U.S. GEOLOGICAL SURVEY RESEARCH IN RADIOACTIVE WASTE DISPOSAL--FISCAL YEAR 1982

By Robert Schneider and N. J. Trask

U.S. GEOLOGICAL SURVEY

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SI UNITS AND INCH-POUND SYSTEM EQUIVALENTS

[SI, International System of Units, a modernized metric system of measurement. All values have been rounded to four significant digits except 0.01 bar, which is the exact equivalent of 1 kPa. Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to measurement of land or water areas. Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases; no prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it. Note that the style of meter^2 rather than square meter has been used for convenience in finding units in this table. Where the units are spelled out in text, Survey style is to use square meter]

SI unit		Inch-Pound equivalent	
Length			
millimeter (mm)	=	0.039 37	inch (in)
meter (m)	=	3.281	feet (ft)
	=	1.094	yards (yd)
kilometer (km)	=	0.621 4	mile (mi)
	=	0.540 0	mile, nautical (nmi)
Area			
centimeter^2 (cm^2)	=	0.155 0	inch^2 (in^2)
meter^2 (m^2)	=	10.76	feet^2 (ft^2)
	=	1.196	yards^2 (yd^2)
	=	0.000 247 1	acre
hectometer^2 (hm^2)	=	2.471	acres
	=	0.003 861	section (640 acres or 1 mi^2)
kilometer^2 (km^2)	=	0.386 1	mile^2 (mi^2)
Volume			
centimeter^3 (cm^3)	=	0.061 02	inch^3 (in^3)
decimeter^2 (dm^3)	=	61.02	inches^3 (in^3)
	=	2.113	pints (pt)
	=	1.057	quarts (qt)
	=	0.264 2	gallon (gal)
	=	0.035 31	foot^3 (ft^3)
meter^3 (m^3)	=	35.31	feet^3 (ft^3)
	=	1.308	yards^3 (yd^3)
	=	264.2	gallons (gal)
	=	6.290	barrels (bbl) (petroleum, 1 bbl = 42 gal)
	=	0.000 810 7	acre-foot (acre-ft)
hectometer^3 (hm^3)	=	810.7	acre-feet (acre-ft)
kilometer^3 (km^3)	=	0.239 9	mile^3 (mi^3)
Volume per unit time (includes flow			
decimeter^3 per second (dm^3/s)	=	0.035 31	foot^3 per second (ft^3/s)
	=	2.119	feet^3 per minute (ft^3/min)

SI unit		Inch-Pound equivalent	
Volume per unit time (includes flow)—Continued			
decimeter^2 per second (dm^3/s)	=	15.85	gallons per minute (gal/min)
	=	543.4	barrels per day (bbl/d) (petroleum, 1 bbl = 42 gal)
meter^3 per second (m^3/s)	=	35.31	feet^3 per second (ft^3/s)
	=	15 850	gallons per minute (gal/min)
Mass			
gram (g)	=	0.035 27	ounce avoirdupois (oz avdp)
kilogram (kg)	=	2.205	pounds avoirdupois (lb avdp)
megagram (Mg)	=	1.102	tons, short (2 000 lb)
	=	0.984 2	ton, long (2 240 lb)
Mass per unit volume (includes density)			
kilogram per meter^3 (kg/m^3)	=	0.062 43	pound per foot^3 (lb/ft^3)
Pressure			
kilopascal (kPa)	=	0.145 0	pound-force per inch^2 (lbf/in^2)
	=	0.009 869	atmosphere, standard (atm)
	=	0.01	bar
	=	0.296 1	inch of mercury at 60°F (in Hg)
Temperature			
temp kelvin (K)	=	[temp deg Fahrenheit (°F) + 459.67]/1.8	
temp deg Celsius (°C)	=	[temp deg Fahrenheit (°F) − 32]/1.8	

U.S. Geological Survey Research in Radioactive Waste Disposal--Fiscal Year 1982

By

Robert Schneider and N. J. Trask

ABSTRACT

The report summarizes progress on geologic and hydrologic research related to the disposal of radioactive wastes. The research is described according to whether it is related most directly to: (1) high-level and transuranic wastes; (2) low-level wastes, or (3) uranium mill tailings. Included is research applicable to the identification and geohydrologic characterization of waste-disposal sites, to investigations of specific sites where wastes have been stored, and to studies of regions or environments where waste-disposal sites might be located. A significant part of the activity is concerned with techniques and methods for characterizing disposal sites and studies of geologic and hydrologic processes related to the transport and (or) retention of waste radionuclides.

INTRODUCTION

It is generally recognized that the transport of radionuclides to the human environment from radioactive wastes at or below the land surface will involve water. The transport of water and its solutes is related to the hydrologic features of the environment which, in turn, are controlled by climatic, topographic, geologic, and geochemical conditions. Owing to the long half lives of some waste radionuclides, certain wastes need to be isolated from the human environment for such long periods of time that it becomes necessary, in selecting disposal sites, to take into account the effects of dynamic geologic processes which could change the hydrologic regime and alter rates and directions of subsurface radionuclide transport. For these reasons and because the U.S. Geological Survey (USGS) is the principal earth-science agency in the Federal Government, the various agencies concerned with nuclear facilities and testing nuclear weapons have requested the advice of the USGS for many years on the relation of geology and hydrology to the isolation of radioactivity from the biosphere.

The research of the USGS as a whole, includes almost every area of earth science. The specific research activities described in this report are part of the USGS program that is directly related to radioactive waste disposal. They include geologic and hydrologic research of general applicability to the identification and characterization of waste disposal sites, investigations of specific sites where wastes have been stored, and studies of regions or environments where disposal sites might be located. The activities discussed in this report are divided arbitrarily into three

categories according to whether they relate most directly to: (1) high-level and transuranic wastes[1/], (2) low-level wastes[2/], and (3) uranium mill tailings.

Some of the generic research in the section on high-level and transuranic wastes, particularly the work on techniques and methods for characterizing disposal sites and studies of geologic and hydrologic processes, could also be applicable to low-level waste disposal. Conversely, the section on low-level wastes includes research on geologic and hydrologic processes that could be useful in problems related to the disposal of high-level and transuranic wastes.

This is the fourth report of progress of USGS research in radioactive waste, the previous one being by Schneider and Trask (1983)[3/].

[1/]High-level wastes include fission products that initially have a high level of beta and gamma radiation and a high rate of heat generation; they also include transuranic elements with a long toxic life. Transuranic waste contains long-lived alpha emitters at concentrations greater than 10 nCi/g and generates little or no heat.

[2/]The term low-level wastes has carried a changing and imprecise definition over the years. Currently, it generally means waste which does not fit the definition of high-level waste and in which the concentration of transuranic elements is less than 10 nCi/g. It consists in part of miscellaneous solid materials that have been irradiated and contaminated through use as well as products of reactors and fuel reprocessing plants.

[3/]Schneider, Robert, and Trask, N.J., 1983, U.S. Geological Survey Research in Radioactive Waste Disposal - Fiscal Year 1981: U.S. Geological Survey Water Resources Investigation Report 83-4105, 122 p.

RELATION TO PROGRAMS OF OTHER AGENCIES

For more than 30 years, the USGS, Department of the Interior (DOI), has provided technical consultation to the Department of Energy (DOE) and its predecessors, the Energy Research and Development Administration and the Atomic Energy Commission. The USGS has also assisted the Department of Defense; the Nuclear Regulatory Commission (NRC); and the Environmental Protection Agency (EPA). The work has included assistance to the DOE staff at Germantown, Maryland, and Columbus, Ohio. A variety of regional and detailed geologic and hydrologic studies and generic research related to waste disposal has been conducted at the Savannah River Plant, South Carolina; Oak Ridge National Laboratory, Tennessee; Idaho Nuclear Engineering Laboratory; the Hanford Reservation, Washington; and to weapons testing and(or) waste disposal at the Nevada Test Site and other localities. These activities are referred to collectively as cooperative programs in contrast to those activities supported by direct Congressional appropriations to the USGS.

With regard to high-level and transuranic wastes, the specific responsibility for selection of sites for waste repositories, as well as their design, lies with the DOE. The NRC and EPA are responsible for licensing the facilities and establishing criteria for judging their environmental effects. The DOE program, known as the National Waste Terminal Storage (NWTS) program, includes support for cooperative investigations by the USGS. The part of the USGS research on high-level wastes that is funded by its own appropriations is designed to complement and augment the DOE program and to provide needed information from an agency that has neither operational nor regulatory responsibilities in waste disposal.

Some sites being studied in foreign countries have provided the opportunity for the USGS to conduct research of mutual benefit to both countries. Some research on borehole geophysical logging is being conducted in cooperation with Atomic Energy of Canada, Limited, at the Underground Research Laboratory in southeastern Manitoba. The geochemistry of ground waters at the Stripa mine site in Sweden is under study in cooperation with the Swedish Nuclear Fuel Supply Company/Nuclear Fuel Safety Project which is operated for the Swedish Nuclear Power Utility Industry (see section on Geochemistry of trace elements in natural waters).

For several years, the USGS has been conducting specific geohydrologic studies at low-level disposal sites on behalf of the DOE at the Idaho National Engineering Laboratory and at the Oak Ridge National Laboratory, Tennessee.

Starting in fiscal year 1982, investigations of low-level waste disposal were conducted for the NRC at Sheffield, Illinois and West Valley, New York.

