RECENT DEVELOPMENTS IN THE CONCEPTUAL GEOLOGIC AND HYDROLOGIC UNDERSTANDING OF THE WIPP SITE, SOUTHEASTERN NEW MEXICO

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ABSTRACT

Hydrologic and geochemical characterization of the WIPP site has progressed significantly since the 1980 WIPP Final Environmental Impact Statement. In 1980, the entire Rustler Formation was modeled as a single hydrologic unit, assumed to be isotropic, single-porosity, and completely confined. Variability within the Rustler was evaluated only on the basis of testing at individual wells. In the 1983 WIPP Site and Preliminary Design Validation effort, the Salado Formation, in which the WIPP facility is being constructed, was assumed to be anhydrous, except for fluid inclusions and mineralogically bound water.

Recent hydrologic and tracer testing at the WIPP indicates: 1) The local importance of dual-porosity behavior in hydraulic response and transport in parts of the Culebra Dolomite Member of the Rustler Formation; 2) the presence of distinct high- and low-transmissivity regions within the Culebra; and 3) the possible importance of vertical fluid flow within the Rustler. Recent analyses indicate that fluids encountered in the WIPP facility and in experimental brine-migration studies are grain-boundary fluids, chemically distinct from fluid inclusions. Fluid-inclination compositions appear to have been determined shortly after the halite deposition. Because of the times required for diagenetic reactions controlling their compositions, the grain-boundary fluids within the Salado probably have a residence time of several million years.

INTRODUCTION

Site-characterization activities at the WIPP site in southeastern New Mexico began in 1976, with the drilling of hole ERDA-9 (Fig. 1). The WIPP facility is being constructed at a depth of 650 m in the layered impure halites and anhydrite "marker beds" of the Salado Formation of Permian (Ochoan) age. The Salado Formation is conformably overlain by the Rustler Formation, also of the Ochoan age. The Culebra and Magenta Members of the Rustler consist largely of gypsiferous dolomite, and are the main water-bearing units of interest at the WIPP, though neither unit contains potable water at the site proper. Where evaporite dissolution is minimal, the Magenta, and Culebra Members are separated and bounded by three members of mixed anhydrite/gypsum, siltstone, and halite.

Hydrologic and transport modeling studies of the Rustler Formation at WIPP were part of the 1980 WIPP Final Environmental Impact Statement (FEIS) (1) and the 1983 Site and Preliminary Design Validation (SPDV) (2, 3).

In the FEIS, the entire Rustler Formation was modeled as a single isotropic, completely confined hydrologic unit. A transmissivity of approximately 4.3×10^{-5} m^2/sec was assigned in regions outside Nash Draw, a solution valley west of the WIPP site. Within Nash Draw, a transmissivity of approximately 1.7×10^{-4} m^2/sec was assigned. In modeling conducted as part of the SPDV studies (2), the Culebra and Magenta Members were modeled as separate, completely confined, anisotropic units. Local transmissivities ranging from 6.5×10^{-10} m^2/sec east of the WIPP site to 6.7×10^{-4} m^2/sec within Nash Draw were assigned on the basis of individual well tests. A uniform matrix porosity of 0.10 was assumed in both the FEIS and SPDV documents.

It was assumed in the SPDV documentation (3) that brine present within the Salado Formation was either bound up in minerals or was present as fluid inclusions. It was thus effectively assumed that any fluids encountered in the WIPP facility would be the result of transient migration along thermal gradients or facility-induced stress gradients.

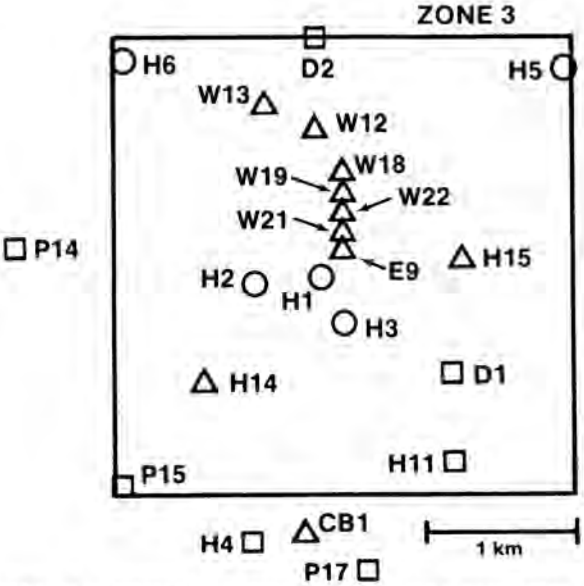


Fig. 1. Hydrologic test holes in and near WIPP Zone 3; ○ available for H-3 test; △ new since April, 1986; □ revised since April, 1986.

