Supplemental road log 1: From Pierce Canyon (First day Stop 6) to New Mexico Highway 31/128 junction north of Salt Lake, via Mescalero Plain, Los Medanos (WIPP) and Nash Draw

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SUPPLEMENTAL ROAD LOG 1, FROM PIERCE CANYON (FIRST DAY STOP 6) TO NEW MEXICO HIGHWAY 31/128 JUNCTION NORTH OF SALT LAKE, VIA MESCALERO PLAIN, LOS MEDANOS (WIPP) AND NASH DRAW

JOHN W. HAWLEY and DAVID W. LOVE

SUMMARY

This 30-mi trip covers an alternative route from First Day Stop 6 at Pierce Canyon to the Potash Enclave via the Mescalero Plains area east of the Pecos Valley and Nash Draw. It rejoins the main tour route at mi 165.5 at the northwest edge of the Laguna Grande de la Sal (Salt Lake) basin. Highlights include overviews of the Gnome and WIPP project areas and a transect across the playa-lake plain near the southern end of Nash Draw. The road log includes a brief discussion of the late Cenozoic geomorphic evolution of the southern Mescalero Plain, a mini-paper overview of late-stage Permian history and two minipapers on WIPP project monitoring by the New Mexico Environmental Department and Environmental Evaluation Group. Environmental concerns related to the 1961 Gnome underground nuclear detonation and modern (1992) earthquake activity are also briefly discussed. This log supplements the field trip guidebook to the northern Delaware Basin-WIPP site area prepared for the 1990 Annual Meeting of the Geological Society of America (Powers et al., 1990; Powers and Martin, 1990).

Mileage

0.0 Begin at First Day Stop 6 (mi 144.9) at Pierce Canyon overlook. Continue east on McDonald Road (Eddy-746). **0.1**

0.1 Sharp bend to left down slope. **0.2**

0.3 Curve to right. Gatulia "red beds" exposed in ditch to right. **0.1**

0.4 Cattle guard. **0.7**

1.1 Crossing small pipeline. Trail to right provides access to middle segment of Pierce Canyon and thick section of ancestral Pecos channel gravels in upper part of "Gatuna Formation" (Bachman, 1984, p. 17-19). **1.1**

2.2 Eddy-746A to left; continue straight (southeast) on Eddy-746. **0.2**

2.4 Trail to right leads to upper Pierce Canyon area where thickest section of lower, finer-grained part of the "Gatuna" is exposed (Powers, this volume). At a few sites, upper Rustler beds crop out at the base of the section. **0.8**

3.2 Dip in road; crossing upper end of Pierce Canyon. **0.3**

3.5 Pipeline crossing. **0.2**

3.7 Junction. Continue straight (southeast). Road to right provides access to divide area between Pierce and Cedar Canyons. **0.7**

4.4 Curve to left (east). Anderson (1981, fig. 4) and Bachman (1984, figs. 10, 13) have described a major solution-subsidence depression resulting from large-scale dissolution of the Salado and Rustler Formations (and parts of the Castile) in the "Poker Lake" area about 2 mi to the south of this point. This feature was first mapped by Maley and Huffington (1953). "Gaturia-age" fill in this south-southeast-trending trough ranges from about 500 to 1100 ft thick according to Bachman (1984) and represents (at least partly) the paleochannel complex of the ancestral Pecos. The channel trend intersects Pierce Canyon near mi 1.1 on this supplemental log (see discussions at mi 97.1 and Stop 6, First-Day Log). **0.4**

4.8 Drill hole to left. **0.5**

5.3 Cattle guard. Route ahead curves right (east) and follows upper reach of Pierce Canyon Draw (to left). **1.1**

6.4 Cattle guard; crossing eastern "rim" of Pecos Valley and ascending to western edge of the Mescalero Plain. At an elevation of 3340 ft, the Plain is here about 550 ft above the Pecos River at Pierce Canyon Crossing (First Day, mi 143). **0.8**

7.2 Junction of McDonald Road (Eddy-746) with Twin Wells Road (Eddy-787). **Turn left (north)** on Twin Wells Road. Large playa lake depression on Mescalero Plain to right. Big Sinks depression located about 4 mi to the southeast is at the northeastern edge of the large solution-subsidence depression described at mi 4.4 (Anderson, 1981, fig. 4). **1.1**

8.3 Curve to right (northeast) at cattle guard. Windmill to left. **1.0**

9.3 Pit to left in "Mescalero caliche" (an informal, "mid-Pleistocene" soil-stratigraphic unit of Bachman, 1976, 1980). **1.2**

10.5 Small playa lake to left is designated Poker Lake on NM Highway Department Map of Eddy County. This is not the "Poker Lake" site described at mi 4.4, which is about 7 mi southwest of this point. **1.0**

11.5 Ranch to right. Prepare for sharp left turn ahead. **0.1**

11.6 **Turn left** at junction and continue north on Eddy-787 (Twin Wells Road). Route crosses saddle in broad ridge (summit elevation about 3550 ft) that rises about 200 ft above the general level of the Mescalero Plain in this area. The ridge, which appears to be formed on Dewey Lake (Quartermaster) Formation with a thin eolian and calcrete veneer, terminates 3 mi northwest of this point at "Centinela Mound." It may be part of a geomorphic surface that is significantly older than the "segment" of the Mescalero Plain on which the WIPP site is located (about 10 mi north). **0.4**

12.0 Pedogenic calcrete, about 6 ft thick with stage V morphology (Hawley, First-Day Road Log minipaper), in caliche pit to right at north edge of ridge. There is a trace of siliceous pebbles in the sandy calcrete matrix and Dewey Lake red beds are poorly exposed in the pit floor below the calcrete zone. **0.7**

12.7 Cattle guard. Dewey Lake in shallow borrow pit ahead on left. **0.8**

13.5 Entering natural gas production area with active drilling in January 1993. Small Bone Spring production (Ingle Wells Field—secs. 31 and 32, T23S, R31E) from a depth of 9300 ft is 7.2 MMCFG, with 2696 bbls oil and 552 bbls water. In the Sand Dunes West field to the northeast (secs. 28, 29, 32, 33), cumulative Morrow production at 14,000 ft is almost 12 BCFG, with 714 bbls condensate and 38,474 bbls water. Production figures from the Delaware at 7900 ft in the same area (1992 discovery) are not yet available. **0.4**

13.9 **STOP 1** at cattle guard. Enter Nash Draw Quadrangle, the only area of detailed geologic quadrangle mapping (15 and 7.5 min) in the New Mexico part of the Delaware Basin (Vine, 1963; Bachman, 1981). Much of this work relates to site characterization for the Gnome and Waste Isolation Pilot Plant (WIPP) projects. The site of the Project Gnome underground nuclear detonation in 1961 is located on the Mescalero Plain about 3 mi west of this point (Gard, 1968). The general geologic setting of the Gnome site is illustrated on Figs. S-1.1 and S-1.2; the stratigraphic summary of rocks exposed in the Gnome shaft is shown in Table S-1.1 and Fig. S-1.3). According to Gard (1968, p. 1-2):

> Project Gnome was a multiple objective experiment conducted by the U.S. Atomic Energy Commission as part of the Plowshare Program to develop peaceful uses for nuclear explosives. Gnome was the first nuclear detonation within the continental limits of the United States outside of the Nevada Test Site since the Trinity shot in 1945.
>
> The Project Gnome experiment consisted of the detonation of a nuclear device of about 3 kilotons equivalent TNT yield at a depth of about 1200 ft below the surface in a thick salt deposit. The Gnome site is in the Nash Draw quadrangle in the approximate center of sec. 34, T23S, R30E, in Eddy County .. .

The objectives of the experiment were fivefold (U.S. Atomic Energy Commission, 1961):

1. To explore the feasibility of converting the energy from a nuclear explosion into heat for the production of electric power.
2. To investigate the practicality of recovering useful radioisotopes for scientific and industrial applications.

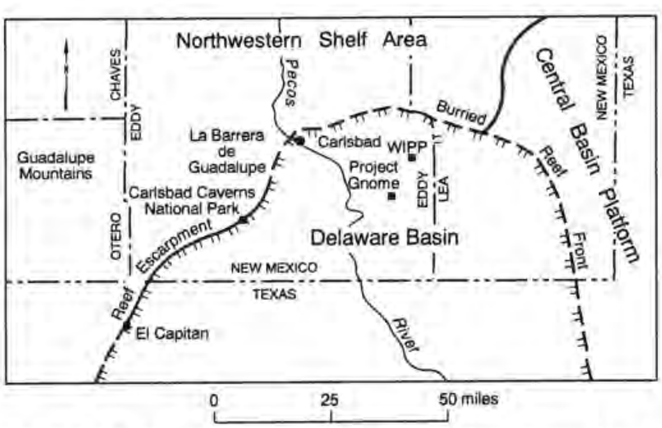

FIGURE S-1.1. Project Gnome area of southeastern New Mexico. Modified from Gard (1968, fig. 2).