BUDGET SUMMARY -- FISCAL YEAR 1982
(in millions of dollars)

High-level and transuranic wastes and related generic research		
USGS appropriation	4.3	
DOE transfer of funds	6.0	
		10.3
Low-level wastes and related research on geologic and hydrologic processes		
USGS appropriation	2.3	
DOE transfer of funds	0.7	
		3.0
Uranium mill tailings		
USGS appropriation	0.1	
		0.1
Total		13.4

HIGH-LEVEL AND TRANSURANIC WASTES

GEOLOGICAL SURVEY PROGRAM FOR IDENTIFYING ENVIRONMENTS SUITABLE FOR DISPOSAL OF HIGH-LEVEL WASTE

By M. S. Bedinger and K. A. Sargent, Lakewood, Colo.

Screening activities to locate sites for radioactive waste repositories have been underway for many years, principally outside the USGS. Typically, they involve the study of successively smaller geographic regions with a progressive increase in the level of detail of study. Only recently, however, has there been an appreciation of the need to consider, at the earliest stage of this process, geohydrologic factors that can provide multiple barriers to radionuclide migration (Interagency Review Group on Nuclear Waste Management, 1979, p. 37-43). The term multiple barriers includes man-made barriers and natural barriers in the form of specified hydrodynamic, geochemical, and geologic characteristics that would impede radionuclide transport. The factors of most significance include a tectonically stable environment, a host rock of low permeability in a flow system with long flow paths to discharge areas downgradient from the repository, and the occurrence in the flow system of rocks of high sorptive capacity. Previously, attention was focused almost exclusively on the potential host rock, particularly its stability. While the host rock remains important, its characteristics must be considered in conjunction with the types of hydrologic and geologic barriers mentioned above.

This study is part of the USGS high-level waste program which was started in fiscal year 1979 with direct Congressional appropriations. Owing to the fact that the DOE has the responsibility for selecting sites, the overall program is closely coordinated with the DOE.

Objective: To identify or contribute to the identification of geohydrologic environments with hydrodynamic, geochemical, and geologic characteristics which provide independent, multiple, natural barriers to the migration of radionuclides and which may warrant intensive study.

Approach: Eleven broad physiographic provinces, encompassing the 48 conterminous states, have been identified as the basic land units in the proposed national screening process. During the screening, the provinces will be subdivided successively into regions, areas, and potential sites. The approach will generally follow the plan proposed by a subgroup of the DOE-DOI Working Group that developed the Earth Science Technical Plan (ESTP), (U.S. Department of Energy and U.S. Geological Survey, Subgroup I of the ESTP Working Group, 1980). Using the Basin and Range Province as a test area, the study will be conducted by a group of State and Federal earth scientists comprising a Province Working Group. The approach stresses the concept of identifying environments with relatively independent, multiple barriers to nuclide transport.

Progress: The Province Working Group, composed of representatives from the participating states of Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah, and two members of the U.S. Geological Survey, was organized and met to establish Province screening guidelines, to examine geologic and hydrologic data which had been assembled for the Province, and to review evaluations of parts of the Province that appeared to be suitable for further study.

Data were compiled for the Province on the distribution of selected rock types, mineral resources, seismic activity, late Cenozoic volcano-tectonic features, areal gravity and magnetic features, ground-water levels, Pleistocene lakes and marshes, and water quality. Ground-water flow systems were delineated, and areas where the depth to water was greater than 150 m were outlined. Depiction of the data on maps of individual States at 1:500,000 scale and of the Province at 1:2,500,000 scale was begun for release as map reports. Guidelines for evaluating geohydrologic environments in the Basin and Range Province were established and described in Part I of USGS Circular 904 on Province characterization and evaluation, (Bedinger, Sargent, and Reed, in press).

The initial evaluation to identify prospective environments for isolation of high-level waste, resulted in the identification of six regions where further study and evaluation appeared to be warranted (fig. 1). Reports on the characterization of the Province, Part II, and evaluation of the Province, Part III, were begun.

Report

Bedinger, M.S., 1982, Hydrologic features of flow systems in the Basin and Range Province (abs.): Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 148.

References

Interagency Review Group on Nuclear Waste Management, 1979, Report to the President by the Interagency Review Group on Nuclear Waste Management: Springfield, Virginia, National Technical Information Service, TID 29442.

U.S. Department of Energy and U.S. Geological Survey, Department of the Interior Subgroup I of Earth Science Technical Plan Working Group, 1980, Plan for identification and geological characterization of sites for mined radioactive waste repositories: U.S. Geological Survey Open-File Report 80-686, 73 p.

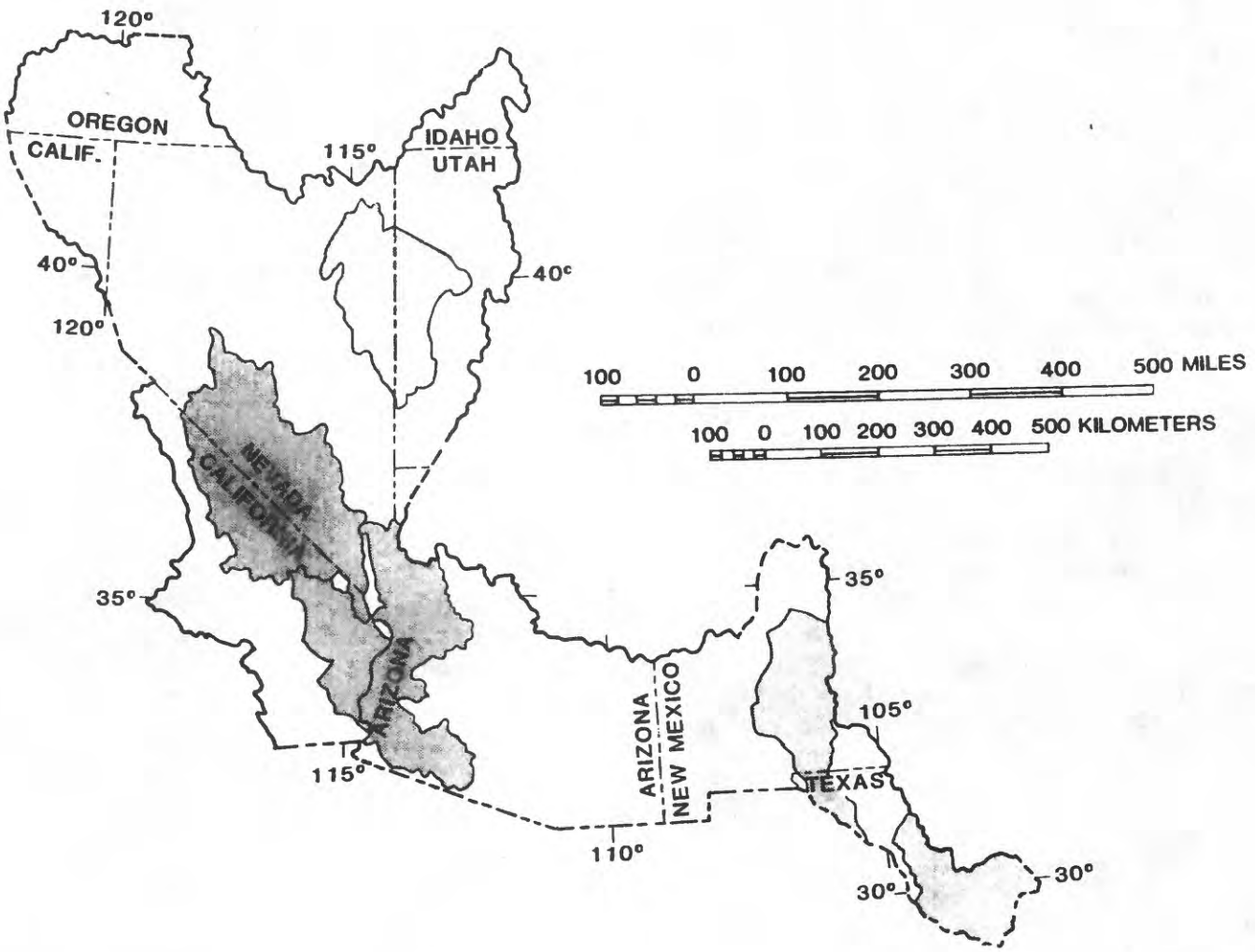


Figure 1.--Basin and Range Province showing regions selected for further study.

DEPARTMENT OF ENERGY PROGRAM FOR LOCATING AND CHARACTERIZING DISPOSAL SITES

The Geological Survey is conducting various scientific investigations for the DOE which has the responsibility for developing repositories for the permanent isolation of nuclear wastes. The DOE's National Waste Terminal Storage program, established in 1976, is composed of three separate coordinated elements which include many investigations related to locating and characterizing disposal sites: the technical program of the Office of Nuclear Waste Isolation (ONWI) of Battelle Memorial Institute located in Columbus, Ohio; the Basalt Waste Isolation Project (BWIP) in Hanford, Washington; and the Nevada Nuclear Waste Storage Investigations (NNWSI) at the Nevada Test Site (NTS). This section of the report is confined to those DOE investigations for which the USGS is conducting research. The ONWI investigations, in which the USGS is involved, include the Paradox Basin, Utah, and the Gulf Coast salt-dome region. The Geological Survey is also carrying out geologic and hydrologic investigations related to the Waste Isolation Pilot Plant near Carlsbad, New Mexico, which is intended for the storage of defense generated nuclear waste. This latter work is being done for the DOE's Albuquerque Operations Office.