The major objectives of this paper are to: 1) Summarize the results of recent hydrologic and geochemical studies at the WIPP; and 2) describe the effects of these studies on the overall hydrologic and geochemical understanding of the Rustler and Salado Formations at the WIPP site.

RECENT STUDIES

Southern Multipad Interference Test

A regional interference test of the Culebra dolomite was recently conducted at the H-3 hydropad (Fig. 1), with the objective of directly estimating the regional distribution of Culebra transmissivities over the southern portion of the WIPP site. The pumping phase of this test extended from October 15, 1985 to December 16, 1985; monitoring of recovery continued until April 12, 1986. Ten wells around the H-3 pad were monitored during the test.

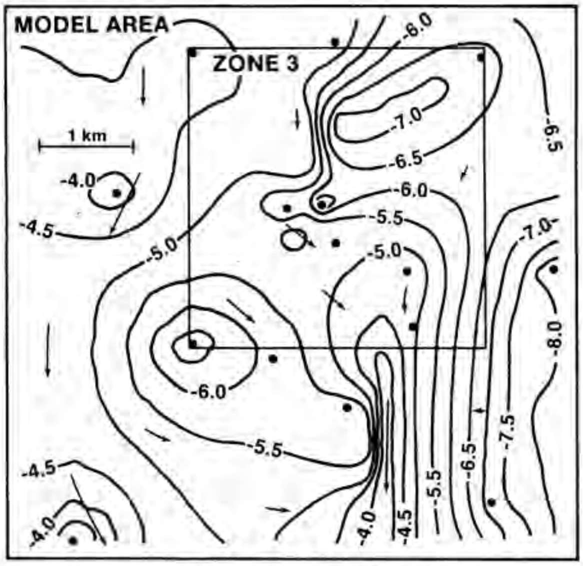
The H-3 pad contains three wells, spaced at the corners of an equilateral triangle nominally 30.5 m on a side. Observation holes H-3b1 and H-3b3 responded within 5 seconds to the beginning of pumping of H-3b2. In fact, it was necessary to interpret these wells as part of the pumped well (4), which thus had an effective hydraulic radius of greater than 30.5 m. The response in the observation holes indicates the importance of dual-porosity hydraulic behavior on the scale of the H-3 hydropad. At early times, almost all of the fluid was derived from fractures; at later times, fluid was derived from both fractures and the porous dolomitic matrix. There was no evidence of significant anisotrophy in the hydraulic response on the H-3 pad.

The system transmissivity at H-3, based on interpretation of the long-term test, is near 2 x 10^{-6} m^2/sec (4). Thus, while there is effective interconnection of the holes on the H-3 pad by fracturing, the overall system transmissivity is relatively low.

Detailed interpretation of conservative-tracer tests operated at the H-3 and H-4 pads has recently been completed (5). The results indicate an effective fracture porosity of approximately 0.002 on the H-3 pad. However, tracer behavior was strongly inhomogeneous, in contrast to the hydraulic response on the pad. The trace behavior at H-3 indicates a strong interaction between fractures and matrix. Measured matrix porosities at the H-3 pad range from 0.07 to 0.30 (5).

During the H-3 multipad test, the responses of observation wells off the H-3 pad varied strongly as a function of both distance and direction (4). Rapid responses at the H-11 hydropad and at well DOE-1 indicate that these locations are well-connected with H-3. This connection is probably by a structure involving fracturing, since both H-11 and DOE-1 responded within three days to the beginning of pumping. In contrast, wells to the north, northwest, and southwest of H-3, either responded quite slowly to pumping (H-1 and H-2) or did not respond at all (H-4), indicating the presence of low-transmissivity domains in these directions.

Numerical modeling of the regional hydraulic behavior of the Culebra, using the code SWIFT II and including the response to the southern multipad interference test, results in the transmissivity distribution shown in Fig. 2 (6). The transmissivity *distribution shown* results from application of kriging techniques to individual measured Culebra transmissivities available as of April 1986 and regional calibration against both the "undisturbed"



UNITS: LOG m^2/s; • DATA POINT; CONTOUR INTERVAL: 0.5 UNITS

Fig. 2. Regional distribution of Culebra transmissivities, based on data available April 1986 (6).