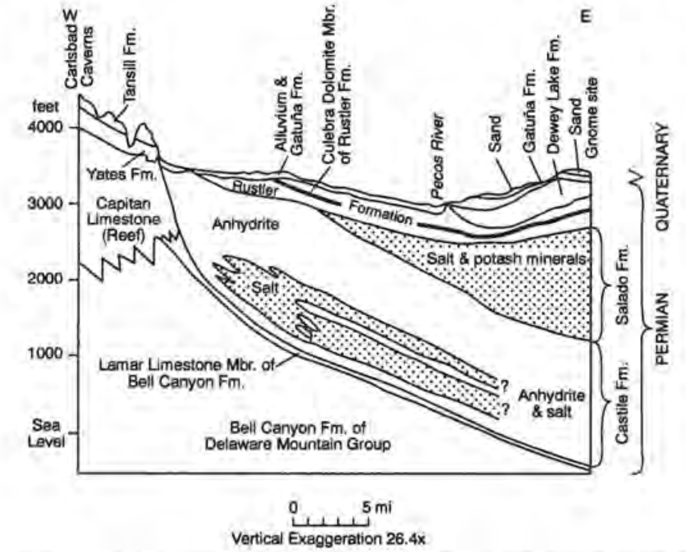

FIGURE S-1.2. Geologic section between Carlsbad Caverns National Park and Project Gnome site. Modified from Gard (1968, fig. 4).

TABLE S-1.1. Generalized description of rocks exposed in the Gnome shaft. Modified from Gard (1968, table 1).

Age	Unit	Lithology	Depth below surface (feet)	Thickness (feet)
Quaternary	Alluvial & eolian deposits	Unconsolidated sand	0-43	43.0
Pleistocene(?)	Gatuña Formation	Friable sandstone & conglomerate	43-91.9	48.9
Late Permian	Dewey Lake Redbeds	Thin bedded siltstone	91.9-294	202.1
	Rustler Formation:			
	Forty-niner Member	Chiefly gypsum & anhydrite	294-361.3	67.3
	Magenta Member	Silty dolomite	361.3-382.2	20.9
	Tamarisk Member	Chiefly anhydrite & gypsum	382.2-495.5	113.3
	Culebra Dolomite Mbr.	Dolomite	495.5-523.5	28.0
	Lower member	Chiefly clay & silt, with some gypsum & anhydrite	523.5-651.2	127.7
	Salado Formation:			
	Leached member	Chiefly claystone & siltstone	651.2-709.3	58.1
	Unleached part	Chiefly impure halite rock, with some anhydrite, polyhalite, & siltstone	709.3-1, 202	492.7
	(Bottom of shaft)			

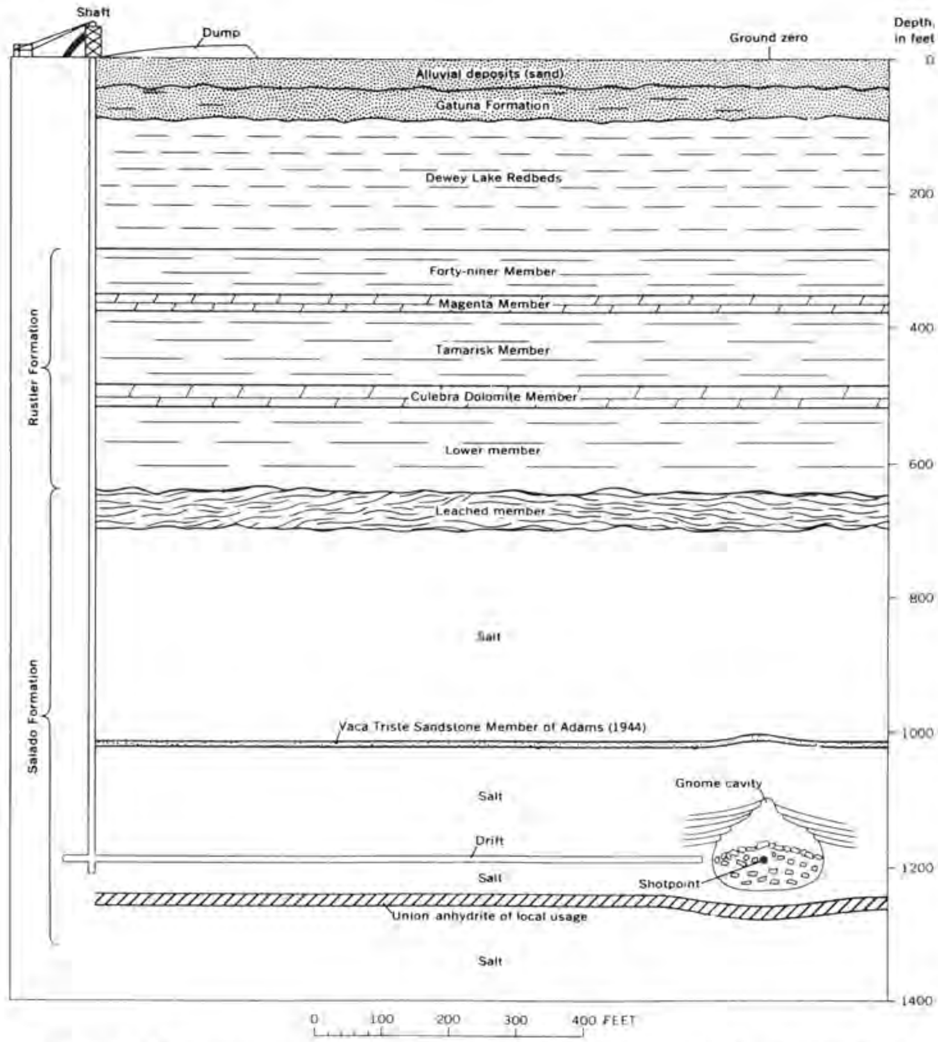

FIGURE S-1.3. Geologic section between shaft and cavity, Project Gnome site (Gard, 1968, fig. 5).

3. To expand the data on characteristics of underground nuclear detonations to a new medium (salt), which differs markedly from the test media of the Nevada Test Site in which previous underground shots had been fired.
4. To make neutron cross section measurements to contribute generally to scientific knowledge and to the reactor-development program.
5. To provide scientific and technical information on design principles useful in developing nuclear-explosive devices specifically for peaceful purposes.

Ground surface elevation at the top of the shaft is about 3400 ft. There is about 220 ft of relief between the surface of the Dewey Lake red beds exposed in the pit at mi 12 (elevation 3530 ft) and the "Gatufia–Dewey Lake" contact in the Gnome shaft (elevation .–-3310 ft). Since only 202 ft of the Dewey Lake occurs below this unconformity at the Gnome site and the complete section of the formation in the Nash Draw area is about 500 ft thick (Bachman, 1981), it appears that much of this relief could be due to late Cenozoic erosion. However, ongoing work for the WIPP project by Powers and associates suggests that this scale of relief on Dewey Lake surfaces could also be the result of draping over solution-subsidence features in the Rustler/upper Salado sequence (Dennis Powers, personal comm., April 1993). Current environmental monitoring activities related to this experiment are discussed by Sanchez, in a minipaper below. 1.9

15.8 Windmill to right. Route for next 1.4 mi is along the eastern edge of the "Los Medarios" field of active and stable sand dunes (Bachman, 1976, 1981). Gard (1968, p. 24) described about 31 ft of post-Gaturia "alluvial bolson deposits (sand)" capped with a 3-ft caliche zone at the southwest edge of the dune field in the Gnome shaft 3.5 mi southwest of this point. The "bolson deposits" probably correlate with the upper part of the Gatufia Formation as mapped by Bachman in the Nash Draw area. 0.3

16.1 Cattle guard. Active gas well drilling in this area in January 1993 has been stimulated by federal land withdrawal actions related to the WIPP project. Cumulative Atoka production (Sand Dunes West field—secs. 7-9, 16-18, T23S, R31E) from a depth 13,850 ft is 4.07 BCFG, with 928 bbls condensate and 71,948 bbls water. 0.9

17.0 Stop sign ahead. **Park on right** south of junction with Jal Highway (NM-128). **0.1**

17.2 **STOP 2.** Overview of WIPP Site area. Jal Highway, both to the east and west, crosses a broad segment of the Mescalero Plain that includes at least one outlier of the Ogallala Formation and an associated remnant of the late Miocene High Plains surface at "The Divide," which is located about 9 mi northeast of this point. Except for the dune fields and areas around several small solution-subsidence depressions, the local landscape has not been affected by significant erosion or sedimentation since deposition of the uppermost Gatufia Formation and initial development of the youngest part of the "Mescalero caliche" at least 0.5 Ma. In terms of surface-geomorphic stability, this upland plain, which includes the WIPP Site (5 mi to north), is one of the most stable parts of the continent. Only the Llano Estacado, with hundreds of square miles of relict or slightly buried late Miocene surfaces, is significantly more stable (see Hawley, Fig. 1.1, First-Day Road Log).

In marked contrast with these observations, is the extreme geomorphic instability of the Nash Draw and San Simon Swale areas that flank this segment of the Mescalero Plain. Nash Draw basin adjacent to the Pecos Valley is part of this tour's itinerary (mi 22.3). San Simon Swale, located about 18 mi to the east, overlies the Capitan reef trend at the western margin of the Central Basin Platform and is flanked on the northeast by a large outlier of the Llano Estacado. San Simon Sink near the Swale's southern end is a large (1 mi diameter), historically active collapse feature that appears to be the surface expression of a breccia pipe rooted in cavernous voids in the Capitan reef zone (Nicholson and Clebsch, 1961; Anderson, 1981, fig. 4; Johnson, this volume; First Day Stop 7 discussion). Bell Lake Sink (about 14 mi east of this point) is a possible deep-rooted feature also recognized by Nicholson and Clebsch (1961, p. 46) that is basinward from the reef trend on the Mescalero Plain. Hill (this volume) discusses sulfate mineralization and aspects of isotope geochemistry of "sink" deposits.

