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Tracing Early Breccia Pipe Studies, Waste Isolation Pilot Plant, Southeastern New Mexico: A Study of the Documentation Available and Decision-Making During the Early Years of WIPP

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A Study of the Documentation Available and Decision-Making During the Early Years of WIPP

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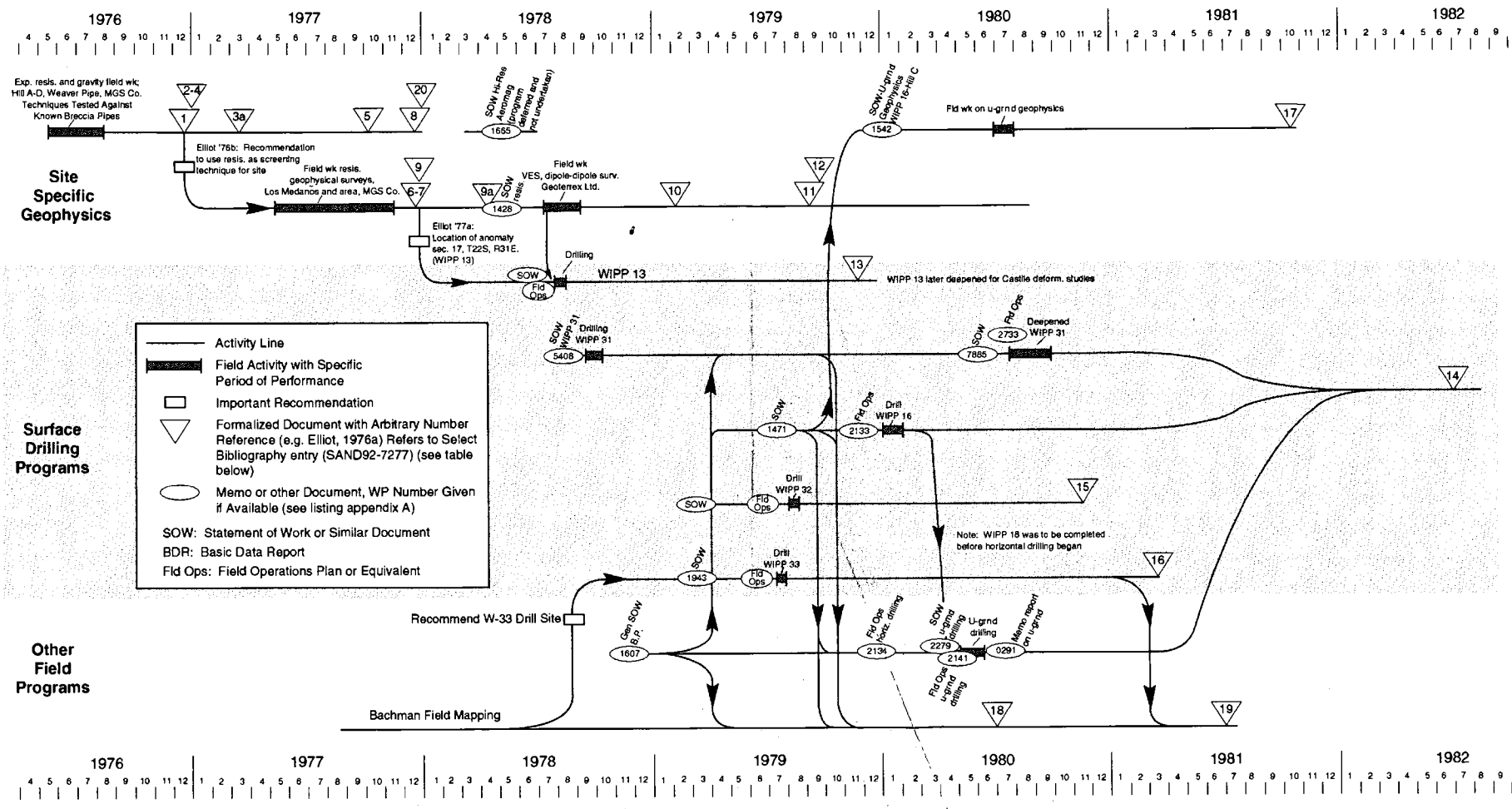

Formalized Document Reference Table

1. Elliot, 1976b; Interp. Exp. Resis. 12/22/76
2. Elliot, 1976a; Interp. Exp. Grav. 12/31/76
3. MGS, 1976; Fld data, Calib. 12/31/76
3a. MGS, 1976; revised w/Appendix 3/77
4. Elliot, 1976c,d; Core data 12/31/76
5. Elliot, 1977c; Interp detail resis., Hills C & D 10/7/77
6. Wieduwilt, 1977; Fld data
7. Elliot, 1977d; Resis. of suspected b.p.
8. Elliot, 1977e; Exp. Resis., Weaver Pipe 12/77
9. Elliot, 1977a; Eval. of site resis.
9a. Approx date of Elliot, 77f,g submittal
10. Bell, R.S., 1979; Logistics Report, Geoterrex
11. Elliot, 1979a; Interp. resis. WIPP 13
12. Elliot, 1979c; resis. data, WIPP 13
13. BDR: WIPP 13 SAND79-0273 (SNL & USGS, 1979a)
14. Snyder & Gard, 1982 OFR82-968, re b.p.
15. BDR: WIPP 32 SAND80-1102 11/80 (SNL & USGS, 1980)
16. BDR: WIPP 33 SAND80-2011 2/81
17. Report on u-grnd geophysics SAND81-7153
18. Bachman, 1980 OFR80-1099
19. Bachman, 1981 OFR81-31
20. Griswold, 1977 SAND77-0946

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Figure 4. Detailed relationships of major programs and documents for early breccia pipe studies for WIPP.

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ABSTRACT

Breccia pipes in southeastern New Mexico are local dissolution-collapse features that formed over the Capitan reef more than 500,000 years ago. During early site studies for the Waste Isolation Pilot Plant (WIPP), the threat to isolation by these features was undetermined. Geophysical techniques, drilling, and field mapping were used beginning in 1976 to study breccia pipes. None were found at the WIPP site, and they are considered unlikely to be a significant threat even if undetected.

WIPP documents related to breccia pipe studies were assembled, inspected, and analyzed, partly to present a history of these studies. The main objective is to assess how well the record reflects the purposes, results, and conclusions of the studies from concept to decision-making. The main record source was the Sandia WIPP Central File (SWCF). Documents reviewed ranged from generally available reports (e.g., SAND reports) to individual memoranda and contracting papers.

The history of WIPP breccia pipe studies is relatively clear. After a potash company mined into breccia during 1975, Sandia and US Geological Survey (USGS) personnel began investigating the threat to WIPP. By 1982, a USGS summary report inferred that breccia pipes are restricted to the Capitan reef, which does not underlie the WIPP site. DOE 2 was later drilled at an alleged dissolution feature. Castile Formation salt was deformed, not dissolved; no further breccia pipe studies have been undertaken.

Available records clearly reveal the efforts to investigate breccia pipes. Early records (about 1975 to 1977) are very limited, however, about details of objectives and plans predating any investigation. Drilling programs from about 1977 were covered by a broadly standardized statement of work, field operations plan, drilling history, and basic data report. Generally standardized procedures for peer, management, and quality assurance review were developed during this time. Agencies such as the USGS conducted projects according to internal standards. Records of detailed actions for individual programs may not be available, though a variety of such records were found in the SWCF. A complete written record cannot be reconstructed. With persistence, a professional geologist can follow individual programs, relate data to objectives (even if implied), and determine how conclusions were used in decision-making.

ACKNOWLEDGMENTS

This report depended heavily on the efforts of Glenda Sweatt (Nuclear Waste Management Library librarian) and Iris Castagna (Sandia WIPP Central File). They searched computer files with the key words, names, or phrases I furnished and copied key documents for me to use in reconstructing the relationships among the projects. Wendell Weart and Susan Pickering provided the general direction for reconstructing this early work effort, and Susan Pickering reviewed progress stages of the reconstruction. Sally Laundre-Woerner (Tech Reps, Inc.) redrafted figures for presentation.

David J. Borns (Sandia National Laboratories) and Richard P. Snyder (USGS) provided official reviews, and I thank them for careful attention to details and very prompt reviews. Rick Bower (Tech Reps, Inc.) edited the final draft and formatted the text for print. Carol Crawford (Sandia National Laboratories) checked and rechecked the many kinds of references in this report to verify and format report citations.

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INTRODUCTION

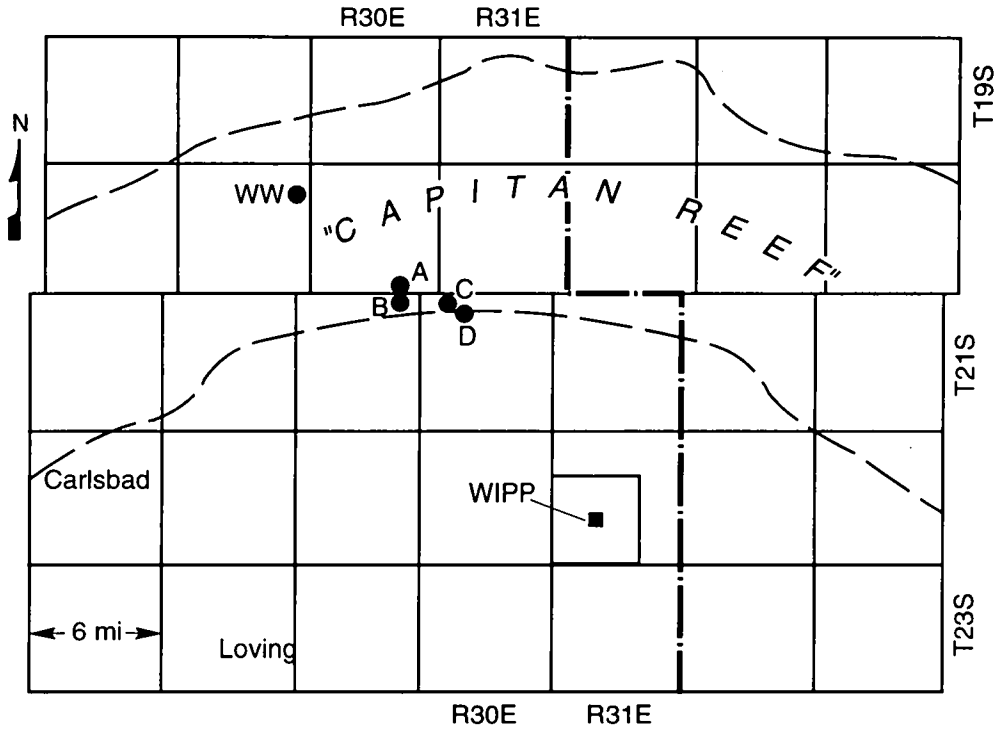
Breccia Pipes

Extensive studies in southeastern New Mexico reveal breccia pipes as generally cylindrical, vertical collapse structures penetrating evaporite beds and characterized by a lithified breccia of downward displaced blocks (Figure 1). These breccia pipes are commonly about 800 ft across and have a domal surface structure with a collapsed central core. Spectacular examples of breccia pipes in evaporites are also known from Saskatchewan, Canada. Breccia pipes in evaporites are distinct in characteristics and origin from magmatic features in volcanic rocks also known as breccia pipes.

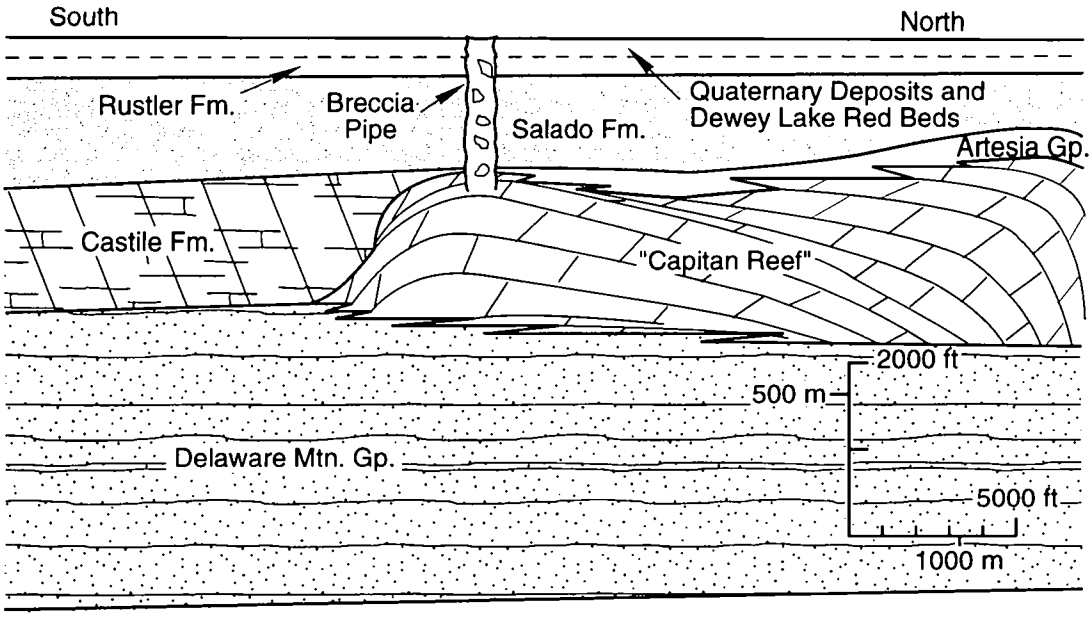
The prevailing explanation of breccia pipes in southeastern New Mexico is that proposed by Bachman (1980, 1987) and Snyder and Gard (1982), similar to earlier concepts proposed by Anderson (1978). In summary, breccia pipes are explained as solution collapse features over the Capitan reef rocks, partially in response to changing hydrologic head conditions of the Capitan. Collapse at, or just above, the Capitan occurred prior to deposition of the late Pleistocene (or older) Gatuña Formation. Shallower evaporite beds were later dissolved regionally, lowering the surrounding surface around the less soluble breccia pipe core and creating a domal structure at the surface. Bachman (1980) explained additional surficial features of the northern Delaware Basin as due to dissolution nearer the surface, rather than dissolution and collapse from processes at the base of the evaporite beds.

The concern with breccia pipes during the early years of the Waste Isolation Pilot Plant (WIPP) project was that the pipes might provide a conduit through the repository to the accessible biosphere. It was important to determine whether a breccia pipe could exist, undetected, in the immediate vicinity of the proposed repository or if an incipient breccia pipe could form during the required period of isolation. The hypothesis of Bachman (1980) and Snyder and Gard (1982) limits breccia pipes to the area overlying the Capitan reef. As no breccia pipes are known in the northern Delaware Basin other than over the reef, the threat is currently considered non-existent for the WIPP site.

The conclusions that have been drawn about the origins of breccia pipes in southeastern New Mexico are not specifically reviewed here; instead I concentrate on the history of, and quality of the record about, the various studies of breccia pipes. Broad background for geological studies of the WIPP can be found in Powers et al. (1978), Lappin (1988), and Powers and Martin (1993).



Generalized Location Map



Generalized Cross Section

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Figure 1. Generalized cross-section of breccia pipes (lower diagram) and location map of hills (or domes) A-D (upper diagram), generally based on Snyder and Gard (1982).

Purpose of Report

This report documents the results of a test case search for records of WIPP studies and decisions about breccia pipes during early phases of the project (approximately 1975 to 1982). During the search, I attempted to reconstruct the paper record from the first stages of recognition of breccia pipes as a concern for the WIPP through the stage at which the concern was considered officially resolved. For different investigative phases or techniques, I attempted to recover important records of steps such as statements of work, field operations plans, logistics reports, basic data or summary reports, and interpretive reports. The reports or written records are broadly discussed as to how well they met explicit quality assurance procedures current at the time of the activity.

Organization of Report

Two sections of this report may appear somewhat repetitive, but they have differing purposes. The PROJECT HISTORY OF BRECCIA PIPE STUDIES describes mainly the history and relationships of the investigations undertaken to understand breccia pipes in southeastern New Mexico. The section is organized chronologically, and the references cited are the principal reports and interpretive documents about breccia pipes.

A later section (ASSESSMENT OF RECORD TRACE RE BRECCIA PIPES) describes the documentation for these studies. Details of the documents and records not covered in the project history will be provided. For clarity, I have separated the discussion of the history in this later section into several segments reflecting mainly differing lines of investigation, such as: Testing of Geophysical Techniques Against "Known Breccia Pipes". This differs from the chronological organization of the PROJECT HISTORY . . ..

