TESTING AND SIGNIFICANCE OF PRESSURIZED FLUID RESERVOIR ENCOUNTERS FOR THE SITE CHARACTERIZATION PROCESS FOR RADIOACTIVE WASTE DISPOSAL FACILITIES

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) project is a U.S. Department of Energy (DOE) research and development activity to demonstrate safe disposal of transuranic (TRU) waste from the nation's defense programs. During the past seven years, an extensive site characterization effort has been conducted in the Los Medanos area of southeastern New Mexico. A portion of the effort addressed the mode of occurrence and origin of flowing artesian brine reservoirs known to exist in the northern Delaware Basin (the WIPP site area). Investigation of these features was performed by comprehensive geological, hydrological and geochemical testing in two DOE boreholes that intersected reservoirs. The testing program plan was found to be a technically sound and cost effective method by which to develop and support hypotheses relative to the characteristics, genesis and history of the reservoirs. Similar testing programs would be applicable to the characterization of similar features at other potential waste disposal sites in bedded salt. The interpretation of the test results indicates that the brine reservoirs in the northern Delaware Basin should have no effect on the integrity of the WIPP facility.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Project is a U.S. Department of Energy (DOE) research and development activity to demonstrate safe disposal of transuranic (TRU) waste from the nation's defense programs. A description of the planned WIPP is given in the WIPP Final Environmental Impact Statement[1] and the WIPP Safety Analysis Report.[2]

The site for the WIPP is located in the Los Medanos area of the northern Delaware Basin, Eddy County, New Mexico (Fig. 1). The Delaware Basin is a structurally downwarped basin of about 31,000 square kilometers that is comprised of about 5500 meters of Paleozoic sediments, 900 meters of which are Permian evaporites. The waste disposal horizon at WIPP will be located in the bedded salt deposits of the Salado Formation, near the middle of the evaporite sequence (Fig. 2). An extensive site characterization effort has spanned the past seven years and has provided a substantial geological data base. Initial site selection and characterization studies revealed the presence of significant geologic structural deformation in the area north and northeast of the site. This deformation is characterized by a series of folded structures including anticlines, synclines and monoclines which are separated by generally horizontal or subhorizontal strata. Drilling in this area by the DOE and hydrocarbon exploration companies resulted in the discovery of several "apparently" isolated and flowing artesian brine reservoirs (Fig. 3). To date, these brine reservoirs have been encountered in regions which exhibit at least minor geologic structure. If such regions exist near other proposed radioactive waste disposal sites in salt, they must be explored fully and understood prior to

