EEG-7

WIPP SITE AND VICINITY GEOLOGICAL FIELD TRIP

A report of a field trip to the proposed Waste Isolation Pilot Plant project in Southeastern New Mexico
June 16 to 18, 1980

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the Waste Isolation Pilot Plant (WIPP), a Federal radioactive waste repository proposed for construction underground in an area near Carlsbad, New Mexico. The objective of the EEG evaluation is to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP. Analyses are conducted by EEG of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations, as they relate to the potential health, safety and environmental impacts of WIPP. These analyses may involve public meetings, site visits and consultations with agencies, professional associations and scientific experts.

The project is funded entirely by the U. S. Department of Energy through Contract #DE-AC-04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

EXECUTIVE SUMMARY

The Environmental Evaluation Group is conducting an assessment of the radiological health risks to people from the Waste Isolation Pilot Plant. As a part of this work, EEG is making an effort to improve the understanding of those geological issues concerning the WIPP site which may affect the radiological consequences of the proposed repository. One of the important geological issues to be resolved is the timing and the nature of the dissolution processes which may have affected the WIPP site. EEG organized a two-day conference of geological scientists, titled "Geotechnical Considerations for Radiological Hazard Assessment of WIPP" on January 17-18, 1980. During this conference, it was realized that a field trip to the site would further clarify the different views on the geological processes active at the site. The field trip of June 16-18, 1980 was organized for this purpose. There were twenty-three participants in the field trip, including seventeen geoscientists from state and federal agencies, universities and the private sector.

It is recognized that the U. S. Department of Energy has plans for continued study of the site over the next several years. Several important geological issues concerning the site are yet to be resolved. On the basis of the January conference and the June field trip, EEG has formed the following conclusions:

1. It has not been clearly established that the site or the surrounding area has been attacked by deep dissolution to render it unsuitable for the nuclear waste pilot repository. Further site characterization, as recommended in this report, should throw light on the nature and validity of the ideas on "deep dissolution" as postulated by Roger Anderson.

2. The existence of an isolated breccia pipe at the site unaccompanied by a deep dissolution wedge. is a very remote

possibility. Their existence in the Basin, other than above the Capitan Reef, has not been settled. However, further work to answer this question probably would not provide useful information for evaluating the potential impact on the integrity of the WIPP repository.

3. More specific information about the origin and the nature of the brine reservoirs is needed. An important question that should be resolved is whether each encounter with artesian brine represents a separate pocket or whether these occurrences are interconnected.

4. Anderson has postulated a major tectonic fault or a fracture system at the Basin margin along the San Simon Swale. It is important to check whether such a fault really exists because of its implications to the tectonic stability of the Delaware Basin in which the site is located.

5. The area in the northern part of the WIPP site, identified from geophysical and bore hole data as the disturbed zone, should be further investigated to clearly understand the nature and significance of this structural anomaly. Other structural anomalies and postulated faults on the WIPP site should be further investigate.

6. A major drawback encountered during the discussions of geological issues related to the WIPP site is the absence of published material that brings together all the known information related to a particular issue. Topical reports on these issues are needed to clarify and aid in the site characterization.

Information concerning the foregoing issues would be of considerable value to EEG in more clearly defining and assessing plausible processes which may affect the repository and the long-term radiation consequences.

The Environmental Evaluation Group therefore makes the following recommendations to the U. S. Department of Energy for work during fiscal year 1981.

1. Prepare detailed review papers on Deep Dissolution, Structural Anomalies and Brine Reservoirs. Publish detailed plans on recovery of mineral resources at and around the WIPP site. Publish reports on the results of investigation of the breccia pipes;

2. Carry out the following exploration work:
    a. A seismic reflection profile across the San Simon Swale to check the presence of a postulated fault;
    b. Explore Bell Lake Sink through shallow holes to see whether it is caused by deep dissolution;
    c. Drill an exploratory core hole in Section 9, 2 miles north of ERDA-9 to explore the "disturbed zone";
    d. Test a brine reservoir by allowing it to flow.

Details of the recommendations are included in the "Summary and Recommendations," Section IV, pp. 101-106.

LIST OF FIGURES

ACKNOWLEDGEMENTS

The Environmental Evaluation Group wishes to acknowledge the contributions made by a large number of individuals and organizations in making this field trip a success.

George Bachman and Roger Anderson suggested the basic itinerary and schedule of field trip stops and provided field notes in advance of the trip. John Hawley, George Griswold and Charles Jones made several helpful suggestions for scheduling. George Bachman and James Channell (EEG) covered the entire route in advance and prepared the road log. Roger Anderson, George Bachman, Charles Jones, John Hawley and George Griswold acted as field trip leaders.

The generous loan of two vans by the City of Carlsbad made the field trip efficient, safe and comfortable. Eddie Lyon, Director of Carlsbad's Department of Development contributed to the logistics and other details upon which the success of any field trip depends. Dale Dawson, Manager of the Holiday Inn at Carlsbad, took person interest in the details of the arrangements of service and facilities. The hospitality provided by the Carlsbad Chamber of Commerce and the elected officials provided an opportunity for the geoscientists to meet and discuss our work with many of the leaders of the community. The Mississippi Chemical Corporation allowed the participants to visit the MCC potash mine to view the breccia pipe underground.

All participants in the field trip generously devoted their time, energy and attention. A large number sent detailed written comments which were of great help in preparing this report.

Lokesh Chaturvedi did yeoman service as Chairperson for the wrap-up sessions at the conclusion of each day; and undertaking the considerable task of distilling, summarizing and evaluating an enormous amount of information in the preparation of this report.

The Environmental Evaluation Group gratefully acknowledges the help, generosity and devotion of all the individuals and organizations mentioned above and others who have contributed to this effort in many ways, including State agencies, the universities of New Mexico, the National Academy of Sciences WIPP Panel, the U. S. Geological Survey, the Nuclear Regulatory Commission and the Department of Energy and its Contractors.

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INTRODUCTION

This is a report of a geological field trip to the proposed Los Medanos site of the U. S. Department of Energy's Waste Isolation Pilot Plant (WIPP). The field trip was organized by the Environmental Evaluation Group (EEG) and was held on June 16-18, 1980. This trip was based in part on the results of a scientific conference, "Geotechnical Considerations for Radiological Hazard Assessment of WIPP," arranged by EEG on January 17-18, 1980.

There were twenty-three participants in the field trip, seventeen of whom were geoscientists. The trip covered the WIPP site, 25 miles east of Carlsbad, New Mexico and the surrounding geologically relevant points within a rectangle encompassing about 1500 square miles. In addition to the staff of EEG, the participants included experts from the National Academy of Sciences, Nuclear Regulatory Commission, U. S. Geological Survey, U. S. Department of Energy and its technical contractors, and universities in New Mexico. A list of the participants, and field trip notes are included in the Appendices.

The purpose of this site visit was to see some of the field evidence which support various hypotheses discussed during the January meeting. These relate to the effect of the past and present movement of fluids underground. There is concern that such movement may affect the stability of the evaporite sequence in the vicinity of the WIPP repository. One hypothesis, proposed by George Bachman, explains all past and presently active dissolution of salts as being the result of a surface-induced circulation of water, thereby removing salt near the top of the evaporite sequence. The other, proposed by Roger Anderson, invokes an additional mechanism of dissolutioning and salt removal by the process of "brine density flow", which depends on the supply of water from deeper aquifers flowing into the lower parts of the evaporite sequence. The importance of the two processes to WIPP lies in their potential effect on the proposed repository. George

Bachman and Roger Anderson selected the field trip stops to show their respective evidence for their hypotheses.

In addition to salt dissolution, there were also discussions about several other specific geological issues concerning the WIPP site. These included the presence or absence of breccia pipes in the Delaware Basin; structural anomalies interpreted from geophysical data and the cores of exploratory holes; and the question of brine reservoirs located in the Castile and Salado formations. Extensive discussion took place at most of the stops, concerning the particular outcrop, its relevance to the general geologic setting of the area, to the particular hypothesis and to the Waste Isolation Pilot Plant. At the end of each day's field trip, there was a session at which features seen in the field and their relevance to WIPP were summarized and additional ideas presented. The participants were requested to provide EEG with written assessments of the geologic and hydrologic issues presented on the field trip which may affect the WIPP site.

The report provides a summary of the field trip activities along with the participants' post field trip comments. Important field stops are briefly described, followed by a more detailed discussion of critical geological issues. The report concludes with EEG's summary and recommendations to the U. S. Department of Energy for further information needed to more adequately resolve concerns for the geologic and hydrologic integrity of the site.

AGENDA

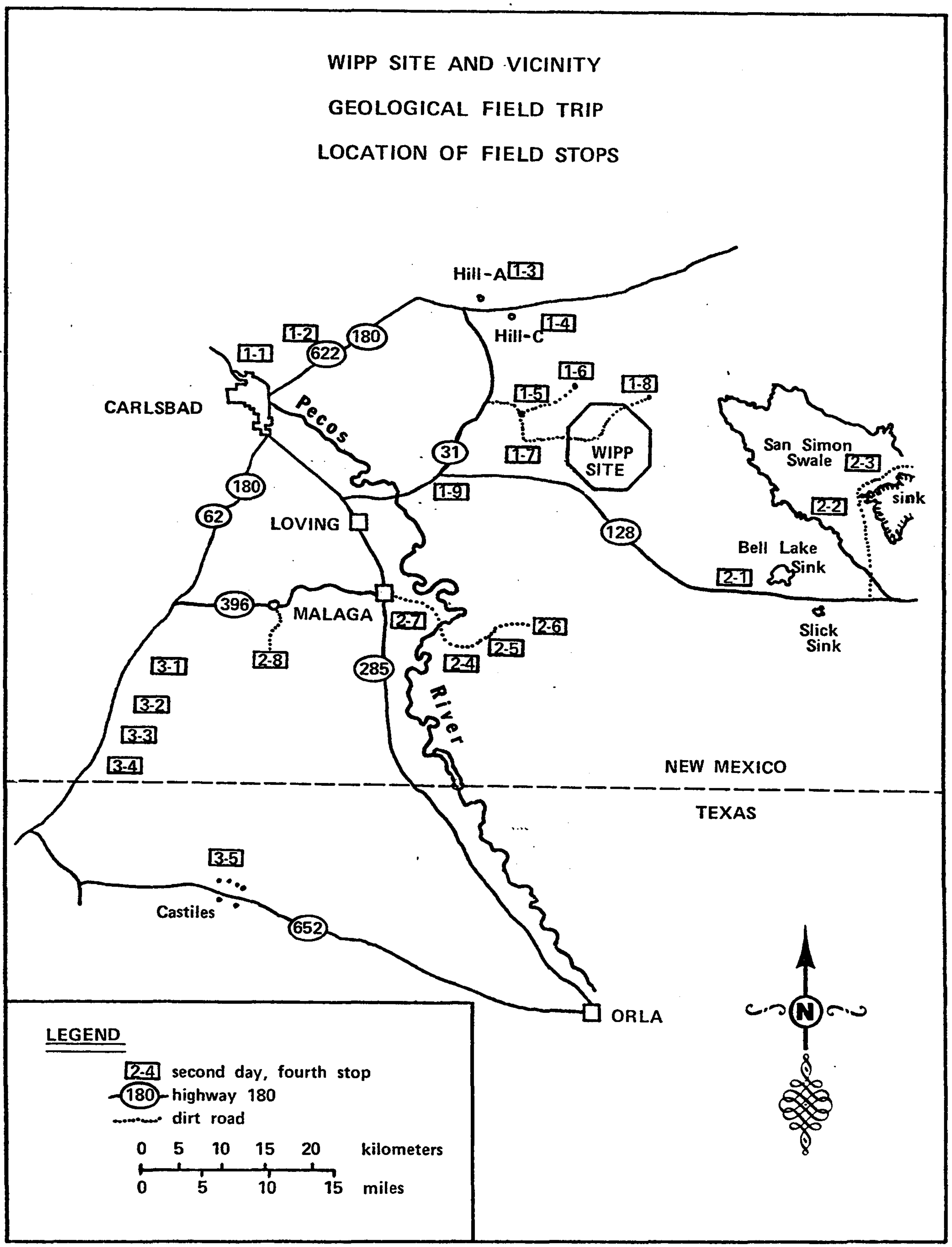

Figure 1. Location of field stops

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WIPP SITE AND VICINITY - GEOLOGICAL FIELD TRIP

June 16-18, 1980

AGENDA

First Day - June 16

STOP NO.	ARRIVAL/DEPARTURE	DESCRIPTION
	a.m.	
Holiday Inn	7:00/7:30	Assemble; Introduction to the day's trip (Anderson, Bachman, & Griswold)
1-1	7:45/8:15	Railroad Cut
1-2	8:45/9:15	Early Cretacious & Triassic Collapse blocks.
1-3	9:46/10:16	Hill A
1-4	10:26/10:56	Hill C
1-5	11:24/11:49	Collapse Sink
	p.m.	
1-6	12:02/12:22	Ash Fall
1-7	12:41/1:41	Spring Deposits, which includes LUNCH BREAK
1-8	2:22/2:52	ERDA-6
1-9	3:37/4:07	Drilled Site
Holiday Inn	4:29/5:00	BREAK
Holiday Inn	5:00/6:00	Meeting in Conference Room for discussion, re-cap & presentations.

Second Day - June 17

STOP NO.	ARRIVAL/DEPARTURE	DESCRIPTION
	a.m.	
Holiday Inn	7:00/7:30	Assemble, Introduction to day's trip (Anderson, Bachman, Griswold)
2-1	8:30/9:00	Bell Lake
2-2	9:31/10:16	San Simon Sink
2-3	10:32/11:02	San Simon Ridge
	p.m.	
2-4	12:37/12:47	Pierce Canyon Bridge
2-5	12:57/1:07	Pierce Canyon Overlook
2-6	1:15/2:15	Pierce Canyon, including LUNCH BREAK
2-7	2:31/3:31	Malaga Bend
2-8	3:53/4:08	Black River
Holiday Inn	4:26/5:00	BREAK
Holiday Inn	5:00/6:15	Meeting in Conference Room, re-cap and presentations.

WIPP SITE AND VICINITY - GEOLOGICAL FIELD TRIP /Agenda June 16-18, 1980

Third Day - June 18

STOP NO.	ARRIVAL/DEPARTURE	DESCRIPTION
	a.m.	
Holiday Inn	7:00/7:30	Assemble, Introduction to day's trip (Anderson Bachman, Griswold)
White City	7:52/7:52	White City
3-1	8:03/8:33	Cretaceous Collapse
3-2	8:36/9:06	Cretaceous Outcrop
3-3	9:11/9:31	Carbonates in Rustler
3-4	9:35/10:05	State Line Outcrop
State Line	10:09/10:09	
3-5	10:28/10:58	Castiles
Holiday Inn	11:58/1:15 p.m.	LUNCH BREAK
Holiday Inn	1:15/5:00 p.m.	Meeting in Conference Room

ROAD LOG

ROAD LOG

Day 1 - June 16, 1980

Mileage	Cumulative mileage	Description
	0.0	Leave Holiday Inn
4.4	4.4	Travel north on Canal Street to Pecos River (Elevation 3120)
1.9	6.3	Continue on Canal Street through La Huerta to a dump located at top of knoll on right. Pull into dirt road and park. Walk 200 yards to railroad cut.

This is Stop 1-1, elevation 3170. The purpose of this stop is to see collapsed blocks of stream gravel intermingled with collapsed Permian rocks. The stream gravels are Middle Pleistocene (Gatuna Formation). The stream which deposited these gravels was at least 50 ft above the bed of the present Pecos River. Collapse occurred before the Mescalero caliche was deposited (about 500,000 years ago).

Mileage	Cumulative mileage	Description
1.6	7.9	Leave Stop 1-1, return south on Canal Street to intersection with stop light. Turn east (left).
2.7	10.6	Intersect Highway 62/180, turn to left (east) on highway.
5.6	16.2	Turn left into dirt road and proceed northerly. This road is about 1.8 miles past the Beker Plant on the north side of highway.
0.8	17.0	Cross railroad track.
0.3	17.3	Turn left (westerly) on dirt road.
1.9	19.2	Proceed westerly on dirt road until you reach Superior Oil pump area marked as S12, T21, R27E.
0.2	19.4	Proceed SW on dirt road that branches just before Superior Oil area.

Mileage	Cumulative mileage	Description
0.2	19.6	Proceed southerly on road to fence line.
0.3	19.9	Turn easterly on road along fence.

This is Stop 1-2. Several orange-painted stakes mark pertinent areas.

These remnants of marine Early Cretaceous rocks are as far to the northwest within the Delaware basin that rocks of this age have been observed. Here they are associated with nearby exposures of Triassic rocks. These exposures are partial evidence for pre-Cretaceous unconformity.

3.7	23.6	Return to Highway 62/180 by same route, turn left onto highway and proceed easterly.
5.5	29.1	Observe Dewey Lake Redbeds overlain by thin Gatuna in cut on south bank of highway.
5.6	34.7	Turn left (north) on dirt road toward Duval Mine. This is about 2.1 miles past the intersection of State Highway 31.
0.4	35.1	Cross railroad track, immediately turn left.
0.4	35.5	This is the east flank, Hill A.

This is Stop 1-3.

This is a known breccia chimney, or breccia pipe, which has been drilled.

0.2	35.7	Proceed to bottom of Hill A, turn around.
1.0	36.7	Return to Highway 62/180, turn left and proceed easterly.
0.3	37.0	Turn to right (south) across cattle guard and take left fork in road.
1.4	38.4	Turn left at fork.
0.3	38.7	This is Hill C.

This is Stop 1-4.

This is the second of two known breccia chimneys which have been drilled.

Mileage	Cumulative mileage	Description
1.7	40.4	Return to Highway 62/180; cross median strip (caution here, this is a steep drop); turn to left and proceed westerly.
2.3	42.7	Turn left on State Highway 31 and proceed southerly.
7.6	50.3	Turn left at Phillips Petroleum A & C oil wells. This turnoff is just before the IMCC potash mill.
0.5	50.8	End of pavement on road, proceed on dirt road.
3.4	54.2	Stop at crest of hill, orange-colored stake on north (left) side of road. Walk north at this point for about 300 yards.

This is Stop 1-5.

This area is an example of "solution and fill" as defined by W. T. Lee (1925). There are at least 30 to 50 collapse sinks of this type in the central part of Nash Draw.

Mileage	Cumulative mileage	Description
0.6	54.8	At Crawford Ranch, take right fork in road.
0.5	55.3	At cattle guard take left fork.
1.6	56.9	Veer left at oil storage tank.
1.2	58.1	Turn right (east) at T in road.
0.6	58.7	Proceed past windmill on left.
0.3	59.0	At top of hill, turn left along Livingston Ridge.
0.3	59.3	Pull off on left side of road.

This is Stop 1-6.

The volcanic ash exposed here in the Gatuna Formation has been identified as Pearlette "O" by Glenn Izett (USGS). This ash originated in the Yelllowstone region and is about 600,000 years old. It is of major importance in placing an upper limit on the age of the Gatuna Formation.

Mileage	Cumulative mileage	Description
1.1	60.4	Proceed back past windmill to T, take left turn and head south.
2.8	63.2	After proceeding past storage tanks come to intersection near Crawford Ranch, turn south.
1.2	64.4	Pull into cleared area on right.

This is Stop 1-7.

Gypsite spring deposits exposed here have yielded camel and horse remains. The deposits are presumed to be late Pleistocene in age. WIPP 25 was drilled here.

0.3	64.7	Proceed easterly along this road; at this point are driving over Dewey Lake Redbeds.
0.5	65.2	Take right fork in road and proceed south along Livingston Ridge.
1.7	66.9	Make a sharp left turn onto pipeline road and head easterly.
1.6	68.5	Closed gate. Open it and continue on.
2.8	71.3	ERDA-9 intersection. Continue straight ahead.
3.1	74.4	ERDA-6 intersection. Turn left and proceed northerly.
0.7	75.1	Take right fork in road to ERDA-6.
1.0	76.1	Take right fork in road.
0.6	76.7	Stop at ERDA-6 gate.

This is Stop 1-8, ERDA-6. The purpose of this stop is to discuss the brine reservoir phenomena which was observed at ERDA-6.

5.4	82.1	Return to ERDA-9 crossroads turn south toward ERDA-9
1.0	83.1	ERDA-9. Continue south.
5.3	88.4	Intersection with State Highway 128. Turn westerly toward Carlsbad.
8.7	97.1	Turn off road to north toward drilled sites

This is Stop 1-9.

This hill was drilled as a suspected breccia chimney but drilling proved a normal Salado sequence.

1.3	98.4	Intersection of State Route 31. Turn south toward Carlsbad.
15.6	114.0	Arrive Holiday Inn, Carlsbad.

Day 2 - June 17, 1980

Mileage	Cumulative mileage	Description
	0.0	At Holiday Inn. Proceed south on Highway 285
9.3	9.3	Intersection of Highway 285 and State Highway 31 proceed easterly on 31.
6.3	15.6	Turn right onto State Highway 128 and proceed easterly.
27.9	43.5	Turn left onto dirt road going to Bell Lake. This road is 9.5 miles east of the Lea County line and 3.2 miles before State Route 21.
1.7	45.2	Proceed north on dirt road to windmill for approximately one mile.
1.0	45.6	Bell Lake.

This is Stop 2-1.

Bell Lake Sink is a large collapse feature that contained a late Wisconsin and Holocene lake and that is a candidate for surface expression of dissolution at depth.

Mileage	Cumulative mileage	Description
2.1	47.7	Return to State Highway 128, turn left and proceed easterly.
3.2	50.9	Turn left on County Road 21 and head north.
13.2	64.1	Take road through gate over cattle guard to right toward southwest.
1.0	65.1	Turn left at fork.
0.5	65.6	Turn right at section corner and drive toward bottom of sink.
0.2	65.8	Stop near WIPP 15.

This is Stop 2-2.

San Simon Sink is a collapse feature above inner reef margin which contains evidence for two "pluvial" episodes in the Wisconsin and a recent collapse history.

Mileage	Cumulative mileage	Description
1.7	67.5	Return to County Road 21. Turn right (toward the east).
1.4	68.9	Turn right through gate and head southerly on pipeline road.
0.4	69.3	Stop at outcrop.

This is Stop 2-3.

San Simon Ridge and associated jointing reef margin and has a Triassic sandstone outcrop similar to sandstone found at the bottom of WIPP-15. Along with San Simon swale, it suggests a Quaternary age for structures.

Mileage	Cumulative mileage	Description
15.0	84.3	Return via County Road 21 to State Highway 128. Turn right.
31.1	115.4	Intersection of State Highway 31, turn left toward Carlsbad.
6.3	121.7	Intersection Highway 285. Turn left southerly toward Loving.
5.8	127.5	Crossing of Black River, south of Loving.

Cemented gravels along banks of Black River have been called Ogallala Formation (Pliocene) by some earlier geologists. However, these are situated on topography more nearly representative of middle Pleistocene.

Mileage	Cumulative mileage	Description
0.7	128.2	At Malaga intersection. Turn east toward Horcun Lake.
1.3	129.5	Turn right at intersection toward south
1.3	130.8	End of pavement. Keep going.
1.2	132.0	Note domal structure on left at 10 o'clock and small closed structure on right at 3 o'clock.

ROAD LOG (cont'd.)

Mileage	Cumulative mileage	Description
0.5	132.5	Take right fork at intersection.
2.7	135.2	Pierce Canyon Bridge.

This is Stop 2-4, Pierce Canyon Bridge.

Here the Gatuna Formation is collapsed.

Mileage	Cumulative mileage	Description
1.5	136.7	Pull off side of road where can get good view of south canyon wall (across the canyon).

This is Stop 2-5.

A gravel channel is well exposed along the south wall of the canyon, This channel is in the Gatuna Formation and is at least 100 feet above the bed of the modern Pecos River.

Mileage	Cumulative mileage	Description
2.1	138.8	Take right fork in road.
0.4	139.2	Stop for lunch and site visit, location marked by orange-colored stakes. Walk 5 minutes into canyon, see outcrop.

This is Stop 2-6.

The Magenta Dolomite (Permian Rustler Formation) is collapsed and intermingled with the Gatuna Formation.

This is Stop 2-7, the Malaga Bend Stop.

Near here are several examples of karst domes. These differ fundamentally from breccia chimneys.

Mileage	Cumulative mileage	Description
3.0	149.8	Malaga intersection. Proceed west from here on Black River Village Road.
2.5	152.3	Cross Black River. Exposed rocks at 3 o'clock have been called Ogalla.
6.9	159.2	At intersection of road to Carlsbad. Turn south on dirt road.
0.9	160.1	Cross Black River. Continue on.
0.2	160.3	Stop, walk to left and view rock outcrop.

This is Stop 2-8.

At this stop there are intraformation breccia of Salado Formation overlain by Rustler Formation.

1.0	161.3	Return to paved road.
13.	173.3	Return to Holiday Inn, Carlsbad.

Day 3 - June 18, 1980

Mileage	Cumulative mileage	Description
	0.0	Leave Holiday Inn. Proceed south on Highway 62/180
18.0	18.0	Whites City Intersection continue south on 62/180
6.9	24.9	Dirt road to left -- with closed gate. Turn into road.

This is Stop 3-1.

This exposure of marine Early Cretaceous rocks is another record of the pre-Cretaceous unconformity. Triassic rocks are presumed to be absent.

Mileage	Cumulative mileage	Description
1.1	26.0	Stop at roadside tables on right side of highway. Walk west across fence about 0.1 mile.

This is Stop 3-2.

Early Cretaceous rocks. Part of pre-Cretaceous unconformity record. About 80 miles west of here in the Cornudas Mountains Early Cretaceous rocks rest on rocks of Middle Permian age.

Mileage	Cumulative mileage	Description
3.5	29.5	Stop where there is a carbonate outcropping near fence on left side of road.

This is Stop 3-3, Carbonates in the Rustler Formation.

Mileage	Cumulative mileage	Description
2.0	31.5	Stop in cut in highway where there are outcroppings on both sides.

This is Stop 3-4.

The State-Line Outcrop of Castile Formation shows microfolding, dissolution breccia, and regional dissolution relationships. Age of microfolding fixes age of salt deformation structures in basin.

Mileage	Cumulative mileage	Description
2.1	33.6	State line
0.1	33.7	Turn left (east) on Farm Road 1108
5.1	38.8	Take left fork (onto Farm Road 652)
4.5	43.3	Take right road (stay on 652)
4.7	48.0	Cross Delaware River
1.9	49.9	Stop at Castiles

This is Stop 3-5. The Castiles.

These limestone buttes contain a brecciated core of biogenic replacement limestone and evidence for dissolution and collapse in the lower part of the evaporites and fluid movements from the Bell Canyon.

Mileage	Cumulative mileage	Description
49.9	99.8	Return to Holiday Inn, Carlsbad.

SECTION 1

DISCUSSIONS IN THE FIELD

SECTION 1

DISCUSSIONS IN THE FIELD

A summary of geological features and an account of discussions in the field at each of the stops are provided in this section. The numbering of stops corresponds with the stops shown in Figure 1. Details of directions to reach each stop are provided in the Road Log included in this report. The heading for each stop includes the name(s) of principal speaker(s) who led the discussion at that stop.

Stop 1-1 -- Collapsed Gatuna (Bachman)

This stop is located about 6 miles north of the Carlsbad Holiday Inn. Here, along a railroad cut, one can see collapsed blocks of Gatuna formation intermingled with collapsed Permian rocks (Fig. 2). The Gatuna formation here consists of stream gravel. According to George Bachman (USGS), the Gatuna is at least 600,000 years old. Bachman interprets the collapse to have taken place in ancient sink holes which were formed in pre-Mescalero Caliche time. Since Mescalero Caliche was deposited about 500,000 years ago and the Caliche overlies the Gatuna "sinks" without being disturbed, the implication is that no collapse has taken place here since 500,000 years ago.

Bachman also pointed out that the gravel deposits of Gatuna time found at this location occur at least 50 feet above the present level of the Pecos River. This shows that a stream system at that time was at least 50 feet above the present system. From this, Bachman draws the conclusion that the hydraulic head in the Capitan aquifer system must have been greater than it is today. Following Gatuna time, the Pecos River entrenched itself in its present position and intercepted the Capitan aquifer system, relieving the hydraulic head. Because of this, Bachman believes

Fig. 2 Collapsed Gatuna gravel deposit intermingled with collapsed Permian rocks, Stop 1-1.

(photo: M. S. Little)

that the conditions are not favorable at the present time for the formation of breccia pipes.

Stop 1-2 -- Cretaceous Outcrop (Bachman)

About 10 miles northeast of Carlsbad, George Bachman pointed out an outcrop which consists of remnants of marine early Cretaceous rocks associated with nearby exposure of Triassic Rocks. Jurassic rocks are not present in this area. He uses this as partial evidence for a dissolutional unconformity below the Cretaceous and infers from this that much of the dissolution in the basin occurred during the Jurassic time.