Nevada Test Site and Vicinity

The USGS has been assisting the DOE in evaluating the suitability of various geohydrologic environments and rock masses for locating repositories on or near the Nevada Test Site (NTS) for the disposal of commercially generated high-level radioactive wastes and wastes from DOE facilities. An essential part of this work is defining the geology and hydrology of the area in order to assess the potential for the transport of radionuclides from a repository to the human environment. In addition, the potential for disruption of a repository as a result of volcanic or tectonic activity or accelerated erosion is being evaluated.

Search for Potential Sites

By Gary L. Dixon and V. M. Glanzman, Lakewood, Colo.

Objective: To locate and characterize rock masses at the NTS and in southern Nevada that are potentially suitable as host media for high-level commercial radioactive wastes and to describe the areal and depth distributions and structure of these rock masses.

Approach: From previous geologic work at NTS, the general geology is well known. Areas likely to have suitable host rocks and hydrologic conditions at depths appropriate for a repository are evaluated by detailed surface mapping, surface geophysical methods, exploratory drilling, and borehole geophysical techniques.

Progress: Efforts were concentrated on characterizing the structural and stratigraphic setting at the Yucca Mountain site (fig. 2). Detailed mapping of intra-cooling units within the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff (table 1) was completed both within and in areas adjacent to Yucca Mountain. Mapping and fracture studies have identified previously undetected faults of small displacement and prominent fracture sets. Based on these structural studies, the area of interest has been divided into six blocks, as indicated on figure 3. Within the northern and central blocks, density of faults is relatively low. Right-lateral strike-slip movement is evident on a few of the northwest-trending fault planes, particularly in the northern block. The two blocks are separated by a subsurface fault and fracture system extending northwestward along Drill Hole Wash. The eastern block, where most structures strike northeast and dip toward the northwest, has a significantly greater number of structural discontinuities. In contrast, many small-scale structures that consistently trend toward the northwest, have been identified within the area designated as Abandoned Wash block on figure 3. Several continuous, subparallel, normal faults of large displacement, associated with zones of breccia, cut the Solitario Canyon block. Mapping of the western block is continuing.

Two prominent fracture sets have been identified at Yucca Mountain. The dominant set ranges in strike from N. 10°W. to N. 40°W., whereas the other strikes from N. 10°E. to N. 35°E. The fracture density commonly varies from 20 to 40 fractures per cubic meter within core of the densely welded portion of the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff, but commonly is less than 1 fracture per cubic meter in nonwelded tuff (Scott and others, 1983).

Detailed subsurface geologic data, collected from locations along the margins of the Yucca Mountain site, indicate that almost all of the major stratigraphic units beneath the central and eastern blocks strike in directions varying from N. 11°W. to N. 5°E., and dip eastward 5 to 8° (fig. 4). In contrast, subsurface units beneath the northern and western blocks strike N. 19°W. to N. 81°E. and dip 3 to 10° to the northeast and southeast, and at the southern margin of the area, strike between N. 22° W. and N. 77°E. and dip 0 to 20° to the southeast, northeast, and northwest. Almost all major units (table 1) are continuous throughout the area of interest except the Yucca Mountain and Pah Canyon Members of the Paintbrush Tuff and the flow breccia, all of which pinch out from north to south. Within the central block, the Topopah Spring Member of the Paintbrush Tuff and tuffaceous beds of Calico Hills range in thickness from 296 to 369 m and 26 to 143 m, respectively. Data from drill holes along the crest of Yucca Mountain show that the entire section designated as the tuffaceous beds of Calico Hills consists of vitric ash-flow tuff and bedded tuff in contrast to locations closer to the static water level, where the same interval has undergone pervasive zeolitization. The Bullfrog Member of the Crater Flat Tuff shows the greatest range in thickness - 96 to 184 m from north to south - of the geologic units in the Crater Flat Tuff within the central block.

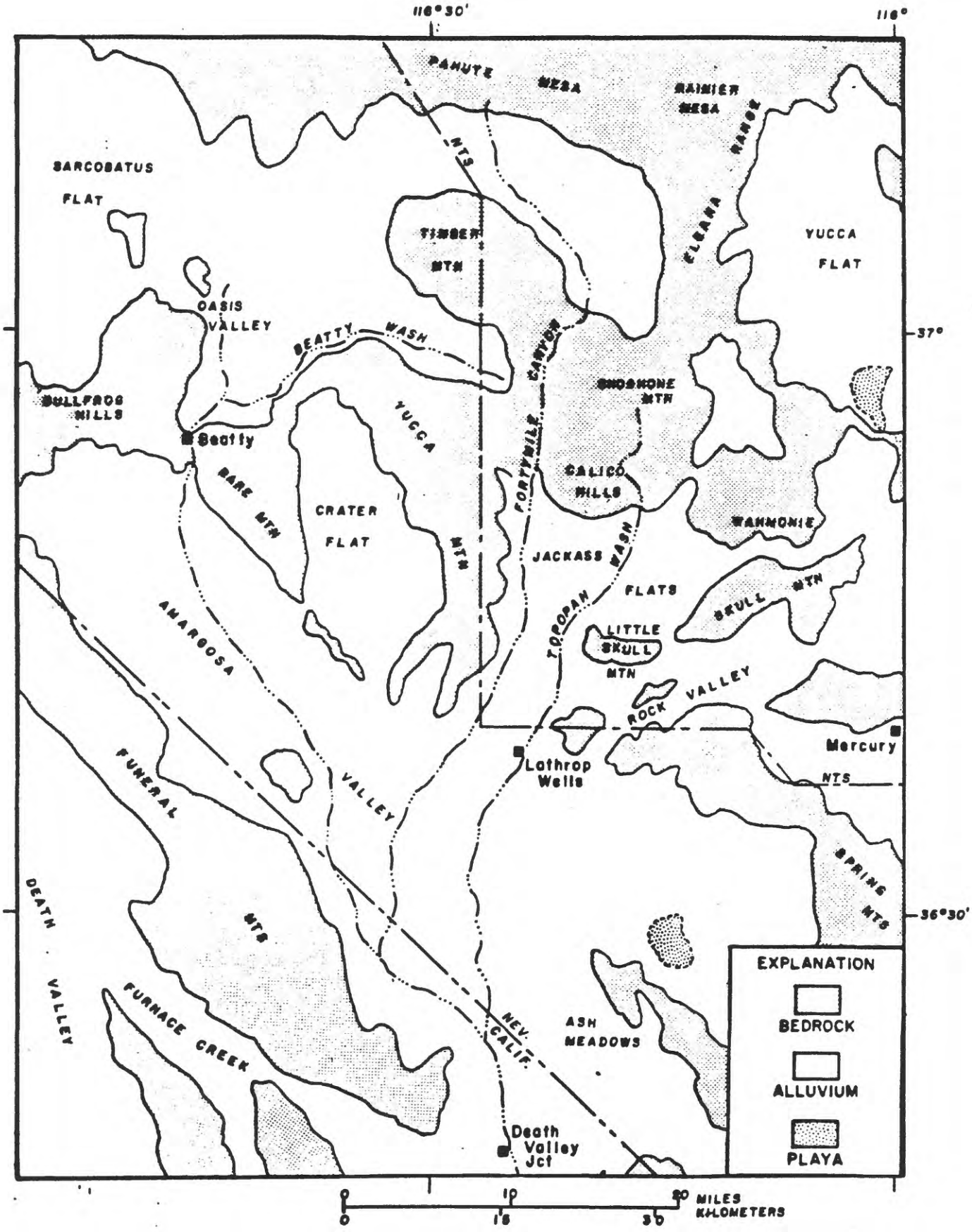


Figure 2.--Location of Yucca Mountain, Nevada.

