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APPENDIX B

Preliminary Geologic Description for the Geochemical Sensitivity Analysis of a Bedded-Salt Site

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Bedded-Salt Site

The geologic and hyrologic setting used for this study are based on the portion of the Palo Duro Basin in Deaf Smith County, Texas (Figure B-1). J. Friemel #1 is the drill hole closest to the proposed repository location. As a result, the stratigraphic data and information in this drill hole are assumed to be the same as those at the site.

Stratigraphy

In J. Friemel No. 1, the units range in age from Pennsylvanian through Tertiary (Figure B-2). The rock of Pennsylvanian age are primarily limestone and granite wash with lesser amounts of silty shale. Changes in the depositional environment are evident in the lower Permian sequence in that granite wash is absent and dolomite is present. Otherwise, this portion of the stratigraphy is dominated by fine clastics and limestone. Higher in the Permian sequence, salt and anhydrite units become common to abundant, and limestone is absent. At the top of the Permian sequence, the units composed of evaporite minerals become progressively less abundant, and these types of units are absent in the rocks of Triassic age. Sandstone layers are common in the Triassic sequence and are predominant to exclusive in Tertiary time.

Regional Ground-Water Flow

Based on potentiometric maps for the Ogallala Fm and the Wolfcamp Series (DOE, 1984), the direction of ground-water flow is different for units at different depths. In the Ogallala Fm, flow across the reference site is from northwest to southeast (Figure B-3). For the much deeper Wolfcamp Series, flow across the site is from southwest to northeast (Figure B-4). Based on the approximate hydraulic-head data at the reference site in Figures B-3 and B-4, the vertical flow gradient is downward.

Geologic Setting

The Palo Duro Basin is located primarily in northern Texas and is separated from adjacent basins by Oldham Nose, Matador Arch, Milnesand Dome, and the Amarillo Uplift (Figure B-5). Although faults that cut the Precambrian basement and those of Cenozoic age are present in the Palo Duro Basin, no earthquake epicenters were recorded within the basin itself between 1907 and 1971 (Northrop and Sanford, 1972). DOE (1984) states that many earthquakes in the Texas Panhandle seem to be associated with the Amarillo Uplift and Anadarko Basin. Faults of recent origin probably are the result of collapse caused by salt dissolution.

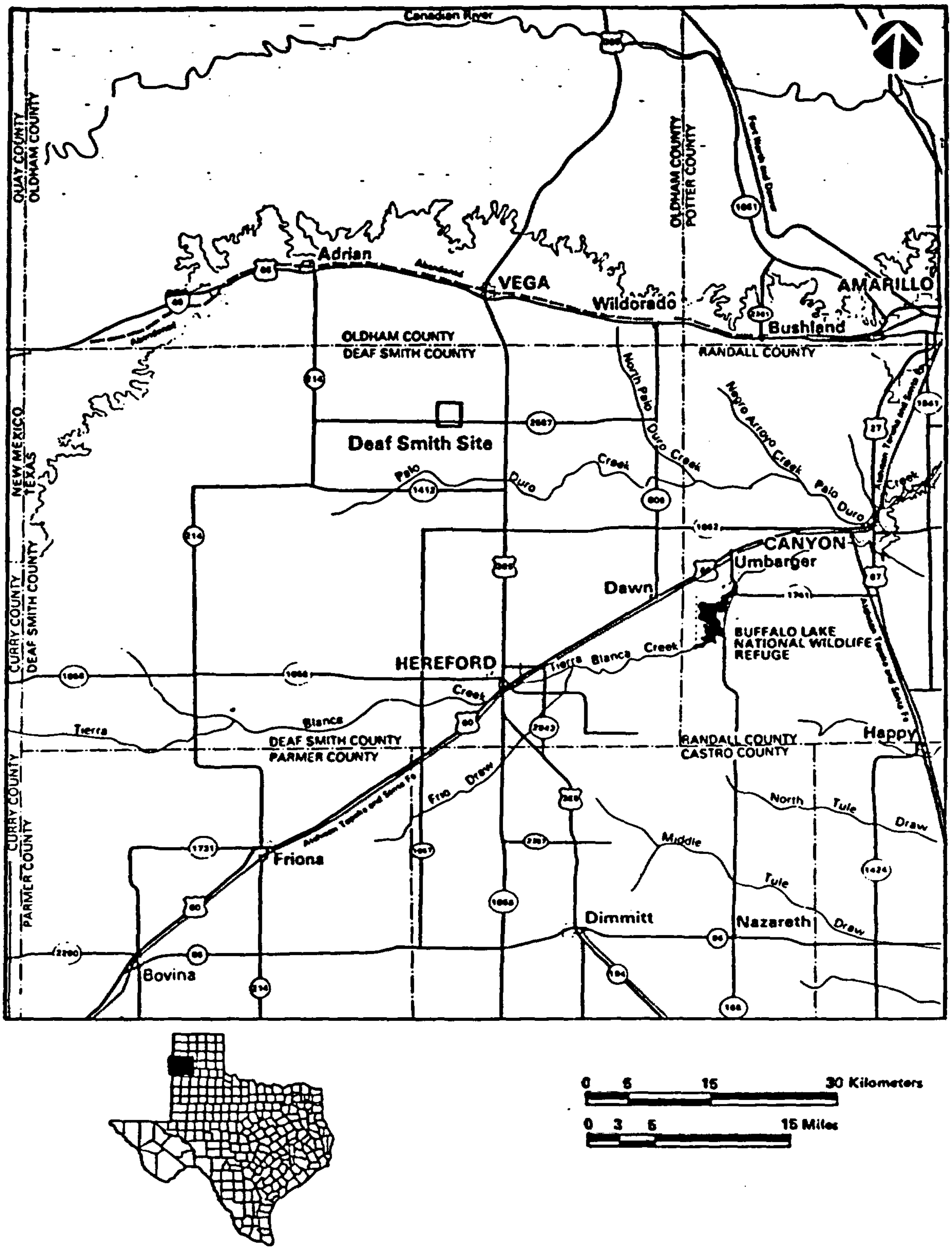

Figure B-1. Bedded-salt reference repository location (after DOE, 1984).

ERA	SYSTEM	SERIES	GROUP	FORMATION
CENOZOIC	QUATERNARY			RECENT FLUVIAL AND LACUSTRINE DEPOSITS
	TERTIARY			OGALLALA
	CRETACEOUS		DAKOTA	
MESOZOIC			FREDRICKSBURG	
			TRINITY	
	JURASSIC			MORRISON
				EXETER
	TRIASSIC		DOCKUM	TRUJILLO
				TECOVAS
PALEOZOIC	PERMIAN	OCHOA		DEWEY LAKE
				ALIBATES
		GUADALUPE	ARTESIA/ WHITEHORSE	SALADO-TANSILL
				YATES
				SEVEN RIVERS
				QUEEN/GRAYBURG
			PEASE RIVER	SAN ANDRES/BLAINE
		LEONARD		GLORIETA
			CLEAR FORK	UPPER CLEAR FORK
				TUBB
				LOWER CLEAR FORK
				RED CAVE
			WICHITA	
		WOLFCAMP		
	PENNSYLVANIAN	VIRGIL	CISCO	
		MISSOURI	CANYON	
		DES MOINES	STRAWN	
		ATOKA	BEND	
		MORROW		
	MISSISSIPPIAN	CHESTER		
		MERAMEC		
		OSAGE		
	ORDOVICIAN		ELLENBURGER	
	CAMBRIAN		UNNAMED SANDSTONE	
	PRECAMBRIAN			

Explanation:

~~~~~ Unconformable Boundary

- - - - Boundary in Dispute

Figure B-2. Stratigraphic units of Palo Duro and Dalhart Basins (after DOE, 1984).
