoided because they may possess vertical permeability that could affect the long-term integrity of the repository. Under the previous section dealing with Geophysical Surveys, it was argued that such pipes can be detected by electric surveys. Such surveys are now being run over the site area. Inspection of aerial photos has revealed a circular but sand-dune-covered feature suggestive of an underlying pipe in the northwest part of Section 14, T23S, R30E. This location is only 4 mi southwest of Zone II (Figure 3). The cluster of depressions shown on the top of Salado in Zone IV (Figure 12) surround the complex seismic anomaly where the Castile appears to be missing. A breccia pipe may be hidden under the flat sand-dune terrain in this area. If the collapsed breccia does not extend to the near surface, then it may not be detected by electrical surveys. High-resolution seismic profiling is being planned for this particular area.

The existence of breccia pipes is indicative of deep-solution cavities. As already mentioned, the pipe encountered in the Mississippi Chemical mine is proof that solution cavities have formed at depths at least as great as the base of the McNutt Member of the Salado. Deep solution could be occurring in the carbonate members of the Delaware Mountain or deeper horizons, but it is more reasonable to assume dissolution of the halites in the Castile or lower Salado.

The source of the dissolving fluid is more speculative. The largest nonsaline groundwater source is the Capitan Reef, and the numerous sinks in San Simon Swale are testimony that cavities are being formed in that area that overlies the reef. The swale is 20 mi east of the site, but the arcuate-shaped front of the reef passes about 8 mi from Zone II. The deformation belt in front of the reef could owe its existence to a combination of décollement of the evaporites due to regional tilting and salt dissolution from waters escaping from the reef.

Another possibility is that the deep dissolution front extends from the Pecos River and is thereby related to suberosion known to be acting at the top of the Salado. This implies that an undercutting wedge is working eastward. If so, then the discharge for the brine must be far to the south,

probably well into Texas. A third source for water of low salinity would be upward movement of formation waters from the Delaware Mountain Group. The discharge could be northward into the reef or southward in solution channels at the base of the evaporites as was just postulated for waters associated with the Pecos River.

The existence of geopressured brine reservoirs in the Castile is further testimony that sub-erosion may occur at the base of the evaporites. The two nearest such reservoirs are shown on the geologic cross section (Figure 6). A summary of the flow rates from these and three other known occurrences is given in Table XII.

TABLE XII  
Brine Flows From Nearby Wells

Well Name	Location	Flow Rate (bbl/day)	Depth of Flow (ft)
ERDA No. 6	Sec. 35, T21S, R31E	600	2709
Hudson Federal	Sec. 1, T23S, R32E	12,000	2802
Culbertson-Erwin	Sec. 26, T22S, R32E	Strong	3515
Bootlegger Ridge	Sec. 36, T22S, R32E	20,000	3671
Gulf 1-A	Sec. 25, T22S, R32E	36,000	3600

A drill-stem test was conducted in ERDA No. 6 to attempt to determine the reservoir size. The test was not completely successful, but analysis of the data indicates that the reservoir ranges from 200,000-2,000,000 bbl. The other four wells were drilled by oil companies who had no interest in the phenomena other than to get the wells back under control so that drilling could continue to deeper objectives. The stronger flow rates indicate that these brine wells tapped even larger reservoirs than we encountered at ERDA No. 6. The fact that these reservoirs are geopressured (i.e., they flow naturally) could be accounted for by collapse of over-lying beds. If this is the case, then such reservoirs may represent isolated pockets localized adjacent to remanent pillars of halite left behind a deep suberosion front. Hence, the flanks and any thicker-than-normal section of Castile should be regarded with caution. No sharp anticline in the Castile has been detected in the WIPP site similar to those at the Belco Hudson Federal No. 1 well or ERDA No. 6. However, a mild anticlinal structure is shown in the northeast part of Zone II (Figure 14). Nearby deep suberosion of Castile halite could have caused the structural lows observed on the structure map of the base of the 124 Marker Bed (Figure 13).

Studies are now under way to investigate deep suberosion phenomena. The program will include seismic profiling and drilling. Additional flow testing of ERDA No. 6 is also planned.

### Dikes

The northeast-trending dike previously mentioned is more than 70 mi in strike length. The magnetic expression is indicative of a belt approximately 1 mi wide rather than a single narrow band as observed in the potash mines. Oil and gas tests have reported igneous material even farther out, suggesting that sills may have formed outward into the pre-Ochoan sediments. The strike of the dike structure parallels the western edge of Nash Draw and Quahada Ridge. This might suggest that the east side of Nash Draw, called Livingston Ridge, may reflect another structural trend. No indications of dikes coincident with this trend were detected in the aeromagnetic surveys.

### Conclusions

The reconnaissance studies completed thus far form a sufficient base of information to determine that the Los Medanos site meets the essential criteria for terminal isolation of radioactive waste. The conflict with mineral resources is more subjective and the decision to preclude their eventual development must be made on the basis of national needs. That decision is not technical and will not be addressed further in this report.

The conceptual design for the WIPP project has indicated that only 3 sq mi will actually be needed for underground storage. This is the polygonal-shaped area centered on the common corner of Sections 20, 21, 28, 29, T22S, R31E. Zones III and IV are control zones beyond the repository to ensure the long-term integrity of the site. A review of the geologic structure maps, Figure 12-17, reveals that Zone II lies in an area of uniform and gentle dips on all horizons ranging down from the top of the Salado Formation to the Devonian Limestone.

The base of the 124 Marker Bed is stratigraphically about 475 ft above the middle of the TRU mining level. The attitude of the 124 Marker Bed is north-striking, with a dip of about 50 ft/mi within the bounds of Zone II. This is considered to be very flat, and the same general conditions should persist down to the TRU mining level.

The middle of the RH mining level lies ~1025 ft below the base of the 124 Marker Bed and 160 ft above the top of the Castile. There were insufficient drill-hole intercepts in the site area to compile a structure map of the top of the Castile. Instead, the most uniform seismic reflector within that formation was used to compile the structure shown in Figure 14. This horizon is estimated to be 900 ft below the middle of the RH mining horizon. The middle of the Castile horizon reveals a closed anticline in the northeast corner of Zone II. The steepest dips are on the southwest flank of that anticline and are estimated at 250 ft/mi. If the two postulated faults shown extending into the northwest corner of Zone II do in fact exist, then steep dips may be encountered in that area at the RH mining level. Experience would indicate that plastic flow within the salt has probably kept any faults of this magnitude tightly closed, and only a flexure in the pure salts would be expected at the mining levels.

Suberosion of salt from the Rustler appears to be in various stages of development over Zone II. Rotary drilling through this zone of salt removal at ERDA No. 9, and subsequent hydrologic testing at the three hydrologic test locations (H-1, -2, and -3) appears to indicate that complete subsidence has occurred, and there is no thick zone of brecciation. The suberosion process has not removed any salt from the Salado Formation in Zone II. The structural contours of this surface (Figure 12) and the isopach of the thickness between the top of the Salado and the base of the 103 Marker Bed (Figure 11) indicate no salt removal in Zones II and III. The suberosion front at the top of the Salado appears to be just entering Zone IV from the west-northwest. The two principal aquifers in the Rustler, the Magenta and Culebra, reveal (as expected) uniform dips that are in general agreement with the markers in the underlying Salado Formation.

The Dewey Lake Formation provides from 390-530 ft of cover over the Rustler in Zone II. Although the Santa Rosa has been stripped in the southwest quadrant, it provides additional cover of up to 150 ft in the northeast (Figure 10).

The surface of Zone II is completely sand-covered, and no topographic anomaly is present. The general drainage is to the southwest and conforms with the subsurface erosional pattern revealed on the isopachs of the Santa Rosa and Dewey Lake Formations.

The two mining horizons selected meet the general criteria for thickness and uniform physical properties for salt as determined from the wireline geophysical logs. In addition, the chemical and X-ray analyses of drill cuttings taken every 10 ft indicate the beds are > 95 percent halite, with the remainder being anhydrite and minor clay. Visual examination of the core confirms these general conclusions. The results of drill-stem testing in ERDA No. 9 have given proof that no anomalous quantities of brine or gases were present.

Mining operations for the WIPP program can be expected to encounter no more difficulties in excavation or ground support than have been learned in a half century of experience of potash mining in the Salado Formation. The beds selected for waste disposal are somewhat deeper than the potash mining horizons, but the fact that mining will be conducted in near-pure halite rather than in a mixture of sylvite and halite should at least compensate for the added depth. Also, mining extraction will be held to a conservative 30 percent versus the potash mining, which normally extracts 60 percent or more of the ore bed.

## References

The contributions of several individuals and companies are acknowledged by listing the various reports now on file with Sandia concerning Los Medaños site evaluation.

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Shallow Reflection Seismic Survey, Charles B. Reynolds & Assoc., Inc. (6 pp, 31 fig.).

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Interpretation of Geophysical Data, Los Medaños and Vicinity, G. J. Long and Assoc., Inc., October 1976 (10 pp, 7 fig.).

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C. L. Elliot, A Preliminary Geophysical Study of a Trachyte Dike in Close Proximity to the Proposed Los Medaños Nuclear Waste Disposal Site, Elliot Geophysical Company, December 1975 (19 pp and 2 fig.).

### Physical Properties of Rocks and Cores

C. L. Elliot, A Laboratory Investigation of Magnetic Physical Properties of Igneous Dike Samples from Kerr-McGee, Hobbs Plant, Section 31, T.20S., R.32E., Elliot Geophysical Company, December 1976 (10 pp).

C. L. Elliot, A Laboratory Investigation of Magnetic Density and Resistivity Physical Properties of Drill Core Samples from AEC No. 8 Well, Elliot Geophysical Company, December 1976 (14 pp).

C. L. Elliot, A Laboratory Investigation of the Density and Resistivity Properties of Drill Core Samples from ERDA No. 9 Geologic Investigation Well and USGS No. H-1 Hydrologic Investigation Well, Elliot Geophysical Company, December 1976 (11 pp).

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J. E. Taggart and J. Renault, Mineralogical Analysis of Insoluble Residue from Sandia WIPP Drill Hole No. 9, NMIMT, December 1976 (2 pp).

Analytical Reports No. 676169 dated June 25, 1976; No. 776132 dated July 21, 1976; and No. 9761 dated September 2, 1976. (These reports give water soluble analysis and amount of insoluble residue of cuttings from 1076 to 2886 ft in ERDA No. 9.) Martin Water Laboratories, Inc.

#### Geologic

C. L. Jones, B. M. Madsen, and D. F. Fuguas, Well Record, ERDA No. 9, U. S. Geological Survey, no date.

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Roger Y. Anderson, Potential Geologic Hazards in the Los Medaños Area, UNM, September 1976 (9 pp).

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John Lorenz and Raymond Cheesman, Potash Ore Reserves in the Proposed Waste Isolation Pilot Plant Area, USGS, 1977 (in preparation).

#### Brine Reservoirs

D. Tiab, Reservoir Calculations on Brine Accumulation at ERDA No. 6 and Other Locations in the Vicinity of the Los Medaños Site, NMIMT, March 1977 (7 pp).

Walter Rose, Development of a Conceptual Model to Explain Brine Flowage into Wells Drilled Through the Salado-Castile Formation in Locations such as ERDA No. 6 Site, NMIMT, March 1977 (12 pp).

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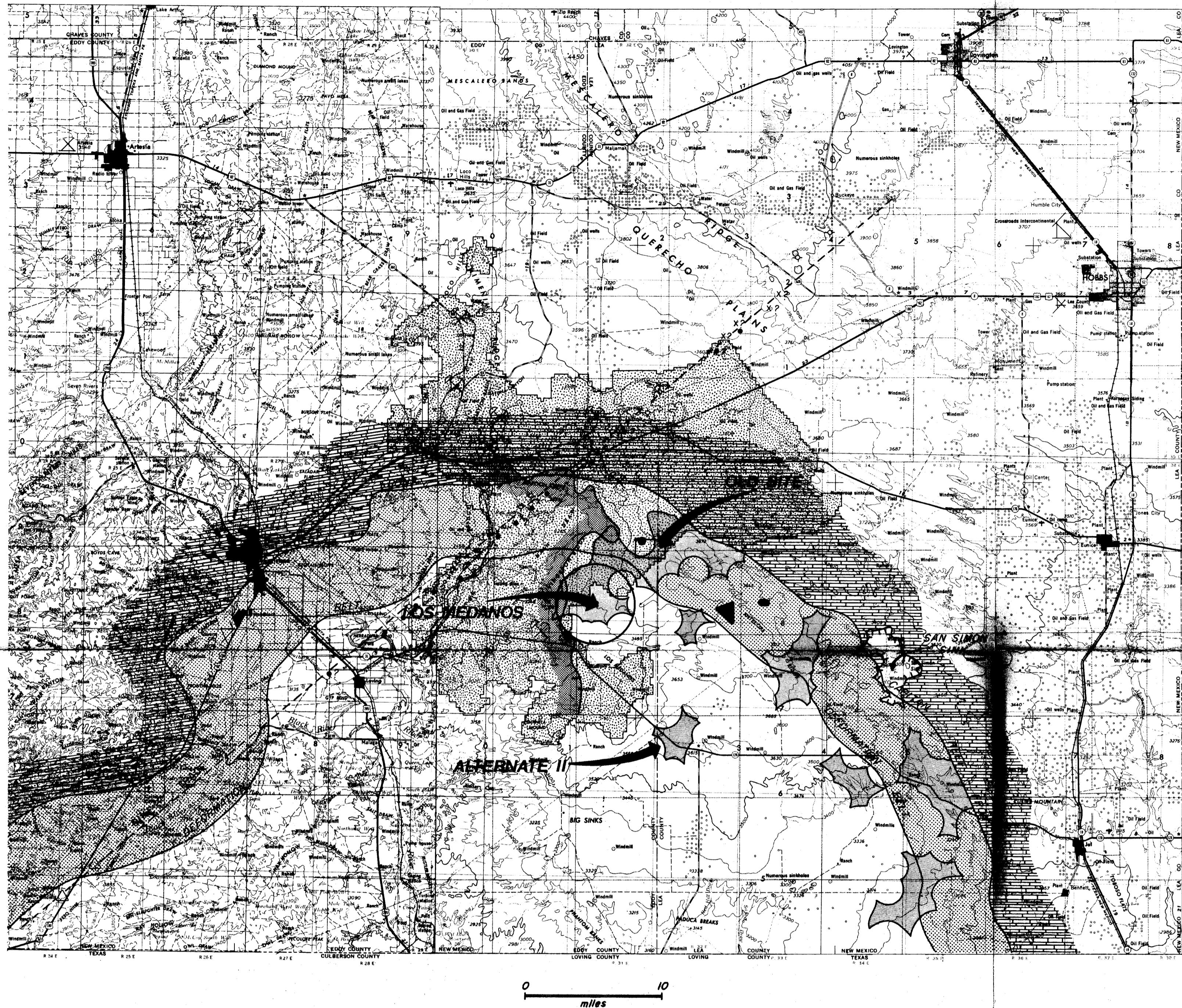
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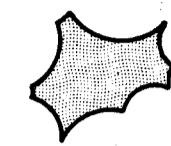
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### EXPLANATION



#### CANDIDATE AREAS

From C. L. Jones, U.S.G.S., 1975



#### CAPITAN REEF FRONT

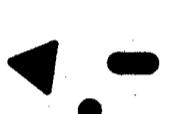


#### DEFORMATION BELT



#### SUBEROSION FRONT

From U.S.G.S., 1974. Front is at top of Salado



#### GEOPRESSURED BRINE RESERVOIRS

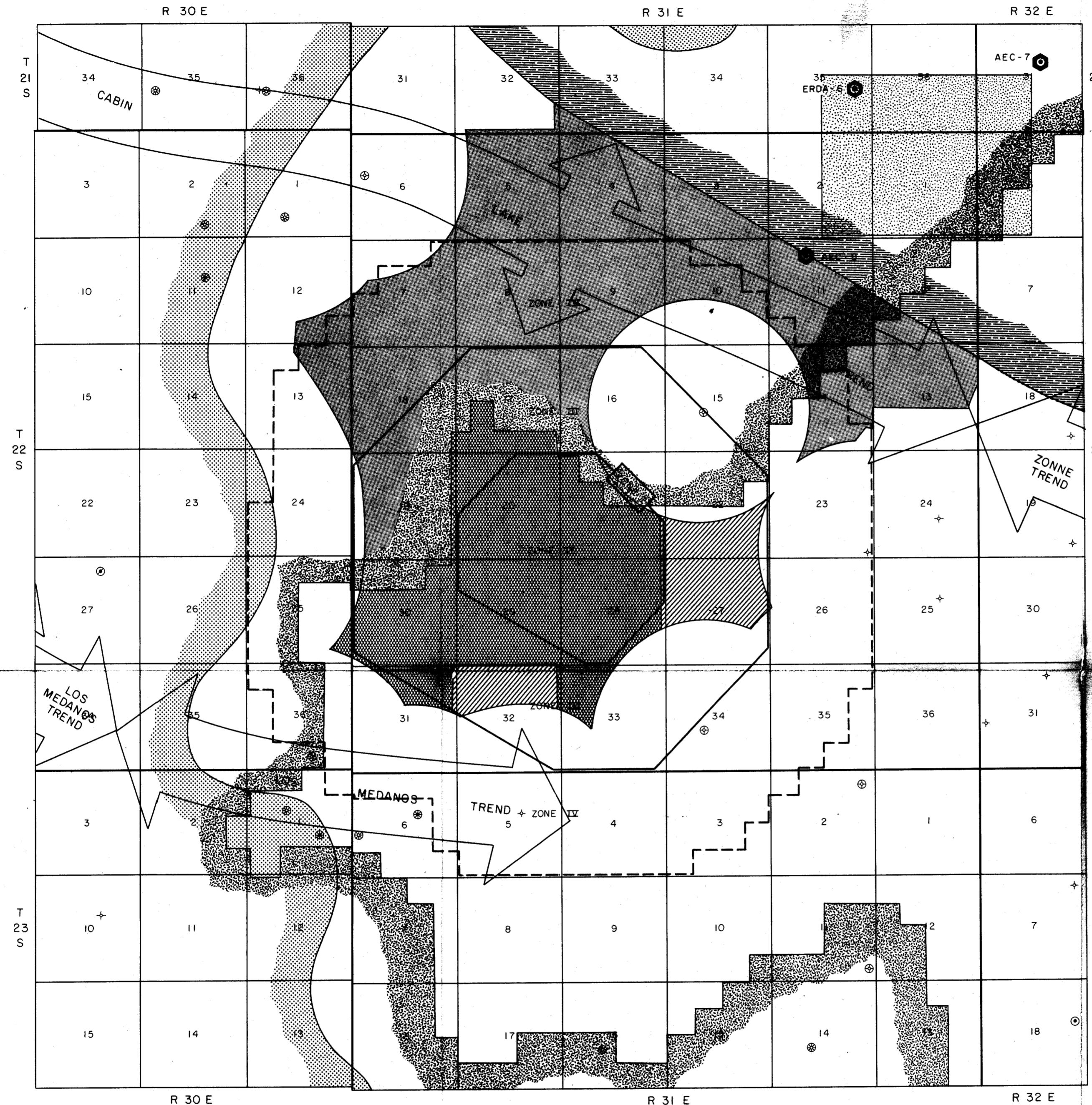


#### KNOWN POTASH ENCLAVE

From U.S.G.S. Conservation

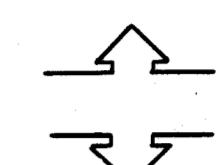
#### DIKE TREND SYMBOLS

- △ Outcrop of Dike
- Well Intercept of Dike
- Airborne Magnetic Response - 1960
- ✗ Airborne Magnetic Response - 1963-64



**FIGURE 2**  
**SITE SELECTION**  
**CRITERIA OVERLAY**

**EXPLANATION**



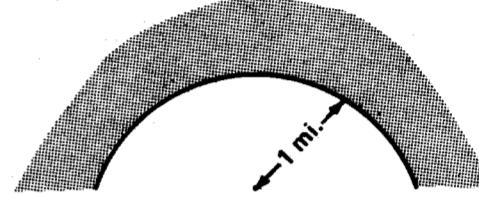
**OIL AND GAS TRENDS**

From an ORNL study conducted by Lee Nealing and Associates, 1974



**SUBEROSION FRONT**

From U.S.G.S., as known in 1974



**BUFFER FROM DEEP HOLE**

One mile radius from any hole drilled through Ochoan evaporites



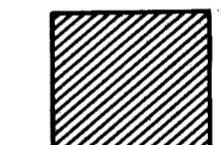
**KNOWN POTASH ENCLAVE**

As defined by U.S.G.S. Conservation Division

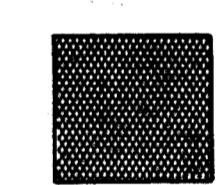


**DEFORMATION BELT**

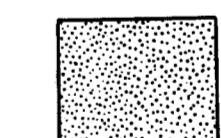
A belt six miles out from the Capitan Reef