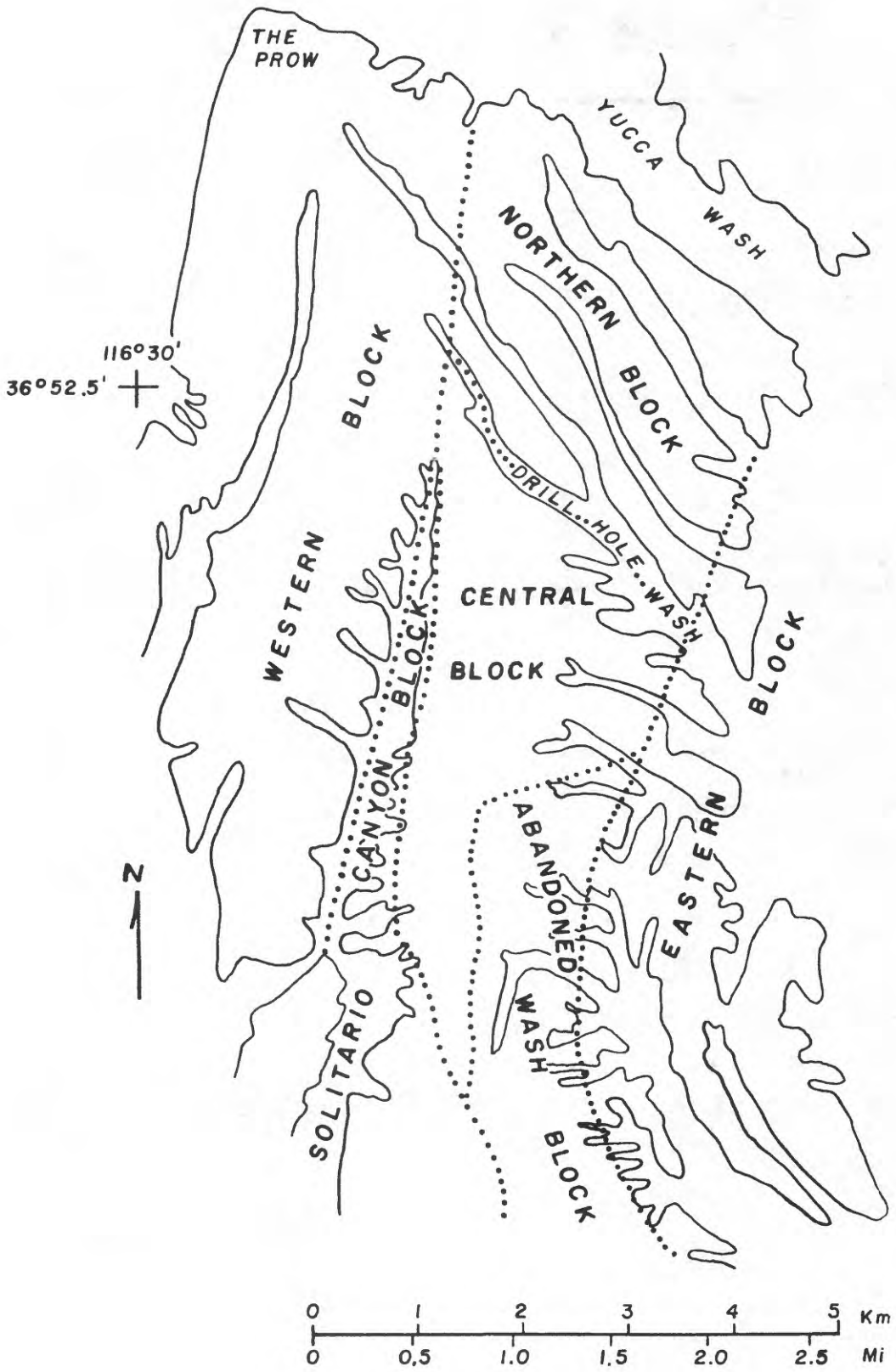
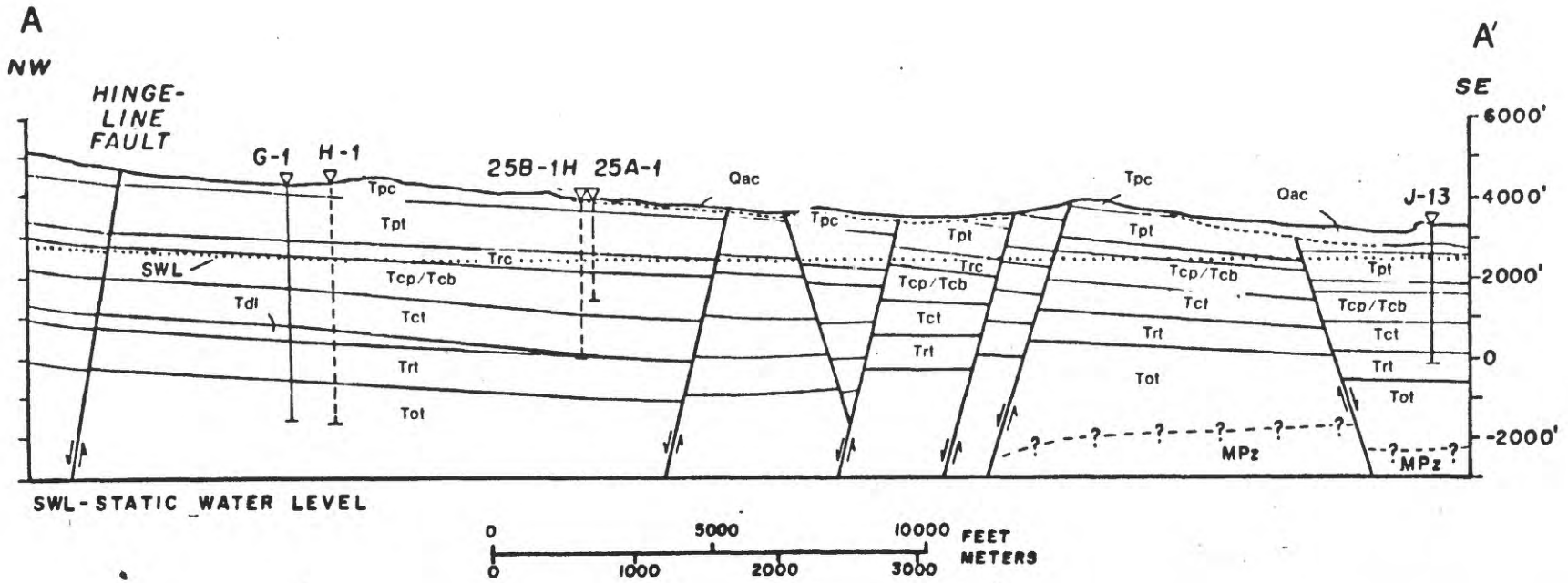


Figure 3.--Structural blocks at Yucca Mountain, Nevada.

Table 1.--Major geologic units identified in drill holes, Yucca Mountain, Nevada Test Site and Vicinity

Rock unit	Range of thickness[1] Feet	Meters
Alluvium and colluvium----------	0-150	(0-45.7)
Paintbrush Tuff (Miocene)		
Tiva Canyon Member----------	0-243	(0-74.1)
Yucca Mountain Member----------	0-100	(0-30.5)
Bedded tuff----------	0-155	(0-47.3)
Paintbrush Tuff (cont'd.)		
Pah Canyon Member----------	35-261	(10.7-79.6)
Topopah Spring Member----------	995-1,225	(303.4-373.5)
Tuffaceous beds of Calico Hills---------	353-947	(107.6-288.7)
Crater Flat Tuff (Miocene)		
Prow Pass Member----------	373-597	(113.7-182.0)
Bullfrog Member----------	300-521	(91.5-158.9)
Tram unit----------	499-1,078	(152.2-328.7)
Dacite lava and flow breccia----------	0-392	(0-119.5)
Tuff of Lithic Ridge----------	632-994	(192.7-303.1)
Older ash-flow and bedded tuffs---------	47-1,060	(14-323)
Flow breccia and lava (Drill hole USW-G2)	0-1,132	(0-345)

[1]Thickness includes thin bedded tuffs underlying each ash-flow tuff.



Qac	Alluvium	Tct	Tram unit of Crater Flat Tuff
Tpc	Tiva Canyon Member of Paintbrush Tuff	Tdl	Dacite flow breccia
Tpt	Topopah Spring Member of Paintbrush Tuff	Trt	Tuff of Lithic Ridge
Trc	Tuffaceous beds of Calico Hills	Tot	Older tuffs (Tertiary)
Tcp/Tcb	Prow Pass and Bullfrog Members of Crater Flat Tuff	MPz	Mesozoic and Paleozoic rocks

Figure 4.--Diagrammatic geologic cross-section of Yucca Mountain area, Nevada. (Location shown on fig. 5).

A decrease in gravity to the northwest in the vicinity of Drill Hole Wash has been interpreted by Snyder and Carr (1982) as being associated with the eastern edge of an extinct caldera centered over Crater Flat, where the modeled depth to basement (Paleozoic rocks) is about 2,400 m below sea level or about 3,500 m below the surface of Crater Flat. The model shows, however, that the depth to basement may be as shallow as about 1 km under the southeast part of Yucca Mountain. Gravity work is continuing to better define depth to basement and to provide gravity control across an east-west magnetic high that crosses the potential repository site about 2 km south of Drill Hole Wash.

Aeromagnetic and ground magnetic anomalies are being analyzed to interpret the geologic structure in a 165-square-kilometer area that includes the proposed repository site at Yucca Mountain. Short-wavelength aeromagnetic data, measured 120 m above the surface, and ground traverses have defined anomalies produced by faulted volcanic flows. Analysis of anomalies near the traces of known faults has revealed details of the structure of the flow comprising the Topopah Spring Member of the Paintbrush Tuff, particularly near the Solitario Canyon block. Longer wavelength aeromagnetic anomalies, measured 1 km above the surface, indicate possible intrusive and associated metamorphosed sedimentary rocks buried beneath the volcanic flows. These anomalies extend westward into the potential repository area from Calico Hills. An east-west anomaly of intermediate wavelength crosses the central part of the small area proposed for the repository, and results from a still unknown source deep within the volcanic pile. The anomaly is poorly defined by east-west air traverses 120 m above the surface, and north-south aeromagnetic and ground traverses are currently being measured to provide data of better resolution.