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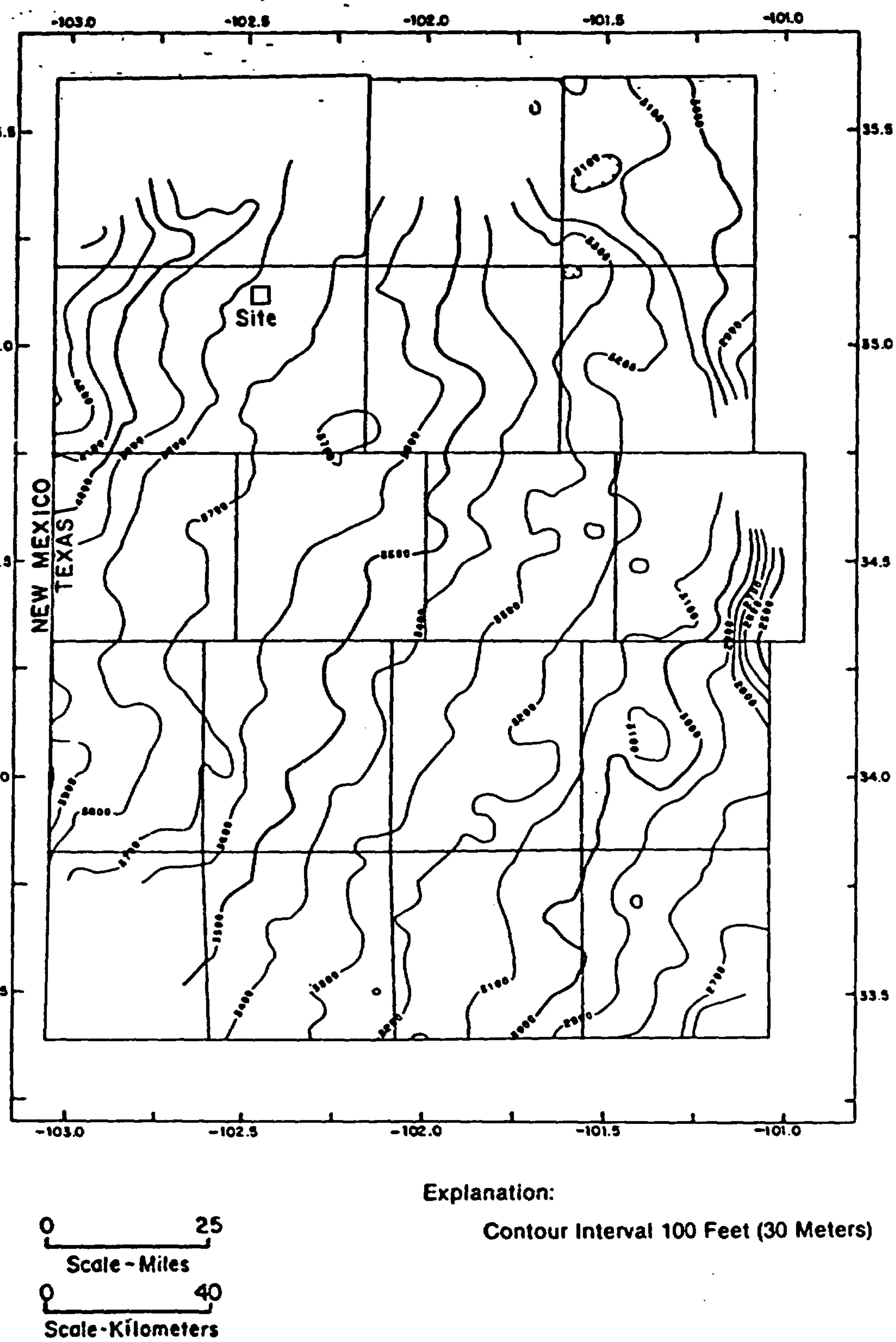


Figure B-3. Ogallala potentiometric-surface map for 1981 (after DOE, 1984).

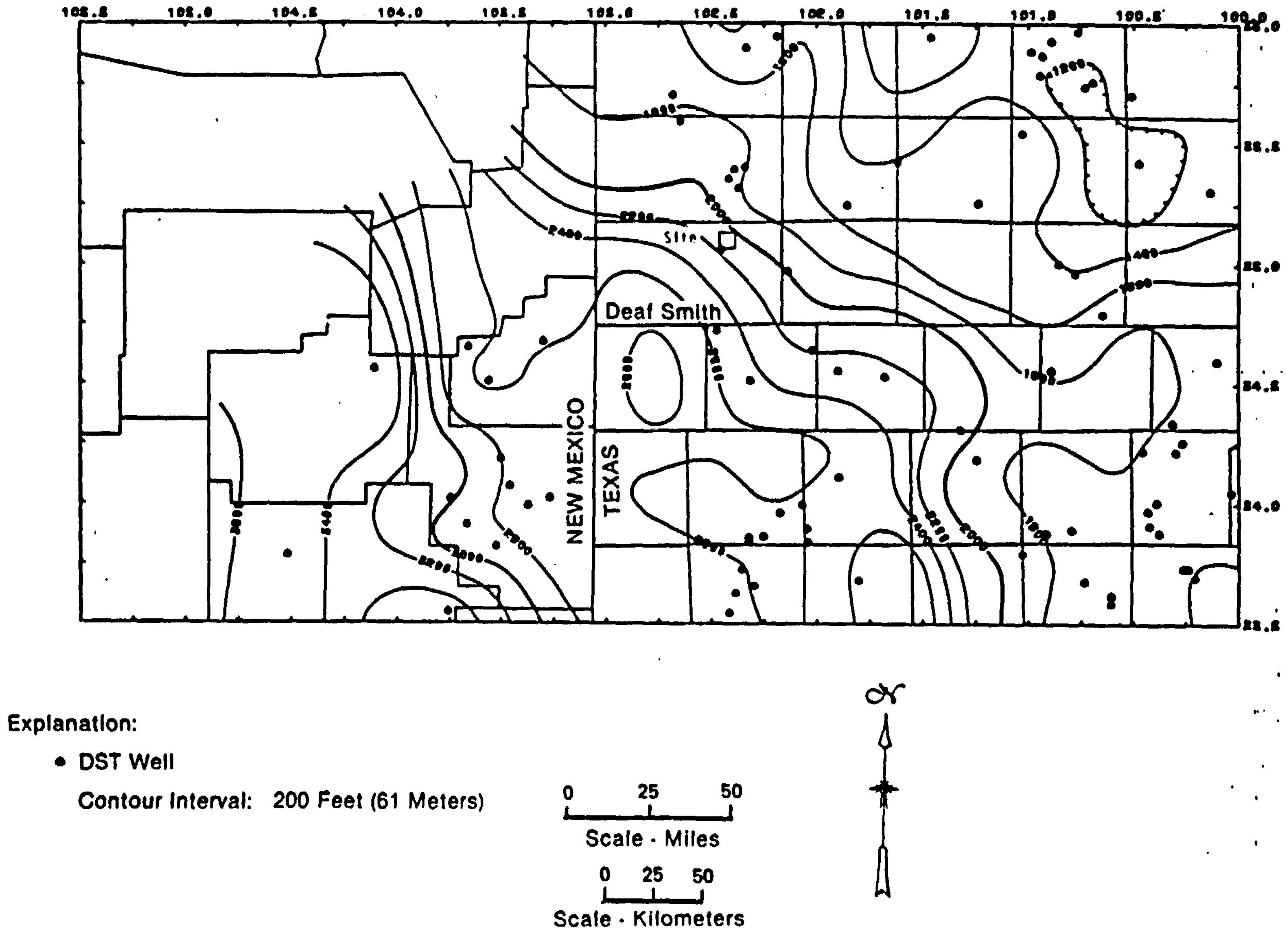
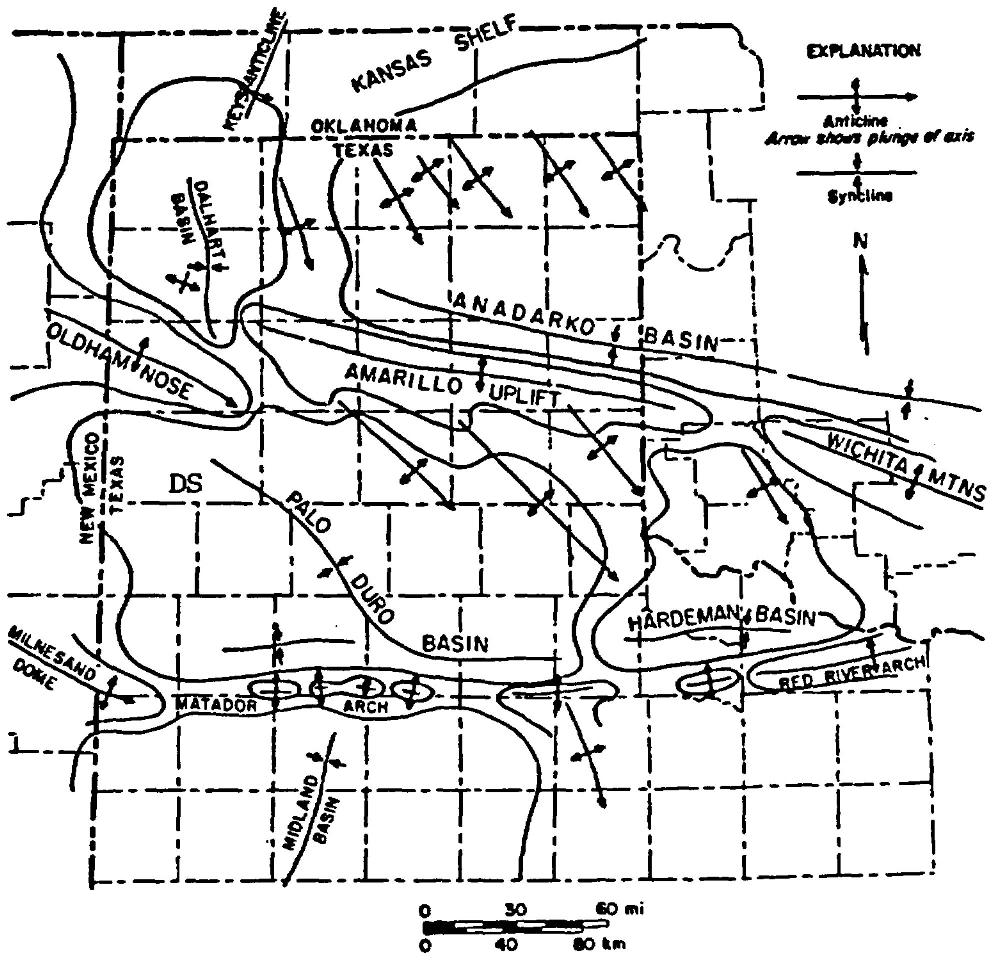


Figure B-4. Wolfcamp potentiometric-surface map (after DOE, 1984).



DS - Deaf Smith County

Figure B-5. Major structural elements of the Texas Panhandle (after Dutton and others, 1979).

Salt dissolution is an ongoing process in the Palo Duro Basin. Figure B-6 illustrates areas of active dissolution and paleodissolution. Whereas salt units within the Seven Rivers Fm are being dissolved in Deaf Smith County (Figure B-2), these units are at least 900 feet stratigraphically above the proposed host unit.

No volcanic activity has occurred in the Palo Duro Basin since Precambrian time.