Stop 1-3 -- Hill A (Jones)

The purpose of this stop was to visit Hill A which is one of the "domal features" that Vine described (Ref. 8). On Figure 3, note the dipping Dewey Lake red beds below, and to the right of the pole. According to C. L. Jones (USGS), drillhole WIPP-31 was drilled in October 1978 to a total depth of 810 feet to see whether or not the salt has been dissolved at this location. Only 50 feet of core was recovered. Breccia was encountered throughout the total depth and the formation at 810 feet consisted of brecciated red beds which appeared to be a residue of Dewey Lake red beds. In the normal stratigraphic sequence Halite should have been found at this depth. Thus Hill A is a confirmed "Breccia Pipe". The drillhole WIPP-31 is loaded with brine-based mud to keep it from collapsing. According to Wendell Weart (Sandia), this hole is being deepened and cored to the "root" of the breccia pipe. This work started on July 31, 1980. The total depth of the well, from ground surface is expected to be approximately 2100 feet. However, the well will be drilled deeper if necessary, until undisturbed beds are encountered. Continuous testing for the presence of water is being carried out to detect any water in

Fig. 3 Hill A - the top of a confirmed breccia pipe, Stop 1-3.

(photo: M. S. Little)

the formations. The investigation of this confirmed breccia pipe will help in understanding the origin of these features.

Stop 1-4 -- Hill C (Jones)

Hill C is the surface expression of the breccia pipe that is seen at the McNutt Potash Zone in the Mississippi Chemical mine. Jones described this feature as follows:

In the mine, the rock surrounding the breccia pipe dips into the pipe all around. Within a distance of about 140 feet at the mine level, due to steep dips, one climbs 75 to 80 feet stratigraphically. There is displacement by faulting in the mine outside the pipe. The rim of this faulting is exposed on the surface at Hill C in a trough. The breccia pipe lithology in the mine consists of blocks of halite and anhydrite in a clay matrix which also consists of small clasts of anhydrite, halite and polyhalite. The exposure on the surface at Hill C consists of sandstone clasts in a clay matrix.

Well WIPP-16 was drilled at the edge of the breccia pipe on Hill C for the primary purpose of determining the possibility of drilling across the pipe horizontally. It was also an exploratory hole to check the stratigraphy, lithology and texture of the rock units in the breccia pipe. WIPP-16 encountered Triassic rocks at the surface, followed by a great mass of Triassic blocks and some intervals of breccia. This is essentially what one sees at the outcrop at Hill C. Further down in WIPP-16, Dewey Lake red beds and the Rustler formation were encountered. At the center of the pipe, one would expect a chaotic structureless mass of clay with sandstone fragments in it. The first rock salt in the drillhole was encountered in the basal part of Rustler.

Jones hypothesized that the presence of blocks of anhydrite, polyhalite and rock salt in the breccia pipe at the mine level and the rock salt encountered about 80 feet above the mine level in the lower part of Rustler (in WIPP-16), indicates that there was brine but no fresh water involved in the formation of the breccia pipe. Jones pointed out that several drillholes in that area, e.g., U.S. Potash #121, 124, 164, 183 and 185, showed that Rustler Salt has been dissolved outside the pipe. This is interpreted by him to mean that the dissolution outside the pipe post dates the dissolution within the pipe. The dip of Mescalero Caliche away from the breccia pipe is also interpreted to indicate that the salt in the area was removed after the formation of the breccia pipe.

The occurence of crude oil seep near the breccia pipe in the mine was mentioned by some of the participants. Jones stated that he believes the oil seeped up from lower lying hydrocarbon deposits, along the fractures associated with the breccia pipe. Weart stated that the oil from the seep is being chemically analyzed by U.S. Geological Survey and that the question of its source is not yet settled.

Stop 1-5 -- Nash Draw Sink (Bachman)

This stop was to see a collapse sink in the Nash Draw (Fig. 4), as an example of the "solution and fill" features described by W. T. Lee (Ref. 5). Bachman pointed out that there are thirty to fifty of these features in the Nash Draw. This sink is an example of the "solution and fill" process which is proposed as the mechanism by which Nash Draw depression was formed (see Figure 4 and Bachman, Appendix II).

Stop 1-6 -- Volcanic Ash in Gatuna (Bachman)

This stop was to visit the volcanic ash outcrop associated with the Gatuna formation discovered by George Bachman and Richard Kelly (a NMSU student) in the summer, 1979. This ash has been identified by Glenn Izett of U.S.Geological Survey as Pearlette "O", which originated in the Yellowstone region about 600,000 years ago.

Fig. 4 A collapse sink in Nash Draw, Stop 1-5.

(photo: M. S. Little)

Presence of this volcanic ash in the Gatuna has confirmed a minimum age of the Gatuna formation to be 600,000 years.

Stop 1-7 -- Gypsite Spring Deposits in Nash Draw (Bachman)

The gypsite spring deposits in Nash Draw indicate near surface dissolution by meteoric water seeping into the ground at the Livingston Ridge area and seeping out from the ground in Nash Draw, thus precipitating gypsite. These deposits are presumed to be late Pleistocene in age. Skeletal remains of horses and camels have been found here. The presence of these deposits indicates shallow dissolution as a process of major importance in the formation of Nash Draw.

Stop 1-8 -- ERDA-6 - Cancelled

The trip to ERDA-6 well, planned to stimulate discussion on brine reservoirs, was cancelled due to lack of time.

Stop 1-9 -- WIPP-32 (Bachman and Jones)

This stop was to visit the site of a suspected breccia pipe in the Delaware Basin southwest of the WIPP site. An exploratory stratigraphic hole, WIPP-32, was drilled at this site in August 1979 to a total depth of 390 feet. George Bachman and Charles Jones provided the following descriptions at this stop:

This feature is located in the southwest corner of Nash Draw, north of the salt lake Laguna Grande de la Sal. Bachman prefers to call it a "breccia mound", which he defines as "an erosional remnant of insoluble residuum in an area of regional Karst development." There is a good deal of brecciation here but it is a surficial, regional brecciation. For example, the Magenta dolomite, exposed on a ridge near WIPP-32, is highly brecciated. South of the salt lake, there are locations where the Magenta formation is seen essentially on top of the Culebra with most of the gypsum between the two having been dissolved out. At least some of this regional dissolution must have occurred before Gatuna time, because to the east of the salt lake there are some exposures of undisturbed Gatuna within Nash Draw, which lies on brecciated Magenta. Sinkholes in the Gatuna show evidence of some dissolutioning during and after Gatuna time.

Jones stated that east of the WIPP-32 location, the thickness of gypsum increases between Culebra and Magenta in the subsurface until it is about 90 feet thick on the east side of Nash Draw. The area at WIPP-32 is part of a belt of subcropping in which all the chloride and all the sulfates have been removed between the Magenta and Culebra, leaving behind a residue which is about 5 to 10 feet thick. It is a subsurface phenomenon in places overlain by about 300 feet of Gatuna formation. The top of salt in this hole (WIPP-32) is the top of the potash zone in the Salado -- approximately the same as found in WIPP-29 (3/4 mile to the southeast). The zone of dissolution residue in WIPP-32 extends from the surface to about 5 feet into the McNutt Potash zone. There is a total removal of all soluble salts (chlorides) from the upper part of Salado -- 400 to 500 feet of salt is missing -- with a dissolution residue taking its place. However, WIPP-32 showed that there is a normal bedded salt sequence with a normal regional dip below the McNutt Potash Zone. WIPP-32 Basic Data Report has not yet been published.

<u>Stop 2-1 -- Bell Lake Sink</u> (Anderson)

At the Bell Lake Sink (Fig. 5), located about 15 miles southeast of the WIPP site, Roger Anderson led the discussions and described the features as follows:

Bell Lake Sink is a depression about 2 miles in diameter containing two well-defined sinks and some smaller ones within the large depression. Old Red Soil, originally derived as sheet sand from the Ogallala formation during a drier period of Pleistocene, has since become stabilized and broken down to form a deep red soil which covers most of the surface at this location. At several locations around the Sink, this soil shows faulted margins and at some places one can see Mescalero Caliche faulted off. This big depression is therefore not an eolian deflation feature but is a structural collapse feature. This probably is true also for the Slick Sink (two miles to the south.)

According to Anderson, the Old Red Soil fixes a lower limit of 100,000 years for the age of this feature. The soil probably started developing in the Pleistocene between 100,000 and 300,000 years ago, during the Wisconsin Period. A unique feature of the Bell Lake Sink is the presence of three levels of "gypsum clay dunes". These dunes are known to form under a combination of geologic, topographic and climatic conditions. The process starts with intermittent seasonal drying in a playa flat to form gypsum crystals and clay pellets in the playa mud. In all the playas in various parts of the world which have been studied, it has been shown that there should be chloride available to form the clay pellets and calcium sulfate for the gypsum crystals. The clay pellets and the gypsum crystals are carried by the wind to form the clay dunes. The clay dunes thus formed are about half gypsum pellets and half clay pellets. These do not blow too far. The wind scoops them and stacks them around the edge of the playa. During the next wet period, the clay pellets break down and make a paste over the top and the dunes stabilize soon after they are formed. Anderson has reconstructed the size of the lake from the position of these gypsum clay dunes. Three stages of gypsum-clay-dunes development have been identified in Bell Lake Sink and are shown in Fig. 5 of Anderson's paper (Appendix II). These three stages represent conditions from Wisconsin to Holocene -- strong seasonal climate when the lake was at a high level. Bell Lake Sink is situated on a broad divide area without much drainage -- which means that there must have been relatively little catchment water flow. From where, then, did the water for a

Fig. 5 A view of the Bell Lake Sink, Stop 2-1.

(photo: Lokesh Chaturvedi)

lake of this size come? And from where did all the gypsum and salts found in the dunes originate?

Anderson cited a report by Nicholson and Clebsch (Ref. 6) who theorized that the upward movement of water from the Permian evaporite beds at depth brought sulfates and chlorides to the surface. Soils and exposed rocks in Southern Lea County are not gypsiferous or rich in chloride. The closest source of these materials is the Rustler formation which is about 1000 feet below the ground at this location.

With regard to the relationship of Bell Lake and Slick Sink to the WIPP site, Anderson suggested that this area appears to have developed due to collapse and rising sulfate rich water through fractures that originate in the evaporite. If the fractures connect the surface down to evaporites, how do we know that they did not originate deeper? Since these young features are in the basin and not on the reef, Anderson uses them as possible evidence for deep dissolution (in lower Salado and Castile) in the basin.

In answers to questions at the site, Anderson stated that the hydrologic head in the Rustler is most likely not high enough now for the water to ascend all the way to the surface. During the Wisconsin time, the head must have been higher. Anderson also stated that there were two shallow wells in the area, about 100 feet deep which yielded very salty water and the rancher abandoned them. He also said that around the margins of this Playa, one finds large nodules of barite and celestite, which indicate some recent movement of fluids, perhaps from the evaporite source.

<u>Stop 2-2 -- San Simon Sink</u> (Anderson)

This stop was to visit the San Simon Swale and Sink. San Simon Swale is an elongated, broad depression trending northwest with its northwest margin about 10 miles east of ERDA-9 (center of the WIPP site). San Simon Sink is the most recent collapse feature in the southeastern part of the Swale and lies about 20 miles east-southeast of ERDA-9. The Swale is approximately 20 miles long and 6 to 10 miles wide. The Sink (collapsed part) has a diameter of approximately one mile. Roger Anderson described these features as follows:

At the center of San Simon Sink there is a dead sugarberry tree. According to local ranchers, the lower limbs of the tree were once high enough that a horse and rider could pass beneath. Now these branches are barely 4 feet above ground. This represents recent deposition in the Sink. According to Nicholson and Clebsch, the absence of precipitates at the bottom of the sink indicates a leaky bottom where seepage is too rapid for effective evaporation (Ref. 6). The most recent collapse event occurred in 1927. A local rancher told Anderson that just before the collapse occurred, there was a period of heavy rain and the Sink had standing water. Perhaps the weight of the water provided the triggering mechanism for the collapse. At any rate, when it happened, "it sounded like a thousand cannons." The collapse left annular fissures, which are still well incised, around its rim (Fig. 6). The main fissure was about 15 feet deep. It has been filled in since, so that now it is only 2 to 3 feet deep and goes about half way around the Sink. According to Nicholson and Clebsch, deposition in the Sink is continuing at a rapid rate, estimated to be about 1 foot every 5 years (Ref. 6). Figure 7 shows the center of the sink.

The Sink is elongated in the northwest-southeast direction. East of the prominent ring fissure is a diatomite bed. The same diatomite bed is present at the bottom of the Sink as well. A lake with a surface area of about 12.5 square miles occupied the lower, southeastern part of San Simon Swale during the last

Fig. 6 The fissure around the rim of the San Simon Sink from the most recent collapse event of 1927, Stop 2-2.

(photo: Lokesh Chaturvedi)

Fig. 7 Center of the San Simon Sink showing sugarberry tree and diatomite beds in the background, Stop 2-2.

(photo: Lokesh Chaturvedi)

"pluvial" episode of the Wisconsin. San Simon Sink is a much smaller feature near the center of the old lake area. It collapsed to its present expression following the last high lake stand.

The hills around the sink are dune ridges (Fig. 8). Diatomite is overlain by 30 to 50 feet of mixed diatomite and reworked old lake beds. Under the diatomite, there is a layer of green sand with diatomite mixed with it. At the surface one finds calcified reeds. Diatoms are episodic organisms deposited in shallow water around reeds. Using a hand lens, one can identify a fair percentage of a calcareous algae. Therefore, this is a calcareous, diatomaceous, mixed sediment. Well WIPP-15 was drilled at the center of the sink to find where this bed occurs at depth to calculate the total drop.

This diatomite bed grades into a sandy-silty material with gastropod shells. Based on an age determination of the gastropod shells, Anderson calculates that the diatomaceous bed was deposited during the last part of the Wisconsin glacial age (15,000 - 20,000 years). Subsequent to its deposition a fair amount of collapse has taken place.

Anderson interprets the San Simon Swale and Sink as the northernmost reef margin depressions which are filled with deep Cenozoic fill as described by Maley and Huffington (Ref. 7). The Swale and the Sink are perhaps the youngest of these "string of bead" depressions. The Salado salt is totally missing in these depressions. Anderson's interpretation is therefore that these depressions are formed by localized dissolution of Salado along the reef margin from waters moving through fractures from the Capitan or Bell Canyon aquifer systems followed by collapse and filling by Cenozoic sediments.

As evidence for his deep-solutioning and collapse hypothesis for the sink, Anderson demonstrated cores obtained from WIPP-15.

Fig. 8 Diatomaceous dune ridges around the San Simon Sink, Stop 2-2.

(photo: Lokesh Chaturvedi)

Logs of these cores are shown in Fig. 9 of Anderson's field trip notes (Appendix II). WIPP-15 was drilled at the center of the sink and was cored to a depth of 810 feet. At the bottom of the core, a hard, micaceous Triassic sandstone was encountered, which may be the Santa Rosa. The sandstone can be compared with the sandstone on the ridge. At about 547 feet, the bottom of a uniform textured bed of sand was encountered. This sand, which is identical in composition and texture to the sand found on the surface covering the Old Red Soil, was encountered for 300 feet in the hole. Then, for the next 150 feet upwards, one finds zones with Caliche pebbles in sand. Anderson interprets this as representing a collapse event -- the sand must have been rapidly washed into the sink. Overlying this is a "pluvial" clay bed with artemisia pollens, followed by a 40 feet thick clay bed which is marly at the bottom. Above this is 30 feet of sticky clay with sand grains. The clay beds represent a "pluvial" period. Above the clay is a green sand bed and then marl again, overlying the green sand. This marl at the top has diatoms, which are the same as found in the diatomite beds on the surface.

Since these diatoms represent a lake margin and WIPP-15 is in the middle of the basin, the interpretation is that the lower clay as well as the marl is equivalent to the diatomite and a later collapse event made the marl slump into the depression. There is 250 feet of vertical collapse evident from this stratigraphy since the diatomite was formed. If one assumes the upper marl as equivalent to diatomite, then 150 feet of collapse has taken place since the last high stage of the lake. In either case, there was 150 feet to 250 feet of collapse since the last high lake stand, 18,000 to 20,000 years ago. After the collapse, playa sediment was deposited with bits and pieces of grass and local vegetation, mostly carbonate.

According to Anderson, the collapse of the Sink occurred only about 7,000 to 8,000 years ago -- sometime after the last lake stand.

Bachman stated that he believes the San Simon Swale was created by an old drainage system. He has seen gravels which are reworked out of Triassic and Gatuna formations, in the San Simon Swale north of the Sink. Further discussion on this point was held at the next stop.

Stop 2-3 -- San Simon Ridge (Anderson and Jones)

This stop was to see the outcrop of the Triassic sandstone which, according to Anderson, has faulted down between the San Simon Ridge and the San Simon Sink (cored in WIPP-15 at 810 feet depth). The major joints (Fig. 9) at this outcrop are parallel to the San Simon Ridge and the Capitan Reef. According to Anderson, the sandstone at this outcrop is indistinguishable from that cored in WIPP-15, in hand or under a petrologic microscope. Anderson claims a vertical displacement of almost 1000 feet between this outcrop and WIPP-15 -- only 1/2 mile apart. Anderson's field trip notes (Appendix II, Fig. 10) show a schematic cross section across the San Simon Swale, with interpreted displacements.

Jones (USGS) pointed out that since Triassic sandstone was not cored to its bottom in WIPP-15, we do not have a datum to calculate the displacement. Also, there is only about 30 feet of Rustler salt missing at this location. Bachman and Jones stated that they believed that there is an unconformity between the ridge and WIPP-15 location and the Triassic sandstone may have thinned to the west from this outcrop. Jones stated that he believes that the San Simon Sink is formed due to dissolution in the Rustler. Triassic formations were eroded in a valley along the Swale. The maximum dissolution was under that valley. According to him, processes similar to the ones which are known to have created Nash Draw, i.e. shallow dissolution through water seeping to the surface, were responsible for creating San Simon Swale.

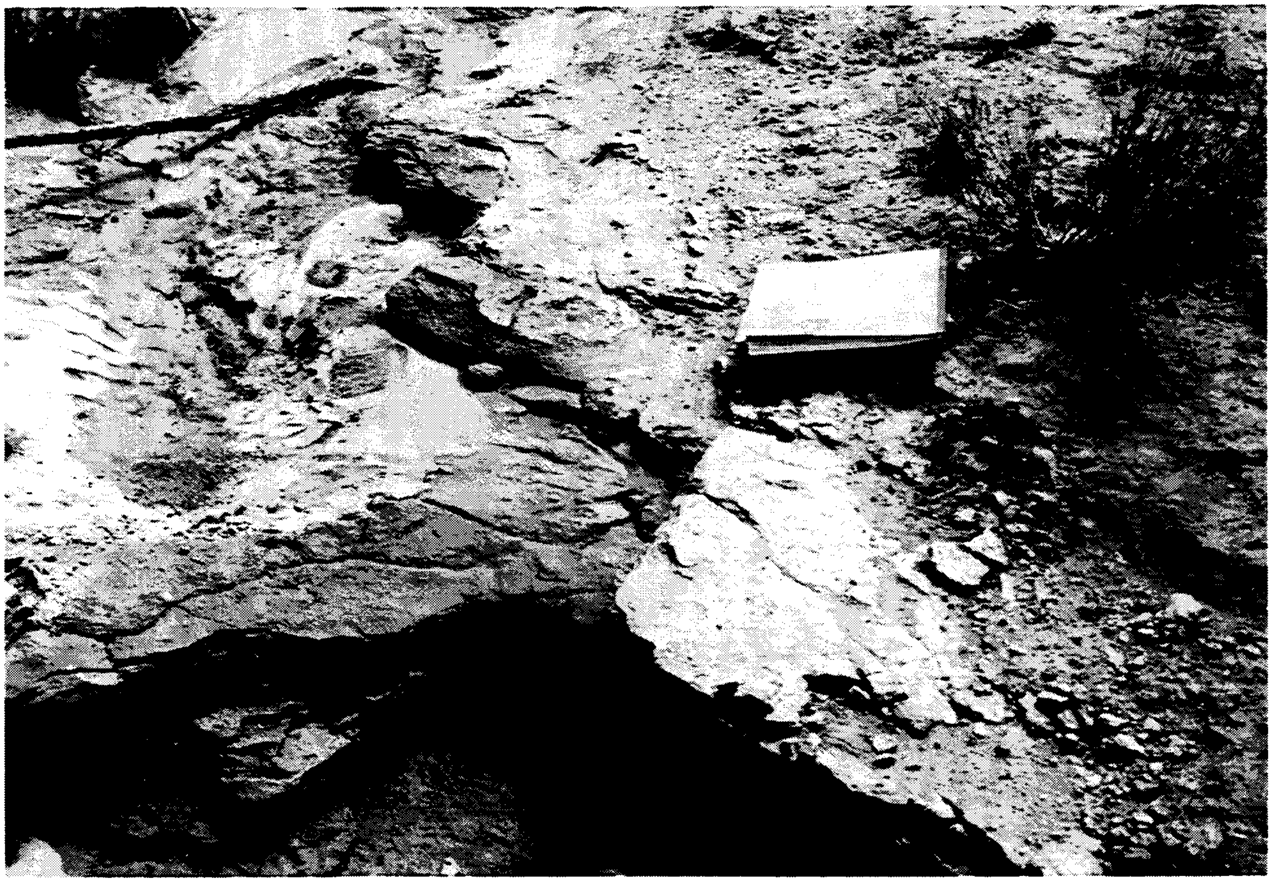

Fig. 9 Joints in the Triassic sandstone, Stop 2-3.

(photo: Lokesh Chaturvedi)

Anderson emphasized the regional setting, a string of depressions along the reef margin and the missing Salado beds in these depressions which point to deep dissolution as the mechanism. Jones emphasized that the dissolution is at the top of the evaporites and not at the bottom. This point is discussed further in Section 2.

Stop 2-4 -- Pierce Canyon Bridge (Bachman)

An outcrop of dipping Gatuna beds is present at this location. The beds are seen to be dipping 30^{o} to 45^{o} and they were not deposited that way. Bachman interprets the tilting of Gatuna formation to have taken place due to collapse of the underlying formations as a result of dissolution in the Rustler formation. Bachman emphasized that this represents only local Gatuna collapse and that there has not been widespread dissolution and collapse since Gatuna times.

Stop 2-5 -- Outcrop of Gatuna Formation

Gatuna formation, mainly consisting of conglomerate beds, is well exposed along the south wall of the Pierce Canyon at this location. Mescalero Caliche overlies the Gatuna formation and forms a crust exposed on the mesa. A gravel channel, representing an old stream bed during the Gatuna time, is exposed about 100 feet above the bed of the present Pecos River, in the south wall of the canyon. Bachman uses this stream channel presence as evidence for the hydraulic head being higher 600,000 years ago compared to the present.

Stop 2-6 -- Collapsed Rustler Outcrop (Bachman)

At this stop one sees an outcrop of Magenta Dolomite (part of the Rustler formation), which has collapsed and intermingled with the

Gatuna formation. Bachman showed this as evidence for dissolution in the Rustler formation at this locality. According to Bachman, dissolution in the Rustler which is at the top of the evaporite sequence, is the only major dissolution feature in this area. Its extent is known and it is not a threat to the WIPP site.

Stop 2-7 -- "Karst Domes" at Malaga Bend (Bachman)

This is one of the best localities in the Delaware Basin where the "structural domes" first described by Vine (Ref. 8) are exposed. Bachman has called these circular features "Karst domes", and has shown the difference between these features and the "breccia pipes" in Fig. 2 of his field trip notes (Appendix I). At this location near Malaga Bend, many of the domes are almost perfectly circular and others are elongate or irregular. Many of these are breached and partly eroded, exposing the older rocks at the center. According to Bachman, each one of these "domes" contains brecciated Salado formation at the center, surrounded by brecciated Rustler formation. Most of these show Culebra dolomite, a part of the Rustler formation, forming a ring around the feature. Some of these domes are not yet breached and do not expose the brecciated Salado. Bachman interprets these to be a kind of "solutional remanent" and compared these with features known as "Tower Karst", which consist of high (800-900 feet) towers of limestone formed in a random pattern. Such towers are found in China. Bachman stated that he does not quite understand the mechanism of formation of these circular domal features, but that they are very different from the breccia pipes.

Anderson pointed out that at least one of these dome-like structures has brecciated Salado gypsum accompanied by post-Culebra rock breccia at the center and could be a breccia pipe.

Stop 2-8 -- Intraformation Breccia in Salado (Bachman and Jones)

Bachman has described the process of formation of intraformation breccia through dissolution adjacent to aquifers (see Appendix II). This stop was intended to show such breccia in the Salado formation. Jones pointed out that a residue of salt beds about 20 feet thick, remains at this outcrop (Fig. 10). This bed must have been about 600 to 650 feet thick originally. The chloride is leached out by circulating ground water and the recrystallized nodules present probably have gone through three or four stages of recrystallization. In some of these nodules one can still see the crystal faces preserved. The brecciated Salado is overlain by broken up Rustler formation.

Stop 3-1 -- Outcrop of Cretaceous Rocks (Bachman)

This is one of the three localities in the vicinity of the WIPP site where early Cretaceous strata with marine fossils is exposed. The other localities are at Stops 1-2 and 3-2. Bachman has used the presence of Cretaceous strata which, according to him, "transgressed across the eroded edges of the underlying Triassic and Permian strata" as evidence for his belief that much of the regional dissolution in this area must have occurred before Cretaceous time.

Stop 3-2 -- Another Cretaceous Outcrop (Bachman)

Another outcrop of early Cretaceous rocks is present at this locality, which Bachman showed as a part of his postulated pre-Cretaceous unconformity record. Bachman pointed out that about 80 miles west of this location, in the Cornudas Mountains, early Cretaceous rocks rest on rocks of middle Permian age, displaying the unconformity.

Fig. 10 Intraformational breccia in Salado, Stop 2-8.

(photo: Lokesh Chaturvedi)

Stop 3-3 -- Carbonates in the Rustler Formation (Jones and Anderson)

This stop was to observe several outcrops along the road. Jones showed a breccia mass with carbonates from the Rustler and red gypsum derived from polyhalite probably belonging to upper Salado. No biogenic calcite or sulfur is present at this outcrop which means that the water from the Delaware Mountain Group has not been responsible for the brecciation here. Jones also showed an outcrop, where biogenic calcite with no laminations is present, which appears to have been formed by water from the DMG.

A few feet to the south, one can see the trace of the lamprophyre dike which is also exposed in Kerr-McGee and IMC mines, north and northwest of the WIPP site (Fig. 3.5-2, GCR). At this location only a change in color for about 15 feet, representing the weathered material derived from the dike is seen.

About 100 feet south of the dike, to the west side of the road, Anderson showed an outcrop of two "limestone dikes" which cross the highway. The replacement limestone at this outcrop closely resembles the unreplaced laminated anhydrite of the Castile formation, but generally contains less than 1% calcium sulfate. Obviously, the Castile anhydrite has been replaced by biogenic limestone, locally accompanied by sulfur. This area is in the basin, far from the Capitan Reef. The reduction of sulfate and its replacement by porous carbonate with a high carbon ratio (C-12/C-13) can only be ascribed to bacterial action. Bell Canyon aquifer is the only possible source for the water and organic matter needed for this process to flourish. Kirkland and Evans have proposed that artesian meteoric water and hydrocarbons (mainly gas) moved up from the Bell Canyon aquifer through fractures in the Castile formation and initiated the process of bacterial reduction fueled by hydrocarbons in the presence of aqueous solutions (Ref. 4). It is also noteworthy that there is no significant stratigraphic displacement of the Castile, as a result of this alteration.

Anderson used this outcrop to point out that water from the underlying Bell Canyon aquifer has moved up, through fractures, into the overlying evaporite sequence in this part of the Delaware Basin. He pointed out that the presence of hydrogen sulfide in drill holes in other parts of the basin suggests that the process may be taking place elsewhere in the basin as well. If this were so, Anderson implied, an important component of his proposed mechanism for deep dissolution and breccia pipe formation in the evaporite sequence would prove to be present.

Stop 3-4 -- Stateline Outcrop (Anderson)

This outcrop provides an excellent exposure of the Castile formation and the development of Castile microfolding. Anderson described the features at this outcrop as follows:

A limestone bed (L-bed), a few feet thick, occurs near the top of the road cut (Fig. 11) and can be seen "holding up" the prominent ridge and its extension to the south. This bed is traceable in the lower part of Halite-III unit in the Castile, all over the Delaware Basin, and is easily recognizable on gamma-ray and sonic logs of bore holes. At this outcrop in the northern part of the basin, the L-beds occur close to the top of the Castile. To the south, this bed is found at lower and lower stratigraphic positions. Anderson has correlated the logs (Fig. 13, Appendix II), and finds increasingly thicker salt sections in the Castile from north to south. In the southern part of the basin an entire salt unit is present above the marker bed. The Castile/Salado boundary is the top of the salt, and it is always the top salt bed that is chopped off in each successive section from north to south. Otherwise the salt beds are perfectly traceable all the way across from north to south within the Basin. Anderson interprets these observations to indicate that the Castile/Salado interface is an erosion/dissolution surface from north to south, truncating these individual salt beds.