A schematic diagram (Figure 2) of this history will help the reader track the relationships of the different projects leading to resolution of concerns about breccia pipes.

Sources of Information

As a project participant since 1975, I had acquired an extensive library of geotechnical reports and documents relevant to WIPP, and I began to assemble the document framework with my own files. The search was also conducted through the Sandia WIPP Central File (SWCF) records at Sandia National Laboratories (SNL) and by telephone or personal conversations with several participants in these early efforts: Wendell Weart (SNL), Leslie R. Hill (SNL), William S. Twenhofel (USGS, retired), Charles L. Jones (USGS, retired), R.P. Snyder (USGS, retired), and George B. Griswold (former SNL employee). In addition, some individual files or archives were examined by me or other individuals. Other archive data at Sandia National Laboratories or USGS may provide additional documents and files; these archives are being assembled at Sandia for continuing research on project history. The WIPP Project Record Service (PRS) computer records and data base were not accessible during the period of

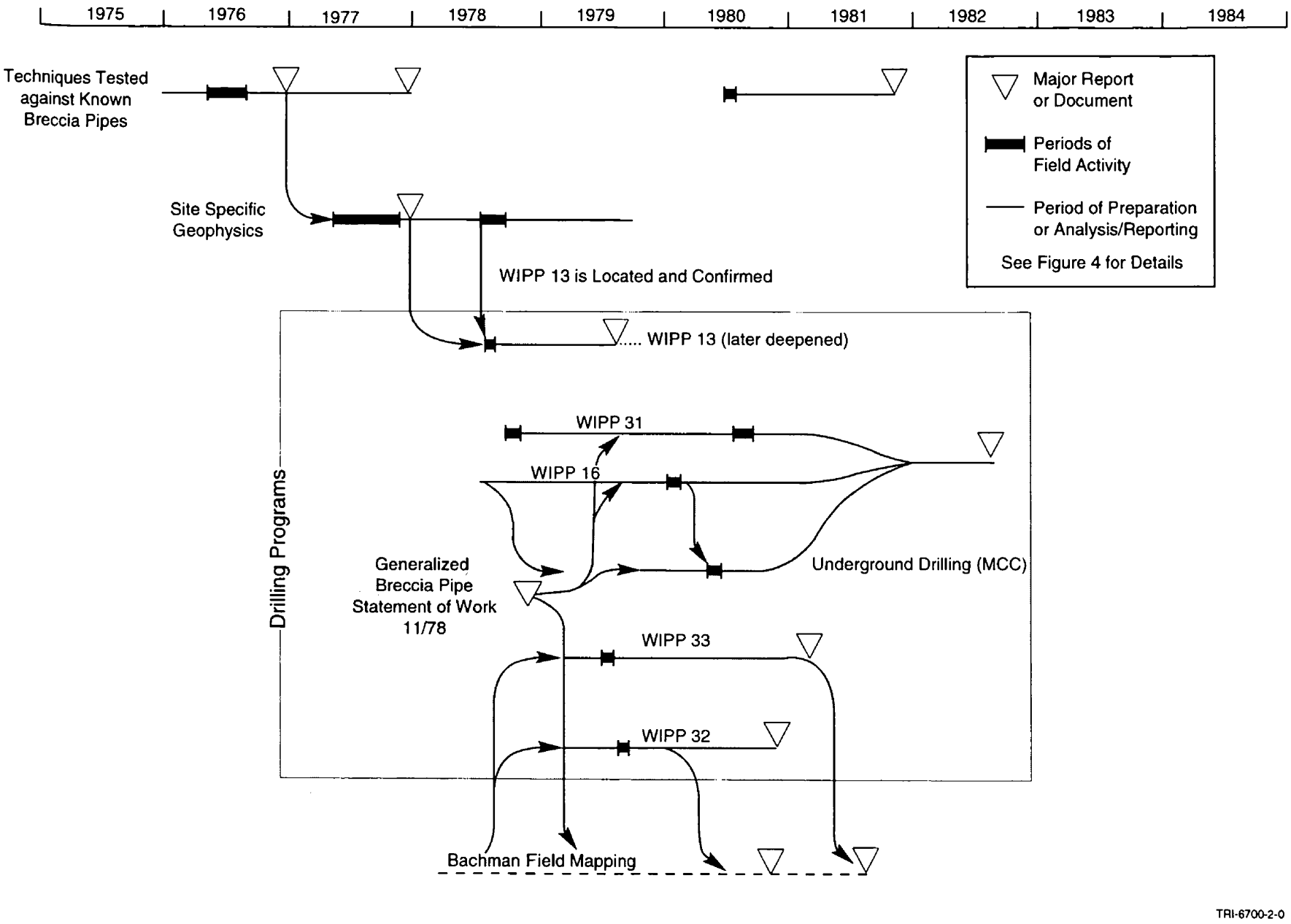

Figure 2. Schematic diagram of time and program relationships for major breccia pipe programs. See Figure 4 for additional details.

this study (June 1993 to March 1994). The search was conducted at a "reasonable" level; SWCF computer databases, personal knowledge, and document cross-references guided the search rather than exhaustive study of all existing paper. The PRS in Carlsbad, the principal repository of information still partially unexamined, will be of little use until the computer data base is again accessible. The data base and software were physically being transferred from Los Alamos National Laboratory to Carlsbad during the later phases of my research, and PRS personnel were being trained to use it. Then it will be useful for obtaining records generated by DOE and other participants during the early years. I previously used the PRS to obtain records regarding the re-orientation of the WIPP experimental and disposal areas for the addendum to the No-Migration Petition (US DOE, 1990a, Volume VII, p. 1-1). The Bechtel database maintained by PRS was checked initially during early March 1994, but no additional relevant documents were obtained.

For this subject, I first read several reports concerning breccia pipes from my library and reviewed some of the history of breccia pipe studies. I compiled some possible key words, names, and phrases and supplied them to the SWCF. A search of the SWCF database using the key words, names, and phrases provided a list of several hundred records, many not relevant to this project. The potential records were winnowed down to about 100 documents likely to provide part of the breccia pipe story, and SWCF copied all or significant parts for closer examination. Almost all proved relevant to breccia pipe investigations. Shorter, more detailed lists of specific documents and key words subsequently were supplied to SWCF to verify that some original data was deposited in the files, to glean additional documents, and to obtain further listings of documents of possible interest. The initial search of my library and two searches of the SWCF database yielded most of the documents examined during this research project. A few gaps were filled with specific requests to individuals or other organizations.

The research was underway quickly because I am personally familiar with the topic and project work during the period from 1977 through 1982. An individual otherwise not familiar with the project would probably find initial access most efficient through the SWCF database using the key phrase of "breccia pipe;" another entry point would be to review USGS Open-file Report 82-968 (Snyder and Gard, 1982). Further investigation through the SWCF database, using additional key words or phrases based on research into either beginning point, would quickly begin to yield a significant amount of the documentation of specific investigations. Some of the summary reports and documents (e.g., Bachman, 1980) might escape notice for some time for those personally unaware of the project history. The select bibliography now available (Powers and Martin, 1993) will also provide an important entry point for such research, though the SWCF will always be a primary source for obtaining the less formal documents so important in a search such as this.

Relevant memoranda and other documents not available as SAND or other readily accessible reports are cited by date and a reference number (usually WP#) in the text. These references are listed in Appendix A, ordered by date.

Pre-Trace Status

There is no prior official and single document assimilating and reporting the relationship of various investigations of breccia pipes and the incorporation of the results into decision-making documents. Several reports were prepared on specific studies, and several additional reports indicated the status and conclusions from studies in progress. These will be noted through the review of the several programs contributing to our current understanding of breccia pipes.

PROJECT HISTORY OF BRECCIA PIPE STUDIES

This section describes chronologically the history and relationships of the investigations undertaken to understand breccia pipes in southeastern New Mexico.

Pre-WIPP Knowledge of Breccia Pipes in Southeastern New Mexico

The individual domal features at the northern end of Nash Draw (Hills A-D; Figure 3) are now considered to be breccia pipes; the surface features were clearly identified first by Vine (1960). Reddy (1961) also commented on these domal features and possible relationships to similar features in the Queen Lake-Malaga area (Figure 3). Vine (1960, 1963) was concerned with the significance of the features while mapping in the area in support of Project Gnome, the first (in 1961), and only, of the planned nuclear explosions in the Salado Formation. Vine did not theorize that these features connected underlying units with the surface through the entire evaporite sequence, and there was no consideration of the area for radioactive waste disposal at the time.

Oak Ridge National Laboratories (ORNL) and the USGS investigated southeastern New Mexico as a possible location for a waste disposal site during the early 1970s and selected an initial site for drilling in 1974. Gera (1974) reports gravity and magnetic investigations of Hill D initiated because of slight concerns that the domal structures could be due to salt diapirism (Gera, 1974, p. 3). Hill D may have been chosen for study over other domes because it is not breached by erosion (Gera, 1974, p. 5). Magnetic studies were inconclusive, and gravity data suggested a shallow mass deficiency. Mississippi Chemical Corporation (MCC; then Teledyne Potash Co.) mined under Tower Hill, about 2 miles west of Hill D, without evidence of Salado disruption. As a result, Gera (1974) interpreted these features as relatively shallow solution features, occurring above the Salado Formation and due to the brine aquifer at the contact of the Rustler and Salado formations. It was expected that the process could be confirmed by hydrological testing.

WIPP-Era Recognition of Breccia Pipes in Southeastern New Mexico

During 1975, MCC found downward dipping beds in the 15L and 16L drifts and then mined into breccia in the 16L drift. The disrupted strata are located directly under the surface feature called Hill C (Figure 1). No written record has been recovered describing the events during late 1975 and early 1976 by which WIPP personnel both became aware of this feature at MCC and began to consider its significance to WIPP. From discussions with several individuals, it is believed that Charles L. Jones, in his capacity with the USGS, was soon aware of the breccia pipe. George Griswold (SNL) was contacted by Tim Hall (then Mine Engineer, MCC) and Jim Walls (then Manager, MCC) about the feature sometime probably during late 1975 or early 1976. The features were discussed in meetings (personal communication; Griswold, Jones to Powers) during that time by an informal peer review and contractor group convened by Griswold (Griswold, 1977), but no record of meeting minutes has been recovered. It was decided that some geophysical studies could be appropriate for these features, and

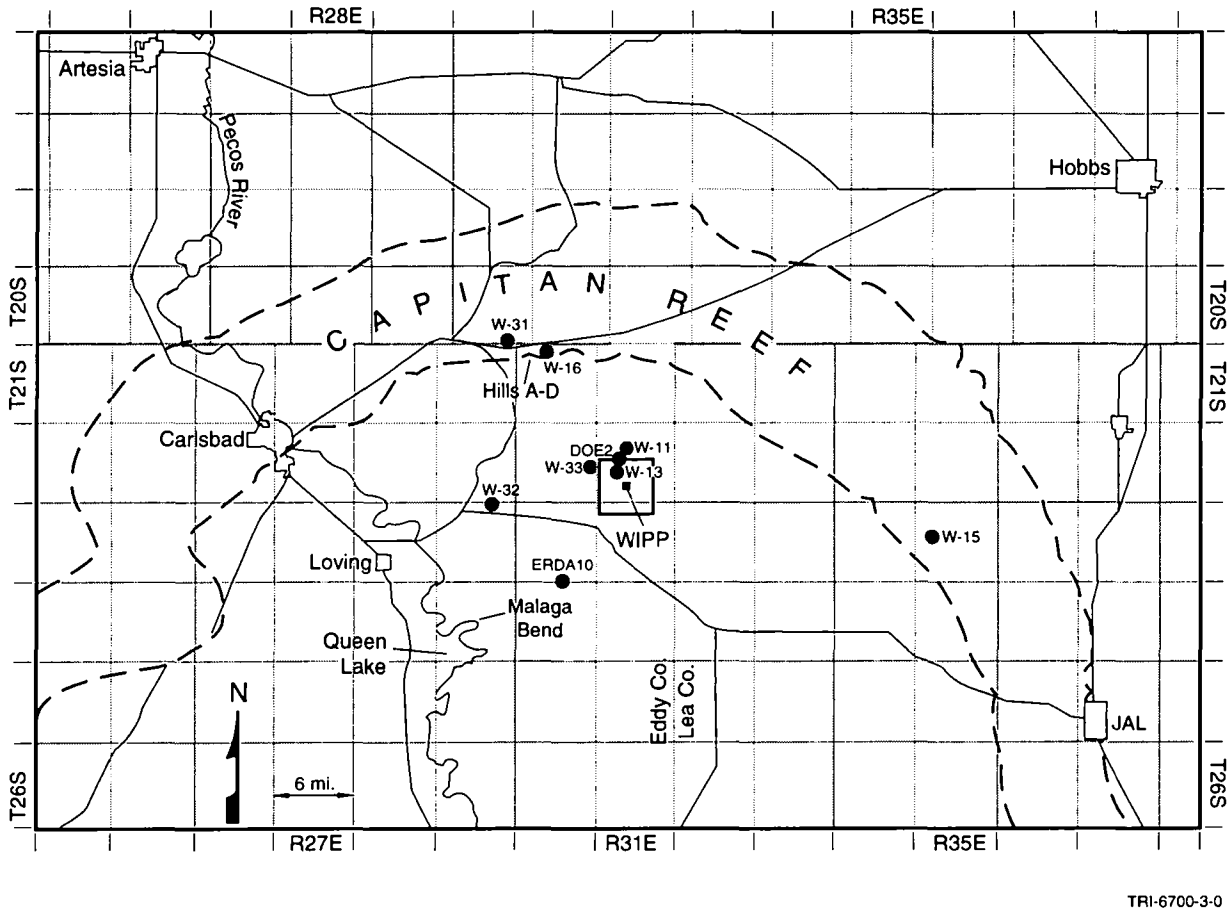

Figure 3. General location map of important features in southeastern New Mexico related to breccia pipe studies.

by May 1976, Mining Geophysical Surveys initiated field work on several of these features to test several techniques (Elliot, 1976a,b; Mining Geophysical Surveys, 1976). These actions demonstrate that the domal features at the northern end of Nash Draw were recognized by project personnel as solution features that affected the Salado Formation and posed an undetermined threat to the WIPP site further to the southeast.

Investigations of Breccia Pipes (1976-1982)

During 1975-76, breccia pipes were recognized to involve the Salado Formation in which the WIPP repository was to be located. The earliest contemporary records recovered from this time are an internal memorandum (06/18/76; WP06380) by J.D. Vine of the USGS and a memorandum (08/19/76; WP01582) by R.Y. Anderson. The USGS memorandum by Vine describes his concept of the origin of the breccia pipes; he concludes they developed early in the basin history and are not a current threat. The memorandum by Anderson outlines a basic research program that could be conducted and included a draft figure showing the distribution of features he considered breccia pipes. It is not directly apparent how either memorandum affected subsequent exploration of breccia pipes for WIPP. Vine's suggestion was superseded by information about the distribution of breccia pipes and relationship to the Capitan. Elements of the program suggested by Anderson certainly became a part of the study program as it developed.

It was also understood during 1976 that some breccia pipes might not have easily recognized surface features. "Weaver pipe" (WW, Figure 1) has no obvious surface pattern; the feature was apparently known to Charles L. Jones as a deep brecciated mass drilled during the 1950s (e.g., Elliot, 1976b). Given the limited information available, means of identifying possible breccia pipes by indirect or remote means, i.e., geophysical techniques, were investigated. The set of features at the northern end of Nash Draw were termed "known breccia pipes" because they were thought at the time to be breccia pipes, although only Hill C was demonstrated to have brecciation at depth. If "known breccia pipes" could be identified by such techniques, it would then be possible to apply these same techniques in a reconnaissance exploration of the WIPP site. Specific geophysical techniques considered for testing against "known breccia pipes" included electrical, gravity, and seismic methods.

Electrical and gravity data were acquired during 1976 as an initial test (Elliot, 1976a,b). From the experimental testing, Elliot (1976a) concluded that gravity data were not consistent over "known breccia pipes" and that gravity measurements were not appropriate as a reconnaissance tool for the WIPP site. In addition, it is a more expensive field technique to apply in detail over such a broad area. Elliot (1976b) concluded that resistivity techniques do provide consistent indicators over breccia pipes and are therefore appropriate as a screening tool; electrical methods are also relatively effective in cost. Elliot's recommendation became the basis for site-specific resistivity screening beginning in May 1977.