Drilling exploration for oil and gas has occurred throughout the Palo Duro Basin. This activity is likely to continue at least into the short-term future. Whereas Deaf Smith County has had a very low level of exploration in the past, non- and low productivity areas tend the be reexamined when energy prices rise.

Drill holes from resource exploration or from site evaluation for the repository could be particularly troublesome. The generally abundant water supply of the Ogalla aquifer and the high downward hydraulic gradient could result in substantial salt dissolution if a drill hole connects the Ogallala aquifer with a deeper aquifer.

Proposed Host Unit for Repository

The candidate unit for the repository is Lower San Andres Unit 4 (Figure B-2). For this study, the canisters placed in the repository are assumed to be 10 feet long, and the top of the canisters are at the midpoint of the salt unit.

Flow Paths

Because of the substantially higher downward hydraulic gradient (approximately two orders of magnitude) relative to the horizontal gradient at the site and the relatively low hydraulic conductivity of the units, radionuclides released from a repository in a host salt unit would migrate downward until a unit with substantially higher horizontal conductivity was encountered. Upon reaching such a unit, significant horizontal migration could occur.

The DOE pathway (DOE, 1984) consists of downward flow from the repository to the dolomite unit at the top of the Wolfcamp Series (Figure B-7). Horizontal flow in the dolomite is to the accessible environment. The sparsity of conductivity data for other units at and near the site leaves open the possibility that other units stratigraphically higher than the Wolfcamp dolomite could provide the horizontal pathway to the accessible

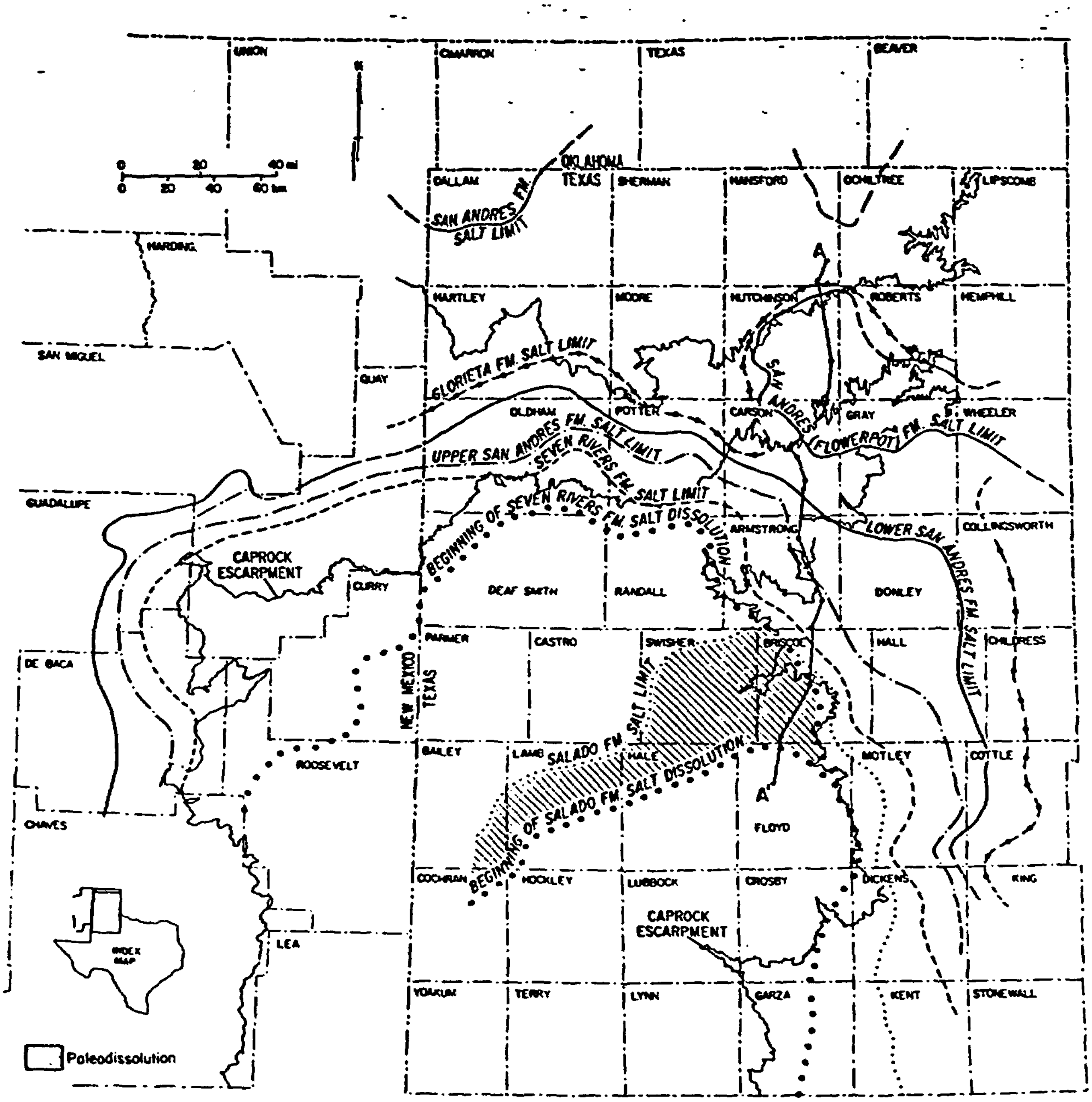


Figure B-6. Salt dissolution zones, Texas Panhandle and eastern New Mexico (after Gustavson and others, 1980).

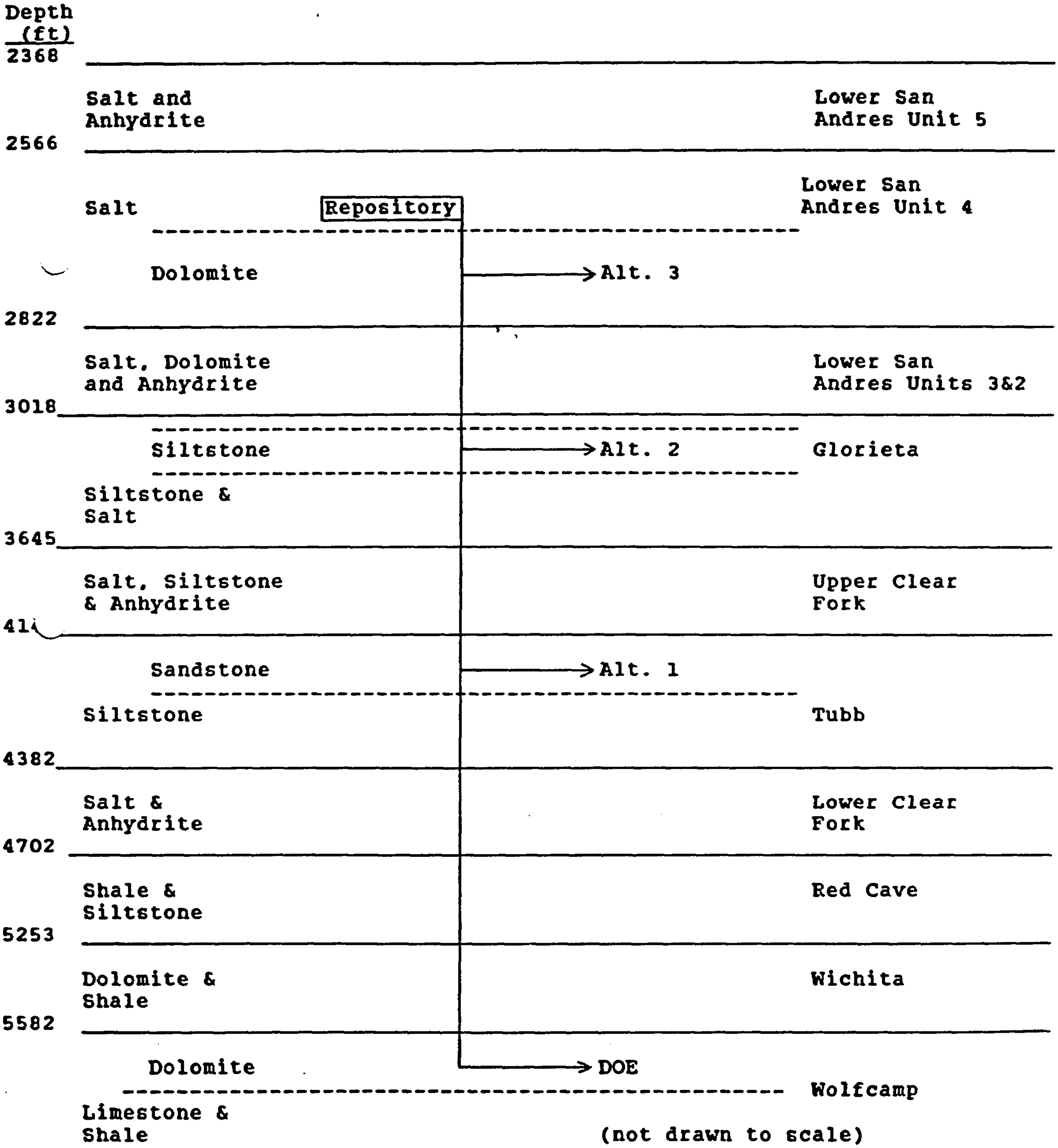


Figure B-7. Schematic diagram of DOE and alternative flow paths at bedded-salt site.

environment. In this study, three alternative horizontal flow path legs are proposed (Figure B-7):

1. The sandstone at the top of the Tubb Fm. Although no data exist for this unit, the sandstone should have the highest hydraulic conductivity of the clastic units in the Permian sequence. This alternative path also eliminates the ground-water flow through the substantial thickness of shale in the Red Cave Fm as required in the DOE path.