Fig. 11 Exposure of Upper Castile formation showing the L-Bed, Stateline outcrop, Stop 3-4.

(photo: Lokesh Chaturvedi)

Another interesting point is that all the other Halite units in the Castile are at their thickest in the northern corner of the basin, except Halite-III bed which has been eroded, truncated and cut off. Figure 14 of Anderson's field trip notes (Appendix II) shows that if the position of L-bed is plotted on the isopach map of the H-III unit, it conforms almost exactly to the trace of the Castile and Salado interface as represented by the edge of the H-III isopach. Thus, during the erosion-dissolution interval between the Castile and Salado, this same limestone bed appears to have formed the top of a "ridge" marking the northern margin of H-III salt in the basin.

Another feature to notice at this outcrop is microfolding within the larger folds (Fig. 12). Several mechanisms have been proposed to explain their mode of formation e.g., earthquakes, slipping and sliding, old current ripple marks or the volume change involved in the conversion of anhydrite to gypsum or vice-versa. On the basis of detailed correlations of laminae and association of microfolding with macrofolding, Anderson concludes that the microfolding is related to macrofolding and is caused by tectonic forces. Two kinds of deformation are seen in these microfolds based on the thickness of a layer. Thin layers undergo "buckle shortening" while thick layers merely swell and undergo "layer shortening".

Anderson has used the study of these microfolds to date the salt flow structures encountered in ERDA-6 cores. According to him, the axes of microfolds correspond with the axes of the larger folds and these, in turn, correspond with the basic Cenozoic structural grain of the basin. Therefore he believes that the microfolds developed during the Cenozoic time. Anderson showed a sample of ERDA-6 core which shows boudinage type separation of the thick calcite layer. This is typical of Anhydrite II in ERDA-6. There is about 40% stretching which must have been caused by the development of salt flow structure underneath and associated dragging of this anhydrite bed. ERDA-6 core also shows

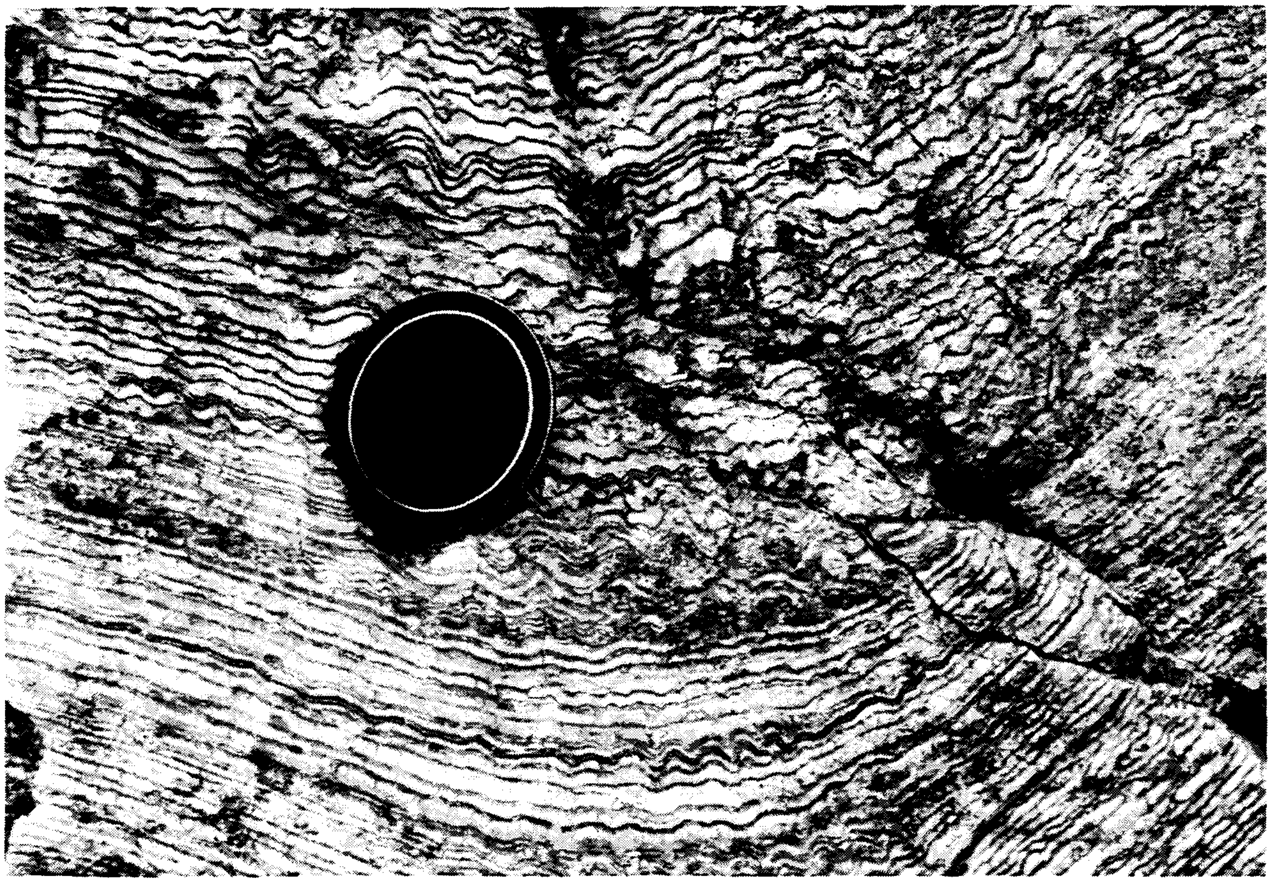

Fig. 12 Microfolding in Castile at the Stateline outcrop, Stop 3- 5. Camera lens-cap is for scale.

(photo: Lokesh Chaturvedi)

stretching of microfolds. If microfolding is a Cenozoic event, the age of ERDA-6 stretching being post-microfolding would also be Cenozoic or post-Cenozoic. Some other structural anomalies at the present WIPP site could also be related to the process of salt flowage structures as found in ERDA-6.

Jones expressed another view of the origin of the microfolds and stretching of layers. He termed it, "Subaqueous Brecciation" and described it as having taken place due to rupturing of the brittle material during tilting of the basin and the material from the brittle layers filling up the fractures between the non-brittle layers.

Dennis Powers stated that conversion from anhydrite to gypsum involves a volume increase in excess of 30% and asked whether this was not responsible for the microfolding? Anderson replied that microfolding only involved anhydrite and not gypsum. Where there was conversion, it resulted in swelling and break up.

<u>Stop 3-5 -- Castiles Limestone Buttes</u> (Anderson)

Kirkland and Evans (Ref.4) have described a number of locations of Castiles (limestone buttes) in the Western Delaware Basin (Fig. 15, Anderson, Appendix II). These buttes consist of brecciated masses of laminated limestone, many of which stand over 70 feet above the surrounding Gypsum Plain. This stop was to visit the exposure of Castiles (Fig. 13) marked as (3) on Kirkland and Evans map (Fig. 15, Anderson, Appendix II). Anderson described the features as follows:

The brecciated Castiles found on the Gypsum Plain in the western part of the Delaware Basin represent replacement limestone masses which have been exhumed. The process of replacement of original anhydrite with calcite perserving the original Castile structure of a breccia made up of finely laminated clasts is similar to that

Fig. 13 The limestone buttes (Castiles), Stop 3-6.

(photo: Lokesh Chaturvedi)

described for the "limestone dikes" at stop 3-3. If these buttes represent replacement of collapsed breccia chimneys, the collapse event may have provided additional access for waters, hydrocarbons, and bacteria from the Bell Canyon aquifer to facilitate replacement of anhydrite by sulfate-reducing bacteria. Four "Castiles" are present at this stop.

SECTION II

DISCUSSION OF ISSUES

SECTION II

DISCUSSION OF ISSUES

This Section summarizes the comments and interpretations concerning the field evidence seen at each stop, and concerning other geologic or hydrologic issues discussed at the field trip and important to the characterization of the WIPP site. This summary relates to (1) shallow dissolutioning involving formations down to the Rustler-Salado interface; (2) deep dissolutioning involving the Salado, the Castile, and the Delaware Mountain Group; (3) breccia pipes or similar domal features arising from dissolution; (4) tectonic faulting in the northern Delaware Basin; and (5) brine reservoirs in the Castile or Salado, particularly those of a size, location and pressure which may affect the integrity of the proposed repository. These issues are discussed in detail below.

1. Shallow Dissolution

The question of regional dissolution involving the top of the evaporite section (Rustler-Salado interface and above) was addressed by George Bachman at a number of field stops, viz. 1-1, 1-2, 1-5, 1-6, 1-7, 2-4, 2-5 and 2-6. The main thrust of Bachman's field evidence is that much of the regional dissolution in the Delaware Basin occurred before the development of Mescalero Caliche, i. e. prior to 500,000 years, and that the dissolution was the result of "shallow" processes dissolving the top of the evaporites through surface-induced water. At several of the stops mentioned above, there is very good evidence of dissolution, during the Gatuna times (600,000 years) but the Mescalero Caliche which has remained undisturbed, caps the dissolution features. The presence of stream channel deposits of Gatuna age shows that the conditions for dissolution were good at that time. The stream channel deposits in the Gatuna formation are found at least 50 feet above the present drainage system of the Pecos River. Bachman has interpreted this to indicate a greater hydraulic head during the Gatuna time compared to present.

Bachman used the outcrops of Cretaceous rocks at Stops 1-2, 3-1 and 3-2 as evidence for a dissolutional unconformity below the Cretaceous. No rocks of Triassic and Jurassic age are exposed in the western part of the Delaware Basin and Bachman has interpreted this to indicate that this part of the Basin was well above sea level and therefore subjected to surface erosion during all of Triassic and Jurassic time. The estimated rate of lateral shallow dissolution in the western part of the Delaware Basin, according to Bachman, is about 6 to 8 miles per million years (DEIS, p. 7-75). Based on a study of the local and regional distribution of early Cretaceous outcrops in the Delaware Basin, Bachman indicated that his previous estimate of the rate of regional lateral shallow dissolution as given in the DEIS is too high. Bachman now believes that a great deal of dissolution in the Basin occurred during the Jurassic time.

Bachman also showed a sink in the Nash Draw (Stop 1-5) and pointed out that there are at least 30 such sinks that he has seen in the Nash Draw depression. He described the mechanism of "Solution and Fill" first proposed by W. R. Lee (Ref. 5) and hypothesized that Nash Draw originated through this mechanism of regional lowering of the surface. Bachman used the gypsite spring deposits in Nash Draw (Stop 1-7) as additional evidence for near surface dissolution by meteoric water seeping into the ground.

Bachman's field evidence for a great deal of dissolution activity during the Gatuna time (600,000 years ago) is very good. The appearance of an intact Mescalero Caliche layer overlying collapsed Gatuna outcrops does indeed indicate lack of dissolution activity in those areas since the Mescalero Caliche time (500,000 years). However, the tilting of Gatuna beds at the Pierce Canyon Bridge and elsewhere suggest at least local post-Gatuna dissolution and collapse. Shallow dissolution due to meteoric water seeping through the ground does appear to be the dominant process for the creation of the dog-bone shaped depression called Nash Draw, west of the WIPP site. The evidence for most of the dissolution having taken place during Jurassic time has not yet been cogently presented by Bachman. The three outcrops of early Cretaceous rocks that were visited during the field trip (stops 1-2, 3-1, 3-2) conclusively show the presence of Cretaceous sea in the area. Extensive dissolution activity being limited to Jurassic times, however, appears to be speculative at this time. The proposed publication of Bachman's work on this issue referred to in the DEIS should provide the evidence for this.

2. Deep Dissolution

Roger Anderson is the main proponent of the idea of extensive dissolution having taken place in the Delaware Basin in the Salado and Castile formations at depth. According to this idea, relatively fresh water from the Capitan Reef aquifer and the underlying Bell Canyon aquifer has moved into the lower parts of the evaporative section and has advanced dissolution wedges from the reef margins towards the center of the basin. In defense of his thesis, Anderson presented field evidence at Stops 2-1, 2-2, 2-3, 3-3, 3-4 and 3-5. His evidence consisted of the following:

a. Bell Lake Sink and Slick Sink are good candidates for being the surface manifestations of the effects of deep dissolution.

b. San Simon Sink represents continued active dissolution at depth.

c. Correlation of the Triassic sandstone outcrop at San Simon Ridge and that encountered in WIPP-15 indicates a major displacement along the eastern edge of the Swale.

d. Limestone dikes (Stop 3-3) provide evidence for fresh groundwater from the Bell Canyon aquifer having invaded the overlying evaporite sequence in the middle of the Basin.

e. Correlation of Castile varves (such as seen at Stop 3-4) across the Delaware Basin provide evidence for a large western dissolution wedge apparently migrating eastward across the Basin (Ref. 1).

f. Brecciated Castiles on the Gypsum Plain (such as seen at Stop 3-5) have undergone biogenic replacement of anhydrite by calcite in the presence of water and hydrocarbons from the Bell Canyon aquifer.

Anderson outlined his model of deep dissolution for the Delaware Basin as a whole. The basic mechanism for the model is through "brine density flow" which consists of a supply of unsaturated water finding its way from the Capitan Reef or Bell Canyon aquifers through fractures to the overlying evaporites. As the water dissolves the salt and becomes heavier it flows downward and fresh water is propelled to the salt beds to replace it. This density-difference provides a convective flow for a continued dissolution process.

Anderson emphasized that one should look at the Basin as a whole for evidence of past and present deep dissolution. He pointed out that one can see practically all the stages of development of the deep dissolution process at the present time around the margin of the Basin. On the west side, the dissolution started earliest due to high hydraulic head and the gradient toward east. The presence of breccia pipes represented by hills A and C and the age and time of development of solutional collapse features in the Gatuna (being older than 1/2 million years) are logical consequences of deep dissolution that started early. On the other hand, there is relatively recent development in the north-eastern part of the Basin. The optimum conditions for dissolution and collapse in the Basin have shifted with time. At the present time these optimum conditions are found in the northeast part of the Basin. These conditions have produced features like San Simon Sink, Bell Lake Sink and perhaps the most recent

Kermit Sink. Possible changes in the climatic conditions would conceivably rejuvenate active dissolution in the western part of the Basin.

Jones pointed out that the geological and hydrological evidence in the northwest part of the Basin indicates that the flow is from the Guadalupe Mountains into the Basin. No collapse structure younger than the Mescalero Caliche (500,000 years) has been found in this area. All collapse involves materials which were accumulated during the Pleistocene time. There appears to be a barrier somewhere which makes the hydrologic system on the northwest side totally different than that on the northeast side. The subsidence and collapse of material in the northwest side occurred in a different geological environment than today's.

Anderson agreed with Jones about the timing and conditions of dissolution and collapse in the northwest part of the Basin. However, he pointed out that if one studies only the northwest part of the Basin, one may get the impression that the big pulse of dissolution took place during pre-Mescalero Gatuna times and that it is essentially over, but it is not so. He said that the process of dissolution in the Basin started soon after the Basin was uplifted, about 47 million years ago. It started in the west and in the south and has shifted throughout the Basin following the optimum conditions for development.

According to Anderson, the Bell Lake Sink (Stop 2-1) and Slick Sink which are 2 miles and 1 mile in diameter respectively are good candidate sites that display the effects of deep dissolution. Nicholson and Clebsch proposed (and Anderson concurs) the mechanism of upward moving water from the evaporite sequence accounts for the sulfate and chlorides in the Sinks (Ref. 6).

Slick Sink and Bell Lake Sink are on the margin of the Delaware Basin. If a line connecting the two is extended to the northwest, one finds some other suspicious subsurface features in that alignment. For example, Perry Federal #1-31 well, approximately 5 miles southeast of ERDA-9, falls in this alignment. The sonic log of this well shows that about 200 feet of infracowden salt (lower Salado) is missing. In addition, there are structural complexities in the northeast part of the site itself. Since these young features are in the basin and not on the reef, Anderson uses them as possible evidence for deep dissolution (in lower Salado and Castile) in the basin.

According to Anderson, the area of most active deep dissolution today is San Simon Swale and Sink. The profile of sediments cored from WIPP-15 shows that San Simon Swale is a young feature perhaps originated less than 30,000 years ago. San Simon Sink is even younger. This area shows that the dissolution in the Basin is an ongoing process.

Two different hypotheses for the formation of San Simon Swale and Sink were presented in the field and during the discussion sessions. Bachman proposed that there was a drainage channel along the Swale axis, overlying the reef, in which the dissolution began. According to him, there is no evidence that the dissolution has progressed towards the Basin. On the other hand, Anderson believes that the dissolution originates at the contact between the evaporite beds and the reef. The Cenozoic filled depressions to the south, which Malley and Huffington (Ref. 7) have described, root on the reef where the Salado has been dissolved out. San Simon Swale occupies almost the identical position along the inter-reef margin as these other "string of beads" depressions to the south. Anderson noted that there appears to be general acceptance that the breccia pipes at

Hills A, C and D root at the Reef aquifer. Since they occupy almost exactly the same position with respect to the Reef, why cannot a similar mode of origin be accepted for San Simon Sink? He emphasized that the simplest explanation for the uniform textured sand filling the deepest part of San Simon Swale is that the depression developed and was filled by sand. If there was a fluvial channel, some gravel should have been preserved in the section.

With regard to the vertical displacement between San Simon Ridge and San Simon Sink, postulated by Anderson, there was much discussion in the field and during the discussion sessions. Jones disagreed with Anderson's postulation and emphasized that it is not necessary to think in terms of massive displacement to explain the Triassic Sandstone Ridge outcrop at the San Simon Ridge and its encounter at 800 feet depth in WIPP-15 at the center of the San Simon Sink. According to him the dip of the Sandstone is sufficient to explain the drop, since the Sandstone encountered in WIPP-15 may be from a lower stratigraphic horizon than that seen in the Ridge area.

The invasion of the evaporite sequence by groundwater from the underlying Bell Canyon aquifer in the Delaware Basin (away from the Capitan Reef) appears to be clearly demonstrated by biogenic replacement of Castile anhydrite by limestone. Such replacement limestone is exposed in "limestone dikes" and in "Castiles." This has been used by Anderson as a strong evidence for one component of his proposed mechanism for deep dissolution in the Basin.

For additional evidence of deep dissolution, Anderson referred to his work on the correlation of halite beds and dissolution breccias across the Delaware Basin (Ref. 1). The tracing of identified dissolution horizons to large areas of deep dissolution west of existing halite beds shows that it is the removal of salt from the lower part of the Salado and upper part of the Castile formations that has caused collapse of the depressions in the Delaware Basin.

The phenomenon of deep dissolution and its time and place of occurrence may be significant for the WIPP site. If deep dissolution has started at the evaporite/reef contact, it involves a lateral sapping and progression in the evaporite beds towards the center of the Basin and thus towards the WIPP site. In this case the task would be to define the present location of the dissolution front, and its rate of advance. If, on the other hand, all the dissolution is at shallow depths, at the top of the evaporites, the potential danger to the site may be much less.

3. Breccia Pipes

Five of the trip stops, viz. 1-2, 1-3, 1-9, 2-7 and 3-5, related directly to the question of breccia pipes. Two known breccia pipes at Hills A and C were visited. Some of the field trip participants also visited the breccia pipe outcrop in the Mississippi Chemical Corporation's mine which is the same breccia pipe that outcrops at Hill C.

The origin and formation of these features are not yet clearly understood, although such pipes or chimneys of brecciated rock are encountered in many evaporite basins of the world. Anderson's hypothesis of their formation through upward stoping propelled by "brine density flow" appears to be the most favored explanation at present.

Two main points of discussion concerning the breccia pipes emerged during the field trip:

a. Whether or not the breccia pipes are confined to the Capitan Reef area;
b. Whether the present hydrologic system in the Reef and the Basin is capable of forming the breccia pipes.

Regarding point (a), according to Anderson and Kirkland, "Recent studies in the Delaware Basin ... have identified hydrologic systems that appear to be responsible for the development of a variety of brecciated and collapsed dissolution features" (Ref. 2). Anderson points to a number of features in the Basin which may be breccia pipes or their manifestations. Among such features are several unexplored "Vine's domes" in the Basin, the Castiles and the features where Salado marker beds show closed steep depressions in structural contours. Bachman emphasized that he believes that the breccia pipes occur only above the Capitan aquifer system, and do not exist in the Basin. No confirmed breccia pipe has been identified in the Delaware Basin as yet.

There was some discussion during this field trip concerning the origin of the cluster of circular features at Malaga Bend (Stop 2-7), called "Karst domes" by Bachman. Bachman's field trip notes (Appendix II) explain the difference between a "Karst dome" and a "breccia pipe'. Although Bachman believes that they are not breccia pipes, due to older rocks being in the center surrounded by younger ones, the question is not yet settled. Some of these features are remarkably circular. Many have not been breached at all and so their internal structure is not exposed. Whether these domes have resulted from shallow solution in the Salado, or they represent the tops of deep breccia pipes, is open to question. Drilling at the center of a dome that is the most likely candidate for being a breccia pipe might settle the question. If the drilling found the dome to be a breccia pipe, it would show that breccia pipes do occur in the Delaware Basin, and therefore could be present at the WIPP site.

Regarding point (b), Bachman showed Gatuna formation outcrops being 50 to 100 feet above the present drainage system of the Pecos River, implying that the drainage system about 600,000 years ago was that much higher. From this, Bachman concludes that the hydraulic head in the Capitan Reef aquifer was higher during the major dissolution activity in the Gatuna time. Also, since the proven breccia pipes at Hills A and C are older than the Mescalero Caliche (500,000 years), Bachman believes that the higher hydraulic head during the pre-Mescalero Caliche times was responsible for creating the breccia pipes which lie over the Capitan Reef aquifer.

Peter Davies, who is a graduate student at Stanford University conducting research on the mechanics of collapse of breccia pipes, pointed out that Anderson's "density-difference" driven model for the formation of breccia pipes is not dependent on a hydraulic head. A change in the hydraulic head would not therefore change the rate or amount of dissolution. Anderson agreed with this statement and pointed out that the optimum conditions for a breccia pipe developing is like a wave front that passes across the Basin and one sees evidence for different stages of development at different points in the Basin. Development of a breccia pipe at one location uses up the available fractures and moves on to the next stage.

Jones disagreed with Anderson and stated that the geologic and hydrologic system in the northwest part of the Basin is different than that in the northeast (San Simon Swale area) part of the Basin. According to Jones, the subsidence and collapse of material seen at Stops 1-1, 1-2, 1-3 and 1-4 took place in a different geologic and hydrologic environment than what we see today.

Wendell Weart pointed out that if there is no head, the water from an underlying fresh water aquifer would not reach the evaporite beds. He agreed, however, that there is sufficient head in the Capitan Reef aquifer system at present for the water to reach the evaporites if a connection existed. He stated that when there is sufficient information, we will find that there is no one single explanation for the location and time of formation of these features. A combination of factors, such as a reduction in head, change in salinity, etc. may have changed the process. There is simply not sufficient information today to answer these questions. Weart then outlined the plans for deepening the drillhole WIPP-31 (at Hill A). The plan is to drill to the bottom of the collapsed rubble zone to see where it originates. During drilling it is planned to check for water and to calculate the present hydraulic heads. The chemistry of water in different zones also will be analyzed. This information is expected to be very valuable in understanding the phenomenon of breccia pipes.

4. Recent Tectonic Faulting

The question of recent tectonic faulting in the Delaware Basin came up during discussions at the San Simon Ridge (Stop 2-3). As discussed in Item 2 (Deep Dissolution) in this section, Anderson believes that the exposure of Triassic Sandstone at the San Simon Ridge and the cores from WIPP-15 in the San Simon Sink combine to indicate tectonic faulting, which may be responsible for initiating deep dissolution in this area. To further support this idea, Anderson said the alignment of joints at the Ridge outcrop is north-northeast which is also parallel to the general tectonic grain in this area (see Figure 11, Appendix II). Since the collapse in the San Simon Sink is geologically very recent, Anderson argues the postulated fault to be also recent and perhaps presently active.

Jones and Bachman did not believe it was necessary to invoke faulting to explain the stratigraphic relationship of the Triassic Sandstone at San Simon Ridge outcrop and that encountered in WIPP-15. Weart thinks that jointing parallel to the Swale would be expected as a response to Swale subsidence and need not depend on tectonic faulting. The question of the presence of tectonic faulting in the Basin therefore remains unresolved.

During the January 17-18 meeting, Jonathan Callender (UNM) raised the issue of possible tectonic activity in the Delaware Basin associated with the Rio Grande Rift. That issue was not discussed during the field trip. The report of the January 17-18 meeting contains a summary of Callender's arguments (EEG-6, pp. 23-24).

5. Brine Reservoirs

The scheduled field trip stop to ERDA-6 well location was cancelled to conserve time and since there is not much to "see" at that location. George Griswold distributed a four-page note concerning the occurrence of brine reservoirs near the WIPP site. This note, included in Appendix II, contains the locations, flow and pressure data and the geochemical analyses of brine occurrences in wells near the WIPP site.

There was discussion about this issue during the last day of the field trip. The main point made by the speakers, principally George Griswold, was that despite knowledge of their existence in this area for several years, little is known about their origin, pressure, size and interconnection. Such information is needed to permit an evaluation of their potential impact on the WIPP repository.

Griswold mentioned an additional occurrence of brine which is not reported in his note (Appendix II), or in any other publication relating to the WIPP project. On inquiry after the field trip, Jones provided the following information concerning this occurrence:

Sometime in the 1930s, an exploration well known as "H and W Danford well No. 1" was drilled in Section 9, Township 22 South, Range 29 East, about 12 miles west of the center of the WIPP site, west of Nash Draw. The well was drilled by cable tool method to a total depth of 3322 feet. At approximately 2200 feet below the surface, the drillers encountered a dike (igneous rock) in Halite II bed of the Castile formation. A pocket of brine was encountered associated with the dike. The brine rose in the hole indicating it was under pressure. No data on the pressure, quality or quantity of the brine is now available.

In referring to this occurrence of brine, Griswold pointed out that the lithium in geothermal water is generally connected with a magmatic source. In this case, the brine was encountered at the same location as the dike. Could there be a genetic connection between the two? According to Jones (personal communication), lithium can be enriched in evaporite basins and does not necessarily represent a volcanic source. There is a need for research on the origin of brine. its possible association with igneous material, the possibility of offshoot sills from the dike and the possible connection between the thermal flux represented by the dike and the tectonic activity represented by the Rio Grande Rift.

SECTION III

POST FIELD TRIP COMMENTS

SECTION III

POST FIELD TRIP COMMENTS

The Environmental Evaluation Group requested the participants to send them written comments on the field trip and its relevance to the geotechnical issues of the WIPP site. Eleven participants responded to this request. Their comments, arranged here in alphabetical order of the author's name, have been used in formulating the recommendations outlined in Section IV of this report.

WIPP SITE FIELD TRIP - RESPONSE

1.-2. Geologic-hydrologic questions:

The crux of the regional dissolution problem centers on two somewhat different views of the progress of dissolution in the basin. One view, which I do not hold, is that much dissolution is very old (pre-Cenozoic) and that the situation has essentially stabilized with little activity since Mescalero time (last 500,000 years) and this activity is confined to near-surface effects.

The alternate view, which I hold, is that the dissolution potential is determined by the late Cenozoic and still existing structural and hydrologic geometry of the basin. Given this geometry, there is no reason to believe that dissolution should stop or markedly slow and that it is a continuous on-going process. The most active dissolution older than Mescalero is naturally and logically demonstrated in the western and central parts of the basin. Just as logically, the present areas of active dissolution have shifted with time to the central and eastern part of the basin. The several stops of the trip, including the Castiles, breccia chimneys, Nash Draw springs, and San Simon Sink nicely illustrate the increasing youthfulness of dissolution to the east.

The question of the integrity of the evaporite sequence above the reef and in the basin remains unresolved. Collapse structures above the reef are now recognized by all concerned; however San Simon Sink, although it occupies the same position as Hill C with respect to the reef, is sometimes dismissed as near-surface (top of evaporite) feature. Similar features to the southeast along the reef are associated with a deep-seated dissolution wedge that is working its way into the basin at the disposal horizon. The fact that San Simon Sink and swale (in part) may be less than 50,000 years old and represents continuing activity conforms to the view that the area of most active dissolution in the basin is now the northeastern part. It also raises a question concerning the long-term integrity of the site from on-going wedge-like dissolution.

The integrity of the evaporite sequence in the basin is unproven. The presence of brecciated collapse chimneys (Castiles) in the exhumed western part of the basin and the proposed mechanism for their formation indicates collapse of evaporites from below. It is not known how far this process extends eastward into the basin. Bell Lake and Slick Sinks are possible surface expressions of such features. Similarly, several depressions in geophysical logs north and east of the site as well as local loss of continuity in a number of seismic profiles suggest that collapse events may already have moved into the eastern part of the basin. To my knowledge, these possibilities remain untested and should be considered real until proven otherwise.