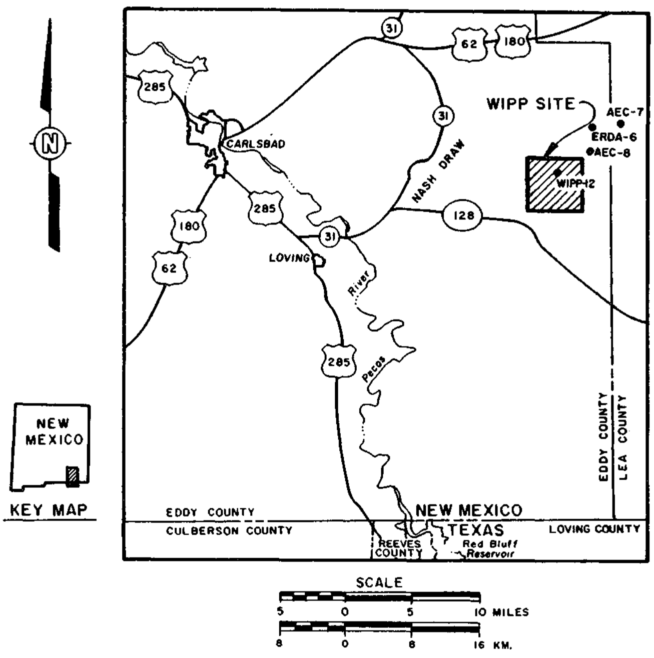
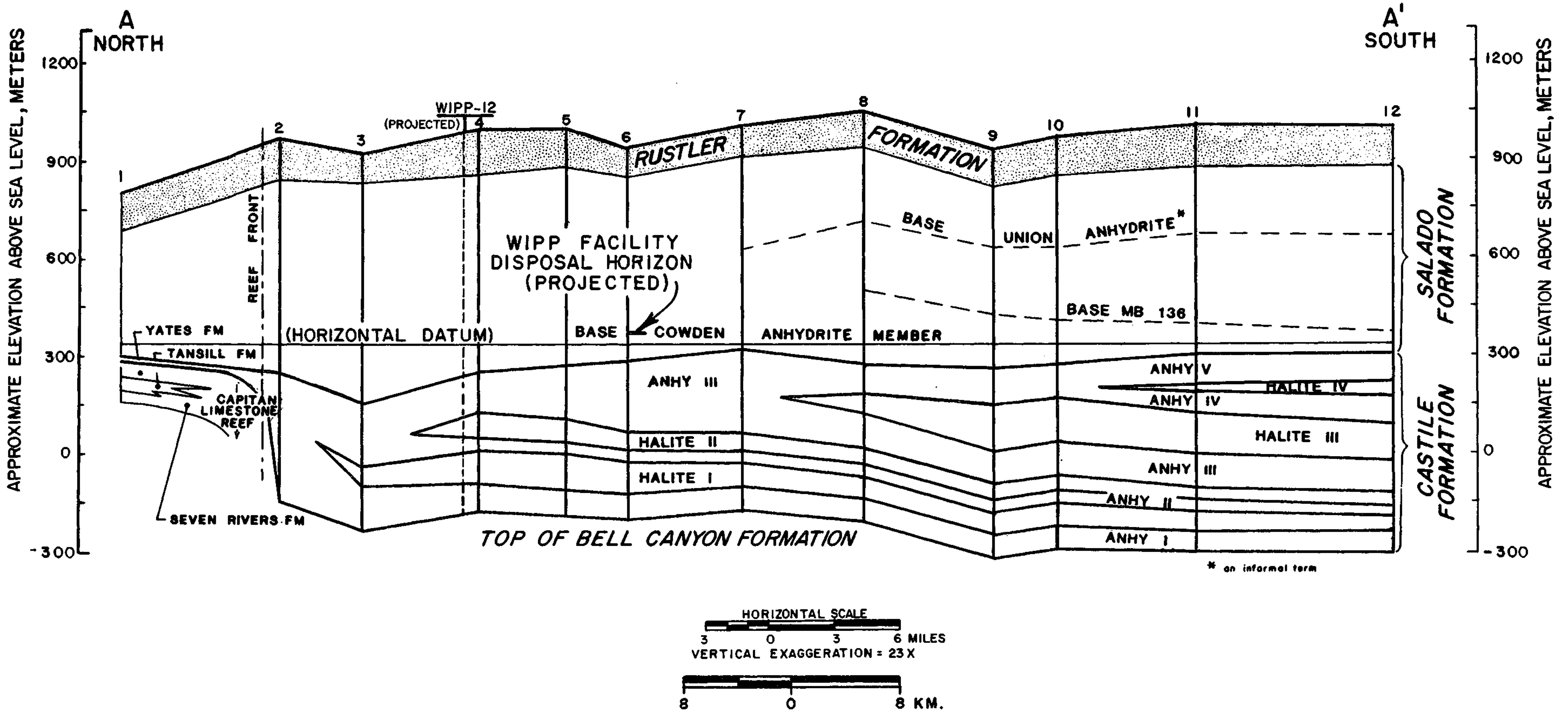
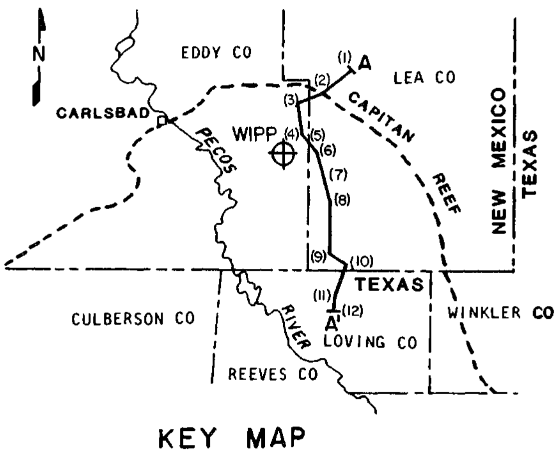


Fig. 1 Location of WIPP Site and Boreholes AEC-7, AEC-8, WIPP-12 and ERDA-6

a decision to construct a disposal facility. Two such brine reservoir encounters, in boreholes ERDA-6 and WIPP-12, were investigated in 1981 and 1982. The results of the data analyses and data interpretation have become available recently and generally demonstrate the effectiveness of the





REFERENCE:

BACHMAN, 1980, USGS OPEN FILE 80-1099

Fig. 2 Simplified Geologic Cross Section of Ochoa Series Northeastern Delaware Basin testing[3] and investigative methods employed. The testing techniques and data gathering activities that were undertaken are applicable to site characterization activities for any proposed radioactive waste disposal facility in salt or other low permeability medium that has the potential to contain fluid at pressures sufficient to force the fluid to the surface upon establishment of a conduit.

DESCRIPTION OF BRINE RESERVOIRS

The occurrence of the two reservoirs intersected by boreholes ERDA-6 and WIPP-12 is not unique; about ten hydrocarbon exploration boreholes (out of hundreds drilled during the past 40 years) have encountered similar features in the northern Delaware Basin (Fig. 3). Since site characterization began, the mode of occurrence and genesis of these reservoirs has been of considerable interest. The most recent (1981) of the two DOE encounters was by a borehole (WIPP-12) located about one mile north of the center of the WIPP site. The brine inflow zone was at a depth of about 920 meters in a thick, fractured anhydrite bed (Anhydrite III) of the Castile Formation (which underlies the Salado). This reservoir is associated with a mild anticline in the Castile (Fig. 4). The earlier (1976) DOE borehole (ERDA-6) intersecting a brine reservoir is located about five miles northeast of the site center. The brine inflow zone in this well was at a depth of about 825 meters in an apparently different (than WIPP-12), thick, fractured anhydrite bed (Anhydrite II) of the Castile Formation[4]. This reservoir is associated with an intensely deformed area in the evaporite section (Fig. 4). After intersection of the reservoirs by the boreholes, brine and associated gas flowed to the surface.