2. The first substantial (>20 m thick) siltstone, which is in the Glorieta FM, beneath the repository (Figure B-7). As with the sandstone, no site-specific hydrologic data are available for this unit. In a sequence containing numerous evaporite beds, siltstone would be a relatively high permeability rock type based on generic data. A siltstone layer exists higher in the sequence than the unit chosen, but the layer is less than 3.5 m thick and as a result is likely to pinch out before reaching the accessible environment. The difference in vertical distance between these siltstones is approximately 13 meters in J. Friemel #1. An advantage of this pathway over alternative 1 above is that substantially fewer low conductivity evaporite units must be crossed in the vertical flow leg.

3. The first dolomite beneath the host salt unit. Although this dolomite has a much lower conductivity than the dolomite chosen by DOE in the Wolfcamp Series (DOE, 1984, Table 3-19), the conductivity is substantially higher than at least the lower end of the range of values for generic salt.

Because of the numerous stratigraphic units at the RRL, the units have been consolidated into a more manageable number, hopefully without significantly altering ground-water flow or the effects of retardation on radionuclide migration. Tables B-1 and B-2 list the data for the DOE and the three alternative flow schemes. Appendix C explains the rationale used in simplifying the stratigraphy for the various flow paths.

Mineralogy of Rock Types

Table B-3 lists the mineral content of the major rock types encountered along the flow paths from the repository to the accessible environment. The sources of data are Fukui (1983, 1984). Modal analyses of thin sections were made for samples from drill holes G. Friemel #1, Grabbe #1, Rex White #1, and Detton #1. The rock names used by Fukui (1983, 1984) were not

Table B-1. Data and si[illegible]lified straligraphy for DOE flow path[illegible]dded-salt site.

Leg	Rock Type	Leg Length (ft)[a]	Gradient	Ref.[b]	Porosity	Ref.	Dist.[c]	Ref.	Hydraulic Conductivity (ft/d)	Ref.	Dist.	Ref.	Bulk Composition[e] S	D	A	St	Sa	Sh
L1	Repository (Salt)	10	0.42	3	3E-4-1E-2	1	LN	d	3.3E-8-5.4E-3	6	LN	d	1					
L2	Salt and anhydrite	231	0.42	3	3E-4-1E-2	1,2	LN	d	3.3E-8-5.4E-3	6,2	LN	d	.77		.23			
L3	Dolomite	138	0.42	3	1E-2-9E-2	3	LN	d	3E-5-9E-3	3	LN	d		1				
L4	Salt	99	0.42	3	3E-4-1E-2	1	LN	d	3.3E-8-5.4E-3	6	LN	d	1					
L5	Siltstone	107	0.42	3	1.9E-2-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L6	Salt	78	0.42	3	3E-4-1E-2	1	LN	d	3.3E-8-5.4E-3	6	LN	d	1					
L7	Siltstone	214	0.42	3	1.9E-1-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L8	Salt	200	0.42	3	3E-4-1E-2	1	LN	d	3.3E-8-5.4E-3	6	LN	d	1					
L9	Siltstone	163	0.42	3	1.9E-1-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L10	Salt and anhydrite	130	0.42	3	3E-4-1E-2	1,2	LN	d	3.3E-8-5.4E-3	6,2	LN	d	.72		.28			
L11	Siltstone	75	0.42	3	1.9E-2-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L12	Anhydrite	75	0.42	3	3E-4-1E-2	2	LN	d	3.3E-8-5.4E-3	2	LN	d			1			
L13	Sandstone	36	0.42	3	7E-2-1.4E-1	5	LN	d	3E-4-3E0	5	LN	d					1	
L14	Siltstone	186	0.42	3	1.9E-2-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L15	Salt and anhydrite	288	0.42	3	3E-4-1E-2	1	LN	d	3.3E-8-5.4E-3	6	LN	d	.70		.30			
L16	Siltstone	111	0.42	3	1.9E-2-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d				1		
L17	Shale	529	0.42	3	3E-2-6E-1	4	LN	d	3E-8-3E-4	5	LN	d						1
L18	Dolomite	293	0.42	3	1E-2-9E-2	3	LN	d	3E-5-9E-3	3	LN	d		1				
L19	Dolomite	1.64E4	0.0045	3	1E-2-9E-2	3	LN	d	3E-5-9E-3	3	LN	d		1				

a. based on unit thicknesses in well J. Friemel No. 1 (DOE, 1984)

b. References
1. Tien and others, 1983
2. anhydrite properties assumed to be same as salt
3. DOE, 1984; assumed $n_e = n_t/2$
4. Isherwood, 1981
5. Freeze and Cherry, 1979
6. Gonzalez, 1983

c. distribution of data: LN = lognormal

d. permeability data for those units plotted in DOE (1984) has a lognormal distribution. Assumed permeability data for all units have lognormal distribution. Because permeability and porosity are closely related, porosity data assumed to be lognormal.

e. proportional composition of each leg based on available data.
S = salt   A = anhydrite   Sa = sandstone
D = dolomite   St = siltstone   Sh = shale

Table B-2. Data and simplified stratigraphy for alternative flow paths for bedded-salt site. (same reference and note designations as Table B-1).

Leg(s)	Rock Type	Leg Length (ft)	Gradient	Ref.	Porosity	Ref.	Dist.	Ref.	Hydraulic Conductivity	Ref.	Dist.	Ref.
Alternative 1 - Horizontal flow in sandstone at top of Tubb Fm												
L1-L12	same	values as	legs for		DOE pathway				Table B-1			
L13	Sandstone	1.64E4	0.0045	3	7E-2-1.4E-1	5	LN	d	3E-5-3E-1	5	LN	d
Alternative 2 - Horizontal flow in first "significant" siltstone in Glorieta Fm												
L1-L4	same	values as	legs for		DOE Pathway				Table B-1			
L5	Siltstone	1.64E4	0.0045	3	1.9E-2-2.5E-1	4	LN	d	3E-4-3E0	5	LN	d
Alternative 3 - Horizontal flow in dolomite beneath host unit in Lower San Andres Fm												
L1	same	values as	leg for		DOE Pathway				Table B-1			
L2	Salt and anhydrite	88	0.42	3	3E-4-1E-2	1,2	LN	d	3.3E-8-5.4E-3	7	LN	d
L3	Dolomite	1.64E4	0.0045	3	1E-2-9E-2	3	LN	d	3E-5-9E-3	3	LN	d

Table B-3. Composition of rock types used for simplified conceptual model of bedded-salt site (data from Fukui, 1983, 1984).

Halite (132)[a]

Mineral/Component	vol. %
Halite	67.3-99.7
Anhydrite	0-27.0
*Clay	0-27.0
Carbonate	0-2.7
Quartz	0-1
Polyhalite	0-3.3
Other	0-1.3

Siltsone (3)

Mineral/Component	vol. %
Quartz	45-61
*Clay matrix	18-28
Sedimentary Rock Fragments	3-14
Dolomite Cement	5-9
Halite Cement	5-7
*Muscovite	1-2
Additional Detrital Components	Tr-1
Halite Pore Filling	0-1
Anhydrite	0-1
Hematite/Geothite	0-1

Anhydrite (4)

Halite	0-34
Polyhalite	0-Tr
Anhydrite	65-99
Carbonate	Tr
*Goethite	0-Tr
*Clay	0-1
Pore Space	0-1
Pyrite	0-Tr

Dolomite (2)

Allochems	23-52
Calcite Cement	30-35
Pore Space	0-13
Barite	0-Tr
Anydrite	Tr
Pyrite	0-Tr
Phosphatic Fossil Fragments	Tr
Micrite Matrix	0-42
Vein Phases	0-3
Halite	0-Tr
Quartz	0-Tr

Shale (1)

Halite	4
*Clay	68
Anhydrite	17
Quartz	8
Gypsum	2
Other	1

Sandstone (0)[b]

Quartz	100

---

a number of thin sections sampled
b no samples analyzed; assumed composition
* important sorbing mineral

the same as those used in the lithologic-log description by DOE (1984) for J. Friemel #1. Tentative correlation of mineral contents and rock types was made by comparison of sample locations in a formation from Fukui (1983, 1984) with relative position in the same formation in J. Friemel #1 (DOE, 1984). Most units along the pathways do not have a corresponding mineral analysis. For these units, analyses of rock of the same general rock type elsewhere in the stratigraphic section were assumed to be applicable to the units along the flow path. No data were available for a rock type that corresponds the the sandstone unit at the top of the Tuff Fm.

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COMMENTS ON ISSUES PERTINENT TO SORPTION MODELS AND EXPERIMENTS IN SUPPORT OF PERFORMANCE ASSESSMENT STUDIES

NRC/ORNL WORKSHOP
Silver Spring, Maryland
May 13-15, 1986

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INTRODUCTION

Geochemical interactions between radionuclides and rocks are but one of several barriers to the transport of radioactive waste from proposed HLW repositories. Performance assessment calculations consider the roles of the waste package, engineered facility and hydrogeochemistry of the repository site in limiting potential releases of radioactivity. The overall objective of geochemical sensitivity analysis is to assess the relative contribution of the uncertainty in geochemical data and models to the overall uncertainty in the predicted performance of candidate HLW repositories.