Environmental and engineering geology issues related to the establishment of WIPP are discussed by Chaturvedi and Corbet and Wallace (this volume); and in the following minipapers (Holt and Powers, Kenney and Sanchez). Additional information on WIPP site geological investigations is presented by Powers et al. (1990).

SUMMARY OF DELAWARE BASIN END-STAGE DEPOSITS

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The Salado, Rustler and Dewey Lake Formations record the end-stage depositional history of the Delaware Basin. After the Delaware Basin became isolated from marine environments at the beginning of the Ochoan Epoch, a unique series of depositional environments produced one of thickest, uninterrupted records of deposition in the world. As the deep evaporitic lagoons that deposited the Castile Formation became hydrologically isolated from marine waters, solutes and sediments were derived from terrigenous sources outside the basin and Salado salt pan and related environments developed. Salado sediments completely filled the basin and extended over the Central Basin Platform and the Northwestern Shelf. Both minor eustatic fluctuations and intermittent meteoric events inundated the basin, producing shallow saline lagoons that deposited sulfate and ultimately evaporated to halite saturation. During Salado and Rustler time, a cyclical pattern of flooding followed by desiccation to evaporitic conditions, subaerial exposure and syndepositional alteration produced a series of characteristic environments and lithofacies. This pattern was broken by middle Dewey Lake time as low-energy fluvial environments dominated sedimentation.

The following discussion summarizes our understanding of the sedimentology and depositional history of the Salado, Rustler and Dewey Lake Formations. It is a short synthesis of nearly ten years of investigation related to the Waste Isolation Pilot Plant (WIPP) site and is based upon the geologic mapping of three WIPP shafts, outcrop investigations, descriptions from numerous cores and the interpretation of over 700 geophysical logs.

The Salado Formation of southeastern New Mexico and west Texas is the middle of three Ochoan evaporite-bearing formations in the Delaware Basin (Castile, Salado and Rustler). It consists of halite, anhydrite and polyhalite with varying amounts of other potassium-bearing minerals. About 85 to 90% of the Salado consists of halite (Jones, 1973). Beds of anhydrite and polyhalite alternate with thicker beds of halite throughout the Salado section. The Salado consists of nearly 600 m of evaporites in the subsurface of the eastern part of the Delaware Basin and only a few meters of brecciated insoluble material at outcrops in the western part of the basin. The Salado is subdivided informally into an unnamed upper member, a middle member locally designated the McNutt potash zone, and an unnamed lower member. Individual beds within the Salado are often traceable for large distances. These aerially persistent beds allow the middle and upper Salado to be subdivided on a much finer scale. A system of numbering aerially extensive beds of anhydrite and polyhalite as markerbeds was introduced by geologists of the U.S. Geological Survey (Jones et al., 1960). The markerbed system is used extensively by mining companies in the Carlsbad potash district and by researchers at the WIPP for smaller-scale stratigraphic control (Barker and Austin, this volume).

Cyclicity within the Salado was first described by Schaller and Henderson (1932) as the vertical succession of clay-anhydrite-polyhalite-halite and minor amounts of polyhalite-halite. Jones (1954, 1972) reported cyclical units consisting of clay-magnesite-anhydrite, polyhalite or glauberite-halite-argillaceous halite capped with mudstone. Lowenstein (1988) recognized two types of depositional cycles within the Salado. His Type I cycle consists of (1) a basal mixed siliciclastic and carbonate (magnesite) mudstone, (2) laminated to massive anhydritepolyhalite, (3) halite and (4) halite with mud. His Type II cycle was an incomplete version of a Type I cycle consisting of halite grading to muddy halite. Lowenstein (1988) interpreted these cycles to represent a deposition in a shallowing upward, desiccating basin. Holt and Powers (1990a) observed little textural difference between halite sequences overlying sulfate interbeds or other halite sequences and documented subaerial exposure on the tops of sulfate interbeds and halite sequences. On this basis, they separated halite sequences from underlying units and recognized only one cyclical pattern in Salado halites consisting of four lithofacies, which include from the base upward: stratified mud-poor halite, podular muddy halite, dilated mud-rich halite and halitic mudstone.

Holt and Powers (unpublished report to the U.S. Dept. of Energy, 1990) described three types of sulfate interbeds produced in saline lagoons of different origin. Very shallow saline lagoons produced by hydrologically isolated low-volume floods deposited thin, isolated sulfate interbeds. Frequent, hydrologically related, low-volume floods repeatedly produced shallow, saline lagoons which quickly reached halite saturation. These lagoons deposited multiple thin sulfate interbeds separated by interbeds of halite with little or no subaerial exposure. Major eustatic changes produced and maintained large-volume, saline lagoon conditions allowing the accumulation of thick sulfate sequences.

The Rustler Formation is the youngest of three Ochoan evaporite-bearing formations in the Delaware Basin and is characterized by a variable lithology consisting of interbedded sulfates, carbonates, elastics and halite (Powers and Holt, 1984, 1990; Holt, 1988; Holt and

Powers, 1986, 1987). The Rustler varies in thickness from a few meters, where exposed and subjected to solution and erosion, to nearly 170 m in the northeastern part of the Delaware Basin. The western margin of the Rustler has been removed by erosion. The Rustler crops out along the Pecos River Valley, within Nash Draw and in an arcuate pattern near the southwestern edge of the Delaware Basin. Where Salado dissolution is extensive, the Rustler has been extensively altered by near-surface ground water. Outcrops of the Rustler are poor at best. Solution and/or hydration of the soluble rocks within the Rustler and frequently the solution of halite from the underlying Salado Formation, extensively modify and disrupt the Rustler. Rustler units may be displaced from their expected position. Where dissolution of the underlying Salado is complete, Rustler outcrops may consist only of broken blocks of less soluble rocks. The upper contact of the Rustler with the Dewey Lake Redbeds has been reported as conformable (e.g., Holt and Powers, unpublished report to the U.S. Department of Energy, 1990). Within the shafts of the WIPP site, Holt and Powers (unpubl. reports to the U.S. Department of Energy, 1984, 1986, 1990) report local minor erosional relief on the contact.

The Rustler is subdivided into five members (Fig. S-1.4): an unnamed lower member, the Culebra Dolomite Member, the Tamarisk Member, the Magenta Dolomite Member and the Forty-Niner Member (Vine, 1963). The unnamed lower member, 40 m thick, consists of elastic sediments with subordinated halite, anhydrite and polyhalite. Near the WIPP site, the Culebra, 8 m thick, is the principal water-bearing unit of the Rustler (Beauheim and Holt, 1990; Corbet and Wallace, this volume). It is a brown, finely crystalline, argillaceous to arenaceous gypsiferous dolomite with vugs that commonly are filled with gypsum and/or anhydrite. The upper zone contains organic-rich claystone and carbonate. The Tamarisk contains upper and lower anhydrites separated by claystone or thicker halite and varies from 30 to 50 m around the WIPP site. The Magenta, about 7 m thick, is composed of light gray to dark brown gypsiferous and arenaceous dolomite with abundant sedimentary structures due to traction. After weathering, the Magenta assumes a purplish cast. The Forty-Niner, similar to the Tamarisk, consists of upper and lower sulfates separated by claystone or laterally equivalent and thicker halite. The member is about 18 m thick around the WIPP site. The upper contact with the Dewey Lake is sharp and conformable within the WIPP area. Holt (1988) and Powers and Holt (1990) found it convenient to use a more detailed informal stratigraphy (Fig. S-1.4).

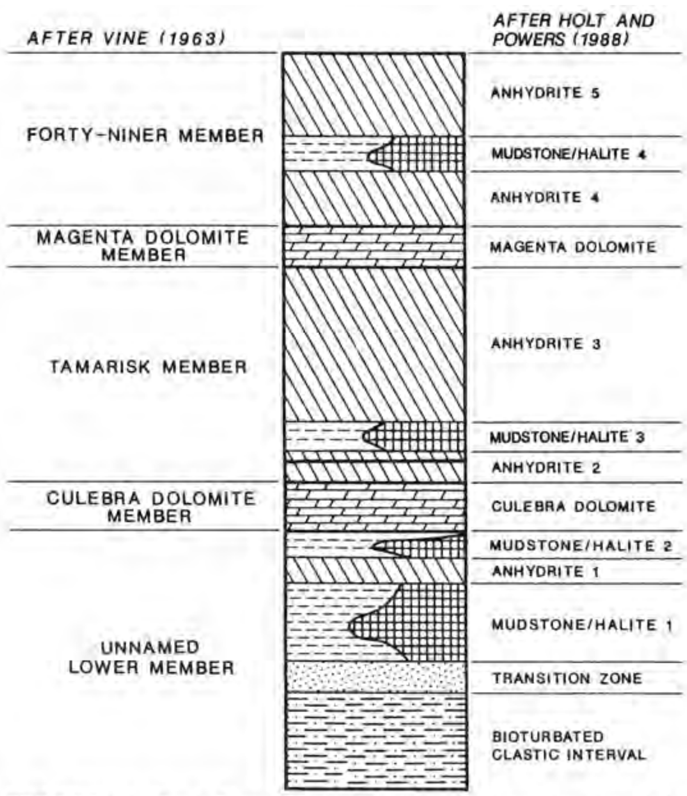

FIGURE S-1.4. Rustler Formation stratigraphic subdivisions, after Vine (1963), and Holt and Powers (unpubl. report to U.S. Dept. of Energy, 1988).