**STATE LAND**

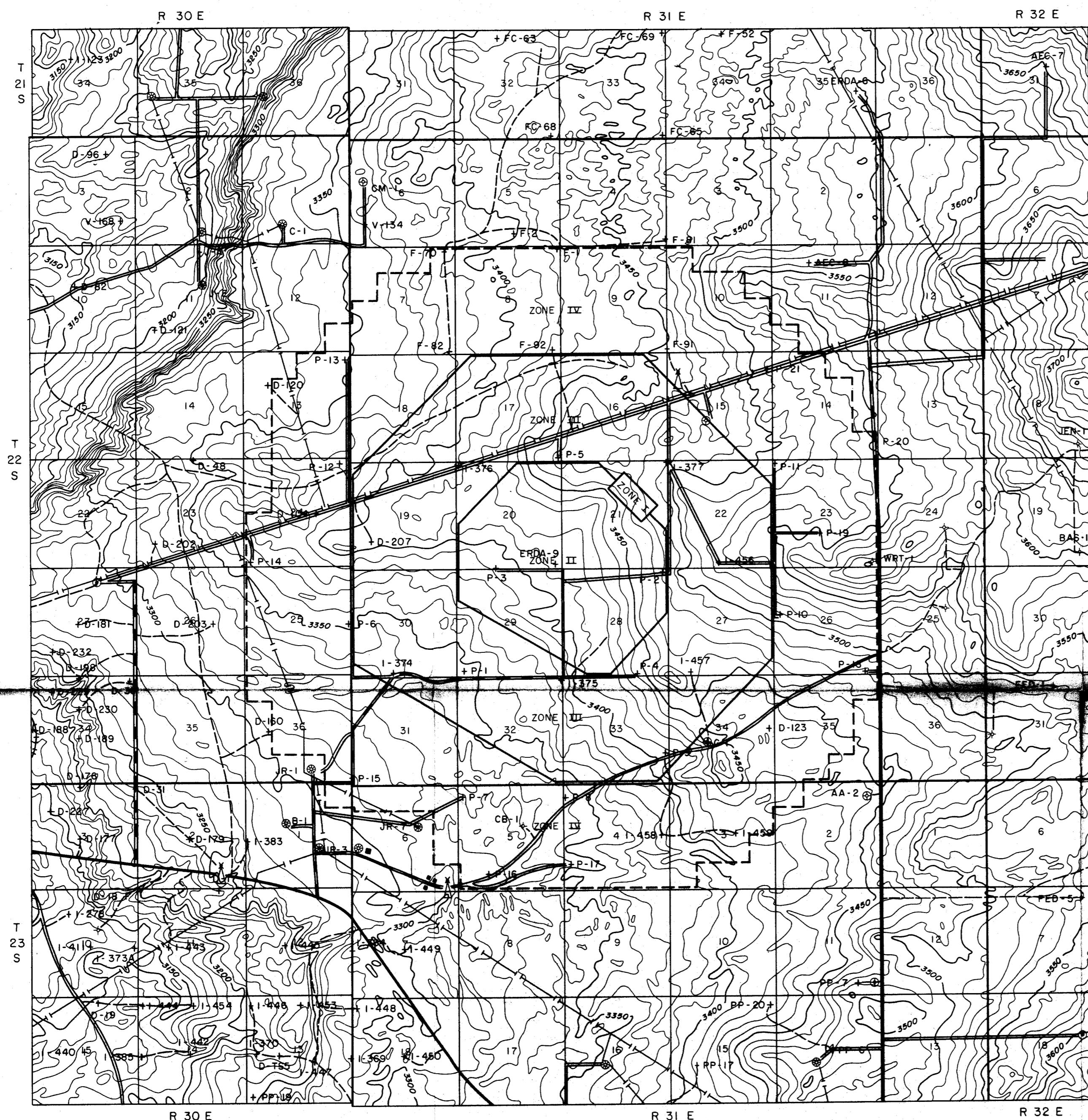


**ACCEPTABLE FOR WIPP**



**OLD SITE**



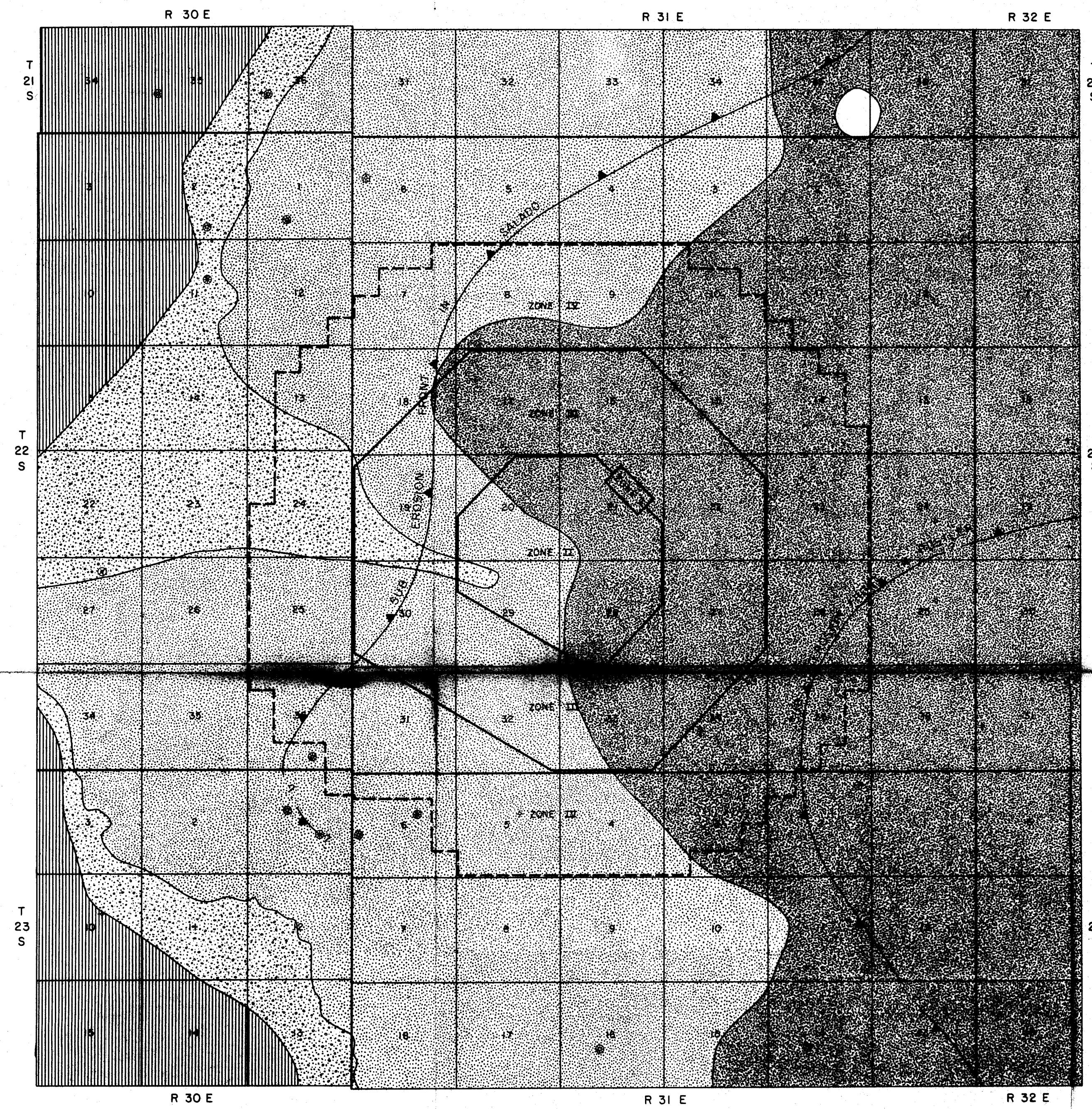


## FIGURE 4

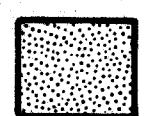
# INDEX OF DRILL HOLES

HOLE NO.	T/R/S	COLLAR ELEVATION	SALADO ELEVATION	BASE 124 ELEVATION	TOTAL DEPTH
I-123	21/30/34	3170	2182	1382	1880
W-7	21/31/31	3333	2743	2046	N/A
FC-63	21/31/32	3409	2719	1997	1483
FC-68	21/31/32	3430	2610	1881	1644
F-52	21/31/34	3485	2625	1970	1623
FC-65	21/31/34	3465	2645	1866	1699
FC-69	21/31/34	3461	2632	1962	1562
ERDA-6	21/31/35	3636	2721	1999	2775
AEC-7	21/32/31	3662	2664	1874	3918
C-1	22/30/1	3357	2727	1954	13660
D-96	22/30/3	3189	2609	2133	1210
V-168	22/30/3	3170	2660	2108	1173
D-82	22/30/10	3149	2669	2102	1136
D-121	22/30/11	3202	2642	2045	1266
J-A	22/30/11	3191	2673	2014	14923
J-E	22/30/11	3220	2626	1991	13660
D-120	22/30/13	3338	2654	1930	1500
D-48	22/30/14	3337	2627	1937	1524
D-202	22/30/23	3323	2703	1981	1443
D-104	22/30/24	3388	2629	1883	1596
P-12	22/30/24	3376	2627	1867	1598
P-14	22/30/24	3358	2671	1939	1545
D-203	22/30/26	3317	2647	1965	1443
D-181	22/30/27	3288	2748	2039	1345
D-198	22/30/27	3258	2748	2059	1302
D-229	22/30/27	3218	2825	2088	1266
D-232	22/30/27	3258	N/A	2053	1221
D-36	22/30/34	N/A	N/A	N/A	N/A
D-180	22/30/34	3210	2790	2083	1230
D-188	22/30/34	N/A	N/A	N/A	N/A
D-230	22/30/34	3231	2821	2067	1196
JR-1	22/30/36	3308	2802	2037	17555
D-160	22/30/36	N/A	N/A	N/A	N/A
F-81	22/31/3	3471	2651	1797	1736
F-2	22/31/5	3404	2629	1818	1690
CM-1	22/31/6	3376	2668	1961	14050
V-134	22/31/6	3363	2622	1898	1563
F-70	22/31/7	3388	2490	1867	1603
F-82	22/31/7	3382	2472	1781	1684
F-92	22/31/8	3420	2470	1688	1818
F-1	22/31/9	3422	2482	1781	1747
F-91	22/31/10	3460	2390	1755	1788
AEC-8	22/31/11	3542	2648	1801	4910
P-20	22/31/14	3653	2450	1662	1995
P-21	22/31/15	3510	2467	1705	1915
P-5	22/31/17	3472	2625	1767	1830
P-13	22/31/18	3345	2624	1874	1576
D-207	22/31/19	3406	2595	1886	1613
ERDA-9	22/31/20	3415	2655	1765	2890
I-376	22/31/20	3410	2570	1819	1702
P-3	22/31/20	3382	2596	1803	1676
I-377	22/31/22	3490	2476	1720	1876
I-456	22/31/22	3520	2451	1667	1975
P-11	22/31/23	3506	2448	1673	1940
P-19	22/31/23	3546	2429	1629	2000
WRT-1	22/31/23	3695	2406	1596	4766
P-10	22/31/26	3608	2422	1620	2008
P-18	22/31/26	3479	2391	1590	1993
P-2	22/31/28	3478	2470	1683	1895
P-4	22/31/28	3441	2611	1688	1857
P-1	22/31/29	3445	2668	1859	1591
P-6	22/31/30	3554	2695	1892	1573
I-374	22/31/30	3340	2735	1931	1538
P-15	22/31/31	3310	2768	1957	1465
P-9	22/31/33	3408	2528	1714	1796
I-375	22/31/33	3390	2600	1788	1746
D-123	22/31/34	3432	2444	1644	1880
G-1	22/31/34	3450	2495	1708	4475
JEN-1	22/32/18	3698	2471	1684	4896
BAS-1	22/32/19	3620	2378	1578	4802
FED-1	22/32/31	3627	2294	1447	4777
B-1	23/30/1	3290	2825	2115	14312
I-383	23/30/1	3272	2832	2051	1307
JR-3	23/30/1	3288	2806	2041	15592
D-1	23/30/2	3241	2809	2032	1310
D-31	23/30/2	3244	2812	2038	1314
D-179	23/30/2	3244	2784	1987	1350
D-178	23/30/3	3197	2782	2076	1223
D-177	23/30/3	3151	2741	2088	1186
D-197	23/30/3	3141	2731	2110	1136
D-227	23/30/3	3248	2818	N/A	1073
D-18	23/30/10	3190	2805	2040	1265
I-278	23/30/10	3120	2780	2035	1217
I-373A	23/30/10	3140	2785	2036	1242
I-411	23/30/10	3128	2763	2041	1208
I-443	23/30/11	3185	2770	2028	1270
I-445	23/30/12	3235	2785	1968	1385
D-TS5	23/30/13	3210	2685	1948	1466
PP-19	23/30/13	N/A	N/A	N/A	N/A
I-370	23/30/13	3220	2740	1996	1341
I-446	23/30/13	3210	2730	1976	1345
I-447	23/30/13	3260	2741	1891	1480
I-453	23/30/13	3240	2730	1953	1406
I-385	23/30/14	3185	2770	2045	1235
I-442	23/30/14	3170	2755	2007	1275
I-444	23/30/14	3130	2745	2003	1240
I-454	23/30/14	3170	2735	2000	1300
D-19	23/30/15	3149	2727	1957	1369
I-440	23/30/15	N/A	N/A	N/A	N/A
AA-2	23/31/2	3453	2983	1583	5190
I-459	23/31/3	3418	2482	1679	1855
I-458	23/31/4	3385	2849	1762	1760
P-8	23/31/4	3336	2621	1791	1660
P-17	23/31/4	3340	2825	1806	1660
P-7	23/31/5	3332	2702	1873	1675
P-16	23/31/5	3323	2677	1853	1666
CB-1	23/31/5	3320	2862	1845	4180
JR-7	23/31/6	3319	2713	1920	14690
I-384	23/31/7	3290	2790	1964	1438
I-449	23/31/7	3310	2880	1906	1515
PP-7	23/31/11	3485	2375	1603	2033
PP-6	23/31/14	3485	2405	1604	2079
PP-17	23/31/15	3418	2468	1689	1920
PP-20	23/31/15	3429	2469	1660	1910
I-369	23/31/18	3280	2715	1871	1638
I-448	23/31/18	3280	2625	1900	1510
I-450	23/31/18	3300	2890	1854	1670
FED-5	23/32/7	3539	N/A	N/A	1710

P—ERDA POTASH HOLE  
V—U.S. POTASH CO. (MISSISSIPPI POTASH)  
D—DTS -DUVAL CORP.  
I—INTERNATIONAL MINERALS  
PP—PERMIAN POTASH  
F—FC -KERR McGEE  
N/A—NOT AVAILABLE



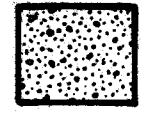
### EXPLANATION



**GATUNA**  
0 to 40' thick



**SANTA ROSA**  
0 to 250' thick



**DEWEY LAKE**  
100' to 540' thick

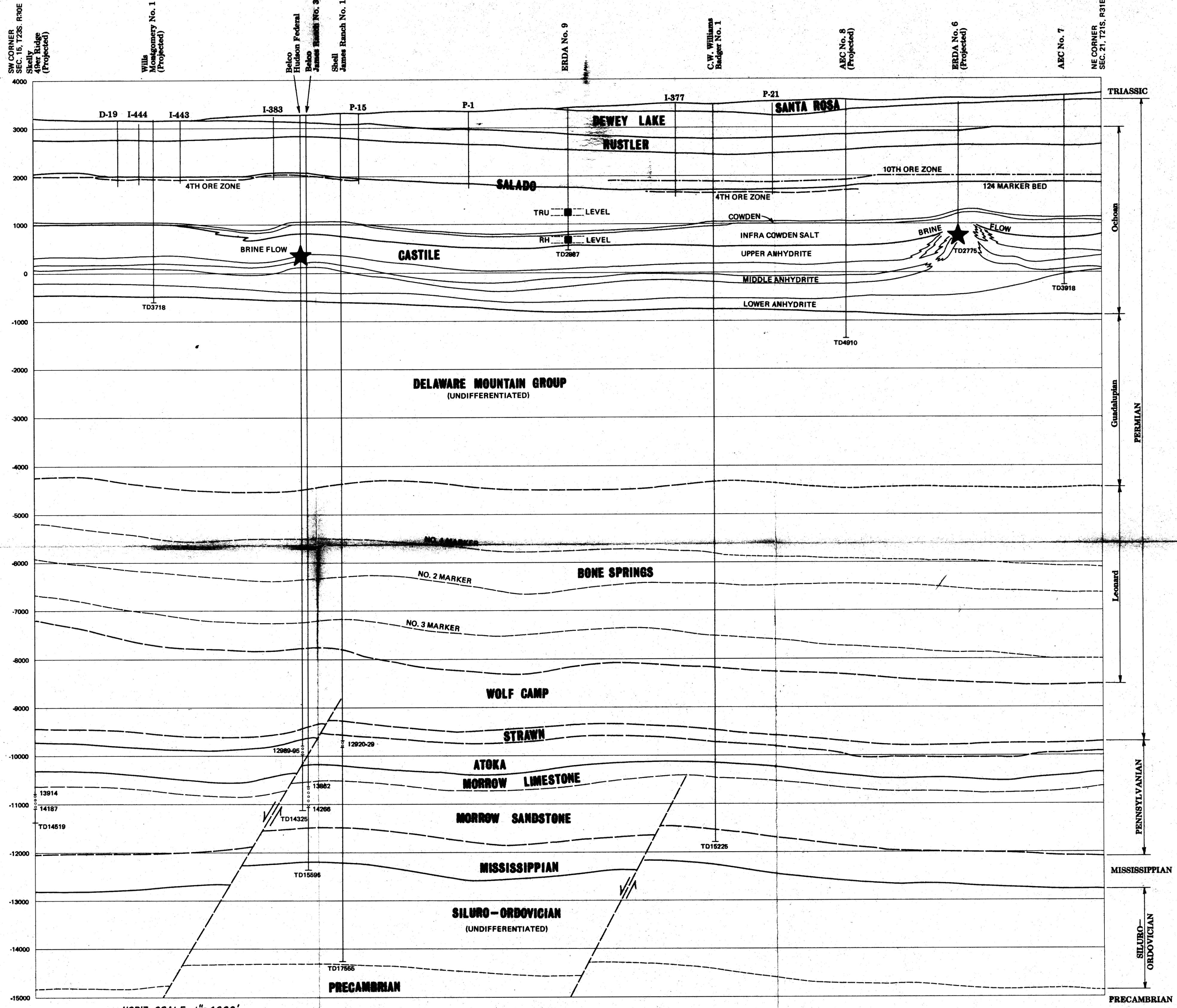


**RUSTLER**  
300' to 400' thick

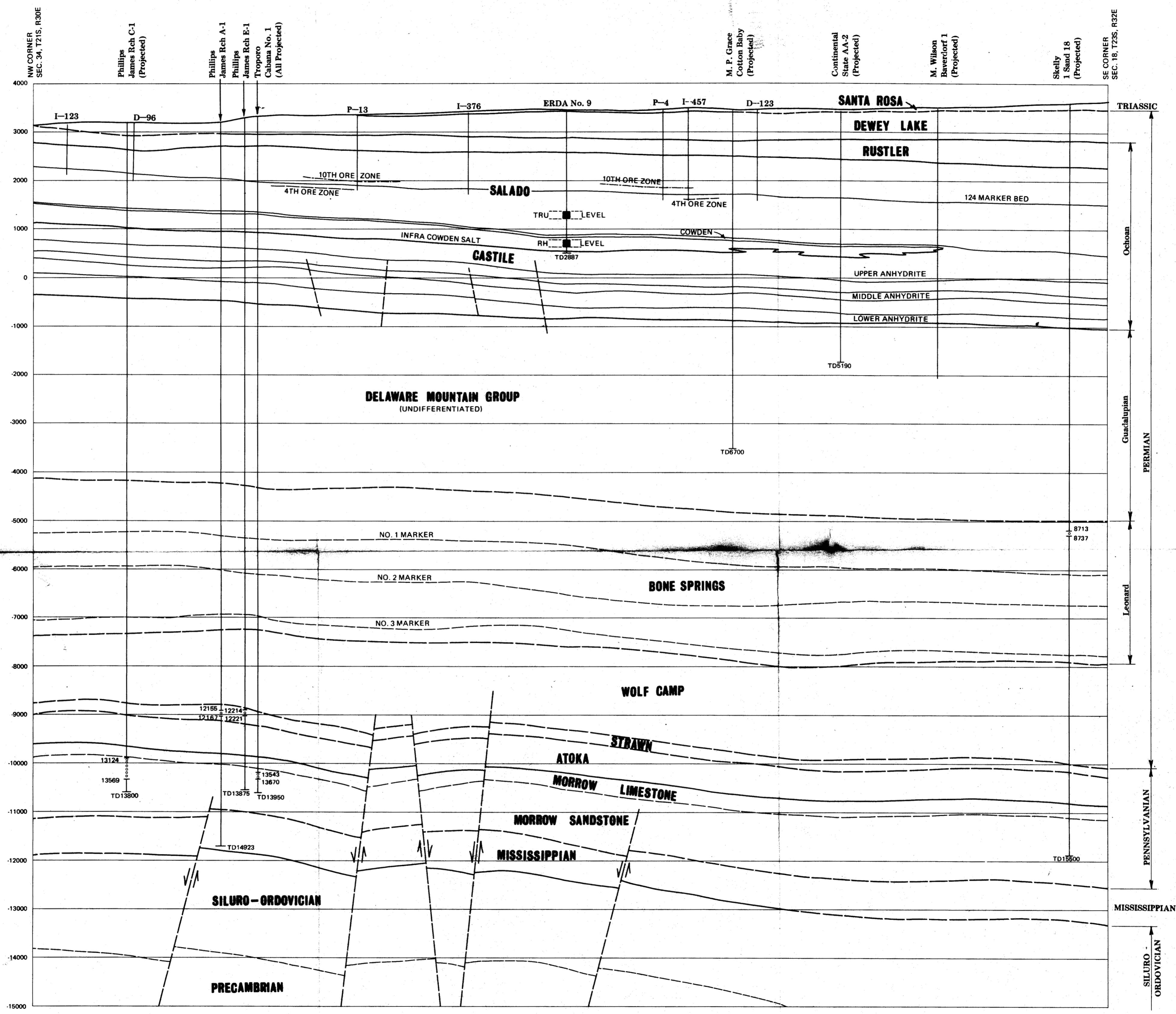
Note: Contacts are fairly accurate in the site area, but inferred outside.

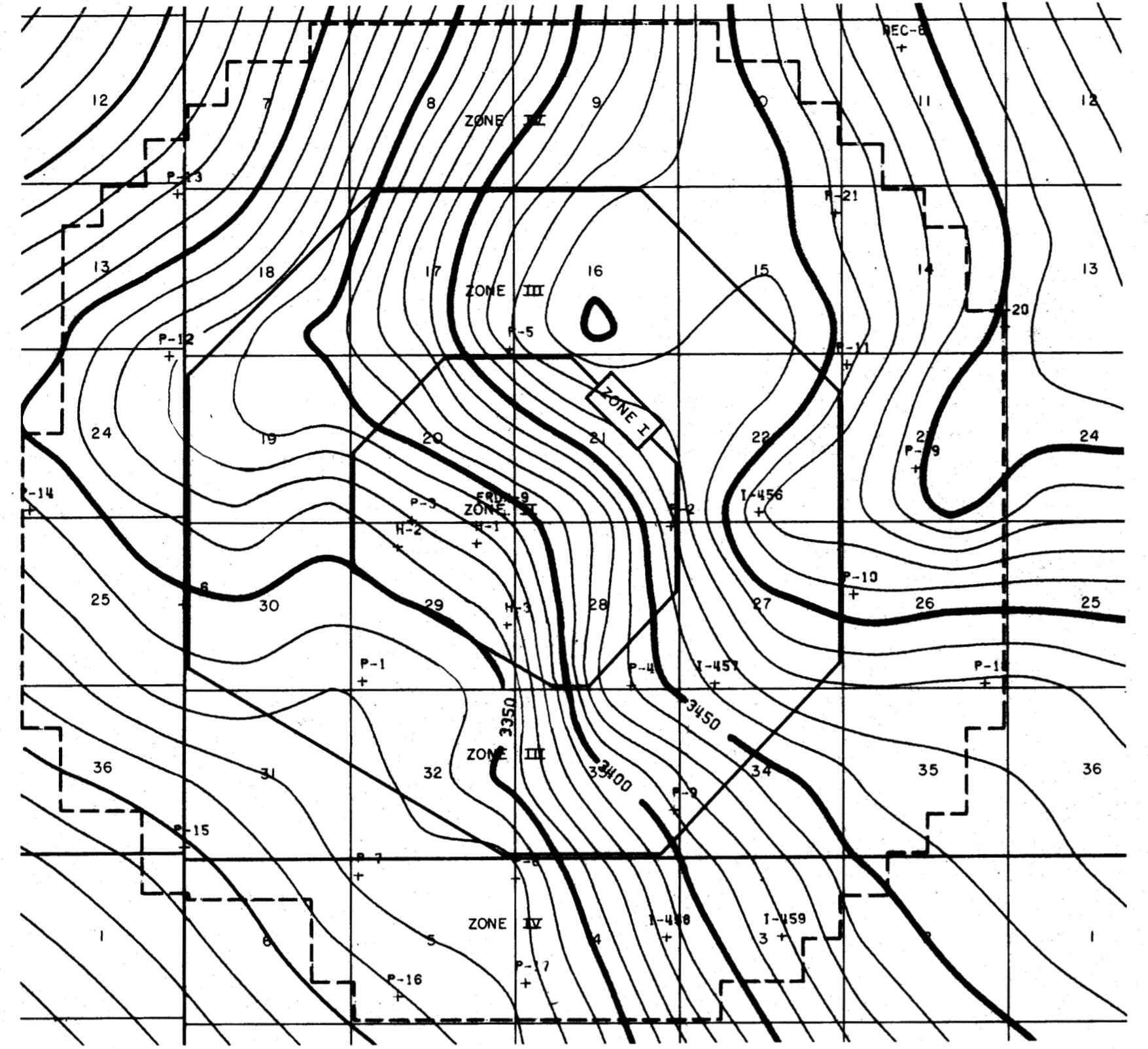
**FIGURE 5**  
**SUBCROP GEOLOGIC MAP**  
**OF**  
**LOS MEDANOS**