In the past, performance assessment calculations have used simple models to represent complex geochemical processes. In particular, solute-water-rock interactions have been represented by retardation factors calculated from empirical sorption ratios (Kd, Rd, or Rs) obtained under conditions which simulate the range of environments predicted to prevail at specific repository sites. Figure 1 illustrates the general structure of calculations carried out at Sandia National Laboratories to assess compliance of hypothetical HLW sites with the EPA Standard 40 CFR Part 191. In these calculations, the discharge of radionuclides at the accessible environment is calculated over a ten thousand year period. The use of simple algorithms to represent geochemical processes has been justified in part by the complexity of the calculation of integrated discharge for solutes which are affected by radioactive decay and production. Statistical sampling of model input parameters and a large number of calculations are required to represent the uncertainties in possible hydrogeologic and geochemical conditions at the candidate HLW sites.

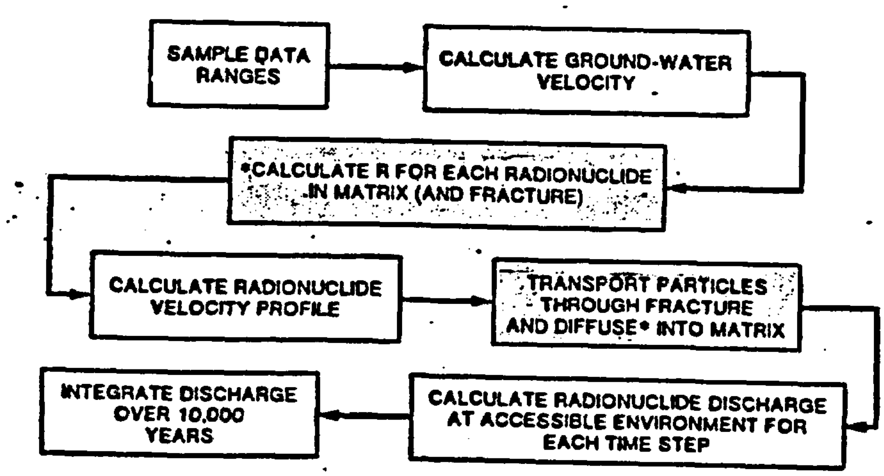


Figure 1. Simplified Outline of Performance Assessment Calculations. Shaded areas indicate steps in which geochemical processes are considered.

The adequacy of the use of simple retardation factors and sorption ratios in calculations of radionuclide discharge has been questioned by a number of researchers. In general, the speciations of the radioelements in the sorption experiments are not known and sorption behavior cannot be confidently predicted for conditions that differ from those of the experiments. Radionuclides are not introduced into the experimental solutions in the forms that would be released from the nuclear waste, and the relatively short duration of the experiments may preclude detection of any slow speciation reactions that could change sorption behavior and lead to increased radionuclide discharge.

Coupled reaction-transport models that explicitly model geochemical reactions have been proposed as an alternative to currently available performance assessment models. These models are clearly useful in providing basic mechanistic insights and identifying key chemical parameters in radionuclide transport; however, the routine use of such codes in performance assessment is impractical. The use of coupled reaction-transport models is hampered in part by the lack of fundamental thermochemical data describing surface complexation reactions. In addition, it is difficult to extrapolate theoretical models of the sorption of trace metals by simple oxides and aluminosilicates to the behavior of natural materials. Finally, the high computing costs associated with realistic calculations of radionuclide discharge over a 10 km distance and 10,000 year period, at present, preclude the use of coupled reaction-transport models in repository performance assessment.

SOME GENERAL QUESTIONS RELATED TO SORPTION MODELS AND EXPERIMENTS IN HIGH LEVEL WASTE PERFORMANCE ASSESSMENT

Can a range of (non-zero) sorption ratios or isotherm parameters be used to:
1. obtain an upper bound to integrated radionuclide discharge?
2. be used to bound maximum radionuclide concentrations?
3. adequately bound the uncertainty due to sorption in performance assessment calculations?

Is it possible to obtain upper bounds to discharge or concentration and bracket the geochemical uncertainty without understanding the detailed mechanisms of radionuclide/water/rock interactions?

Is it useful to obtain fundamental data and a detailed understanding of geochemical processes in laboratory studies even if site characterization will not provide similar data at the repository and 'average' parameter values will be used in performance assessment calculations?

SOME SUGGESTIONS TO RESOLVE SOME ISSUES RELATED TO SORPTION

Table 1 lists some of the data requirements and modeling capabilities that are required in assessments of compliance of candidate repositories with the EPA Standard. The abilities of two codes being used at SNLA in HLW studies to represent these processes are compared in the Table. The issues and questions raised above should be addressed in a multi-dentate program involving short-term, medium-term and long-term activities. The approach described below attempts to satisfy both technical and regulatory needs. It is designed to continuously decrease the level of uncertainty pertaining to geochemical data and models used by the DOE and NRC in support of licensing activities.

Short-term Activities (1-3 years).

Site-specific physicochemical conditions under which the use of isotherms or retardation factors will significantly underestimate radionuclide discharge and peak concentration must be identified. This effort should examine the geochemical assumptions in current performance assessment models and assess the sensitivity of calculated integrated discharge and peak concentration to the relaxation of these assumptions.

Computer codes such as NWFT/DVM and SWIFT can be used in conjunction with sampling techniques such as LHS to examine the importance of geochemical uncertainty relative to uncertainties in other types of processes (eg. hydrology) for realistic conceptual sites.

Previous derivations of criteria for the local equilibrium assumption and first-order physical nonequilibrium transport models should be extended to examine the effects of channeling, fracture geometry, non-linear sorption

TABLE 1. SOME REQUIRED AND CURRENT CHARACTERISTICS OF TRANSPORT CODES

FEATURE	TRANQL	SWIFT/NWFT	NRC
********	*******	**********	*****
Max. concentration	yes	yes/no	yes
Precipitation/ dissolution	no	no	?
Sorption	yes but needs work	Kd,Freundlich	?
Number of sorbing species/run	2	no limit, but one per nuclide	>8
Number of substrates/run	>1	no limit	3-15
Number of GW/run	>1	no limit	1-5
Kinetics	no	no	?
Brines (chemical)	no	no	?
Brines (physical)	?	yes	yes
Dimension	1,2	1,2,3	1-3
Dispersion	T,L	T,L	T,L
Sat/unsat	yes	sat/unsat?	yes
Porous media	yes	yes	yes
Radiodecay	simple	yes	yes
Coupled heat/flow	no	yes	yes
Fractured media with matrix diffusion	maybe	yes	yes
Radioactive production	no	yes, 10 member chains	yes
Integrated discharge	under dev.	yes	yes
Efficient for multiple runs	no	yes	yes

and hydrodynamic effects. Previous parametric studies of the effects of slow chemical reactions on integrated radionuclide sorption should be extended to other time-dependent phenomena such as changes in sorption capacities of the rocks along flow paths or ground water evolution.

Available thermodynamic data, theoretical models and codes should be used to gain insight onto potential variations in sorption behavior due to the presence of competing cations and complexing ligands produced by dissolution of non-radioactive components of the repository system (eg. canister,concrete and other sealing materials). This assessment should be made within the context of the behavior of the whole repository system and consider the behavior of all system components. The required level of precision of thermochemical data should be assessed by sensitivity analyses in geochemical calculations.

The results of these sensitivity studies should be used to obtain criteria for future DOE and NRC experiments. Experimental efforts should be initiated to examine mineral surfaces present in batch and column sorption experiments to determine if sample preparation techniques and water-rock equilibration techniques produce substrates that are relevant to natural conditions or at least produce conservative sorption data.

Mid-term activities: (3-7 years)

At the present time there are no robust theoretical models nor fundamental data that can be used to predict the sorption of radionuclides onto rocks such as tuff or basalt. In the mid-term, experimental efforts should be focused to understand a single well-defined nuclide/rock system under site-specific hydrochemical conditions. The data and model obtained from this investigation can be used in sensitivity calculations. For example, the integrated discharge calculated with the data in a coupled speciation/transport code could be compared to that calculated with a retardation factor in a code such as NWFT/DVM or SWIFT. Such a comparison could give insight into the degree of geochemical complexity that must be represented in performance assessment calculations. Measurement of geometric factors for diffusion equations in fractured or porous rock could be carried out at this stage. Such data could be used in support of calculations of matrix diffusion and in comparisons of retardation factors obtained in column and batch tests.

Long-term studies (7-25 years):

Comprehensive studies of radionuclide sorption onto natural materials should be carried out. These projects should provide a theoretical basis for description of nuclide/rock interactions in both dilute and saline waters. Identification of sorbing species and elucidation of mechanisms of nuclide/rock reactions should be attempted. Fully-coupled speciation/transport codes that can represent all important processes (including radioactive production and decay) and that can be run efficiently in sensitivity studies should be written.

APPENDIX B

Preliminary Geologic Description for the Geochemical Sensitivity Analysis of a Basalt Site

Basalt Site

The geology and hydrology of the basalt site are based on those of the Pasco Basin in the Columbia Plateau (Figure B-1). Stratigraphic data for the site are based on lithologic logs from drill holes primarily within the Hanford Reservation (HR). Hydrologic data are from several test wells throughout the HR and primarily those at and near the reference repository location (RRL). Potentiometric maps have been generated by several modeling efforts. As a result of the assumptions made about the flow system for the models and the uncertainties in the data, none of the generated flow patterns has received a consensus of acceptance. The flow pattern used in this study is the result of regional and local models of the site developed by SNLA (Bonano and others, in preparation). Data on rock properties are either from the literature or assumed values.

Stratigraphy

Basaltic lava flows in the Pasco Basin are of Tertiary age (Figure B-2). Overlying the basaltic flows are Pliocene and Pleistocene sedimentary units. When the time interval between subsequent lava flows was sufficiently long, sediments were deposited on one flow and eventually overlain by a later flow. As a result, sedimentary interbeds occasionally occur in the sequence of basaltic lava flows (Figure B-2).