(pre-shaft) head distribution at the WIPP and the present-day distribution of brine densities.

There are four main features discernible in Fig. 2. First, the relatively high-transmissivity zone including H-11 and DOE-1 is shown to extend to the south, beyond the WIPP control zone (Zone 3). Second, a relatively large area of the site, including holes H-1, H-2, WIPP-12, and H-5, and extending eastwards, has a relatively low transmissivity (less than approximately 1 x 10^{-6} m^2/sec). Third, separate zones of relatively high and low transmissivity are indicated in the regions of holes DOE-2 - H-6, and P-15 - H-4, respectively. Finally, fluid flow within the Culebra in and near Zone 3 is directly or indirectly focused toward the high-transmissivity zone to the south. Flow from east of DOE-1 is essentially westward toward the transmissive zone. Flow over much of the western portion of the site is largely towards the south, but becomes more easterly in the southern portion of the modeled area, eventually entering the high-transmissivity zone.

Use of the transmissivity distribution shown in Fig. 2 results in a good match between calculated and measured freshwater heads prior to excavation of the WIPP shafts, as shown in Fig. 3. The match is accurate to within +/- 1 m, except for a difference of + 1.1 m at H-11 and - 1.1 m at P-17. This same distribution successfully reproduces the drawdowns resulting from drilling of the WIPP shafts.

However, responses to the H-3 multipad test were too great at H-1, H-2, WIPP-21, and WIPP-22 to be modeled successfully using the transmissivity distribution shown in Fig. 2. The postulated cause of this discrepancy is a transient increase in leakage into the WIPP shafts during the test.

The density of Culebra brines varies considerably at and near the WIPP site (Fig. 4). Where the Rustler is entirely devoid of halite, Culebra fluids are generally quite low in density. Increasing fluid density correlates with increasing abundance of halite within the Rustler. However, the fluid density at H-6 (1.04 g/cm3) violates this trend, since halite is totally absent from the Rustler at this location.

The steady-state distribution of brine densities has been simulated using the variable-brine-density option of SWIFT II and the transmissivity distribution shown in Fig. 2 (6). It was initially assumed that there was no internal reaction (dissolution) within the Rustler and no movement of fluids across the boundaries of the Culebra.

The agreement between calculated and observed brine densities is satisfactory over much of the site area, i.e. to within +/- 0.01 g/cm3. However, calculated densities are too high over much of the western portion of the model area, due to the relatively high density at H-6 and along the northern boundary of the model, combined with the general southerly flow in this area. In the vicinity of hole P-17, calculated densities are significantly low.

Hole H-6 has been repeatedly sampled, and the brine density is quite stable. Therefore, it appears unlikely that the reported density is significantly in error. Rather, it appears that either dense brine is being locally added to the Culebra at H-6 from below, that the assumption of steady-state fluid flow is invalid on the time scale required for fluid movement across the modeled area, or that low-density fluids are being added to the Culebra from the overlying Magenta Member south of H-6. In this region, though the data are sparse, it is known that Magenta brines are less dense than Culebra brines, and that the Magenta head is the same or greater than that within the Culebra

Recent results at hole H-14 indicate that the Magenta head is greater than that of both the underlying Culebra and the overlying anhydritic Forty-Niner Member, and that the Dewey Lake Red Beds are unsaturated at this locality (7). Thus, while fluids may be moving from the Magenta to the Culebra in this area, the Rustler Formation itself is not being recharged.

Ongoing isotopic studies are consistent with the interpretation that there is little or no recharge of modern meteoric waters to the Rustler at the WIPP Site (8, 9).

At hole P-17, calculated brine densities are significantly low. In this area, halite is present below the Culebra. A very small vertical flux from the unnamed member of the Rustler or the Rustler/Salado contact would increase the density of the Culebra brine sufficiently at P-17. Though the Rustler/Salado transmissivity is very low at P-17, this movement is consistent with the known head distribution (6).