A general seismic reflection survey was conducted over parts of the WIPP site during 1976 (07/21/76; WP01847; also see Hern et al., 1979). The referenced memorandum by McMillan, discussing and interpreting the seismic data, shows that the survey was conducted mainly to determine the overall stratigraphic continuity and structural disturbance of beds at or around the WIPP site. There

are no statements in the memorandum about detecting anomalies or signals indicating breccia pipes. The conclusion by McMillan (WP01847) states that the limitations of seismic reflection to detect breccia pipes are recognized, but that the WIPP site meets or exceeds the "geophysical specifications" for waste disposal.

During 1976, a program of shallow seismic reflection using weight-drop techniques was considered inconclusive (Griswold, 1977); no documentation has been recovered, and the program is not believed to have been directed at breccia pipe investigations.

Proprietary industry and Sandia seismic reflection data were judged to indicate that a properly planned and executed seismic reflection study could detect breccia pipes (Long and Associates, 1976). Seismic reflection data (Hern et al., 1979) later collected over breccia pipes showed no distinctive signature. Because of the high cost and possible ineffectiveness, seismic reflection was not used to screen the site area for undiscovered breccia pipes.

Based on the recommendation by Elliot (1976b), a large resistivity field program was designed and executed in 1977 by Mining Geophysical Surveys as a reconnaissance survey over an area of about 37 square miles around WIPP. The program resulted in about 9000 data points spaced closely enough to cover features of the size of Hills A-D (Wieduwilt, 1977; Elliot, 1977a,b).

During the fall of 1977, seismic reflection techniques were also tested against "known breccia pipes" as part of a larger field program that included significant seismic reflection studies over the WIPP site. The X-series seismic reflection data were collected over the WIPP site area and included the experimental or test data over breccia pipes mentioned above. The line locations were selected to provide general coverage of the site as well as to test some specific areas of interest from previous proprietary data (Long and Associates, 1976); some lines also coincided with initial resistivity anomalies over the general site area.

Late in 1977, Sandia contracted with R.Y. Anderson (University of New Mexico) to provide a summary of evidence as well as his thoughts about dissolution of evaporites in the Delaware Basin. The summary was specifically to support the drafting of the geological characterization report during 1978. Part of the work was a study, which began in late 1977, of surficial features, including Bell Lake and "Slick sink" east of the WIPP site area (see below; also Widdicombe, 1979). Anderson (1978) described a variety of features he attributed to dissolution, including breccia pipes. He proposed a generalized breccia pipe origin from information available at the time, including his research on the Castile Formation in west Texas and New Mexico. The hypothesis included circulation of water from underlying units upward through a low permeability bed (probably fractured) to dissolve overlying halite; overlying rocks collapse into the solution cavity, creating a breccia chimney. The surficial structural form of a dome is created later by areal dissolution of shallower units, especially the Rustler and Salado Formations, lowering the surrounding area relative to the less-soluble breccia. Anderson (1978) created a composite model using features from the northern Delaware Basin as well as from southern New Mexico and west Texas. Much of this model was incorporated into the concepts developed by Bachman and by Snyder and Gard.

Anderson (1978) also included, as an appendix, the fundamental discussion of the concept of brine density flow to explain the mechanics of upward flow of pressurized water from the underlying unit (here the Bell Canyon Formation), dissolution, and subsequent downward movement of the brine, which has a higher specific gravity than the upward-flowing water. Anderson and Kirkland (1980) presented a more formalized version of this mechanism to explain dissolution in the Delaware Basin, including localized features such as breccia pipes or breccia chimneys.

WIPP 15 was drilled during March 1978 near the center of San Simon Sink to obtain paleoclimatic data and stratigraphic information over a feature that has collapsed in part during the 20th century (Sandia National Laboratories and University of New Mexico, 1981). The borehole penetrated 547 ft of Quaternary-age fill and about 264 ft of rocks probably of Triassic age. The sink is believed to overlie the Capitan and may have formed in a manner related to known breccia pipes.

During 1978, G.O. Bachman (US Geological Survey) began a field program in Nash Draw and the Pecos River valley to examine more closely the features attributed to dissolution and the processes responsible. The program was, in part, to investigate features in Nash Draw and in the Queen Lake-Malaga Bend area (Figure 3) interpreted as breccia pipes by Anderson (1978).

Based on the 1977 site reconnaissance resistivity data, Elliot (1977a) located an anomaly in section 17, T.22S., R.31E., with resistivity characteristics and apparent size similar to those of "known breccia pipes." In mid-1978, more detailed electrical surveys were applied to specific locations, including the resistivity anomaly in section 17, to further characterize the features as a prelude to drilling (Bell, 1979; Elliot, 1979a,b). The anomaly in section 17 was drilled during 1978 as WIPP 13, the first borehole deliberately drilled to investigate an anomaly as a possible breccia pipe.

WIPP 13 was drilled and completed by August 14, 1978 (Sandia [National] Laboratories and US Geological Survey, 1979a). WIPP 13 drilling did not reveal a breccia pipe, despite the low resistivity. The borehole was later deepened in a separate program, unrelated to breccia pipes, to acquire data about deformed strata of the Castile Formation in a broad area, known commonly as the "disturbed zone" (Powers et al., 1978), north of the WIPP site center.

Shortly after the resistivity anomaly at the WIPP 13 location was determined not to be a breccia pipe, the focus returned to "known breccia pipes," and WIPP 31 was drilled near the center of the surficial feature called Hill A (Figure 3). The objective was mainly to prospect the location, with further drilling and testing programs to be separately developed if the feature represented a breccia pipe. WIPP 31 was drilled, during September 1978, to an initial depth of about 810 ft. The US Geological Survey described the strata encountered during this initial phase of WIPP 31 in their comprehensive report on the origin of breccia pipes (Snyder and Gard, 1982).

Near the end of 1978, five main elements of breccia pipe studies and objectives were summarized by Lambert and Powers for Sandia [National] Laboratories in a general scope or statement of work (SOW) (11/18/78; WP00039):

1) performing a regional study of the distribution of "breccia pipes," their specific surficial characteristics, and subsurface geologic setting of selected examples.
2) drilling and testing physical characteristics of a "representative breccia pipe."
3) conducting underground mapping, geophysical studies, and coring of breccia pipe in Mississippi Chemical Corporation mine.
4) performing laboratory studies of the rock materials recovered from drilling to determine, where possible, stratigraphic origin of displaced rock and origins and ages of mineral phases associated with dissolution.
5) assessing the geologic threat to the WIPP from "breccia pipes."

These elements covered some programs already underway and some not yet begun. The regional distribution and characteristics were already being examined in part through field programs begun by Bachman. WIPP 31 had been drilled mainly to prospect the location; most of the remaining four elements were yet to be investigated through field programs and assessment. This general SOW provided background for most of the remaining breccia pipe studies.

Some of the laboratory studies (item 4, above) of breccia pipe materials were conducted through late 1978 and 1979 and reported (Register, 1979; Brookins et al., 1980; Brookins and Register, 1981; Brookins, 1981). Though additional work on the ages and geochemistry of the rocks was completed and reported, part of this early work confirmed that polyhalite samples from breccia within the MCC intercept under Hill C yielded dates by K-Ar and Rb-Sr methods similar to undisturbed polyhalite. The results were interpreted to indicate that large amounts of water did not flow through the breccia; otherwise the polyhalite would have dissolved, or yielded a very young age (Brookins et al., 1980).

WIPP 31 had demonstrated clearly that the unique underground discovery of breccia in MCC mine under Hill C was not the only breccia pipe; two of the four hills mapped by Vine (1960, 1963) near the northwestern end of Nash Draw were known to be brecciated at depths equivalent to the Salado, at least. The focus turned back to features that represented possible or potential breccia pipes. During the summer of 1979, two additional features were examined by drilling. WIPP 33 and 32 were drilled in succession to investigate two features considered at the time to be geographically nearest the WIPP and most likely to be breccia pipes.

WIPP 33 was drilled during late July 1979, in a surface depression in section 13, T.22S., R.30E., about 3 miles northwest of the WIPP site center (Figure 3). The depression had been identified by G.O. Bachman as having unusual thickness of surficial fill (Appendix A, Scope of Work, in basic data report; Sandia National Laboratories and US Geological Survey, 1981). The depression and fill were considered possibly related to either the processes which formed Nash Draw or, less likely, an indicator of a breccia pipe. The hole was drilled to the upper Salado Formation and logged without finding breccias (Sandia National Laboratories and US Geological Survey, 1981). Bachman (1980) related the depression and fill to shallow processes responsible for forming and extending Nash Draw. This

feature, near the northwestern margin of WIPP-controlled zones as then drawn, was demonstrated not to be a breccia pipe.

WIPP 32 was drilled during August 1979, on a minor topographic high in Nash Draw identified as the feature closest to WIPP that was most likely to be a breccia pipe, based on earlier work (Sandia [National] Laboratories and US Geological Survey, 1980). Bachman's work in progress (1980, 1981) indicated that the feature was probably due to shallow karst processes, and the drilling became both an initial test of his work as well as a probe of another feature considered by some to be similar to Hills A-D. WIPP 32 was drilled and logged into the upper Salado Formation without finding features of a breccia pipe (basic data report; Sandia [National] Laboratories and US Geological Survey, 1980).

WIPP 32 was the last drilling target selected that was not a "known breccia pipe," testing the geographically nearest topographic feature somewhat similar to "known breccia pipes." During earlier drilling, WIPP 13 tested a resistivity anomaly located rather close to the site center, while WIPP 33 tested a depression with significant fill of relatively recent geological age. No nearer targets or targets with significant features were apparent for drilling. The possibility of drilling a feature in the Malaga Bend area as a test of Bachman's ideas was discussed during the period and somewhat later, but it was not possible to get agreement on a single target in that area as a test of any hypothesis. Bachman was developing his concepts of the origins of breccia pipes and the karst mound and karst domes of the Queen Lake-Malaga Bend area (Bachman, 1980, 1981). WIPP investigations turned again to "known breccia pipes."

As part of a master's thesis on surficial features in southeastern New Mexico, Widdicombe (1979) reported, without much elaboration, that Bell Lake and "Slick sink" were probably deep-seated collapse features, following Anderson (1978). Young sediments at Bell Lake were mapped as offset by more than 10 ft, interpreted as evidence of dissolution of the underlying evaporites. Later, some microgravity geophysical techniques were applied to the Bell Lake location (Barrows et al., 1983), and Hill (1993) has reported and interpreted geochemical data from Bell Lake. Both later works maintain that Bell Lake represents a sink or solution-collapse feature.

By 1980, a lithologic unit important to the timing of breccia pipe formation had been examined for radiometric age data. Szabo et al. (1980) had completed uranium-trend dating of Mescalero caliche samples supplied and described by George Bachman, yielding ages of $570 \pm 110 \times 10^3$ yrs for the lower part and $420 \pm 60 \times 10^3$ yrs for the upper part. Bachman (1980) concluded that the main breccia pipe collapse occurred before the Mescalero formed. He also concluded that subsequent regional dissolution of upper Salado or lower Rustler occurred in the vicinity of the breccia pipes at Hills A and C after the Mescalero had formed. The age of the Mescalero determined by this technique was considered consistent with the age (600,000 years) of the Lava Creek B ash in the upper Gatuña Formation, just below the Mescalero (see Bachman, 1980; Izett and Wilcox, 1982).

"Known breccia pipes" were directly investigated during 1980 through three drilling programs and one geophysical program. Hill C, over the mine workings of MCC, was explored by WIPP 16 from the surface to approximately the depth of the mine workings; WIPP 31, drilled in Hill A, was deepened to the approximate depth where the Capitan reef would be expected; the breccia encountered by MCC

under Hill C was drilled horizontally with short coreholes from MCC mine workings; and radar geophysical techniques (Unterberger, 1981) were tested at the underground exposure of breccia at MCC as a potential tool for use at WIPP. These four investigations completed direct study of breccia pipes for the WIPP.

During 1980, the US Geological Survey published the results of Bachman's field work of 1978 and 1979; Bachman (1980) concluded that the surficial features near Malaga Bend, as well as many others in the region, were formed as a result of relatively shallow dissolution (karst) processes. The topographic feature at WIPP 32 was interpreted as having a similar origin. Bachman (1980) also laid most of the foundation for the explanation of breccia pipes as related to deep-seated collapse at the level of the Capitan reef or related rocks, with surface domal features caused by later shallow dissolution. Snyder and Gard later also followed this line of reasoning in detailing the processes interpreted to be responsible for breccia pipes and chronology of development.

During 1980, Anderson and Kirkland (1980) published their concept of brine-density mechanisms to drive dissolution, especially at points, as would be required for breccia pipe development. The article was based on work by Anderson reported in an appendix to Anderson (1978).

On June 3, 1980, a collapse feature called the Wink sink formed near Wink, TX, southeast of the WIPP site. Baumgardner et al. (1982) concluded the collapse followed dissolution of Salado salt by a brine density mechanism similar to that proposed by Anderson and Kirkland (1980). The collapse feature, likely similar to breccia pipes at Hills A and C, is also located over the rocks of the Capitan reef (Baumgardner et al., 1982). An abandoned borehole located within the sinkhole may have contributed as a conduit of fluid. The study by Baumgardner et al. (1982) was not sponsored or funded by WIPP.

Wood et al. (1982) examined the potential for the brine density mechanism, including the general hydrology of the Delaware Mountain Group underlying the evaporite units, to dissolve halite from the evaporite beds. They concluded that the brine density mechanism can operate but that the hydrological system of the Delaware Mountain Group severely limits the potential for dissolution.

Also during 1982, Palacas et al. (1982) reported the results of an investigation of the oil seeps underground in MCC near the breccia pipe, oil in cores from both WIPP 31 and WIPP 16, and oils from commercial production in the area. The oils from breccia pipes and nearby mine workings were similar to each other and to oils produced from the Permian Yates Formation. Palacas and others (1982) eliminated oil injected during the 1950s into a nearby potash drillhole as a likely source. They also suggest that the oil likely migrated to these locations during or after brecciation and formation of the breccia pipes.

The open-file report by Snyder and Gard (1982) generally marks the conclusion of direct investigations of breccia pipes. Subsequent reports summarizing the understanding of breccia pipes generally are based on the conclusions of Snyder and Gard (1982).

Recent (post-1982) Research Related to Breccia Pipes

Davies (1984, 1989) conducted research, not funded by WIPP, on the processes of dissolution and potential for developing features in evaporites. In a concept similar to that of Anderson (1978), Davies (1989) described a low permeability unit separating an underlying hydrological source from the overlying soluble rocks. A fracture zone through the low permeability unit permits fluid flow of variable magnitude. Salt removal rates are also variable, and salt mechanical behavior can range from brittle behavior for rapid removal to ductile behavior for slower removal. A point solution feature might therefore not develop collapse and brecciation as in the breccia pipes at Hills A and C.

Davies (1984, 1989) referred to a structural low on Salado beds (Griswold, 1977; Powers et al., 1978) about 2 miles north of WIPP as an example of features which might develop from slower removal of salt at depth. This feature was drilled and logged in two phases, beginning in August 1984, and ending in June 1985 (Mercer et al., 1987). The borehole, designated DOE-2, intercepted beds in the lower Salado and the Castile Formations that vary in thickness from those same beds in nearby drill holes. The thickness variations are interpreted to have formed by salt deformation rather than by dissolution (Mercer and others, 1987; Borns, 1987; Anderson, 1987).

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QUALITY ASSURANCE REQUIREMENTS IN PLACE

This section briefly traces some of the formalized documents outlining quality assurance (QA) during the main period of investigating breccia pipe occurrences and relevance to the WIPP. The record of WIPP site characterization demonstrates a growing concern within Sandia National Laboratories to document the site characterization programs and the items of concern. A general example of the growing concern, not specific to breccia pipes, is illustrated by three drill holes for site characterization purposes during 1977 and 1978.

Late in 1977, ERDA 10 was drilled to test ideas about dissolution of salt in the lower Salado Formation and Castile Formation (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1983). WIPP 11 was drilled early in 1978 to test a seismic anomaly about 3 miles north of the WIPP site center (Sandia National Laboratories and US Geological Survey, 1982). WIPP 13 was initially drilled during mid-1978 to test a resistivity anomaly as a possible breccia pipe (Sandia [National] Laboratories and US Geological Survey, 1979a). Each of the basic data reports includes items reflecting statement of work, testing/drilling plan, hole history, and summary data with appropriate conclusions. These documents show a trend toward increasing sophistication; more specific content about objectives, responsibilities, and decision points; and higher levels of Sandia internal review and approval, including involvement of organizations dedicated to QA. Practices during this time became the general standard for Sandia in proposing and carrying out site characterization studies until the early 1980s. These practices included a requirement for a statement of work (SOW) and a field operations plan to guide the actual field work.