In addition to providing time for sediments to be deposited, the time intervals between lava flows can allow for varying amounts of erosion. The extrusion of a liquid lava onto an erosion surface can result in considerable variation in thickness of the flow upon cooling.

As the liquid lava cools, a crust of solidified lava forms wherever the lava is in contact with cooler material, either air or underlying rock. If movement of the flow occurs during cooling, the crust that forms on the flow surface can break up to form a flow-top breccia. This breccia can range from a couple to tens of feet thick.

Once the lava solidifies, continued cooling results in the formation of extension fractures. These fractures typically are vertical and intersect to define generally irregularly shaped, polygonal columns. The fracture density generally varies with different zones in the flow. In addition, the fracture pattern may be fan-shaped. Horizontal cooling fractures also occur in addition to the vertical fractures.

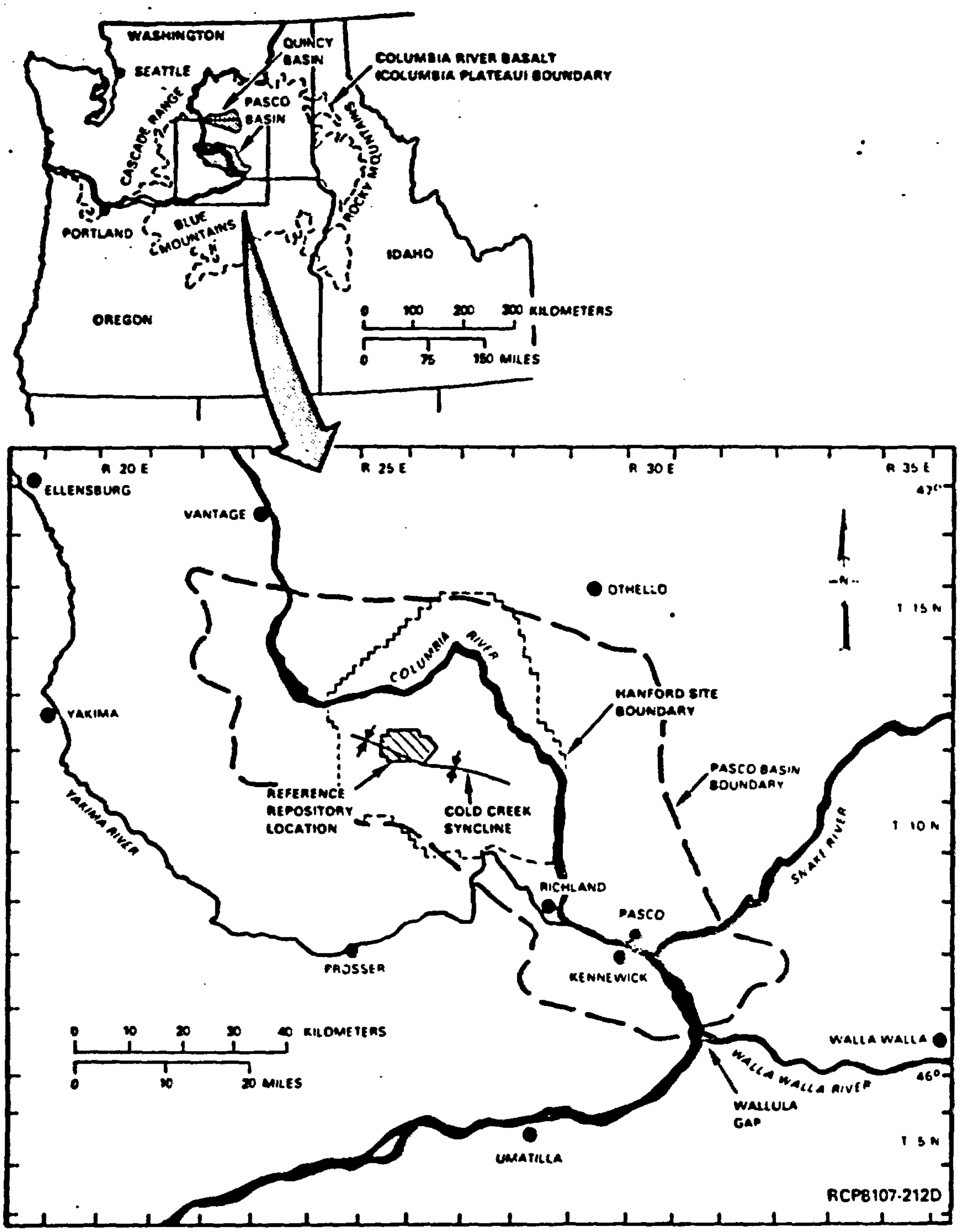
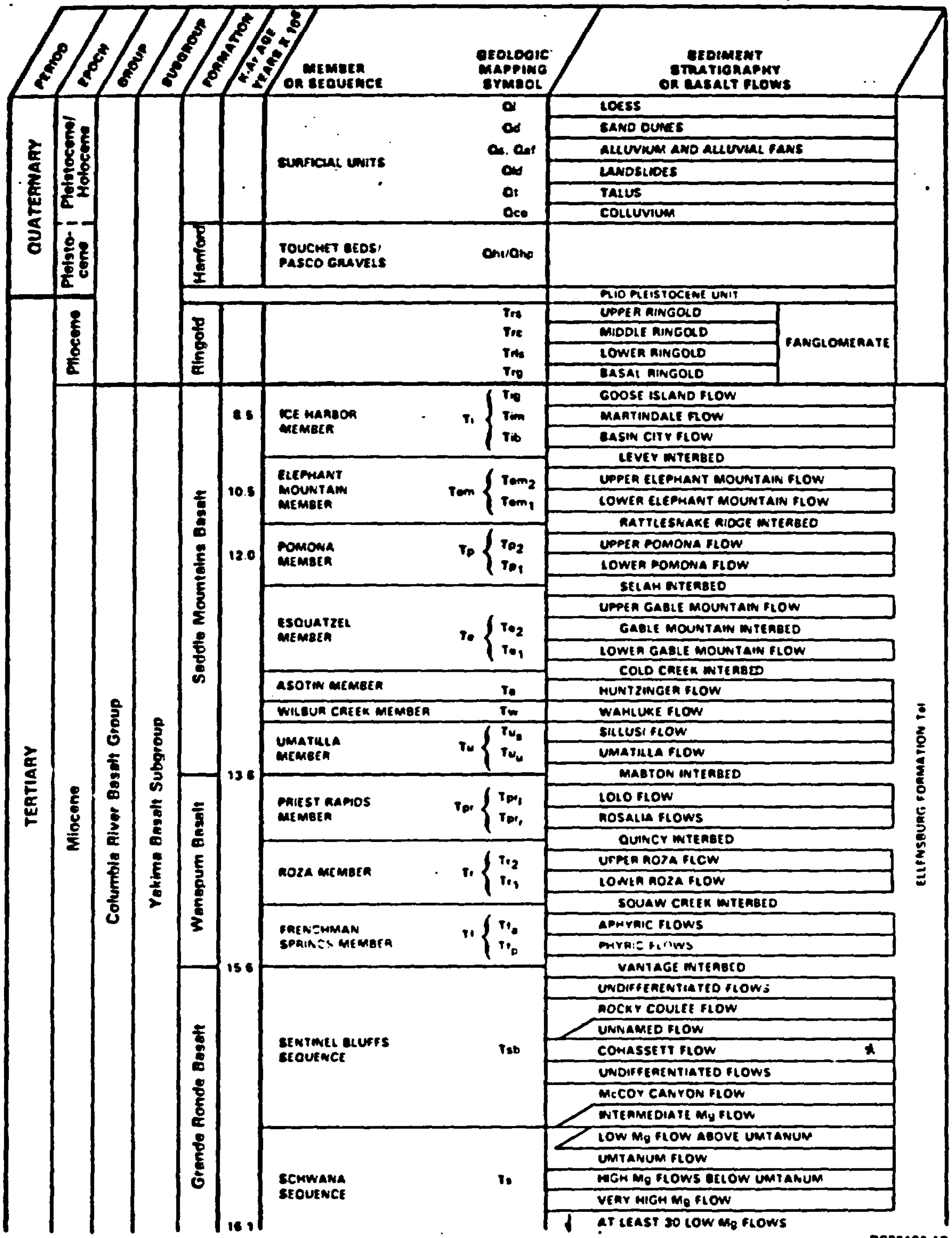


Figure B-1. Location of Columbia Plateau, Pasco Basin, and Reference Repository Location (DOE, 1982).



*Proposed host unit for repository

Figure B-2. Stratigraphic units present in Pasco Basin and proposed host unit for repository (after DOE, 1984).

Regional Ground-Water Flow

The ground-water flow pattern used in this study was determined from the modeling portion of the SNLA basalt methodology development project. Whereas the DOE model has lateral flow from the area of the RRL toward the southeast (DOE, 1984), the preliminary run of the SNLA model has flow from the RRL toward the northwest where Grande Ronde basalt outcrops are exposed along the Columbia River. The horizontal segments of the flow paths for both the DOE and SNLA models are greater than 5km, which is considered to be the distance to the accessible environment.

Based on the boundary conditions and hydrologic properties of the units in the SNLA model, the vertical hydraulic gradient at the RRL was determined to be upward. Well data at and near the RRL in general agree with the upward gradient, although one drill hole (RRL-14) has a downward gradient in the Grande Ronde basalt and another (DC-16A) has no gradient in the Grande Ronde (DOE, 1984, Table 6-5). A summary of the gradients in other drill holes is presented in Guzowski and others (1982).