Eager (1983) related Rustler geophysical log interpretations to descriptions from a core from Culberson County, Texas and concluded that the Rustler was the depositional product of eolian, supratidal carbonate, brine pan and saline mudflat environments based upon lithologic similarities to evaporites in the Palo Duro Basin. Holt and Powers (unpubl. report to the U.S. Dept. of Energy, 1988), Holt (1988) and Powers and Holt (1990) interpreted the depositional environments of the Rustler based upon WIPP shaft descriptions, core description and the interpretation of over 600 geophysical logs. They concluded that the Rustler was the depositional product of five major transgressions followed by episodes of isolation and evaporation to mudflat and salt pan environments.

The Dewey Lake Formation is the uppermost of the four Ochoan formations in the Delaware Basin. It is assigned to the Permian, although that is not supported by local radiometric dating or fossil evidence (see Lucas and Anderson, this volume). The Dewey Lake is characterized by its reddish-orange to reddish-brown color and varying sedimentary structures. At the WIPP site, the Dewey Lake is 144 m thick and consists of interbedded reddish-brown fine-grained sandstone, siltstone, mudstone and claystone (Holt and Powers, 1990b). The Dewey Lake is distinguished from other red bed units by greenish-gray reduction spots, which are liberally sprinkled throughout the formation and by locally abundant fractures filled with fibrous gypsum. The basal contact of the overlying Santa Rosa Formation (or Dockum Group) is sharp and erosional. The lower contact of the Dewey Lake with the Rustler Formation is sharp with a minor amount of erosional relief. This contact is locally disconformable with no evidence of a regional unconformity (Holt and Powers, 1990b). The Dewey Lake thins to the northwest due to pre—Late Triassic erosion.

Miller (1955, 1966) postulated that the Dewey Lake was deposited as eolian material reworked in a shallow marine environment. Based upon the occurrence of gypsum, Hills (1972) suggested that the Dewey Lake was deposited in a playa. Using outcrop data from the northern part of Nash Draw, Schiel (1988) interpreted the depositional environments much differently. Schiel (1988) observed fluvial architecture consisting of vertically stacked, laterally interfingering, broad, winged channels filled with thin horizontal laminations and interpreted the depositional environment of the Dewey Lake to be a fine-grained, ephemeral, fluvial system. Holt and Powers (1990b) divided the Dewey Lake into a lower and upper sequence. The lower sequence (28 m thick at the WIPP) is depositionally continuous with the Rustler and reflects accumulation in mudflat and saline mudflat environments and the upper sequence (116 m thick at the WIPP) displays fluvial features consistent with Schiel's (1988) interpretation.

Carbonate sedimentology. While only minor amounts of carbonate rocks are present near the base of sulfate interbeds in the Salado, the Rustler contains two, thicker, aerially persistent carbonate units, the Culebra and Magenta (Powers and Holt, 1990, 1984; Holt, 1988; Holt and Powers, 1987, 1986). The Culebra consists of laminated dolomicrite containing gypsum-replaced bivalve fragments, pelletal textures, burrows, cryptalgal layering and stromatolites. Culebra sedimentary structures reflect deposition in an upward shallowing, carbonate lagoon. Salinities were initially near marine and increased to gypsum saturation with time. The Magenta is an arenaceous, gypsiferous dolomite that displays abundant cross-laminae, ripple-drift cross-laminae and wavey and lenticular bedding suggesting accumulation in a subtidal to shallow energetic lagoonal environment.

Sulfate sedimentology. Sedimentary structures and textures within Salado and Rustler sulfate interbeds developed during subaqueous, vadose zone and phreatic zone conditions (Holt and Powers, unpubl. reports to the U.S. Dept. of Energy, 1990, 1988; Holt, 1988). Primary depositional fabrics (e.g., bottom-nucleated prismatic gypsum, reworked prismatic gypsum crystals, cryptalgal layering and algal stromatolites) reflect subaqueous accumulation. Some mechanical deformation and chemical alteration also occurred subaqueously (e.g., soft sediment deformation, collapse following solution of underlying material and replacement of sulfate). Prism cracks, weathered sulfate, tepee structures and point solution of soluble minerals developed in the vadose zone. Sulfate cements, displacive halite growth and pseudomorphous replacement of sulfate by anhydrite, polyhalite and halite occurred within the phreatic zone (sediment completely saturated with pore waters).

Halite sedimentology. Salado and Rustler halites often show unequivocal evidence of deposition and accumulation of halite under shallow subaqueous conditions (Holt and Powers, 1990a, 1991). Sedimentary structures reflect varying water-table position. Unmodified sequences of halite consist of a basal lamina of sulfate or clay, medium to coarsely crystalline halite showing chevron and cornet fluid-inclusion zoning and finally layers of finely crystalline halite. Synsedimentary dissolution in the vadose zone initially produced dissolution pits, pipes and macropores; solution lags and irregular pods and lenses of finely crystalline halite developed as dissolution progressed. In the phreatic zone, coarse-crystalline, passive and displacive, halite and bittern salt (e.g., langbeinite and sylvite) cements plugged porosity.

Clastic sedimentology. Most elastic rocks in the Salado, Rustler and lower Dewey Lake consist of mudstone, claystone, siltstone and minor amounts of sandstone. They display sedimentary structures that reflect subaqueous accumulation in mudflats and saline mudflats and deformation during vadose and phreatic conditions (Holt, 1988; Powers, et. al., 1988; Holt and Powers, 1990a, 1990b; Powers and Holt, 1984, 1990). Sedimentary structures observed include flat to contorted laminae, cross-laminae, smeared intraclast textures, rip-up clasts, dish-shaped strata, pedogenic features and prism cracks. Salado and Rustler elastics contain displacive evaporite minerals. The lowermost Rustler elastic unit (bioturbated, elastic interval) contains evidence of deposition in a marine-salinity lagoon (e.g., planar to wavey strata, cross-stratification, extensive bioturbation and preserved casts, molds and halite replacements of fossil bivalves). The upper part of the Dewey Lake consists of interbedded claystone, mudstone, siltstone and fine sandstone and shows sedimentary structures consistent with accumulation in a fine-grained, low-moderate energy, braided fluvial system.

Summary. During Salado time, shallow saline lagoons resulting from flooding/transgressive events deposited Salado gypsum, which was syndepositionally replaced by anhydrite, halite and polyhalite. Most of the lagoons were low-volume and produced thin sulfate interbeds. Algae grew on the substrate, producing algal domes and biscuits. Thicker sulfate interbeds accumulated in deeper lagoons. As many of these lagoons completely desiccated, subaerially exposed sulfate developed desiccation cracks, buckled strata and tepee structures. Early halite cements preserved delicate fenestral pores and other open porosity.

As the basin desiccated, mud-poor salt pan, "hummocky" salt pan, mud-rich salt pan and saline mud flat environments developed. Salado halite accumulated subaqueously and was altered by vadose and phreatic processes. During periods of isolation and evaporation, vadose and phreatic processes increased as marginal facies shifted basinward. Episodic floods continued this cyclical pattern of deposition until a major marine transgression over Salado salt pan deposits initiated Rustler deposition.

Five major Rustler-age marine transgressions or incursions into the Delaware Basin created lagoonal environments which were followed by episodes of isolation and evaporation in saline lagoon and halite pan to mud flat environments. This sequence of depositional environments produced several desiccating-upward sequences in the Rustler, typically consisting of elastic or carbonate rocks at the base, followed by thick sulfate interbeds and ultimately mudstone that grades laterally to halite. The final Rustler cycle includes the lower part of the Dewey Lake. Major transgressive events ceased at the beginning of the last Rustler cycle.

Upon desiccation of the final Rustler lagoon, the lower part of the Dewey Lake was deposited in saline mudflat and mudflat environments. Low-energy streams initially contributed elastic material to mudflats and ultimately dominated sedimentation. By the close of Dewey Lake deposition, fluvial environments prevailed and the Delaware Basin had ceased to be a locus of sedimentation.

ENVIRONMENTAL EVALUATION GROUP'S ENVIRONMENTAL MONITORING OF THE WIPP SITE

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The Waste Isolation Pilot Plant (WIPP) is the U.S. Department of Energy (DOE) candidate deep geological repository for the permanent disposal of transuranic (TRU) radioactive wastes generated from defense activities of the United States (DOE, 1990a). The facility is located in southeastern New Mexico near Carlsbad, NM. The WIPP was exempted from regulatory oversight by the Nuclear Regulatory Commission at its inception (Public Law 96-164). However, as a result of a 1978 contract (DE-AC04-79AL10752) between the State of New Mexico and DOE, the Environmental Evaluation Group (EEG) was established to conduct an independent technical evaluation of the WIPP project to ensure the protection of the public health and safety and the environment.