Basic data reports (e.g., ERDA 10: Sandia National Laboratories and D'Appolonia Consulting Engineers, 1983; WIPP 11: Sandia National Laboratories and US Geological Survey, 1982; WIPP 13: Sandia [National] Laboratories and US Geological Survey, 1979a) show how procedures and approval levels developed through this period. These procedures were more formally expressed later in a memorandum by L.R. Hill (see discussion below).

I have found no explicit statement of QA requirements/program covering site selection and characterization prior to late 1977, though elements of later QA documents began to be developed during 1977 (e.g., SOW for ERDA 10, dated August 2, 1977; Appendix A of Sandia National Laboratories and D'Appolonia Consulting Engineers, 1983). The first explicit statement (obtained during this search) about QA items is a memorandum dated November 8, 1977, from R.D. Statler (WP00897; see Appendix A). Statler listed six representative activities for a drilling program: (1) hole location and elevation; (2) hole dimensions, diameter, depth and direction; (3) formation character and dimensions; (4) taking and logging of core and chips; (5) emplacement of casing; and (6) bore hole plugging. The basic data report for WIPP 11 (Sandia National Laboratories and US Geological Survey, 1982), which was not part of breccia pipe studies, includes a drilling program, schedule and test plans referring to each of the representative activities, and more. This was the first activity after the date of the memorandum.

A memorandum dated January 13, 1978, from F.W. Muller (WP01380; see Appendix A) provides for both general and more specific requirements for quality assurance for exploratory drilling; the

document was specifically provided in support of the WIPP 11 drilling program. Eight areas were identified as special requirements: site selection, surveys, drilling system installation, drilling, testing, coring, core handling, and logging. Two completion requirements were also specified: hole plugging and site cleanup. The main thrust of the document requirements is that "measures shall be established to assure that . . . " or "procedures shall be established and documented to assure that . . . ". The basic data report for WIPP 11 (Sandia National Laboratories and US Geological Survey, 1982) includes procedures and data reported for these areas; however, not every potential requirement included in the memorandum by Muller was checked. As stated previously, WIPP 11 was not a breccia pipe study, but it was the first important activity after the Muller memorandum, and WIPP 11 became an important part in developing the QA guidance for breccia pipe studies as well as other site characterization work.

Another memorandum, dated June 28, 1978, from L.R. Hill (WP00928; see Appendix A) includes a procedure for preparing, reviewing, and approving field projects by Sandia organizations responsible for identifying a need for a field project, for carrying out the field program, for any auditing, and for reporting the results of the project. Sandia personnel who were part of the project and responsible for QA, as well as QA personnel from Sandia organizations not dedicated to WIPP, were included. The memorandum emphasized the organizational responsibilities for review and approval in a timely manner and did not specify content to documents or procedures for carrying out projects.

WIPP 13 (Sandia [National] Laboratories and US Geological Survey, 1979a) was the first field program to fall effectively under the provisions of the Hill memorandum. A field resistivity program related to WIPP 13 was already in contract negotiations, but QA procedures were reviewed, approved, and included in the contract for field work. The original statement of work for WIPP 13 was dated June 12, 1978 (Appendix A, Sandia [National] Laboratories and US Geological Survey, 1979a). It was approved by supervisory personnel but was not reviewed by other organizations. A revision to the statement of work, dated June 30, was also approved but not reviewed. The field operations plan, dated July 26, was reviewed and approved according to the Hill memorandum, and the report was also published in accordance with the memo. I have not found any memorandum of a QA audit and results for this work.

From the WIPP 13 field program on through the rest of the breccia pipe studies, it was common practice to have parallel organizations within Sandia review and approve the statements of work (SOW) and field operations programs that were designed to carry out the work. A spot-check of several efforts indicates the review/approval requirement was met.

Through the latter half of 1978, additional concerns about requirements surfaced as the potential for Nuclear Regulatory Commission involvement developed. Two letters or memoranda, not obtained during this search, are referenced in a letter, dated 10/20/78, from D.T. Schueler (WP01405) about reliability of site characterization work. The memorandum of 10/20/78 requested an assessment of the validity of site work by Sandia and outlined five requirements: provide a set of standards, compare work to standards, identify work meeting standards, identify work not meeting standards, and prepare a report on work "important to [public] safety".

A memorandum (WP00644), dated January 29, 1979, from L.R. Hill sets out "standards for Sandia's geologic site evaluation program," which covers the information from exploratory drill holes, geophysical surveys, field mapping surveys, and hydrologic test programs. The standards for each type of project include four major items reflecting the general phases or sequence of events for a particular project:

1) scope of work;
2) field operations plans;
3) field operations;
4) analyses, reports and conclusions.

For each of the major items, four subheading standards were identified:

a) objective;
b) responsibilities;
c) documentation;
d) controls.

These subheading standards controlled the details and procedures required for each phase of a project. Effective with this memorandum in early 1979, most site investigation projects acquired a relatively uniform external form. This memorandum provided the dominant standard used for the remaining studies related to breccia pipes as well as other site characterization activities.

Another memorandum (WP00910), dated February 9, 1979, from L.R. Hill provided specific procedures for handling, storing, and preserving core samples, including those obtained during breccia pipe studies, within a storage facility. Field operations were controlled by procedures within the field operations plan under which field activities occurred. This procedure for core storage, however, was the fundamental document establishing the formal procedures controlling operation of the core storage facility based on about three years of experience in managing the cores from WIPP investigations.

By March 1979, NUS Corporation (1979) provided a very helpful review of Sandia site investigations and the supporting documents. For programs related to breccia pipes, the documents reviewed by NUS parallel those examined for this report.

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ASSESSMENT OF RECORD TRACE RE BRECCIA PIPES

Within this section, the quality of the available written record concerning different studies or investigations of breccia pipes is discussed. At the end of each element of the program discussed, summary comments are provided in italics. The studies are discussed chronologically according to objectives in order to group together the work and participants. The earlier historical review section (PROJECT HISTORY OF BRECCIA PIPE STUDIES) was more strictly a chronological overview of the project history.

First Recognition of Problem

The general history of pre-WIPP breccia pipe studies is clear from the published record. It is also apparent that the domal structures were believed to originate at the Salado/Rustler contact; they were not seen as a specific threat to isolation (Gera, 1974).

There is no doubt about either the time period during which breccia pipes became recognized as a potential threat to WIPP or of the direct response carried out as an initial field program. There is, however, no significant available (or readily available) formal record of recognition of the potential threat or specification of methods and objectives to investigate it prior to actual field studies. The earliest document recovered directly discussing the significance of breccia pipes for WIPP is a memorandum (6/18/76; WP06380) within the US Geological Survey. Water from gypsum dehydration at greater depths and early in the basin history was proposed as the mechanism for solution and brecciation; breccia pipes were not expected to be active.

Testing of Geophysical Techniques Against "Known Breccia Pipes"

Gravity and Resistivity Surveys, 1976

No documents have been recovered that explicitly state the objectives for the 1976 field tests of gravity and resistivity techniques over the "Weaver pipe," Hills A-D, and other suspect areas. The objectives, as previously discussed, are readily inferred from data and interpretive reports after the fact. Different techniques were to be applied to several features, some demonstrated by drilling or mining as definite breccia pipes, to determine which techniques, if any, could be effective in detecting breccia pipes elsewhere and in screening the WIPP site.

Although purchasing documents are not available, Mining Geophysical Surveys (MGS) was contracted separately to collect the field data, and Elliot Geophysical Company (C.L. Elliot) was contracted to reduce and interpret the data. Elliot also provided independent review of field activities and procedures by MGS, acting in effect as an agent on behalf of Sandia personnel responsible for the

field program, since there were no trained geophysicists available on technical staff at Sandia at that time.

A report by Mining Geophysical Surveys (1976) describes well the procedures, data collected, areas tested, and instrument calibrations. The report includes certifications of equipment calibrations and personnel qualifications.

Two reports by Elliot (1976a,b) present the 1976 data from the gravity and resistivity surveys, respectively, carried out in the field by MGS. These documents present the data reduction and interpretive methods as well as conclusions about the effectiveness of each method to detect breccia pipes. Each document includes a brief review of breccia pipes and the concerns about breccia pipes in the vicinity of the WIPP site; these reports are closest of any document to presenting a concurrent statement of the objectives of the field and interpretive program in 1976.

Elliot (1976a) concluded that gravity was not a reliable indicator of breccia pipes, and he did not recommend further, general use of this technique for screening the site area. Elliot (1976b) reported that resistivity methods were more successful as an indicator of breccia pipes, and the 1977 field program was developed based on his recommendations.

A later report by Elliot (1977c) addressed more specifically the resistivity data collected during 1976 over Hills C and D. He concluded the technique clearly showed a resistivity anomaly associated with Hill C, known to have breccia at depth. The resistivity data over Hill D were considered equivocal. Elliot (1977c) did not revise conclusions drawn earlier (Elliot, 1976b).

The 1976 field program to test gravity and resistivity techniques against "known breccia pipes" was carried out by, or under supervision of, professional geophysicists registered in the State of Arizona. Reports documented experience, procedures, instrument calibrations, data collection, reduction, and interpretation. These geophysical methods were consistent with standard mining geophysical investigations, and procedures established by equipment manufacturers and other researchers were followed. The company responsible for data collection was separate from the company interpreting the data. No specific Sandia documents were recovered setting out a scope of work or equivalent. No specific Sandia quality assurance program for WIPP is known to have existed at this time.

Seismic Reflection Surveys, 1976

As part of the preliminary characterization of the WIPP site under consideration in early 1976, 26 line miles of new seismic reflection data (07/21/76, WP01847; Griswold, 1977; Hern and others, 1979) were collected, mainly to demonstrate stratigraphic continuity and locate structural deformation. No breccia pipes were detected or inferred, and the limitations of the survey for these purposes were noted. Documents including the statement of objectives and operations plan or equivalents have not been recovered. The initial interpretive data and accompanying report (07/21/76, WP01847) were

prepared by a consulting geophysicist (Colin McMillan) under contract to Sandia while a separate company (Dresser Olympic) was contracted to acquire the data in the field. McMillan also was responsible for supervising data collection in the field (Hern et al., 1979).

Few supporting documents are available, but this field project was not a significant part of breccia pipe studies.

Review of Seismic Reflection Surveys, 1976

G.J. Long and Associates was contracted to provide additional geophysical expertise, especially in the field of seismic reflection surveys. Long and Associates (1976) reported on a review of: 1) seismic data (26 line miles) collected for Sandia during 1976 as part of the initial investigation of the WIPP site, 2) seismic data, acquired from several companies and publicly available, and 3) proprietary data, available for examination by consultants to Sandia, but not released for further publication. Nearly 925 line miles of data were examined for various features, including evidence of breccia pipes through disrupted seismic sections. Long and Associates (1976) concluded breccia pipes could be detected by properly planned and executed seismic work. Long and Associates (1976) also reviewed regional gravity data purchased by Sandia and concluded that they could not establish a relationship between breccia pipes and gravity minima.

There is virtually no formal QA to be applied to Long and Associates' examination of proprietary data and summary discussion. Such a program depends on the inherent integrity and professionalism of the company and its employees. The integrity and professionalism are indicated by the fact that competitive companies were willing to permit Long and Associates to examine data from areas where these companies may have conflicting interests.

Seismic Reflection Survey, 1977

New seismic reflection data were collected during 1977 over the sites of "known breccia pipes" at Hills A-D and the "Weaver pipe." Although this can be directly inferred from the location of seismic reflection lines X-10, X-11, X-12, and X-13 (Hern et al., 1979), no documents prior to the fieldwork have yet been recovered that specify this work included a test of technique against "known breccia pipes." As part of a broader field program of collecting seismic reflection data at or around the WIPP site, these four lines were meant to determine the capability of this technique to detect breccia pipes where they were known to exist. The seismic reflection lines over the site area could then be compared to these test lines to determine if anomalies existed at the site similar to the "known breccia pipes." Some data showed loss of reflector continuity and some dipping strata, but they did not demonstrate seismic reflection to be a reliable technique for diagnosing breccia pipes. Because of the expense of acquiring new data and apparent lack of reliability, seismic reflection techniques were not used to screen the WIPP site.

Field data were collected during 1977 by Dresser-Olympic (later Grant Geophysical Company) under contract to Sandia Laboratories (see review by Hern et al., 1979). Long and Associates was separately contracted by Sandia to provide field inspections, data reduction, and interpretation (Hern et al., 1979). No Sandia technical staff member assigned to WIPP at the time was trained as a geophysicist; the Sandia project manager (Weart) at the time was a trained geophysicist. Trained geophysicists were present during field data collection, processing, and interpretation (Hern et al., 1979). Equipment specifications, field layouts, and data reduction techniques have been reported as well (Hern et al., 1979).

No statement of work or objectives have been recovered for the 1977 seismic reflection program, but it can readily be inferred that lines were included to test seismic techniques against "known breccia pipes." The data collection, reduction, and interpretation were conducted by, or under supervision of, trained geophysicists with experience in seismic techniques. The equipment and methods used for the program were consistent with standard industry practice of the time, though data collection points were more closely spaced than was industry custom of the time for this area. The decision not to use this method for extensive screening or investigation for breccia pipes at the site is not apparent from the documents recovered to date.

Underground Radar Surveys, 1980

The final test of geophysical techniques against "known breccia pipes" was in 1980 when radar techniques were applied underground at Mississippi Chemical Corporation mine where the breccia pipe under Hill C was found (Unterberger, 1981). An SOW (01/09/80, WP01542, WP02728) specific to this project was prepared and approved, detailing additional work broadly covered by two other more general SOW's regarding breccia pipes (11/18/78; WP01607) and Hill C (07/05/79; WP01471). The SOW set out program objectives, program approach, decision points, and quality level for this program. No field operations plan has been recovered, and it is not known that such a plan was prepared for this experimental work.

A letter reporting progress (07/02/80; WP01549) describes some possible alternatives for applying radar successfully underground. The final report (Unterberger, 1981) of the subsurface radar applications describes the activity in considerable detail, reporting specifications of the equipment and tests run to confirm operation of the equipment. The test was not successful at delineating the breccia pipe, and, though additional methods (sonar) were suggested, these techniques were not applied at WIPP to penetrate ahead of the working face. Other geophysical techniques, however, have been successfully operated at WIPP in recent years to delineate the disturbed rock zone and measure other parameters.

The available record of this last test of geophysical techniques against "known breccia pipes" consists of the SOW, a "progress report," and final contractor report. The record clearly shows the relationship between objectives and operations, though a detailed field operations plan is not available and probably was not prepared. No record has been recovered of a formal decision not to pursue

further studies as suggested in the contractor report. The available record is a reasonable account of the project, though it does not show all of the elements (lacks specific field operations plan) expected under the QA standards of the time.

Site Specific Geophysical Techniques

Seismic Reflection Surveys, 1976

No SOW or operations plan has been recovered for the initial (1976) seismic reflection work performed over the site to confirm general geological conditions (see previous discussion under Testing of Geophysical Techniques Against Known Breccia Pipes). The interpretive report by McMillan is available (07/21/76; WP01847) as is a later data report (Hern et al., 1979). Original data were not confirmed.

There is a modest "paper trail" for this effort. The results are included in an available report. The work was performed by, or under supervision of, an experienced geophysicist. The work was not a direct effort to obtain breccia pipe data or to systematically screen the WIPP site for their presence.

Reconnaissance Resistivity Survey, 1977

There is no known SOW or field operations plan for the reconnaissance resistivity survey of the WIPP site area during 1977. Purchasing documents are not available, though they likely included at least a partial statement of the survey objectives. The recommendation for the survey (Elliot, 1976b) is clear, and the conduct of the survey, including data, checks, and calibrations, are reported in Elliot (1977a,b,d,e,f,g) and Mining Geophysical Surveys (1976).

The objectives of the reconnaissance survey and its relationship to breccia pipe concerns are clear from the contractor records and reports even though neither separate SOW nor field operations plan is known to exist. The reports of data and interpretation, however, are available, and these were prepared by geophysicists registered in the State of Arizona and are excellent records of procedures, data, and equipment checks and calibrations. The survey was instrumental in identifying potential anomalies in the general site area for further investigation.

Seismic Reflection Survey, 1977

There is also no known SOW or field operations plan for the 1977 seismic reflection survey (see previous discussion under Testing of Geophysical Techniques Against "Known Breccia Pipes") across some anomalies within the WIPP site area that might have been breccia pipes. Hern et al. (1979)

reported generally on field operations, and the data include information about the procedures and equipment used as well as statistics regarding the data collection and processing.