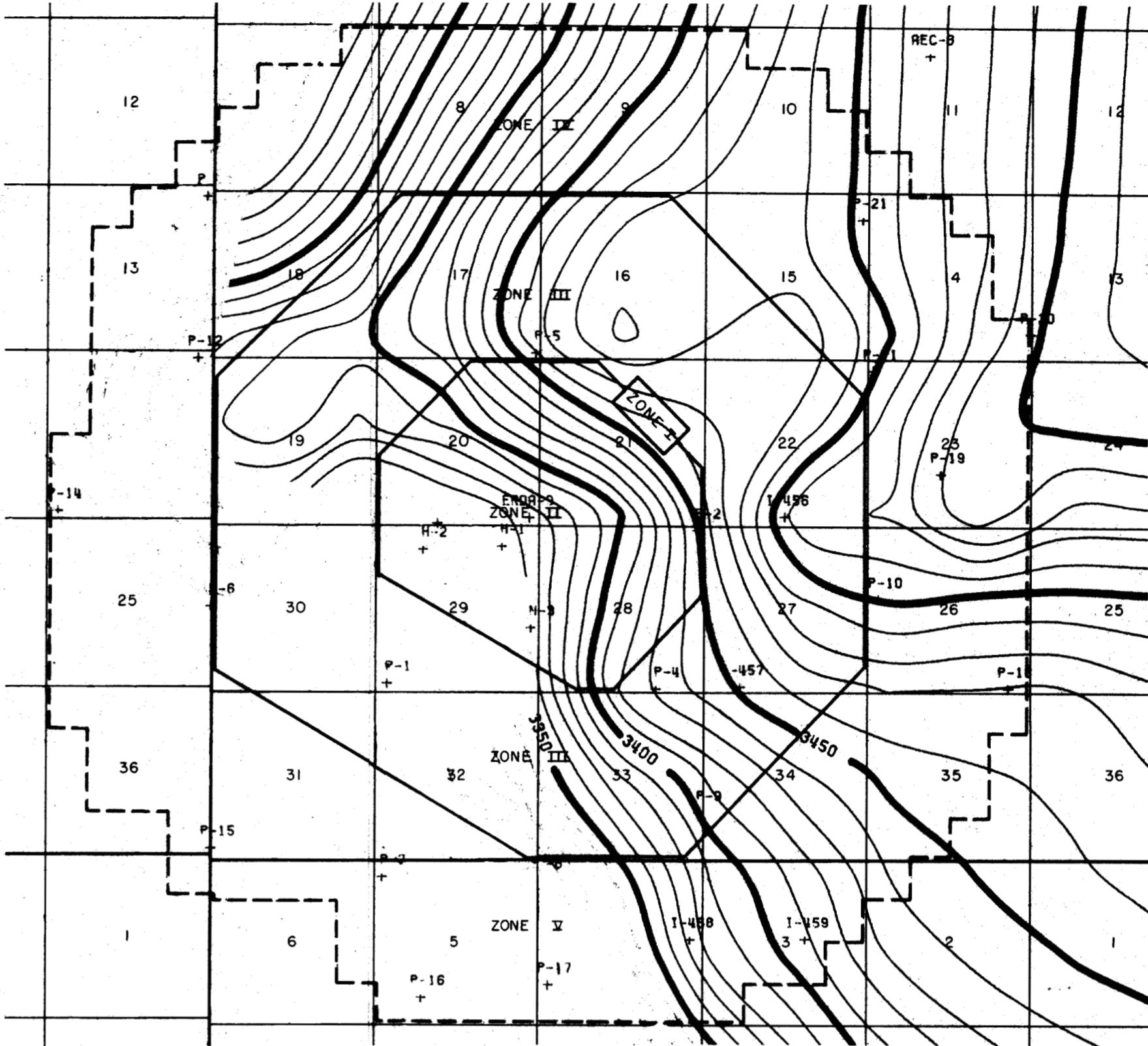


GEOLOGIC SECTION LOOKING NORTHWEST

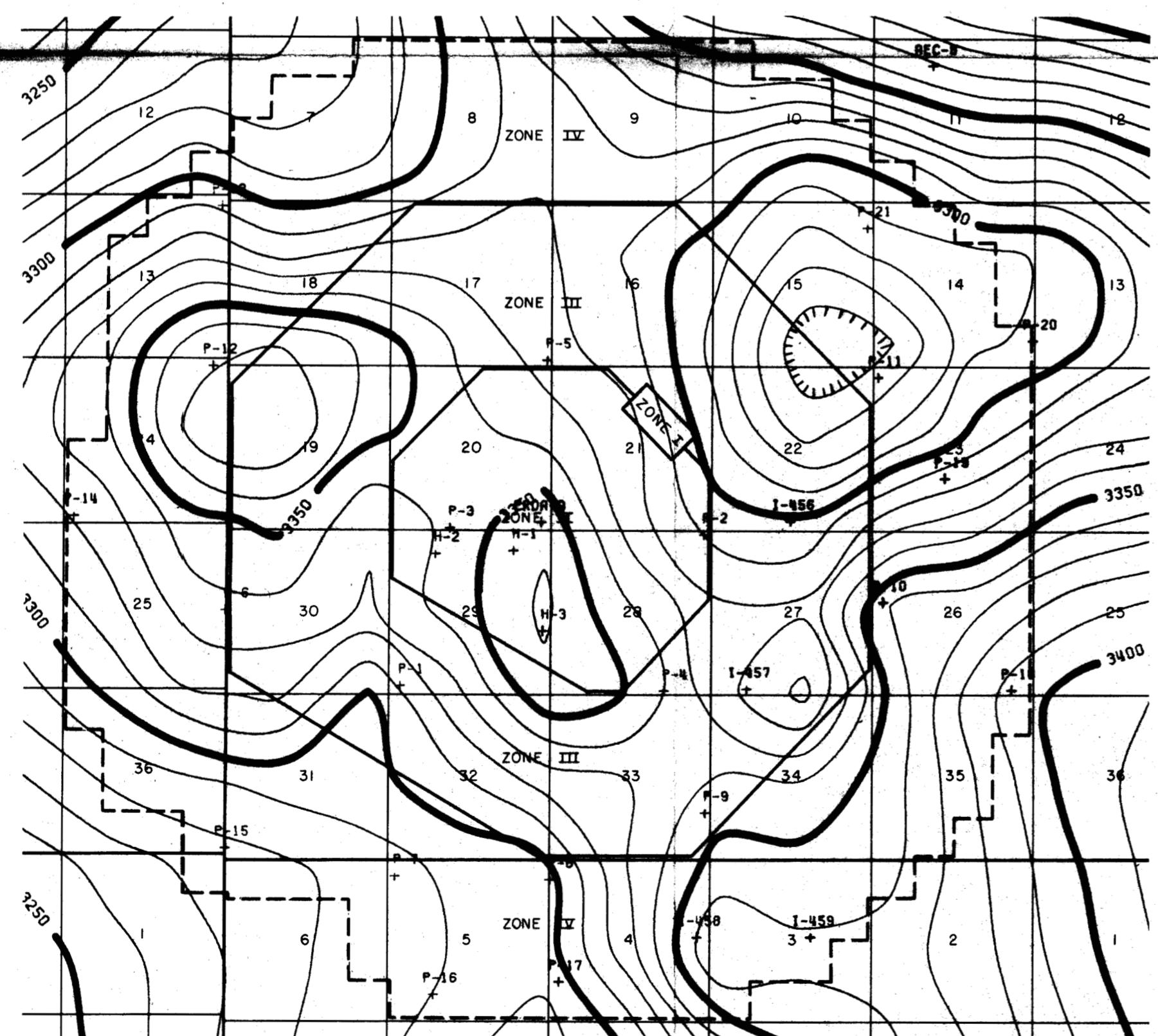




TOP OF GATUNA

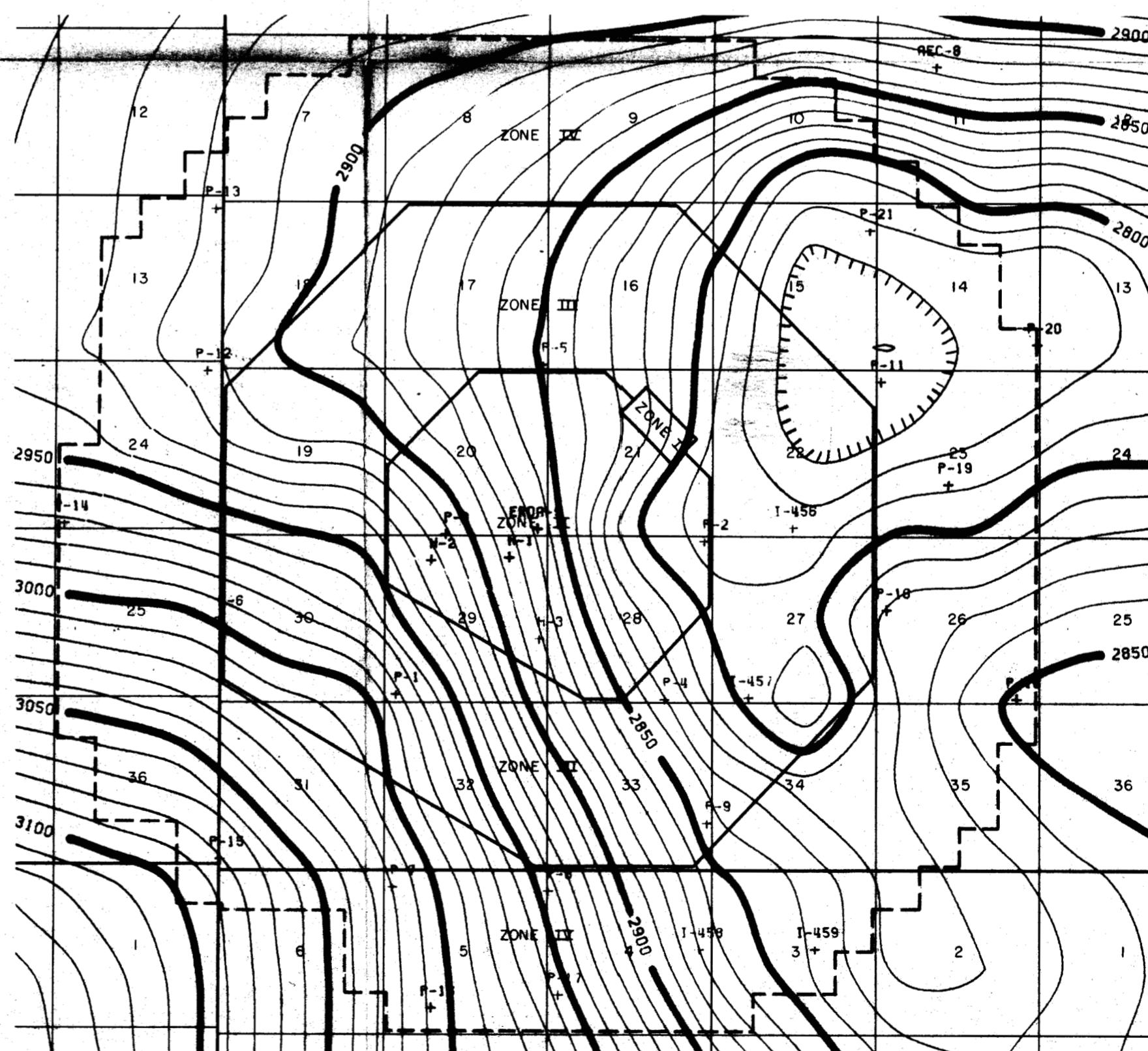


TOP OF SANTA ROSA



TOP OF DEWEY LAKE

SCALE - 1"=4000'



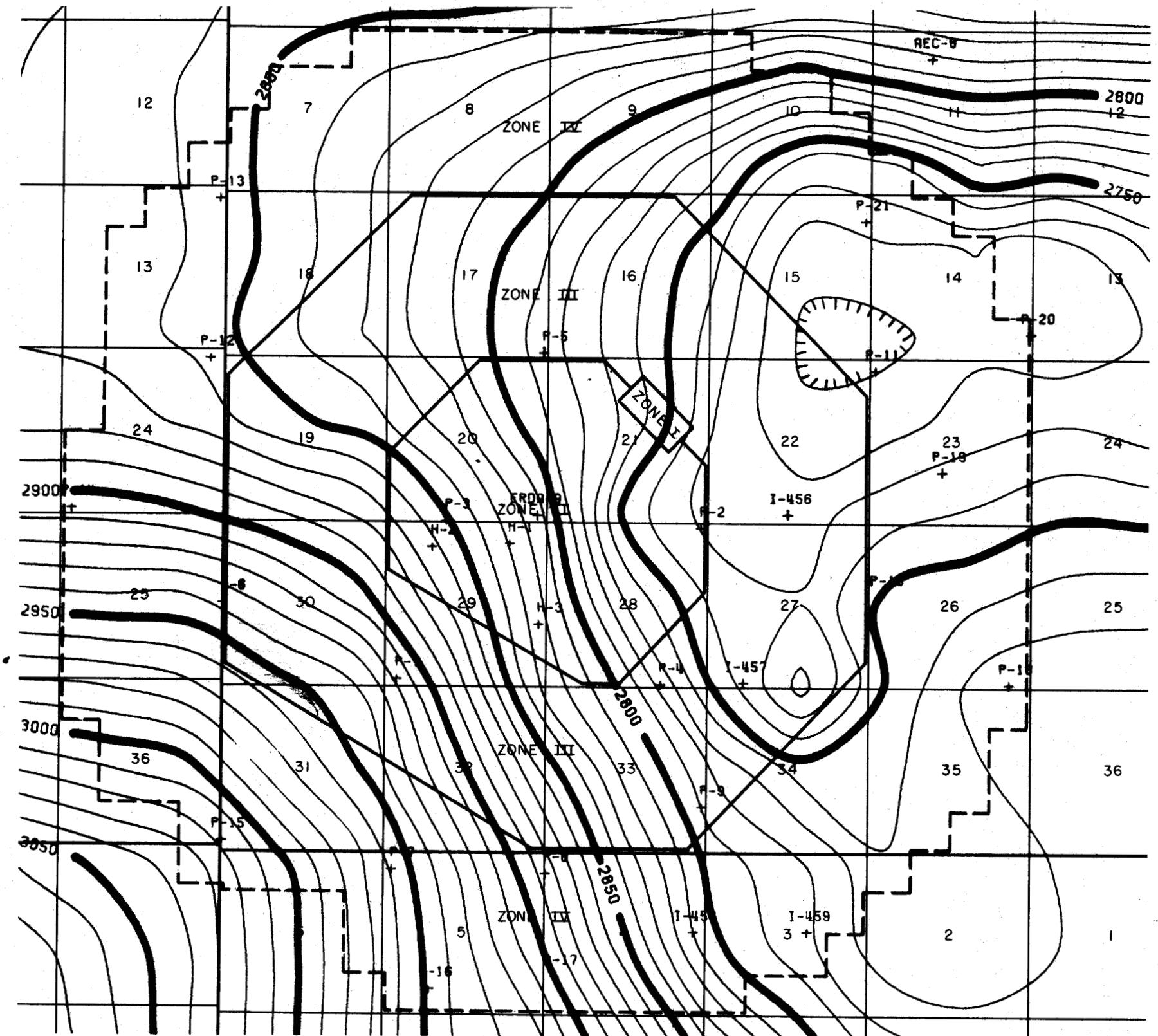
TOP OF RUSTLER

FIGURE 8

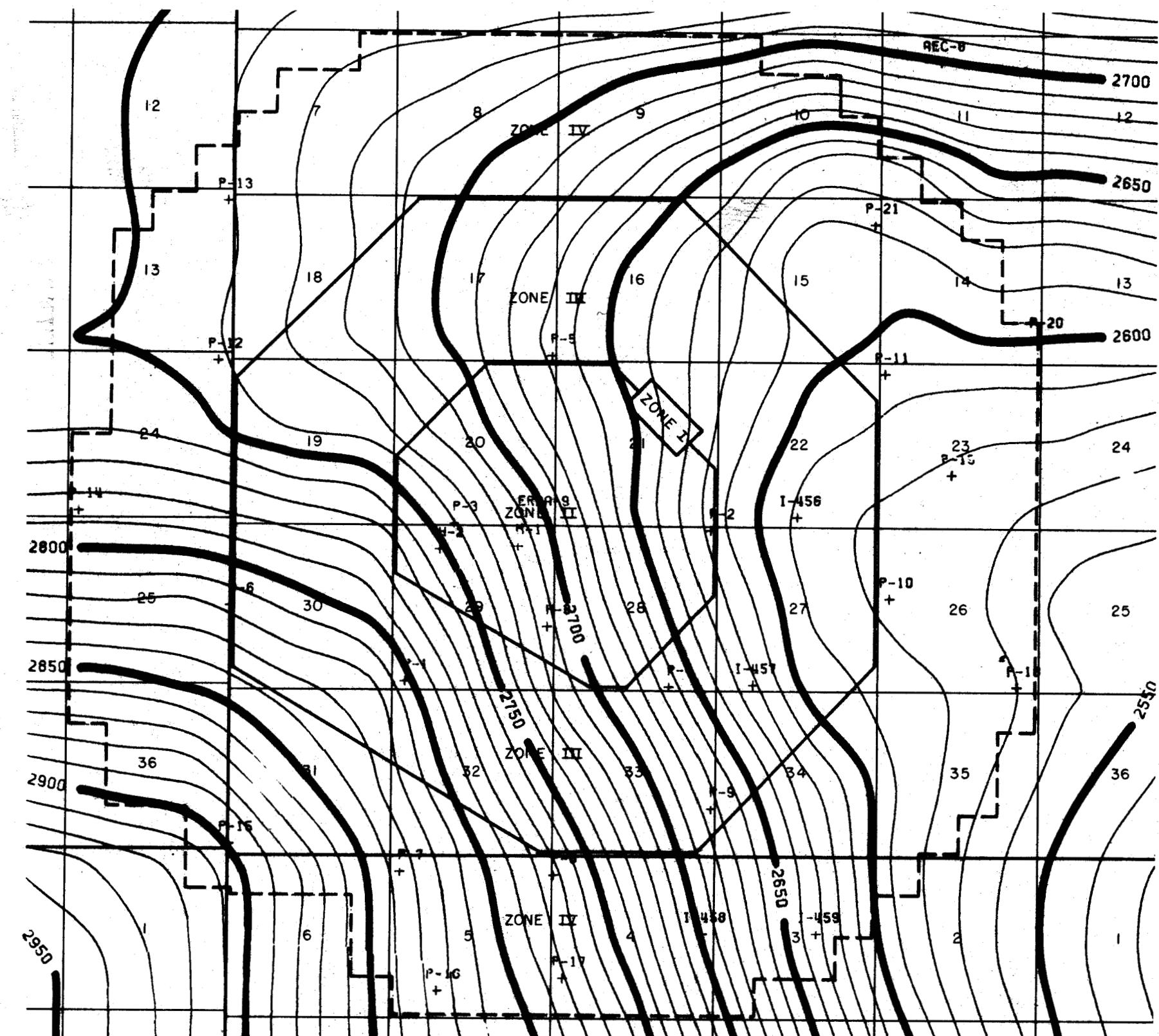
## STRUCTURE MAPS - GATUNA TO RUSTLER



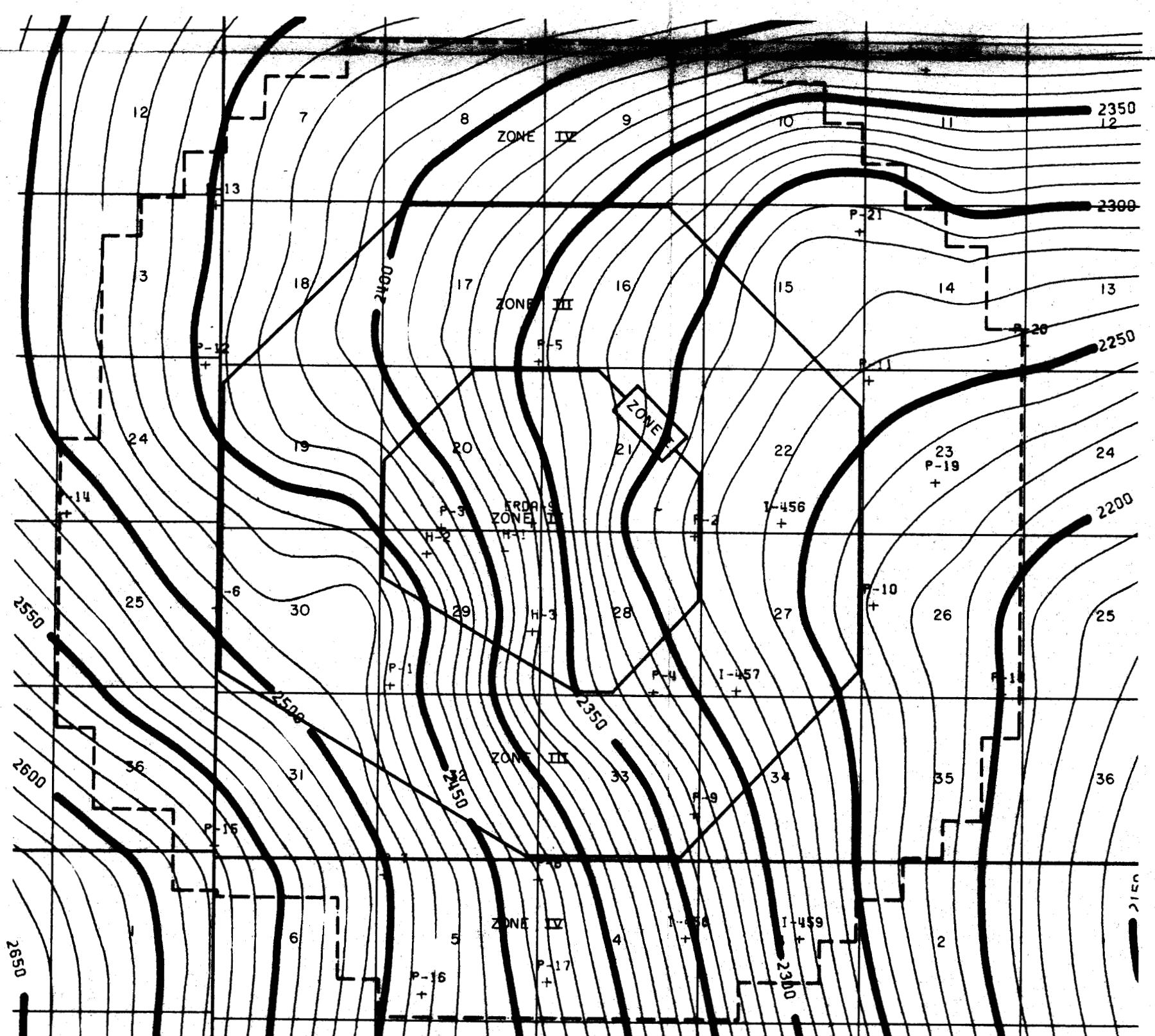
Sandia Laboratories



## TOP OF MAGENTA



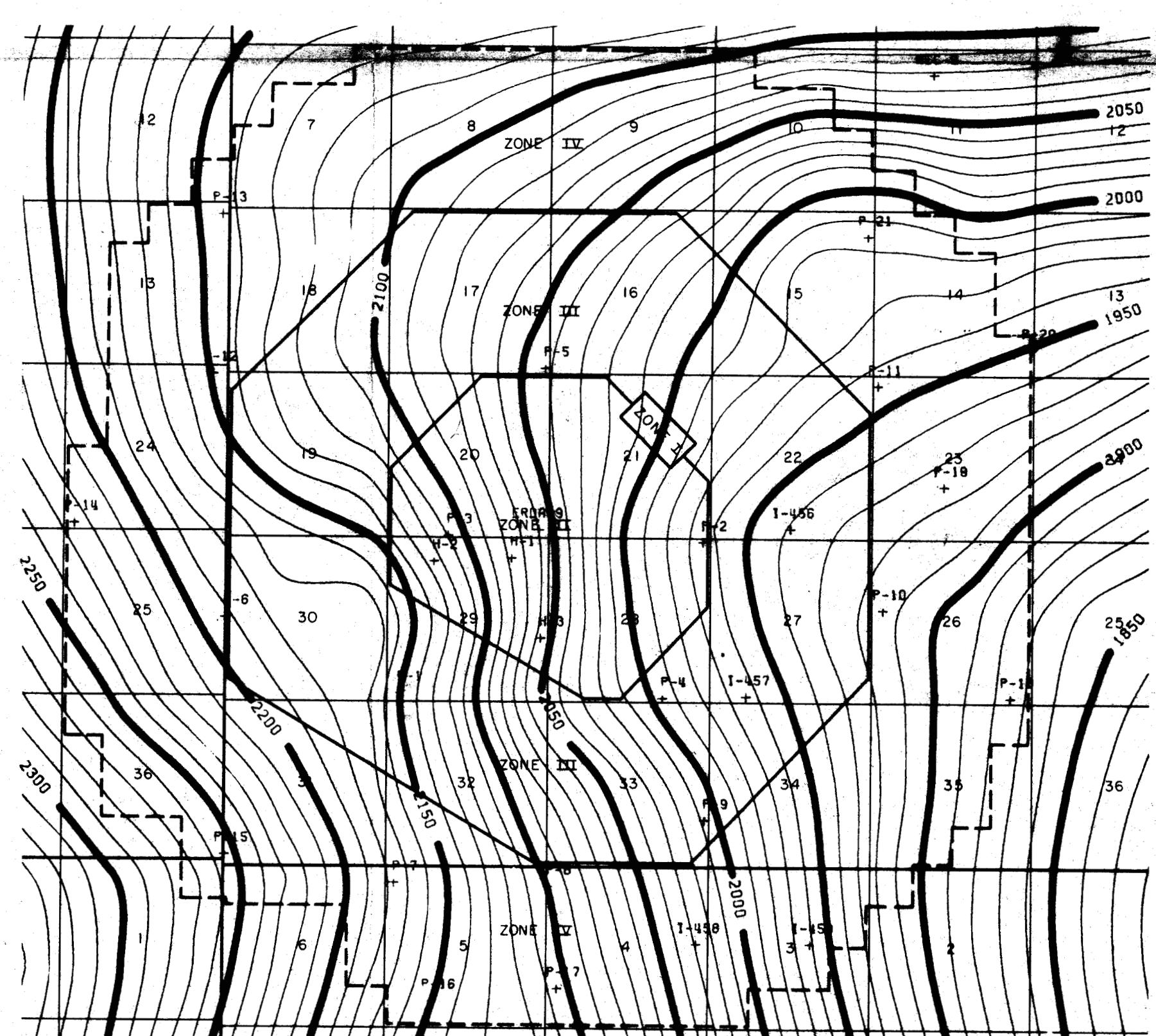
## **TOP OF CULEBRA**



SCALE: 1" = 4000'