The detailed characteristics of reservoirs intersected by hydrocarbon exploration boreholes drilled by commercial exploration firms are not available because testing in these holes was not possible. These reservoirs are expected to be very similar to those tested, however, as all known reservoirs occur at similar stratigraphic horizons (near the base of fractured anhydrite beds in the Castile) and all are associated with similar geologic structural features. Thus, it is thought that the results of the investigation of the reservoirs intersected by ERDA-6 and WIPP-12 could be used to infer the mode of occurrence and genesis of all brine reservoirs in the Delaware Basin.

TESTING PROGRAM FOR BRINE RESERVOIRS

The presence of pressurized reservoirs in the basin raises concerns relative to their potential impact on the integrity of the WIPP facility. Thus, the reservoir testing program was undertaken to determine, to the extent possible, the characteristics of the reservoirs that could have bearing on their potential site impact. These characteristics include the relationship of reservoir occurrence to observable subsurface geology, the degree of reservoir isolation, the general reservoir hydraulic properties, and the composition of the fluids. Determination of these properties, when combined with the geologic and hydrologic data collected during other site characterization activities, provides sufficient information to develop reasonable substantiation for an hypothesis to explain the origin of the reservoir and reservoir fluids. Such an hypothesis allows a reasonable degree of certainty in predicting where such reservoirs might be encountered and whether the processes that led to reservoir formation are on-going or essentially static. Determination of the degree of maturity of the reservoirs is of concern because if they are manifestations of on-going geologic processes, the stability of site could be in doubt.

Consideration of the informational goals and investigative objectives discussed above led to the development of a multifaceted testing program designed to obtain the maximum hydrological and geological data and best geochemical samples in the most cost effective manner. The following paragraphs describe the testing and analyses performed to determine each of the salient characteristics of brine reservoirs and their origin.

Relationship Between Reservoirs and Geology

Whether or not brine reservoirs are closely related to observable (by geophysical techniques or stratigraphic correlations of borehole data) geologic features and the nature of any such relationship is a significant determination relative to predicting where reservoirs might occur. Also, such a determination provides valuable insight into the processes that lead to reservoir creation. On a smaller scale, the characteristics of the brine producing horizon as well as the properties of the rock immediately above and below the producing horizon are important data in discovering the nature and mode of occurrence of reservoirs.

To investigate the relationship of large-scale geologic features to the occurrence of brine reservoirs, data were compiled from earlier WIPP site characterization studies and hydrocarbon companies' exploration records (generally those available to the public). These data consist primarily of the results of seismic reflection studies, drilling records and geophysical logs. From these data, the structural framework of the northern Delaware Basin was constructed and compared to the locations of known brine reservoir occurrences. Additionally, the stratigraphic horizon known to produce brine in each well was determined from examination of geophysical logs.

The detailed characteristics of the reservoir rock were determined at ERDA-6 and WIPP-12 by obtaining conventional 10 cm (nominal) or 7.3 cm (nominal) rock core through the producing zones in each well. Core was obtained from the entire thickness of the Castile Formation at WIPP-12 to permit examination of the rock underlying the reservoir. Examination of rock underlying the reservoir zone was important to a determination of the deformational style exhibited by strata forming the anticline at WIPP-12. To aid in this determination, oriented core was obtained from horizons that were most likely to provide the best graphical representation of small-scale deformational features.

A complete suite of geophysical logs was run in both wells to allow depth correction of core data. Additionally, a U.S. Geological Survey televiewer log was run in WIPP-12 to provide information on fracture orientation and location at the borehole surface.

Degree of Reservoir Isolation

Whether reservoirs represent isolated features with definable boundaries or whether they are connected to one another, comprising a regional brine aquifer, or are connected to area aquifers are important considerations in surmising their potential affect on any proposed disposal site. If multiple reservoir encounters are actually one regional brine aquifer or are one large reservoir, they could provide a pathway for emigration or transport of radionuclides from a facility to the biosphere. If reservoirs are connected to local ground water systems, similar pathways would exist. Further, interconnection of brine reservoirs and aquifers could lead to enlargement of the reservoir system since the local aquifers would contain fluids undersaturated with respect to reservoir rock constituents.

Investigation of the degree of reservoir isolation at the WIPP Site was pursued primarily by hydrological testing and analysis though additional information was obtained from geological and chemical data. First, the hydraulic heads of the reservoirs intercepted by the ERDA-6 and WIPP-12 boreholes were measured under static, shut-in conditions by downhole instrumentation. These data were compared to information gleaned from hydrocarbon exploration drilling records (for those wells that intersected brine reservoirs) and to data available for aquifers in the region. Second, downhole pressure monitoring instrumentation was installed in a third well (AEC-7) that may have intersected a brine reservoir. While testing was performed in ERDA-6, the pressures at WIPP-12 and AEC-7 were monitored; while testing was conducted in WIPP-12, pressure was monitored at the other two wells.