As noted, there is no known distinct SOW or field operations plan for the 1977 seismic reflection field program. The program was conducted with separate contracts and contractors for data collection and interpretation. The interpreters (Long and Associates) also provided field observers on behalf of Sandia Laboratories during data collection. The data were collected and interpreted under the supervision of trained and experienced geophysicists. The seismic reflection surveys of the WIPP site area during 1977 can be inferred, by their location, to include anomalies possibly indicating breccia pipes (e.g., the location later drilled as WIPP 13), but the reports are not very explicit about this. In any case, the main purpose of the site survey was other than to determine if breccia pipes were present.

Electrical Resistivity Surveys, 1978

During 1978, electrical resistivity surveys near the WIPP site were conducted to better define a resistivity anomaly (section 17, T.22S., R.31E.) immediately prior to drilling WIPP 13 (see Drilling Programs for Breccia Pipes below). The SOW (05/03/78; WP01428) for this and related work provided the objectives of the resistivity program, some detail of the methods, data specifications to be met, professional qualifications and contractor relationships. It specifically called for Elliot Geophysical Company to provide independent verification of field operations by the successful bidder for field work and designated Elliot Geophysical Company as the interpreter of the data. A separate contract for field data collection was awarded to Geoterrex, Ltd., based on bids submitted for a purchase requisition (05/04/78; WP01684) (05/16/78; WP01583). The purchase requisition included provisions based on the original SOW.

As contracts were being established for this survey, a procedure was issued for developing the field project criteria and operational plans (06/28/78; WP00928). QA procedures for this particular survey were also being developed and were issued (07/06/78; WP01392) between the time the more general procedure (06/28/78; WP00928) was printed and the field program began. The QA requirements for the resistivity survey specified instruments and calibration, measurement precision, some field procedures, personnel qualifications, and field inspections by Sandia or Elliot Geophysical Company. The logistics (Bell, 1979), data (Elliot, 1979b), and interpretive reports (Elliot, 1979a) provide the information indicating conformance with the QA requirements.

The logistics and data reports confirm that QA requirements were met except for two minor items: 1) there was no record that Geoterrex management was present in the field as the project was being set up, and 2) it could not be ascertained that field notes were forwarded every 3 days. These are minor to trivial deviations.

The survey provided additional confidence in the location of the resistivity anomaly in section 17 (T.22S., R.31E.) immediately before the drilling of WIPP 13. As a result of the survey during July 1978, the location of WIPP 13 was moved a few hundred feet from a pre-survey location (Elliot, 1979a) and then was drilled. The drilling revealed no evidence of a breccia pipe at the location.

The field geophysical survey of an apparent resistivity anomaly in section 17 (T.22S., R.31E.) proceeded according to an SOW with specific contracting and QA requirements. The survey resulted in logistics, data, and interpretive reports by qualified professional geophysicists, and the survey immediately affected the location of drillhole WIPP 13. No specific field operations plan was provided for the survey. The survey objectives, procedures, and results are all recovered through the existing records in the SWCF.

Drilling Programs for Breccia Pipes

WIPP 15

WIPP 15, located about 20 miles east-southeast of the WIPP site, was drilled during March 1978 to investigate whether San Simon Sink is a solution collapse feature or breccia pipe and to obtain a core record for paleoclimatic data. No specific SOW has been recovered for this drillhole. The original concept included two boreholes (WIPP 15, WIPP 17), as outlined in a memorandum (02/17/78; WP02127) that served the general function of a field operations plan and included drilling objectives. Only a single drillhole, WIPP 15, was completed; no record of the decision not to drill WIPP 17 has been recovered. The basic data report (Sandia National Laboratories and University of New Mexico, 1981) includes geological information, data used to infer climatic conditions, drilling history, and logging. The appendices do not include either an SOW or the memorandum (02/17/78; WP02127) that served as a general field operations plan.

Though WIPP 15 was not drilled explicitly as an investigation of a breccia pipe, later interpretations (e.g., Bachman, 1980) of breccia pipes have been extended to include the processes and solution/subsidence feature at San Simon Sink.

There is no record of an SOW for this drillhole. There is no document called a field operations plan, but a memorandum prior to the drilling includes the main elements of such a plan. The data and interpretations are included in a basic data report that is readily available.

WIPP 13

WIPP 13, located northwest of the center of the WIPP site in section 17, T.22S., R.31E., was drilled late in the summer of 1978 to test the resistivity anomaly discovered during the 1977 resistivity survey and located more precisely during the 1978 resistivity survey. Seismic reflection data obtained

during 1977 (line X-5, Hern et al., 1979) did not show any features interpreted to suggest a breccia pipe near this location. The borehole was the first drilled at a geophysical anomaly believed possibly to indicate a previously unknown breccia pipe.

The basic data report for WIPP 13 (Sandia [National] Laboratories and US Geological Survey, 1979a) includes appendices covering statement of work, field operations plan, drillhole history and as-built conditions, and geophysical logs obtained from the drillhole.

The review of records shows that the SOW and field operations plan were prepared and followed during the drilling of WIPP 13, that operations and data were conducted and obtained by professionals from organizations recognized as competent in these areas. The results have been provided in a format generally available. The interpretation that drilling did not encounter a breccia pipe is traceable to the data through the data report as well as through a further interpretive report by Elliot (1979a).

WIPP 33

By early 1979, George Bachman had mapped possible geological features in and around Nash Draw in sufficient detail to suggest that one or more boreholes should be drilled to eliminate the features as possible breccia pipes. The first location, in section 13, T.22S., R.30E., was explored because it had unusually thick fill and internal drainage. The location is near the eastern margin of Nash Draw and near the margin of the WIPP site as it was then defined. Resistivity studies of the area revealed generally low resistivity, but there was no localized anomaly such as was apparent over known breccia pipes. It was anticipated that solution of evaporite beds might have been part of the process that developed the feature, though there was no particular expectation that this feature was a breccia pipe.

This surface feature was drilled as WIPP 33 during mid-summer, 1979. The borehole was deepened to recognizable marker beds within the upper Salado Formation, confirming that the strata from the upper Salado to the surface were not brecciated or displaced (Sandia National Laboratories and US Geological Survey, 1981). The basal beds of the Forty-niner Member of the Rustler Formation beds included cavernous porosity. Bachman (1980, 1981) interpreted the feature at WIPP 33 as a solution sink and that it is forming as part of the process by which Nash Draw is expanding. No evidence indicated that a breccia pipe had formed or was forming at this location.

Appendices for the basic data report for WIPP 33 (Sandia National Laboratories and US Geological Survey, 1981) present an SOW, field operations plan, hole history, and geophysical logs. The objectives, decision points, responsibilities, and data requirements are presented in the SOW, and the data and interpretations within the basic data report are consistent with the SOW requirements. The field operations plan includes details of the proposed operations, responsibilities, and specifies procedures for portions of the field operations. The basic data report clearly shows the progress of the investigation from initial identification of the anomaly through resolution by drillhole data and integration (Bachman, 1980, 1981) into studies of broader processes.

WIPP 32

During FY 79 (Sandia [National] Laboratories and US Geological Survey, 1979a), a broad project objective was to drill and test a breccia pipe, and it was possible to satisfy this objective through studies of "known breccia pipes" or suspect features. Other features that might be breccia pipes were examined by Bachman during his mapping in late 1978 to 1979, and a generalized scope of work (Appendix A, Sandia [National] Laboratories and US Geological Survey, 1980) suggested two locations as possible features for drilling to determine if a breccia pipe was present and amenable to further drilling. [The locations given in the SOW were each given in error as in R.30E., whereas the features are each in R.29E.] By mid-summer, no other features closer to the WIPP site had been identified as possible breccia pipes, and the nearer of the two (section 33, T.22S., R.29E.) to the WIPP site was drilled late in the summer to the upper Salado. The Rustler and upper Salado Formations were not displaced as in a breccia pipe, though salt has been dissolved from the Salado Formation, at least. The stratigraphy is comparable to WIPP 29, which had previously been drilled nearby (Sandia [National] Laboratories and US Geological Survey, 1979b).

The second feature was not drilled. It was further from WIPP than the feature at WIPP 32, and it showed no geophysical characteristics of breccia pipes. Furthermore, Bachman (1980, 1981) was developing the concept of shallow karst mounds/domes to explain most of the features in Nash Draw and west of Malaga Bend.

As with WIPP 33, the basic data report for WIPP 32 (Sandia [National] Laboratories and US Geological Survey, 1980) includes an SOW, field operations plan, hole history, and list of geophysical logs in addition to the basic geological data and interpretation. The track is relatively clear from general objectives through the acquisition and interpretation of drilling data to determine whether the feature represented a breccia pipe. The decision to drill the feature closer to the site is recorded in the basic data report, but the subsequent decision not to drill the second feature is not included.

The basic data report for WIPP 32 has two noticeable errors. The SOW reported locations for the features incorrectly, and the "as-built" survey included in the report was that of WIPP 33. The second error was corrected by a memorandum to the distribution for the basic data report.

WIPP 31, Initial Drilling

The breccia pipe at Hill A was initially drilled (WIPP 31) during September and October 1978, to a depth of 810 ft, confirming the presence of breccia (Snyder and Gard, 1982). An SOW (9/13/78; WP05408) was prepared by Powers for WIPP 31 outlining the objectives, methods, data requirements, responsibilities, and decision points. The principal objective was to determine, through drilling to Marker Bed (MB) 109 of the Salado Formation or the MB 109 equivalent depth of about 800 ft, if Hill A and attendant geophysical anomaly represented a breccia pipe. The drillhole was successful as a

prospecting exercise in identifying a breccia pipe; further work on this feature and Hill C was deferred until 1980.

The record trace for WIPP 31 is discussed below, following the review of WIPP 31 deepening.

WIPP 16

The breccia pipe at Hill C, over the breccia found in the MCC mine, was drilled from the surface with borehole WIPP 16 early in 1980. The activity was covered in a general SOW (11/18/78; WP01607) as well as a more specific SOW regarding activities at Hill C (7/5/79; WP01471). A variety of objectives and methods, including drilling, was specified in the later SOW leading to an understanding of the specific feature at Hill C as well as of breccia pipes in general. This SOW particularly shows the relationship between the vertical and horizontal (underground) drilling programs; the vertical borehole (WIPP 16) was considered necessary to demonstrate safety to MCC workings from horizontal drilling. If either brine or gas was encountered in significant quantities while drilling WIPP 16, the horizontal drilling program would have been abandoned (see below). Though not specifically discussed in the SOW, the vertical drilling depth was limited to the approximate depth of MCC workings as a safety factor; the drillhole was relatively shallow to lessen the possibility of connecting a deeper source of brine or gas to the mine workings through the borehole and breccia.

A field operations plan (08/21/79, WP02139; 11/27/79, WP02133; modified 11/27/79, WP02133) provided details of the drilling plan, incorporating the SOW and other information relevant to the drilling plan. It further details procedures for acquiring geophysical logs, performing testing, and preserving core and other samples. The field operations plan specifies responsibilities for the investigations.

WIPP 16 was drilled during January and early February 1980, to a total depth of 1300 ft, revealing breccia and downdropped units. The lithologies represented included anhydrite and halite, indicating either limitations on volume of water or brine circulated or that the brine was near or at saturation with respect to these more soluble minerals. Borehole conditions in WIPP 16 prevented hydrological testing.

The basic data from WIPP 16 were presented in the interpretive report by Snyder and Gard (1982) about breccia pipes. Hole history data in the SWCF (4/28/80, WP02950) were verified as present.

The documents available for WIPP 16 include the SOW, field operations plan, basic data and an interpretive report. Hole history data were verified. These documents demonstrate a clear trail from concept to interpretation for the drilling of WIPP 16.

Underground Horizontal Drilling

WIPP 16 did not show significant gas or brine, clearing the way for underground horizontal coring from the MCC mine entry into the breccia pipe. Three horizontal cores ranging from about 60 to about 82 ft long were drilled during May and early June 1980 (Snyder and Gard, 1982). It is probable that only one of the cores actually penetrated the boundary of the breccia pipe.

The horizontal drilling was covered by three statements of work. The general SOW for breccia pipe studies (11/18/78; WP01607) called for underground coring as part of the investigations of breccia pipes. The SOW (7/5/79; WP01471) for Hill C related vertical drilling of WIPP 16 to the underground horizontal coring as a matter of safety. The final, specific SOW for the horizontal coring (4/9/80; WP02279) provides the objectives for coring using a small experimental drilling rig. Field testing was designed to demonstrate capabilities of the equipment while also attempting to gain geological information about the boundaries or extent of the breccia pipe relative to some of the surrounding mine workings. The drilling depth was expected to be less than about 100 ft. Decision points reflected the dual purpose of demonstrating equipment capability as well as obtaining core that might include the boundary of the breccia pipe.

Two field operations plans were developed corresponding to project expectations at differing times. An earlier plan (12/21/79; WP02134) provided for extensive coring, with the first borehole length estimated at 1200 ft. Additional coring was not to exceed 1500 ft. The plan outlined the program for drilling and the working relationship to MCC mine. Horizontal drilling was contingent on prior vertical drilling demonstrating the absence of significant brine or gas. The second field operations plan (4/23/80; WP02141) covered the short, experimental coreholes into the breccia pipe from underground; this plan was the only one executed for underground drilling of the breccia pipe at MCC. The operations plan described drilling and sampling procedures, safety requirements, records keeping, and responsibilities. Suggested coring opportunities included three locations, with seven possible coreholes. The experimental nature of the drilling was recognized in the SOW (WP02279) and in the field operations plan.

A post-drilling report (7/3/80; WP00291) describes the three experimental coreholes drilled in the breccia pipe. The report describes the locations, drilling conditions, and general drilling results, and the report states that the coring was suspended after the third corehole was completed " . . . until a decision is made as to whether additional holes are desirable."

The geology of the experimental cores was reported by Snyder and Gard (1982) and incorporated as appropriate in their interpretation of the origin of breccia pipes. The cores were limited in helping to define the boundary of the breccia pipe adjacent to the underground workings.

The horizontal drilling of the breccia pipe from underground workings of MCC is covered by a number of documents, including multiple SOW's and field operations plans, as objectives were defined and revised and operations plans tracked SOW's. There is clear documentation of the relationship between objectives, plans, and results. There is no significant documentation of the reasons why objectives were changed, resulting in a reduced horizontal drilling program, or the justification for no further horizontal coring to define the pipe boundary.

WIPP 31, Deepening

Late in the summer of 1980, drillhole WIPP 31 in the breccia pipe at Hill A was re-entered, deepened, and tested for hydrological properties. A major objective of the program was to determine the features at the base of the breccia pipe. This was the last direct drilling in a "known breccia pipe".

An SOW for re-entering WIPP 31 (5/16/80; WP07885) defined objectives of determining the base of the breccia pipe and testing the hydrological properties of the breccia mass. The SOW included methods, details of the investigations, decision points, responsibilities, quality items, and the potential for related studies. It was anticipated that the final depth of the borehole might be about 1800 ft. The SOW was reviewed and approved by peers, management, and QA personnel.

A field operations plan (6/23/80; WP02733) for the WIPP 31 re-entry and deepening described responsibilities, the drilling program, procedures for particular items requiring quality control (e.g., coring and geophysical logging), and specified reports regarding drilling. The plan was reviewed and approved by peers, management, and QA personnel. A supplement (7/25/80; WP05479) to the field operations plan included field operating procedures for drill stem testing in WIPP 31. Purposes, proposed testing intervals, and responsibilities were specified. The supplement was also reviewed and approved by peers, management, and QA personnel.

The basic geological data for the deepening of WIPP 31 were reported in the summary report by Snyder and Gard (1982). These geological data confirmed brecciation to total depth of 1981 ft. From surrounding boreholes, it was inferred that these strata were downdropped from their normal position. Three successful drillstem tests in WIPP 31 (Mercer, 1982) resulted in calculated permeabilities, at shallower depths, ranging from 0.11 mD to 0.90 mD (millidarcies). Two tests below 1480 ft did not yield enough fluid to calculate permeabilities. A generalized lithologic log and determination of gas produced during drilling is available (9/24/80; WP03905) from a commercial well logging company contracted for this purpose. Geophysical logs of WIPP 31 were obtained by the US Geological Survey, Water Resources Division (WP02114, WP01720, WP02892). The daily drilling logs (borehole history (WP03079) were verified as present in the SWCF.