One of the basic oversight activities of EEG has been the development and operation of an environmental surveillance network including air, water, soil and biota monitoring (Fig. S-1.5, Table S-1.2; Spiegler, 1984). A qualified environmental air monitoring network at regional and WIPP perimeter sites was completed in 1985. Sampling and analysis of brine from WIPP observation wells, surface water in the vicinity of the facility, and drinking water supplied to nearby communities also began in 1985. Soil and biota sampling programs began in 1986. Data collected by this network between 1985 and 1991 is analyzed in four EEG environmental data reports (Kenney et al., 1990; Kenney and Ballard, 1990; Kenney, 1991, 1992).

Contact handled TRU (CH-TRU) waste will be shipped to WIPP in specially designed Type B (double-contained) shipping containers known as Transuranic Waste Package Transporters, or TRUPACT II. Each tractor-trailer will carry three TRUPACT Its each containing 14 drums of TRU waste. These trucks will follow specially designated routes from the DOE facilities across the U.S. to WIPP (DOE, 1990a). These routes will result in a converging flow of highway shipments through communities surrounding the WIPP site. Although the expected number of highway accidents involving TRUPACTs over the life of the project is small (approximately five) and only one is expected to be of sufficient severity to result in a release of radioactivity from the package, these accidents are most likely to occur in the vicinity of Roswell, Carlsbad and Artesia, where the shipments converge (Gallegos and Channel!, 1990). The most significant pathway of exposure to transuranics accidentally released into the environment is uptake by inhalation (Dodd and Humphries, 1988). Accordingly, Artesia, Carlsbad, Hobbs and Loving have been equipped with air monitoring systems by EEG. These systems provide data on airborne radionuclide concentrations, needed to assess the consequences of transportation accidents in the communities surrounding the WIPP site, should such accidents occur. They have provided background data on radioactivity in the air at these regional sites since 1985 and will continue to supply such data after radioactive material is shipped to the WIPP site. These data are necessary to understand the preoperational radiological status of each of the regional urban areas, as well as of the site itself and the conditions that may influence natural and fallout radionuclide concentrations in the air sheds of the region.

In addition to the community air surveillance systems, EEG also operates three low volume air sampling (LVAS) systems within the WIPP site boundary. Two of these samplers are positioned in the predominate downwind direction from the underground exhaust stacks at

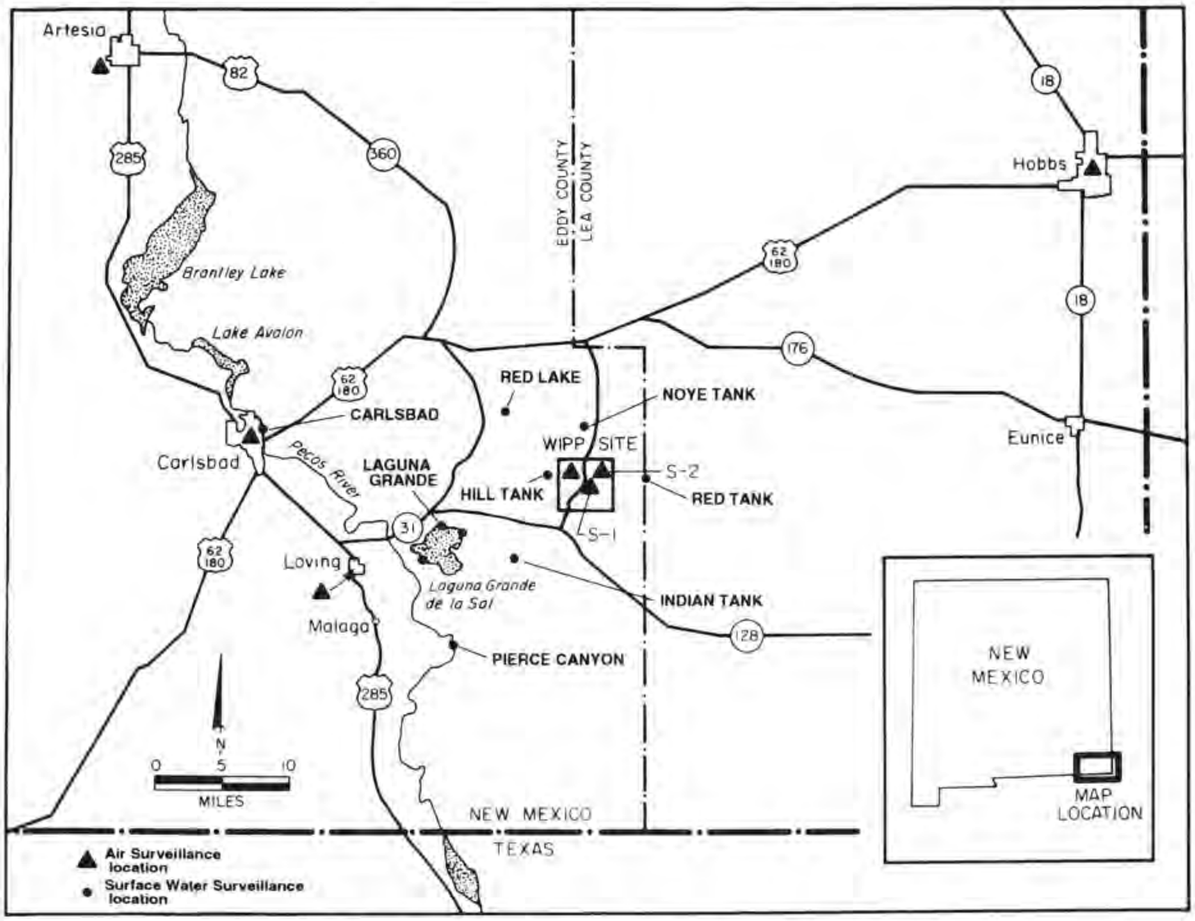

FIGURE S-1.5. Air and surface-water sampling locations, WIPP area.

WIPP. The third LVAS is located downwind of the exhaust stack during strong spring winds. Location of LVAS systems is in accordance with U.S. Environmental Protection Agency (EPA) total suspended panic-ulate sampling requirements (EPA, 1985). All LVAS continuously sample at a flow rate of 142 Um through a 102 nun glass fiber filter. Typically this produces a sample volume of 17128 m^3/quarter for each sampling location. Air flow is controlled using a pressure diaphragm regulator. Calibration of air flow is performed using a venturi air flow meter with a magnehelic gauge which, in turn, is calibrated using a Meriam laminar flow element with a calibration traceable to the U.S. National Institute of Standards and Technology. The LVAS motor, pump, regulator, elapsed time meter and exhaust system are located inside a locked weather house. The sample head containing the filter is located a minimum of 61 cm above the top of the weather house. The distance above the weather house is adequate to overcome air deflection and sample direction bias created by the weather house. The inlet for this sampler is a 360° radial design based on an inlet for a sampler for particles of 10 m diameter developed at the Particle Technology Laboratory at the University of Minnesota (Liu and Pui, 1980).

In addition to the LVAS systems, EEG also collects samples from the underground exhaust air duct at the WIPP site (known as Station A) using a fixed air sampler (FAS). The exhaust air effluent from the underground mine is not continuously filtered because of the large air flow rate required for mine safety. Provisions have been made to filter exhaust air through the high efficiency particle attenuation (HEPA) filters should a release be detected. The pressure drop across the HEPA filters is large and would result in much lower exhaust air flow rates. Hence, there is the potential for continuing, unfiltered, low-level releases of TRU material during WIPP operations. Discrete, large releases could result from an accident that occurs before the exhaust air is shifted to flow through the HEPA filters. The FAS sampler located at WIPP Station A consists of a shrouded probe located in the 4.55-m-diameter exhaust shaft approximately 6.8 m below the ground surface and supported by a vertical transport line. The shrouded probe is a sampling inlet designed and built to assure representative sampling of effluent discharges. The technical basis for the application of the shrouded probe to representative stack sampling is described by McFarland et al. (1992). The vertical transport line enters a 3—way splitter block, which supplies 56.6 1/min of air flow to three FAS sample holders collecting samples on 47 mm diameter Versipore 3000 acrylic copolymer membrane filters. Test of the shrouded probes and transport lines used at WIPP Station A and B indicated that greater than 50% of 10 m particulates were transported to the FAS filter and correspondingly larger fractions of smaller size particles (DOE, 1989a). Collection efficiencies conform to representative stack sampling design objective first proposed by EEG (Rodgers, 1987). A normal 24-hour sample period yields a sample volume of 81.5 m^3. Each quarterly composite has an average sample volume of approximately 6852 m^3. Air samples have been collected weekly from each LVAS site and screened at the EEG laboratory in Carlsbad. Each sample is desiccated and weighed to determine airborne particulate mass. Samples are then allowed to decay radioactively for a minimum of 170 hours before they are screened for gross alpha and gross beta activity. The decay period is long enough to allow short lived radon and thoron daughters to decay away before counting. Following screening, the samples at each station are stored and composited for later radioisotope-specific radiochemical assay. The radiochemical analyses are performed quarterly by an independent, commercial laboratory.

EEG measures environmental concentrations of TRU elements and naturally occurring radionuclides in surface water near the WIPP facility, ground water (brine water and fresh water), soil and biota. Observation well samples are obtained as split samples from the DOE contractor. Biota samples include crops grown in Eddy County, game

TABLE S-1.2. New Mexico Environmental Evaluation Group preoperational radiological surveillance program.