Magnetic properties were measured at intervals of about 3 m in core from drill holes USW G-1 and USW G-2 (fig. 5). Measurements have identified a number of units, both normal (N) and reversed (R), as potential sources of magnetic anomalies. In descending stratigraphic order the units which are observed to possess an average total magnetization of greater than 1 A/m (amperes per meter) over a stratigraphic interval of at least 60 m at one or more localities are: Tiva Canyon (R), Pah Canyon (R), and Topopah Spring (N); Members of the Paintbrush Tuff; Bullfrog Member (N) and Tram unit (R) of the Crater Flat Tuff; and a dacite lava (N) encountered at a depth of nearly 1,800 m in drill hole USW G-2 at the northern end of Yucca Mountain.

In spite of numerous attempts to obtain seismic reflection information under Yucca Mountain, including state-of-the-art noise studies, no interpretable results have been attained. Geologic relations, based on seismic reflection data, can not be established.

Seismic refraction data collected from four explosions at the NTS have been interpreted in conjunction with information from local geologic studies, seismic refraction surveys, borehole measurements, and the subsurface density

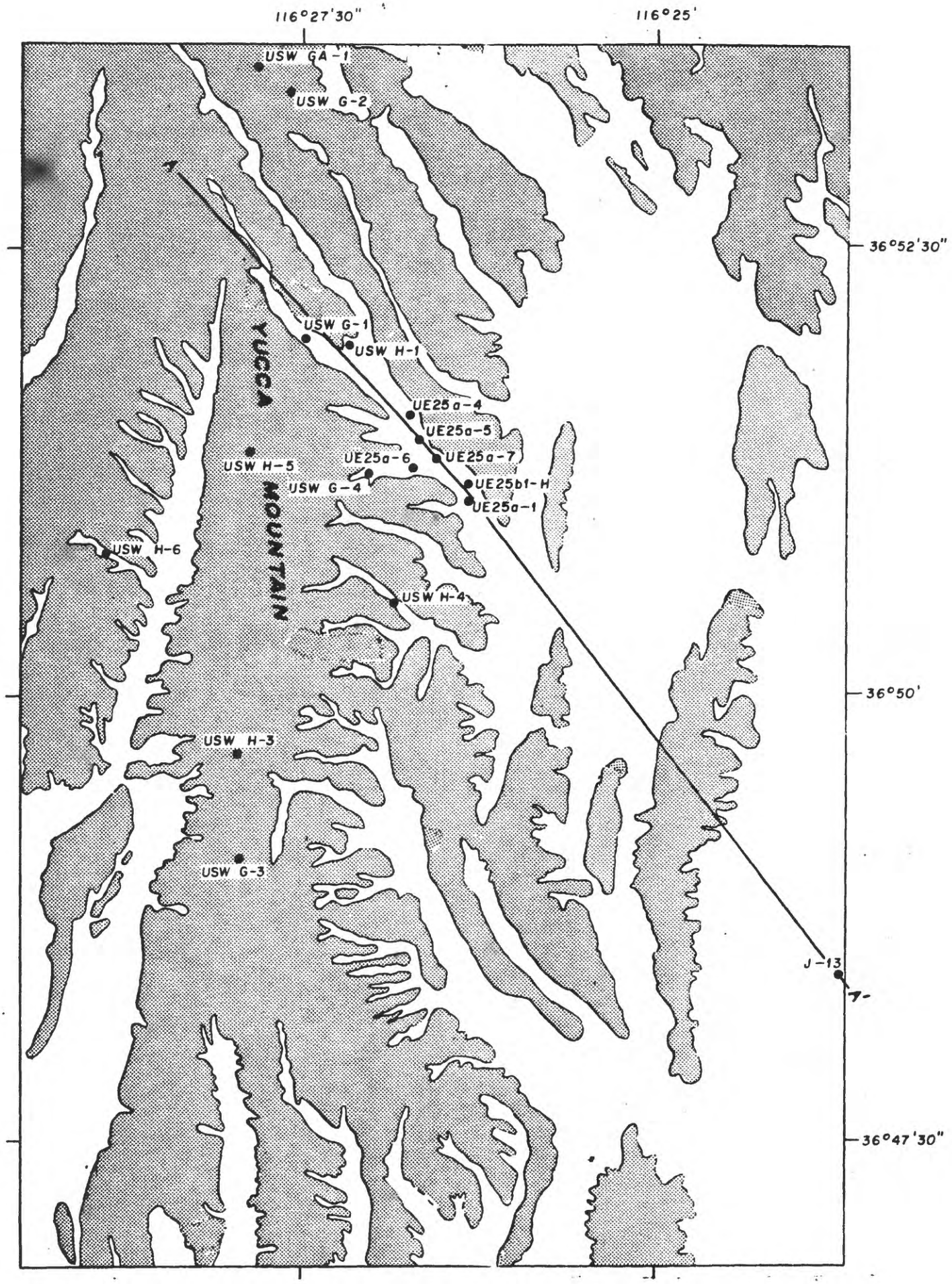


Figure 5.--Location of drill holes at Yucca Mountain, Nevada.

distribution as inferred from detailed gravity modeling. All of the refraction data are unreversed, are of high quality (showing excellent signal-to-noise ratio), and provide information concerning the structure to a depth of 3,962 m below Yucca Mountain. The data show large wave traveltime delays across Yucca Mountain and Crater Flat relative to the surrounding area, and a conspicuous midcrustal reflector. These observations have been used to develop a structural model in agreement with the gravity data, described below.

Single-ended refraction profiles provide only non-unique structural models. Therefore, the gravity model of Snyder and Carr (1982) was used as a starting model. The final model, obtained by raytrace calculations, shows Paleozoic rocks at a depth of 3,962 m beneath Crater Flat and Yucca Mountain (305 m deeper than the gravity model) and depicts a laterally heterogeneous cross-sectional structure from Bare Mountain to Jackass Flats. The prominent reflector is due to a crustal feature at a depth of 13 km below sea level beneath Yucca Mountain.

Sass and Lachenbruch (1982) reported on data acquired intermittently over the past two decades for 60 wells in and around the test site. In this region, there are 15 determinations of heat flow with values ranging from 29 to 130 mWm^{-2} (0.7 to 3.1 HFU). The complicated distribution of heat flow in this region is probably the result of hydrologic processes, both regional and local. Additional data acquired at Yucca Mountain support the working hypothesis that the site is part of the regional hydrologic system which controls the Eureka heat-flow low.

Physical-property measurements on core samples from boreholes UE25a-4, -5, -6, and -7 (fig. 3) indicate that patterns of variation noted on the plots of density, resistivity, and sonic velocity are notably similar to those of the porosity plot, demonstrating the overall dependence of the indicated rock properties on textural rather than compositional changes within the rock. Porosities of welded tuffs of the Topopah Spring Member of the Paintbrush Tuff averaged about 13 percent, whereas, the poorly consolidated bedded tuffs and ash flows of the overlying Yucca Mountain, Pah Canyon, and Tiva Canyon Members generally had porosities in excess of 40 percent. Despite the relatively high porosity of the welded tuffs, measured water permeabilities were low, in the range of 10-200 microdarcies. The low permeabilities can be attributed to the fine-grained nature of the rock and the apparent redistribution of unattached mineral grains within the pore spaces which tends to impede water flow. Remanent magnetization is 2-4 times greater than the induced magnetization, and thus is the major component responsible for producing the magnetic anomaly in the Yucca Mountain region.

Zones of high resistivity and correspondingly low porosity are evident in core from USW G-3 in the Topopah Spring Member of the Paintbrush Tuff, and the Bullfrog Member and central section of the Tram unit of the Crater Flat Tuff. These zones are associated with densely welded tuffs. The induced polarization response is typically above normal background. Zeolites and clay are generally the cause of the high polarization; however, in the tuff

of Lithic Ridge, the response has been enhanced by the presence of disseminated pyrite in addition to the other polarizing minerals.

Hydraulic fracturing stress measurements completed in hole USW G-1 in the depth interval from 645 to 1,288 m indicate that the least horizontal principal stress magnitudes are significantly lower than the vertical stress, as expected in normal faulting environments. The direction of the least principal stress was found to be about N. 75° W. The low minimum stress magnitudes measured in the borehole are near the values at which frictional sliding might be expected on normal faults striking about N. 15° E.

An acoustic borehole televiewer log was run between depths of 451 to 1,315 m in conjunction with the hydraulic fracturing measurements. The most striking aspect of the televiewer data was the extensive drilling-induced hydraulic fractures in the hole. The fractures apparently formed when fluid pressures during drilling exceeded the very low magnitude of the least principal stresses measured in the hole. Another aspect of the televiewer data was the indication of stress-induced borehole spalling throughout most of the length of USW G-1. The preferred orientation of this spalling in a WNW-ESE direction is consistent with expectations based on the directions of the horizontal principal stress as inferred from the drilling-induced hydraulic fractures. The occurrence of borehole spalling in a preferred direction, and the very consistent direction of drilling-induced hydraulic fracturing, is indicative that the principal horizontal stresses at USW G-1 are unequal in magnitude.

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Tectonics, Seismicity, and Volcanism of the Southern Great Basin

By W.J. Carr, Lakewood, Colo.; A.M. Rogers, Golden, Colo.; and
B.M. Crowe, Los Alamos National Laboratory, Los Alamos, New Mexico

Objective: To assess the potential for faulting, damaging earthquakes, recurrence of volcanism, and local acceleration of erosion in parts of the southern Great Basin.