3. Brine reservoirs:

The brine reservoir problem relates to the age and origin of the so-called "disturbed" area which involves the site and the area to the northeast. The seismic profiles I have seen indicate that the larger structures penetrate the DMG as well as the lower evaporites. The degree of "Blocky structure" and disorientation is difficult to reconcile with simple salt flowage structures and there is a real possibility that dissolution effects involving the basin aquifer are involved in this region. The penetration of structures by brines remains to be explained and needs to be explained. The age information from ERDA 6 indicates a Cenozoic origin which leaves open the possibility that relatively young dissolution may be partly responsible for the complex structure.

It is disconcerting that this large and significant a feature, associated with pressurized brine, and beneath the site, remains so much a mystery. I would recommend at least one completely independent geophysical evaluation of all data and some additional inputs as to the type and origin of the structures and the brine. This should be followed by several test holes at key locations to prove or disprove ideas concerning origin.

Roger Y. Anderson
July, 1980

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RECEIVED
JUL 2 2 19..
ENVIRONMENTAL
EVALUATION GROUP

Mr. Robert Neill
Environmental Evaluation Group
320 E. Marcy Street
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Dear Bob:

COMMENTS ON EEG FIELD TRIP TO WIPP SITE AND VICINITY

In answer to your request, the following comments are made regarding the field trip to Carlsbad.

The EEG is to be congratulated on the excellent organization of the trip. The logistics and itinerary were well planned. The people responsible for this can take pride in a job well done. The stops on the field trips and the descriptions provided primarily by Anderson, Bachman, and Jones were very beneficial and informative.

In our opinion, the differences in interpretations were not resolved by the field trip; but at least, they were aired and the opportunity provided to examine all issues and discuss the differences.

The central issue appears to be the question of the effect of dissolutioning and the development of breccia pipes on WIPP during the required period of isolation. The location of Hills A and C on or near the reef and their modes of development have been investigated adequately enough to remove concern that these phenomena pose a threat to the WIPP site. Regional dissolution, which characterized the Malaga Bend and Castiles areas, is not seen near WIPP. Anderson's gravity flow model and his concern that such a mechanism might operate at WIPP is not supported by anything observed on the field trip.

Obviously, opinions on these issues vary, and differences will persist regardless of the amount of investigation performed. In matters of geologic phenomena and processes, questions will always remain incompletely answered. The point must be reached, however, where we say that the next step should be taken with an acceptable level of risk. That step is the SPDV, which involves no risk to the public (only the inherent risk to workers in the underground) and is the only way to obtain the next increment of information necessary to directly assess the repository zone and the processes operating therein.

We appreciate the opportunity to be part of the field trip. The dialogues and communications established by the trip are very beneficial to all, regardless of point of view.

Sincerely,

Bill

William P. Armstrong
WIPP Project Office

Alan Kuhn

Alan K. Kuhn
WIPP Project Technical
Support Contractor

WIP:WPA (4145)

cc: W. Weart, 4510, SNLA

Box 1028 Star Rte
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June 28, 1980

Dr. Robert H. Neill, Director
New Mexico Environmental Evaluation Group
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Dear Bob:

I am very impressed by the efforts of you and your staff to arrive at a fair and just evaluation of the WIPP site. You have a difficult task and I congratulate you on the work you are doing.

In response to your letter of June 27 I send the following comments:

1. The field trip addressed three major geotechnical questions.
   a. Types of dissolution. In my opinion these processes include surface and near-surface dissolution such as "erosion by solution and fill", other karst related phenomena, and so-called "deep dissolution". The latter is a poorly defined process. Field and drilling evidence do not support the concept of deep, blanket dissolution of salt units in the Castile Formation deep in the Delaware basin during Cenozoic (esp. Quaternary) time. The substantiated breccia chimneys are probably the only result of deep-seated dissoltuion.
   b. Breccia chimneys (breccia pipes). Features known definitely to be breccia chimneys are restricted to areas overlying, or back reef from, the Capitan aquifer complex. On the basis of extensive field evidence and limited drilling no breccia chimneys are known within the Delaware basin in the strict sense. Breccia chimneys do appear to have a deep-seated origin within the Capitan aquifer system but field evidence indicates that major collapse in both Hills A and C (known breccia chimneys) occurred during Gatuna time (at least 600,000 years ago) and certainly before the beginning of Mescalero deposition (at least 500,000 years ago).
   c. Dissolution during geologic time. Field evidence suggests that dissolution of soluble rocks in the Delaware basin began as an active process soon after these rocks were deposited in Permian time. Dissolution has occurred during two broad intervals: (1) after Permian and before Cretaceous time, and (2) since Cretaceous time. It is a continuing process at some places today. Owing to the long history of dissolution

and the redistribution of various rock types by dissolution and reprecipitation it is essentially impossible to establish a rate of dissolution for a hypothetical "dissolution front". In my opinion the concept of a neatly geometric "dissolution front" is invalid.

2. Relevance of field trip stops. All stops were designed to address one of the above major geotechnical questions. Only one stop (2-8) was arranged as a spectacular--to show field trip participants the chaotic results of dissolution of major salt beds in the Salado Formation.

3. I am not qualified to comment at length on the significance of "brine reservoirs". Based on the geographic position of known reservoirs I suspect that they may be related to activity in the Capitan aquifer system during Middle Pleistocene time.

4. Time was inadequate for a complete summary of questions addressed on this trip. My main summary statement is that I can not accept the concept of "deep dissolution" within the Delaware basin for the following reasons:

a. Regional stratigraphic evidence indicates that some dissolution occurred along the western edge of the Delaware basin before Cretaceous time. At that time the region was more nearly at sea level than at any time since. Consequently, it is not necessary to resort to a deep-seated dissolution.

b. I have not seen evidence for the "blanket" dissolution of salt beds in the Castile as advocated by Roger Anderson. There is minor brecciation in the Castile (as at stop 3-4) but this is not comparable to the chaotic brecciation of the Salado where the latter is exposed at the surface (as at stop 2-8).

c. I have not seen evidence that salt deposition in the Castile sea was basin-wide at any given time. On the contrary there is overwhelming evidence in the subsurface that salt beds in the Castile were deposited in discrete "pans" or local sub-basins. These are facies deposits. This fact introduces the improbability of correlating individual breccias (if they exist) across the entire basin. In the interior of the basin individual salt beds are well preserved in the Castile in the subsurface. Around the fringes of the basin the salt beds are absent because they were never deposited.

5. It would be intellectually stimulating to pursue many more geotechnical problems in southeastern New Mexico but at this point in the history of the WIPP site I do not see how further complex studies can be justified to the taxpayer.

In my opinion the Salado Formation within a radius of at least 3 miles around the proposed WIPP site has been stable throughout most of Tertiary time and dissolution has been relatively inactive at least since Middle Pleistocene time. Dissolution of the Rustler Formation along the eastern margin of Nash Draw during Late Pleistocene time does not appear to have affected the Salado Formation.

Yours sincerely,

George O. Bachman

George O. Bachman

cc. Armstrong (DOE)
Jones (USGS)
Powers (Sandia)
Weart (Sandia)

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Environmental Evaluation Group
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P.O. Box 968
Santa Fe, New Mexico 87503

Dear Bob:

I want to tell you that I think you and your group did an excellent job organizing last week's field trip. The trip ran smoothly and the exchange of ideas and information was effective.

Enclosed are my comments on a number of features that were observed and discussed during the trip and which I feel are particularly important to WIPP. I have also enclosed a recent report of mine that contains some information on dissolution-collapse in other salt-bearing basins, which you may find useful. The references and research cited in my field trip comments are also contained in this report.

I look forward to reading the EEG summary of last week's trip.

Sincerely,

Peter B. Davies

Comments on June 16-20 EEG Evaporite Dissolution Field Trip

Peter B. Davies
Dept. of Applied Earth Sciences
Stanford University
June 25, 1980

The June 16-20 field trip, organized by EEG, provided an effective forum for discussions concerning evaporite dissolution in the vicinity of the WIPP site. Both trip leaders, George Bachman and Roger Anderson, did an excellent job in their selection of field trip stops and discussion of pertinent field evidence. George and Roger demonstrated quite clearly that a wide variety of dissolution processes have occurred within the Delaware Basin at various times and locations.

Relative to WIPP, I feel that a central question is whether or not there has been, or could be, deep-seated dissolution in the interior of the Delaware Basin. By deep-seated dissolution I mean dissolution in the lower portion of the Salado and/or in the Castile. This dissolution could be either regional or local, though I think that in many cases, localized dissolution represents the earliest stages of regional removal of salt.

Roger Anderson has presented strong evidence for deep dissolution in the interior of the basin in the Big Sinks area. At this location, Maley and Huffington (1953) noted the correlation of marked thinning of salt in the Salado and Castile Formations with large depressions that are filled with Cenozoic alluvium. Anderson has used lithologic and geophysical log correlations to show that the removal of salt has occurred in the lower portion of the evaporite sequence (lower Salado and Castile), rather than at the top. This information was discussed at Stop 2-5 and is also presented in the New Mexico Bureau of Mines and Mineral Resources Circular 159 (Anderson, 1978). Also at Stop 2-5, George Bachman desribed the alluvial material as being Gatuna Formation with capping Mescalero Caliche. If this relationship holds for the entire Big Sinks area, it implies a mid-Pleistocene age for this deep dissolution-collapse activity.

The Bell Lake Sink (Stop 2-1) is a feature that might be attributed to deep-seated dissolution during late Pleistocene. At present, the best piece of evidence for a deep-seated origin is the requirement for a source of sulfate and chloride for the formation of the gypsum-clay dunes, which are now observed on the flanks of the sink. One logical source for this material would be the underlying evaporites at a depth of approximately 1000 feet. In Anderson's interpretation, the pathway to the surface for the sulfate and chloride is provided by a deep-seated collapse structure. A possible historic analog to this senario is the Meade Salt Well in Kansas. This sink occurred in March, 1879 and the sinkhole was partially filled with brine from dissolution of the underlying evaporites at a depth of somewhere between 500 and 1000+ feet (Johnson, 1901; Frye and Schoff, 1942).

Further work is required to fully determine whether or not Bell Lake Sink (and/or Slick Sink) is a surface manifestation of deep dissolution. A series of shallow holes would show the presence or absence of the 300,000 year old "red soil" horizon at depth in the sink. If this soil is present, indicating that Bell Lake is not a deflation feature, a deeper hole into the evaporites would be warranted. The objective of this deeper hole would be to look for vertical displacements, collapse deformation and dissolution residues. If these relatively young sinks are deep-seated features, the significance for WIPP would be the demonstration that localized, deep-seated dissolution has occurred within the portion of the Delaware Basin that has been considered completely stable.

Two other features that clearly require further analysis are the two depressions in the 124 Marker Bed within and adjacent to the WIPP site. One important observation made by George Griswold is that, if deep dissolution has been occurring at these locations, then these depressions are what we would expect to occur as a result of subsidence associated with this dissolution. Another important comment was made by Charlie Jones. He noted that in these depressions and in other features that he felt were similar, there has been intraformational redistribution of material resulting in the thickening of salt beds within these structures. The preliminary results from my work on the mechanics of collapse show that the thickening of salt beds described by Charlie is also a structural feature that one would expect to find during the early stages of collapse. This work has been summarized in Section 4.2.3 of the accompanying report and the specific conclusion regarding bed thickening is cited on page 33. I agree with George Griswold that tying these depressions to deep dissolution at the present time is speculation. However, because these structures contain features that one would expect to find associated with subsidence caused by deep-seated dissolution, and because of their proximity to the WIPP site, further analysis is definitely warranted. Additional seismic data on these structures may already exist, though it has not yet been released (to my knowledge). Also, deepening of WIPP-34 would provide information on the presence or absence of dissolution residues within the underlying Castile Formation.

Does deep dissolution represent a serious threat to the long-term integrity of the WIPP repository? My conclusion is that we lack sufficient information at the present time to answer this question with a high level of confidence.

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GEORGE B. GRISWOLD, PH.D.
PRESIDENT

July 2, 1980

Mr. Robert Neill, Director
State of New Mexico Environmental
Evaluation Group
P.O. Box 968
Santa Fe, N.M. 87503

Dear Bob:

I thoroughly enjoyed the field trip to Carlsbad. My conclusions are short, consisting of the following:

1. The concepts of salt dissolution and breccia pipes were well expressed by both George and Roger. I see plausibility in both arguments, and as with most geologic processes there is strong likelyhood that both are correct! Some features may be restricted to the reef and some may manifest themselves only in the basin.

2. No additional information concerning reservoirs is on hand over what we had back in 1975-1976. For that matter, we may be a little further behind, because according to Dennis Powers the seismic profile over the Belco well that Colin Mc Millan ran for me back in the summer of 1976 is not conclusive. Colin and I thought it revealed a definite anticline with thinning of salt on the flanks. Dennis indicated that no new seismic profile has been run in that area; therefore I am left in limbo as to whether seismic surveys can detect a known brine bearing salt anticline. At one time I was under the hopes that brine reservoirs were restricted to the middle of the Castile. Charlie Jones has provided evidence that they can occur anywhere in the Castile. If this is true, could they occur up in the Salado?

3. I believe that a lot of dollars and time have been spent on WIPP. Decisions as to where to proceed from here are the responsibility of the management of the project. Further discussion or field conferences will not add to the understanding of salt dissolution.

July 2, 1980

4. My most essential conclusion was that most people will treat you a lot nicer if you are pro site geology rather than someone like Roger who has a propensity for pointing out possible flaws in our geologic interpretations.

Best of luck on your consolidated report.

Sincerely yours,

GEORGE B. GRISWOLD

GBG:tcj

cc: Dennis Powers, Sandia National Laboratories
Roger Anderson, UNM
George Bachman, USGS
Charles Jones, USGS

New Mexico Bureau of Mines & Mineral Resources
Socorro, NM 87801

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Information: 505/835-5420
Publications: 505/835-5410

July 1, 1980

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ENVIRONMENTAL
EVALUATION GROUP

Dr. Robert H. Neill, Director
Environmental Evaluation Group
N.M. Health and Education Department
P.O. Box 968
Santa Fe, NM 87503

Dear Bob:

This is in response to your letter of June 27, 1980 requesting brief commentaries from participants on the June 16-18 field trip of the WIPP region. 1) Views on major geologic or hydrologic questions addressed: The surface evidence for solution-subsidence features that could effect repository integrity was reviewed in the field. Where available, subsurface data were presented and related to the surface features (e.g. Stop 1-4, Hill C). Questions invariably arose when there was inadequate subsurface evidence (geological, geochemical, geophysical, or hydrological) to answer basic questions related to site integrity over an appropriate interval of geologic time. Questions on basic causes and aerial distribution of "recently" active features (breccia chimneys and sinks) were usually unresolved. However, there was general agreement that known breccia chimneys (Hills A & C) and modern collapse features (San Simon Sink) are in some way related to the Capitan Reef trend and aquifers.
2) Comments on relevance of stops and suggests for further studies: Most stops were quite relevant to the WIPP site investigation. The "castiles" may be an exception to this observation.

Further test drilling is definitely recommended in areas of possible collapse reasonably close to the Los Medanos site (e.g. Bell Lake-Slick Sink, and a "disturbed" area southeast of Stop 1-9 (Drilled Site) and east of Salt Lake mentioned by Roger Anderson). I personally favor Bachman's inference that these features probably don't have a deep-seated (breccia chimney) root. However, WIPP research efforts will never gain credibility without careful subsurface investigation of at least one or two features of possible deep-seated collapse origin that are located within the Delaware Basin and close to the WIPP Site.

A geophysical (seismic) profile is recommended, which would tie WIPP 15 at San Simon Sink to the Triassic bedrock outcrops to the east (Stop 2-3). This investigation is needed to establish presence (or absence) of an eastern fault boundary zone for San Simon Swale (as proposed by Anderson).

3 and 4) Comments on relevance and significance of brine reservoirs, and problems not addressed on the field trip: Hydrologic questions discussed at the January 1980 conference could not be adequately addressed on the trip. This was partly because of absence by the key persons with expertise on hydrology of the region (e.g. Hiss, Mercer, and Gelhar).

5) All in all the trip was very worthwhile, if only because of the chances to get a diverse group together in the field and to gain better perspective of the time and space scale of geologic features involved. A positive result, personally, was that I now feel that deep burial in salt is a viable repository option and that the Delaware Basin Salado Formation is a reasonable place to locate such a repository. However, I do not feel that an important component of the scientific community (or the general public) will accept this option until technical doubts are laid to rest on several possible breccia-pipe features near the WIPP site (including those mentioned under 3 and 4). I believe it is unfortunate that the sites early designated for detailed investigations were limited to the specific Divide-Los Medanos area. Places to the south (in both Texas as well as New Mexico segments of the Basin) with preserved Salado-Castile sections should also have been considered for the pilot project repository. In fact this option may still have to be explored if breccia chimneys are indeed present in the Delaware Basin area contiguous to the Los Medanos site (e.g. between Slick Sink and the site).

Sincerely,

John W. Hawley

John W. Hawley
Environmental Geologist

JWH/ld

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

DEPARTMENT OF GEOLOGY
School of Earth Sciences

21 June 1980

Dr. Robert Neill
Environmental Evaluation Group
Santa Fe, New Mexico

Dear Bob:

Here are a few impressions from the Carlsbad field trip. They are strictly my personal views, and should not be taken as representing opinions of the National Academy or the WIPP panel.

It was really a great trip, and I want to thank you once more for inviting me. To spend a few days in the field with advocates of various positions about the WIPP site and its surroundings was a valuable experience. I'm sure the interchange of opinions will go a long way toward resolving some of the long-debated issues in characterizing the site.

I've had enough experience with field trips to appreciate how much work went into organizing and conducting this one. I think your organization did a remarkable job -- everything went smoothly, the whole group seemed satisfied, and we had ample opportunity to see all the important outcrops and to discuss them thoroly. You and the EEG should be heartily congratulated.

With best regards,

Konnie

Konrad B. Krauskopf

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ENVIRONMENTAL
EVALUATION GROUP

Ruminations on field trip to WIPP site and vicinity 16-18 June 1980

The field trip was concerned with evidence for and against recent movement of fluids at depth in the evaporite beds, movement that might jeopardize the integrity of a repository in the Salado at the WIPP site. There was little or no discussion of other possible objections to the site, for example Jon Callender's worry about tectonic activity and the often cited alarm over the presence of exploitable potash and hydrocarbon resources. Regarding fluid movement, arguments revolved around three subjects: (1) regional deep dissolution (2) breccia pipes (3) brine pockets.

Regional dissolution. Evidence for large-scale regional dissolution is overwhelming, but controversy remains as to the timing and depth of the major dissolution episode or episodes. Roger Anderson's correlation of varves suggests strongly that the surface of the Castile was partly dissolved before the Salado was deposited; George Bachman has good evidence for a dissolutional unconformity below the Cretaceous. Whether extensive dissolution has occurred more recently is less clear. The widespread preservation of the Mescalero caliche cap, and apparently undisturbed structures in the Gatuna at Pierce Canyon, indicate that post-Gatuna dissolution is minor; on the other hand, the tilting of Gatuna beds at the Pierce Canyon bridge and elsewhere suggest at least local post-Gatuna collapse. The best evidence for very recent dissolution is the subsidence of San Simon sink and the alignment of basins from San Simon swale along the Capitan reef margin to the southeast. The rate of dissolution and the depth at which it occurs remain debatable. Roger's evidence for much dissolution in the last few tens of thousands of years is good but not entirely convincing; Charley Jones' evidence from drillholes and seismic surveys for continuity of beds across the swale suggests that deep dissolution is not sufficient to cause major displacements. To settle the controversy would require drilling a deeper hole in the sink.

Would such a drillhole be worthwhile? Certainly yes, from an academic standpoint; but I doubt that it would add much useful information regarding the integrity of a repository at the WIPP site. Take the worst possible case: suppose that a deep hole demonstrates that water in a Bell Canyon aquifer at present is actively undermining the Castile and causing collapse of overlying beds. The sink is some 30 km from the WIPP site; but Nash Draw, where dissolution is certainly in progress today, is only about 7 km from the site, and the dissolution front is estimated to advance so slowly that a repository would be safe for at least a million years. It seems most unlikely that a front moving west from the San Simon sink would disturb Salado beds at the WIPP site in a shorter time.

The same argument would hold for possible deep dissolution under the Bell Lake sink, and a fortiori for the dissolution front far to the south of the WIPP site, where Roger has evidence for the absence of a salt wedge in the lower Salado presumably caused by dissolution.

Breccia pipes. The existence of breccia pipes extending to consideable depths apparently has been demonstrated only at a few places close to the Capitan reef. Many structures elsewhere in the Delaware Basin seem similar from evidence at the surface, but proof is lacking that thay are actually deep pipes; alternatively, they may be local collapse structures resulting from dissolution at fairly shallow depths. Origin of the breccia pipes remains controversial, but Roger Anderson's hypothesis of upward stoping by relatively fresh water from aquifers below the evaporite sequence is currently favored. The timing of their formation remains controversial: the ones whose nature has been established are older than the Mescalero caliche, but there is no proof that similar structures cannot be in process of formation at the present time. If an old, inactive pipe should be encountered at depth at the WIPP site, it might endanger a repository by providing a channel for fluid movement thru the salt beds; on the other hand, there is no proof that permeability of a breccia pipe is appreciably greater than that of massive salt, and it would seem possible in repository construction either to avoid the pipe or to render it impermeable by engineering methods. The greatest danger, it seems to me, is the possibility that an active pipe, slowly ascending from depth at the present time, might someday invade a repository. To test this possibility it is important to know whether breccia pipes are rare or common in the Delaware Basin and whether any are actively forming at present.

The fact that Bell Canyon water has invaded the overlying evaporite sequence at places other than the immediate vicinity of the Capitan reef seems clearly demonstrated by the replacement of Castile anhydrite by biogenic limestone, locally accompanied by sulfur, in the western part of the Delaware Basin. The reduction of sulfate and its replacement by porous carbonate with a high carbon 12/13 ratio is clearly the work of bacteria, and the organic matter needed for bacteria to flourish could have come only from the Bell Canyon. Whether the present outcrops of brecciated biogenic limestone were once at the base of breccia pipes is not determinable, and the time at which the limestone formed is not known. The locality is far from the WIPP site (circa 100 km), but it seems reasonable to suppose that similar reactions could have occurred (or possibly could still be occurring) elsewhere in the basin.

Of the various structures that might represent the tops of breccia pipes, the ones at Malaga Bend seem the best candidates. Some of these are remarkably circular, some elongate or irregular. In general they are broad domes of Culebra dolomite, breached in some of them to expose red gypsum of a variety known to be formed by replacement of polyhalite at the top of the Salado. The gypsum forms a large-scale breccia, but it is not accompanied by fragments of post-Culebra formations as it would be in a typical well-developed breccia pipe. Mescalero caliche is present at the side of at least one of these structures, but its relation to the structure is not clear. These dome-like structures may be the tops of deep breccia pipes, or they may result from shallow solution in the Salado (which here is near the surface). To settle the question would require drilling.

Would such drilling be worthwhile, from a practical standpoint with respect to the WIPP site? If a single hole were drilled in the most likely of the circular domes, and if the existence of a deep pipe were established, this would certainly show that pipes are a general phenomenon of the Delaware basin and are not limited to the vicinity of the Capitan reef. If the hole showed that brecciation was limited to shallow depths, the question about frequency of breccia pipes would remain open; perhaps the wrong dome was chosen for exploration. (Even near the reef, drilling has shown that not all dome-like structures are the tops of breccia pipes.) Suppose the drillhole does prove that a pipe exists here; would this be significant for WIPP? Only, it seems to me, in the sense that builders of the repository would be alerted to the fact that they might expect to encounter breccia pipes in the underground development. Thus in my opinion a single drillhole, altho obviously of great academic interest, would be only marginally useful in a practical sense.

How determine whether breccia pipes are forming today? The most likely place for such an occurrence, it seems to me, would be San Simon sink. A deep drillhole in the sink might well disclose ongoing dissolution and collapse, if such a phenomenon is indeed taking place. Even such a demonstration, however, seems to me only marginally significant. Surely, if the present-day formation of breccia pipes is at all common, they would have been encountered in some of the many deep holes that have been drilled in the Delaware Basin in search of oil and gas. The chance of one forming directly under the WIPP site seems to me about the same as the chance of a meteorite impact.

Brine pockets. The existence of brine pockets in salt beds has been known for a long time, and it seems surprising that more specific information about them is not available. With regard to WIPP, the important question is simply this: is a brine pocket an isolated cavity, completely surrounded by impermeable salt, or does it connect with other cavities to form a widespread fluid reservoir? If the former, encountering a brine cavity at the WIPP site should be no more than a minor annoyance, correctable by pumping the fluid from the cavity. But a series of interconnected pockets, from which water flows even after prolonged pumping, would cast grave doubts on the suitability of this site. A good many brine pockets are known, according to George Griswold, and it would seem only prudent to test some of these to see how readily and how completely their brine content can be exhausted.

General. From my personal point of view, the stability of the Salado salt beds with respect to groundwater movement has been demonstrated as conclusively as it can be from observations at the land surface, geophysical measurements, and study of drill-cores. Academically speaking, I would like to see new deep boreholes drilled in San Simon sink and in one of the domal structures near Malaga Bend. These holes would give some indication of underground water circulation in the eastern part of the Delaware Basin, the possibility of breccia-pipe formation at the present time, and the possible existence of breccia pipes away from the Capitan reef. Because such information would suggest much more complete understanding of subsurface conditions under the basin, the holes might be justified simply as a means of reassuring the public as to the amount and depth of scientific study that has been devoted to this area. But I doubt very much that the holes would add a great deal to presently available technical knowledge directly pertinent to characterization of the WIPP site.

What is needed most urgently now, in my opinion, is a small exploratory shaft into the Salado beds, with a large enough excavation at the bottom to accommodate a horizontal drill for exploring the beds in all directions. Brine cavities and breccia pipes, if any exist, should be easily detected by such a program, and geophysical measurements in the cavity at the base of the shaft should pick up any abnormalities within a short distance of the roof or floor. Most of the remaining hydrological uncertainties could be resolved with the exploratory shaft. The shaft I visualize would be a very simple one, no more than 5 or 6 feet in diameter, which could be constructed for a few million dollars -- not the big, complex double shaft that DOE is now considering.

There remain three kinds of uncertainties with regard to WIPP, which the hydrological arguments do not address: (1) the physical and chemical stability of the waste package in a salt environment, (2) the possibility of disruptive tectonic movement, and (3) the possibility of human intrusion to recover mineral resources below and above the repository horizons. The first of these will require in-situ experiments, which are another excellent reason for sinking an exploratory shaft without delay. Possible tectonic activity associated with the Rio Grande rift zone has been emphasized by Jon Callender; I do not find his published arguments convincing, but I hesitate to express an opinion when I have not talked with him or seen his field evidence. The demonstrated presence of exploitable mineral resources -- langbeinite above the repository levels and hydrocarbons below -- poses the major remaining uncertainty, to my mind, about the suitability of the WIPP site. It is often said that both kinds of resources can be recovered at any later time without disturbing a sealed repository, but I think this claim should be documented in great detail.

Konrad B. Krauskopf
Stanford University
21 June 1980

NEW MEXICO LEGISLATIVE COUNCIL SERVICE
Santa Fe, New Mexico
June 23, 1980

Information Memorandum No. 205.87-80

TO: The Radioactive Waste Consultation Committee

FROM: Jonelle Maison

SUBJECT: EEG GEOLOGY FIELD TRIP--WIPP SITE AND VICINITY--
CARLSBAD, NEW MEXICO

The committee has requested a report of the EEG field trip, June 16-18, 1980. The following is submitted in response to that request.

The purpose of the EEG field trip was to visit and discuss geological evidence relative to presentations and discussions at the January 17-18, 1980 meeting on geotechnical considerations for radiological hazard assessment of WIPP. The field trip leaders were Dr. Roger Anderson, UNM; Dr. George Bachman, USGS, ret.; and Dr. George Griswold, Tecolote corporation. Attached are a list of participants and a copy of the agenda.

The major controversy centered around deep dissolution and attendant breccia pipes, and I have abstracted what I think are the arguments for and against deep dissolution. Brine reservoirs were also considered, but there was relatively little discussion on the subject; sources for that presentation are primarily from the EEG-6 report of the January 17-18 meeting, a letter from Dr. Griswold to EID and a post-conference telephone conversation with Dr. Griswold.

The following is simply a report of the positions taken during the field trip and does not attempt to evaluate, judge or analyze the positions.