ENVIRONMENTAL MEDIUM	LOCATION	SAMPLING/ANALYSIS FREQUENCY	PARAMETER
Air	4 Off-site and 3 On-site Low Volume Air Sampler Locations	Continuously/ Quarterly Composite	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Cs-137, Sr-90, Th-228, Th-230, Th-232, Ra-226, Ra-228
Surface Water	Pecos River 2 Locations Laguna Grande de La Sal Surface Stock Tanks 5 Locations	Annually/Annually	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Tritium, Cs-137, Sr-90, Ra-226, Ra-228, U-233+234, U-235, U-238, Th-228, Th-230, Th-232
Groundwater	22 Wells	Annually/Annually	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Tritium, Cs-137, Sr-90, Ra-226, Ra-228, U-233+234, U-235, U-238, Th-228, Th-230, Th-232
Municipal Drinking Water	4 Systems	Annually/Annually	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Tritium, Cs-137, Sr-90, Ra-226, Ra-228, U-233+234, U-235, U-238, Th-228, Th-230, Th-232
Soil and Sediment	3 Sites	Annually/Annually	gross alpha, gross beta, Pu-238, Pu-239+240, Cs-137, Sr-90, U-233+234, U-235, U-238, Th-228, Th-230, Th-232
Biota	2 Specimens*	Annually/Annually	Pu-238, Pu-239+240, Am-241, Tritium, Cs-137
Facility Effluents			
Air	2 Underground Ventilation Exhaust (Stations A & B)	Continuously/ Quarterly Composite	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Cs-137, Sr-90, Th-232, Th-230, Th-228, Ra-226, Ra-228
Sewage	1 Lagoon	Semiannually	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Tritium, Cs-137, Sr-90, Ra-226, Ra-228, U-233+234, U-235, U-238, Th-228, Th-230, Th-232
Storm Water Runoff	WIPP Zone I	Annually	gross alpha, gross beta, Pu-238, Pu-239+240, Am-241, Tritium, Cs-137, Sr-90, Ra-226, Ra-228, U-233+234, U-235, U-238, Th-228, Th-230, Th-232

*Sampling performed by DOE

species collected near the site and naturally occurring flora collected near the site. Water, soil and biota are not screened but are sent to a commercial contract laboratory for radiochemical analysis.

In order to better support EEG's environmental program, EEG is developing a radiochemical laboratory in Carlsbad that will participate in the Environmental Radiation Laboratory Inter-comparison Studies Program, sponsored by EPA and in the Environmental Measurements Laboratory Quality Assessment Program, sponsored by DOE. The EEG laboratory will perform radioisotope specific analyses of various environmental media (Table S-1.2).

Since 1985 EEG has collected 2443 air samples, 202 water samples, 16 biota samples, 13 soil/sediment samples, including those received as split samples. A total of 5926 specific radionuclide analyses have been performed on these samples. EEG data are consistent with similar data reported by DOE in their annual site environmental reports for WIPP (Reith et al., 1985; Randall et al., 1988; DOE, 1989b, 1990b, 1991)

NEW MEXICO ENVIRONMENT DEPARTMENT DOE/WIPP OVERSIGHT

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The Waste Isolation Pilot Plant (WIPP) is a controversial facility in the State of New Mexico. As authorized by the United States Congress, the WIPP facility is a U.S. Department of Energy (DOE) test program to demonstrate the viability of disposing radioactive mixed transuranic "TRU" waste in a deep geologic repository. A variety of external oversight groups oversee technical and safety issues at the WIPP, including the New Mexico Environment Department (NMED). NMED is the lead agency representing the State of New Mexico at the WIPP site under a 1990 agreement with the U.S. Department of Energy (DOE). For nearly two years NMED staff have been stationed full-time onsite, involved in activities ranging from evaluating DOE/WIPP environmental monitoring systems and facility design to investigating waste generator sites. One current activity involves a review of hydrogeologic and environmental databases for WIPP-area boreholes (Fig. S-1.6).

Over the next few years, DOE and Sandia National Laboratories (SLD) will attempt to demonstrate compliance with regulations governing long-term management and disposal of hazardous and radioactive waste. Geologic and hydrogeologic unknowns include sorption and retardation characteristics of the waste at the 655-m repository level and within overlying geologic formations, long-term fluctuations in climatic and hydrologic regimes and interaction of the waste with the repository environment. The research conclusions to date are preliminary and it will take some time to evaluate long-term consequences of the WIPP project.

In the meantime, the presence of NMED staff at the WIPP site has been constructive. Staff recently concluded a review of the seismic safety of the WIPP facility following the January 2, 1992 Rattlesnake Canyon earthquake. Work on the WIPP project also enlightened staff to another legitimate environmental issue about 14 km southwest of the WIPP site, Project Gnome. For general interest, NMED contributes this brief review of the seismic event and an informational update on the decommissioned nuclear program at Project Gnome.

On January 2, 1992, a moderate earthquake (M_D = 5.0) shook the WIPP site and much of southeastern New Mexico. The earthquake was

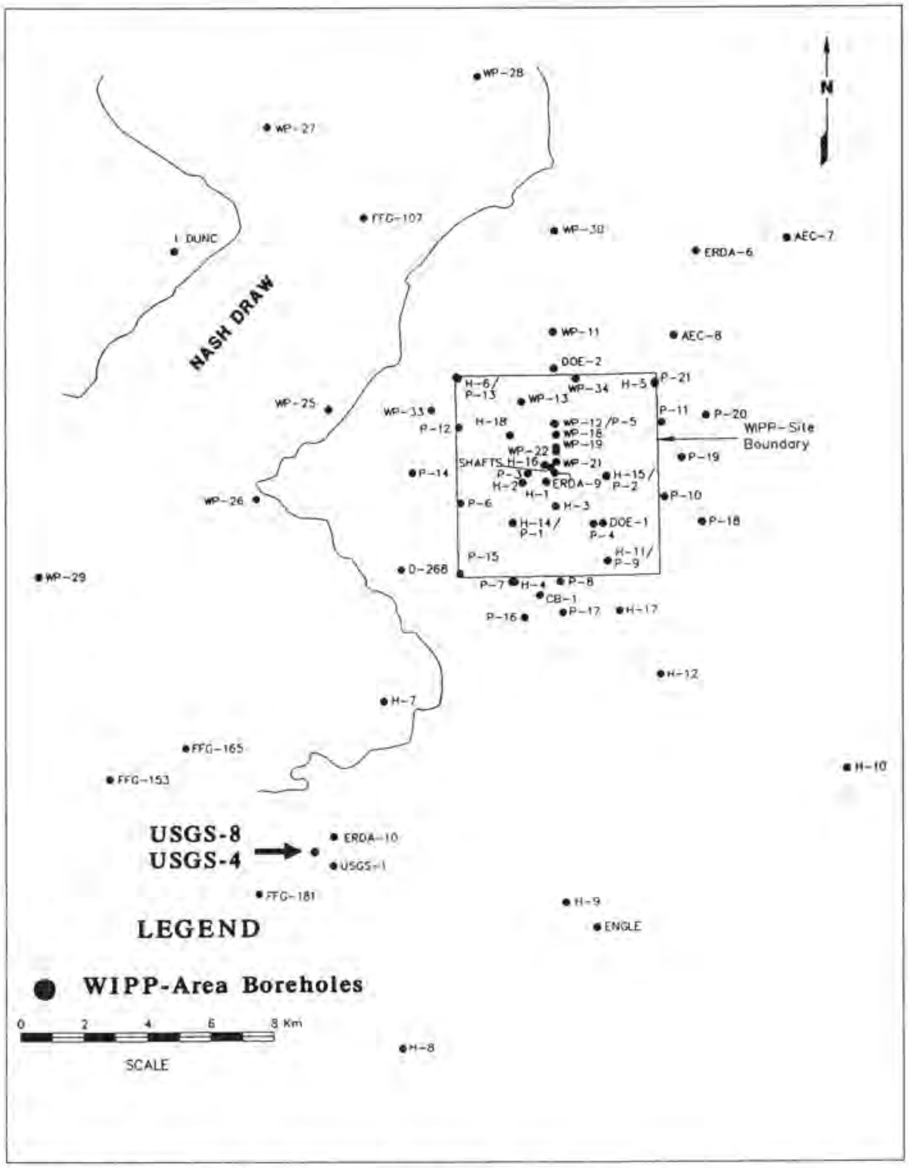


FIGURE S-1.6. WIPP area boreholes used for site characterization, hydrologic studies and environmental monitoring, after Cauffman et al. (1990).

centered approximately 60 km east-southeast of the WIPP site on the Central Basin Platform (CBP). Interposed between the Delaware and Midland Basins, the CBP is a northwest-trending, buried horst that has displayed seismicity since monitoring began in the early to mid-1960s. The CBP and Rio Grande rift were both considered potential seismic sources in the probabilistic seismic risk assessment for the WIPP facility.

NMED staff coordinated with researchers Dr. Allan Sanford of the New Mexico Institute of Mining and Technology and Dr. Diane Doser of the University of Texas at El Paso to verify the dynamics of the earthquake. Both agree that further work must be conducted to establish the cause of seismicity on the Central Basin Platform, which conventionally has been linked to secondary oil recovery operations. Notwithstanding different focal mechanism solutions (reverse vs. normal), different focal depths (assumed 5.0 km vs. 12 $\pm$ 2 km) and different epicentral locations reported, other nonseismological data are needed to establish whether the Rattlesnake Canyon earthquake was tectonic or induced by oil field operations (Sanford et al., 1993; Doser et al., in press). From a geologic perspective, several research needs are apparent in regard to the origin of seismicity of the CBP.

