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 minipaper 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 Sharp bend to left down slope.
0.2 Curve to right. Gaturia "red beds" exposed in ditch to right.
0.4 Cattle guard.
0.7 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 "Gaturia Formation" (Bachman, 1984, p. 17-19).
1.1 Eddy-746A to left; continue straight (southeast) on Eddy-746.
1.1 Trail to right leads to upper Pierce Canyon area where thickest section of lower, finer-grained part of the "Gaturia" is exposed (Powers, this volume). At a few sites, upper Rustler beds crop out at the base of the section.
1.8 Dip in road; crossing upper end of Pierce Canyon.
1.3 Pipeline crossing.
1.0 Junction. Continue straight (southeast). Road to right provides access to divide area between Pierce and Cedar Canyons.
1.7 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).
4.8 Drill hole to left.
5.3 Cattle guard. Route ahead curves right (east) and follows upper reach of Pierce Canyon Draw (to left).
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).
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).
8.3 Curve to right (northeast) at cattle guard. Windmill to left.
9.3 Pit to left in "Mescalero caliche" (an informal, "mid-Pleistocene" soil-stratigraphic unit of Bachman, 1976, 1980).
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.
11.5 Ranch to right. Prepare for sharp left turn ahead.
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 from 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).

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.

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

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.

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 det-

![Geologic section between Carlsbad Caverns National Park and Project Gnome site. Modified from Gard (1968, fig. 4).](image)

![Project Gnome area of southeastern New Mexico. Modified from Gard (1968, fig. 2).](image)
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-subside 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-Gatufia "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 the 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 McNut 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 marker bed 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-aquagelous 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 anhydrite-polyhalite, (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, nodular muddy halite, dilated mud-rich halite and halite 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, clastics and halite (Powers and Holt, 1984, 1990; Holt, 1988; Holt and
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 clastic 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 (Beauchem 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 gyspum and/or anhydrite. The upper zone contains organic-rich claystone and carbonate. The Tamarisk contains upper and lower anhydrites separated by claystone or laterally 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.

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The Dewey Lake Formation is the uppermost part of the Rustler Formation. The Rustler is 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 part of the four Ochoa 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 gyspum. 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 asolian material reworked in a shallow marine environment. Based upon the occurrence of gyspum, 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 lamination 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 dolomite containing gyspum-replaced bivalve fragments, pelletal textures, burrows, crytgalal layering and stromatolites. Culebra sedimentary structures reflect deposition in an upward shallowing, carbonate lagoon. Sulfates were initially near marine and increased to gyspum saturation with time. The Magenta is an arenaceous, gypsiferous dolomite that displays abundant cross-laminae, ripple-drift cross-laminae and wavy and kuncated 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 gyspum, re-
Dewey Lake was deposited in saline mudflat and mudflat environments within the phreatic zone (sediment completely saturated with pore waters). 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 coarse-crystalline halite showing chevron and corner fluid-inclusion zoning and finally layers of finely crystalline halite. Synsedimentary dissolution in the vadose zone initially produced dissolution pits, pipes and macro-pores; 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 clastic 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). Sulfate cements, 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 syn-depositionally replaced by anhydrite, halite and polyhalite. Most of the lagoons were low-volume and produced thin sulfate interbeds. Algale grew on the substrate, producing algal domes and biscuits. Thicker sulfate interbeds accumulated in deeper lagoons. As many of these lagoons completely desiccated, subaerally 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 mudflat 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 overran Dewey 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 cease 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.
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 particulate sampling requirements (EPA, 1985). All LVAS continuously sample at a flow rate of 142 L/min through a 102 nm glass 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 magnemetric 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$^\circ$ 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). 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 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
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 radionuclide 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 (Mp = 5.0) shook the WIPP site and much of southeastern New Mexico. The earthquake was...
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 ± 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 relationships between surface rupture and earthquake magnitude are developed for the western United States, an area of relatively thin crust (10-20 km). 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 commun. 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 commun. 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 Plow-
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, which was originally contaminated during an initial decontamination and decommissioning process. 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. The tracer consisted of a mixture of tritiated water (20 curies), iodine-125 (4.0 curies), strontium-90 (10 curies) and cesium-137 (10 curies). The tracer was injected into the Culebra Dolomite Member of the Rustler Formation 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 3000 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-125 (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).

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Radionuclide</th>
<th>Concentration (pCi/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well USGS-8</td>
<td>Cs</td>
<td>6.4 x 10^4</td>
</tr>
<tr>
<td>Well USGS-4</td>
<td>H</td>
<td>1.2 x 10^4</td>
</tr>
<tr>
<td>Well LRL-7</td>
<td>Cs</td>
<td>1.8 x 10^4</td>
</tr>
<tr>
<td>Well DD-1</td>
<td>Cs</td>
<td>1.4 x 10^4</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>2.8 x 10^4</td>
</tr>
<tr>
<td></td>
<td>Sr</td>
<td>5.4 x 10^3</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>1.1 x 10^4</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>8.2 x 10^4</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>7.6 x 10^4</td>
</tr>
</tbody>
</table>
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 southeastern 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. **1.0**

23.7 Milepost 6. **STOP 3.** Route ahead on apron of 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 gypsic-soil crust truncates crossbedded gypsum dune 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 yacon 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.