ARGUMENTS

BRINE RESERVOIRS

Dr. George Griswold

The presence of brine reservoirs is not in question; brine has been encountered in 10 out of 60 deep drill holes in the vicinity of the WIPP site. Dr. Griswold's argument is predicated on two main points: current methods for the prediction of reservoir locations are inadequate; and, after five years, no progress has been made in understanding the phenomenon. According to Dr. Griswold, not enough is known about the origin of the brine reservoirs to state they are present only in anticlinal areas and there is not enough evidence to say they are only limited to the Castile. He suggests that the "disturbed zone" in the northern region of the site would be the best place to look for brine reservoirs and evidence of deep dissolution, and thinks the two phenomena may be related. Dr. Griswold thinks that if more were known about either phenomenon many of the questions about the other would be answered.

While he agrees that the probability of hitting a geopressured brine reservoir at the site is low, Dr. Griswold believes that if that happened the consequences could be disasterous, not to the surface environment but to the miners because of the associate poisonous gas. However, he sees such a position as an argument for the site preliminary design validation (SPDV) program. In a letter to Mr. Dennis McQuillan, EID, regarding the notice of intent to discharge, he said:

> In closing, I wish to restate that underground excavation is the only practical method of proving the WIPP site is actually acceptable. Risks do exist, whether it be brine reservoirs, breccia pipes, faults, salt flowage or other factors not yet considered. I believe this is the strongest argument for the SPDV program, and not that underground conditions are as predictable as one would gather from reading the DOE report.

DEEP DISSOLUTION

Dr. George Bachman

Dr. Bachman stated that there is no need to invoke deep dissolution as a mechanism to explain the geology of the Delaware basin, that the process can be explained by near-surface percolation. He points to Nash draw as an example of erosion by solution and fill incorporating local dissolution. Dr. Bachman further takes the position that some deep dissolution may have taken place when the rocks were exposed, but that the salt around the WIPP site has not dissolved nor is there any danger of it doing so in the near (geological) future.

It seems to me that while not discounting deep-seated dissolution in the past, e.g., recognition of breccia pipes in the area, given the overall stability of the basin Dr. Bachman does not see it as a present or future occurrence. Also, Dr. Bachman claims that there are no known breccia pipes in the Delaware basin, they are found only over the reef. According to Dr. Bachman, during Gatuna time, circa 600,000 years ago, the hydraulic head in the Capitan aquifer system was considerably greater than it is at the present; the head drove fresh water upward through fractures, creating breccia pipes. However, following Gatuna time, the Pecos river entrenched itself in its present position and intercepted the Capitan aquifer system near Carlsbad, relieving the hydraulic head. Dr. Bachman does not believe conditions are favorable for the formation of breccia pipes in the future.

Dr. Roger Anderson

Dr. Anderson argues that deep dissolution is, in fact, taking place in the eastern part of the Delaware basin at the present time, and cites several geologic features as evidence of an advancing dissolution front. In support of his argument, Dr. Anderson points to Bell lake and Slick sinks as candidates for surface expression of relatively young dissolution at depth and San Simon sink and ridge showing young, active deep dissolution along and above the reef.

I think it is also his contention that the state-line outcrops of the Castile, showing dissolution breccias and microfolding, as well as other phenomena in the western portion of the basin can be extrapolated to uphold his conclusion that deep dissolution is evident throughout the basin and active in the east and northeast areas.

Given the geology of the western basin and the instability in the east, Dr. Anderson believes that conditions point to deep dissolution and are favorable for the formation of breccia pipes at the WIPP site, and he does not think the site is a good geological risk.

CONCLUSIONS

On deep dissolution, the questions seem to be: has the basin stabilized; is there evidence of active deep dissolution today; and is there enough hydraulic head to cause dissolution at depth?

The surface geology map shows Nash draw, Bell lake and Slick sinks and San Simon swale as unstable areas. There is also a "disturbed zone" northeast of the WIPP site. Dr. Anderson contends that these areas illustrate his argument for active dissolution. Dr. Bachman disagrees with that interpretation, saying that the dissolution which has occurred did so at least 600,000 years ago, was localized and can be explained in the main by erosion by solution and fill. Dr. Bachman also argues that the hydraulic head of the Capitan aquifer is no longer available for deep dissolution. Dr. Anderson maintains that the tilt of the basin does give the head necessary for such a process.

Both sides presented cogent arguments in support of their positions, and it is difficult for a lay person to make a determination as to the validity of either posture. It was my observation that there were disagreements with and counterpoints to each argument from the "uncommitted" participants.

I talked with Dr. Parizek on Thursday and his points seemed to be the most reasonable, if only because he addressed the entire issue of WIPP rather than a single area. Seeing merit in Dr. Anderson's argument, he agreed with other participants that more testing should be done, particularly in the sinks, and, if the data cannot be conclusive, it may at least allay some of Dr. Anderson's fears of the repository being breached. Also, the sensitivity of the project demands that testing be as complete as possible in areas of concern. His other point was that since there cannot be one hundred percent surety, the process should then slant to consequence analyses and methods for the prevention of radionuclides reaching the biosphere at some future time.

After the participants have submitted written comments and EEG has published its report, the committee will have a better idea of the arguments and, further, if and how they may be resolved. Also, I think the next meeting of the national academy of sciences' WIPP panel will be important, due to the participation of Dr. Parizek and Dr. Krauskopf and their conclusions after both EEG meetings.

HEALTH & ENVIRONMENT department

STATE OF NEW MEXICO

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Larry J. Gordon, M.S., M.P.H.
DEPUTY SECRETARY

MEMORANDUM

TO: Robert H. Neill, Director, EEG

FROM: Dennis McQuillan, Water Resource Specialist, WPCB

THRU: Bruce Gallaher, Water Resource Specialist, WPCB

SUBJECT: Comments on the WIPP Site and Vicinity Geological Field Trip June 16-19, 1980

DATE: July 22, 1980

You and your staff are to be commended for sponsoring a productive and fascinating geological field trip. The following are my comments as requested.

1 Vertical dissolution structures

1.1 Castiles - I agree with Anderson that the occurrence of Castiles below undeformed salt indicates suberosion of salt perhaps by artesian meteoric waters although Castiles may not be a direct analog to the Hill A etc. breccia pipes.

1.2 Crude oil in the MCC (Hill C) breccia pipe - I agree with Jones informal statements that available data strongly suggest the crude oil is a natural occurrence.

1.3 San Simon sink - It is unfortunate that WIPP-15 is not deep enough to conclusively determine the origin of this structure. Anderson's interpretation of this structure seems most reasonable to me.

1.4 Present and future breccia pipe formation - I agree with Bachman that the hydraulic head for the Capitan aquifer system was somewhat higher during Gatuna time before the Pecos River entrenched itself in its present position and intercepted the Capitan aquifer system. However, figure 2.5-1 in the SAR indicates that the elevations of the potentiometric surface of the Guadalupian aquifer system north of Hill C and at the center of the WIPP are approximately 2920' and 3370' respectively. I believe this is a favorable condition for the creation of vertical dissolution structures today.

2.1 Bell Lake and Slick sinks - These sinks are suspected as relatively young dissolution structures and they are within the Delaware Basin rather than at the Basin margin like San Simon sink. If Bell Lake and Slick sinks are a result of suberosion of salt by artesian meteoric ground waters than I can think of no reason why this process could not occur at the WIPP. Determining the origin(s) of these sinks is of critical importance and I would suggest a core-drilling program. If resources permit drilling only one sink, Bell Lake should be drilled.

2.2 Crude oil in the MCC (Hill C) breccia pipe - With regard to the nearby well into which crude oil was introduced, the following information would be useful in resolving the question of whether or not the crude oil in the breccia pipe is a natural occurrence:

a) completion details for the well, and
b) the elevation(s) and rock unit(s) at which the crude oil was introduced.

Jones indicated these data may not be available.

2.3 Future exploratory drilling

2.3.1 Resource limitations - Sandia National Laboratories exploratory drilling efforts appear to be hindered severely by resource limitations in certain cases. I would recommend that, whenever possible, minimum diameter coreholes be drilled. In the case of WIPP-15, a smaller diameter core would have been sufficient.

2.3.2 Priorities - Determining the origin of Bell Lake sink should be top priority, in my opinion. It would also be useful to know the origin of Slick sink, but not at the expense of the suggested Bell Lake sink studies. If existing wells are to be deepened, WIPP-15 should be first.

3.1 It is difficult to generalize on the significance of brine reservoirs to the proposed WIPP without understanding what governs their origin, evolution and occurrence. Brine reservoirs constitute a geological risk but to what degree remains to be shown.

3.2 Jones presentation of his theory on the origin of brine reservoirs sounds plausible. I would prefer not commenting further until this theory is presented in a reviewable scientific paper format.

4 As discussed on pages 40 and 41 of EEG-6, the arguments against Anderson's views on deep dissolution cannot be properly examined because they are not available in a "reviewable" coherent form. Anderson has published some of his views subjecting them to critical review by the scientific community. Anderson also documented his views in his well organized field trip notes for Salt

Dissolution Features in the Delaware Basin, June, 1980. I would suggest that critics of Andersons views also document their arguments.

Sandia National Laboratories
Albuquerque, New Mexico 87185

July 8, 1980

Dr. Robert H. Neill, Director
New Mexico Environmental
Evaluation Group
P.O. Box 968
Santa Fe, New Mexico 87503

Dear Bob:

Ref: Ltr, R. H. Neill to W. D. Weart, dtd 6/27/80, subject: EEG Field Trip

I offer the following thoughts on the first two days of the recent EEG sponsored field trip. Since I was ill the third day, I will have no trip comments although I do have some thoughts on the subjects covered the third day which I will provide for no extra charge.

First of all let me congratulate you and your staff for undertaking a difficult but obviously useful exercise. I believe all parties profited from this opportunity and it went very smoothly. The field trip provided an opportunity for interested individuals to see first hand the evidence for the various dissolution phenomena in the area and to judge the information that bears on the time, rate and location of these processes. One of the useful diagnostic methods available but not observed is the core from many drill holes emplaced to search for shallow and deep dissolution. Brine pockets were discussed but none of the field observations shed any light on this issue. Furthermore, while there was stimulating discussion of the various geologic processes, there was relatively little discussion of their relevance to adequacy of the repository site. This latter is unfortunate because without this discussion there is a tendency to assume these processes are, by definition, unacceptable whereas in fact they may have little or no impact on site safety.

In my view the following major issues were addressed by the field trip.

1. Dissolution at the top of the evaporite section - location, time, rate, etc.
2. Deep (below the top of Salado) dissolution - location and time of occurrence.
3. Breccia pipe development and explanation of other domal features in the northern part of the basin.
4. Recent tectonic faulting in the Northern Delaware Basin.

Because these phenomena are so closely tied together in terms of geologic processes, it is not appropriate, in most instances, to say that a particular field stop applies to only one issue. An exception may be #4, tectonic faulting, where the only stops bearing directly on this issue were those at San Simon (2-2,3).

1. Dissolution at top of evaporite section

This type of regional dissolution is well established in the Delaware Basin and its development in the vicinity of the WIPP site is relatively well defined (in location) by the numerous drill holes that penetrate the top of Salado. The question addressed by many of the stops, especially 1-1, 2, 6, 7 and 2-4, 5, 6, was the issue of when the dissolution occurred. The evidence is convincing that much of the past dissolution occurred prior to development of the Mescalero caliche and that considerable salt was probably removed prior to the Cretaceous. The conditions were certainly appropriate for dissolution. The significance of this is that the long-term rate of advance of the dissolution front toward the site is less than that estimate provided earlier by Bachman and used in the WIPP EIS. One cannot specify a specific rate but can say the existing values are an absolute upper bound for the past long-term average rate.

Other features which could be discussed here are the domal features in the basin or the Bell Lake-San Simon "Sinks" but these are perhaps more appropriate in one of the other general topic areas.

I believe Bachman's work has conclusively established the above premise and no further work is required specific to the shallow dissolution process. The proposed repository is in no jeopardy from this process.

2. Deep Dissolution

For the purposes of this discussion, deep dissolution will be separated from the localized phenomena such as breccia pipes, sinks, etc., even though they may be closely related. Only the regional dissolution within or at the base of the evaporites will be considered in this section.

The most conclusive evidence for or against the presence of deep dissolution was not observed - the core from deep drill holes. None of the deep WIPP holes encountered deep dissolutioning of the nature under discussion. Missing halite (Halite III) in ERDA 10 is due to depositional phenomena and not Cretaceous dissolutioning.

The chaotic collapse in the Malaga Bend area and on to the south into Texas may be ascribed to deep dissolutioning although stop 2-8 also exhibits shallow Rustler and Salado dissolution. There is no direct way of estimating rates of deep dissolution from the geologic record but the evidence from issue 1 implies conditions (emergent) which could be expected to result in pre-Cretaceous dissolution. Nash Draw is known (from drill data) to be due to shallow dissolution and erosion and ERDA 10 shows no deep dissolution. The relevant question remaining is whether Slick Sink-Bell Lake and their apparent alignment toward a structural low at the northern edge of the site implies a deep dissolutioning hazard for the repository. First of all, the evidence that Bell Lake and Slick Sink are due to deep dissolutioning is not at all convincing. Either shallow dissolution or deflation could be responsible for these features. Neither, however, can deep dissolution be ruled out. But these features are remote from the site and are of significance to WIPP only because they may lend strength to the credibility of deep dissolutioning at the site structural low. Consequently, the most useful investigation, with respect to site acceptability, would be a deep drill hole in the center of the structural low in Section 9. Drilling Bell Lake or Slick Sink could establish their origin but still not address their significance to WIPP. To evaluate the origin of these sinks would require at least one and possibly two drill holes and is not as relevant to site acceptability as a deep hole in Section 9.

3. Breccia Pipe Development

Breccia pipes, if they should develop at the WIPP site, have usually been assumed to be an unacceptable threat to repository integrity. However, the examination of the known collapse chimneys does not necessarily support that assumption and neither does the conservative safety analysis conducted for this scenario even when high permeability is assumed for the chimney. However, collapse chimneys do not exist in the site and the only proven chimneys are three which exist over the Capitan Reef or back reef. Several of the stops (1-3, 4, 5, 9 and 2-7 and 3-5) were to illustrate the surface features of known chimneys and other structures (domes and castiles) thought by some to represent chimney development. The field evidence is, in my view, very convincing that the sinks, domes and castiles are not collapse chimneys. Several of these features have been drilled and the others mapped sufficiently to disprove their chimney origin. It is not productive to drill every suspected structure when geologic mapping is by itself sufficient proof. It would seem, therefore, to be well demonstrated that collapse chimneys, like Hill C, do not occur in the basin - only over the reef - and pose no threat, present or future, to the site. Furthermore, even the other structures (domes) occur only where there has been extensive deep dissolution. Since the earlier discussion rules out the existence of deep dissolutioning at the WIPP site, even these features, based on existing correlations, do not seem likely to develop at WIPP. Finally, the evidence provided at these stops shows that these collapse chimneys have not been active since the Mescalero caliche started to form, approximately 600,000 years ago. In other words, they are not developing in this part of the basin today.

We do not now fully appreciate the combination of features that were necessary to start, stop and localize collapse chimneys. However, this is not necessary if it can be demonstrated that they are limited to areas underlain by the reef system.

Regardless of this fact, all arguments about breccia chimneys are clearly more convincing if we can understand the origin of these features. Coring WIPP 31 to the depth of undisturbed stratigraphy and conducting drill stem tests will aid in developing this understanding.

4. Recent Tectonic Faulting

Geologic mapping by Bachman has not revealed any quaternary tectonic faulting near the WIPP site. The closest such faulting identified is on the west side of the Guadalupe Mountains. R. Anderson believes the exposures in the San Simon area and core from WIPP 15 combine to indicate tectonic faulting, which may in fact be responsible for dissolutioning in the sink. Since recent collapse has occurred in the central part of the sink and its overall development is geologically recent, Anderson argues for recent faulting. However, it is not necessary to invoke faulting to explain the evidence cited. Normal dips and a different but equally likely identification of the stratigraphic position of the Triassic sandstone is adequate to explain the observations. Jointing parallel to the swale would be expected as a response to swale subsidence and need not depend on tectonic faulting. Extensive drilling would be required to prove faulting and is not warranted since, even if such faulting existed at this distance, it is no threat to repository integrity. No microtremors have been detected from this area, implying the area is not currently an active tectonic zone.

Brine reservoirs in the Castile were listed as a topic for discussion but there was no field evidence presented on the trip which addressed this topic. All reservoirs of the size under discussion are associated with Castile anhydrites and with significant anticlines in the Castile. The WIPP site has avoided the latter (a gentle anticline at the northern extremity has been drilled (WIPP 11) and the hole did not encounter either brine or the fracturing in anhydrite necessary to allow a reservoir to develop) and the repository level is several hundred feet above the Castile anhydrites where brine has been encountered in other locations. Consequently, based on the existing evidence, it is considered most improbable that a brine reservoir exists at the WIPP site much less affect the repository integrity and safety. Small fluid (usually gas) pockets do exist in the Salado. They are encountered in the potash mines but are believed less common in the deeper, purer repository horizons. Normal precautions will assure the safety of mine workers during repository operations and these features are not a threat to long-term repository integrity.

In summary, I would say that the only scenario discussed on the trip which may pose a possible threat to the site is hypothesized deep dissolutioning as a cause of the structural low in Section 9. This low should be drilled, is in the FY 81 plan, and will be drilled if funding is available.

Sincerely yours,

Wendell

Wendell D. Weart, Manager
Waste Management Technology
Department 4510

WDW/pz

cc: File

NEW MEXICO TECH
SOCORRO, NEW MEXICO 87801

THE GRADUATE OFFICE
(505) 835-5513

July 21, 1980

Robert H. Neill
Director
Environmental Evaluation Group
320 E. Marcy Street
P.O. Box 968
Santa Fe, NM 87503

Re: Field Trip 16-18 June

Dear Bob:

I want to express my personal appreciation for including me in the WIPP site field trip. It was a splendid followup of the visit the Governor's Advisory Committee made down there in January of 1976. It lent a major feeling of reality to these site factors we have been talking about for so long.

My responses follow your outline in the letter of June 27.

1. Major questions addressed:
   a. Breccia pipes. Are they restricted in occurrence to the reef, or might they be found and or develop in the basin proper?
   b. Collapse features, e.g. Bell Lake and San Simon Sink. Where all do these occur and what is the mechanism of formation?
   c. What are the characteristics of the formation where dissolution has occurred in the past? We saw evidences of this in the western and southern parts of the Delaware basin.
   d. What is the relevance of the current surface hydrology to the proposed WIPP site?
   e. Brine reservoirs. What is the record of occurrence in the Basin, and what is their origin?

2. a. Breccia pipes. Hills A & B give dramatic evidence but more investigation is definitely needed to provide information relative to their origins. Are they really "creatures" of the reef?
   b. Collapse features. Examine well-logs in area to get clues. How do they originate? This question may be especially significant for the relatively near-term integrity of WIPP.

3. Brine reservoirs. The number of occurrences, the pressures involved, and their volumes are enough to cause serious concern. We need to devise methods for excluding the possibility of their occurrence in the vicinity of the repository site.

4. The field trip, almost by definition, directed attention to surface features which might cause problems at depth. Almost no attention was given to hydrologic models and the data required for their examination which would provide reasonable assurances with respect to possible dissolution processes affecting site integrity in the future. More than anything else this struck this observer as the important next step. Perhaps a symposium or conference should address the topic.

5. The trip was very worthwhile in its special frame of reference; however, proper site characterization here or elsewhere requires sharp focus on things that require more sophisticated analysis.

Sincerely,

Marvin

Marvin Wilkening
Dean of Graduate Studies

MW/lac

SECTION IV

SUMMARY AND RECOMMENDATIONS

SECTION IV

SUMMARY AND RECOMMENDATIONS

This field trip provided a unique opportunity to clarify the geological issues confronting the WIPP site and to sharpen the focus on arguments for and against various hypotheses regarding the geological and hydrological conditions in the area.

The main point of controversy which has emerged out of all the discussions and the field evidence may be summarized by the following question: Has there been in the recent geologic past, or is there now, dissolution of salt occurring in the Delaware Basin involving the lower Salado or Castile formations, and has such "deep dissolution" occurred near enough to the WIPP site to pose a threat to the proposed repository? The question implies the flow of relatively fresh water from the DMG aquifer or from the Capitan Reef aquifer into the Ochoan evaporite beds. For such a flow to achieve dissolution of the evaporites, there would have to be sufficient hydraulic heads in the aquifers, structural features to provide a pathway for the flow of water, and the continuous supply of relatively fresh water to maintain the dissolution process. The mechanism proposed by Roger Anderson for this process to take place depends upon the density difference between saturated brine and unsaturated water. Anderson believes that once this process starts, it will be self-propelled and will continue as long as the fresh water is available and the fracture remains unsealed.

Anderson has proposed that deep dissolution in the Delaware Basin has reached a stage of maturity and that it is a continuous process. He cites San Simon Sink, Bell Lake Sink and Slick Sink as possible surface expressions of deep dissolution resulting in the collapse of evaporites. He also cites the limestone dikes and the castiles as evidence for the DMG aquifer water rising up to the evaporite sequence. Further, he cites the data from geophysical logs and several cores to show that salt has been removed from the Salado and Castile salt beds in various part of the Basin. In addition, he points to the local loss of continuity in a number of seismic profiles across the WIPP site as possible evidence for localized deep dissolution at the site itself. Anderson has argued that the long-term integrity of the site from on-going wedge-like dissolution at depth cannot be guaranteed and that there is a possibility that the advanced effects of such dissolution may already have reached the site. Because of such inferred instability of the site, Anderson has recommended abandoning this site in favor of more stable salt beds or other geologic media.

George Bachman believes that the evidence from geologic mapping and drilling does not support the concept of deep, blanket dissolution of salt units in the Castile formation in the Delaware Basin during Cenozoic time. According to him, the substantiated breccia chimneys located over the Capitan Reef, are probably the only evidence of deep-seated dissolution. Bachman also does not believe that salt deposition was basin-wide at any given time. According to him, "there is overwhelming evidence in the subsurface that salt beds in the Castile were deposited in discrete pans or local sub-basins." Because of this, Bachman does not accept Anderson's correlation of individual breccias across the Delaware Basin. According to Bachman, "in the interior of the Basin individual salt beds are well preserved in the Castile in the subsurface. Around the fringes of the Basin the salt beds are absent because they were never deposited, or were removed through surface erosion when the beds were nearer the surface."

After studying the field evidence and the comments from field trip participants, EEG concludes that it has not been established that the site or the surrounding area has been attacked by deep dissolution to render it unsuitable for the nuclear waste pilot repository. There are, however. several geological features at and around the WIPP site whose significance to the future integrity of the repository needs to be understood. While a reasonable amount of future work on geological characterization may not be able to answer all the questions raised about the site, it should be possible to resolve some of the more important aspects of the deep dissolution hypothesis.

The question of whether breccia pipes are confined to the Reef aquifer or could exist also in the Basin remains unresolved. Although the two confirmed breccia pipes are located over the Reef, several features in the Basin may also prove to be breccia pipes on further exploration. An exploration effort to prove or disprove their existence in the Basin may not be of value in the hazard assessment of WIPP. If an isolated breccia pipe is encountered during the repository construction, it may not pose a construction problem on the basis of its nature -- lithology, texture, permeability, etc. The possibility of an active pipe, slowly ascending from depth directly under the site at the present time and breaching the site sometime in the future cannot be completely discarded. The probability of such occurrence appears remote, however, in view of the number of deep exploratory wells in the area, none of which have been reported encountering a breccia pipe. It appears that such an occurrence cannot be detected from surface geophysical or geological methods. An analysis of the consequences of a possible breach of the repository through an ascending breccia pipe should therefore be carried out, using reasonable estimates for the dimensions and the rate of ascent of a pipe.

There were several other subjects discussed at the January meeting and the field trip which formed the basis for certain of the EEG recommendations below. A general consensus of the field trip participants indicated that more specific information should be gathered about the quantity and quality of brine in the artesian brine reservoirs encountered near the WIPP site. The question of tectonic faulting in the Delaware Basin was raised by some geologists, particularly with respect to the area near the

San Simon Sink, where the presence of a fault with approximately 1000 feet of displacement has been postulated by Anderson. And finally, there is concern about the nature of the disturbed zone in the northern part of the WIPP site where seismic reflection profiles show discontinuities and the drill holes indicate structural anomolies.

The Environmental Evaluation Group therefore would like to make the following recommendations to the U.S. Department of Energy for work during fiscal year 1981.

1. Review Papers. Prepare detailed review papers on the following topics:

   (a) Deep dissolution - Specifically addressing Roger Anderson's hypothesis about extensive deep dissolution in the lower part of the Ochoan evaporite deposits in the Delaware Basin.

   (b) Structural anomalies at and near the WIPP site - This should include the anomalies interpreted from geophysical data and from drill cores. The discussion should include the details of geological interpretation of the anomalies and the work being planned or conducted to resolve the seismic data discrepencies, as stated in the Safety Analysis Report, pp. 2.7-65 and 2.7-66.

   (c) Occurrence of brine reservoirs/pockets in the evaporite beds of Delaware Basin - This should include available information on location, quantity, pressures, quality, ideas on origin, methods of handling it in mines, etc.

   (d) Details of DOE plans to allow recovery of potash and hydrocarbon resources without disturbing the sealed repository.

   (e) Basic data and interpretations of boreholes WIPP-31 and WIPP-16 - drilled at hills A and C respectively to obtain more information on the origin of these breccia pipes.

2. Exploratory Program

(a) Run a seismic reflection profile across the San Simon Swale to pass over WIPP-15 (sink) from the Antelope Ridge to San Simon Ridge. This should answer the question regarding the postulated fault between the sink and the ridge.

(b) Drill 4 or 5 shallow holes across Bell Lake Sink or Slick Sink to reach the Red Soil horizon and drill one deep exploratory hole to the evaporites, if Red Soil is not missing. Even though it is far from the WIPP site, this testing program will answer an important question about the presence of deep dissolution in the Basin itself.

(c) Drill one core-hole to the lower Castile in Section 9, northern part of the WIPP site.

(d) Reopen one of the brine reservoir wells: AEC-7, Pogo or ERDA-6; allow it to flow for 10 days; measure the depletion of pressure and levels in all three and test the brine at regular intervals.

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EEG-6 = Environmental Evaluation Group. Geotechnical Considerations for Radiological Hazard Assessment of WIPP: A Report of a Meeting Held on January 17-18, 1980 (EEG-6), April 1980.

APPENDICES

APPENDIX I

LIST OF ATTENDEES

WIPP SITE AND VICINITY GEOLOGICAL FIELD TRIP

1. Roger Y. Anderson - University of New Mexico
2. Bill Armstrong - U. S. Department of Energy
3. George Bachman - U. S. Geological Survey (Retd.)
4. James K. Channel - Environmental Evaluation Group
5. Lokesh N. Chaturvedi - New Mexico State University
6. Peter Davies - Stanford University
7. John Dunlap - Consulting Geologist - Dallas, Texas
8. Bruce Gallaher - Water Pollution Control Bureau - EID
9. George Griswold - Tecolote Corporation
10. John W. Hawley - Environmental Geology - State Bureau of Mines
11. Charles L. Jones - U. S. Geological Survey
12. Konrad B. Krauskopf - Stanford, National Academy of Sciences
13. Alan Kuhn - Technical Services Contractors
14. Marshall Little - Environmental Evaluation Group
15. Jonelle Maison - WIPP Consultative Committee
16. Dennis McQuillan - N. M. Environmental Improvement Division
17. Jack Mobley - Environmental Evaluation Group
18. Robert H. Neill - Environmental Evaluation Group
19. Richard Parizek - Penn State University - National Academy of Sc.
20. Dennis W. Powers - Sandia National Labs
21. Wendell D. Weart - Sandia National Labs
22. Marvin Wilkening - N.M. Institute of Mining and Technology
23. Robert J. Wright - Nuclear Regulatory Commission

APPENDIX II

FIELD TRIP NOTES BY

Roger Anderson
George Bachman
George Griswold

Field Trip Notes

for

Salt Dissolution Features in the Delaware Basin

Compiled by:

Roger Y. Anderson

June, 1980

INTRODUCTION

We will visit several localities that illustrate the processes of dissolution taking place in the basin and that perhaps give some perspective as to the timing and rate at which dissolution is taking place. Some of these localities have been only partially studied and what is happening in the subsurface is not definitely known. However, there will be a chance to compare field observations with previously written materials and obtain an overview of the dissolution potential of the basin. Figure 1 shows the location of most of the features we will visit.

These notes deal only with five of the stops scheduled for the field trip. These include a drive-through at Bell Lake Sink where we will see the surface expression of a possible deep-seated dissolution feature; stops at San Simon Sink and Ridge which show young and active dissolution at some depth along and above the reef; a stop at the well-known State-Line outcrop of the Castile which shows microfolding, dissolution breccias, and larger regional relationships; and finally, a stop at the Castiles to show brecciated chimneys in the lower part of the evaporite sequence.