## TOP OF BASE 103 MARKER BED

## FIGURE 9

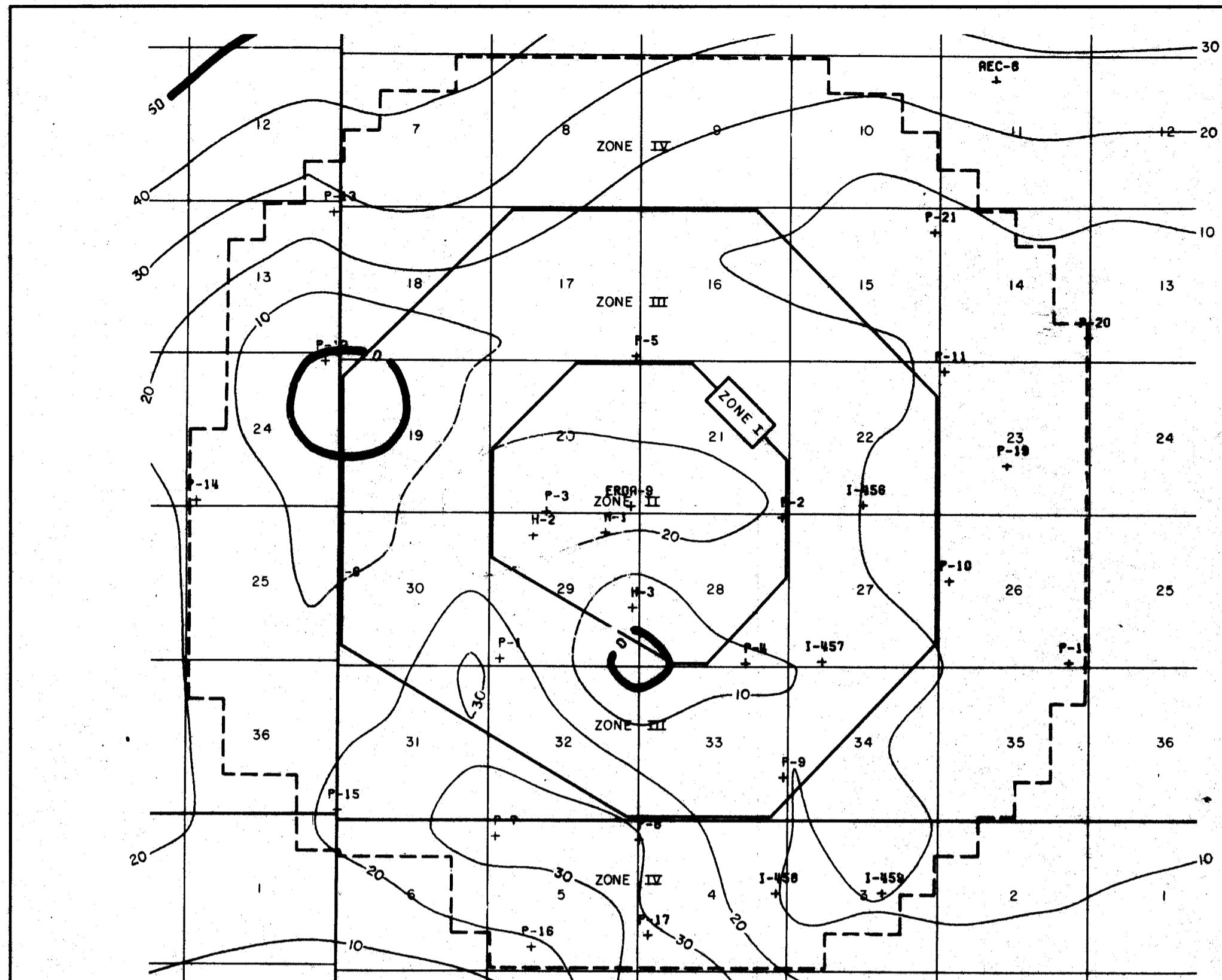


## TOP OF VACA TRISTE

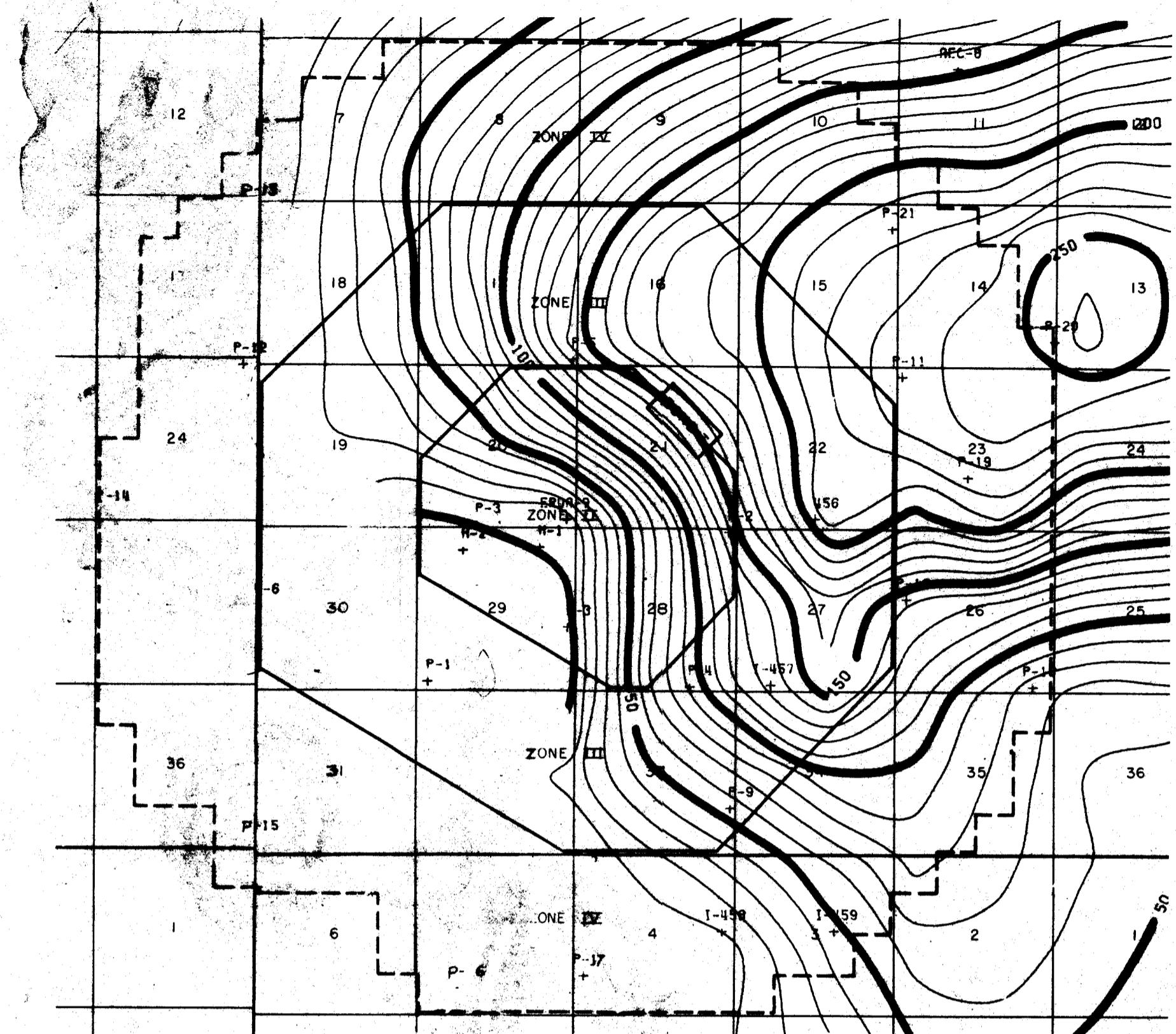


# STRUCTURE MAPS - MAGENTA TO VACA TRISTE

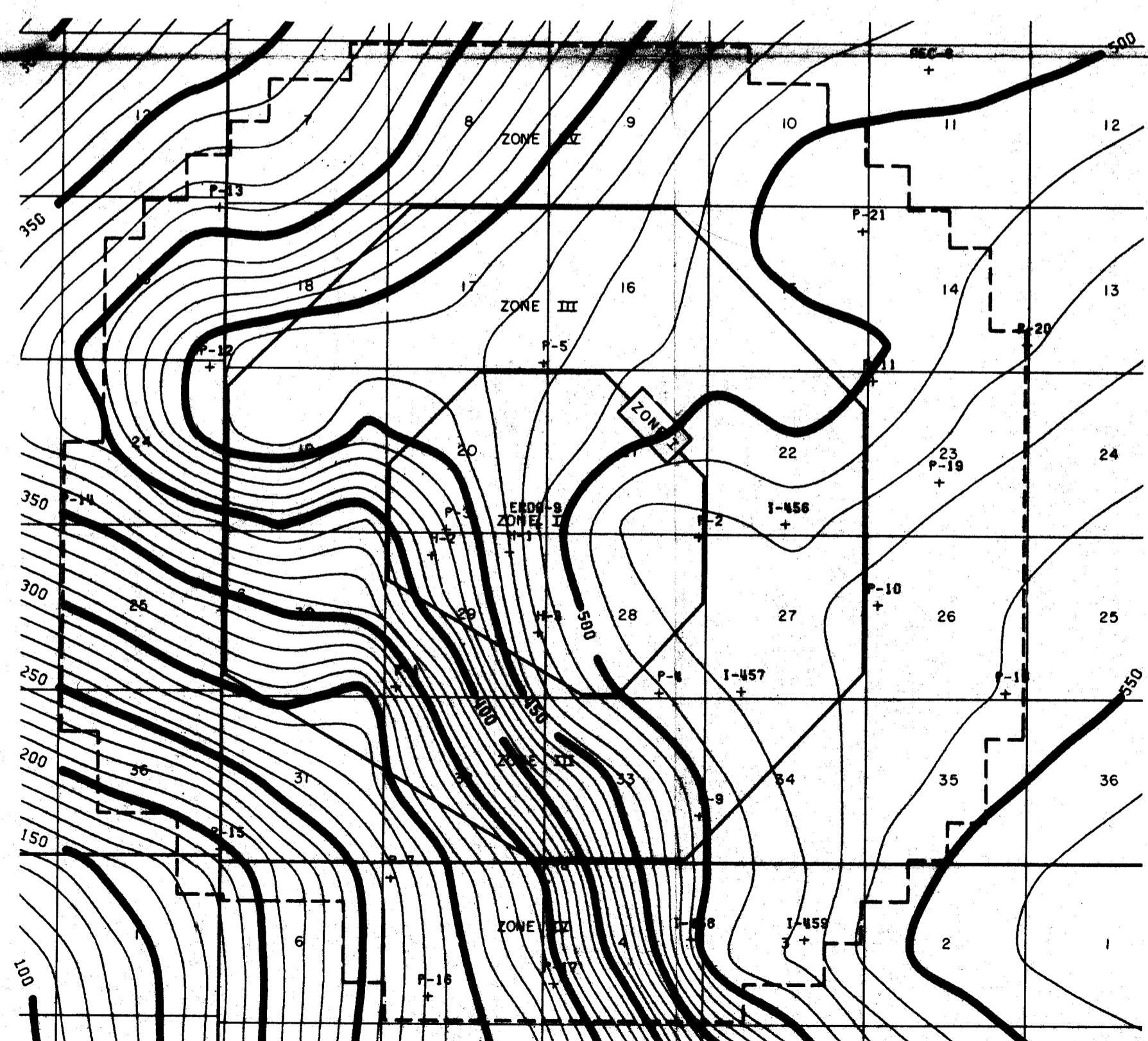




TOP OF GATUNA TO TOP OF SANTA ROSA

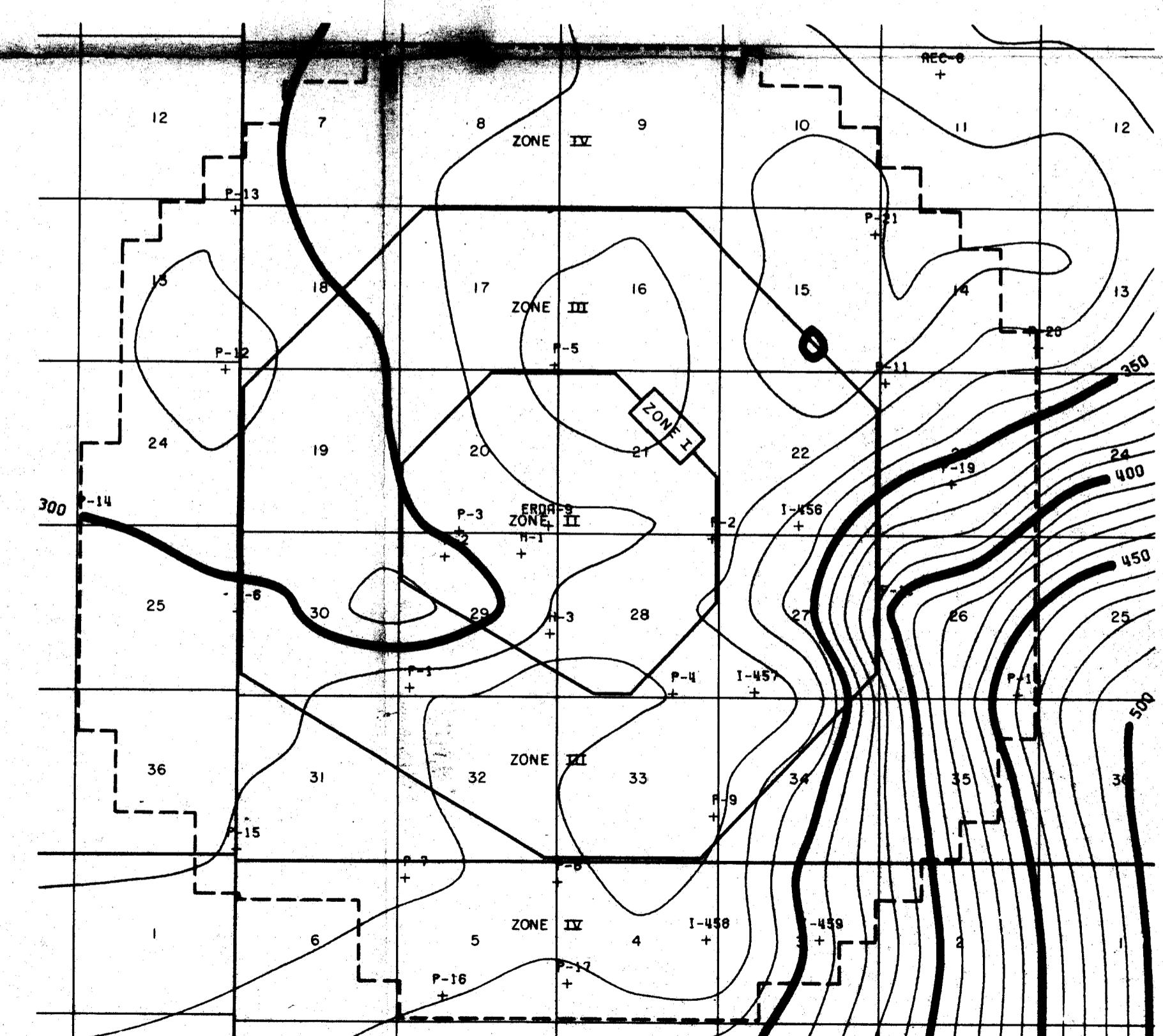


TOP OF SANTA ROSA TO TOP OF DEWEY LAKE



TOP OF DEWEY LAKE TO TOP OF RUSTLER

SCALE: 1"=4000'

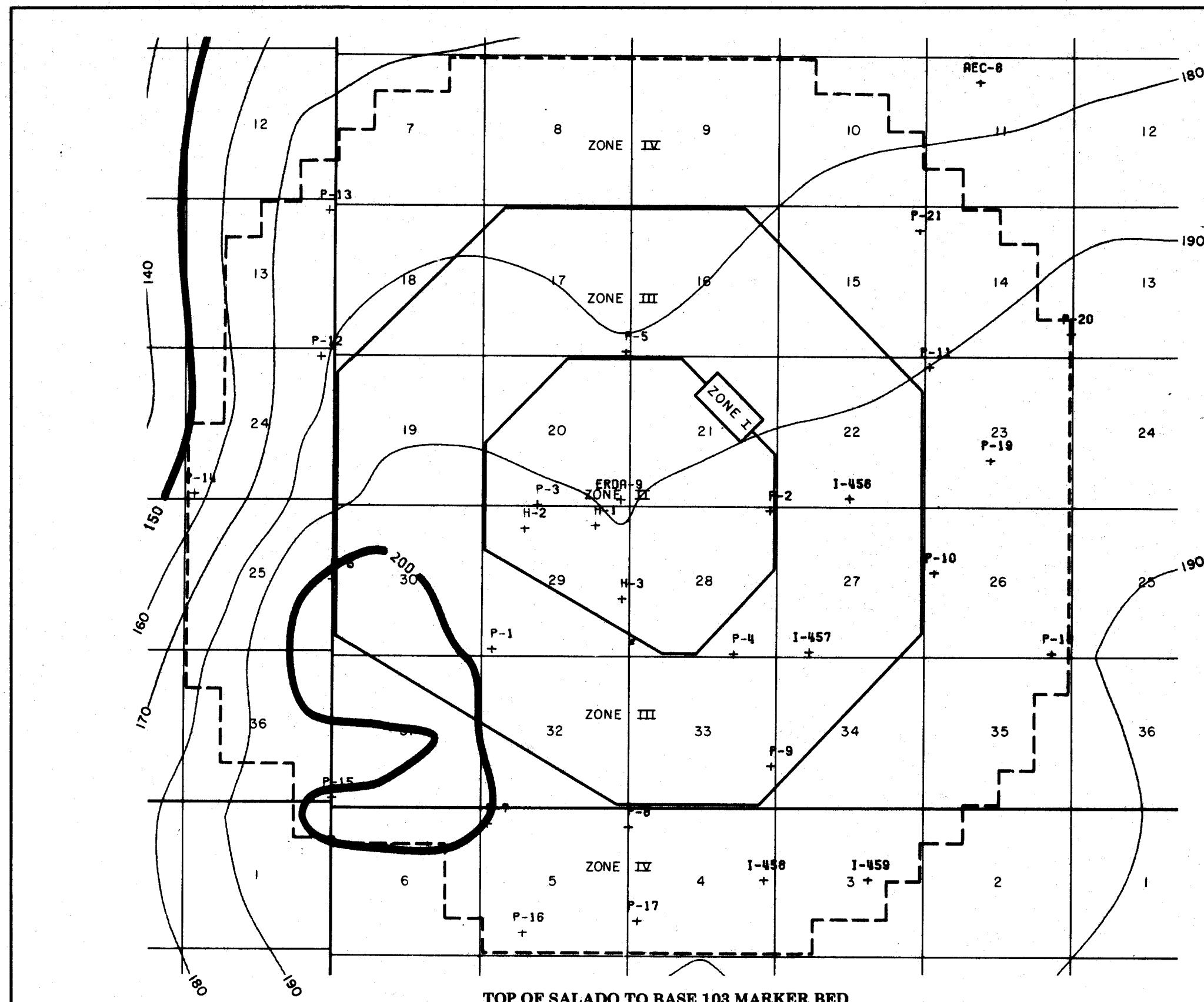


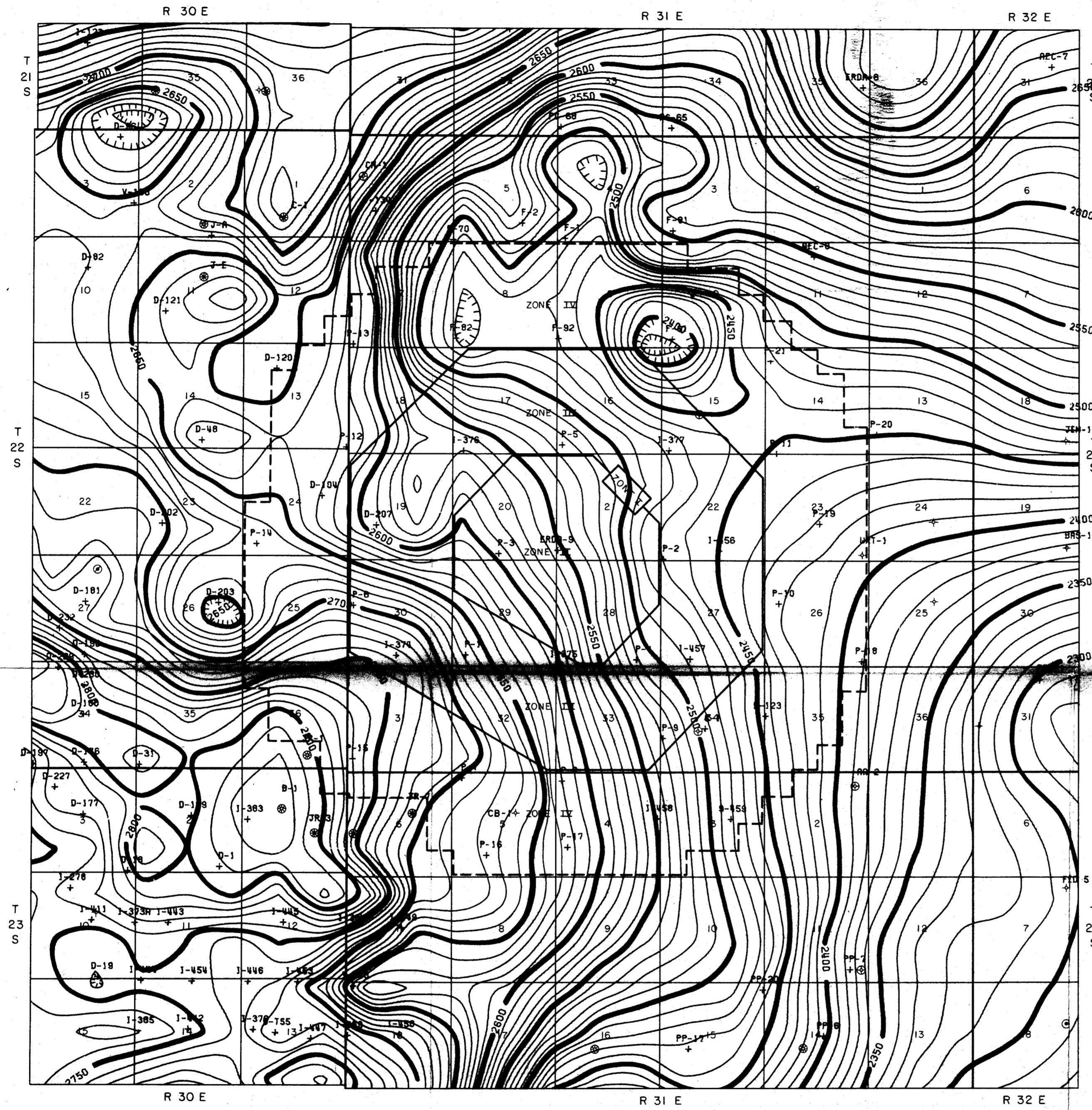
TOP OF RUSTLER TO TOP OF SALADO

FIGURE 10

## ISOPACH MAPS - GATUNA TO SALADO







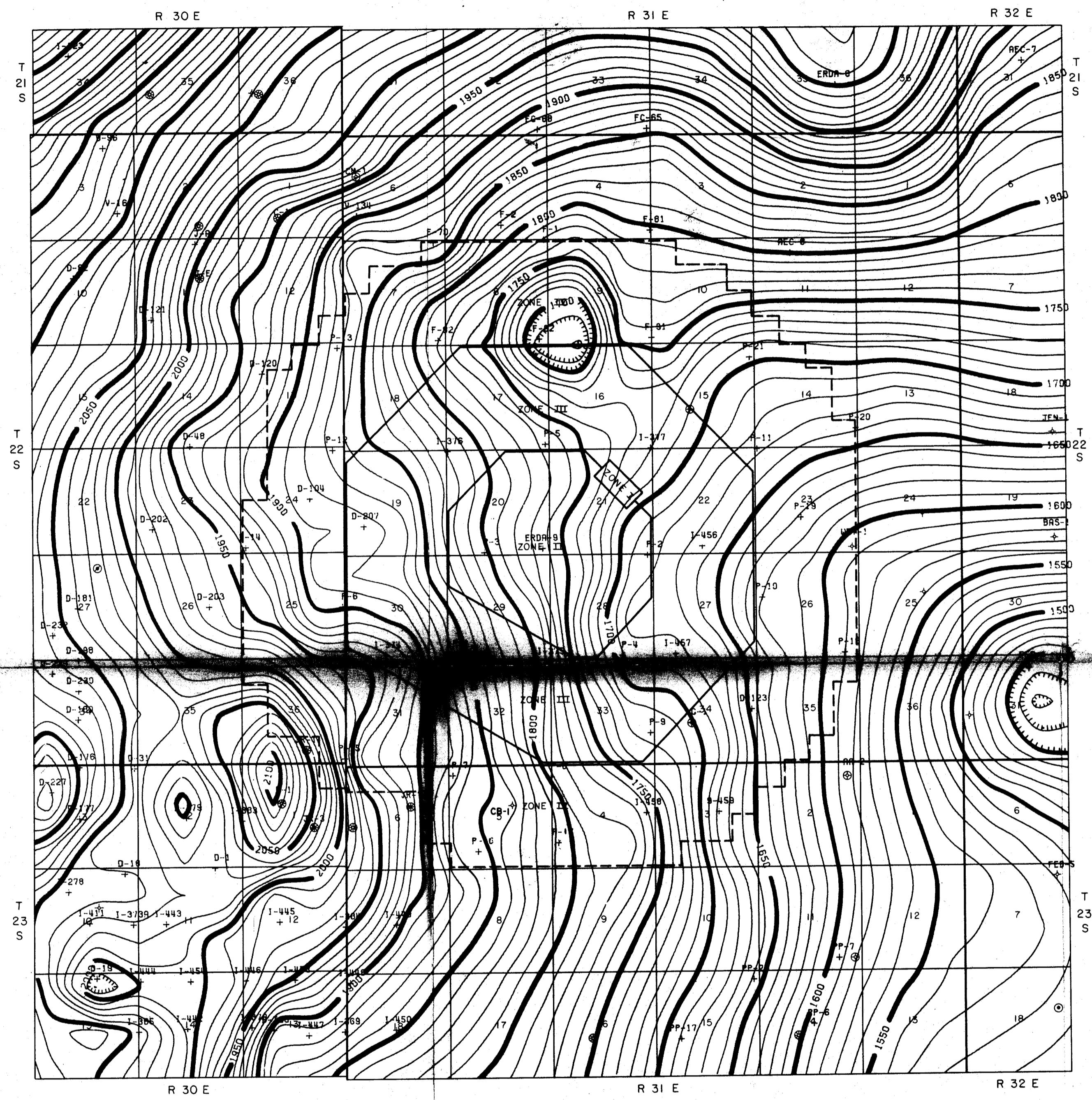
## **EXPLANATION**

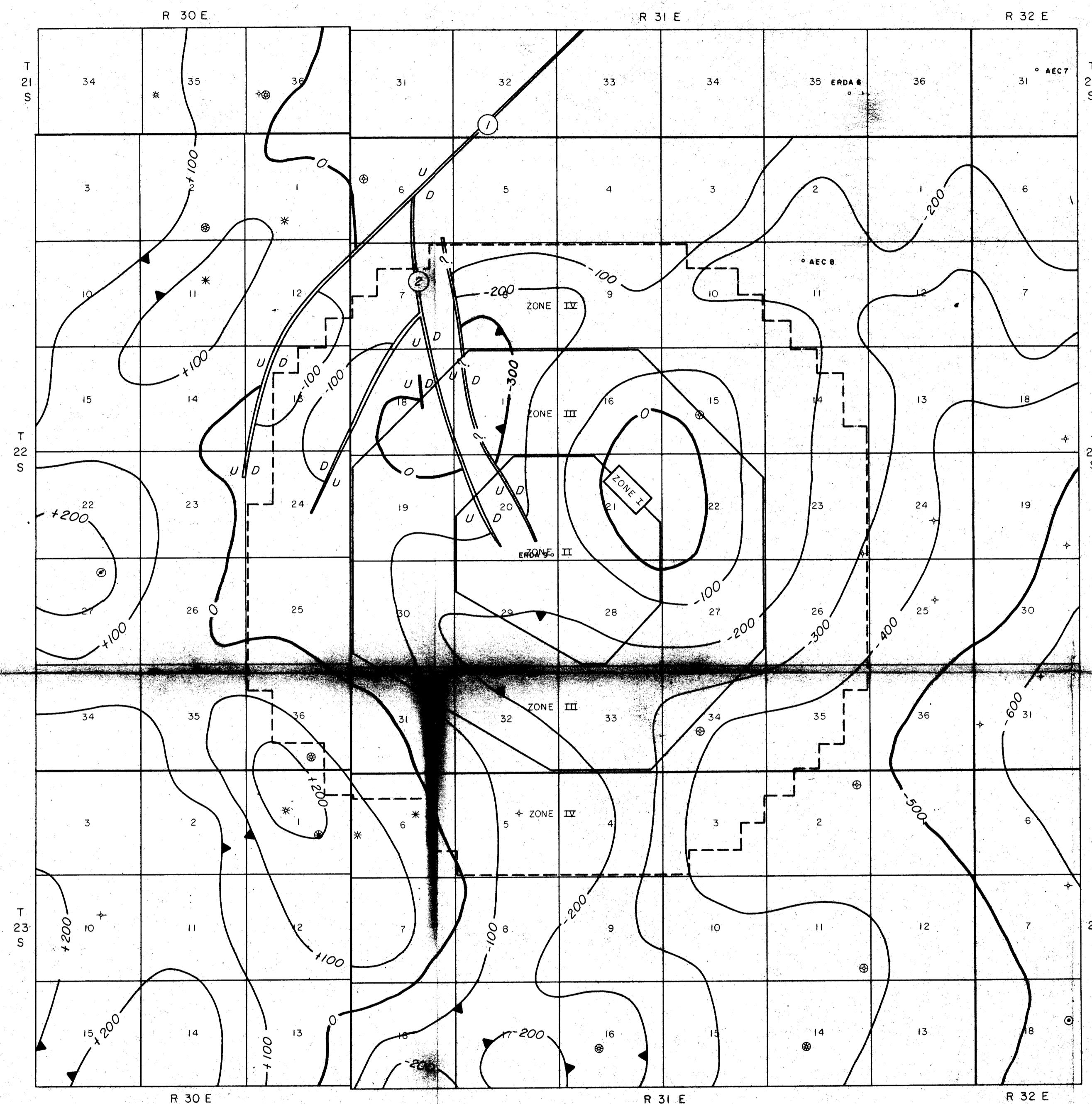
Contours based on geologic logs of ERDA and industry potash exploration logs. In the site area, i.e., within Zones I-IV, the contours are considered accurate within 10 feet in elevation. Outside Zone IV they are approximate, and the error may exceed 50 feet in some areas. The Top of Salado may be higher in the west because drill records report only "top of salt". Datum is sea level.