Several studies cite the absence of surface fault morphology as evidence that the CBP is not likely to experience an earthquake larger than magnitude 6.0 (DOE/WIPP, 1990). However, empirical relation ships between surface rupture and earthquake magnitude are developed for the western United States, an area of relatively thin crust (10-20 kin). The CBP lies close to the transitional boundary between the Basin and Range and Great Plains Provinces and crustal thickness may measure up to 40 km in eastern New Mexico (D. I. Doser, personal comm. 1993). Based on historical events in the midwest and eastern United States, large damaging earthquakes may never rupture the surface in areas of thick crust (Coppersmith, 1991).

Paleoliquefaction studies have been used to assess earthquake risk in the eastern United States (Obermier et al., 1985) and may be useful for characterizing the paleoseismicity of the CBP. The playas observed along Jal Highway (NM-128) might preserve features associated with liquefaction. Trenching the playas would also provide the dual benefit of investigating climatic changes over the last 10,000 years. Lastly, cataloging oil production and withdrawal activities during the period including the January 2, 1992 earthquake may reveal anomalous fluid pressures or sheared oil casings (A. Sanford, personal comm. 1992). In the meantime, the tectonic or induced origin for the earthquake and seismicity on the CBP remains unresolved.

On December 10, 1961, a 3.1 kiloton nuclear device was detonated 365 m underground about 7.5 km south of the Jal Highway at Mobley Ranch road. Part of the former U.S. Atomic Energy Commission Plowshare Program, "Project Gnome" was the first in a series of experiments to explore the use of nuclear detonations for peaceful purposes (see discussion, Stop 1 of this road log). Coincidentally, the Project Gnome explosion occurred in the Salado Formation, the same formation being studied at the WIPP site for long-term disposal of mixed transuranic waste. The blast opened up a hemispherical cavity up to 60 m across and approximately 23 m high in the thick, massive salt (Gard, 1968). Subsequent studies reported that the uppermost portion of Salado was raised 1.5 m and the land surface permanently domed .60 m around ground zero. Geologic mapping of the cavity revealed a number of unique blast-induced geologic structures, including radial fractures and complex thrust faults associated with intrusive breccia veins.

The hydrogeologic units in the area are analogous to those considered for the WIPP project. The closest transmissive unit to the blast occurs at the Rustler/Salado contact, where a brine aquifer flows west and southwest toward Nash Draw and southward to the Pecos River. Like the WIPP project, the Culebra Dolomite Member of the Rustler Formation is located about 60 m above the top of the salt and considered the principal aquifer at the Gnome site. The Magenta Member of the Rustler and the overlying Dewey Lake and Gatulia Formations also yield varying amounts of water to wells in the area. The U.S. Geological Survey concluded that the Culebra Dolomite "probably was not significantly ruptured by the explosion," based on long term water-level measurements indicating no leakage from or to the aquifer following the blast (Cooper and Glanzman, 1971, p. 22).

It has been over 30 years since the blast at Project Gnome. While the benefits from the project may not be apparent, the environmental implications of the project are becoming clear. As recently as July 1991 the U.S. Department of Energy, Nevada Operations Office (NVO) of Environmental Restoration and Waste Management (ERWM) announced that a significant problem involving radioactivity in the ground water and soil exists at Project Gnome (USDOE, unpubl. Site Specific Plan for NVO/ERWM, 1991). According to the document, plans are in place for remediation of the Gnome site, but the time frame for initiating and completing such action will not be finalized for some time. An interagency agreement between the State of New Mexico, the Environmental Protection Agency (EPA) and the Department of Energy (DOE) will eventually be forged to manage the remediation.

Contamination of surface soils is evident from over 3300 radiological samples collected and analyzed in a 1972-1978 Phase 1 investigation for DOE (Reynolds Electrical & Engineering Co., unpubl. report DOE/NVO/0410, 1978). Radiation levels are documented for cesium-137 at 15.8 pCi/g and strontium-90 up to 3.0 pCi/g. Both are manmade isotopes resulting from nuclear fission and only two of several isotopes produced by the project. Contamination of nonoperational areas is also reported, which is attributed to surface water run-off and atmospheric venting to the northwest of the shaft following the blast.

Four wells in the vicinity of the Gnome site are also contaminated: D-1, LRL-7, USGS-4 and USGS-8 (Fig. S-1.6). Completed in the Salado Formation, wells DD-1 and LRL-7 were contaminated during an initial decontamination and decommissioning process. USGS-4 and USGS-8 were intentionally contaminated for a tracer experiment to study adsorption reactions of radionuclides introduced into the Culebra. The tracer consisted of a mixture of tritiated water (20 curies), iodine-131 (4.0 curies), strontium-90 (10 curies) and cesium-137 (10 curies). Recent analytical results for the wells are compiled in Table S-1.3 (EPA, 1990).

The EPA Environmental Monitoring Systems Laboratory (Las Vegas, Nevada) has taken ground water samples and released reports annually for the Gnome site since 1972. The EPA "Long-term Hydrological Monitoring Program" for the Gnome site, however, is not required to assess the possible movement or transport of contaminants away from the site. The only present migration indicator is based on well USGS-1, located about 490 m southeast of USGS-4 and USGS-8 and 460 m southwest of DD-1 and LRL-7 (Fig. S-1.6). Currently utilized by local ranchers, USGS-1 is sampled annually but has not yet revealed any contamination. Cooper and Glanzman (1971) reported, however, that ground water flow in the Culebra is generally to the southwest at about 0.15 m/day, suggesting migration from USGS-4 and USGS-8 is completely unmonitored. Undertaking a more comprehensive monitoring program seems prudent and could have applications to contaminant transport models being developed for the WIPP project.

TABLE S-1.3. EPA Project Gnome analytical results for man-made radionuclides, calendar year 1990 (pCi/l = picocuries per liter).

Sampling Location	Radionuclide	Concentration (pCi/l)
Well USGS-8	^{137}Cs	6.4×10^1
	^{3}H	1.2×10^3
Well USGS-4	^{3}H	1.5×10^3
Well LRL-7	^{137}Cs	1.8×10^2
	^{3}H	1.4×10^4
Well DD-1	^{137}Cs	7.9×10^3
	^{3}H	2.8×10^7
	^{238}Pu	5.4×10^{-2}
	$^{239+240}$Pu	1.1×10^0
	^{90}Sr	8.2×10^3
	^{40}K	7.6×10^3

17.2 Stop sign at junction of Eddy-787 with Jal Highway (NM-128). **Turn left** and continue northwest on NM-128. Route for next 1.9 mi crosses the Los Medatios (dune) field. 0.5

17.7 Milepost 12. Large transverse dune ridges of the most active part of the Los Medatios field about 1 mi to north (1:00-2:00). **1.4**

19.1 Dip; road curves left. Small outcrop of Dewey Lake (Quartermaster) Formation in gully to left. **0.3**

19.4 Junction with Eddy-802 to right. Continue west on NM-128. **Caution!** Very heavy traffic on route ahead in early mornings and late afternoons. Surface facilities for the Waste Isolation Pilot Plant Project are located 4 mi to the northeast on Eddy-802. **0.3**

19.7 Milepost 10. Crossing western border of Mescalero Plain for next 2 mi. Stage IV-V calcrete (Mescalero caliche) is here developed on a pebbly sand Gaturia veneer that is unconformable on lower Dewey Lake red beds (Bachman, 1981). In this area the plain is about 300 ft above the floor of Nash Draw 5 mi to the west (2950-2980 ft). **1.6**

21.3 Cimarron Road (Eddy-796) to right, provides access to central and northern Nash Draw. While mapping Nash Draw NE Quadrangle in 1978-1979, R. E. Kelley and G. **0.** Bachman discovered a deposit of Lava Creek B volcanic ash in uppermost Gaturia beds below the "Mescalero caliche" in the NW'/4 sec. 29, T21S, R31E (about 9 mi to the NNE; Bachman, 1981). This tephra unit is derived from the last major eruption of the Yellowstone volcanic center about 0.6 Ma (Izett and Wilcox, 1982). The presence of the ash confirms a tentative correlation made by Hawley et al. (1976) between the youngest part of the Gatufia Formation with uppermost Santa Fe beds (Camp Rice Formation) in the Rio Grande Valley near Las Cruces (Hawley, this volume, fig. 2). **0.6**

21.9 Nash Draw Vegetative Study Area to right. Complex of active collapse sinks in area of low hills and shallow basins south of highway is formed in the upper part of the Rustler Formation (Bachman, 1981). **0.4**

22.3 Mobley Ranch Road to left (Eddy-795) leads to Gnome site (5 mi to south). The route descends into Nash Draw on a downwarped surface capped by "Mescalero caliche." Thin, uppermost Gatufia sands with scattered siliceous pebbles are completely engulfed by pedogenic carbonate (stage IV-V) and unconformably overlie the upper Rustler Formation. **0.4**

22.7 Milepost 7. Nash Draw Road (Eddy-794) to right. Nash Draw (potash) mine of Western Ag Minerals is located 1.5 mi to north. Route ahead descends to floor of southern Nash Draw (basin) across distal part of "Mescalero caliche"-capped slope. Younger alluvial and colluvial deposits form a discontinuous veneer on the Tamarisk Member (middle gypsiferous unit) of the Rustler Formation in gullied areas to right (Bachman, 1981). **1.0**

23.7 Milepost 6. **STOP 3.** Route ahead on apron of gypsiferous, upper Quaternary alluvial and eolian deposits, with a gypsic-soil crust, that fringes the (partly flooded) playa lake plain at the southern end of Nash Draw. This large solution-subsidence basin was mapped in detail by Bachman (1981). Much of the basin floor is a gypsum karst plain including an extensive, shallow cave network developed in the Rustler Formation. Bachman (1980, 1981, 1984, 1987) described the complex "solution and fill" process that has produced large depressions such as Nash Draw in the Mescalero Plains region. The conceptual model of this process was originally developed by Lee (1925).