Single-Hole Hydraulic Testing

At the time of the WIPP FEIS, the major location for considering contaminant transport was at Malaga Bend, considered a point of potential discharge from the WIPP site. The Environmental Protection Agency's (EPA) 1985 criteria for repository performance (40CFR191) place increased emphasis on transport within the controlled zone of the WIPP site itself, indicated as Zone 3 in Fig. 1. In response to the increasing emphasis on near-site properties, the Culebra was tested in several individual holes in and near Zone 3 during late FY86 and early FY87. The locations of recently tested holes are included in Fig. 1; recently determined transmissivities are listed in Table I (7).

In some holes, the more recent properties are different than those available as of April 1986. For example, hole DOE-2, which was shown by previous testing to be very badly "damaged" (10), was treated with hydrochloric acid, eliminating the near-well damage and allowing a better estimate of the effective transmissivity. The recent results indicate increased size of the high-transmissivity zone in the region H-6 - DOE-2 - WIPP-13. In addition, detailed interpretation of test results at DOE-1 indicates that the transmissivity at this well is somewhat lower than that used in modeling of the H-3 multipad test. As shown in Table I, however, the other holes recently tested have relatively low transmissivities, less than 1 x 10^{-6} m^2/sec.

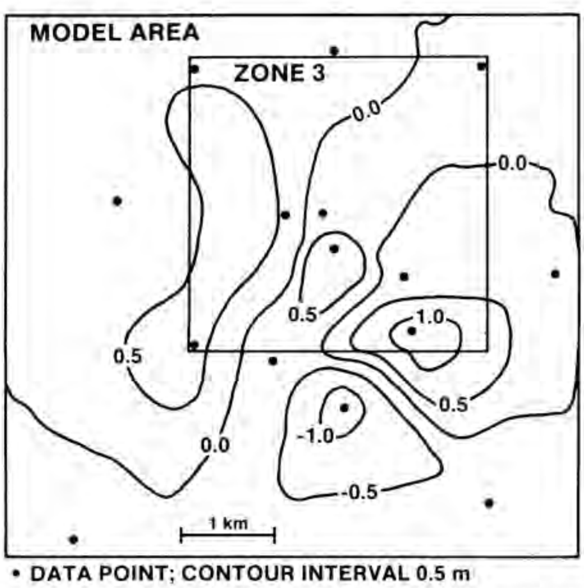


Fig. 3. Difference between modeled and measured preshaft Culebra heads (6).

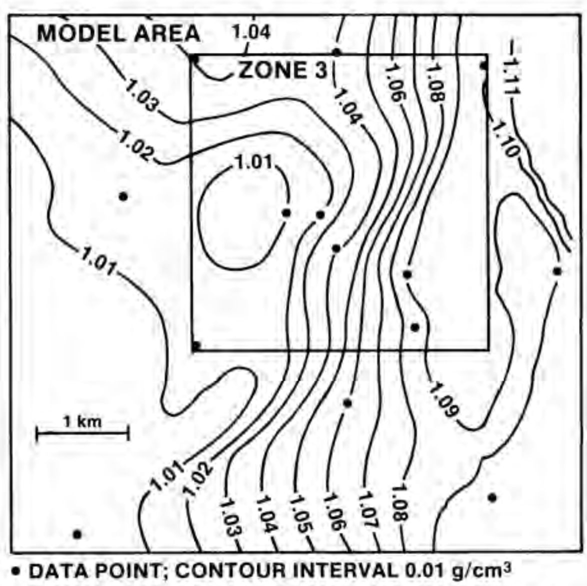


Fig. 4. Measured Culebra brine densities in and near WIPP Zone 3 (6).

TABLE I

Culebra Transmissivities
Determined Since April 1986 (7)

Hole	Transmissivity (m^2/sec)
WIPP-18	3.2×10^{-7}
WIPP-19	6.5×10^{-7}
WIPP-21	2.7×10^{-7}
WIPP-22	4.0×10^{-7}
ERDA-9	5.0×10^{-7}
H-4c	7.0×10^{-7}
P-17	1.1×10^{-7}
H-14	3.2×10^{-7}
H-15	1.1×10^{-7}
DOE-2	9.7×10^{-7}
WIPP-13	4.3×10^{-7}
DOE-1	1.2×10^{-7}

The recently determined or revised transmissivities, when added to the data that formed the basis of Fig. 2, will have four major impacts on the regional interpretation of Culebra properties. First, the Culebra data base in and near Zone 3 will be more than doubled. Second, the regions of relatively low transmissivity, both northeast and southwest of the center of the WIPP site, will be expanded. Third, the zone of relatively high transmissivity northwest of the site center will be expanded. Finally, because of the expansion of zones of both high and low transmissivity, transition zones between the larger areas will be narrowed.