# **FIGURE 12**

## **STRUCTURE OF TOP OF SALADO FORMATION**





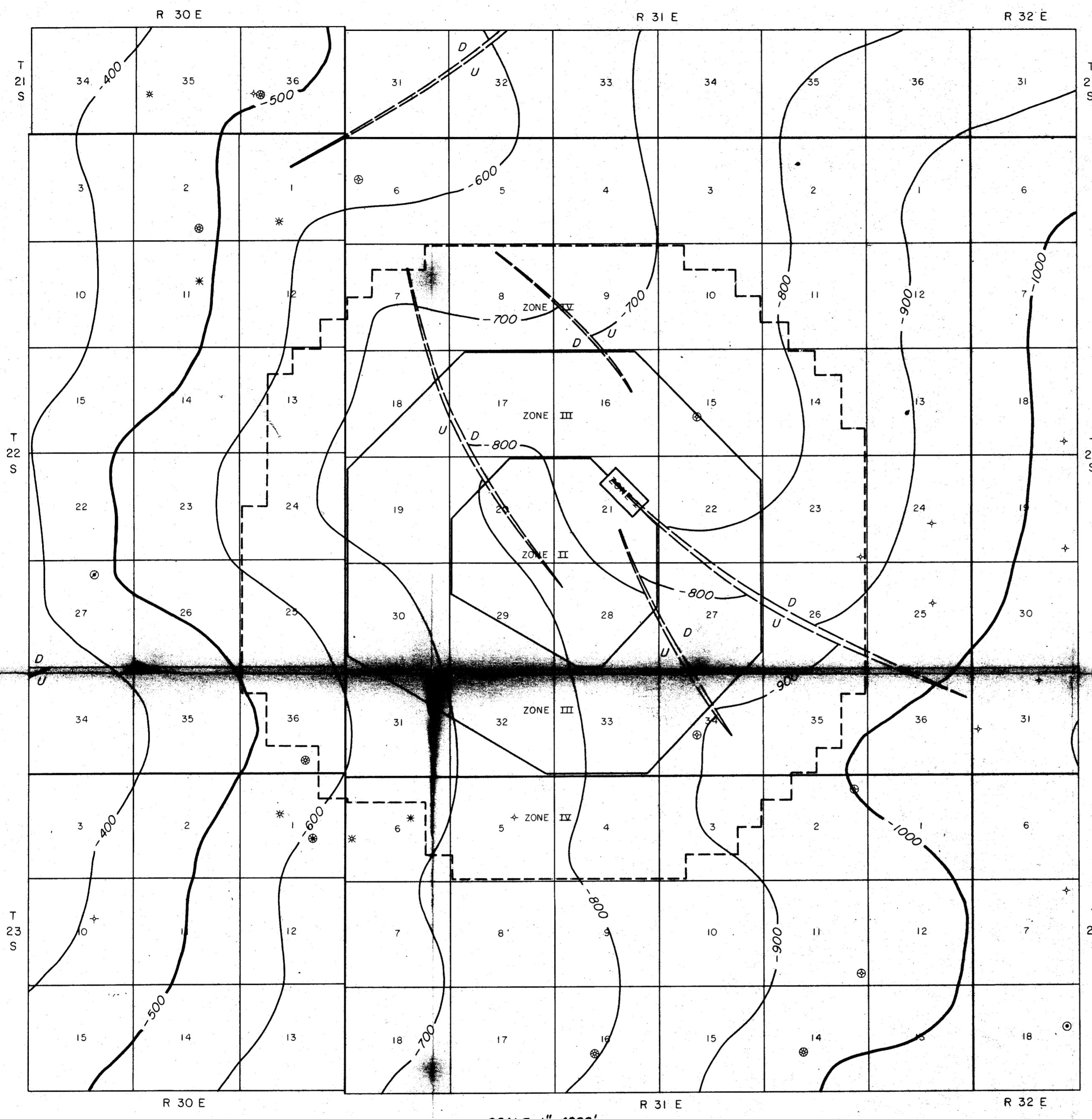


### EXPLANATION

Contours compiled from all seismic geophysical information available. The structures shown are the best that can be given at this time. Future high resolution surveys are planned and significant revisions may result. Datum is sea level.

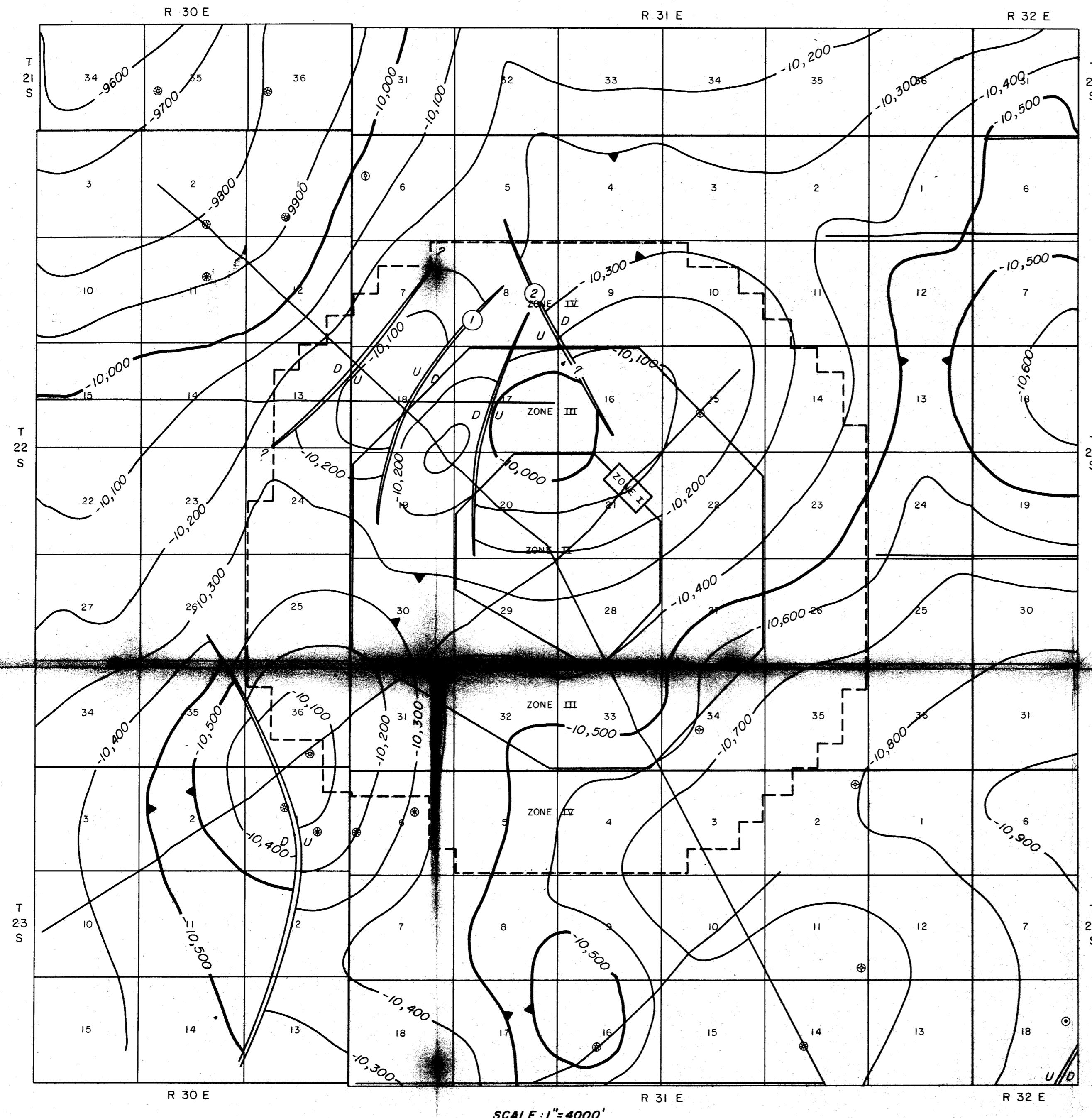
**FIGURE 14**  
**STRUCTURE OF A HORIZON**  
**IN THE MIDDLE OF**  
**THE CASTILE FORMATION**





### EXPLANATION

This map represents a "generalized" interpretation of all geophysical-geological information available to us at this time. Due to the numerous vintages of seismic data involved, conflicting velocity and weathering correction techniques applied to the original data and different zones of interest for which the data was recorded versus the shallow interest Sandia Laboratories has in this area, it is extremely difficult to evaluate structure in the Permian. Future high resolution surveys are recommended, and in which case extensive revision of structure contouring may result. Datum is sea level.



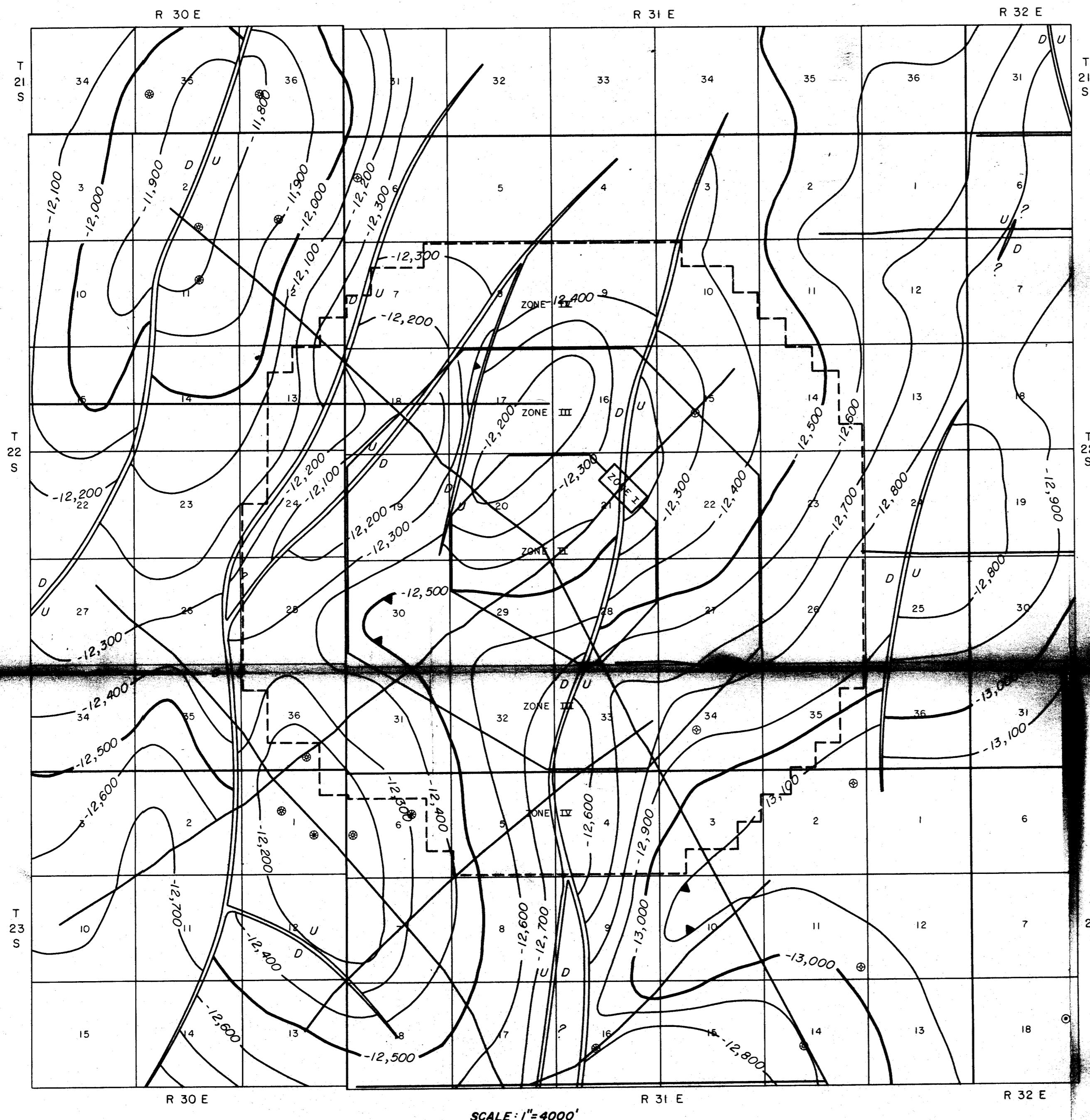
### EXPLANATION

Principal seismic profiles lines used in the interpretation are shown. Datum is sea level.

FIGURE 16

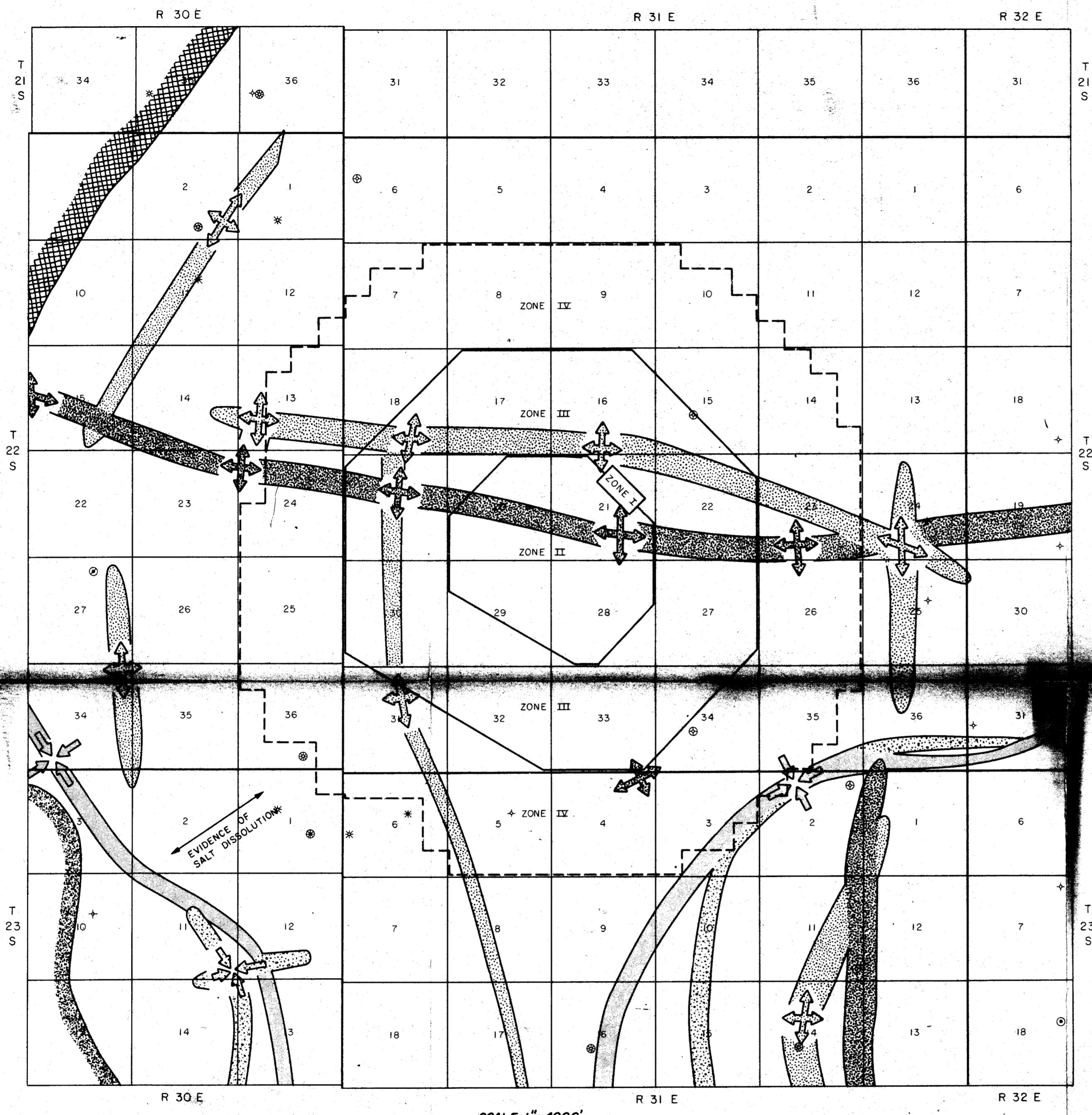
## STRUCTURE OF THE MORROW LIMESTONE





### EXPLANATION

Principal seismic profile lines used in the interpretation are shown. Datum is sea level.

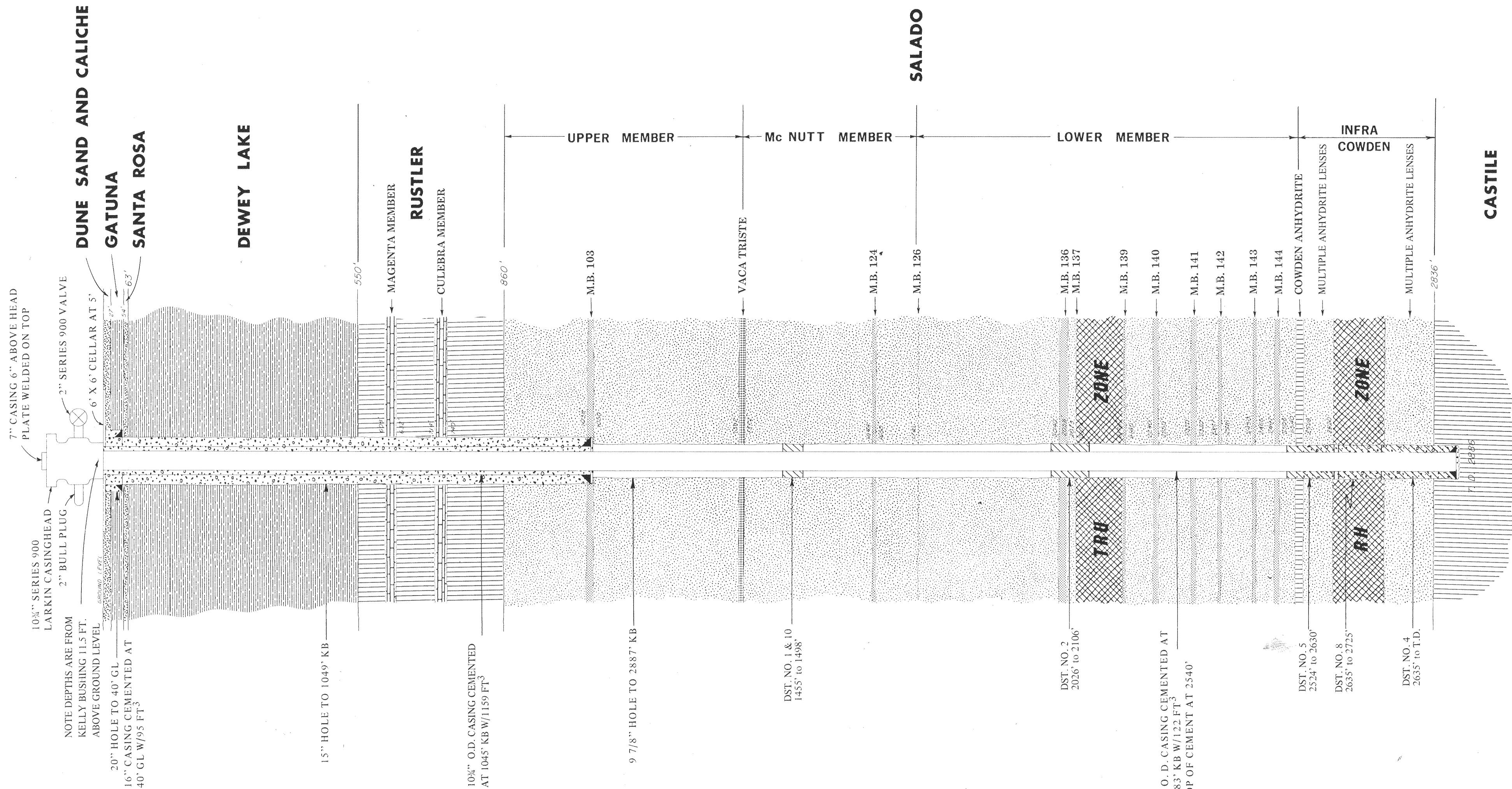


### EXPLANATION

- SHALLOW HIGH TRENDS (Delaware)
- DEEP HIGH TRENDS (Devonian)
- SHALLOW LOW TRENDS (Delaware)
- DEEP LOW TRENDS (Devonian)
- BOUNDARY OF "ZONE OF ERRATIC DATA"
- APPROXIMATE BOUNDARY OF "NASH DRAW"