About 5 mi northeast of this point (sec. 15, T22S, R30E), fossil molluscan and vertebrate faunas of middle (?) to late Pleistocene age have been collected from gypsiferous basin floor sediments interpreted as spring deposits by Bachman (1980, 1981). Studies of the molluscan faunas by Ashbaugh and Metcalf (1986) indicate that the sediments were deposited in a cienega environment, which included local permanent bodies of water, during a cooler and more moist interval of the late Wisconsin. Paleoclimatic conditions in the WIPP area during the late Pleistocene are discussed in more detail by Swift (1993). **0.9**

24.6 Crossing "Laguna Quatro," an informally named, shallow brine lake (surface elevation 2981 ft) that is the highest of a series of connected playa lake basins crossed by NM-128 for the next 3.5 mi (Powers and Martin, 1990, p. 18). Only the lowest lake plain, Laguna Grande de la Sal (Salt Lake), is naturally flooded (elevation of spring-fed lake surface, 3949 ft). The other depressions are now flooded by brine effluent from potash-mill operations. **0.5**

25.1 Crossing interlake dune ridge. Flat surface with gypsic soil crust truncates crossbedded gypsum dune deposits (east-dipping) exposed in roadcuts ahead. **0.3**

25.4 Rawhide Road (Eddy-793) and IMC Mine Shaft (No. 5) to left. **0.6**

26.0 Crossing "Laguna Tres" brine lake (surface elevation 2971 ft). **0.5**

26.5 Northwest shore of "Laguna Tres" to right. This is the site of a 1990 Geological Society of America tour stop (3-1) led by Powers and Martin (1990, p. 18). They noted that this edge of the lake receives more natural surface runoff than the southern area where there is a much greater "influx from (potash-mill) tailings water." As a result of this difference in brine composition, gypsum crystallizes here for most of the year, while halite crystallizes in the active inflow area to the south. Professors L. Jones and R. Vreeland and students of West Chester University (England) have also studied effects of algae/bacteria interactions with lake brines from this area, as well as with other aspects of bacterial ecology. According to Powers and Martin "these studies should be helpful in determining any bacterial influence on diagenesis and crystal growth."0.4

26.9 Crossing complex of gypsum eolian sand and playa deposits for the next 1.5 mi. This area is immediately northeast of Laguna Grande de la Sal. **1.2**

28.1 WIPP 29 drilling site about 250 ft north of road. This test hole encountered 131 ft of Rustler Formation just below the surface and 105 ft of underlying "Salado dissolution residue" (Bachman, 1981, table 2). The thickness of remaining Salado evaporites from the base of this zone to marker bed 101 is 32 ft according to Bachman, whereas this interval near the WIPP Site (where there is no evidence for Salado dissolution) is about 117 ft. The low hill to the north of WIPP 29 (across railroad) is a Rustler-cored karst mound (Magenta/Culebra) that has about 80 ft of local relief and is capped with "Mescalero caliche" (Bachman, 1981). WIPP 32, which was drilled in this structure, encountered deeper marker beds even though the upper part of the Salado was dissolved, thus demonstrating that the mound is a shallow-rooted feature (Powers and Martin, 1990, p. 17). **0.7**

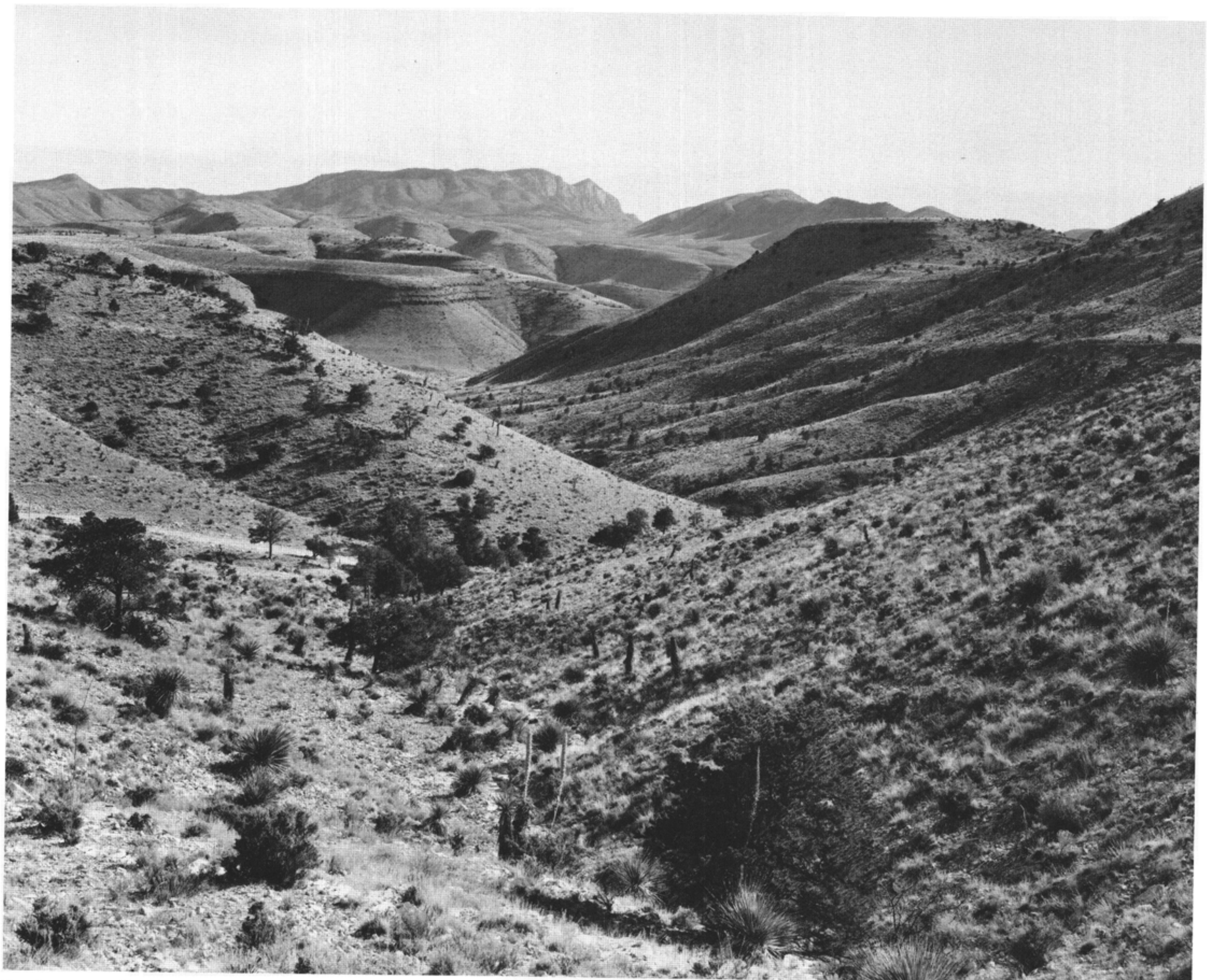
28.8 Crossing low ridge with roadcut exposures of Gatufia Formation capped with calcrete. **Park on right for tour stop. 0.1**

28.9 **STOP 4** north of Laguna Grande de la Sal (Salt Lake). Ridge to south of highway overlooks the Surprise Spring area at the northern edge of the lowest level of the Nash Draw playa lake system (elevation 2949 ft). The basin floor is essentially at the same level as the adjacent channel of the Pecos River, which is located about 1.5 mi to the southwest across a very low surface divide. Surprise Spring and the adjacent part of the lake-plain that is permanently flooded are located about 1 mi south of this stop. Limited access to the Laguna Grande area is provided by the poorly maintained road west of the ridge (mi 28.95). **0.7**

29.6 Railroad crossing. Stop sign ahead. **0.1**

29.7 Junction of NM-128 with Potash Mines Road (NM-31) and First-Day Road Log mi 165.5.

End of Supplemental Road Log 1.



Southern part of Brokeoff Mountains; Guadalupe Mountains in distance. View is S11°E down western tributary to South Tank Canyon. Slopes and summits in near to intermediate distance are in Grayburg Formation. Crests of Guadalupes are Seven Rivers, Queen, Goat Seep and Capitan formations. Scattered trees are mainly piñon pine. Sotol and yucca are common on the hillsides. Camera station is in NE¼ sec. 31, T25S, R20E, about 10 km west of El Paso Gap. Altitude is approximately 1684 m. W. Lambert photograph No. 85L107. November 15, 1985, 2:29 p.m. MST.