Geological data from the many boreholes not encountering brine indicate that anhydrite beds in the Castile Formation are generally fractured, suggesting that a regional brine aquifer or reservoir does not exist. Chemical data were obtained from samples collected from the reservoirs intercepted by ERDA-6 and WIPP-12 (see later section) and were compared to determine if compositional differences exist between reservoirs that would suggest a lack of communication.

Reservoir Hydraulic Properties

A precise determination of the hydraulic properties of the reservoirs is not essential to evaluation of the effect that reservoirs might have on the WIPP facility. Certain reservoir characteristics, however, such as volume, driving mechanism and permeability are of interest in the development of a model of the reservoirs.

Hydrological testing of the reservoirs intercepted by the ERDA-6 and WIPP-12 boreholes consisted of a series of drillstem tests (DSTs) and flow depletion/pressure build-up tests. DST's provided an initial set of data on the permeability and volume of the reservoirs. These preliminary data provided guidance in development of plans for more extensive testing. It was determined that from an overall programmatic viewpoint the most useful hydrological testing technique would be long-term flow testing. Long-term flow testing (flow periods of a few days) was conducted by allowing the reservoir fluids to flow through the open wellbore to the surface. After the reservoir brine and gas reached the surface, it flowed through a series of flow meters and flow lines equipped with ports to allow samples to be collected (Fig. 5). A gas/liquid separator was installed near the end of the flow line to allow collection of gas samples and measurement of the gas/liquid ratio of the *discharged fluid*. At WIPP-12 difficulties were encountered during flow periods by precipitated salt plugging the flow lines and meters. As a result, a similarly equipped flow line was placed in parallel to the first line and the flow was diverted to the open line while the plugged line was flushed. After the well had been allowed to flow for a few days with accurate measurements of total flow volume and flow rates obtained, the well was shut-in and pressure recovery was measured. Pressure recovery was measured initially by downhole pressure transducers, placed adjacent to the producing zone. Pressure measurements were recorded at the surface onto magnetic tape and plotted by a desk-top computer system. After the period of rapid pressure recovery had passed (in about 30 days) the downhole instrumentation was removed from the well (due to the large expenditure and extensive maintenance requirements of the system) and replaced by a simple, high-precision, dial-type pressure gage and mechanical recorder at the surface. This gage was manually read at least once a day and the measurement recorded. The reliability of all instrumentation and flow lines was adversely affected throughout the tests by the high percentage of H_2S gas associated with the reservoir brine.

Knowledge of the rate of flow and the rate of pressure recovery with respect to duration of flow or time since the well was shut-in, respectively, allows a reservoir model to be developed and supported. The amount of pressure depletion resulting from removal of a known volume of fluid from the reservoir is indicative of the reservoir's total drainable volume.

Composition of Reservoir Fluids

Determination of the chemical and isotopic composition of the reservoir brine, gas and rock is essential to an understanding of the reservoir system. These data also form the basis for development and support of a hypotheses for the origin and history of the reservoir fluids. The potential for the reservoir to expand by dissolution and the degree of connectivity of reservoirs to other reservoirs or to local aquifers (see earlier section) can also be addressed by examination and analysis of the chemical data.

A fluid sampling program was developed to obtain a full suite of brine and gas samples collected in a manner appropriate for the analysis to be performed. To allow samples to be collected under various conditions (under pressure, under no pressure, mixture of liquid and associated gas, etc.) and at various times during flow periods, a series of sampling ports were installed in the flow line (Fig. 5). The ports were designed to be compatible with the sampling containers appropriate for each type of sample.

Before samples were collected for laboratory analyses, it was necessary to determine that contaminants (such as drilling fluid) were flushed from the well. This evaluation was performed by analysis or measurement of certain key parameters (Table I). When the measured values for these parameters stabilized, it was assumed that samples collected at the surface were representative of reservoir fluids. These analyses were performed in an on-site geochemical laboratory set-up at each well for this purpose. The on-site laboratory also provided facilities to analyze samples for parameters that would be affected by storage or transportation (Table I).

After the brine samples were collected, they were analyzed for a full suite of major and minor elements and the stable isotopic composition of the