**FIGURE 18**  
**COMPOSITE OF**  
**GRAVITY AND SEISMIC**

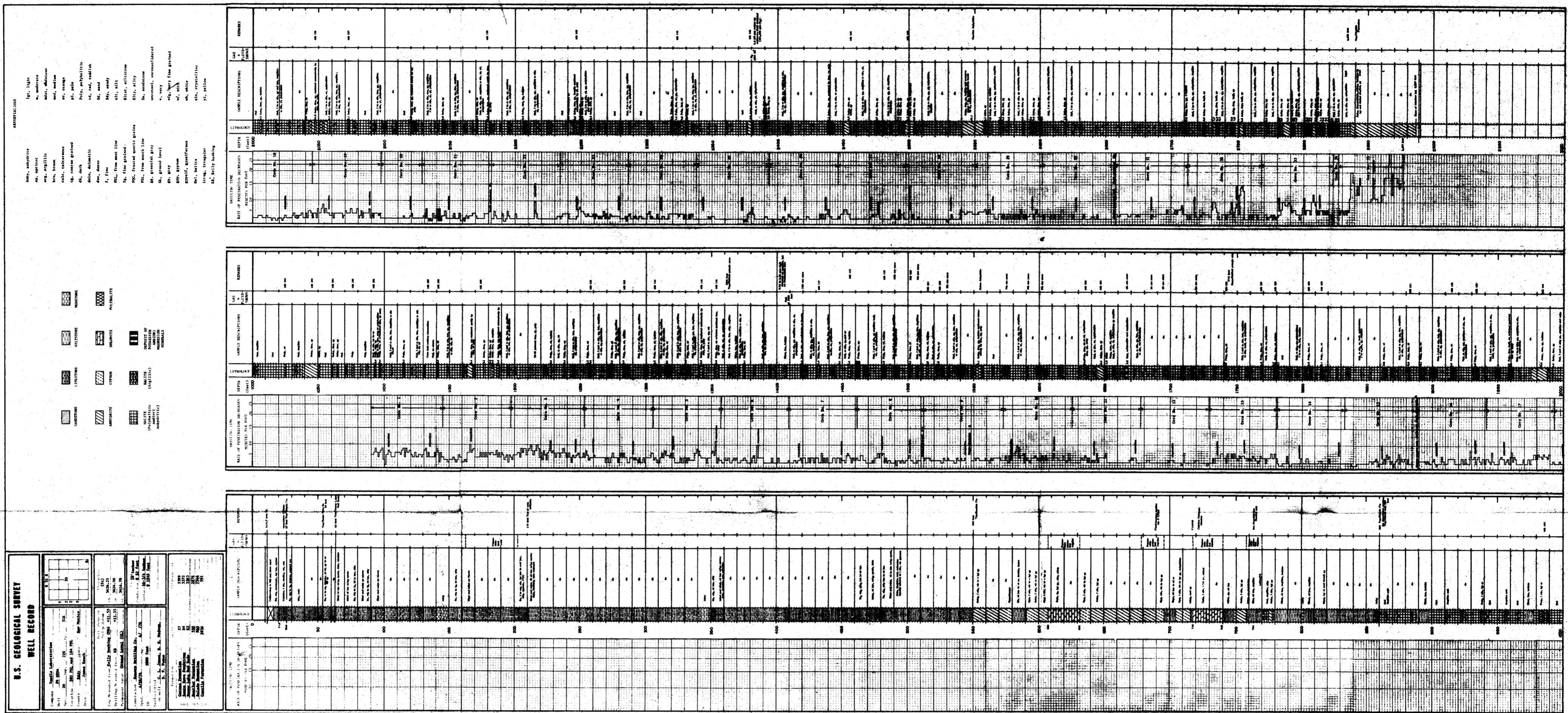




# FIGURE 19

## ERDA NO. 9 SCHEMATIC DIAGRAM

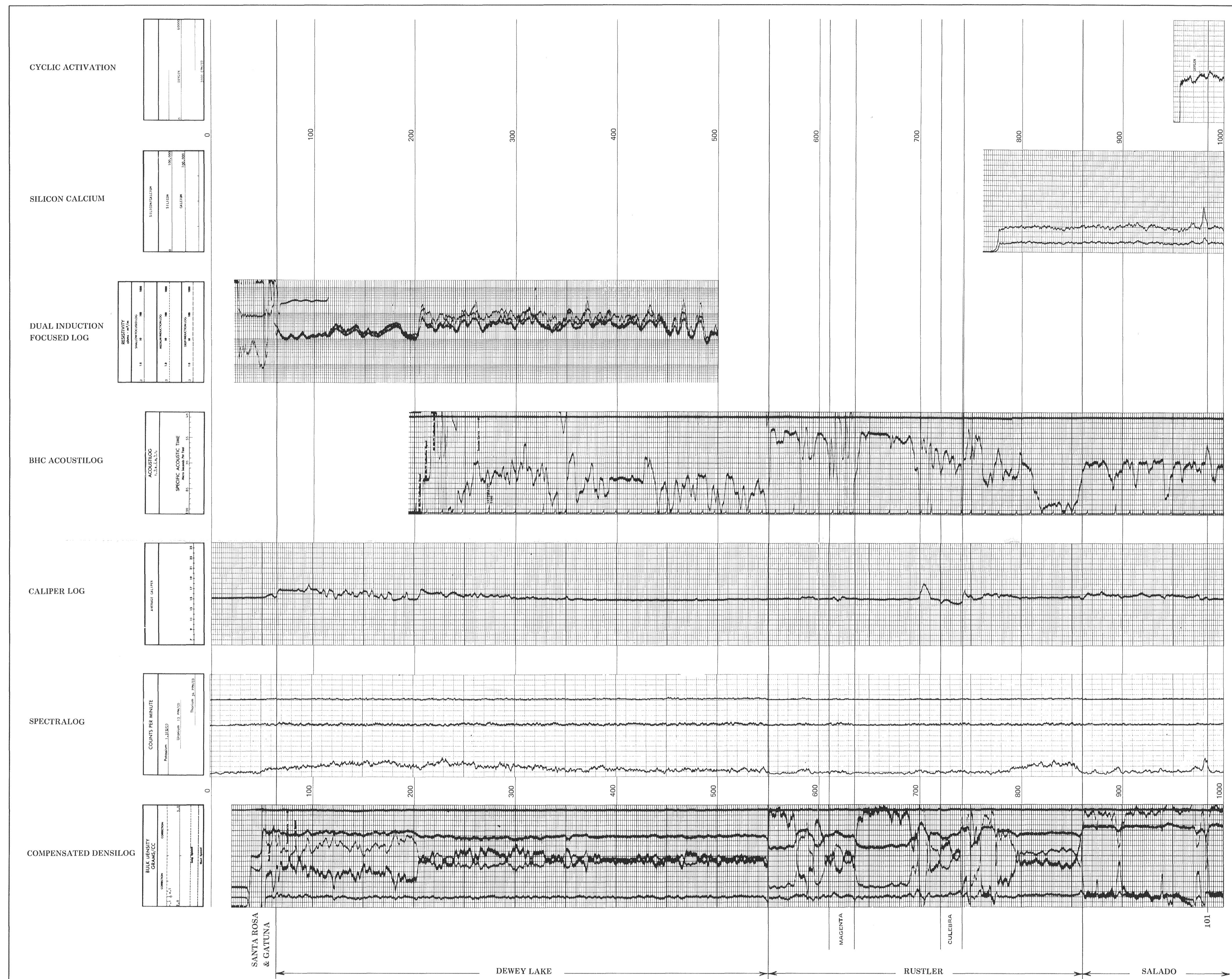




## FIGURE 20

# U. S. GEOLOGICAL SURVEY WELL RECORD - ERDA NO. 9



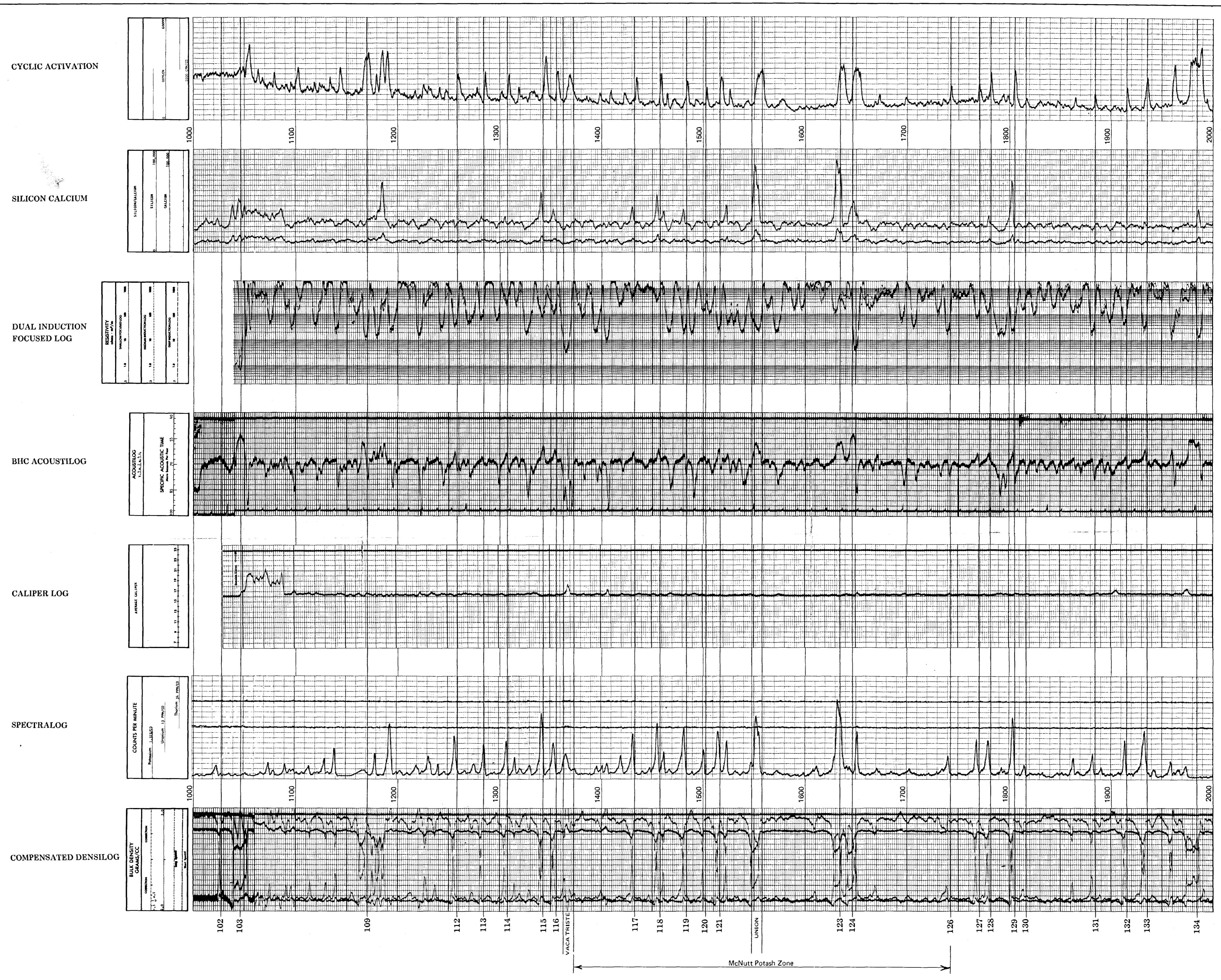


**FIGURE 21**

**BOREHOLE GEOPHYSICAL LOGS FOR ERDA NO. 9 - 0' TO 1000'**



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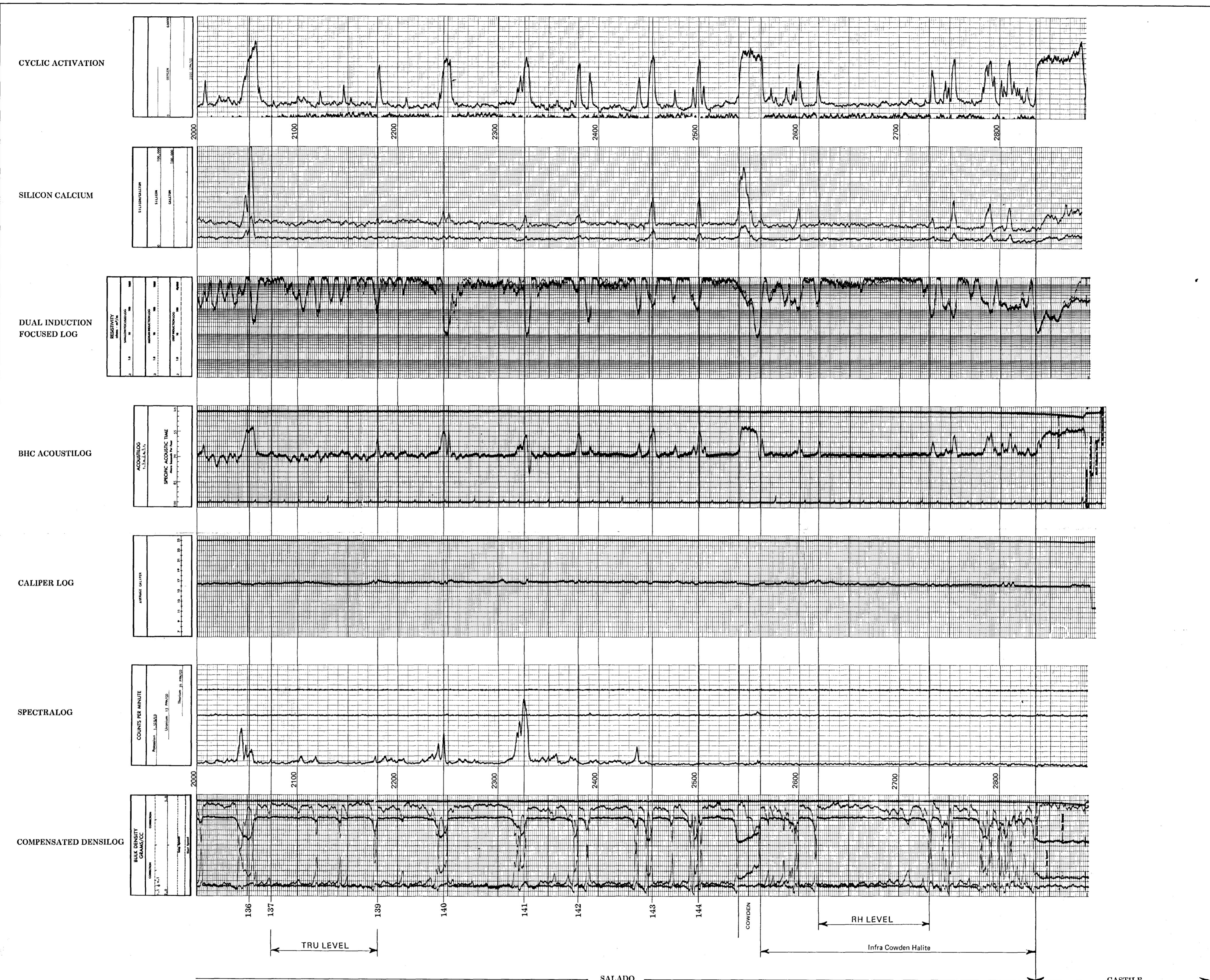


## FIGURE 22

# BOREHOLE GEOPHYSICAL LOGS FOR ERDA NO. 9 - 1000' TO 2000'



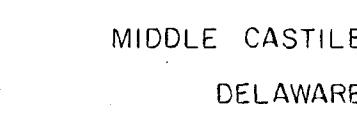
 Sandia Laboratories



**FIGURE 23**  
**BOREHOLE GEOPHYSICAL LOGS FOR ERDA NO. 9 - 2000' TO TD**



Sandia Laboratories



## FIGURE 24

# **SANDIA SEISMIC PROFILE LINES 1 AND 2**



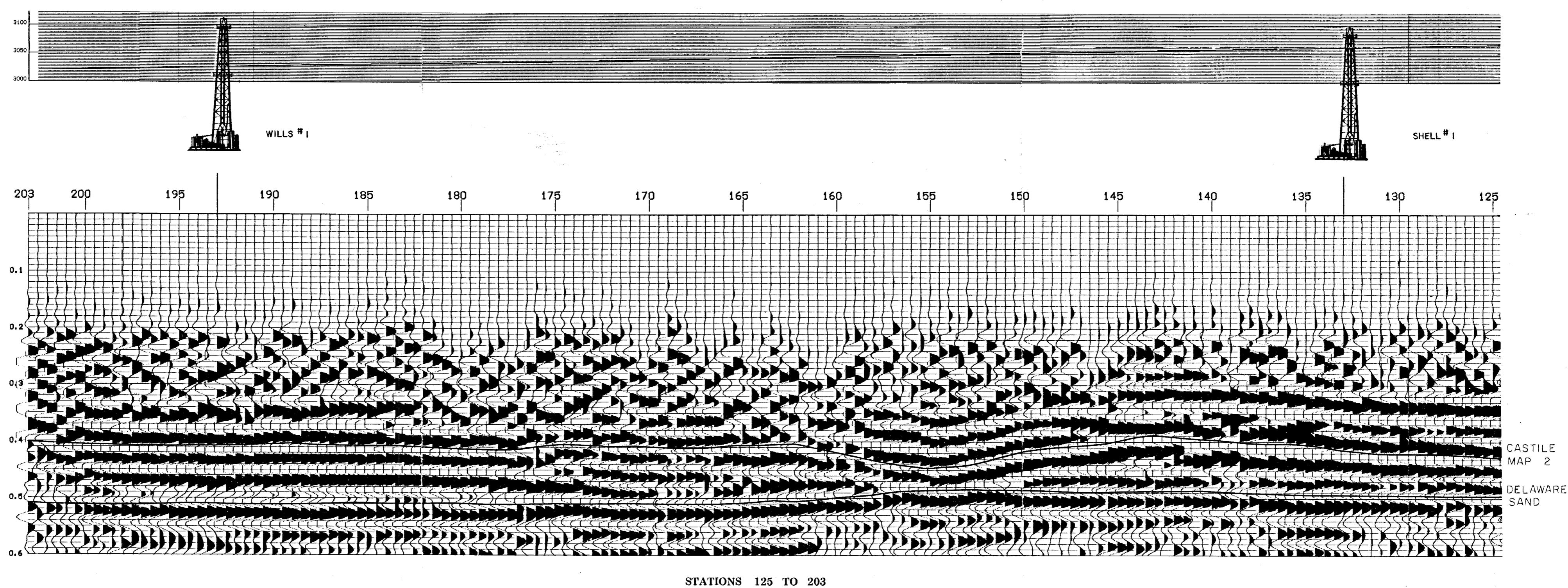
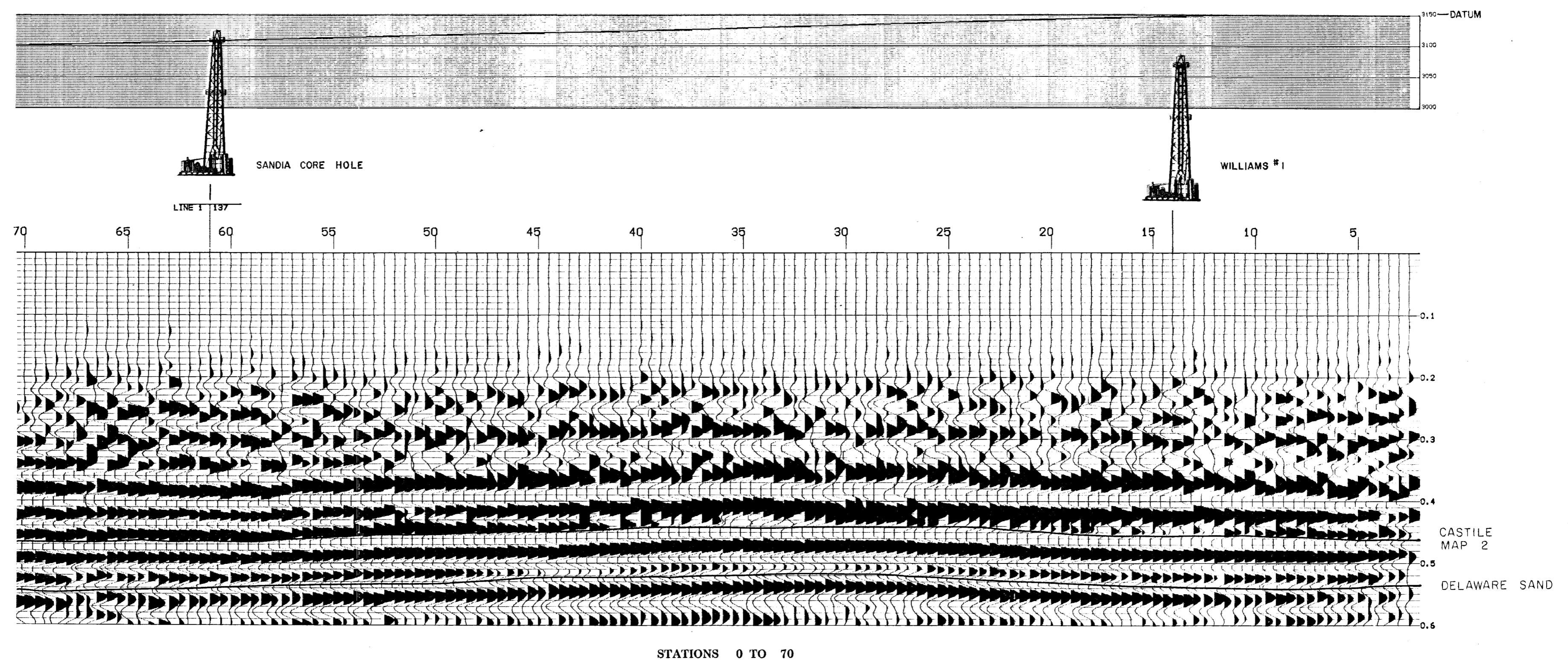
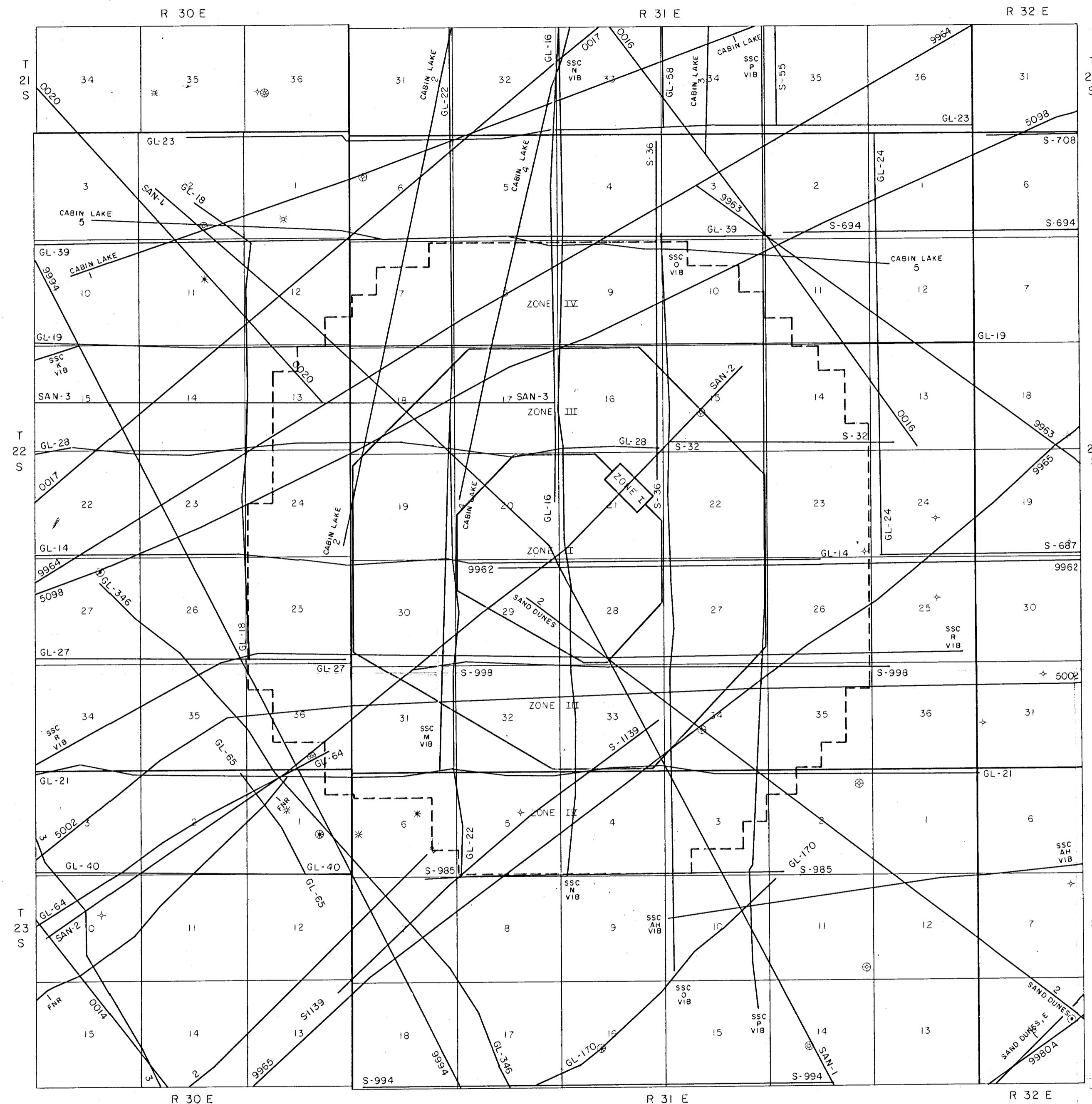


FIGURE 25

DETAILS OF TWO ANOMALIES ALONG SEISMIC PROFILE LINE 2



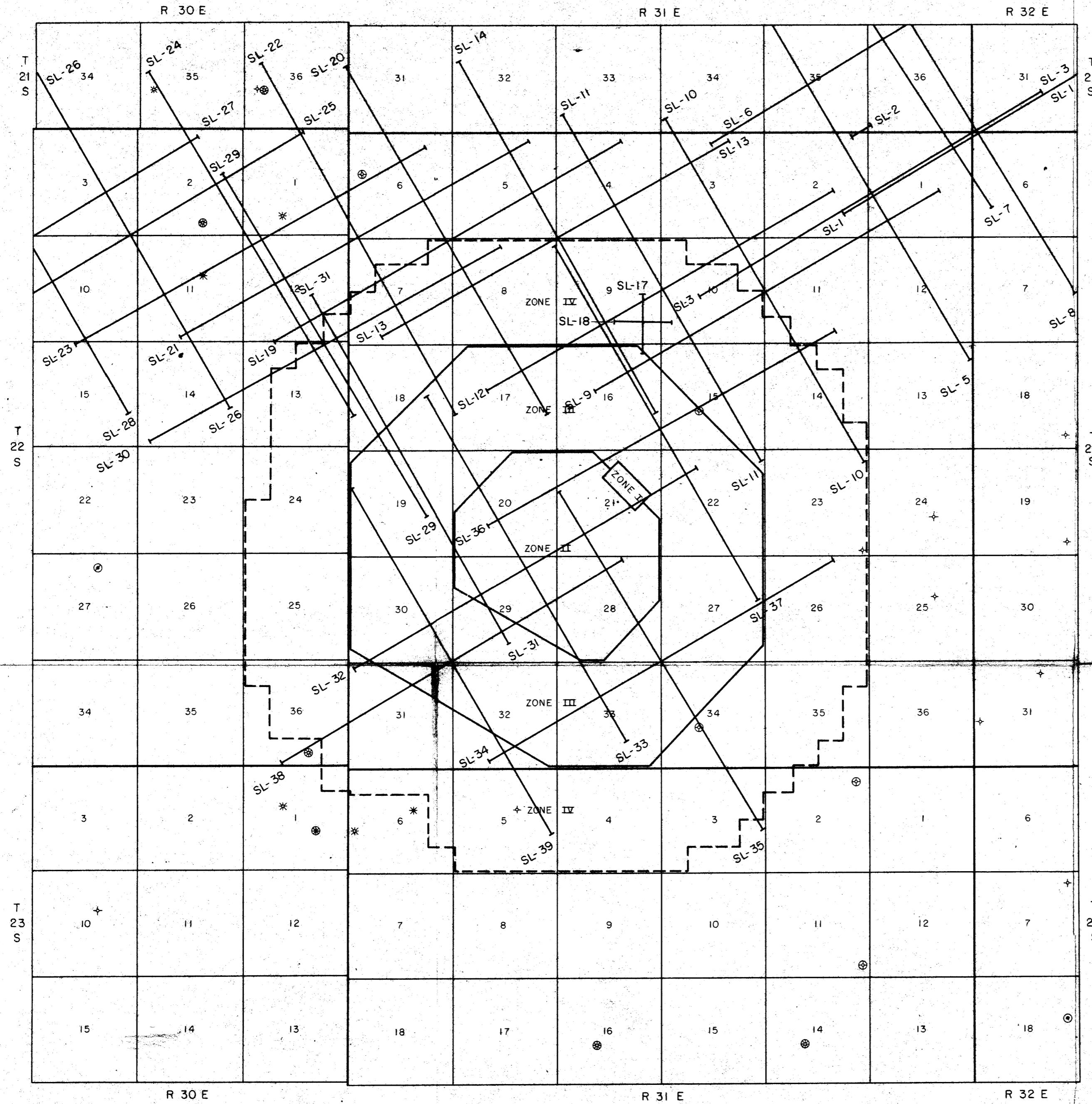
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### EXPLANATION

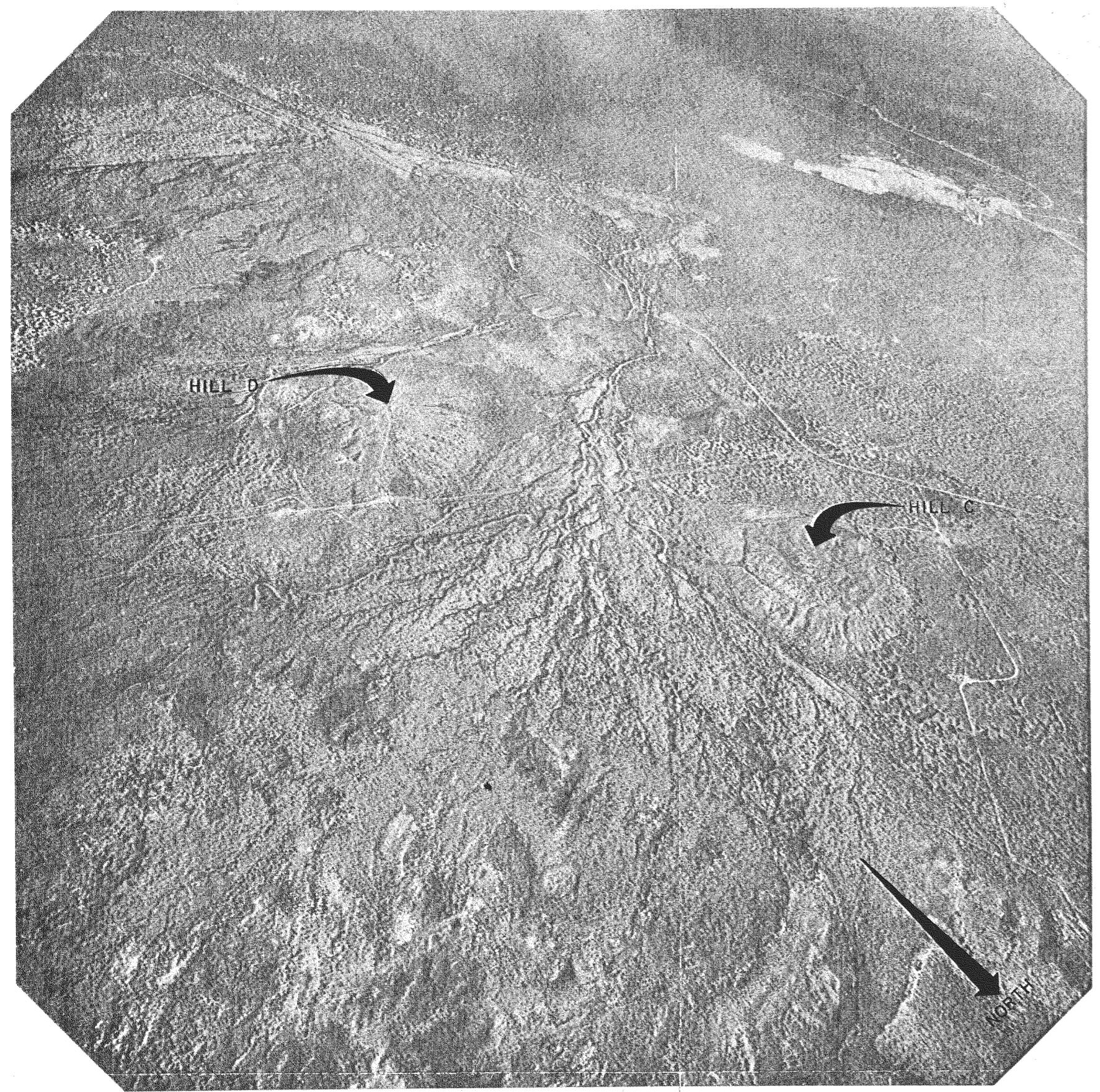
All lines shown were at least partially available to Sandia, i.e. down through the Delaware.  
Only Sandia Lines 1, 2, and 3 are available for inspection.