Approach: Work is focusing on the region surrounding the southern part of the Nevada Test Site by (1) investigating the rate, intensity, and distribution of faulting, particularly during the last 10 m.y.; (2) monitoring and interpreting seismicity; (3) studying the history of volcanism and deriving estimates of the risk of recurrence of volcanism in certain areas; and (4) developing a better understanding of regional and local tectonics and structure in relation to hydrology and to rates of erosion and deposition. W.J. Carr and M.D. Carr are interpreting the tectonics and regional structure. D.L. Hoover and W.C. Swadley are analyzing the geomorphology and mapping and interpreting the surficial deposits. The work is done in close collaboration with A.M. Rogers on seismology, and J.N. Rosholt, B.J. Szabo, C.W. Naeser, and R.F. Marvin on geochronology. B.M. Crowe and D.T. Vaniman of Los Alamos National Laboratory are principal investigators of basaltic volcanism.

Progress: Tectonics--Cartographic and stratigraphic problems have delayed completion of several maps of the surficial deposits in the region around Yucca Mountain, but the Big Dune quadrangle has been reviewed and submitted for publication. Mapping was begun by R.L. Hay and R.E. Pexton of lake and spring deposits and alluvium in Ash Meadows, an important discharge area for ground water moving southward from parts of the Nevada Test Site. Preliminary results show that northerly trending normal faults are present in Plio-Pleistocene lake beds and tufas, and a few small faults with east to northeast trend cut surfaces of mid-Pleistocene age. Plio-Pleistocene tufa deposits are more abundant and widespread than those forming at present. Local swarms of travertine veins, representing former feeders for springs, occur at several newly-discovered locations, but they are no higher in elevation than those noted by Winograd and Doty (1980). Most of these veins are the same age, or slightly younger than Plio-Pleistocene alluvium, which is between about 1.0 and 2.5 m.y. in age.

Structural arrangement of the Paleozoic and Proterozoic rocks is important in understanding the hydrologic flow system at Yucca Mountain and in the southern NTS region. Preliminary results from work by M.D. Carr and S.A. Monsen on Paleozoic structure at Bare Mountain west of Yucca Mountain (fig. 6), indicate that Bare Mountain consists of rocks in both the lower and upper plates of a thrust fault that is probably part of a regional thrust system. Their work suggests that the structural situation is similar to that in the area to the east around Yucca Flat, where the CP thrust is

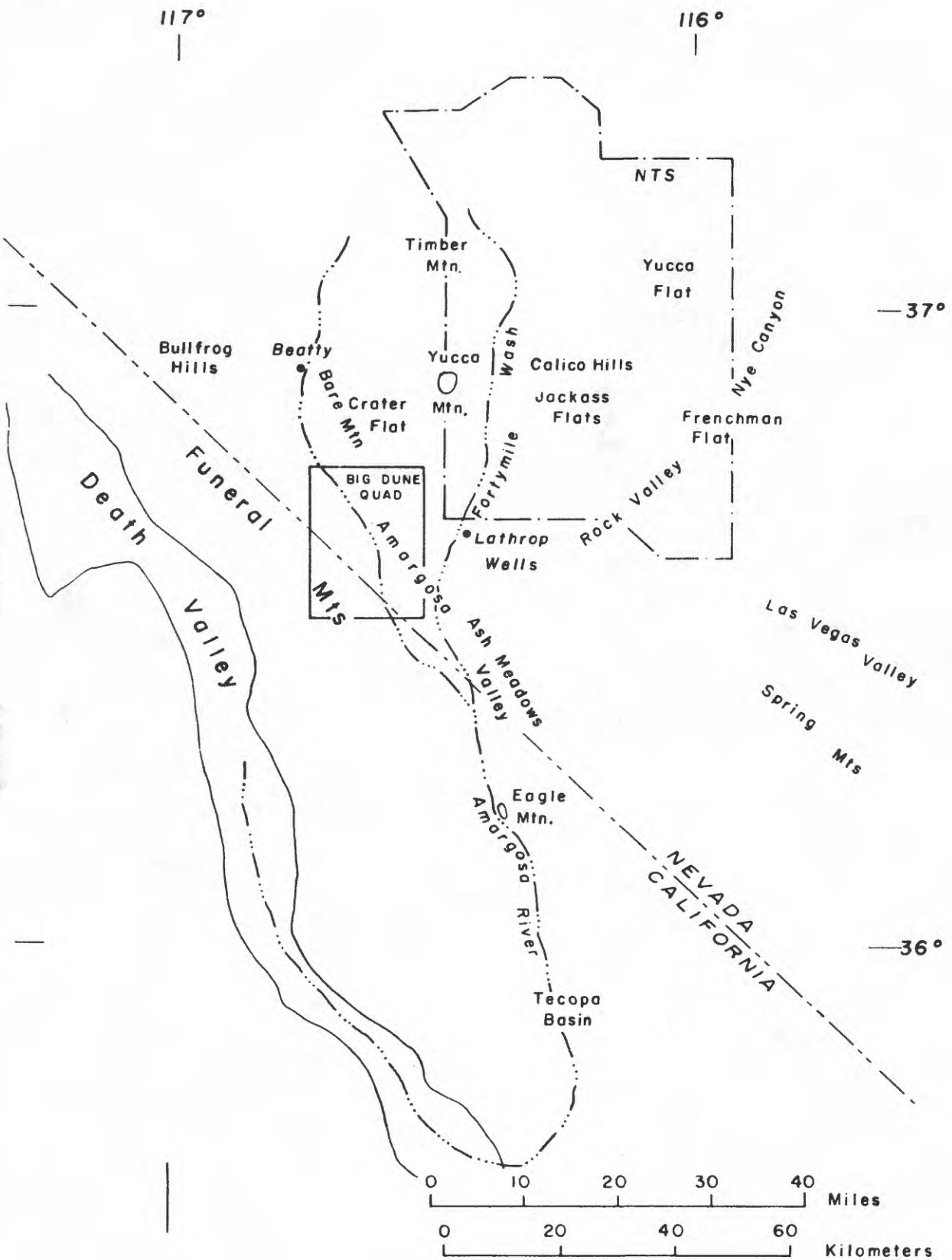


Figure 6.--Index map of southern Nevada Test Site region.

gently folded over the Eleana Range (fig. 2), and gravity-slide blocks have moved across portions of the Eleana Formation. Metamorphism as high as staurolite grade affects the Cambrian and Proterozoic rocks of the northwestern part of Bare Mountain. The metamorphism may be due, at least partly, to granitic plutons underlying Bare Mountain. These may be part of an east-trending zone of intrusives beneath the Bullfrog Hills, Bare Mountain, Yucca Mountain and Calico Hills. North-trending faults in the northwestern part of Bare Mountain show highly variable dips, but are basically right-lateral oblique-slip. Their relationship to Tertiary dikes indicates most of the displacement on these faults occurred more than about 14 m.y. ago.

About 17 trenches have been dug at Yucca Mountain in locations where alluvium overlies fault projections. No disturbance of Holocene materials has been found, and it is probable that in most cases the youngest alluvium affected by the faulting is at least 0.5 m.y. old, although the age of the youngest possible movement cannot be firmly established, other than pre-Holocene. A 10-m.y.-old basalt dike, previously thought to postdate the latest movement on the fault it intrudes, was found to be displaced at least a few feet.

A comparison of rates of vertical tectonic movement for various locations in the region during approximately the last 10 m.y., indicates that Yucca Mountain has been relatively stable during this period (Table 2). Although the rates determined are very approximate, they serve to place Yucca Mountain in a regional perspective and show its relative stability.

Seismicity--Earthquake data for the southern Great Basin are being collected from a network of 53 stations covering an area extending about 150 km from Yucca Mountain. Over 1,600 earthquakes have been located from 1979 through mid-1982; magnitudes ranged from about 0 to 4. The regional stress field favors activity on faults with north to northeast trend, but many areas, such as Yucca Mountain, remain seismically quiet.

The accuracy of relative locations of hypocenters was increased by the use of a revised crustal velocity model obtained from refraction and other data which differs significantly from that used previously (Rogers and others, 1981).

Station velocity anomalies were found to be largely due to near-surface velocity changes. These anomalies were used to improve earthquake locations for the entire catalog for 1978-1981, resulting in tighter trends and clusters and reduction of residuals and standard errors. The revised crustal model and relocated hypocenters permitted reevaluation of focal mechanisms presented previously (Rogers and others, 1981). For all those earthquakes analyzed, strike-slip mechanisms are indicated. Earthquake focal depths in the monitored part of the southern Great Basin are concentrated between 1 and 10 km; very few events occur below 10 km.

Table 2.--Approximate maximum rates of relative vertical tectonic movement in selected areas of the southwestern Great Basin during about the last 10 million years.

Location	Rate (m/1000 yr)	Comment
1/ Southern Amargosa	<0.01	Based on an ash bed in lake deposits about 5 m below the surface; "Ewing" clay pit, just north of Ash Meadows.
Yucca Mountain	0.04	Based on maximum of 460 m of offset of tuffs in last 11 m.y. For the Quaternary, a more realistic estimate is <0.01 m/1000 yr, based on maximum possible amount of displacement (20 m) of Quaternary deposits.
1/ Northwest part of Frenchman Flat	0.06	Ash bed at depth of 195 m in drill hole Ue5n; not in most active part of Frenchman Flat basin.
Southern part of Yucca Flat	0.16	Based on amount of displacement of a basalt in drill hole Ue1h at depth of 239 m; basalt is 8.1 m.y. old from K-Ar date (R.F. Marvin, written commun., 1980).
1/ Searles Valley, Calif.	0.22	Ash bed in core at depth of 691 m.