There is a clear relationship between the SOW, field operations plan and supplement, and the report and interpretation of data. The program yielded the desired information about the lower parts of the breccia pipe and data on hydrological properties of the breccia. The final report was prepared by geologists of the US Geological Survey and conforms to the standards for an open-file report of that organization. It is widely available by purchase. Details of the daily activities and borehole history have been recovered during the search.

Other Field Programs

The main program related to breccia pipes in this category was field mapping by G.O. Bachman of the US Geological Survey. Bachman's mapping was designed to examine the effects of dissolution

on the geological history of the Pecos valley and vicinity of the WIPP; breccia pipes were within the mapped area. The program plans for FY 1979 and FY 1980 include brief reference to this program. No other documentation was found providing the background justification and objectives. Final reports of the work (Bachman, 1980, 1981) were prepared by a geologist of the US Geological Survey in accordance with the standards for open-file reports. These final reports do state the objectives of the field program.

The programs of the US Geological Survey were carried out in cooperation with Sandia National Laboratories, but they were not subject to the QA requirements of Sandia.

Related Programs and Studies

No specific documents have been recovered setting out the objectives and procedures for the summary studies of Anderson (e.g., 1978) of dissolution, including discussion of breccia pipes. The final summary report to Sandia Laboratories (Anderson, 1978) describes the objectives and methods of the study. Other publications by Anderson in New Mexico Geological Society publications (Anderson, 1981) or professional journals (Anderson and Kirkland, 1980) were subjected to peer reviews as required by those organizations or journals.

Much of the geochronologic work with K-Ar and Rb-Sr was undertaken by Brookins and his colleagues (e.g. Brookins et al., 1980). Some of the work was funded internally by the University of New Mexico, while some projects were contracted by Sandia National Laboratories. Essential information regarding breccia pipes was also reported in the open literature through the peer review process (Brookins et al., 1980); the early documents related to this work were not reviewed.

The study by Wood et al. (1982) of the hydrological significance of the Delaware Mountain Group as an agent of dissolution of the overlying evaporites was carried out under subcontract through the Technical Support Contractor to the Department of Energy. The report includes statements of purpose, methods, analysis and conclusions. The report also includes a signature page for review and approval by peers and management. No further documentation was sought concerning this report.

Ph.D. dissertation studies by Davies (1984), in which he extensively reviewed the data regarding breccia pipes and derived alternative interpretations of their origins, were not funded by WIPP, directed by WIPP personnel, or subjected to WIPP requirements; standard dissertation review and approval in accordance with Stanford University procedures were obtained.

Davies' alternative concepts of the formation of breccia pipes resulted in the proposal that a structural low within Salado Formation units north of the WIPP site might represent dissolution without collapse. DOE-2 was drilled to examine this feature; it was concluded that salt deformation had

occurred, but not as a consequence of salt dissolution (Mercer et al., 1987; Borns, 1987; Anderson, 1987). The program was not a test explicitly of a breccia pipe, but of an alternative hypothesis.

The basic data report (Mercer et al., 1987) included an SOW regarding the dissolution/deformation hypothesis, a field operations plan for the investigation, and basic data derived from the borehole. The SOW and field operations plan were reviewed and approved by peers, management, and quality assurance personnel.

DECISION-MAKING, BASIS, AND INCORPORATION INTO PERFORMANCE ASSESSMENT

The geological characterization report (Powers et al., 1978) has been used extensively as a reference for decision-making for the WIPP project. Since the effective date of this publication (August 1978) predates much of the more informative research on breccia pipes, they were not ruled out as a potential problem, and the document has not been cited as a source for such a conclusion.

By the time of publication of the Final Environmental Impact Statement (FEIS) (US DOE, 1980a,b), some of the geophysical and drilling programs had been completed, though not all results had been reported. The investigations and conclusions about dissolution features and processes, including breccia pipes, were discussed in some detail (US DOE, 1980a, p. 7-97 to 7-101). The FEIS reported Bachman's conclusion that breccia pipes are related to the Capitan reef and will not form as long as the present hydrologic regime of the Capitan is maintained. It was noted that site-specific studies of particular features have not revealed any breccia pipes, consistent with the conclusions that breccia pipes are limited to the Capitan reef area. The FEIS also cited Anderson's (1978) belief that deep dissolution is continuing and his suggestion that dissolution would not affect the WIPP site for the next million years.

The Site and Preliminary Design Validation (SPDV) program provided some additional information bearing on the site suitability, mainly from activities around the site and through underground access. None of the SPDV activities were specifically designed to further investigate the distribution or origin of breccia pipes. A summary of SPDV results (US DOE, 1983) also includes a summary of the site suitability by Weart (1983) describing factors met by the site. Dissolution was considered a site suitability factor. Weart (1983) reviewed major results of breccia pipe studies, concluding that known breccia pipes occur over the Capitan reef, that features within the basin explored by drilling were found not to be breccia pipes, and that known breccia pipes have little permeability at depth. Based on this review, Weart (1983, p. 18) concluded that "[t]he WIPP site is qualified with respect to dissolution."

Lambert (1983), in a general review of dissolution features and processes, also considered breccia pipes to be restricted to the Capitan reef, consistent with Bachman (1980) and Snyder and Gard (1982). The report by Lambert (1983) was among those required by agreement between the DOE and the Environmental Evaluation Group (NM).

Lappin (1988) described the general geology of the WIPP site area as part of an initial development of a conceptual model of the geology and hydrology. Lappin (1988, p. 12) briefly reviewed the results of drilling DOE-2 as well as the conclusions of Snyder and Gard relating known breccia pipes to the area overlying the Capitan reef rocks. He concluded " . . . that point-source dissolution of Castile and/or Salado evaporites is not operative either within the main part of the basin or at the WIPP site". In a more extensive review (p. 22-23), Lappin (1988) discussed the views of Anderson (1978, 1981) and Davies (1983) regarding point-source dissolution driven by the hydrology of the Bell Canyon Formation, *and he concluded* that the studies by Wood et al. (1982) and Lambert (1983) demonstrated the mechanism would be ineffective within 10,000 years. In another section (3.1.2, p. 37-38), Lappin

describes some of the evidence from DOE-2 that led to the conclusion that the structure there is due to deformation of the evaporite section rather than dissolution of the evaporites by fluids from the Bell Canyon, as proposed by Davies.

Lappin et al. (1989) and Lappin et al. (1990) examined site factors affecting the behavior of the isolation system and radionuclide transport. In these documents, the systems analysis concentrated on known features of the WIPP site considered most important to isolation (e.g., Rustler hydrology, underground "disturbed rock zone"). Breccia pipes are not referred to in the analyses and discussions in either report, nor are a variety of other phenomena generally not considered a threat to isolation for the WIPP.

The Final Supplement Environmental Impact Statement (SEIS) (US DOE, 1990b, vol. 1) has no explicit mention of breccia pipes in section 4.0, which covers the geology and hydrology of the site. Section 4.3.5.1 briefly describes the potential of the Bell Canyon Formation for point-source dissolution and concludes there is little. Vol. 3 of the SEIS includes a comment and response (7.7.2-4, p. 203) about salt dissolution from point-sources. The response reviews the results from drilling DOE-2 indicating no evidence of dissolution; Lappin (1988) is cited as drawing the conclusion that hydrological and geochemical evidence indicate point-source dissolution is not an issue for WIPP. A response (7.8-7) to another comment concluded that "localized dissolution . . . will not take place at WIPP during the present climatic regime."

Volume 1 of the No-Migration Petition (US DOE, 1990a) refers briefly twice to breccia pipes, citing Anderson (1978) as the principal source of information. In this summary document, one factual error (p. 4-3, identifying only one known breccia pipe) is included. Appendix L of the Petition describes breccia pipes in more detail, but the sources of information cited are Anderson (1978) and Griswold (1977). The data included in this appendix are inadequate and incomplete, considering the 1990 date of the report. An Addendum (Volume VII) includes a more thorough review of the data and properly cites later documents such as Snyder and Gard (1982) as authoritative sources for the conclusion that these features are limited to the Capitan reef area in the northern Delaware Basin (p. 3-20). The studies specifically of breccia pipes are not uniformly cited in various parts of the No-Migration Petition. In Appendix C (Closure and Post-Closure Plans), there is a statement that no breccia pipes have been found at the WIPP site. This is the most explicit indication that breccia pipes were eliminated from consideration through the decision-making process in the Petition.

I have not recently examined the Final Safety Analysis Report (Westinghouse Electric Corporation, 1990) to determine how, if at all, the studies of breccia pipes were incorporated into decision-making through that document.

Brinster (1991) reviewed at length the concepts and information about breccia pipes included in a variety of documents as a preview of geohydrological conceptual models for performance assessment. Most of the significant documents were included in Brinster's review, which is cited as a source for later discussions of breccia pipes in performance assessment (PA) documents. In addition to reviewing data and hypotheses, Brinster proposed that breccia pipes may have affected the hydrology of the Rustler Formation by connecting it with the Capitan reef as well as with the surface.

Volume 1 (p. 4-24, 4-28, 5-7, 5-10) of the Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991 (WIPP Performance Assessment Division, 1991) presents a brief review of work on breccia pipes as well as a previous approach to assessing the significance of breccia pipes for WIPP by Hunter (1989). The studies by Anderson (1978, 1981, 1983), Snyder and Gard (1982), and Lambert (1983) are the most significant for the review. It is concluded that breccia pipes are associated with the Capitan reef; have not been identified within the interior of the Delaware Basin; and that "[b]ased on the association of known chimneys and reefs, the deep dissolution that produces breccia chimneys is not physically reasonable at or near the WIPP." The conclusion is reiterated in the summary statement as well (p. 4-28). Breccia pipes are briefly mentioned elsewhere (p. 5-7, 5-10, G-3) without adding to the conclusions.

The third comparison to 40 CFR 191 (WIPP Performance Assessment Department, 1992-1993) refers (Vol. 1, p. B-38, Comment and Response 59) very briefly to the hypothesis of Snyder and Gard (1982) relating to breccia chimney formation over the Capitan reef and countering hypothesis by Davies relating dissolution to the Bell Canyon Formation. The comment reiterates that the EEG accepts the lack of threat to the WIPP from deep dissolution but requests Davies' hypothesis be presented as part of the discussion in future revisions of the comparisons to 40 CFR 191. In volume 2 (WIPP Performance Assessment Department, 1992-1993, p. 2-10), Brinster (1991) is cited as indicating that existing breccia pipes are limited to the vicinity of the Capitan reef rocks. As in the 1991 comparison, formation of dissolution cavities from deep dissolution is screened out as an event or process as physically unreasonable (p. 4-5).

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REVIEW GROUP ASSESSMENTS

Of the several review groups that have existed through the life of the WIPP project, the Environmental Evaluation Group (EEG) of New Mexico and the WIPP Panel (and predecessors) of the National Academy of Sciences have been most active in reviewing the work to understand breccia pipes and the potential threat to the WIPP. Both groups have concluded that breccia pipes do not pose a threat to the WIPP, and it is helpful to trace a part of the path followed, and evidence used, to reach that conclusion. Major documents prepared by each group or members have been reviewed for this summary, but I have not exhaustively researched breccia pipes references by these review groups.

Environmental Evaluation Group (EEG) of New Mexico

During a review meeting hosted by the EEG (Environmental Evaluation Group, 1980), the work for WIPP as well as work by Bachman and Anderson regarding breccia pipes was presented and discussed. The summary of discussion regarding deep dissolution and breccia pipes focused on strengths and weaknesses of differing hypotheses. It was recommended that reviewable papers or reports on the work in progress by WIPP project personnel were necessary to assess both the arguments being made and the evidence presented in support of these arguments. It was also suggested that some features of interest highlighted by the discussion should be further investigated. Some of the phases or elements of possible breach scenarios discussed at this meeting are similar to breccia pipe formation, though breccia pipes were not explicitly mentioned within the scenarios. No conclusions were drawn at this time regarding the EEG assessment of breccia pipes and the differing concepts of origin.

The EEG sponsored a field trip to the Carlsbad area during mid-June 1980, to visit a variety of features of geological interest to the WIPP (Chaturvedi, 1980), including known and alleged breccia pipes. Points of discussion (p. 62) included whether breccia pipes are restricted to the Capitan reef area and whether the hydrologic system in the area is capable of forming breccia pipes. It was concluded that a breccia pipe, if already existing at the site but undetected, would probably not be a construction problem. An active pipe, in early stages of formation, could not be ruled out, but the probability seemed low based on the drilling in the basin. Consequences of a breccia pipe should be analyzed. Further field work to determine if breccia pipes exist within the Delaware Basin was not seen as useful. Major studies of breccia pipes were known to the EEG, though some of the last programs (e.g., deepening WIPP 31) had not been completed at the time of the field trip.

A workshop convened by the EEG (September 1981) focused discussion on release scenarios and consequences for the WIPP project (Environmental Evaluation Group, 1982). Dissolution and breccia pipes were discussed in some detail by various participants, including EEG staff members. P. Davies (Stanford University) presented initial estimates that slower dissolution might result in salt deformation rather than collapse and brecciation. Spiegler (EEG) reported his conclusions that catastrophic collapse would not occur in the vicinity of the WIPP site because of the volume of salt; gradual subsidence would instead occur. Spiegler also reported his conclusions that, even if catastrophic collapse occurred, radionuclide releases would be less than regulatory limits. The major studies of breccia pipes

by the WIPP are evident by the discussion and references, though Snyder and Gard (1982) was not yet available. The summary concludes that the consequences of breccia pipe formation at WIPP are bounded by scenarios within the FEIS and that transport of radionuclides to the surface through breccia pipe formation is very unlikely.

Spiegler (1982) formalized his analyses of breccia pipe formation and consequences in a separate report. He concluded that it was not reasonable to expect a breccia pipe to form at the site area by collapse of a cavern. Even if a breccia pipe formed, Spiegler believes ^{239}Pu reaching the surface would be less than permissible limits. Spiegler did not have Snyder and Gard (1982), as it was not yet distributed. In a footnote (p. 5), however, Spiegler (1982) cited personal communication from R. Snyder to include some details from the drilling of WIPP 16 and WIPP 31. This publication separates and formalizes much of the information provided by Speigler for the workshop of September 1981 (Environmental Evaluation Group, 1982).

The Stipulated Agreement between the State of New Mexico and the Department of Energy required reports on breccia pipes and a variety of other topics. The EEG (Environmental Evaluation Group, 1983) reviewed the draft report by Snyder and Gard (1982) submitted to fulfill part of the requirements. The EEG concluded that the report met the requirements of the agreement; general and specific comments on the report were provided to the USGS by the EEG.

The summary conclusion by the EEG regarding breccia pipes (Neill et al., 1983) refers to the main studies of breccia pipes, including Snyder and Gard (1982). The EEG concluded (p. 22) that " . . . breccia pipes, by themselves, do not pose a threat to the WIPP repository." The EEG was reviewing the suitability of the WIPP site with respect to a variety of geological issues.

DOE-2, though not explicitly proposed as a breccia pipe location, was concluded not to represent a dissolution feature by EEG on the basis of the core evidence as evaluated by Anderson (1987) and Davies (as cited in a letter from Neill to Tillman, 09/09/87).

Recent publications by the EEG or staff members (e.g., Chaturvedi, 1993) reiterate in some fashion the conclusion of Neill et al. (1983) that breccia pipes are not considered an issue for radioactive waste isolation by the WIPP.

National Academy of Sciences (NAS)

The WIPP Panel for the NAS extensively reviewed available reports and concepts about breccia pipes in their interim review of site suitability (National Research Council, 1983). Major reports of data and analysis were available to the panel and are extensively cited. The panel concluded (p. 24) that " . . . the likelihood of encountering an old pipe or a new one forming de novo near the WIPP site is practically nonexistent."

The final report of the WIPP Panel on site suitability (National Research Council, 1984) is very similar to the 1983 report and has the same conclusion about breccia pipes.

Both the EEG and NAS, as independent reviewers of WIPP project work on breccia pipes, reached the conclusion that breccia pipes are not a threat. This conclusion was reached on the basis of both the geological record and the analysis of the consequences if a breccia pipe did exist. The reviewers did not necessarily agree that all issues with respect to the origin of breccia pipes were settled, but the record was considered sufficient for them to draw their conclusions.

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CONCLUSIONS

Re Project History of Breccia Pipe Studies

The project history of breccia pipe studies is relatively clear from study of available documents, though the initial time and manner of recognizing them as a potential threat to the WIPP are not apparently recorded. Soon after breccia pipes were recognized as such during 1975-76, field programs were implemented to determine how to detect unknown breccia pipes by testing techniques against "known breccia pipes". Geophysical techniques were selected for reconnaissance screening of the WIPP site, and one anomaly within the WIPP site boundaries was drilled, proving that a breccia pipe had not formed at that location. Over several years, additional geophysical techniques were applied to "known breccia pipes" as well as to areas of concern. Three boreholes were drilled at locations having features considered possible indicators of solution, if not collapse, and all were demonstrated not to be breccia pipes. Two "known breccia pipes" were also drilled to determine characteristics and depth.