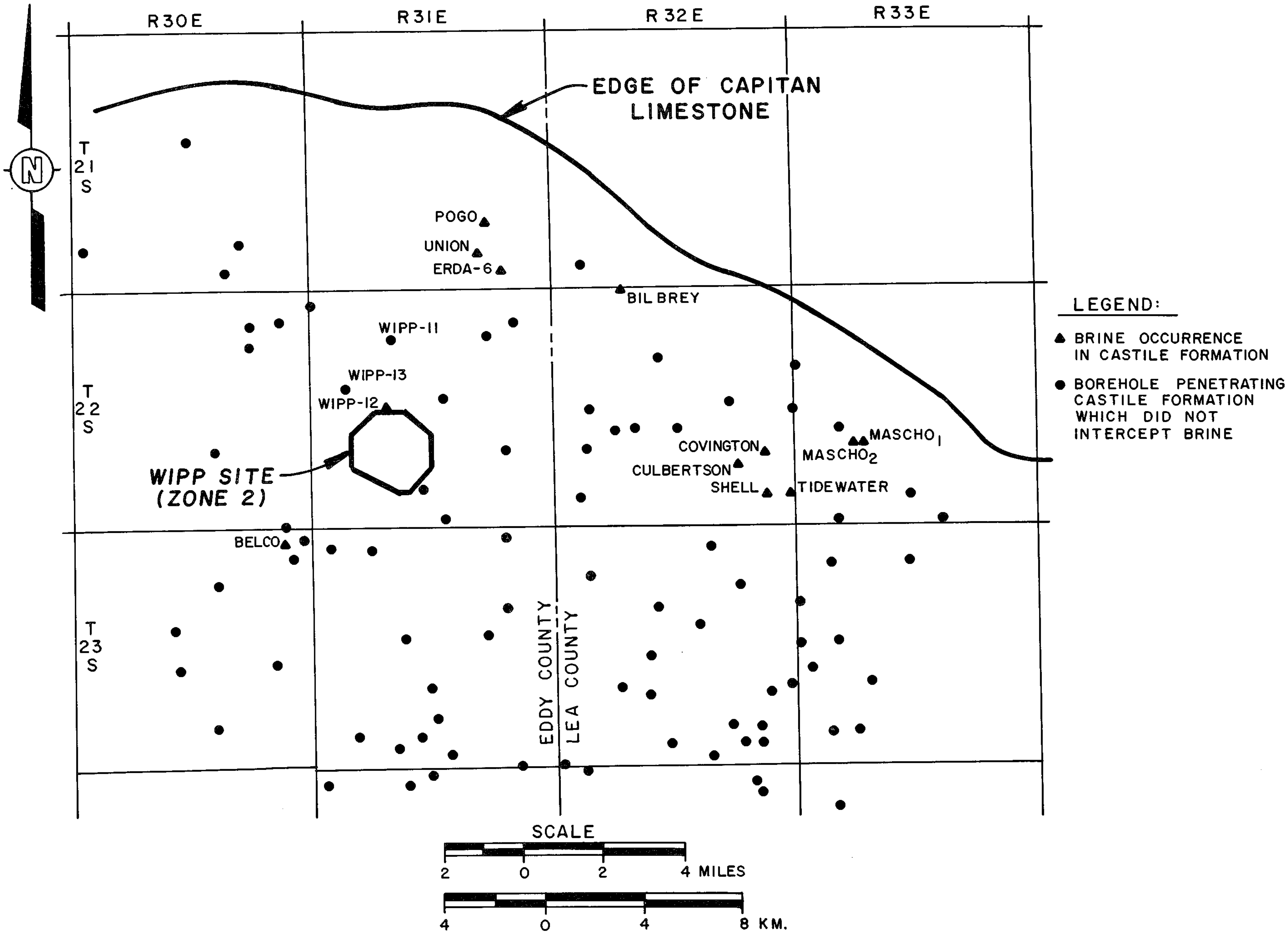


Fig. 3 Wells Drilled Through the Castile Formation Showing Brine Reservoir Occurrences