Hydraulic and conservative-tracer tests at the WIPP generally reveal some effect of dual-porosity behavior if the local transmissivity is 1×10^{-6} m^2/sec or more (see for example, 5, 7). Therefore, the transmissivity distribution shown in Fig. 2 indicates that both porous-medium and dual-porosity behavior will be effective over large portions of the region near the WIPP site. These areas will be more precisely defined after interpretation of a northern multipad interference test, begun at well WIPP-13 in January 1987.

Calculations completed as part of the modeling of the H-3 multipad test (6) indicate that dual-porosity behavior is not required to explain the regional head distribution or regional response to hydraulic stresses at the WIPP. Calculations to assess regional dual-porosity effects on contaminant transport are presently ongoing.

Salado Brine Studies

Preliminary geochemical results reported in FY86 indicated the distinction between fluid-inclusion and grain-boundary brines within the Salado Formation. This study has recently been expanded (11). Figure 5 indicates the overall variability and compositional *distinctions* between fluid inclusions and macroscopic brine accumulations within the WIPP facility. Fluid-inclusion compositions to the left of the seawater-evaporation line in Fig. 5 appear to be controlled by diagenetic formation of polyhalite, probably by alteration of gypsum or anhydrite; those to the right of this line by crystallization of magnesite. Both polyhalite and magnesite are common accessory minerals in the WIPP facility. The compositions of fluids in weeps and holes in the floor appear to be dominated by diagenetic reaction of brine with detrital silicates, giving rise to both Mg-depleted fluids and an anomalously Mg-rich silicate assemblage including authigenic quartz (11).

Recent radiometric-dating studies indicate that polyhalites at the WIPP are more than 200 m.y. old (12), suggesting that the composition of fluid-inclusion brines was fixed nearly contemporaneously with halite deposition. Similarly, it is known that silicate reaction kinetics at diagenetic temperatures are extremely slow. Therefore, although fluids encountered in the WIPP facility are predominantly grain-boundary fluids, and may be part of an interconnected system, the indications are that flow within this system is extremely slow in the absence of facility-induced stress gradients, and that fluid residence times are probably millions of years.

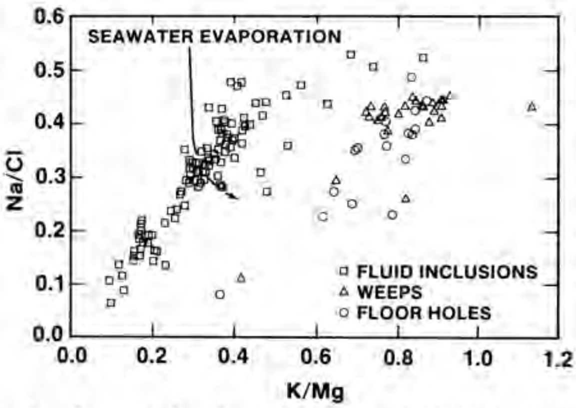


Fig. 5. Compositional variability of fluid-inclusion and macroscopic brines in the WIPP facility (11).

SUMMARY

In the WIPP FEIS, the Rustler Formation was modeled as a single, completely confined, porous unit. Recent hydrologic and tracer testing of the Culebra dolomite at the WIPP has demonstrated the importance of dual-porosity effects in both hydrologic and transport behavior in relatively transmissive areas, at the hydropad scale. In this behavior, there is strong interaction of fractures and the porous matrix of the Culebra. Dual-porosity behavior is not required to explain the regional pattern of head potentials; calculations are ongoing to determine if dual-porosity effects are important to contaminant transport on the scale of the WIPP site.

Recent regional-scale and single-hole testing of the Culebra indicates the presence of discrete zones of high and low transmissivity. High-transmissivity zones are known in the vicinity of H-11 (extending to the south) and in the region DOE-2 - WIPP-13 - H-6. The center of the WIPP site, including the WIPP shafts appears to be dominated by low transmissivities.

Better definition of these zones will be available in reporting to be completed January 1988.

The 1983 SPDV documentation assumed the Salado Formation was dry, except for fluid inclusions and mineralogically bound water. Recent analyses indicate that fluids encountered within the WIPP facility are grain-boundary fluids, chemically distinct from fluid inclusions. These brines, however, appear to be quite old.

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