Location	Rate (m/1000 yr)	Comment
Death Valley-foot of Black Mountains, Calif.	0.3	Based on displacement of Artist's Drive Formation, which is 6-8 m.y. old according to Fleck (1970). Estimated to be about 1,500 m in 5 m.y.
Sierra Nevada-Owens Valley-White-Inyo Mountains, Calif.	0.4 (Range: 0.2-1.0)	Average of 9 estimates from various sources 2/ Quaternary rate is probably higher.

1/ Subsidence rate is based on an ash bed believed to be correlative at these three locations (Izett, 1981; Sarna-Wojcicki and others, 1980; R.L. Hay, written commun., 1979) and dated at about 3 m.y. by paleomagnetic, stratigraphic, K-Ar, and fission-track techniques (Liddicoat and Smith, 1979).

2/ Owens Valley, Calif. (Bachman, 1978); central Sierra Nevada, Calif. (Curry, 1971; and N.K. Huber, written commun., 1980); Mono Lake basin, Calif. (Gilbert and others, 1968).

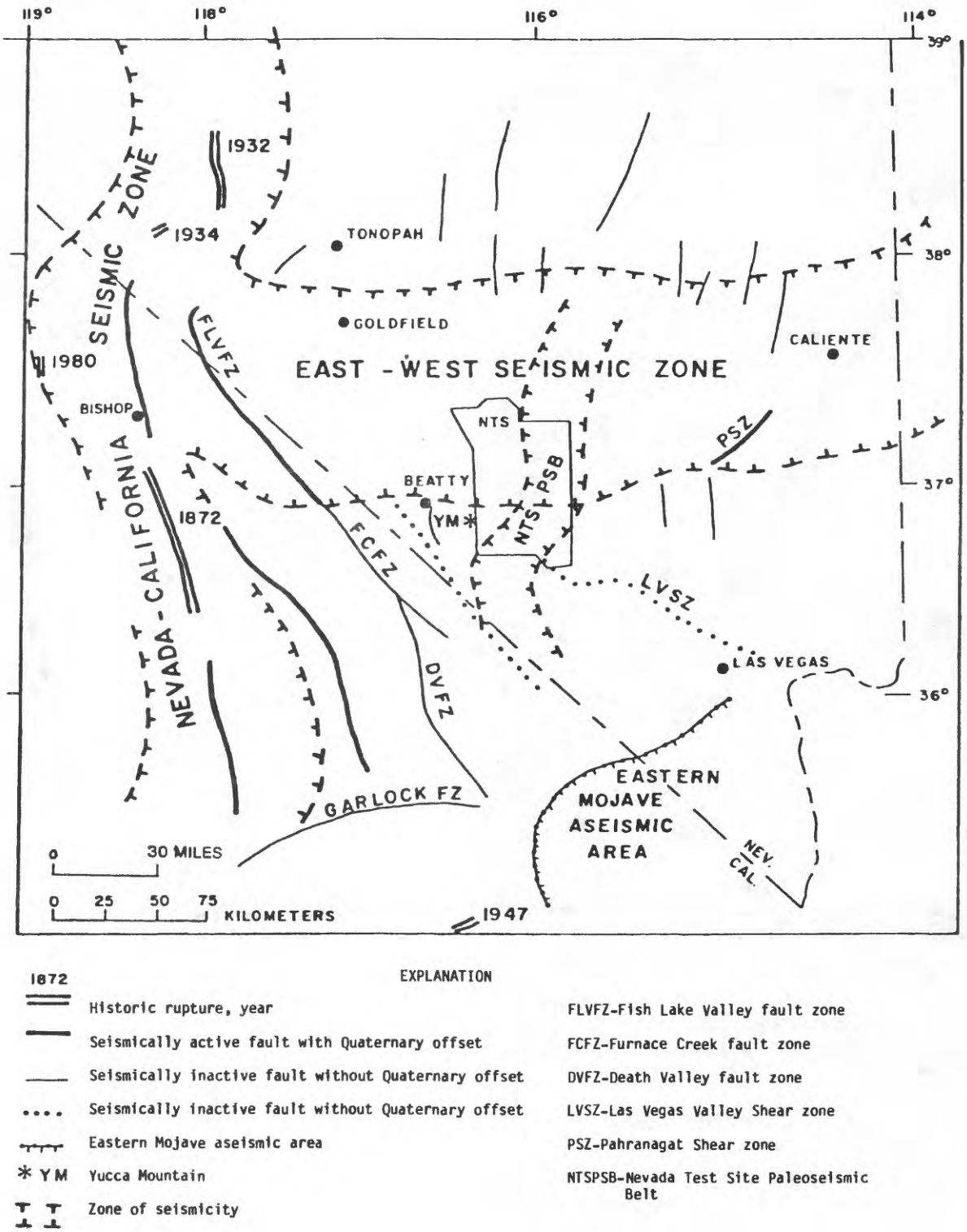
The general pattern of seismicity in the southern Great Basin is widespread diffuse activity punctuated by tight clusters of earthquakes. Fewer earthquakes occur near the northern and southern edges of the network, resulting in an east-west seismic bridge or belt connecting the Intermountain seismic zone of Utah with the Nevada-California seismic zone (fig. 7). The tectonic significance of this East-West seismic belt is unknown. The northeast trending fault zones of the region, such as the Pahranagat shear zone, localize a large percentage of the regional earthquakes.

Fault orientation appears to be more important than age in determining microearthquake occurrence, at least in the Nevada portion of the southern Great Basin. Nearly all faults of northwest strike are inactive, but many of those with north to northeast trends are active. Only a few very small (<2.0 magnitude) earthquakes have been recorded in the Yucca Mountain area, however. The northerly orientation of faults at Yucca Mountain, together with the hydraulic fracturing stress data which suggest that some of the faults are near failure (M. Zoback and J. Healy, written commun., 1982), indicate that fault movement there cannot be ruled out, even though the present level of seismicity and the geologic history of the area suggest relative stability.

Volcanism--The complete cessation of silicic volcanism in the NTS region more than 5 m.y. ago suggests that the hazard of future silicic volcanism at Yucca Mountain is negligible. The hazards of basaltic volcanism have been calculated by combining hazard appraisal and risk assessment. The conditional probability of the recurrence of basaltic volcanism and the resulting disruption of a repository are bounded by the range of 10^{-8} to 10^{-10} for a 1-year period (Crowe and others, 1982). The potential effects of repository disruption and waste dispersal from magmatic penetration of a repository are controlled primarily by the geometry of basalt feeder systems, by the mechanism of incorporation of waste in magma, and by the eruptive process.

The southern Great Basin, including the NTS, is transected by a north-northeast trending medial belt of basaltic volcanism that developed 8-10 m.y. ago, generally after the end of major silicic volcanism and contemporaneous with migration of basaltic activity toward the southwest margin of the Great Basin (fig. 8). Two general types of eruptions have occurred in the volcanic fields in the belt: (1) large-volume, long-lived basaltic and local rhyolitic eruptions with numerous centers, and (2) small-volume eruptions associated with scattered basaltic scoria cones. The NTS area contains only basalts of the second type.

Chemically, the basalts of the NTS region are classified as straddle A-type basalts of the alkalic suite. Petrological studies indicate a volumetric dominance of evolved hawaiite magmas. Trace and rare-earth element content of younger basalts (<4 m.y.) of the NTS region and southern Death Valley area indicates an enrichment in incompatible elements, with the exception of rubidium. This work is being continued in order to better understand the magmatic and tectonic processes involved in eruption of basaltic magma in the southern Great Basin.



EXPLANATION

1872 Historic rupture, year

Seismically active fault with Quaternary offset

Seismically inactive fault without Quaternary offset

Seismically inactive fault without Quaternary offset

Eastern Mojave aseismic area

* YM Yucca Mountain

Zone of seismicity

FLVFZ-Fish Lake Valley fault zone

FCFZ-Furnace Creek fault zone

DVFZ-Death Valley fault zone

LVSZ-Las Vegas Valley Shear zone

PSZ-Pahranagat Shear zone

NTSPSB-Nevada Test Site Paleoseismic Belt

Figure 7.--Generalized tectonic features in the vicinity of the Nevada Test Site that are relevant to the assessment of seismic hazard.