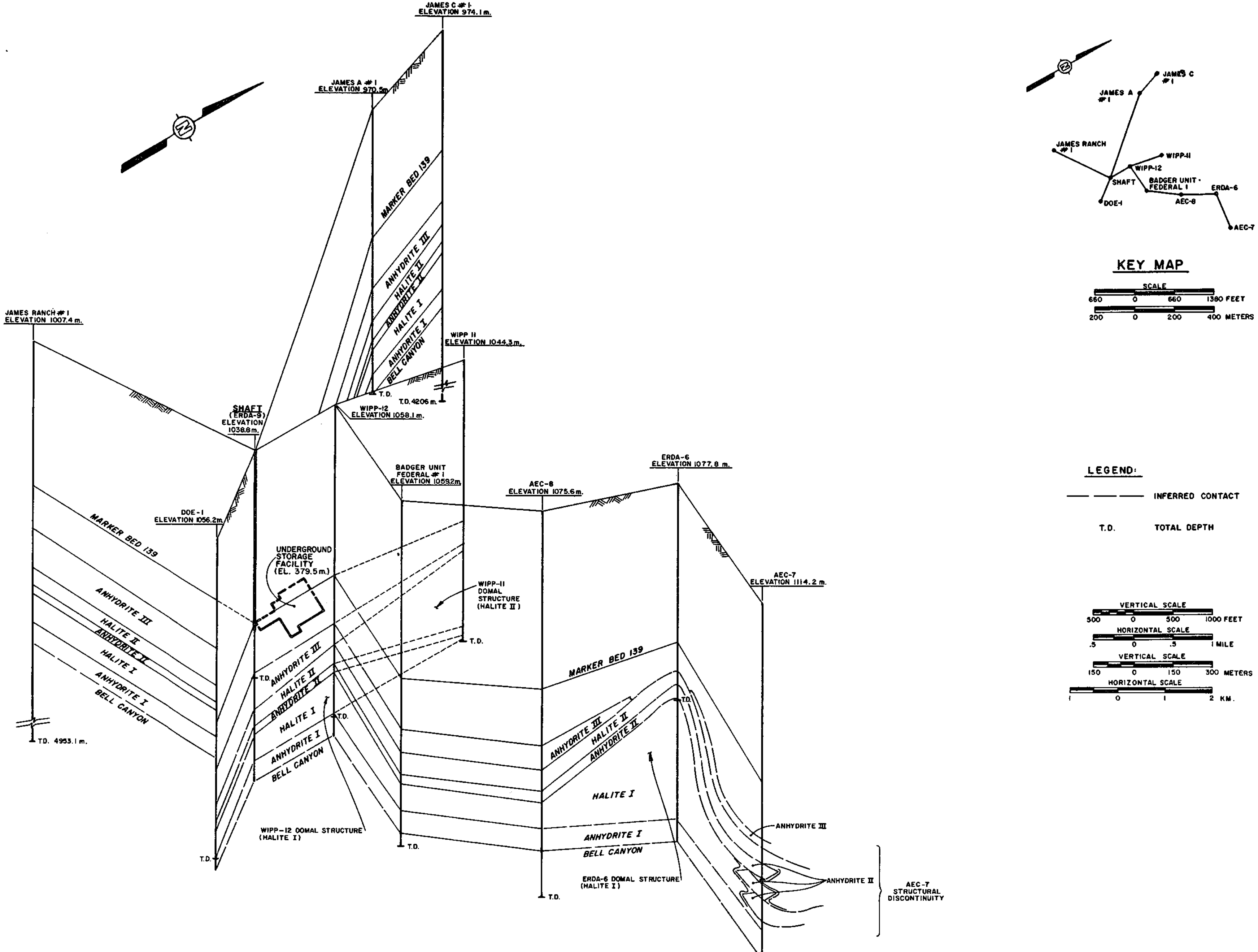


Fig. 4 Fence Diagram of the Geology of WIPP Site Vicinity

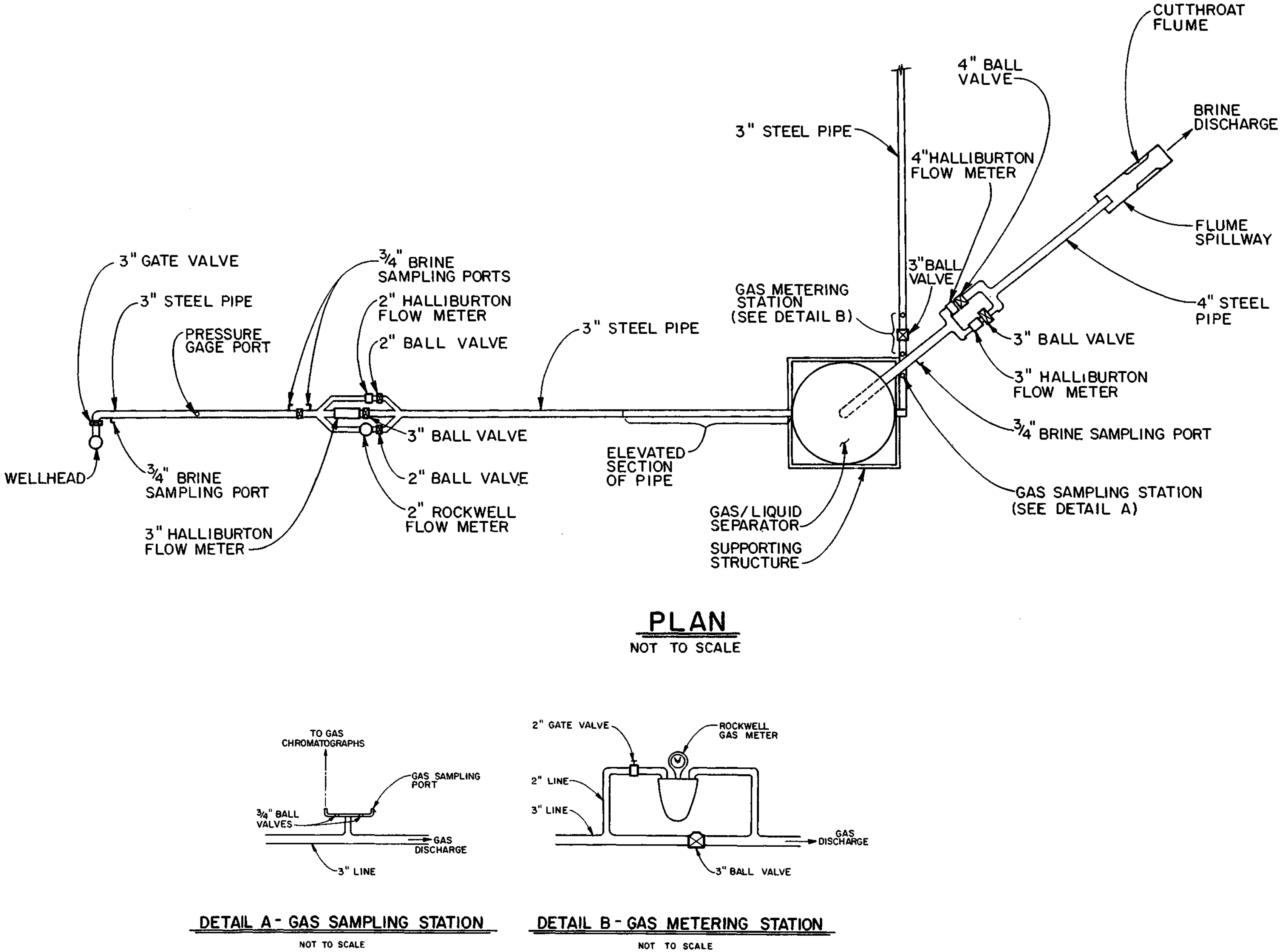


Fig. 5 Diagram of Instrumentation For Flow and Pressure Monitoring

TABLE I
SUMMARY OF ELEMENTAL AND PARAMETRIC ANALYSES PERFORMED ON BRINE SAMPLES

Field Determinations

Temperature	Hydroxide
pH	Chloride
Eh	Sulfate
Specific Gravity	Total Hardness
Specific Conductance	Total Iron
Alkalinity	Hydrogen Sulfide
Carbonate	

Laboratory Determinations

Total Dissolved Solids	Bromide
Total Suspended Solids	Chloride
Barium	Fluoride
Calcium	Iodide
Cesium	Ammonia
Lithium	Nitrate
Magnesium	Phosphate
Potassium	Aluminum
Sodium	Boron
Strontium	Copper
Manganese	Iron
Silica	Zinc

water and some of the solutes. Gas samples were analyzed to determine their composition and stable isotopic make-up. Samples consisting of both gas and liquid (collected under pressure) were analyzed to determine approximate values for the gas/liquid ratio in the reservoir. In addition, mineral separates from samples of rock core obtained from the reservoir rock were analyzed for their stable isotopic composition (Tables I, II and III).

TABLE II
SUMMARY OF STABLE ISOTOPIC ANALYSES PERFORMED ON BRINE, GAS AND MINERAL SAMPLES

Parameter	Components Analyzed
D	H_2O in brine; CH_4 and H_2S in gas.
^{13}C	CO^{2-} in brine; CO^{2-} in calcite and dolomite from reservoir rock; CO_2 and CH_4 in gas.
^{18}O	H_2O and CO^{2-} in brine; CO^{2-} in calcite and dolomite from reservoir rock; CO_2 in gas.
^{34}S	SO^{2-} in brine; SO^{2-} in anhydrite from reservoir rock; H_2S in gas.

TABLE III
SUMMARY OF GASES ANALYZED IN GAS SAMPLES

Hydrogen Sulfide	Iso-Pentane
Nitrogen	N-Pentane
Carbon Dioxide	Hexane (and higher molecular weight hydrocarbons)
Methane	
Ethane	
Propane	Oxygen
Iso-Butane	Argon