Although the flow pattern determined by the SNLA model is preliminary and the model was not calibrated, future refinements of rock properties are not expected to substantially change the overall pattern. The inclusion of large-scale structural features in the model may result in different flow patterns. Because the results are preliminary, potentiometric maps are not available for distribution or citation at this time.

Geologic Setting and Relationship to Release Scenarios

The basalt site is located in a structural basin within the Columbia Plateau. This plateau is the result of an accumulation of flood basalts erupted from earlier than 16.5 my ago until approximately 8.5 my ago (Myers and others, 1979). Low heat flow and the isolation of the plateau from contemporary igneous provinces suggest that renewed volcanism in the Pasco Basin is unlikely.

Regional compression deformed the plateau into a series of anticlines and synclines (Figure B-3). Most of this activity occurred from the Miocene and into the late Cenozoic (DOE, 1984). Whereas the Pasco Basin presently is undergoing nonuniform compression, the amount is extremely small (Savage and others, 1981).

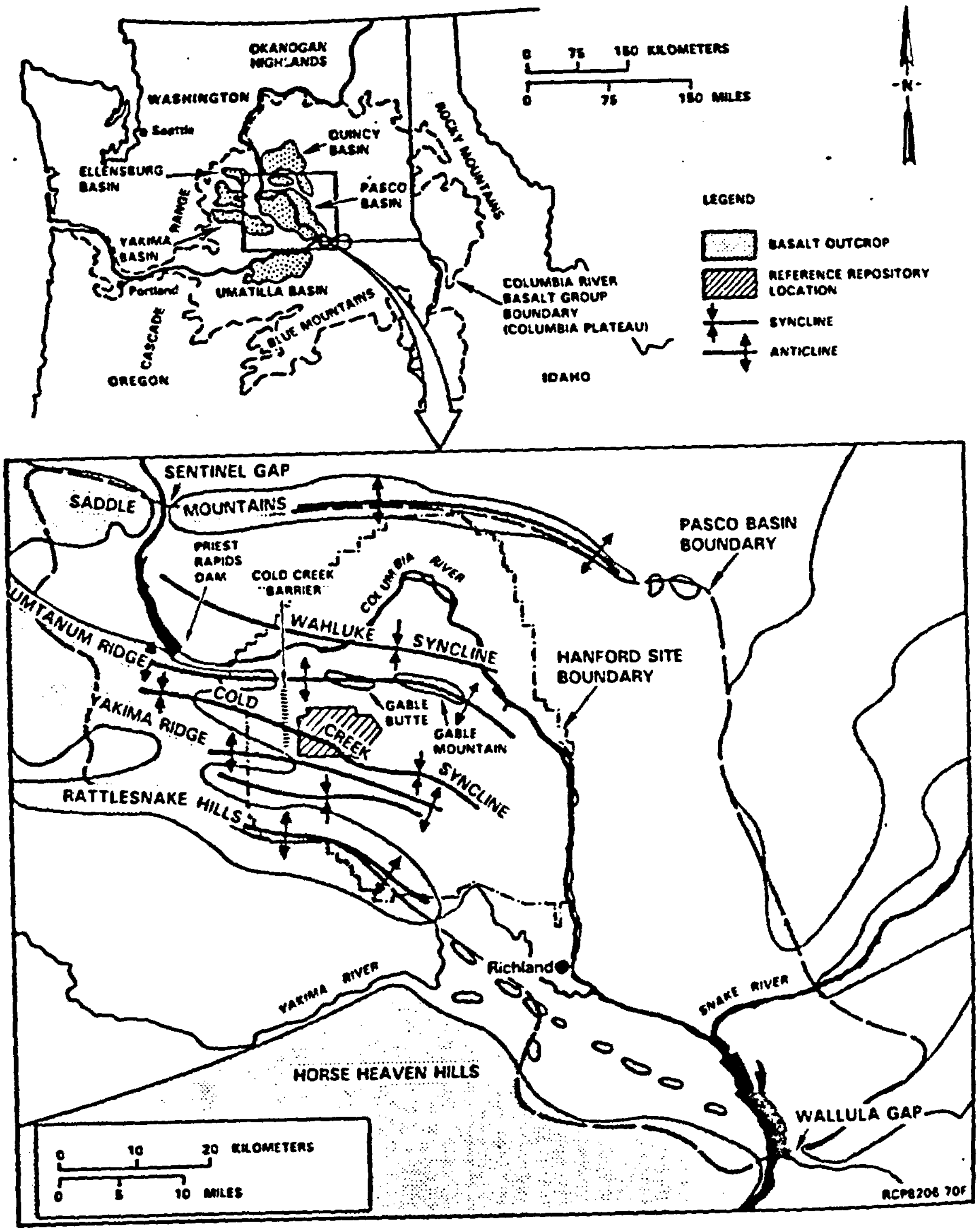


Figure B-3. Large-scale folds in the Pasco Basin (DOE, 1984).

Natural gas was produced from an interbed in the basalt sequence at the Rattlesnake Hills during the 1920's and early 1930's. Shell Oil Company has drilled or planned to drill along anticlines to determine the energy potential of the sediments beneath the basalts (McCaslin, 1981). Future drilling will depend on the costs of various energy resources and the results of exploration.

The Pasco Basin was not glaciated in Pleistocene time. Predictions as to the possibility of renewed glacial climate and the extent of future glaciers are complicated by the increase of carbon dioxide in the atmosphere and the resultant "greenhouse effect" caused by the burning of hydrocarbons. During the Pleistocene, the Pasco Basin was subjected to flooding because of the melting of glaciers. Renewed glaciation of similar extent to the previous glaciation probably would subject the basin to renewed flooding. One of the effects of this flooding could be rerouting of the Columbia River.

A preliminary set of release scenarios was developed for a repository site in the Columbia Plateau by Hunter (1983).

Host Unit

In this study, the repository is assumed to be in the dense interior of the Cohassett basalt. The initial run of the SNLA model had the flow interior divided into two layers with the radionuclide release point in the upper layer. For this reason, the top of the canisters are assumed to be at the midpoint of this upper layer.

Flow Path

The flow paths generated by both the SNLA and DOE (1984) modeling efforts result in radionuclide releases from the repository traveling upward to the flow-top breccia of the host unit. After reaching the breccia, flow is lateral within this breccia to the accessible environment. Whereas the DOE flow model has lateral transport from the area of the RRL toward the southeast, the preliminary results of the SNLA model has lateral flow to the northwest. The upward hydraulic gradient at the RRL requires that releases from the canisters pass through the backfill in the mined facility. To simplify the flow path, the backfill is not included in the calculations for this report.

Figure B-4 illustrates the flow path used in this study, and Table B-1 contains the appropriate data.

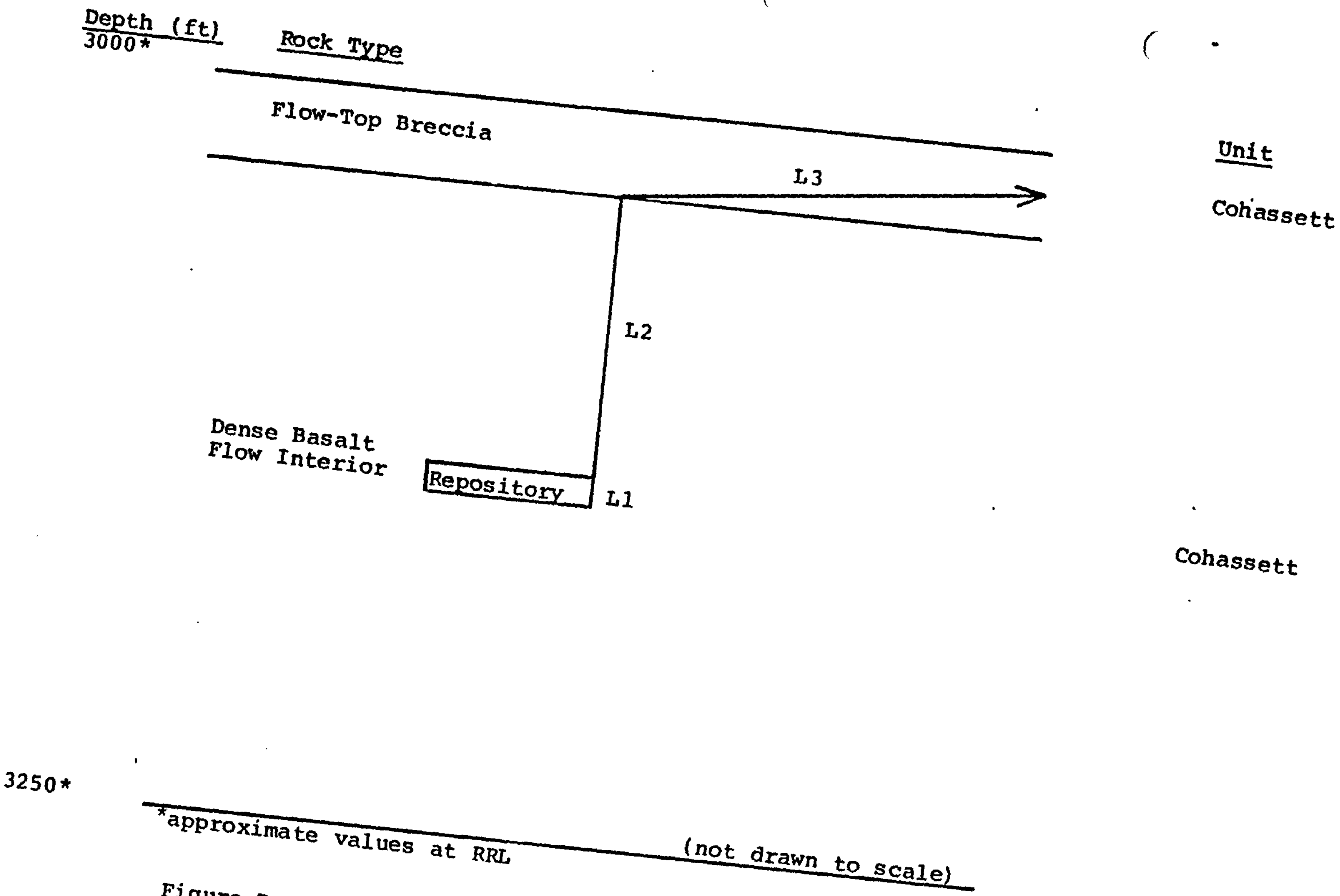


Figure B-4. Schematic representation of SNLA-determined flow path for basalt site.