**FIGURE 26**  
**COMPILED OF**  
**SEISMIC LINES**



**FIGURE 27**  
**LOCATION OF**  
**SCHLUMBERGER EXPANSION ARRAYS**





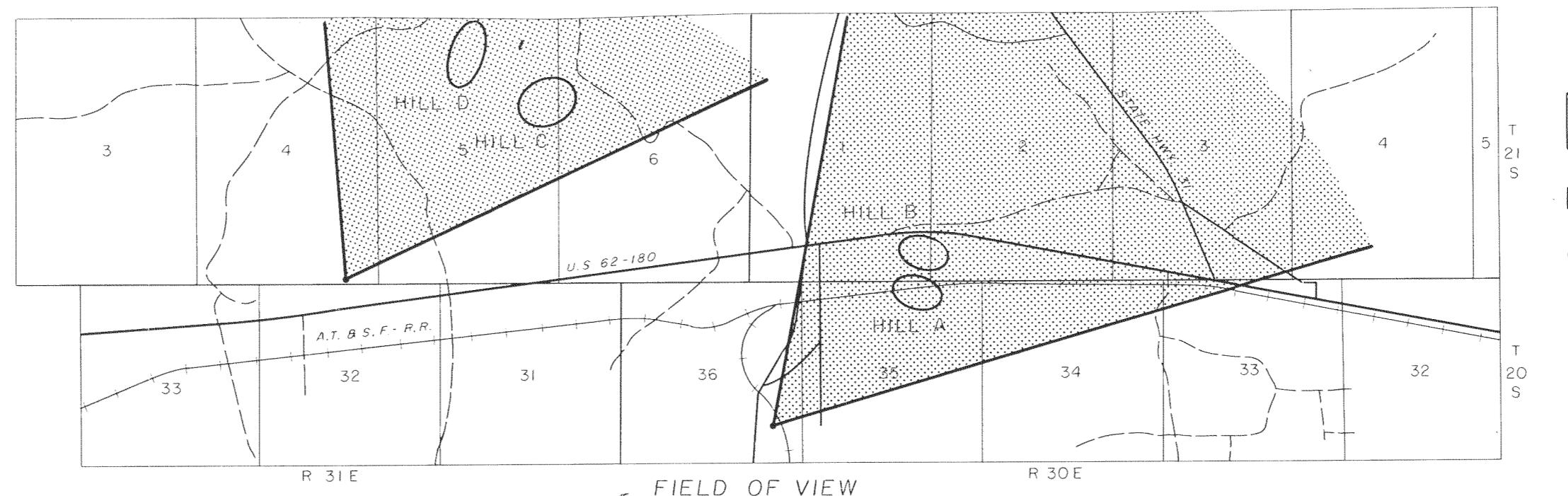
HILL C AND D

Hill C has collapsed. The rim is similar to that of Hill A. Santa Rosa and Dewey Lake form the center of the collapse. Hill D is oblong and may not be a breccia pipe.

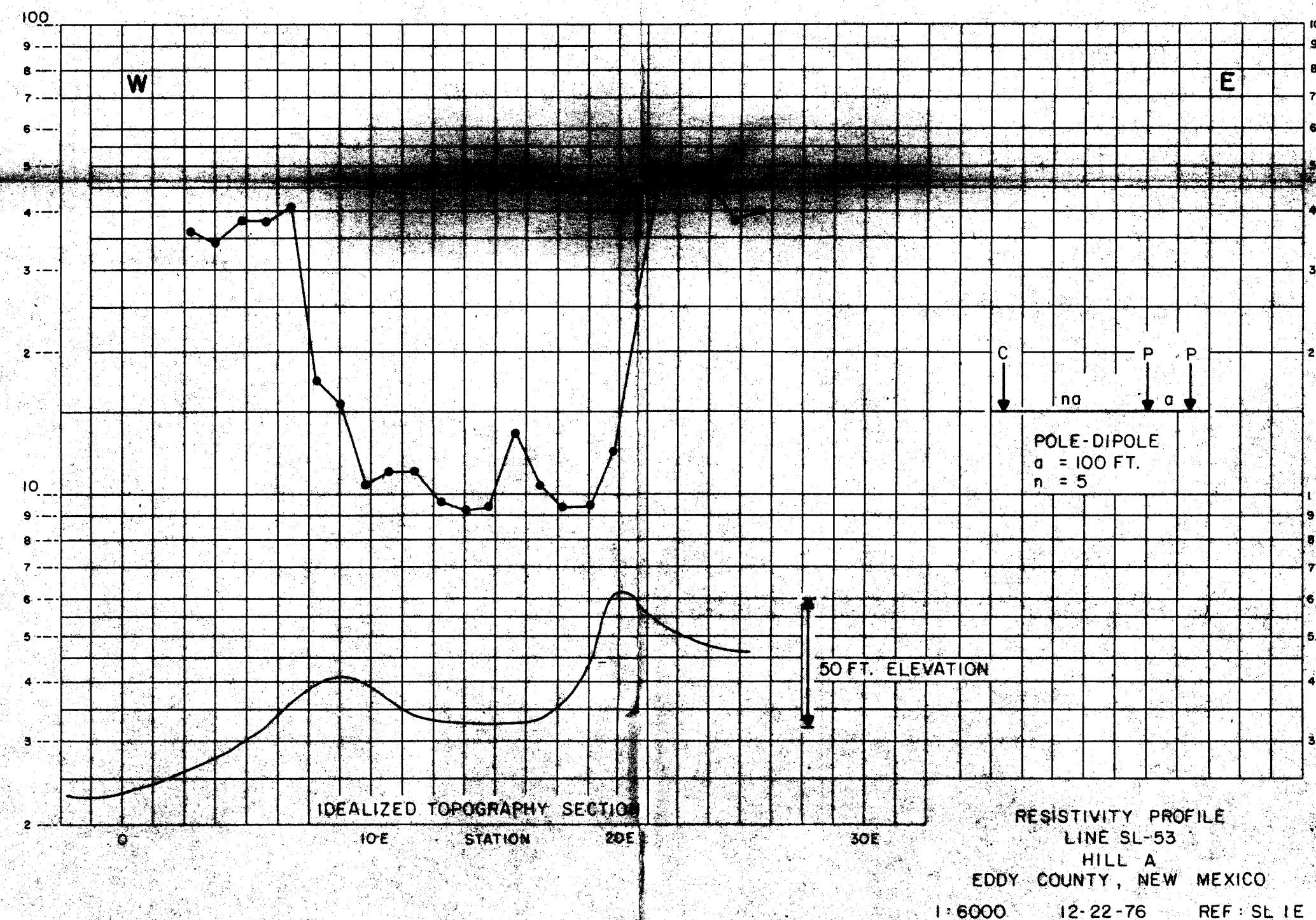
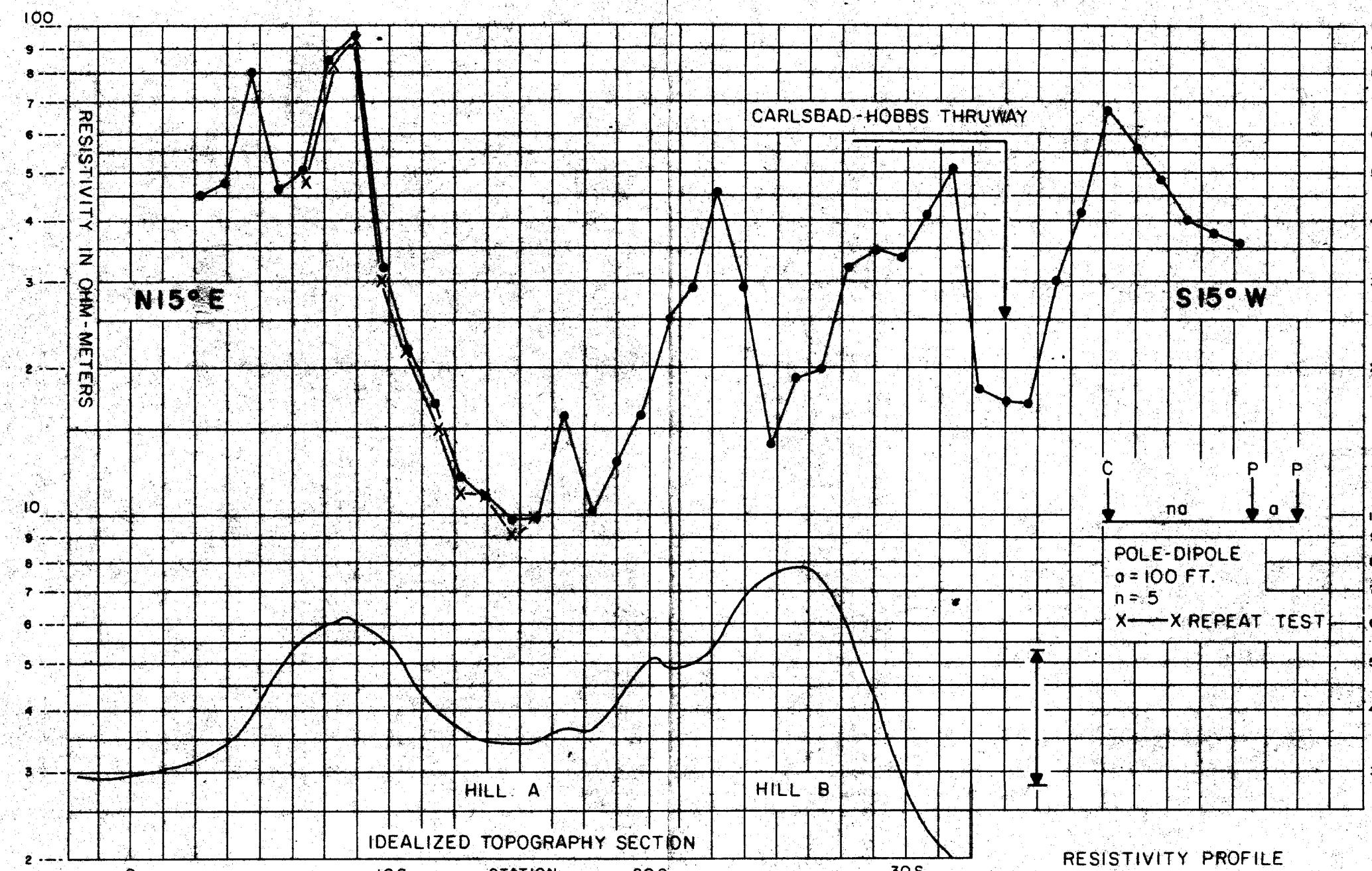
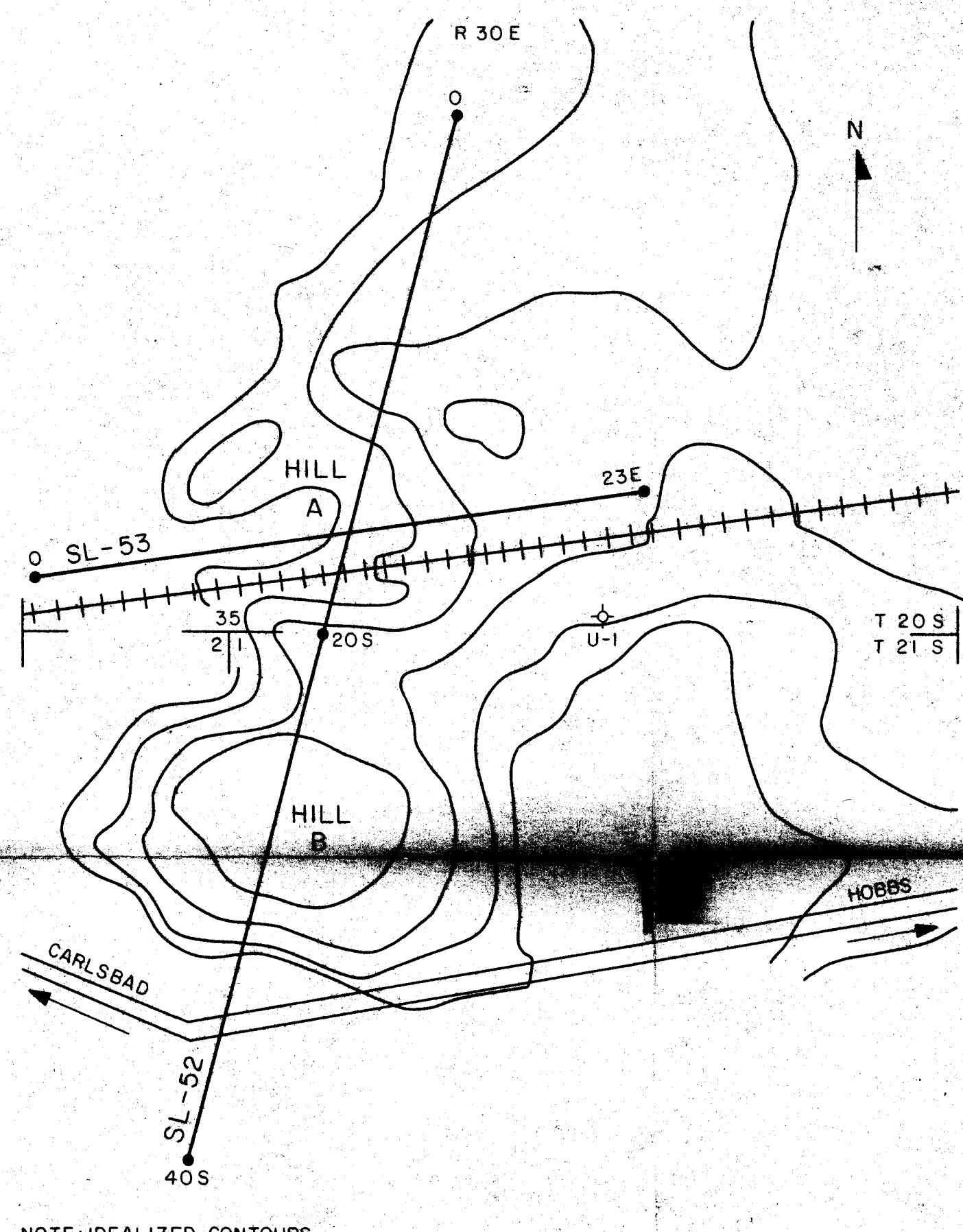


HILL A AND B

The "crater" rim of Hill A consists of Gatuna and Dewey Lake beds capped by caliche. Blocks of Santa Rosa are present inside crater. Hill B is caliche capped, but partial collapse has occurred on the southwest side of the hill where some Santa Rosa is exposed.

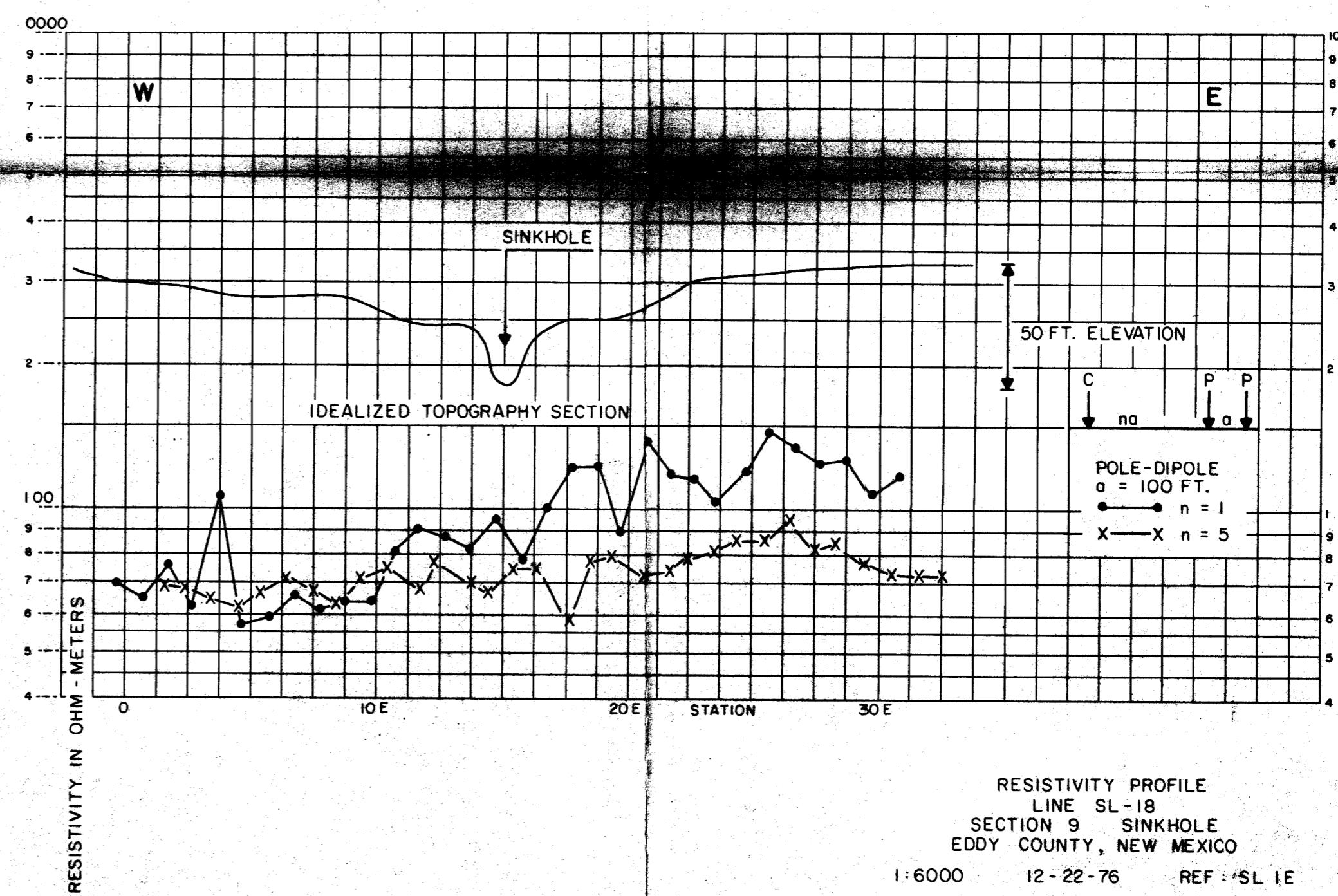
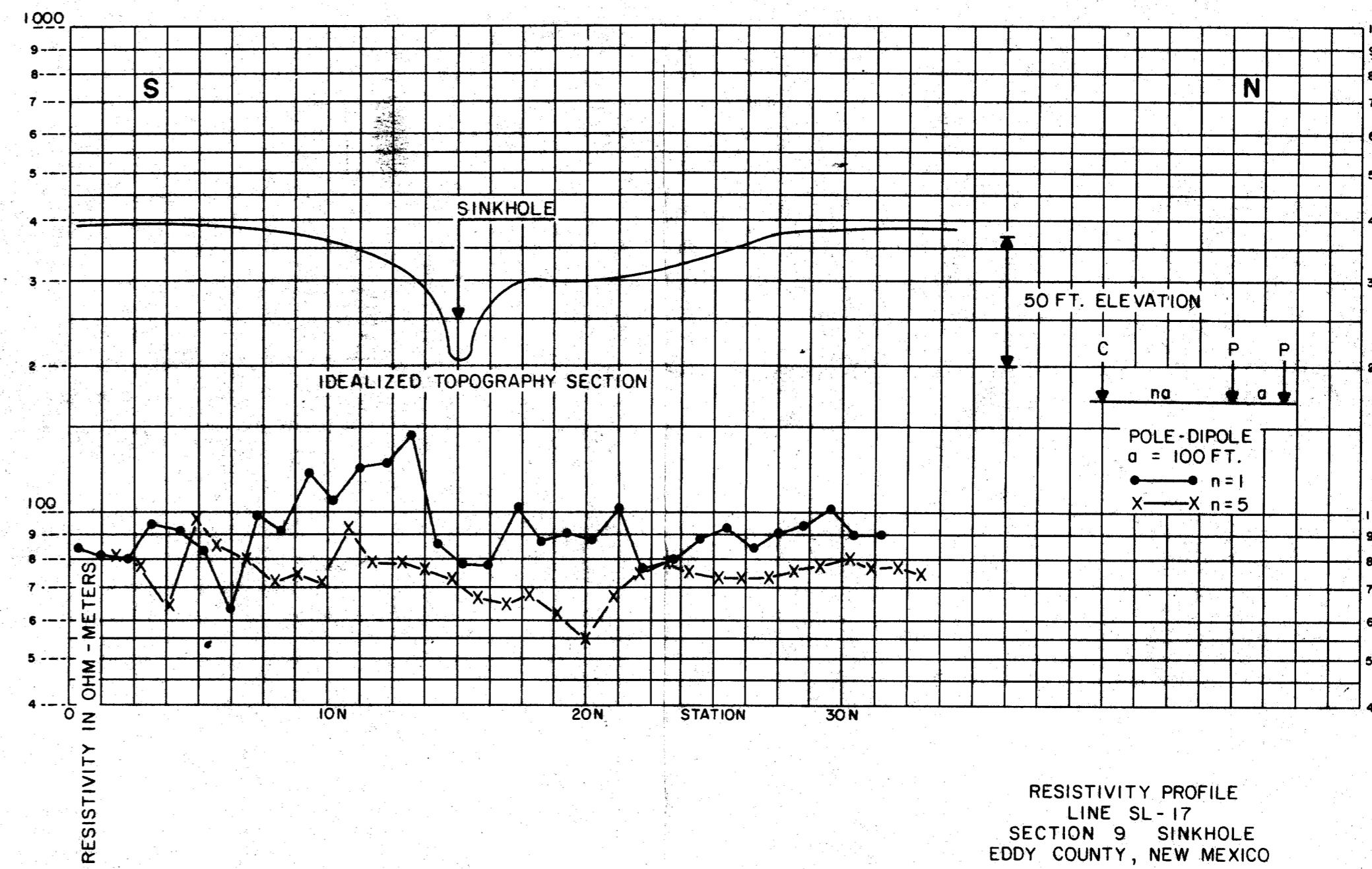
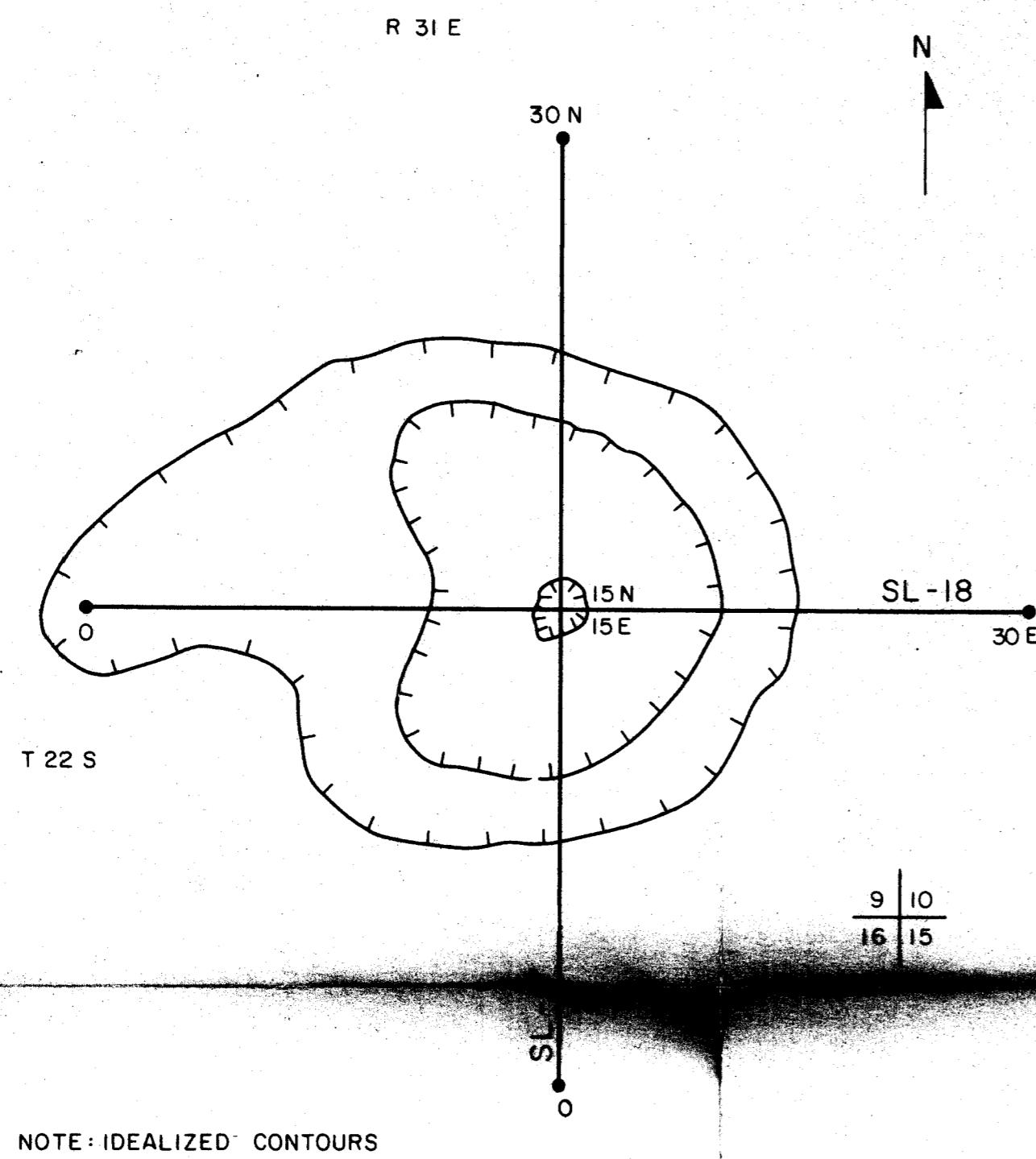


**FIGURE 28**  
**INCLINED AIR PHOTOS OF**  
**BRECCIA PIPES**



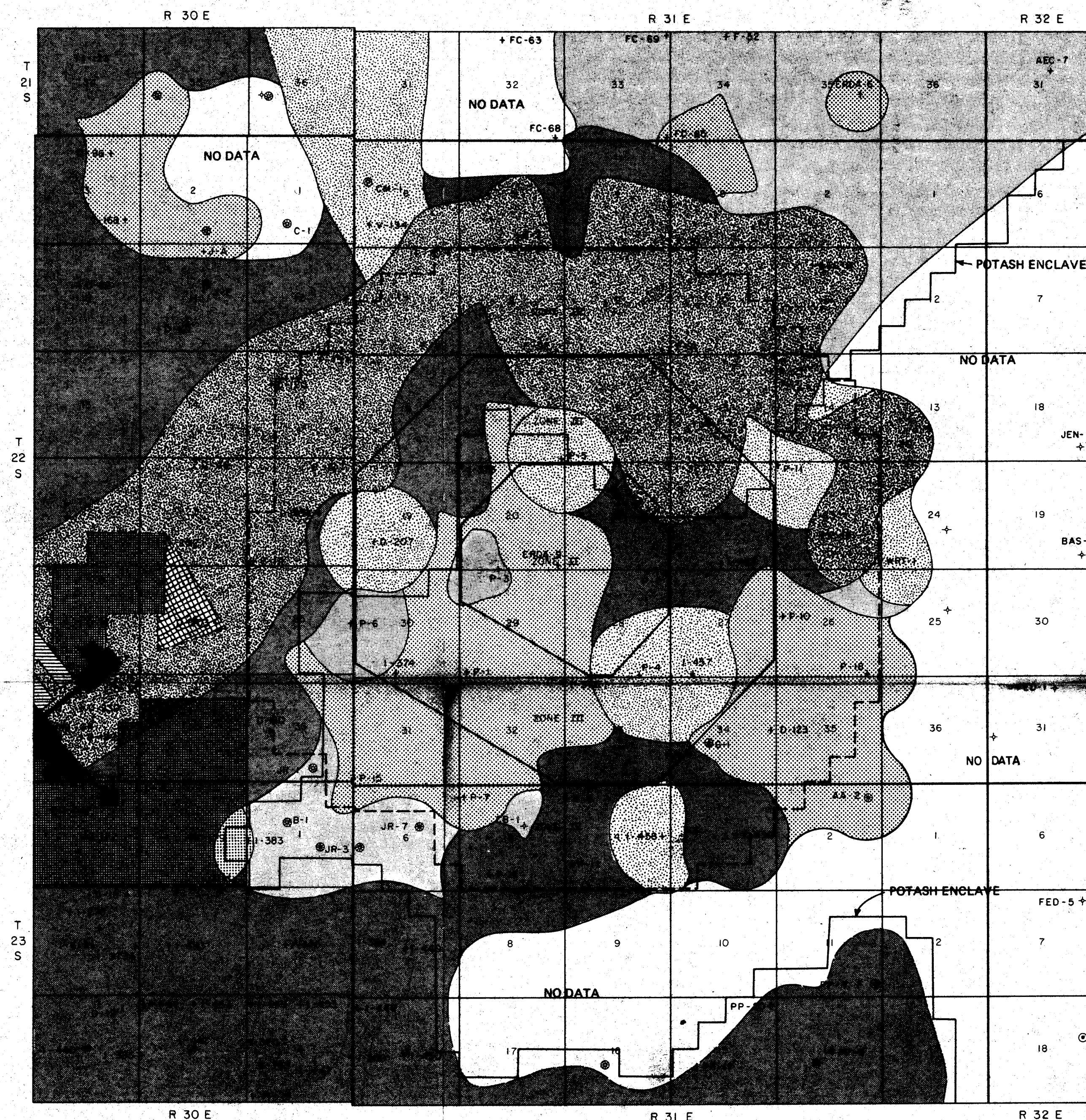
**FIGURE 29**  
**ELECTRICAL SURVEY RESULTS OVER  
A BRECCIA PIPE (HILL A & B)**