Field mapping and the results of various studies were summarized in reports by Bachman (1980, 1981, 1987) and Snyder and Gard (1982), leading to the hypothesis generally prevailing to explain these features. Davies (1984) extensively reviewed WIPP studies as well as other work on breccia pipes; he concluded that catastrophic collapse was not necessary in the formation of breccia pipes. A structural anomaly within the Salado Formation about two miles north of the WIPP site center was drilled in two phases in 1984 and 1985 (Mercer et al., 1987) as a possible example of Davies' concepts. This was the last direct investigation of breccia pipes by the WIPP project.

Despite the fact that the general project history is relatively clear, most of the project decision-making documents poorly reflect either the history or the background to conclusions about breccia pipes. The geological characterization report (Powers et al., 1978) reports on studies in progress and relevant to breccia pipes, but it predates much of the important work from 1978 through 1980. Lappin (1988) is a better reference, but the overall history and discussion is curtailed. That report provides the first decision-making statement that breccia pipes are not of concern to the WIPP because they are restricted to the area of the Capitan reef, well away from the WIPP site. The statement is based on the conclusions of Snyder and Gard (1982). The preliminary hydrogeological conceptual model (Brinster, 1991) provides more discussion of the data and concepts, and it reaches the same conclusion about breccia pipes not being present at the WIPP site. Later PA-related documents exclude breccia pipes from consideration as a threat to the WIPP as "physically unreasonable," based on the conclusion that breccia pipes only form over the Capitan reef. Brinster (1991), Lappin (1988), and, less commonly, Snyder and Gard (1982) are cited as authority for this conclusion, without extended discussion.

The general project history of breccia pipe studies is clear and can be broadly ascertained from readily available documents such as Griswold (1977), Powers et al. (1978), Bachman (1980, 1981, 1987), Snyder and Gard (1982), and Lambert (1983). Many unpublished documents (e.g., reports by

Elliot) are also cited in the more-readily available literature, making it possible to obtain and reconstruct a reasonable project history of breccia pipe studies for WIPP with reasonable effort.

Assessment of Record Trace re Breccia Pipes

The record trace for breccia pipes has been relatively successful overall. All major WIPP documents known, or indicated to exist through cross-reference, have been found and examined. Documents of this kind can all be found in the Sandia WIPP Central File; many are also available through various sources such as the on-site library at WIPP. These documents and reports provide both general relationships of investigations and results, as well as considerable detail about the individual activities. On a general, professional basis these studies can be well-defended as a good record of the objectives, findings, and interpretations of the studies of breccia pipes carried out for the WIPP project. Professional geologists would generally accept the record as more than adequate to trace and understand the conclusions reached.

Nonetheless, neither the overall study of breccia pipes nor the individual programs would match a stricter standard demanding a complete "paper trail" from concept through project completion. Virtually no documented record from the time of recognition of the problem to the initial field programs (geophysical studies) was recovered. There are few items setting out objectives for the early studies before they were initiated. The standards for a paper trail were developing from 1975 through 1978, finally settling into a format of statement of work, field operations plan, basic data report, or data and interpretive report. At some level, the paper trail fails as well for later programs. Items such as daily logs for drillholes or checklists for geophysical logging have commonly not been recovered.

Field programs from about 1977 are represented in SWCF files by a considerable record. Further records could probably be obtained from individual files, archives, or the PRS in Carlsbad. Contracting records for Sandia National Laboratories are only kept for the last six years (personal communication from G. Pullen; 11/04/93). Nevertheless, an intensive search for such records is not warranted unless a specific concern and need can be identified; a few gaps filled while others remain will not be a good use of time and resources. The record will likely not ever be established as a complete paper trail; the decision needs to be made to accept the existing record as an adequate basis for the conclusions in PA regarding breccia pipes.

RECOMMENDATIONS

There are few recommendations from this project. I see little to be gained in expending considerable resources on this subject to try to fill in some of the gaps in the record, as there will still be significant areas without a paper trail. Particular items or documents might be sought if there is a well-defined purpose or objective to be achieved by that search.

Some modest efforts to substantiate breccia pipe background are recommended for the future:

- The PRS should be researched for early documents about the breccia pipe program mainly to determine the extent of the records as a resource. The main record of breccia pipe studies has already been recovered, and it should not be expected that the PRS will reveal a significantly different story. A supplement or revision to this document may be appropriate when PRS records can be researched.

- There are some specific documents, indicated in the general record by cross-reference, that should be sought with some special care, though these documents do not necessarily relate to breccia pipes. In particular, there does not appear to be copies of the seismic reflection work by C.B. Reynolds during 1976; it is not critical to the breccia pipe review as the study was not designed to detect breccia pipes, and it was not considered successful.

The main recommendations relate to records retention and searching:

- Special care and marking may be appropriate for specific data such as magnetic tapes and original, unique information, in contrast to copies of formal reports, which have been widely distributed and stored. Some information, such as photography, is important but has received even less attention than has data on magnetic tapes.

- A general system of records key words or phrases needs to be developed and superimposed on the existing system by someone reasonably knowledgeable about records categories and the WIPP. The form of the key word or phrase system will follow a defined function. For example, if the main purpose is to guide relatively inexperienced staff to the literature and documents about broader subjects, a series of broad categories can be developed with fewer subheadings. If the purpose is to help staff identify more closely an individual document concerning a more specific topic, the key words or phrases will have to be more detailed and hierarchical. An example of the latter is the final indexing system used for the select bibliography (Powers and Martin, 1993). An alternative massive conversion of documents to hypertext or other system such as optical disks for direct search is becoming practical.

REFERENCES

Anderson, R.Y. 1978. "Report to Sandia Laboratories on Deep Dissolution of Salt, Northern Delaware Basin, New Mexico." Report to Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029527-WP029530.)

Anderson, R.Y. 1981. "Deep-Seated Salt Dissolution in the Delaware Basin, Texas and New Mexico," *Environmental Geology and Hydrology in New Mexico*. Eds. S.G. Wells, W. Lambert, and J.F. Callender. New Mexico Geological Society Special Publication No. 10. [Socorro, NM]: New Mexico Geological Society. 133-145.

Anderson, R.Y. 1983. "Evidence for Deep Dissolution in the Delaware Basin." Report to Environmental Evaluation Group, Albuquerque, NM. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029531.)

Anderson, R.Y. 1987. "Report to New Mexico Environmental Evaluation Group (EEG) on Evaluation of Drillhole DOE-2." (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029532.)

Anderson, R.Y., and D.W. Kirkland. 1980. "Dissolution of Salt Deposits by Brine Density Flow," *Geology*. Vol. 8, no. 2, 66-69.

Bachman, G.O. 1980. *Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico*. Open-File Report 80-1099. Denver, CO: US Geological Survey.

Bachman, G.O. 1981. *Geology of Nash Draw, Eddy County, New Mexico*. Open-File Report 81-31. Denver, CO: US Geological Survey.

Bachman, G.O. 1987. "Evaporite Karst in the Pecos Drainage, Southeastern New Mexico," *Geology of the Western Delaware Basin, West Texas and Southeastern New Mexico*. Eds. D.W. Powers and W.C. James. El Paso Geological Society Guidebook 18. El Paso, TX: El Paso Geological Society. 118-123.

Barrows, L.J., S-E. Shaffer, W.B. Miller, and J.D. Fett. 1983. *Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretation*. SAND82-2922. Albuquerque, NM: Sandia National Laboratories.

Baumgardner, R.W., Jr., A.D. Hoadley, and A.G. Goldstein. 1982. *Formation of the Wink Sink, A Salt Dissolution and Collapse Feature, Winkler County, Texas*. Report of Investigations No. 114. Austin, TX: Bureau of Economic Geology, University of Texas at Austin.

Bell, R.S. 1979. *Logistics Report on a Resistivity Survey Conducted on Behalf of Sandia Laboratories by Geoterrex Limited July 14 to September 4, 1978*. SAND79-7031. Albuquerque, NM: Sandia National Laboratories.

Borns, D.J. 1987. *The Geologic Structures Observed in Drillhole DOE-2 and Their Possible Origins: Waste Isolation Pilot Plant*. SAND86-1495. Albuquerque, NM: Sandia National Laboratories.

Brinster, K.L. 1991. *Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment*. SAND89-7147. Albuquerque, NM: Sandia National Laboratories. [With errata].

Brookins, D.G. 1981. "Geochronologic Studies Near the WIPP Site, Southeastern New Mexico," *Environmental Geology and Hydrology in New Mexico*. Eds. S.G. Wells, W. Lambert, and J.F. Callender. New Mexico Geological Society Special Publication No. 10. [Socorro, NM]: New Mexico Geological Society. 147-152.

Brookins, D.G., and J.K. Register. 1981. *Potassium-Argon and Neutron Activation Analysis Studies of Polyhalites Near the WIPP Site*. SAND81-7071. Albuquerque, NM: Sandia National Laboratories.

Brookins, D.G., J.K. Register, Jr., and H.W. Krueger. 1980. "Potassium-Argon Dating of Polyhalite in Southeastern New Mexico," *Geochimica et Cosmochimica Acta*. Vol. 44, no. 5, 635-637.

Chaturvedi, L. 1980. *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.* EEG-7. Santa Fe, NM: Environmental Evaluation Group.

Chaturvedi, L. 1993. "WIPP-Related Geological Issues," *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society Forty-fourth Annual Field Conference, Carlsbad, NM.* Eds. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J.M. Barker. [Socorro, NM: New Mexico Geological Society]. 331-338.

Davies, P.B. 1983. "Assessing the Potential for Deep-Seated Salt Dissolution and Subsidence at the Waste Isolation Pilot Plant (WIPP)," *State of New Mexico Environmental Evaluation Group Conference: WIPP Site Suitability for Radioactive Waste Disposal, Carlsbad, NM, May 12-13, 1983.* (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029533.)

Davies, P.B. 1984. "Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits." Ph.D. dissertation. Stanford, CA: Stanford University.

Davies, P.B. 1989. "Assessing Deep-Seated Dissolution-Subsidence Hazards at Radioactive-Waste Repository Sites in Bedded Salt," *Engineering Geology*. Vol. 27, 467-487.

Elliot, C.L. 1976a. "An Experimental Detailed Gravity Survey of Known or Suspected Breccia Pipes at Weaver Hill, Hills A & B, and Hills C & D, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. Vol. 1-3. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029534-WP029535, WP029601.)

Elliot, C.L. 1976b. "An Experimental Detailed Resistivity Survey of Known or Suspected Breccia Pipes and Sinkholes, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029513.)

Elliot, C.L. 1977a. "Evaluation of the Proposed Los Medaños Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy & Lea Counties, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029536.)

Elliot, C.L. 1977b. "Maps to Accompany Evaluation of the Proposed Los Medaños Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy & Lea Counties, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029603.)

Elliot, C.L. 1977c. "An Experimental Detailed Resistivity Survey of Hills C and D, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP09015.)

Elliot, C.L. 1977d. "An Experimental Detailed Resistivity Survey of Suspected Breccia Pipes, Eddy County, New Mexico, An Addendum Report." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP09019.)

Elliot, C.L. 1977e. "Experimental Resistivity Soundings Near a Known Breccia Pipe, Weaver Area, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP09017.)

Elliot, C.L. 1977f. "Resistivity and Gravity Survey Data, 1976 and 1977, Los Medaños Site Area and Experimental Surveys of the Surrounding Areas, Eddy and Lea Counties, New Mexico, Volume I." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029602.)

Elliot, C.L. 1977g. "Resistivity and Gravity Survey Data, 1976 and 1977, Los Medaños Site Area and Experimental Surveys of the Surrounding Areas, Eddy and Lea Counties, New Mexico, Volume II: Contents of Accompanying Magnetic Tape." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029596.)

Elliot, C.L. 1979a. "A Detailed Resistivity Survey of a Suspected Breccia Pipe Anomaly in Section 17, T22S, R31E, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029521.)

Elliot, C.L. 1979b. "Resistivity Survey Data, 1978, Los Medaños Site Area, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029522.)

Environmental Evaluation Group. 1980. *Geotechnical Considerations for Radiological Hazard Assessment of WIPP: A Report of a Meeting Held on January 17-18, 1980.* EEG-6. Santa Fe, NM: Environmental Evaluation Group.

Environmental Evaluation Group. 1982. *Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981.* EEG-16. Santa Fe, NM: Environmental Evaluation Group.

Environmental Evaluation Group. 1983. *EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983.* EEG-22. Santa Fe, NM: Environmental Evaluation Group.

Gera, F. 1974. *On the Origin of the Small Hills in Nash Draw and Clayton Basin, Southeastern New Mexico.* ORNL 74-2-29. Oak Ridge, TN: Oak Ridge National Laboratory. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM.* SAND77-0946. Albuquerque, NM: Sandia National Laboratories.

Hern, J.L., D.W. Powers, and L.J. Barrows. 1979. *Seismic Reflection Data Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND79-0264. Albuquerque, NM: Sandia National Laboratories. Vols. 1-2.

Hill, C.A. 1993. "Barite/Celestite/Selenite/Calcite Mineralization at Bell Lake Sink, Lea County, New Mexico," *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society Forty-Fourth Annual Field Conference, Carlsbad, NM.* Eds. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J.M. Barker. [Socorro, NM: New Mexico Geological Society]. 317-320.

Hunter, R.L. 1989. *Events and Processes for Constructing Scenarios for the Release of Transuranic Waste From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-2546. Albuquerque, NM: Sandia National Laboratories.

Izett, G.A., and R.E. Wilcox. 1982. *Map Showing Localities and Inferred Distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds (Pearlette Family Ash Beds) of Pleistocene Age in the Western United States and Southern Canada.* Miscellaneous Investigations Series Map I-1325. US Geological Survey. Scale 1:4,000,000.

Lambert, S.J. 1983. *Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas.* SAND82-0461. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R. 1988. *Summary of Site-Characterization Studies Conducted from 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND88-0157. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, D.P. Garber, and P.B. Davies, eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, P.B. Davies, D.J. Borns, M. Reeves, J. Pickens, and H.J. Iuzzolino. 1990. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; September 1989.* SAND89-1996. Albuquerque, NM: Sandia National Laboratories.

Long, G.J., and Associates, Inc. 1976. *Interpretation of Geophysical Data, Los Medanos and Vicinity, Lea and Eddy Counties, New Mexico.* Houston, TX: G.J. Long and Associates, Inc. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Mercer, J.W. 1982. "Drill-Stem Tests, WIPP 31," *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site.* R.P. Snyder and L.M. Gard, Jr. Open-File Report 82-968. Denver, CO: U.S. Geological Survey. 67-73.

Mercer, J.W., R.L. Beauheim, R.P. Snyder, and G.M. Fairer. 1987. *Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-0611. Albuquerque, NM: Sandia National Laboratories.

Mining Geophysical Surveys. [1976]. "Experimental Geophysical Surveys of the Los Medaños Site and Surrounding Areas for Waste Isolation Pilot Plant Program, Eddy and Lea Counties, New Mexico." [Tucson, AZ]: Mining Geophysical Surveys. (Copy on file at the Sandia WIPP central Files, Sandia National Laboratories, Albuquerque, NM as WP029515 - WP029520, WP029524 - WP029526.)

National Research Council. Board on Radioactive Waste Management. Panel on the Waste Isolation Pilot Plant. 1983. *Review of the Criteria for the Site Suitability, Design, Construction and Operation of the Proposed Waste Isolation Pilot Plant (WIPP), Interim Report: July 1, 1978 to July 31, 1982.* DOE/NE/93023-3. Washington, DC: National Academy of Science.

National Research Council. Board on Radioactive Waste Management. Panel on the Waste Isolation Pilot Plant. 1984. *Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP).* DOE/DP/48015-1. Washington, DC: National Research Council, Board on Radioactive Waste Management.

Neill, R.H., J.K. Channell, L. Chaturvedi, M.S. Little, K. Rehfeldt, and P. Spiegler. 1983. *Evaluation of the Suitability of the WIPP Site.* EEG-23. Santa Fe, NM: Environmental Evaluation Group.

NUS Corporation. 1979. *Report of Geologic Data Review for the New Mexico WIPP Site.* NUS-3324. Rockville, MD: NUS Corporation. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WP029523.)