N-Butane	

In addition to the sampling and analysis program, the composition of gases associated with the brine was monitored on a nearly continuous basis during reservoir flow periods by on-site instrumentation (Table IV). Upon completion of the laboratory and field studies, the data were evaluated using standard geochemical techniques for comparison of possible hypotheses and the data. These included comparisons of major and minor elements (see Figure 6 for a typical evaluation) and isotopic composition.

TABLE IV
SUMMARY OF GASES ANALYZED ON A NEARLY CONTINUOUS BASIS DURING BRINE FLOW

Hydrogen Sulfide	Methane
Nitrogen	Ethane
Carbon Dioxide	

SUMMARY AND CONCLUSIONS

The characteristics and origin of the brine reservoirs in the northern Delaware Basin were investigated using geologic, hydrologic and chemical testing techniques. The testing techniques provided a data base sufficient to develop and support a model of the reservoir origin and history (Table V). The same types of testing could be utilized in other areas to investigate flowing artesian reservoirs or aquifers.

The interpretation of data collected by testing at ERDA-6 and WIPP-12 is the subject of a report[3] scheduled for completion in the near future. Using the techniques described in this paper, it has been shown that the brine reservoirs encountered near the proposed WIPP facility are isolated, stagnant systems which are currently in equilibrium with their host rock. Therefore, no credible natural mechanisms exist at this time to provide a connection between the reservoirs, the future storage horizon and the biosphere. For these reasons, it has been determined that the pressurized fluid encounters in the Castile Formation, of the type recently studied, do not present a threat to the integrity of the WIPP Site.