BELL LAKE SINK

Bell Lake Sink (and nearby Slick Sink) are candidates for the surface expression of relatively young dissolution at considerable depth in the eastern part of the basin. Soluble rocks of the Rustler Formation are about 1000 feet beneath the surface and the lowest salt of the Castile is more than 4000 feet beneath the surface.

The geologic map (Fig. 2) compiled by Widdicombe (1980), shows several sink-margin faults with faulted-off or downdropped Mescalero caliche and Old Mescalero soil suggesting that the sink is truly a collapse structure rather than a deflation feature. The volume of gypsum dune sand blown out of the playas suggests rising sulfate-rich waters as a source for the gypsum (Nicholson and Clebsch, 1961).

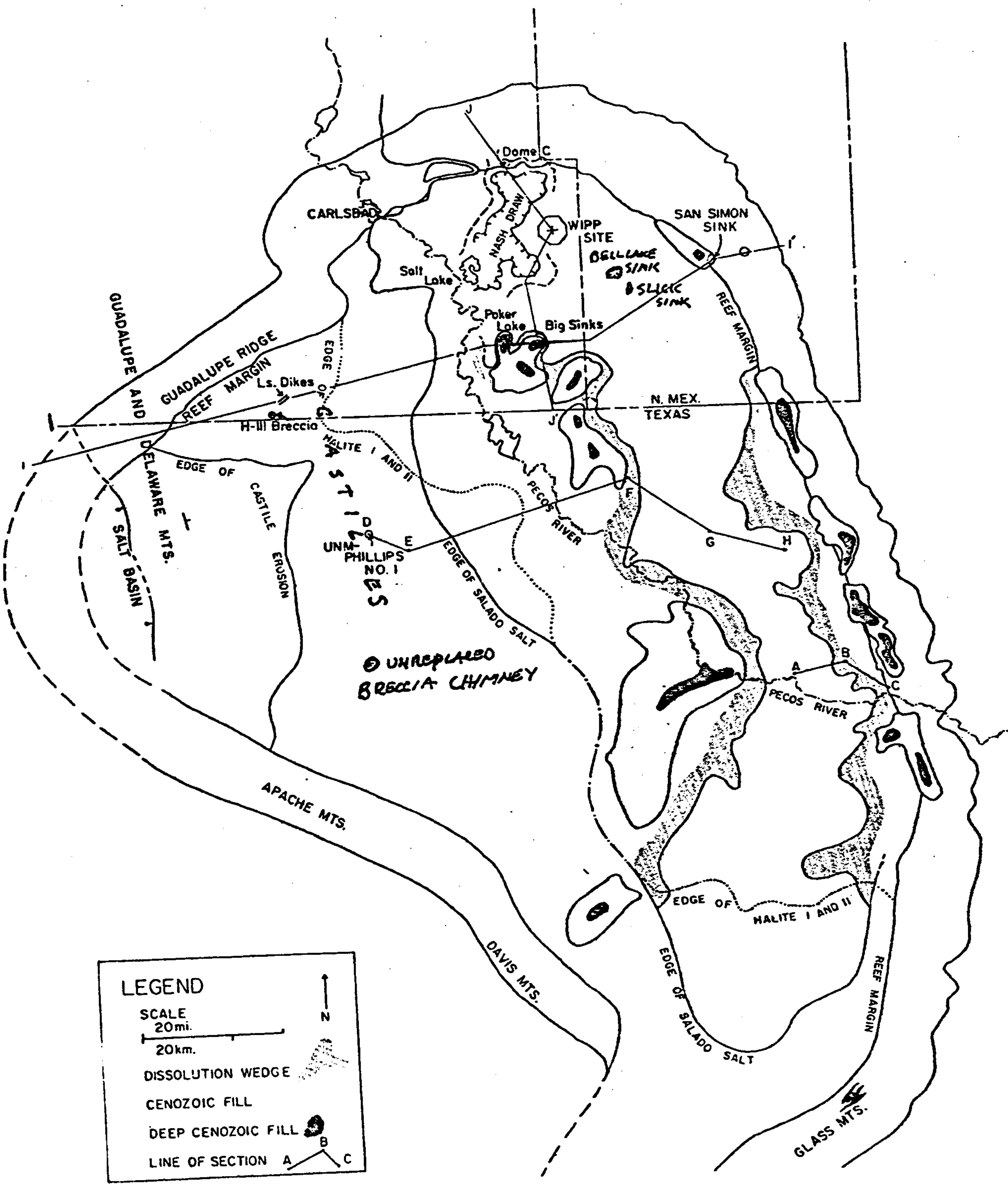

Dome C
J
CARLSBAD
WIPP SITE
SAN SIMON SINK
Salt Lake
NASH DRAW
Poker Lake
Big Sinks
REEF MARGIN
GUADALUPE AND DELAWARE MTS.
GUADALUPE RIDGE
REEF MARGIN
Ls. Dikes
EDGE OF
H-III Breccia
N. MEX.
TEXAS
J'
HALITE I AND II
EDGE OF CASTILE EROSION
SALT BASIN
PECOS RIVER
D
E
F
G
H
UNM-PHILLIPS NO. I
EDGE OF SALADO SALT
A
B
C
PECOS RIVER
APACHE MTS.
EDGE OF HALITE I AND II
DAVIS MTS.
EDGE OF SALADO SALT
REEF MARGIN
GLASS MTS.
LEGEND
SCALE
20mi.
20km.
N
DISSOLUTION WEDGE
CENOZOIC FILL
DEEP CENOZOIC FILL
LINE OF SECTION
A
B
C

FIG. 1

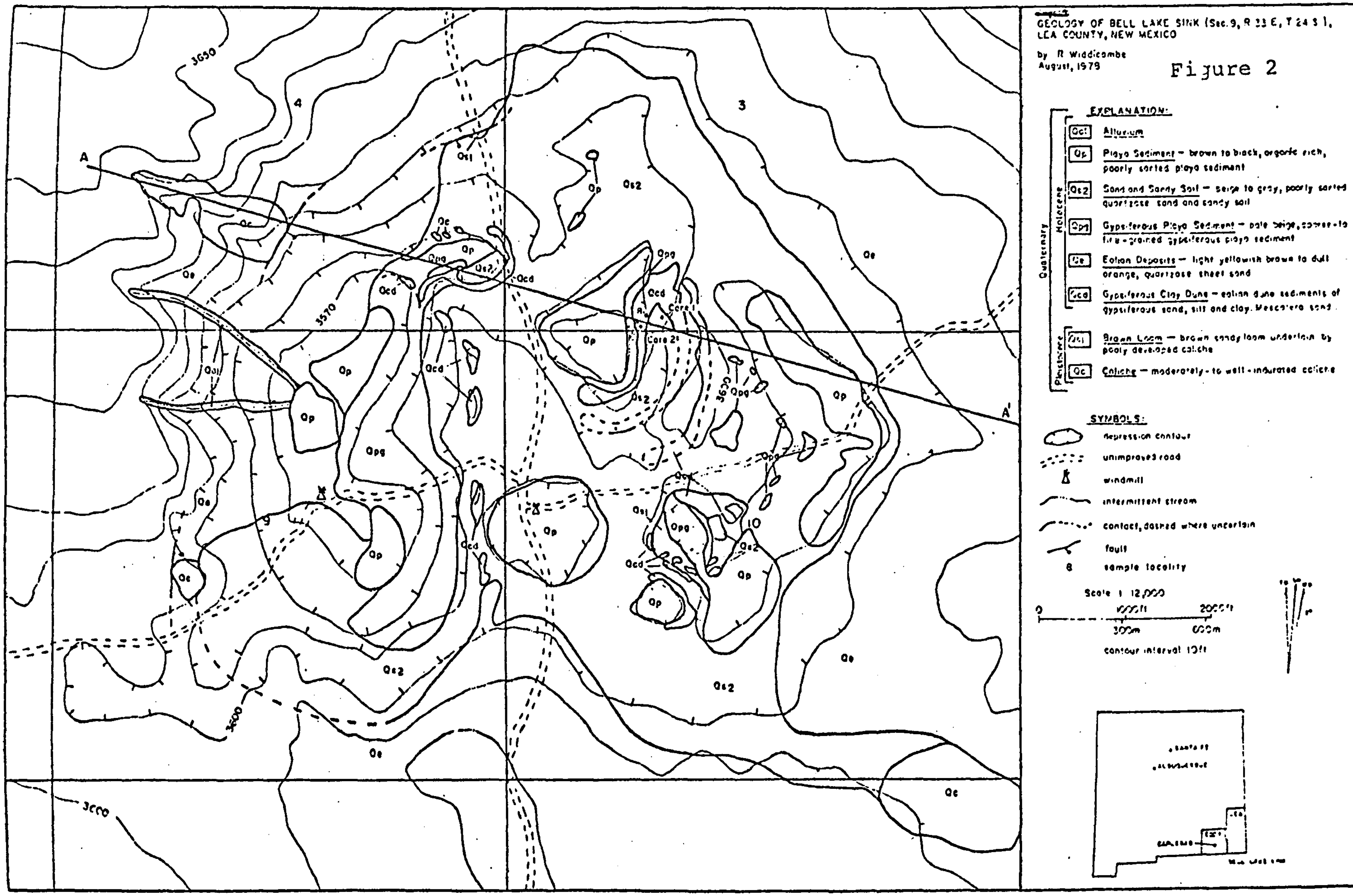
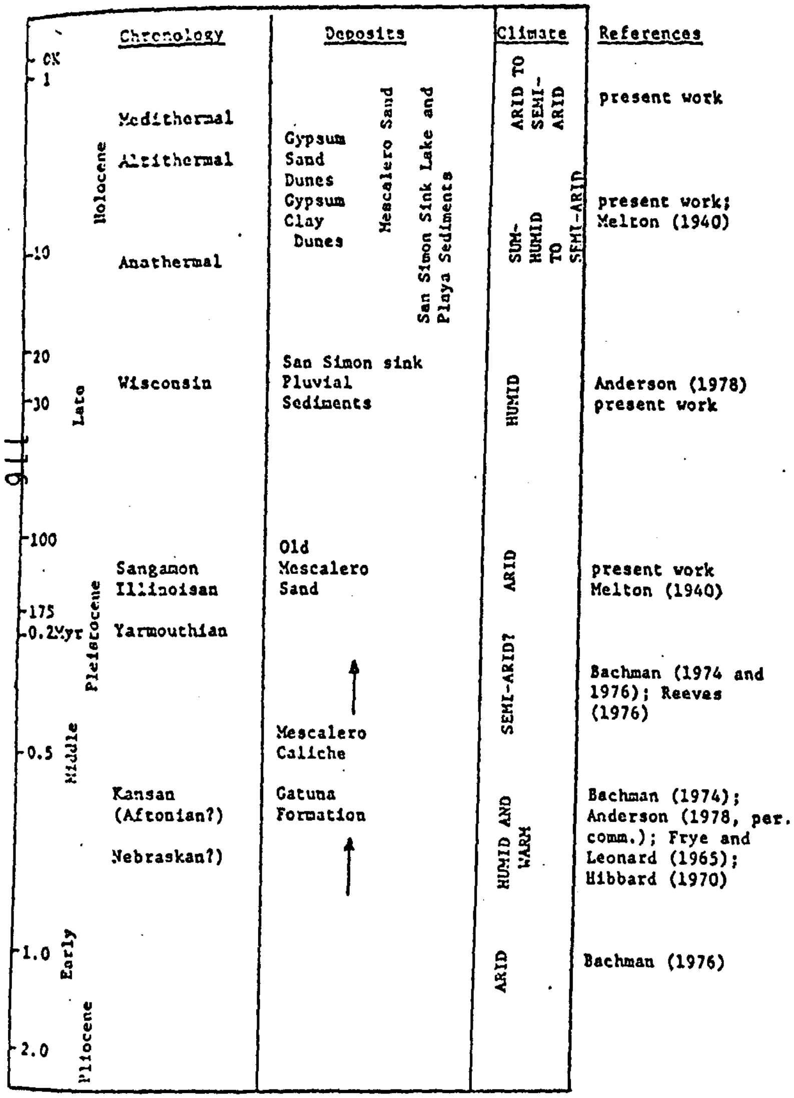

GEOLOGY OF BELL LAKE SINK (Sec. 9, R 33 E, T 24 S), LEA COUNTY, NEW MEXICO
by R Widdicombe
August, 1979
Figure 2
EXPLANATION:
Quaternary
Holocene
Qal Alluvium
Qp Playa Sediment — brown to black, organic rich, poorly sorted playa sediment
Qs2 Sand and Sandy Soil — beige to gray, poorly sorted quartzose sand and sandy soil
Qpg Gypsiferous Playa Sediment — pale beige, coarse- to fine-grained gypsiferous playa sediment
Qe Eolian Deposits — light yellowish brown to dull orange, quartzose sheet sand
Qcd Gypsiferous Clay Dune — eolian dune sediments of gypsiferous sand, silt and clay. Mescalero sand
Pleistocene
Qs1 Brown Loam — brown sandy loam underlain by poorly developed caliche
Qc Caliche — moderately- to well-indurated caliche
SYMBOLS:
depression contour
unimproved road
windmill
intermittent stream
contact, dashed where uncertain
fault
sample locality
Scale 1:12,000
0
1000ft
2000ft
300m
600m
contour interval 10ft
A
A'
3650
3570
3600
3630
3600
3600
Core 1
Core 2
Qal
Qp
Qs2
Qpg
Qe
Qcd
Qs1
Qc

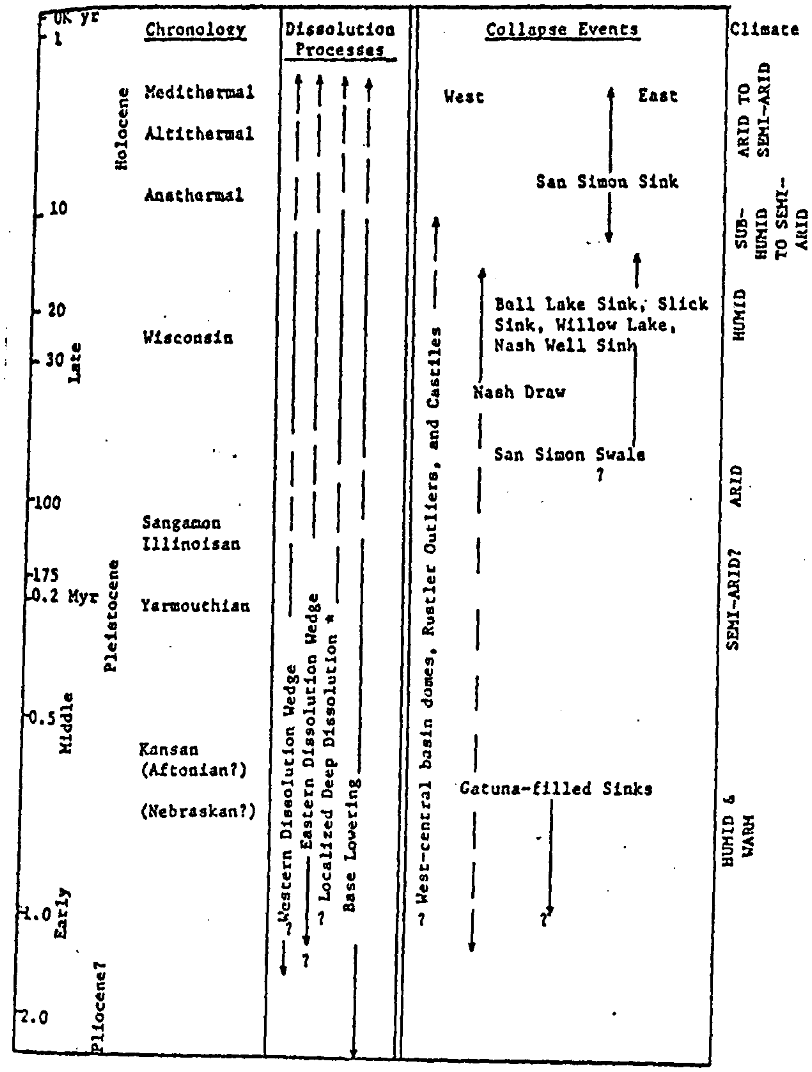
Figure 3. Relationship between Quaternary deposits and climate.



116

From Widdicombe, 1980

Figure 4. Relationship between dissolution processes, collapse events, and climate.



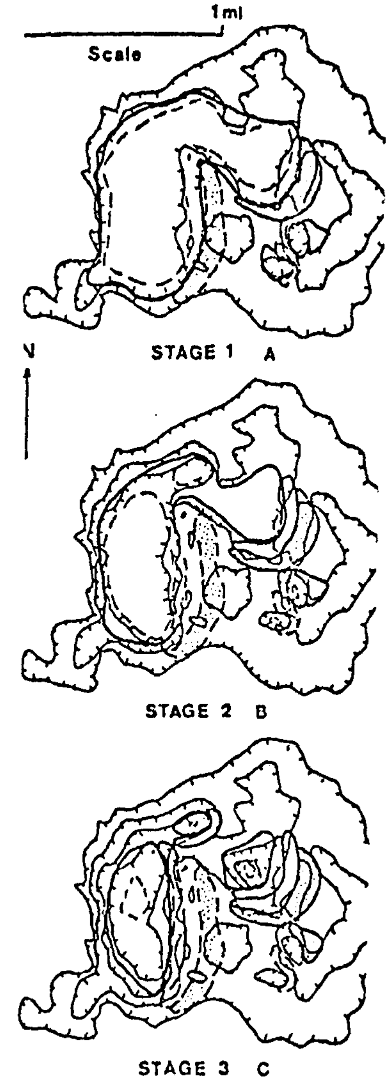


FIG. 5

The fault relationships suggest that the sink is younger than Old Mescalero sand (less than about 100,000 years; see Figs. 3 and 4). A series of 3 gypsum-clay dunes formed during the early Holocene as lake levels receded episodically, following a maximum lake stand in late Wisconsin (Figs. 3 and 5). These features suggest a Wisconsin age for Bell Lake and Slick sinks and Widdicombe (1980) has suggested a collapse association with humid climate (Fig. 4).

SAN SIMON SINK AND SWALE

A lake with a surface area of about 35 km^2 occupied the lower, south-eastern part of San Simon Swale during the last "pluvial" episode of the Wisconsin (Fig. 6). The present sill is at 3370 feet but beach and dune ridges indicate a stand about 20 feet higher. San Simon Sink proper is a much smaller feature near the center of the old lake area. It collapsed to its present expression following the last high lake stand. The last recorded collapse event was in 1927 and the scarp is still clearly visible, bounding the northwest margin of the sink (Fig. 7).

The center of the sink was cored to 810 feet (WIPP 15) and encountered Triassic Chinle shale at 545 feet. The core bottomed in a hard, micaceous Triassic sandstone which may be the Santa Rosa. The Triassic beds show minor normal faulting, dips to 20°, but no evidence for major brecciation.

The development of San Simon Swale basin in the area of the sink was accompanied by the influx of a large volume and thickness of relatively pure sand that is virtually identical in composition and texture to the Old Mescalero sand at the surface (compare Figs. 8A and 8B). No texture coarser than fine-sand occurs in the core with the exception of pebbles of caliche and Triassic sandstone which were washed into the swale depression beginning about 150 feet above the base of the sand section; suggesting swale-margin collapse morphometry.

The sand has a clay matrix which increases in proportion upward in the sequence, culminating in 40-foot thick nearly pure clay bed containing suspended sand grains at a depth of about 200 feet (Fig. 9). The base of this clay bed is rich in carbonate and contains a "pluvial" Artemisia pollen flora. Figure 9 shows that an interval of sand deposition returned following this first "pluvial" lake stand. "Pluvial" condition, however, gradually returned, forming a white carbonate-rich marl above 95 feet in the core. This marl correlates with the white diatomite beds exposed along the northeastern margin of the sink. A radiocarbon date from gastropod shells in this unit has an age determination of 20,570 years. A date from charophyte oogonia in the diatomite was greater than 32,000 years, indicating the presence of dead carbon, and suggesting that the 20,570 date is a maximum estimate.

San Simon Sink proper collapsed sometime following this last high lake stand. Vertical relief between the diatomite bed and the marl in the core indicates about 150 feet of collapse for the sink. The upper 40 feet of the WIPP 15 core contains playa-type sediments with gypsum layers and plant fragments and probably represents post-collapse deposition in the deeper part of the sink.

My interpretation is that no sediments older than Wisconsin are present in this deeper part of the swale basin. The swale may contain older Quaternary sediments around the margin but the main lake-filled depression was formed prior to or during the "pluvial" episodes of the Wisconsin. Mescalero-type sand derived from the Old Mescalero soil, and available on the surface, was washed fluvially and rapidly into the depression, and no main external drainage existed after formation of the depression. The upper marl represents the last "pluvial" pulse of the Wisconsin, some 15,000 to 20,000 years ago and the older lake clays containing the "pluvial" pollen flora must represent previous mesic episodes in the Wisconsin; hence the swale basin is probably younger than 60,000 years.

SAN SIMON RIDGE

Triassic sandstone and shale crops out on both sides of San Simon swale; along the eastern slope of Antelope ridge to the west and along San Simon Ridge to the east. The hard micaceous sandstone at the bottom of WIPP 15 at 810 feet is similar petrologically to sandstones on both

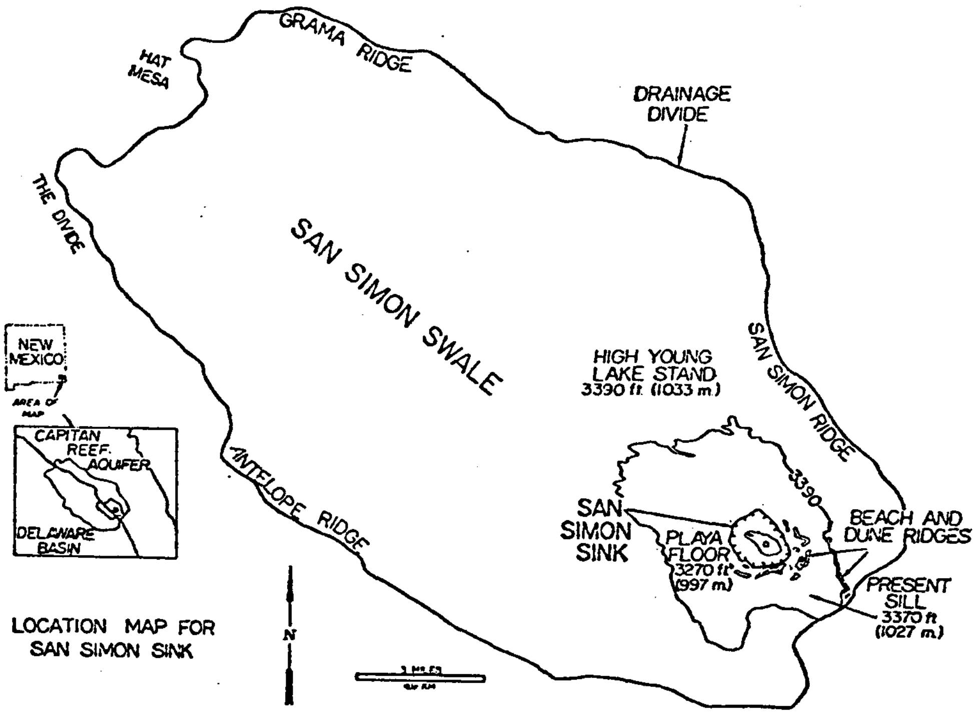


Figure 6 Location map

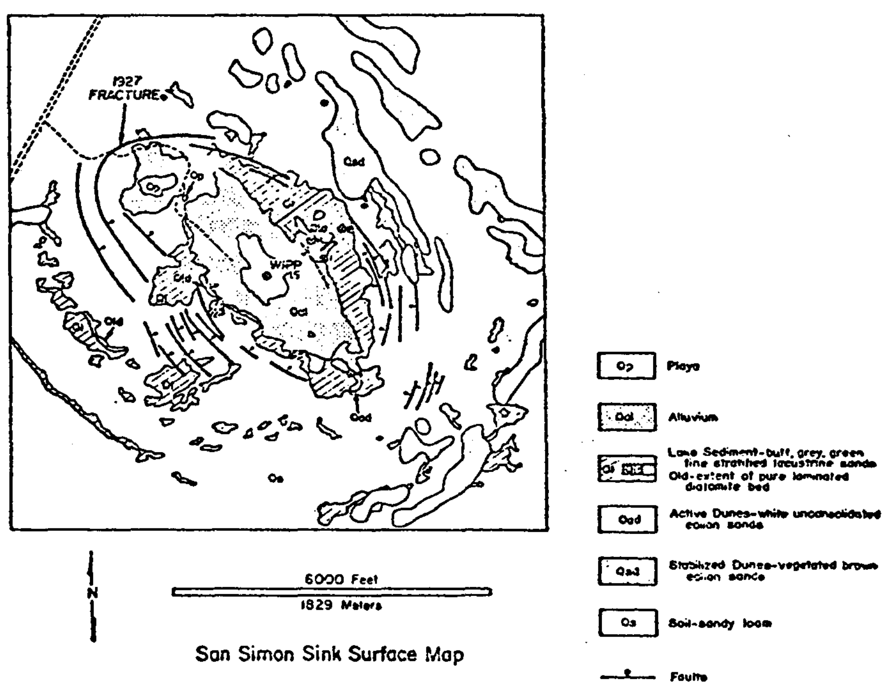
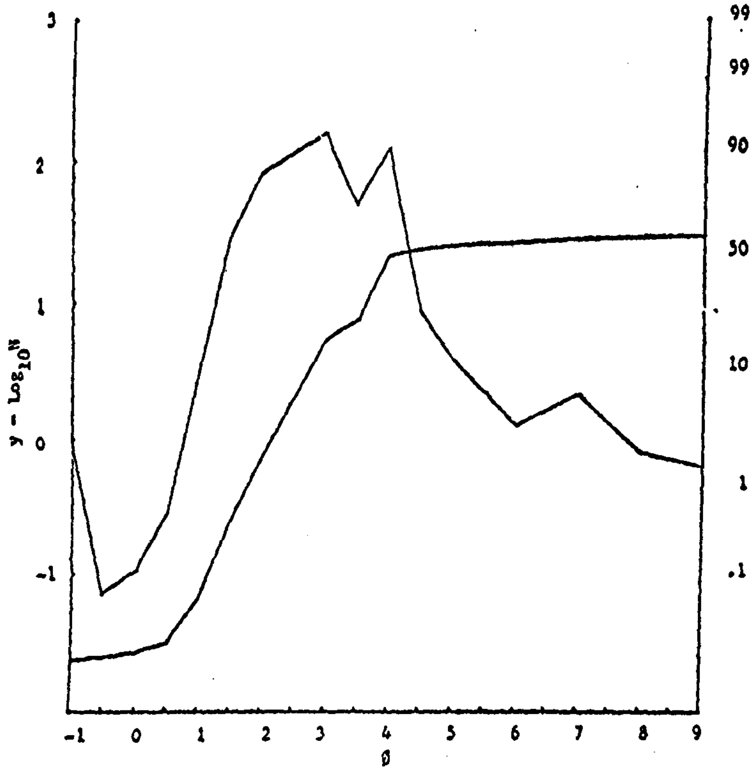


Figure 7



Sample # N20 Old Mescalero Sand

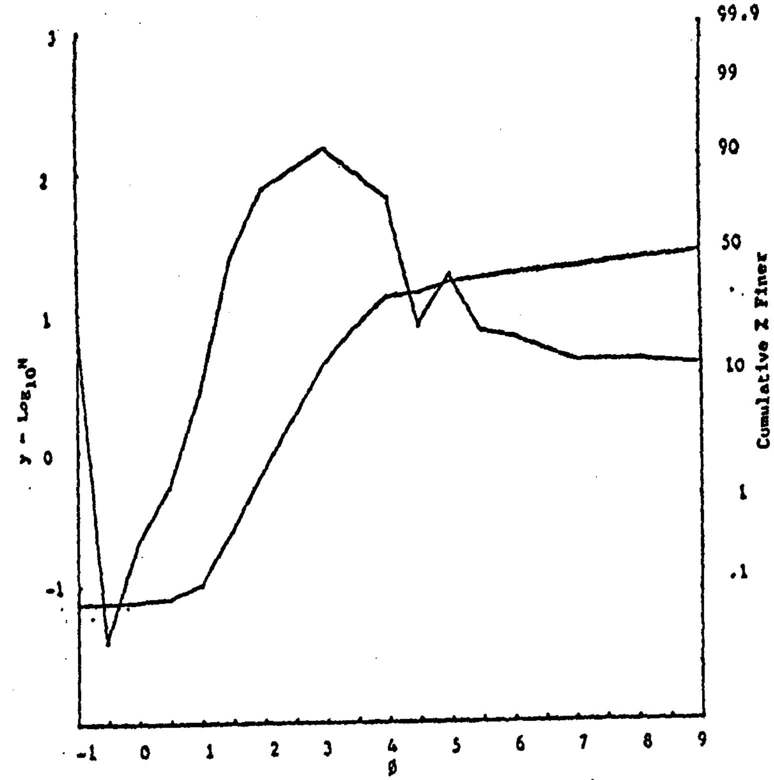
Moment Statistics:

Mz =	2.84 Ø	fine sand
σ =	1.86	poorly sorted
SkO=	0.43	strongly fine skewed
K_G =	2.72	very leptokurtic

Color: strong reddish orange

Figure 8A

Widdicombe, 1980



Sample # 640 San Simon Sink Core, 91 m (300 ft)

Moment Statistics:

Mz =	4.77 Ø	coarse silt
σ =	2.87	very poorly sorted
SkO=	0.51	strongly fine skewed
K_G =	3.79	extremely leptokurtic

Color: light brown

Figure 8B

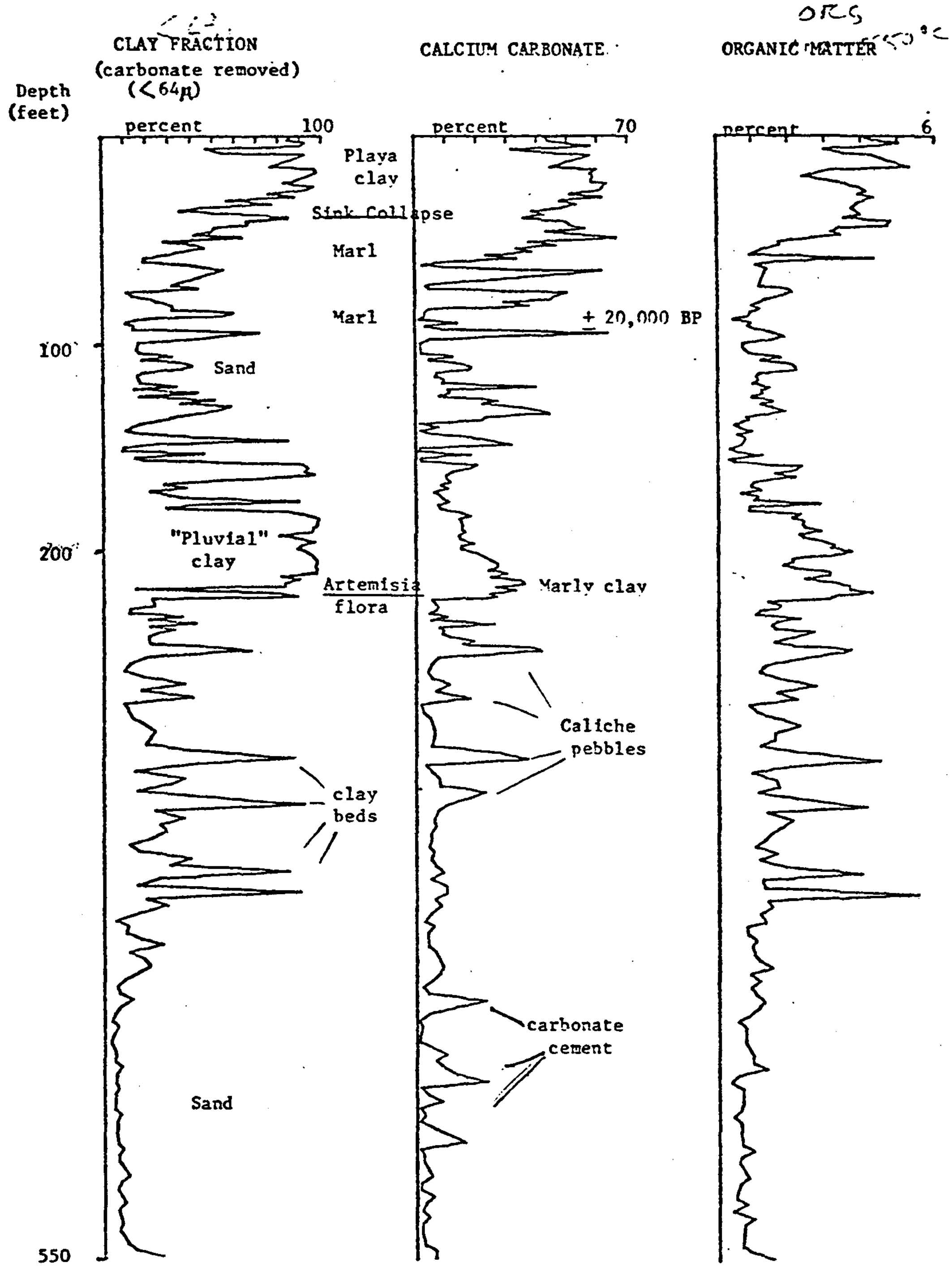


Fig. 9. Vertical profile of texture and composition of Pleistocene sediment in San Simon Swale.

Antelope Ridge and San Simon Ridge. A compilation of vertical structural relief between San Simon Swale and Ridge, based on the outcrop, WIPP 15, and geophysical logs (Figs. 10) indicates about 900 feet of vertical displacement within a distance of less than a half mile. This cross section suggests that the swale is part of a larger reef-top structure that could be related to solution and collapse within the reef itself or to a regional trend of Quaternary faulting (Fig. 11). Sandstone outcrops along San Simon Ridge exhibit pronounced jointing parallel to the reef, the ridge, and the swale.

STATE LINE OUTCROP

This famous outcrop has been visited by many of the world's geologists because of the excellent exposure of the Castile Formation and the development of Castile microfolding. The microfolds occur in pods in the axes of larger gentle megafolds and have a strike to the northwest (Fig. 12) which conforms to the Cenozoic structural grain of the basin. At ERDA 6, these microfolds have been pulled apart in boudinage structures formed as a result of flowage of salt in the salt anticline, indicating that the salt structures are post-microfolding or Cenozoic in age.

This outcrop also contains a bed of dissolution breccia from the Halite III unit of the Castile Formation. This outcrop is quite close to the western margin of the basin (Fig. 1) and shows that the salt beds in the Castile probably extended to the western as well as the eastern margin of the basin. The present edge of H-III and Lower Salado salt is almost 50 miles to the east (Fig. 1) and overlain by salt beds of the middle and upper Salado, indicating that salt has been selectively dissolved from the middle of the Castile-Salado evaporite sequence.

A limestone bed a few feet thick occurs at the upper end of the outcrop and can be seen "holding up" the prominent ridge of the outcrop and extensions of this ridge to the south. This limestone bed occurs in the middle of the H-III unit and appears as a definitive kick on gamma-ray and even sonic logs (Fig. 13, L-Bed). During the erosion-dissolution interval between the Castile and Salado, this same limestone

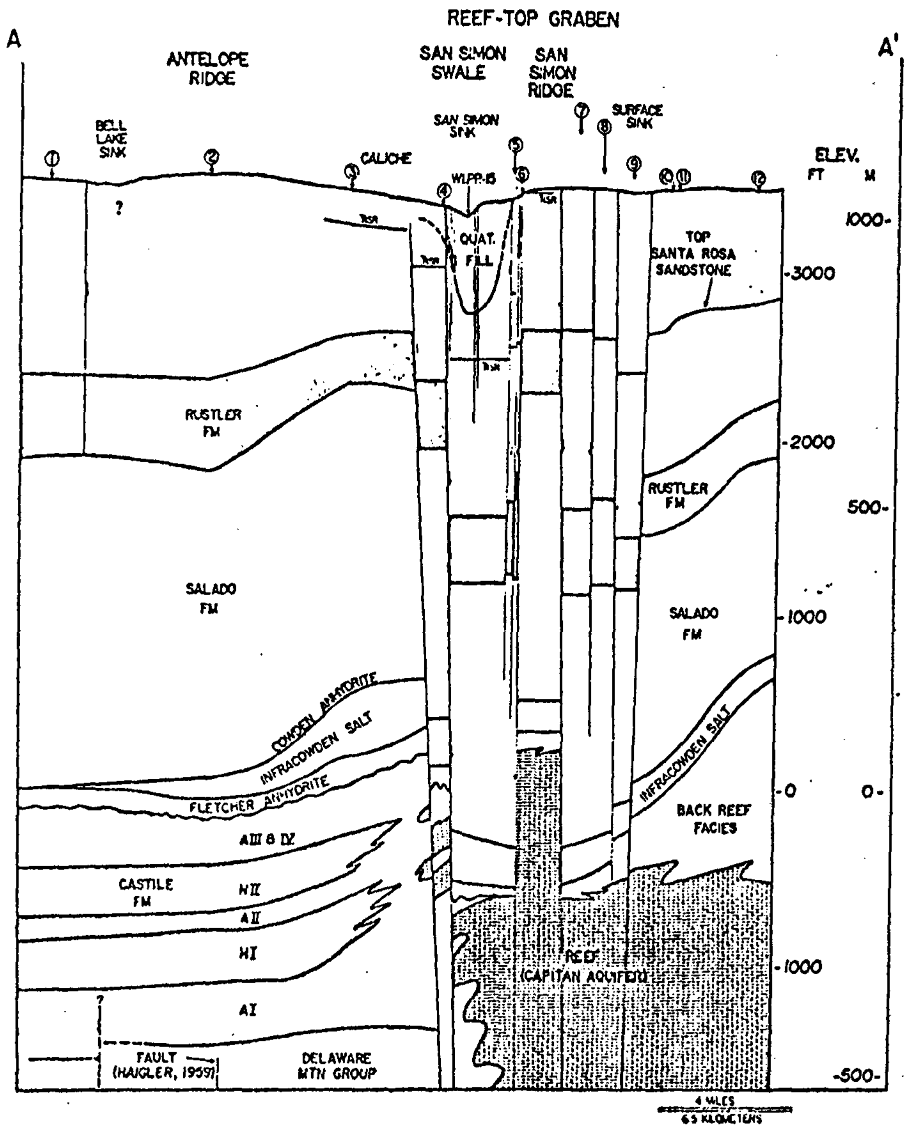


Figure 10 Cross section (diagrammatic) across San Simon area.

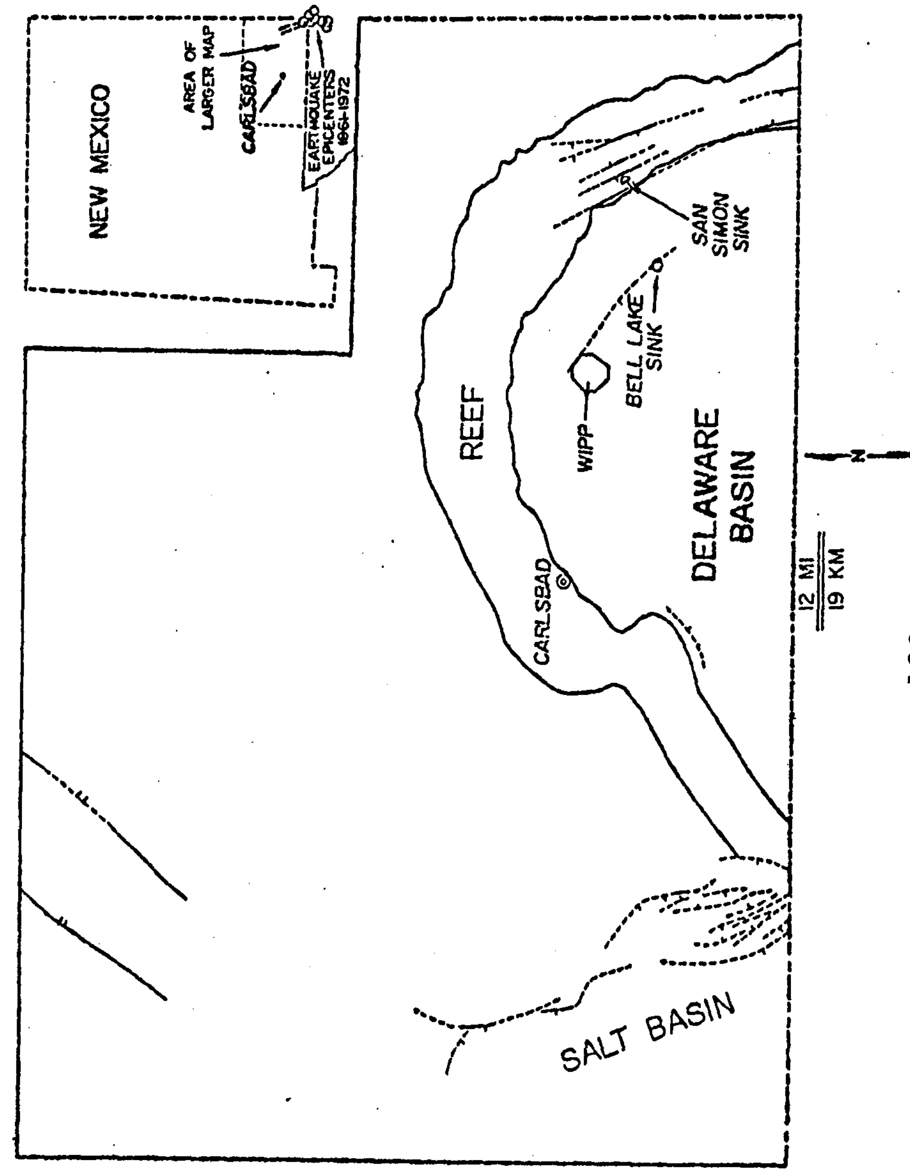


Figure 11 Quaternary faulting in the Delaware Basin area (modified from Callender and Seager)

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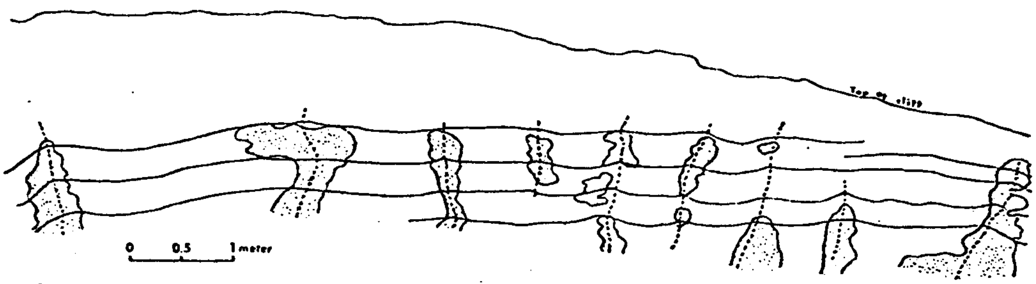

Figure [illegible]. Map of cliff near southwestern end of state line outcrop, Eddy County, New Mexico, showing relationship between megafolding and microfolding. Area of microfolding stippled; megafolding delineated by four easily traceable anhydrite laminae and by the trace of the intersection of the axial planes of mega-anticlines (dashed); the cliff is nearly normal to the fold axes.

report. The lateral distribution of microfolding is controlled chiefly by the wavelength of cover and extensive fracturing; scattered microfolded areas are present, however.

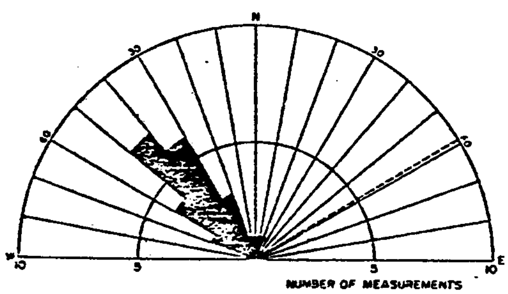

Figure [illegible]. Rose diagram for strikes of 26 microfold axes in Castile gypsum; dashed line indicates strike of cliff; state line outcrop, Eddy County, New Mexico. (*See* Fig. 8 for general location at outcrop.)

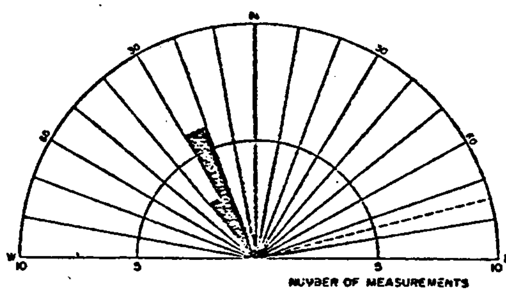

Figure 7. Rose diagram for strikes of 10 microfold axes in Castile gypsum; dashed line indicates strike of cliff; state line outcrop, Eddy County, New Mexico. (*See* Fig. 9 for general location at outcrop.)

uppermost lamina delineated in Figure 8. The section below the mapped portion of the cliff could not be mapped accurately because of

Microfolds are usually more strongly folded than associated megafolds. Also, the intensity of microfolding appears to be related approxi-

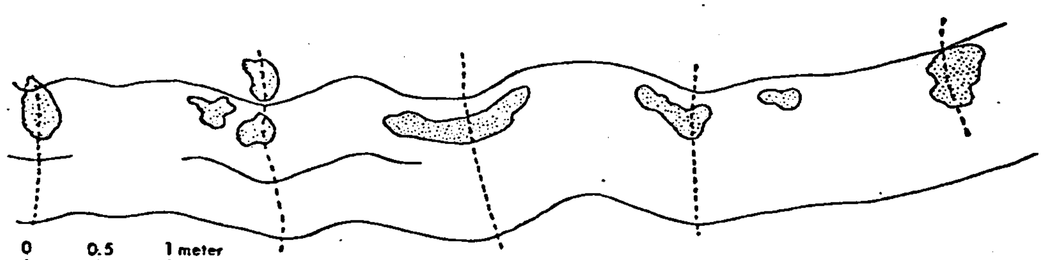

Figure [illegible]. Map of cliff near the northeastern end of state line outcrop, Eddy County, New Mexico, showing the relationship between megafolding and microfolding. Area of microfolding stippled; megafolding delineated by three easily traceable anhydrite laminae and by the trace of the axial planes of mega-synclines (dashed); the cliff is nearly normal to the fold axes.

Figure 12

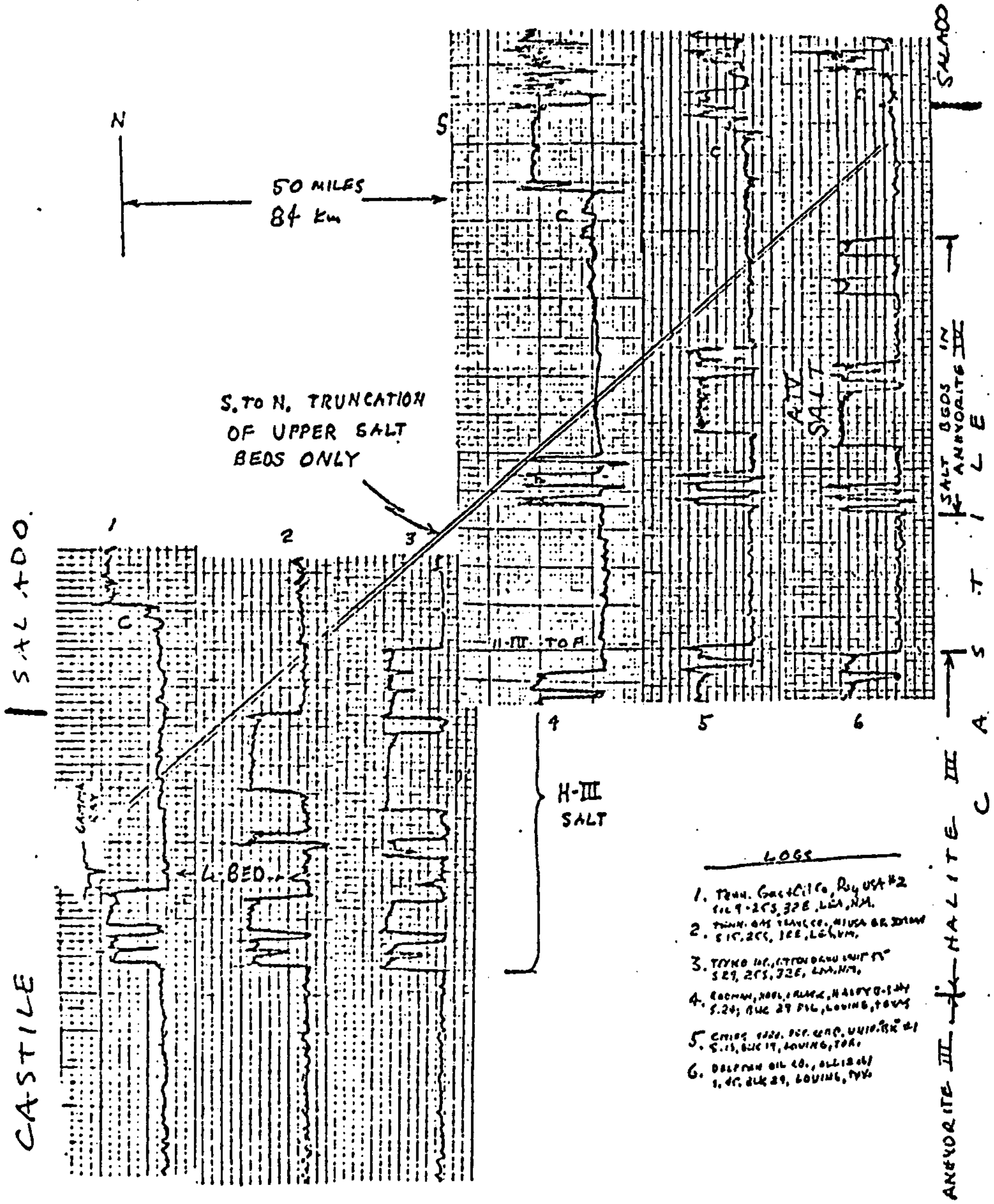

Figure 13 N-S sonic log section through eastern part of Delaware Basin.

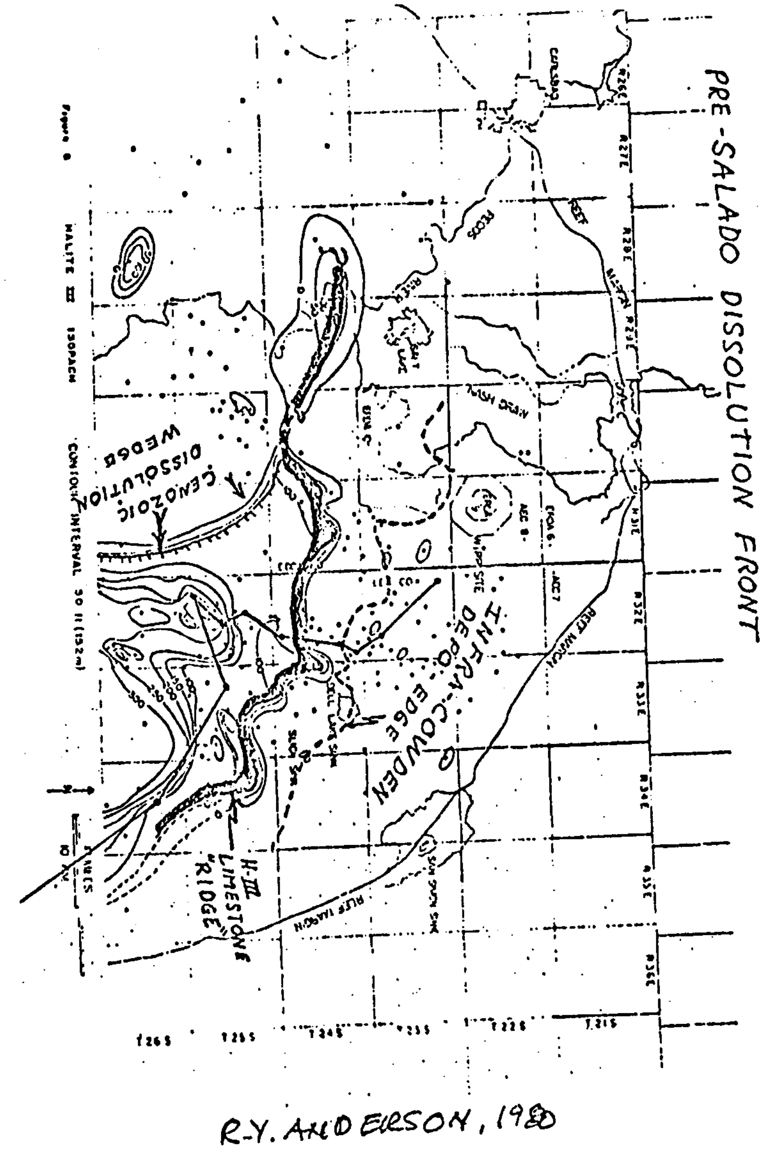

Figure 14 Isopach oh H-III salt beds of Castile Fm.

bed appears to have formed the top of a "ridge" marking the northern margin of H-III salt in the basin, because it corresponds to the edge of the H-III isopach (Fig. 14). The removal of Castile salt beds associated with this erosion-dissolution interval can also be seen in a N-S sonic log section which shows that it is always the uppermost salt bed that is removed as the Castile was truncated from the north to the south in the basin (Fig. 14).

CASTILES

Replacement limestone masses are of particular interest because they may represent the movement of waters up through the evaporites from aquifers below. Replacement masses generally occur as brecciated Castiles on the Gypsum Plain where the Castile has been exhumed to deep levels (Fig. 1, Fig. 15). However, replacement has not been confined to the brecciated chimneys of the Castile and can be seen as two "limestone dikes" crossing the highway about a mile north of the State-Line outcrop. The same area of the dike's also has collapse structures, containing blocks of Cretaceous sediments, which extend upward into the Salado. Replacement masses have also penetrated these structures.

Replacement limestone closely resembles the unreplaced laminated gypsum of the Castile Formation but generally contains less than 1% calcium sulfate. With replacement, the $\delta^{13}C$ values in the carbonate of the Castile Formation shifted from +6 to -23.5. Similarly, the $\delta^{34}S$ values of unaltered anhydrite shifted from +10.7 to as much as -15.1 for associated sulfur (Kirkland and Evans, 1976). Kirkland and Evans have proposed bacterial reduction, fueled by hydrocarbons, and taking place in the presence of aqueous solutions as the process responsible for replacement. The $\delta^{18}O$ values ranging from -9.0 to -5.6 in the brecciated castile calcite suggest equilibriation with meteoric waters.

Kirkland and Evans visualise artesian meteoric waters and hydrocarbons (mainly gas) moving up from the Bell Canyon through fractures in the Castile Formation as driving the replacement process. The common association of limestone replacement with breccia chimneys implies a further stage of development in which dissolution and removal of salt,

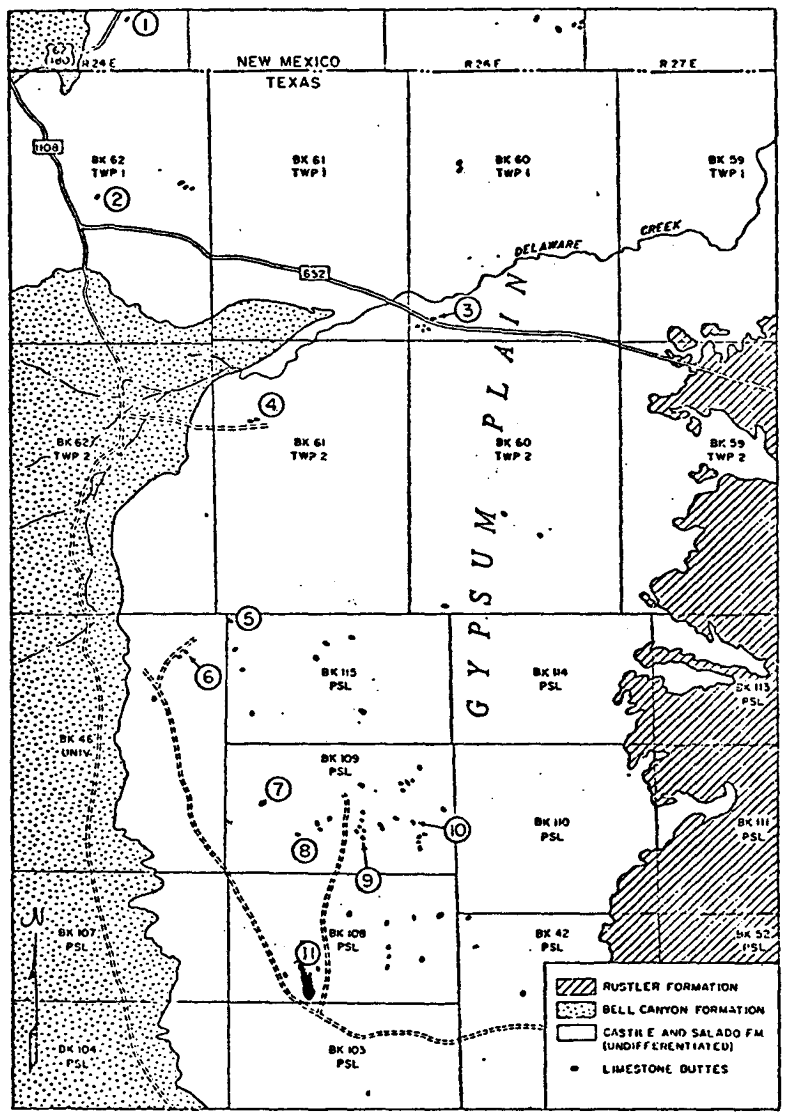

Figure 15. Location of Limestone Buttes, Texas and New Mexico.

perhaps from brine density flow associated with the same waters (Anderson, 1980), has resulted in brecciation and collapse. The collapse may have provided additional access for waters, hydrocarbons, and bacteria and the replacement of the chimneys.