Palacas, J.G., R.P. Snyder, J.P. Baysinger, and C.N. Threlkeld. 1982. *Geochemical Analysis of Potash Mine Seep Oils, Collapsed Breccia Pipe Oil Shows and Selected Crude Oils, Eddy County, New Mexico*. Open-File Report 82-421. Denver, CO: US Geological Survey.

Powers, D.W., and M.L. Martin. 1993. *A Select Bibliography with Abstracts of Reports Related to Waste Isolation Pilot Plant Geotechnical Studies (1972 - 1990)*. SAND92-7277. Albuquerque, NM: Sandia National Laboratories.

Powers, D.W., S.J. Lambert, S-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*. SAND78-1596. Albuquerque, NM: Sandia National Laboratories. Vols. 1-2.

Reddy, G.R. 1961. "Geology of the Queen Lake Domes near Malaga, Eddy County, New Mexico." M.S. thesis. Albuquerque, NM: University of New Mexico.

Register, J.K., Jr. 1979. "Rubidium-Strontium and Related Studies of the Salado Formation, Southeastern New Mexico." M.S. thesis. Albuquerque, NM: University of New Mexico.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1983. *Basic Data Report for Drillhole ERDA 10 (Waste Isolation Pilot Plant - WIPP)*. SAND79-0271. Albuquerque, NM: Sandia National Laboratories.

Sandia [National] Laboratories and US Geological Survey. 1979a. *Basic Data Report for Drillhole WIPP 13 (Waste Isolation Pilot Plant - WIPP)*. SAND79-0273. Albuquerque, NM: Sandia National Laboratories.

Sandia [National] Laboratories and US Geological Survey. 1979b. *Basic Data Report for Drillhole WIPP 29 (Waste Isolation Pilot Plant - WIPP)*. SAND79-0283. Albuquerque, NM: Sandia National Laboratories.

Sandia [National] Laboratories and US Geological Survey. 1980. *Basic Data Report for Drillhole WIPP 32 (Waste Isolation Pilot Plant - WIPP)*. SAND80-1102. Albuquerque, NM: Sandia National Laboratories.

Sandia National Laboratories and US Geological Survey. 1981. *Basic Data Report for Drillhole WIPP 33 (Waste Isolation Pilot Plant - WIPP)*. SAND80-2011. Albuquerque, NM: Sandia National Laboratories.

Sandia National Laboratories and US Geological Survey. 1982. *Basic Data Report for Drillhole WIPP 11 (Waste Isolation Pilot Plant - WIPP)*. SAND79-0272. Albuquerque, NM: Sandia National Laboratories.

Sandia National Laboratories and University of New Mexico. 1981. *Basic Data Report for Drillhole WIPP 15 (Waste Isolation Pilot Plant - WIPP)*. SAND79-0274. Albuquerque, NM: Sandia National Laboratories.

Snyder, R.P., and L.M. Gard, Jr. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, With Section on Drill-Stem Tests*. Open-File Report 82-968. Denver, CO: US Geological Survey.

Spiegler, P. 1982. *Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository*. EEG-13. Santa Fe, NM: Environmental Evaluation Group.

Szabo, B.J., W.C. Gottschall, J.N. Rosholt, and C.R. McKinney. 1980. *Uranium Series Disequilibrium Investigation Related to the WIPP Site, New Mexico. Part I: A Preliminary Study of Uranium-Thorium Systematics in Dissolution Residues at the Top of Evaporites of the Salado Formation, Implications to Process and Time. Part II: Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposits Near WIPP Site, New Mexico*. Open-File Report 80-879. Denver, CO: US Geological Survey.

US Department of Energy. 1980a. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Washington, DC: US Department of Energy. Vols. 1-2.

US Department of Energy. 1980b. *Executive Summary Environmental Impact Statement Waste Isolation Pilot Plant (WIPP).* DOE/EIS-0026. Albuquerque, NM: US Department of Energy.

US Department of Energy. 1983. *Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program*. WIPP-DOE-161. Albuquerque, NM: US Department of Energy.

US Department of Energy. 1990a. *Waste Isolation Pilot Plant No-Migration Variance Petition.* DOE/WIPP-89-003. Carlsbad, NM: Westinghouse Electric Corporation, Waste Isolation Division for the US Department of Energy.

US Department of Energy. 1990b. *Final Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. Washington, DC: US Department of Energy. Vols. 1-13.

Unterberger, R.R. 1981. *Final Report on Subsurface Radar Application in the Delaware Basin, Covering the Period June 1, 1980 through January 31, 1981*. SAND81-7153. Albuquerque, NM: Sandia National Laboratories.

Vine, J.D. 1960. "Recent Domal Structures in Southeastern New Mexico," *American Association of Petroleum Geologists Bulletin*. Vol. 44, no. 12, 1903-1911.

Vine, J.D. 1963. *Surface Geology of the Nash Draw Quadrangle Eddy County New Mexico*. Geological Survey Bulletin 1141-B. Washington, DC: US Government Printing Office.

Weart, W.D. 1983. *Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability*. SAND83-0450. Albuquerque, NM: Sandia National Laboratories.

Westinghouse Electric Corporation. 1990. *Final Safety Analysis Report, Waste Isolation Pilot Plant, Carlsbad, New Mexico*. WP 02-9, Rev 0. Carlsbad, NM: Westinghouse Electric Corporation.

Widdicombe, R.E. 1979. "Quaternary Surficial Features in the Delaware Basin, Eddy and Lea Counties, New Mexico." MS thesis. Albuquerque, NM: University of New Mexico.

Wieduwilt, W.G. 1977. "Electrical Geophysical Surveys of the Los Medaños Site and Surrounding Areas for the Waste Isolation Pilot Plant Program Eddy and Lea Counties, New Mexico." Tucson, AZ: Mining Geophysical Surveys, Inc. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

WIPP Performance Assessment Department. 1992-1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992*. SAND92-0700/1-5. Albuquerque, NM: Sandia National Laboratories.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991*. SAND91-0893/1-3. Albuquerque, NM: Sandia National Laboratories.

Wood, B.J., R.E. Snow, D.J. Cosler, and S. Haji-Djafari. 1982. *Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico*. TME 3166. Albuquerque, NM: US Department of Energy.

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APPENDIX A: DOCUMENT LIST FOR SANDIA WIPP CENTRAL FILES (SWCF) HOLDINGS RELEVANT TO BRECCIA PIPE "TRACE"

SWCF Document List for Breccia Pipe "Trace"[1]

Date	SWCF #[2]	Author/Source	Description/Title
06/18/76	06380	Vine, J.D.	Memo: Origin and significance of breccia pipes in the vicinity of the ERDA radioactive waste disposal site in New Mexico.
07/21/76	01847	McMillan, C.	Letter report: Los Medanos Area Lea and Eddy Counties, New Mexico.
08/19/76	01582	Anderson, R.Y.	Memo: Recommendation for a study of the origin and distribution of conduit and collapse structures in the Castile and Salado evaporites.
12/01/76	00340	Anderson, R.Y.	Short report: Addendum to geologic evaluation of the Los Medanos (ERDA #9) W.I.P.P. site, Eddy Co., New Mexico.
02/02/77	01605	Elliot, C.L.	Letter report: Geophysical methods of discovery and delineation of buried breccia pipes other than by gravity and resistivity means.
07/06/77	01869	Griswold, G.B.	Memo: Future deep drilling at Los Medanos.
11/08/77	00897	Statler, R.D.	Memo: WIPP Field Engineering, Standard Operating Procedures for Quality Assurance.
11/22/77	02115	Statler, R.D.	Memo: Permission to drill exploratory well, WIPP no. 15 in Township 23S, Range 35E, Section 18, Lea County, New Mexico.
01/13/78	01380	Muller, F.W.	Memo: QA program for exploratory drilling operations.
02/17/78	02127	Statler, R.D.	Memo: WIPP Nos. 15 & 17 drilling program, schedule and coring plan.
04/03/78	01681	Elliot, C.L.	Letter: Inventory of pertinent data for the WIPP project.
04/18/78	02067	Schermer, S.C.	Archaeological clearance report for Sandia Laboratories Weaver site, proposed breccia pipe drill site, WIPP #13 drill location, and WIPP #12 access road.

[1] Not all documents in this listing were referenced in the main text.

[2] All document numbers are preceded by **WP** unless otherwise indicated.

Date	SWCF #	Author/Source	Description/Title
05/03/78	01428	Powers, D.W.	Memo: Resistivity program.
05/04/78	01684	Castillo	P.R.: Geophysical data.
05/05/78	01665	Powers, D.W.	Memo: High resolution aeromagnetic survey.
05/16/78	01583	Powers, D.W.	Memo: RFQ for 13-0822.
06/28/78	00928	Hill, L.R.	Memo: Procedure for issuing field project criteria and field operational plans.
07/03/78	03078	Wetterhus, C.W.	Survey: WIPP 31 location.
07/06/78	01392	Powers, D.W.	Memo: Quality assurance procedures for resistivity studies under contract 13-0830 to Geoterrex, Ltd.
07/26/78	02036	Statler, R.D.	Field Operations Program of Sandia Labs WIPP site investigations resistivity anomaly [WIPP 13].
08/07/78	03076	Schueler, D.T.	Letter: re Cooperative agreement and drill sites for WIPP 31.
08/17/78	03072	Orr, G.K.(BLM)	Letter: Authorization to drill WIPP 31.
09/05/78	03071	Statler, R.D.	Letter: Application to USGS to drill WIPP 31.
09/06/78	01683	Castillo	P.R.: Geophysical consulting services from Elliot Geophysical Co.
09/08/78	03073	Wright, J.I.	Letter: Approval from State of NM to drill WIPP 31.
09/11/78	02732	Statler, R.D.	Field Operations Program of Sandia Laboratories WIPP site investigations resistivity anomaly [WIPP 31].
09/12/78	n/a	Bresson, J.F.	Letter: Action items resulting from quality assurance site characterization meeting on September 7, 1978.
09/13/78	05408	Powers, D.W.	Memo: WIPP 31, scope of work.
10/05/78	03082	DresserAtlas	BHC Acoustilog, WIPP 31.
10/05/78	03083	DresserAtlas	Compensated densilog, WIPP 31.
10/05/78	03085	DresserAtlas	Compensated neutron gamma ray log, WIPP 31.
10/05/78	03086	DresserAtlas	Dual laterolog, WIPP 31.
10/05/78	03087	DresserAtlas	Micro-laterolog, WIPP 31.
10/06/78	03081	Sperry-Sun, Inc.	Directional survey report, WIPP 31.

Date	SWCF #	Author/Source	Description/Title
10/20/78	01405	Schueler, D.T.	Letter: Reliability of site characterization work.
[11/09/78]	03070	Reddy, D.R.	As built survey plat, WIPP 31.
11/18/78	01607	Powers & Lambert	Memo: General statement of work regarding breccia pipes.
01/29/79	00644	Hill, L.R.	Memo: Standards for Sandia's geologic site evaluation program.
02/09/79	00910	Hill, L.R.	Memo: Procedures for core storage, handling, and distribution.
03/08/79	01943	Powers, D.W.	Memo: Scope of work, borehole(s) in section 13, T22S, R30E. [WIPP 33]
04/23/79	02757	Anderson, R.Y.	First draft of preliminary report to EEG: Mechanism and rates of development of regional and localized dissolution features in and below evaporites.
06/04/79	02865	Reddy, D.R.	Survey plats proposed drill hole location Hill "C" [WIPP 16].
06/04/79	02952	Reddy, D.R.	as above (Alternate 3).
06/18/79	02943	Schermer, S.C.	Archaeological clearance report for Sandia Laboratories Hill "C" (Alternates 1-4) [WIPP 16].
07/05/79	01471	Powers, D.W.	Memo: Hill C, Statement of work.
07/26/79	02138	Jones, C.L.	Letter: Forecast stratigraphy for WIPP-16.
07/27/79	03075	Statler, Wright	Notice of intention to drill exploratory hole, and approval, New Mexico State Engineer.
08/16/79	05401	Statler, R.D.	Memo: Supplement to field ops plan for WIPP-32.
08/20/79	03091	Fenix & Scisson	Instructions to logging company [for WIPP 32].
08/20/79	03090	Fenix & Scisson	Log quality report [for WIPP 32].
08/21/79	02139	Statler, R.D.	Site investigations for WIPP 16 (Hill "C").
09/05/79	02855	Statler, R.D.	Memo: Priorities and completion schedule of WIPP drilling program - September 1979.
11/07/79	02144	Statler, R.D.	Memo: Technical criteria and recommended practices for drilling and testing WIPP-16 (Hill "C").

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11/07/79	02132	Weart, W.D.	Memo: Request for engineering and field support for the drilling of exploratory hole, WIPP 16.
11/27/79	02133	Weart, W.D.	Memo: Modification to technical criteria and recommended practices for drilling and testing WIPP-16 (Hill "C").
12/21/79	02134	Statler, R.D.	Memo: Tech criteria for horizontal coring underground beneath Hill "C" for the WIPP program.
01/03/80	01000	Beckner, E.H.	Approval of PR 49-2195 to obtain contract for taking horizontal core across breccia pipe in Mississippi Chemical Corporation potash mine.
01/09/80	01542	Barrows, L.J.	Memo: Scope of work for subsurface geophysical survey of the Hill C breccia pipe.
01/24/80	02728	Beckner, E.H.	Subsurface geophysical survey of the Hill C breccia pipe, P.O. 49-5808.
02/06/80	02949	Sperry-Sun, Inc.	Gyroscopic survey, WIPP 16.
02/06/80	02948	USGS	WIPP 16 caliper log.
02/06/80	02946	USGS	WIPP 16 neutron log.
02/06/80	02947	USGS	WIPP 16 gamma log.
02/07/80	02945	USGS	WIPP 16 bulk density log.
02/06/80	02955	MORCO	Mud log WIPP 16 with lithology, drilling rate.
02/07/80	02135	Sperry-Sun, Inc.	Direction survey report WIPP No. 16.
02/11/80	02131	Statler, R.D.	Memo: Logging program for WIPP-16, non-conformance report.
02/14/80	n/a	Tierney, M.S.	Memo: Dissolution notes for breccia pipe formation.
04/01/80	02142	Gard, L.M.	Use of Sandia drilling apparatus in Mississippi Chemical Co. potash mine.
04/09/80	02279	Powers, D.W.	Memo: Statement of work for short, experimental coreholes into breccia pipe from Mississippi Chemical Corporation mine.
04/23/80	02141	Statler, R.D.	Field operations plan: Experimental coreholes into breccia pipe from Mississippi Chemical potash mine.
04/28/80	02950	Fenix & Scisson	Hole history data, WIPP 16.
05/08/80	02903		Record: Breccia pipe horizontal core holes.

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05/15/80	02143	Snyder, R.P.	Memo: Change in plans for the horizontal drilling in Mississippi Chemical Company mine.
05/16/80	07885	Powers, D.W.	Statement of Work: Deepening and testing WIPP 31.
05/20/80	03077	Statler, R.D.	Letter: Application to US Dept. Interior to deepen and test WIPP 31.
05/22/80	03074	Wright/Statler	Letter: Application to, and approval from, State of NM for deepening WIPP 31.
06/23/80	02733	Weart, W.D.	Field operations plan: Site investigations for WIPP-31 re-entry and deepening.
07/02/80	01549	Unterberger, R.R.	Letter: Trip report re underground radar survey.
07/03/80	00291	Seward, P.D.	Memo: Post-drilling report for experimental corehole into breccia pipe from Mississippi Chemical potash mine.
07/25/80	05479	Weart, W.D.	Memo: Supplement #1 to field operations plan for WIPP 31 re-entry.
09/24/80	03905	MORCO	Mud log, WIPP 31, with lithology, drilling rate.
09/24/80	02114	USGS	WIPP 31, neutron log.
09/24/80	01720	USGS	WIPP 31, caliper log.
09/24/80	02892	USGS	WIPP 31, bulk density log.
10/14/80	03079	Fenix & Scisson	Hole History Data [WIPP #31 Recompletion]
02/26/81	00416	Seward, P.D.	Memo: Mine access and operating procedures for Mississippi Chemical potash mine.
08/04/81	01566	Powers, D.W.	Memo: Statement of work for releveling first order baseline.
07/12/82	01551	McGough, J.M.	Letter: Breccia pipes report, Appendix B, stipulated agreement.
07/11/85	05834	Lappin, A.	Memo: Response to NM/EEG (Chaturvedi) comments on the "Bachman" report (SAND84-7178).
09/09/87	n/a	Neill, R.H.	Letter: re DOE-2 evaluation; to J.B. Tillman (DOE).

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