REFERENCES

1. U.S. Department of Energy, 1980, Waste Isolation Pilot Plant Final Environmental Impact Statement, DOE/EIS-0026.

2. U.S. Department of Energy, 1980, Waste Isolation Pilot Plant Safety Analysis Report (as amended in January, 1983).

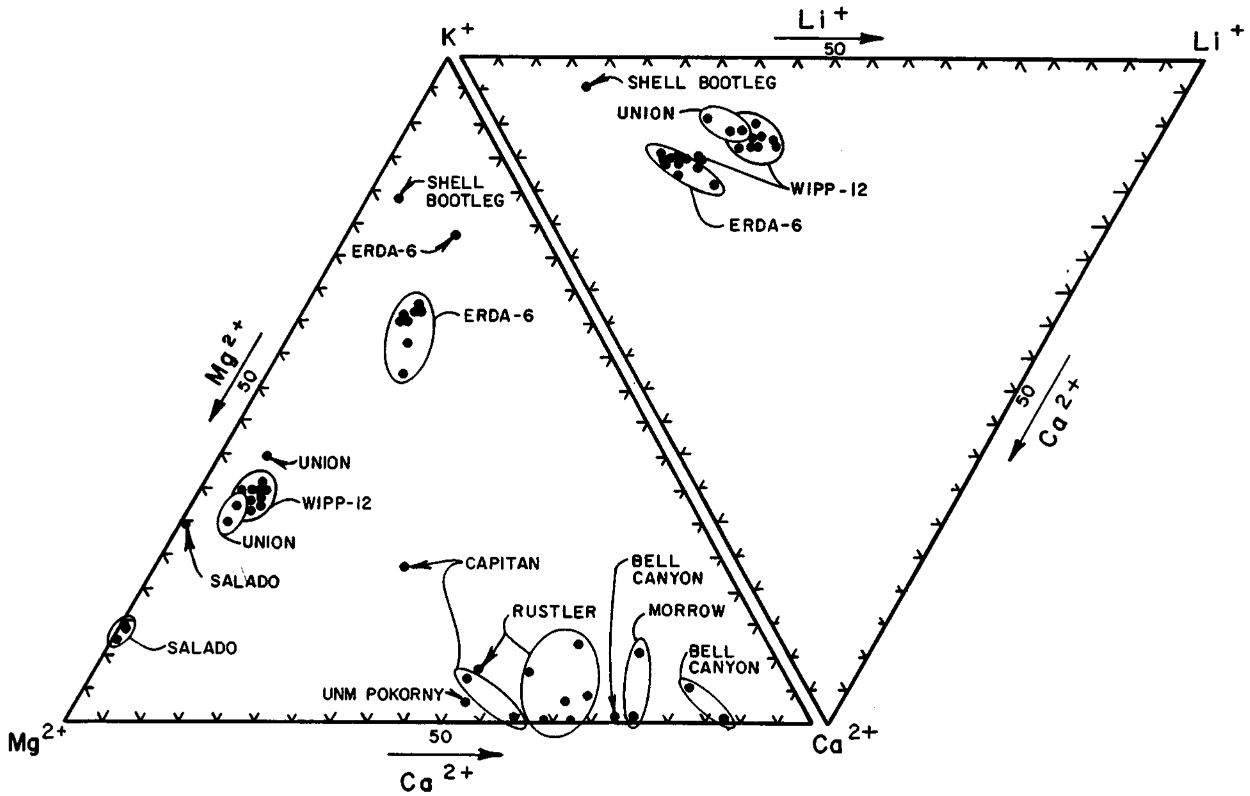
3. R. S. Popielak, R. L. Beauheim, S. R. Black, W. E. Coons, C. T. Ellingson, and R. L. Olsen, in preparation, Brine Reservoirs in the Castile Formation, Southeastern New Mexico, TME 3153, prepared for the U.S. Department of Energy.

4. C. L. Jones, 1981, Geologic Data for Borehole ERDA-6, Eddy County, New Mexico, U.S. Geological Survey Open-File Report 81-468.

TABLE V
CORRESPONDENCE BETWEEN CHEMICAL DATA AND HYPOTHETICAL ORIGINS FOR BRINE RESERVOIRS NEAR WIPP

Origin	Major/Minor Element Chemistry	Water Isotopes	Other Isotopes	Trace Elements Chemistry	Physical Evidence
1. Meteoric Water	No	No	No	No	Yes
2. Waters of Dehydration	No	Maybe	Maybe	No	Maybe
3. Ancient Seawater	Yes	Yes	Yes	Yes	Yes
4. Mixture of Current Meteoric Water and Seawater	No	Maybe	No	Yes	Yes
5. Mixture of Ancient Low-TDS Meteoric Water and Seawater	Yes	Yes	Yes	Yes	Yes
6. Mixtures of Dehydration Waters and Seawater	Yes	Yes	Yes	Yes	Maybe

"No" indicates data do not support hypothesis.
"Yes" indicates data do support hypothesis.
"Maybe" indicates data may or may not support hypothesis.



NOTES:

1. CASTILE WELLS = ERDA-6, WIPP-12, UNION, SHELL BOOTLEG AND UNM POKORNY.
2. NUMBERS EXPRESSED IN RELATIVE PERCENT EQUIVALENTS.

Fig. 6 Typical Comparison of ERDA-6 and WIPP-12 Brines with Regional Ground Waters