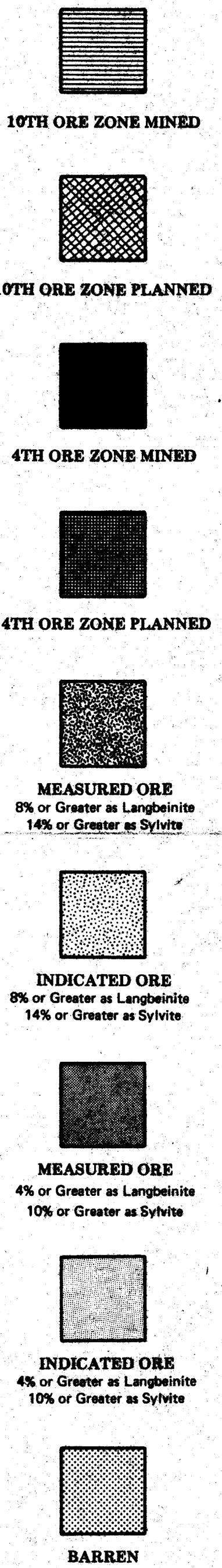


**FIGURE 30**  
**ELECTRICAL SURVEY RESULTS OVER**  
**A SHALLOW SINK HOLE IN SECTION 9**





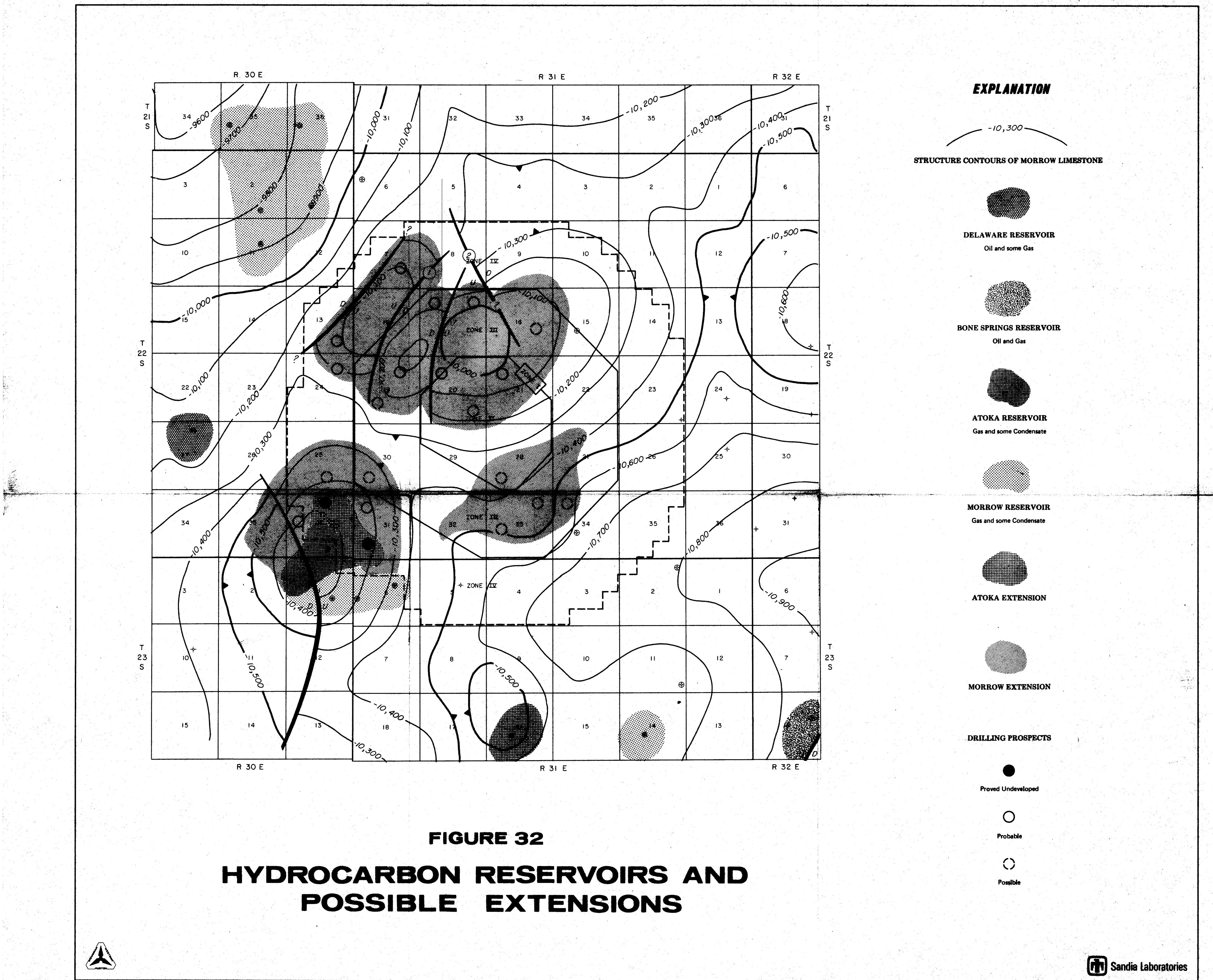
## **EXPLANATION**

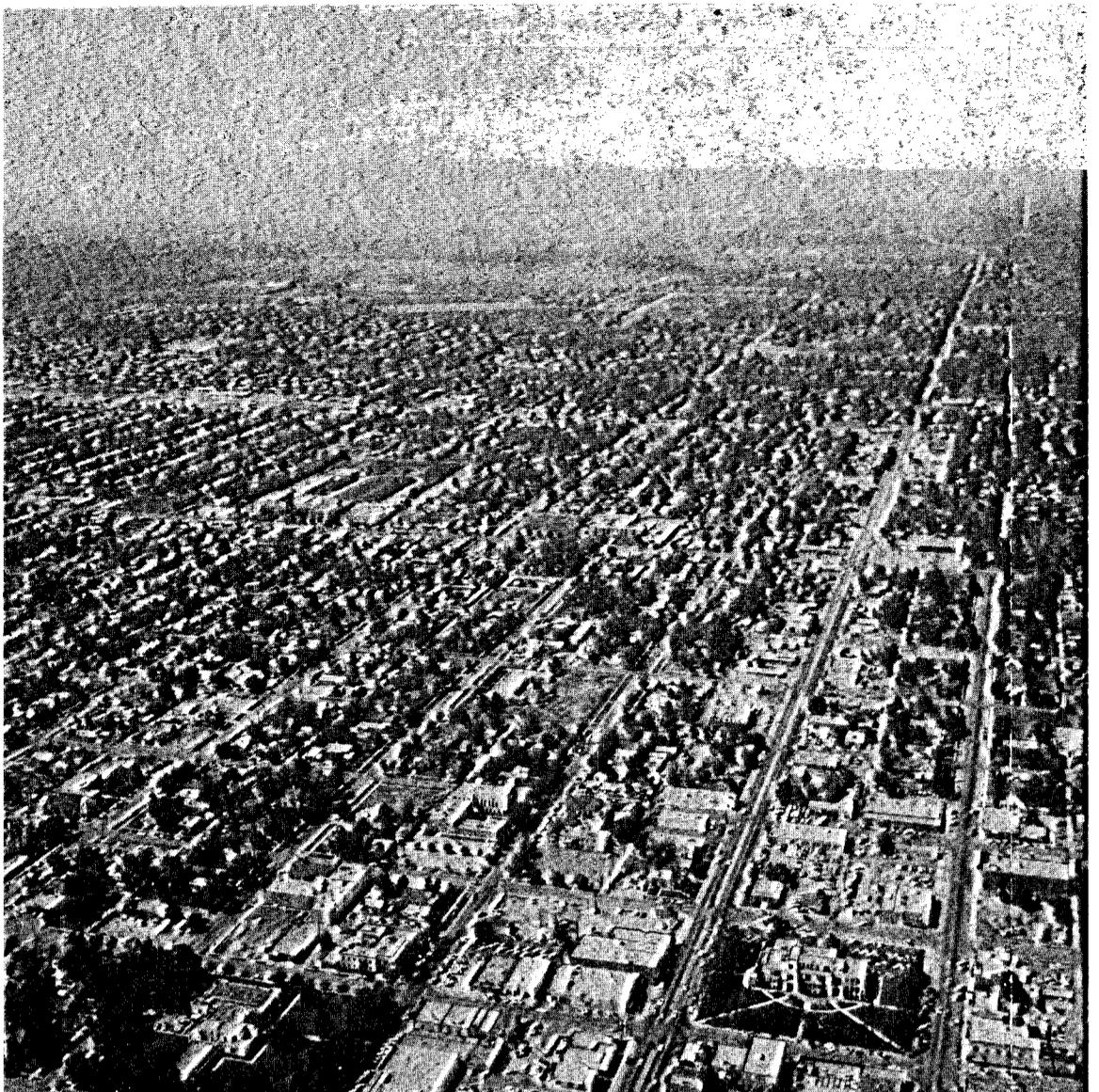


# FIGURE 31

## POTASH RESOURCES

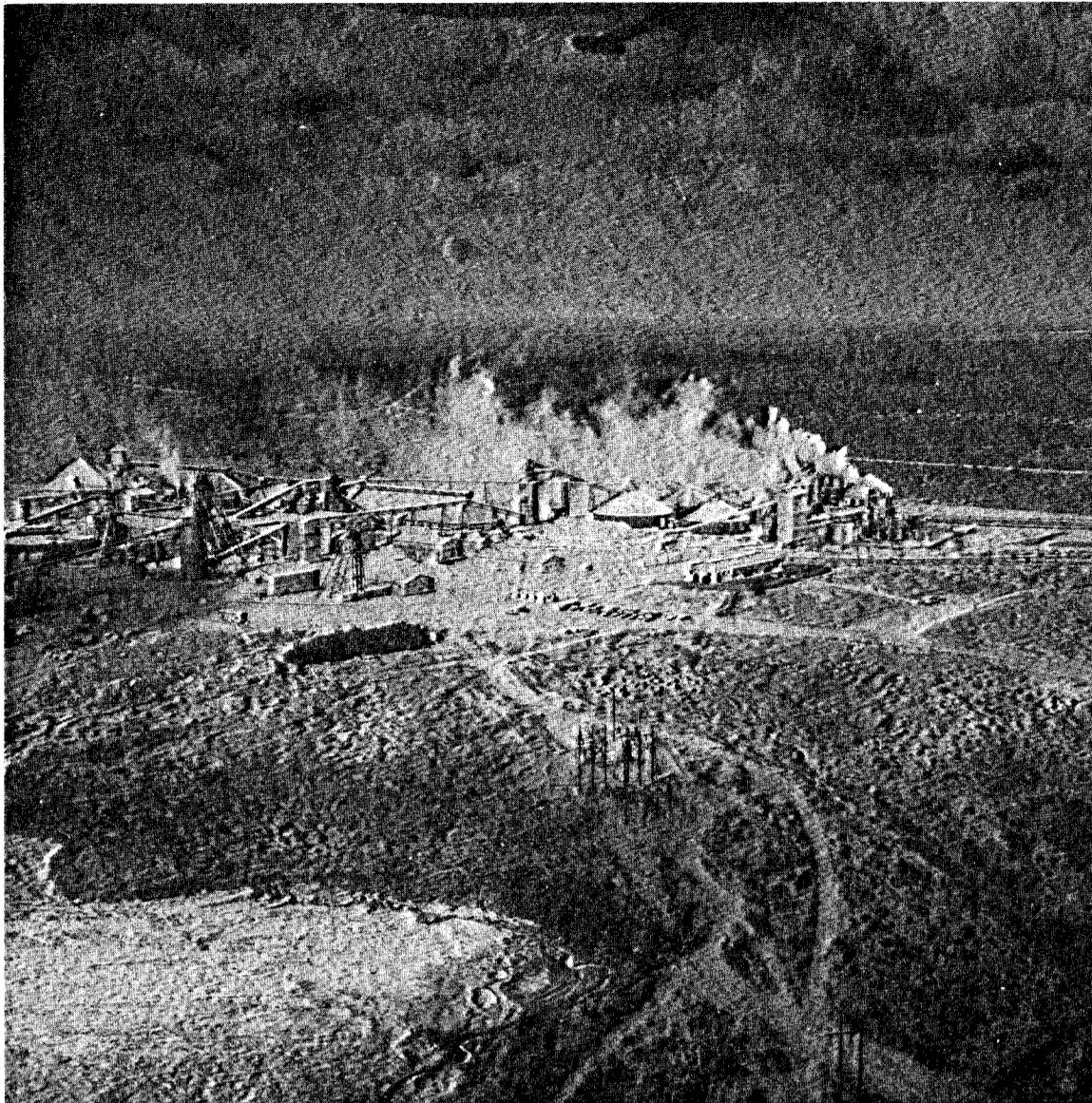






**CITY OF CARLSBAD**

View is to the north. County Court House in lower right.



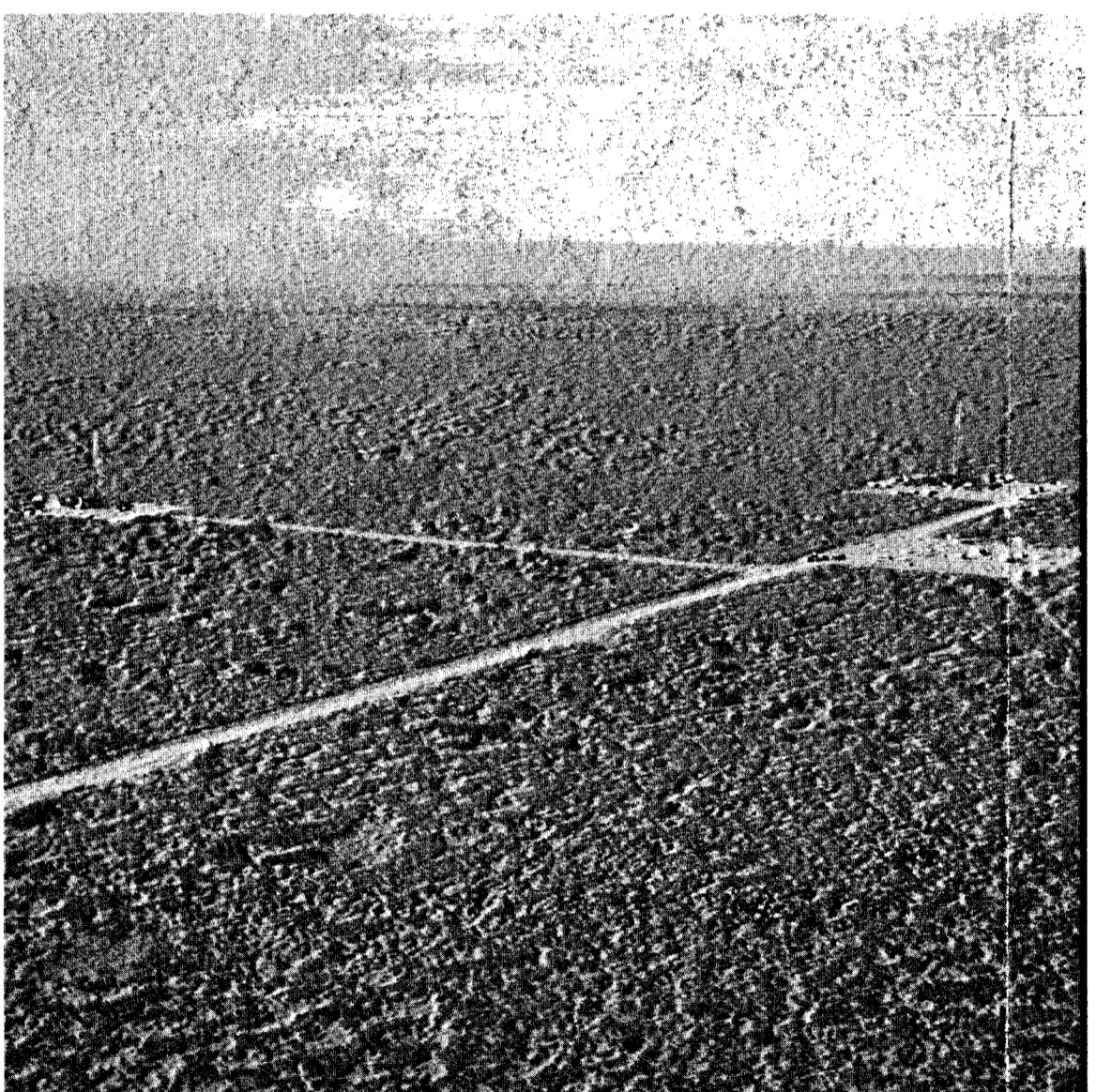
**POTASH REFINERY**

Owned by Duval Corporation located 20 miles west of Carlsbad.



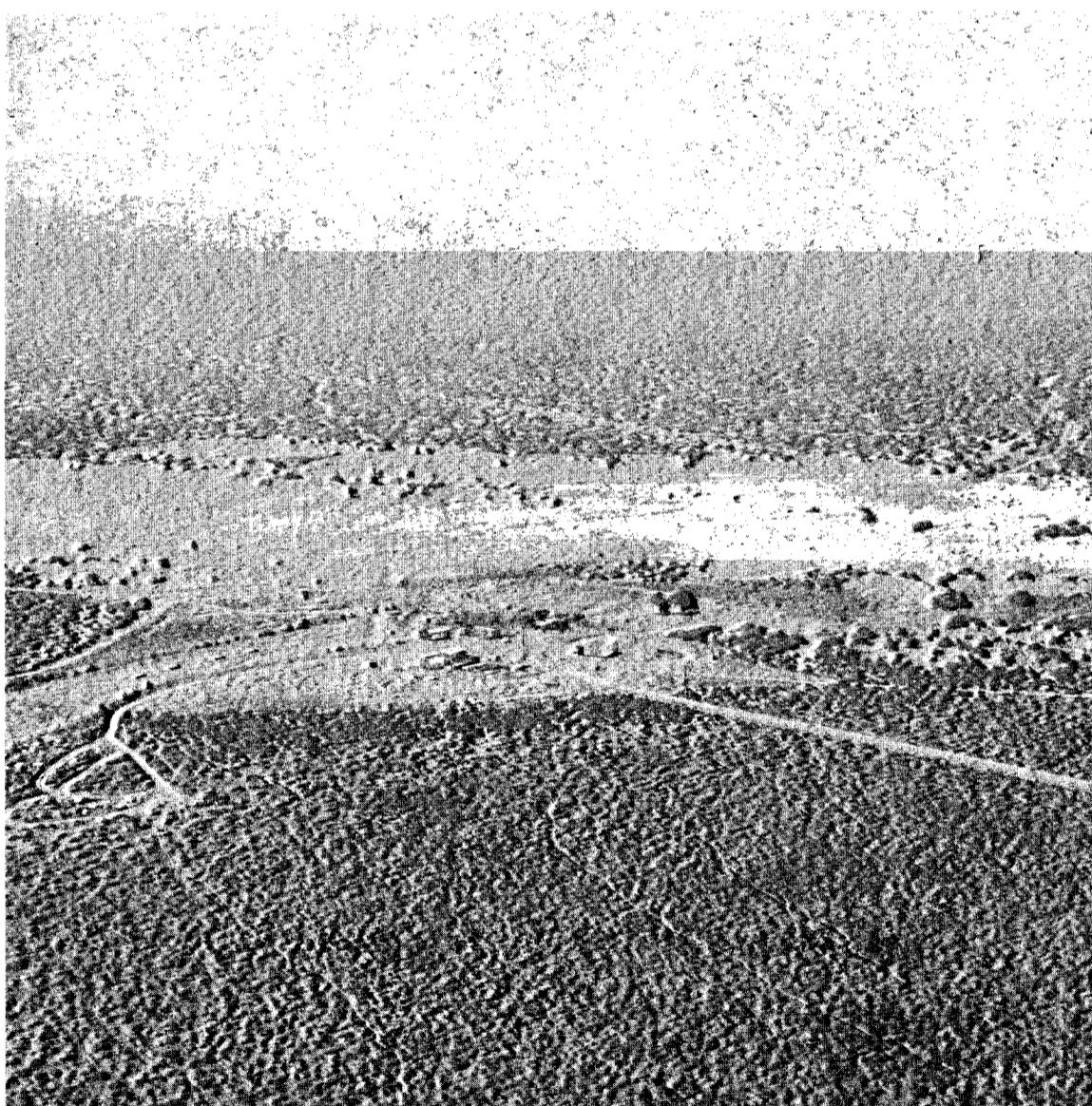
**CARLSBAD CAVERNS**

Located 22 miles southwest of Carlsbad and 40 miles west southwest from the WIPP site.



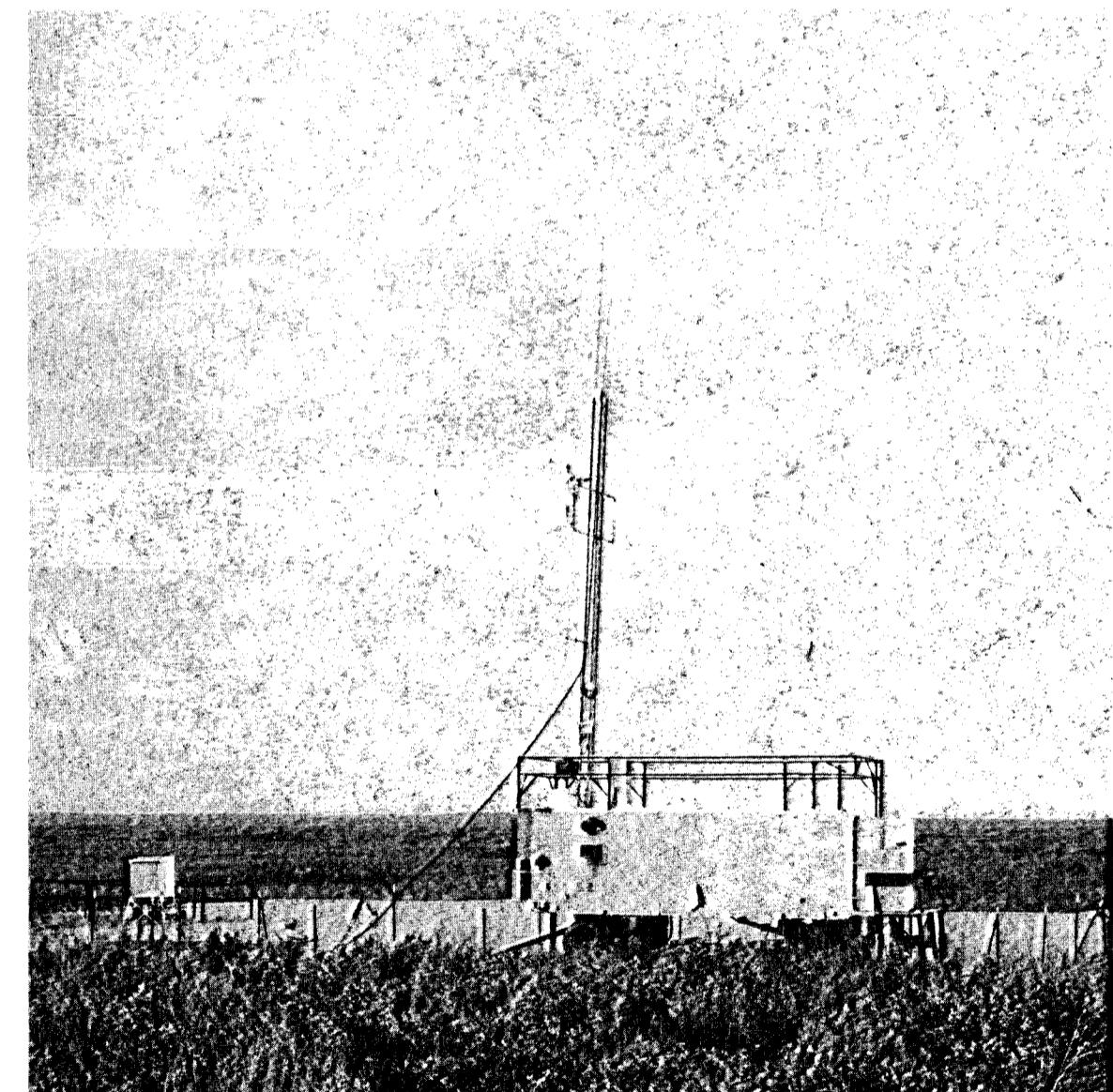
**AIR VIEW ACROSS WIPP SITE**

View is to the northwest. Drilling rigs working on ERDA No. 9 (in upper right) and H-1 (far left).



**JAMES RANCH HEADQUARTERS**

Located 3 miles south of the site. Note active sand dunes. View is to the southeast.



**TEMPORARY METEOROLOGICAL STATION**

This station was located at AEC No. 7 drill location. A new station has been erected within the WIPP site area. Vegetation in foreground is typical of the area.

**FIGURE 33**  
**GENERAL FEATURES**



**Sandia Laboratories**