Table B-1. Data for DOE and SNLA Flow Paths, Basalt Site.

Leg	Rock Type	Leg Length (ft)	Ref.[a]	Dist.[b]	Gradient	Ref.	Dist.	Porosity	Ref.	Dist.	Ref.	Hydraulic Conductivity (ft/d)	Ref.	Dist.	Ref.
L1	Repository (Basalt)	[10][c]	d	NA	7E-3-1E-2 (0.18)[g]	1	U	[1E-7-1E-2]	e	LU	f	[3E-8-3E-0]	e	LU	f
L2	Dense Basalt	85-124 (21.8)	2	U	7E-3-1E-2 (0.18)	1	U	[1E-7-1E-6] (1E-3)	h	LN	3	3E-8-3E-6 (1.1E-6)	3	LN	i
L3	Brecciated Basalt	1.64E4	j	NA	1E-4-1E-3 (1.4E-3)	1	U	[1E-4-1E-2] (1E-3)	h	LU	f	3E-3-3E0 (5.2)	h	LU	i

a. References
   1. DOE, 1984
   2. Cross, 1983
   3. DOE, 1982

b. Distribution of Data
   NA - not applicable
   U - uniform
   LN - log normal
   LU - log uniform

c. [] - assumed values, see Ref. column for explanation

d. assumed length of canisters

e. repository is hypothetical, assumed properties are full range of dense and brecciated basalt

f. type of distribution is not known, can be varied in sensitivity analysis

g. () - input into or results from preliminary run of SNLA basalt methodology

h. These values estimated from the relationship between porosity (Leonhart and others, 1982) and conductivity (DOE, 1982) for the McCoy Canyon flow top

i. distribution assumed same as for porosity because of close relationship between porosity and conductivity (see Note h).

j. equivalent to 5 km distance to accessible environment

Mineralogy of Rock Types

Table B-2 lists the modal mineralogy of nine samples of Cohassett flow interior from drill hole RRL-2 (Figure B-5). Whereas the samples are differentiated with respect to being from the colonnade or from the entablature portion of the flow, this distinction is not practical at this point in the site analysis. Table B-3 lists the relative percent of minerals in fractures for samples of Cohassett flow interior from RRL-2. Table B-4 lists the estimated volume percent of the minerals in fractures for samples from RRL-2. This estimated volume percent is based on the volume percent of the minerals in fractures, the mean width of the fractures, and the estimated number of fractures per unit volume of the Cohassett basalt.

No data are available for the mineralogy of the flow-top breccia. Because the breccia was exposed to weathering at the surface after deposition and because the relatively high porosity has allowed large volumes of ground water to flow through the pores since burial, the breccia should be more highly altered than the flow interior. Use of the same mineralogy as the flow interior will underestimate the amounts of minerals that can cause retardation of radionuclides.

Table B-2. Modal mineralogy of Cohassett basalt based on nine samples from drill hole RRL-2 (data from Long, 1983).

Mineral/Component	Colonnade	Entablature	Total Range
Plagioclase	38.38 - 45.38	29.38 - 36.77	29.38 - 45.38
Pyroxene	23.50 - 28.28	13.10 - 19.50	13.10 - 28.28
Mesostasis	20.37 - 29.03	36.03 - 50.20	20.37 - 50.20
Fe-Ti Oxide	2.38 - 3.50	2.28 - 3.13	2.28 - 3.50
Apatite	0.45 - 1.13	Tr[b] - 0.05	Tr - 1.13
Alteration Products [a]	1.80 - 7.40	4.73 - 11.53	1.80 - 11.53
Others	0.63 - 1.93	Tr - 0.08	Tr - 1.93
Sulfide Blebs	Tr - 0.13	Tr - 0.03	Tr - 0.13

a. alteration product is clay, except for trace amounts of zeolite and silicon

b. Tr = Trace amount

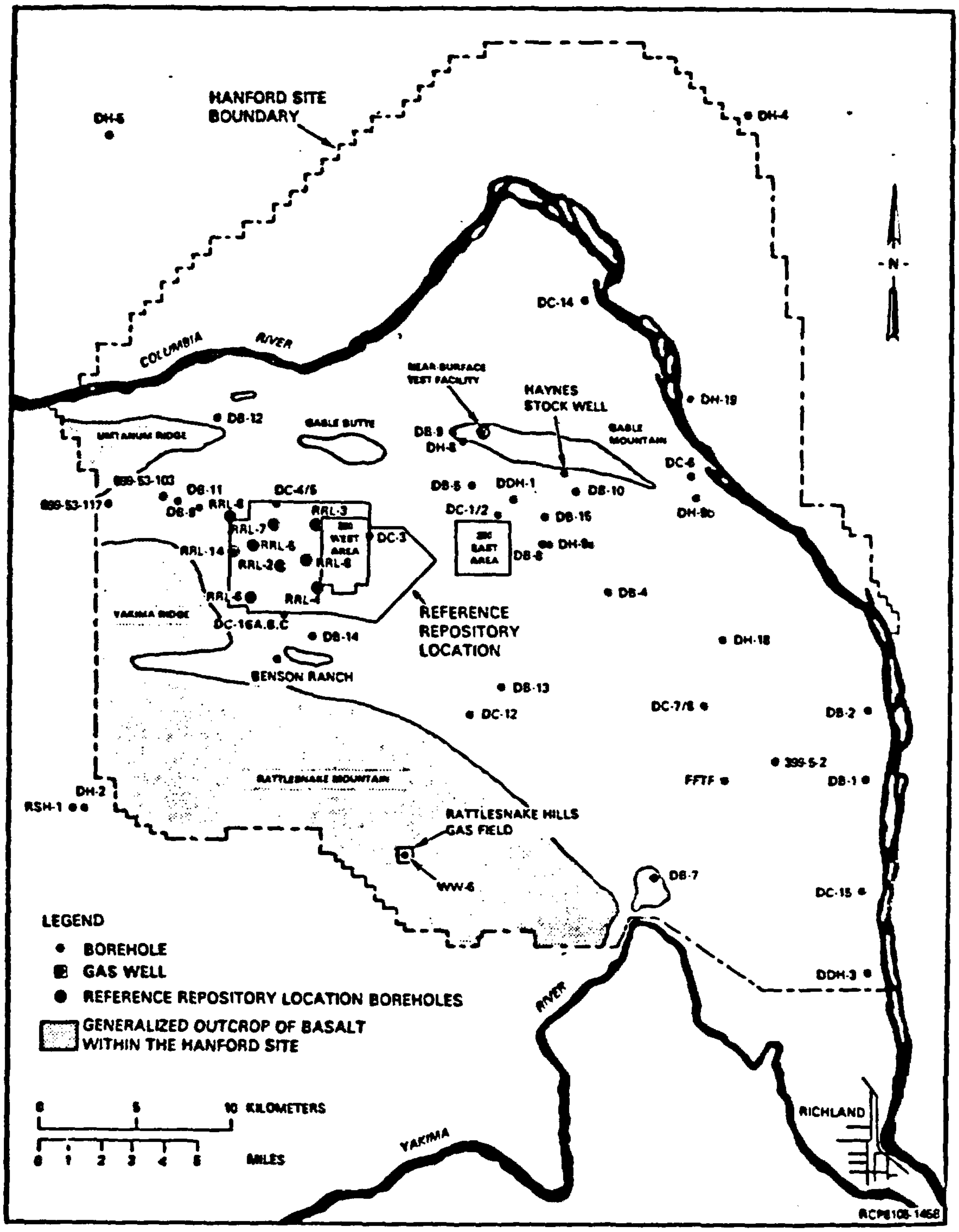


Figure B-5. Location of key drill holes, Basalt Waste Isolation Project (DOE, 1982).

Table B-3. Relative percent infilling material in fractures for samples of Cohasset basalt from RRL-2 (after Long, 1983)

Volume %

Rock Type	Clay	Zeolite	Silica	Pyrite	Mean Fracture Width (mm)
Entablature	97	3.3	0.03	0.01	0.15
Colonnade	88	10	1.8	0.4	0.12
Overall	89	9.3	1.2	0.2	0.13

Table B-4. Estimated volume percent of core comprised of fractures and infilling material, Cohasset basalt, drill hole RRL-2 (after Long, 1983)

Volume %

Rock Type	Clay	Zeolite	Silica	Pyrite	Total
Entablature	0.21	0.007	0.0001	0.00002	0.22
Colonnade	0.088	0.01	0.0018	0.0004	0.10
Overall	0.12	0.012	0.0016	0.00003	0.13

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