Not all breccia chimneys in the lower part of the evaporites have been replaced, however, as we encountered an unreplaced breccia chimney in a core in Culberson County, Texas (Fig. 1).

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COMMENTS ON WIPP SITE GEOTECHNICAL PROBLEMS

by

George Bachman

INTRODUCTION

Geotechnical problems confronting the Wipp Project may be classified in four broad categories:

1. Dissolution (including "breccia pipes").
2. Paleoclimate and its bearing on dissolution.
3. Erosional history (especially evolution of the Pecos River system and its related geomorphic surfaces).
4. Brine reservoirs.

The first three of these categories are summarized here as background material for the field conference of June 16-18, 1980. Table 1 summarizes the stratigraphic sequence of rocks discussed during the conference.

Table 1.--Major stratigraphic and time divisions, southeastern New Mexico. (Time divisions from Berggren, 1972, in part.)

Era	System	Series	Formation	Age estimate
Cenozoic	Quaternary	Holocene	Windblown sand	
		Pleistocene	Mescalero caliche Gatuna Formation	ca. 500,000 years ca. 600,000+ years
				1.8 million years
	Tertiary	Pliocene	Ogallala Formation	5 million years
		Miocene		26 million years
		Oligocene Eocene Paleocene	Absent Southeastern New Mexico	65 million years
Mesozoic	Cretaceous	Upper Lower	Absent SE N. Mex. Detritus preserved	136 million years
	Jurassic		Absent SE N. Mex.	190-195 million years
	Triassic	Upper Lower	Dockum Group Absent SE N. Mex.	225 million years
Paleozoic	Permian	Ochoan	Dewey Lake Red Beds Rustler Formation Salado Formation Castile Formation	
		Guadalupian Leonardian Wolfcampian	Capitan-Bell Canyon Fms. Present but not discussed in this report	280 million years

DISSOLUTION

For purposes of this discussion dissolution is divided into three general types:

1. Local, near-surface dissolution in the vadose zone. This includes the process of "erosion by solution and fill" (Lee, 1925).
2. Region, or bulk, dissolution which may occur in either the vadose or phreatic zone.
3. Deep-seated dissolution initiated in the phreatic zone.

All these processes are active in gypsum, anhydrite, and halite. They are dependent on the proximity of these soluble rocks to an open system of conduits which allows free movement of fresh water to dissolve and remove the rocks.

The process of erosion by solution and fill incorporates local dissolution and is an active process today in Nash Draw. It has been the dominant process in the formation of this depression. As this process was defined by Lee (1925) runoff from rain drains through arroyos into fractures in gypsum. The water dissolves the gypsum to form caves and during subsequent storms surface debris is washed into the caves. By this process the arroyo gradient is lowered and headward cutting of the arroyo follows (Fig. 1). Stops 1-5 and 2-6 on this trip are at localities which illustrate this process.

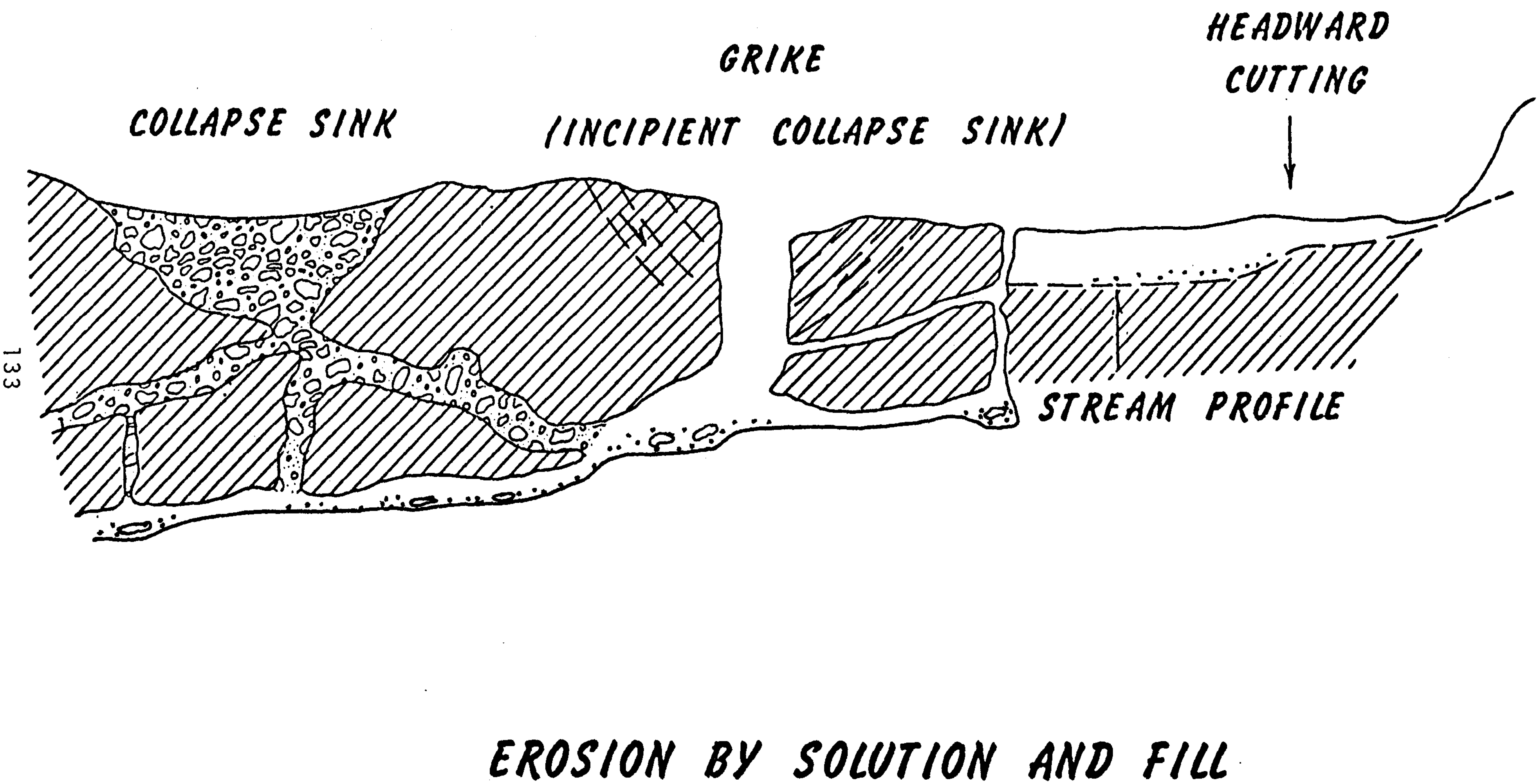
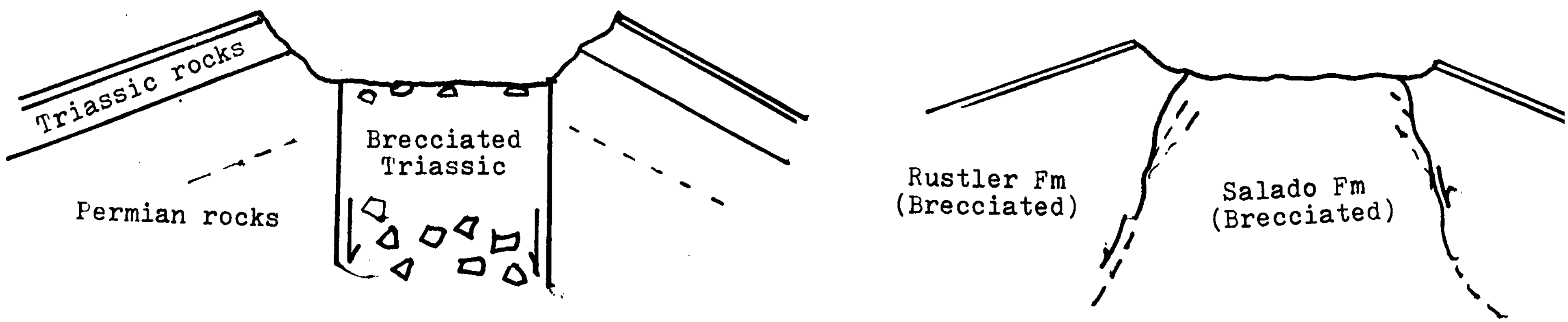


Figure 1. Diagrammatic cross-section to illustrate process of erosion by solution and fill.

Regional, or blanket, dissolution occurs where unsaturated water penetrates a permeable bed adjacent to soluble rocks and moves laterally through the permeable bed dissolving the soluble rocks near its path. This process differs from "solution and fill" by dissolving rocks adjacent to aquifers rather than rocks adjacent to surface drainage. By this process intraformational dissolution breccias are formed and where the dissolution occurs relatively near the surface extensive areas of collapse may result. Results of this process will be observed at localities 2-7 and 2-8. Unique karst features, such as karst domes which will be observed at locality 2-7, may accompany this process (Fig. 2).

Although regional dissolution is an active process at present, the distribution of Cretaceous rocks (Fig. 3) indicates that much regional dissolution must have occurred before Cretaceous time. From the end of Permian time to the early part of Cretaceous time the western edge of the Delaware basin was above sea level. During that time a groundwater system accompanied by dissolution would have developed in this area. Cretaceous seas later transgressed across the eroded edges of the underlying Triassic and Permian rocks (Fig. 4 and localities 1-2, 3-1, 3-2). These Cretaceous marine rocks have since collapsed along with the underlying rocks but their presence at a few localities is sufficient to record this sequence of events and the major unconformity underlying them.



Diagrammatic cross-section of breccia chimney

Diagrammatic cross-section of karst dome at Malaga Bend

Figure 2. Diagrams comparing breccia chimney with karst dome.

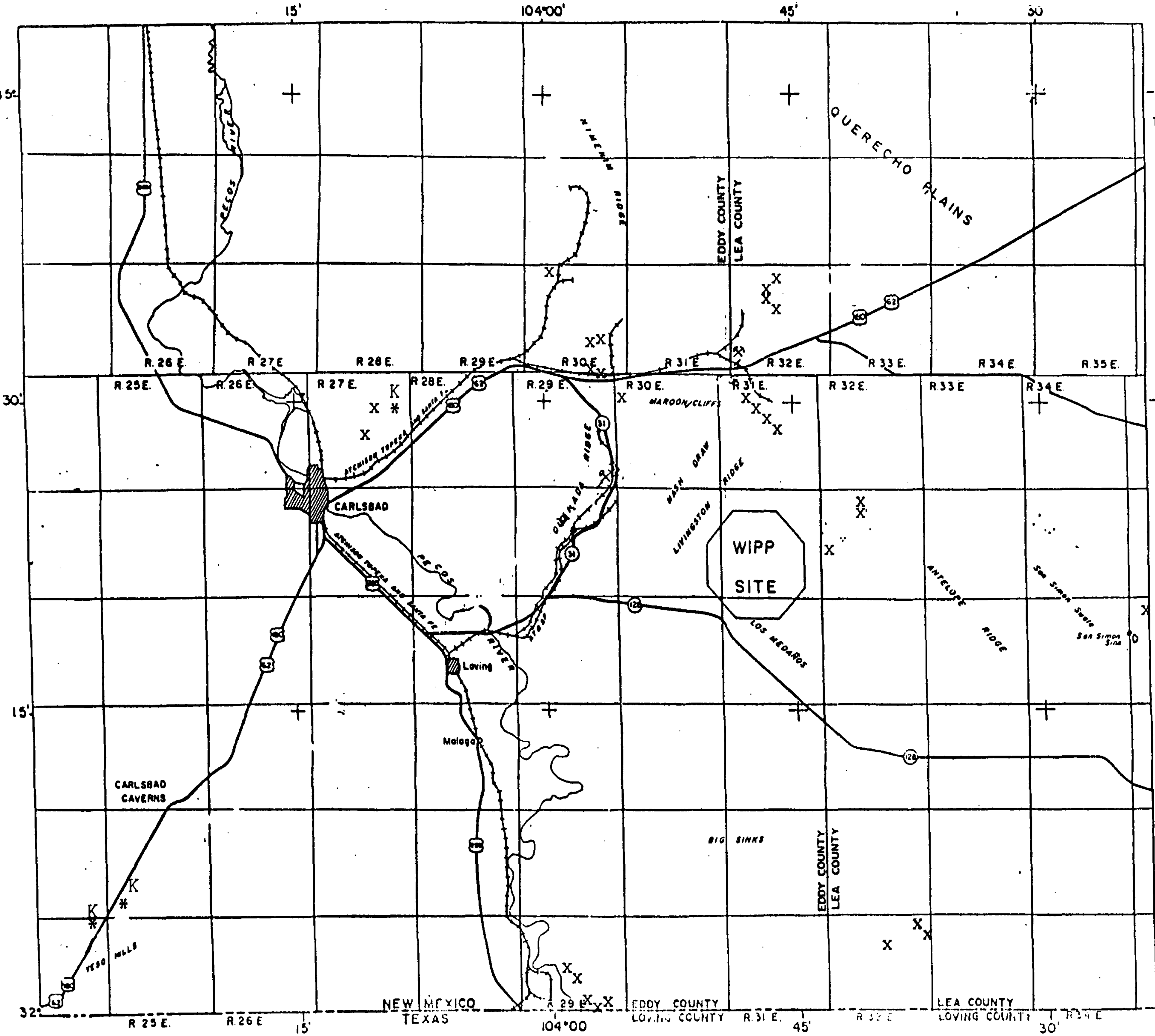


Figure 3. Distribution of Cretaceous (K*) and Triassic (X) rocks.

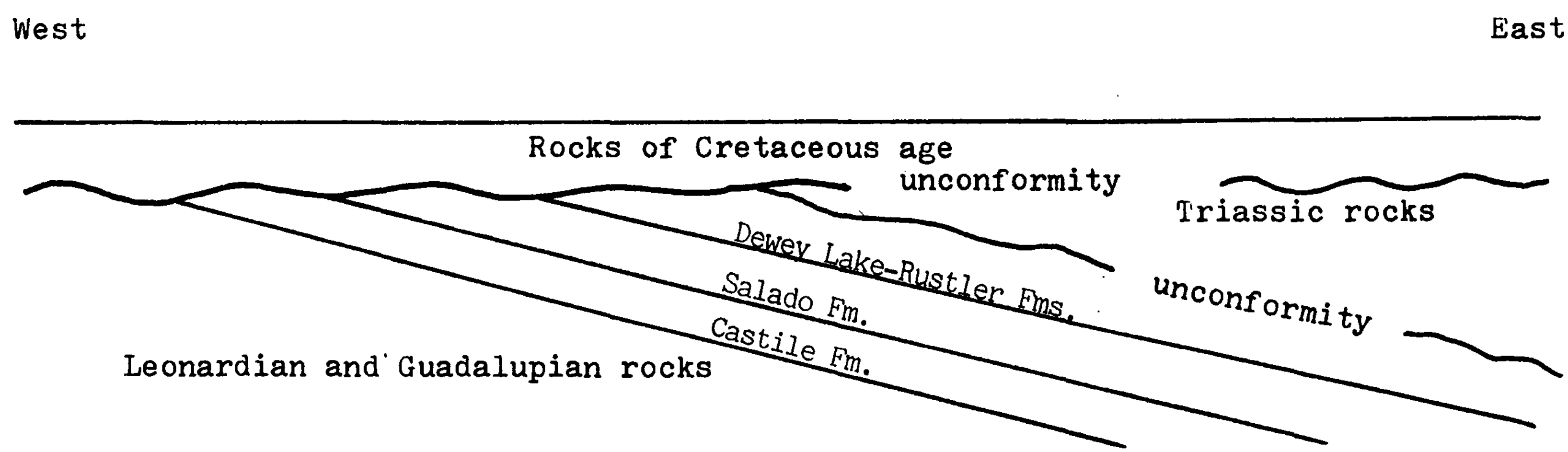


Figure 4. Diagram showing stratigraphic relations of Cretaceous and older rocks, western part of Delaware basin, New Mexico.

Deep-seated dissolution initiated in the phreatic zone is a contributing process in the formation of major cavern systems and results in less common features such as breccia chimneys, or "breccia pipes" (Fig. 2). During Gatuna time, about 600,000 years before the present, the hydraulic head in the Capitan aquifer system was considerably greater than at present. (At localities 1-1 and 2-5, this field conference, stream deposits in the Gatuna Formation are observed from 50 to more than 100 feet above the modern Pecos drainage system. This is evidence that the hydraulic head at that time was greater than at present.) This hydraulic head drove fresh water upward through fractures to dissolve soluble rocks in its path. This dissolution resulted in deep-seated cavities into which overlying rocks collapsed. These collapse sinks are preserved today as breccia chimneys, or breccia pipes.

Hills A and C (localities 1-3 and 1-4) are breccia chimneys which overlie the Capitan aquifer system at the margin of the Delaware basin. (The so-called "Capitan aquifer system" includes parts of the adjacent back-reef facies, the Tansill, Yates, and Seven Rivers Formations) These chimneys are characterized by the collapse of stratigraphically younger rocks into surrounding older rocks (Fig. 2). Shallow collapse sinks (Fig. 1) are widespread in southeastern New Mexico but deep-seated breccia chimneys have been recognized only overlying the Capitan aquifer system outside the Delaware basin.

Following Middle Pleistocene (Gatuna) time the Pecos River entrenched itself in its present position and intercepted the Capitan aquifer system near Carlsbad. Carlsbad Springs resulted from this interception and relieved the hydraulic head. It is improbable that conditions are favorable for the formation of breccia chimneys in the future.

Karst domes (Fig. 2, locality 2-7) differ fundamentally from breccia chimneys. The cores of karst domes are composed of rocks stratigraphically older than the surrounding rocks. Overlying rocks dip away from the core and the gross characteristics are more suggestive of structural domes than collapse sinks.

PALEOCLIMATE

Sedimentary deposits with their accompanying fossils and soils suggest that the climate in southeastern New Mexico has ranged from semiarid to semihumid since Gatuna time during the past 600,000 years. Although the Gatuna Formation is correlative in part with the Kansan glaciation stage in the Midcontinent region, there is no evidence of glaciation in in southeastern New Mexico at this time or during any other Pleistocene stage. However coarse conglomeratic lenses in the Gatuna Formation indicate that during its deposition streams had more carrying capacity than at any time since. Impressions of grasses and reeds in overbank and flood plain deposits indicate a more dispersed drainage system than the present Pecos system. All these features suggest higher rainfall during Gatuna time. By the end of Gatuna time an extensive constructional geomorphic surface had been built in southeastern New Mexico.

The Mescalero caliche was deposited as part of an extensive soil profile on this constructional surface. The Mescalero formed in part during the Yarmouthian interglacial stage in the Midcontinent region. Calcareous soils, of which the Mescalero is an example, are not known to form in areas where rainfall exceeds 25 to 30 inches per year nor in areas where rainfall is less than 3 to 4 inches per year. The optimum climate for the formation of thick calcareous soils is in rainfall of 10 to 15 inches per year.

The Mescalero caliche began to form about 500,000 years ago. It is probable that since this soil began to form the region has not been exposed to extended periods of rainfall which exceeded 30 inches per year nor to extended periods of aridity of less than 3 inches per year. Humidity, accompanied by chemical action destroys calcareous soils; aridity and desertification destroy these soils by dessication.

The Berino soil began to form about 300,000 years ago and is preserved in limited areas around the WIPP site. Carbonates have been flushed out of this soil by infiltrating surface water and minor amounts of clay have been translocated in the soil. The parent material of the Berino soil around the WIPP site is wind-blown sand but its present physical characteristics suggest that after deposition this sand was stabilized in a semihumid environment.

Following the formation of the Berino soil deposits which indicate conditions of past climates are dispersed over the region and the sequence of events is less evident. However, much regional data has been accumulated and models developed for late Wisconsinan glacial time from about 30,000 to 12,000 years before the present. Some workers have advocated a cold, dry full-glacial climate with reduced evaporation to explain the many lakes and ponds of that time interval in the southwestern United States (Galloway, 1970; Brackenridge, 1978). However, others have presented evidence for full-glacial pluvial climates--periods of relatively cool temperatures, lower evaporation rates and increased rainfall (Reeves, 1973; Leonard and Frye, 1975; Wells, 1979).

Additional evidence gathered during the present investigation with Artie Metcalf (Univ. Texas at El Paso) suggests that climate was more temperate and rainfall more effective during late Wisconsinan time. Clam shells dated to be 13,620 $\pm$ 300 years old were collected from ancient gravels in the bed of the Pecos River below Macmillan Dam. These shells indicate less turbid water than at present. Absolute age on snail shells from the Clayton Basin north of the WIPP site is not available but is presumed that lake deposits there are of Wisconsinan age. Nearer the WIPP site spring deposits in Nash Draw (locality 1-7) may be Wisconsinan.

During late Wisconsinan time precipitation and runoff may have increased by 50 percent (Reeves, 1973) and much of southeastern New Mexico was a pinyon-pine woodland. Wells (1979), on the basis of plant remains in widely distributed rat middens, has estimated that the pinyon-Juniper woodland. Wells depressed in elevation as much as 800 to 1200 m (2620 to 3935 ft) in the eastern Chihuahan Desert of which southeastern New Mexico is an extension. Erosion is less severe in vegetated areas, such as woodlands, than in sparsely vegetated areas such as modern mesquite-creosote terrain. However, dissolution is probably a more active geologic process in temperate vegetated areas where rainfall is more effective.

EROSIONAL HISTORY

It may be assumed that during late Cenozoic (Pliocene) time streams flowed from the Sacramento and Guadalupe Mountains southeasterly towards the High Plains but deposits of that drainage system have not been recognized in the Pecos River Valley. The earliest antecedents of the modern system which have been preserved are gravel and related stream deposits of the Gatuna Formation. Gatuna drainage was dispersed in a broad system which flowed south to southeasterly. Today Pierce Canyon flows westerly and cuts at right angles across channel and overbank deposits of the Gatuna Formation (localities 2-5, 2-6). These early stream deposits are as much as 100 feet above the Pecos River. Since Gatuna time, the Pecos River has entrenched itself a mile or more to the west of this ancient drainage.

The modern Pecos is generally a low energy stream and at numerous places it follows dissolution channels more readily than erosion channels. However, northward from Carlsbad to the Seven Rivers embayment (about 10 miles northwest of Carlsbad) limestone gravels occupy the Pecos channel and fill many collapse sinks. These gravels are assumed to be late Pleistocene (Wisconsinan) in age because ^{14}C dates of clam shells in these gravels indicate and age of more than 12,000 years for the gravel.

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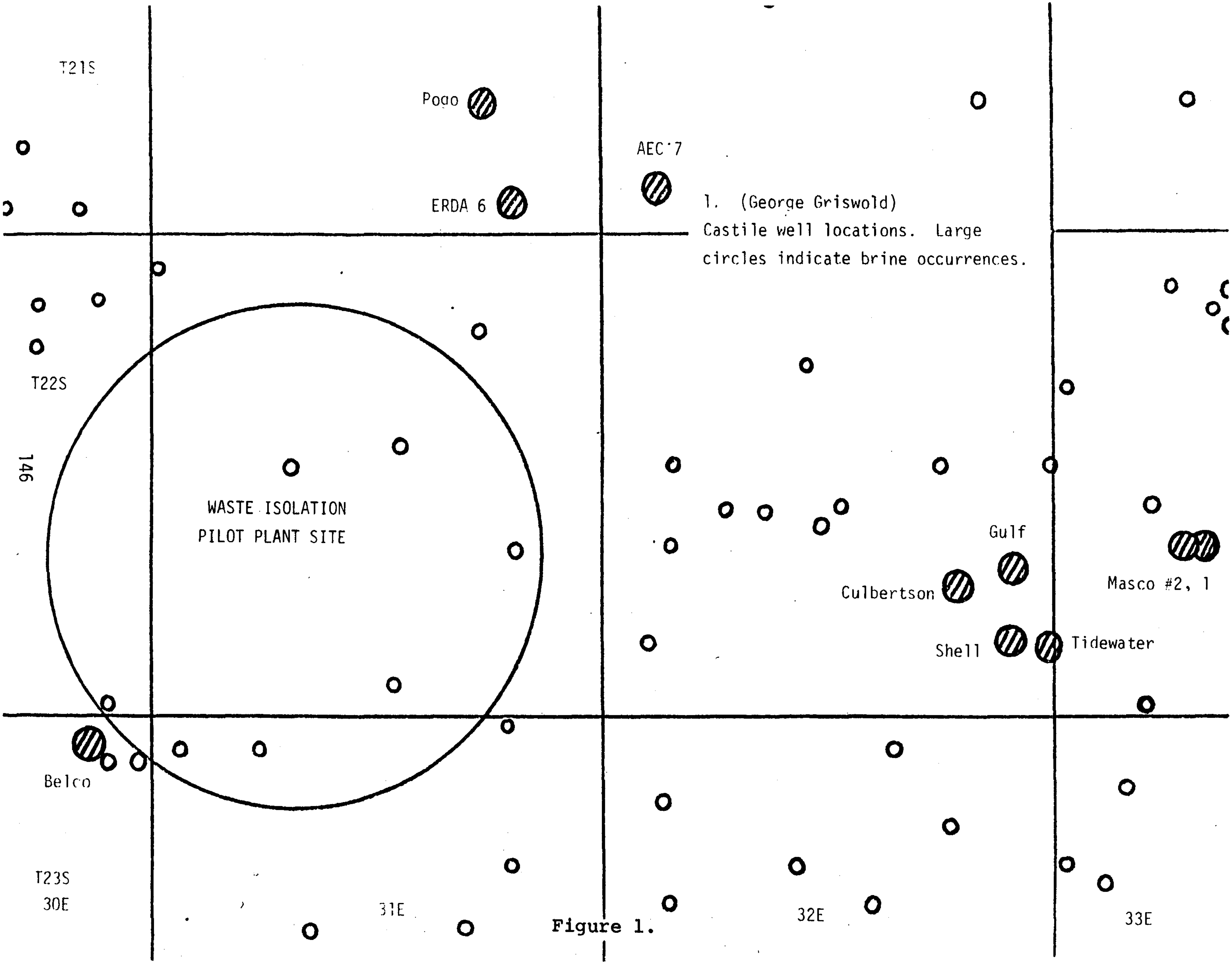
KNOWN BRINE RESERVOIRS IN THE VICINITY OF THE WIPP SITE

(A Summary prepared by George Griswold)

The location of 10 wells which encountered Castile brine reservoirs are shown on Figure 1. All reservoirs were geopressured (flowed naturally to the surface) except for the occurrence at AEC 7. Only limited geochemical and pressure data are presently available, see Tables 1 and 2. Flow testing is needed before reservoir size or possible interconnection of adjacent wells can be established.

A large salt anticline is now known to exist in the POGO-ERDA 6-AEC 7 area. It has been postulated that brine reservoirs are related to these anticlines. Additional work is needed to confirm this concept. The reservoirs are only slightly geopressured (0.6 to 0.7 psi per foot). If the reservoirs were pressured by simple salt flowage the pressure gradient should have been lithostatic(in the order of 1.0 psi per foot).

ERDA 6 has a 200 foot cement plug set above the entry point of the brine reservoir. The well awaits additional testing.



1. (George Griswold)
Castile well locations. Large circles indicate brine occurrences.

Figure 1.

TABLE 1. FLOW AND PRESSURE DATA

Well Name	Date Drilled	KB-GL (ft ASL)	Brine Depth	Reservoir Press (psi)	Gradient (psi/ft)	Q (bbl/day)
Masco No. 1	1938	3621	3265	NA	>0.528	2400
Masco No. 2	1938	NA	3363	NA	>0.528	12,000
Culbertson	1945	3720	3315	NA	>0.528	strong
Tidewater	1962	3745	3730	2322	0.622	strong
Shell	1964	3775	3671	NA	>0.528	20,000
Gulf	1975	3761	3600	2002	0.556	strong
Belco	1974	3318	2802	1630	0.582	12,000
ERDA No. 6	1975	3536	2709	1900	0.701	660
AEC No. 7	1979	3662	NA	------	no flow	------
POGO	1979	3551	3322	2255	0.679	10,000

TABLE 2. GEOCHEMICAL DATA FOR 4 WELLS

	Shell	AEC 7	ERDA 6	POGO
Ca	550	341	560	488
Mg	1860	1730	360	748
K	As Na	3950	4900	As Na
Na	124,450	115,000	121,000	135,190
Li	NA	313	160	285
SO_4	16,800	19,600	13,400	17,280
Cl	185,000	199,800	174,000	197,433
HCO_3	1481	1195	970	2245
Sp Gr.	1.22	1.2	1.2	1.2
Lab	Shell	N.M. Tech	CoreLab	Martin