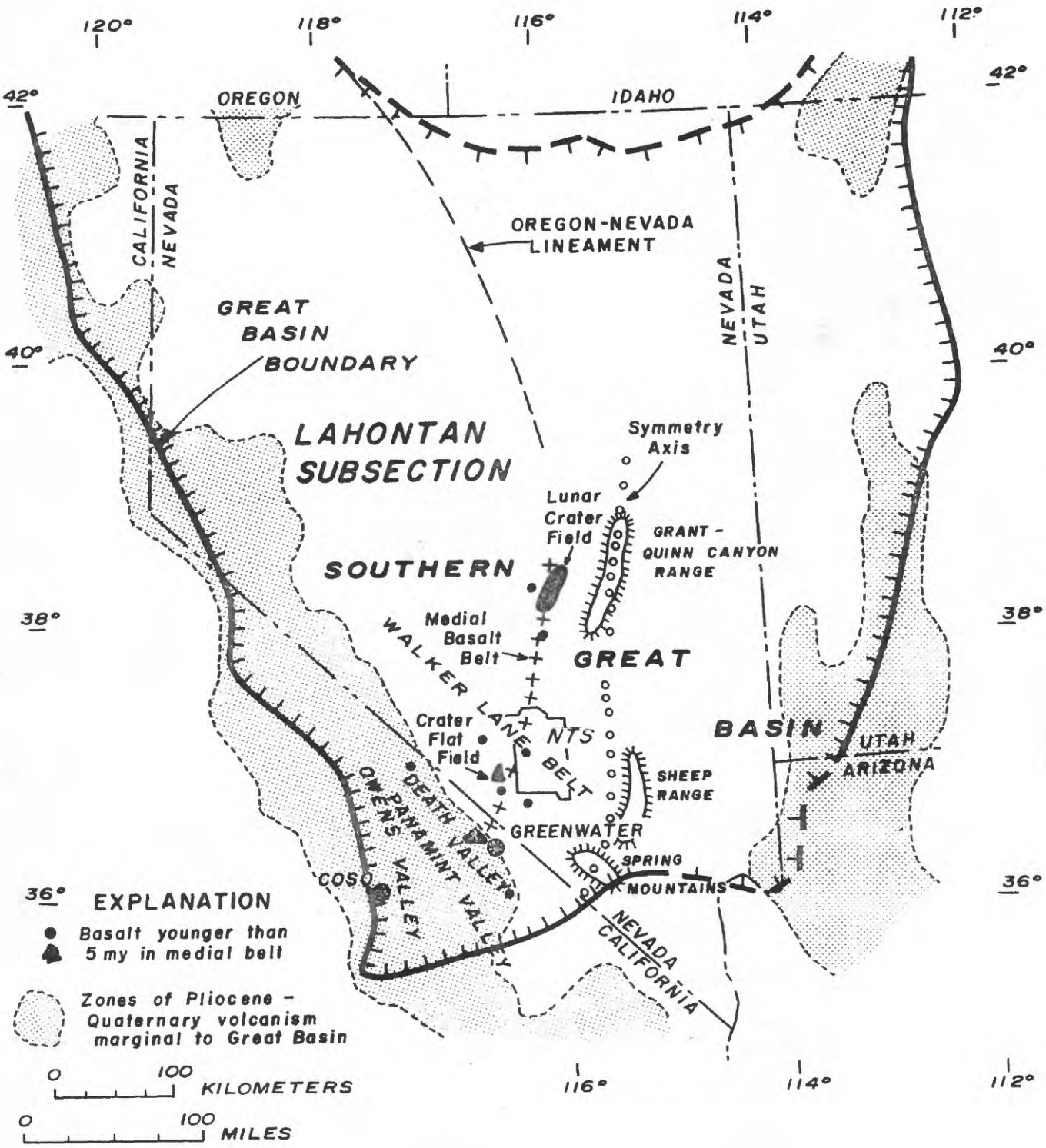


Figure 8.--The Southern Great Basin, showing selected volcanic, structural, and physiographic features.

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Hydrology

By William E. Wilson, Lakewood, Colo.

Objective: To determine present and past hydrologic regimes of the Nevada Test Site and vicinity in order to predict the potential for ground-water transport of radioactive waste from a proposed repository in Yucca Mountain to the accessible environment.

Approach: Test drilling and hydraulic testing are being conducted in both the saturated and unsaturated zones to characterize in detail the hydrologic regimes of the Yucca Mountain area. Results will be used to interpret potential ground-water flow pathways and bulk hydrogeologic properties of unsaturated and saturated rocks, and to obtain information on the chemistry and age of the ground water.

Digital models simulating ground-water flow and solute transport are required to predict rates and directions of movement of radioactive species and their concentrations in ground water if they should be released from a repository on or near the NTS. The regional hydrology of southern Nevada has been defined, and ground-water flow and transport from the Yucca Mountain site to points of present and possible future discharge will be characterized in greater detail.

Worldwide changes in climate during the Pleistocene Epoch (glacial and interglacial stages) resulted in repeated changes in the ground-water regime. Future climatic changes are probable in the time period of significance to a repository for high-level and transuranic wastes. Paleohydrologic studies are being used to estimate recharge flux, water-table depths, hydraulic gradients, and flow paths to points of ground-water discharge during Pleistocene pluvial cycles in order to assess the differences between present hydrologic regimes and those that will prevail under wetter climates in the future.

Progress: Piezometers were installed in test hole USW H-1 (fig. 5) to depths ranging from 640-1,806 m, under the direction of J.H. Robison. Measurements made while water levels in the piezometers were still equilibrating show that the three shallower piezometers have water levels within a meter of each other and near the original composite level. The deepest piezometer, which is open to the older ash-flow and bedded tuffs (table 1) has a water level about 50 m higher than the others. The vertical distribution of head in this hole indicates an upward hydraulic gradient near the bottom of the hole.

Hole USW H-3 was drilled to a depth of 1,220 m at the south end of Yucca Mountain. The Topopah Spring Member of the Paintbrush Tuff, and the Prow Pass and Bullfrog Members of the Crater Flat Tuff are all above the water table. An attempt to test pump the hole resulted in a sustained yield of about 0.3 L/s. On the basis of this test, the initial estimates of low permeability of the Tram unit of the Crater Flat Tuff and underlying tuff of Lithic Ridge, which were based on injection tests, have been revised downward.

Located in a wash east of the Yucca Mountain block boundary, hole USW H-4 was drilled to a depth of 1,220 m. The water table is in the Prow Pass Member of the Crater Flat Tuff, and the more permeable zones are broadly distributed in the Prow Pass and Bullfrog Members and upper part of the Tram unit, with a thin zone in the tuff of Lithic Ridge. The transmissivity of this section is about 40 m^2/day.

Hole USW H-5, located on the ridge of Yucca Mountain, due west of the proposed site of the exploratory shaft, was drilled to a depth of 1,220 m. The water table is near the top of the Bullfrog Member of the Crater Flat Tuff at an altitude of 775 m, about 45 m higher than the level in USW H-3. Permeability of the Bullfrog Member is relatively high compared with the underlying Tram unit and the tuff of Lithic Ridge. The hole was pumped initially at 9.5 L/s with 5.8 m of drawdown and, after making additional perforations in the casing, at 7.6 L/s with only 2.5 m of drawdown. The transmissivity is about 20 m^2/day.

Hole USW H-6, located west of a hingeline fault that cuts the Solitario Canyon block (fig. 3), was drilled to determine local permeability of the rock units and to establish the degree of hydraulic continuity with the Yucca Mountain block. Water levels west of the block may indicate the direction of ground-water movement toward and within the block. The water-level altitude in USW H-6 is 780 m above sea level, or similar to that in USW H-5. Water levels in and near the block suggest that ground-water flow within the block is to the southeast.

Under the direction of R.K. Waddell, test wells UE-29a-1 and UE-29a-2 were drilled in upper Fortymile Canyon, about 9 1/2 km (6 mi) northeast of test hole USW-G2, as part of the regional hydrology program. Only one hole was planned, but loss of the bit and drill collars at a depth of 65 m necessitated drilling UE-29a-2, which was drilled to a depth of 422 m and tested.

Testing of formations consisting primarily of rhyolite flows with a few bedded tuffs was performed in two stages: (1) in the open hole, from the bottom of the casing at a depth of 248 m to 354.5 m; and (2) through perforations in the casing extending from 87 to 213 m. During the second stage, a bridge plug was set in the casing beneath the lowermost perforation. Testing in both stages consisted of running pumping and recovery tests, tracejector surveys, and sampling for water chemistry.

The most significant result obtained from these holes is that the potentiometric level is much higher than expected, suggesting the presence of a barrier between these holes and well J-13. The rocks at the site have a relatively high transmissivity. Both potentiometric and carbon-14 data indicate that downward flow occurs at the site. Carbon-14 ages of 2,300 yr, 3,800 yr, and 4,100 yr were obtained from three samples taken progressively deeper at the site.

Water samples taken from different depths shortly after all pumping was completed, and kept in sealed containers, show that dissolved-oxygen content decreases from about 4 ppm at 200 m to about 2 ppm at 300 m.

A new map of potentiometric levels throughout a large area extending from Death Valley to Tonopah, about 160 km northwest of Beatty, and east to Pahranagat Valley, about 150 km northeast of Lathrop Wells, was compiled by R.K. Waddell. This map confirms and refines previous interpretations of the ground-water systems. Three ground-water basins (Oasis Valley, Alkali Flat-Furnace Creek Ranch, and Ash Meadows) have been defined. A map showing the availability of carbon-14 and hydrogen and oxygen isotopic data was also compiled.

Computer techniques for designing and analyzing tracer experiments were devised by J.R. Erickson. These experiments should provide estimates of natural ground-water velocities, and, in conjunction with other well-test data, a means for determining effective porosity. A series of these experiments is being planned for the Yucca Mountain area.

A two-dimensional, finite-element, flow and transport code was developed by R. K. Waddell that allows simulation of transport of members of sorbing decay chains. Inventory of the radionuclides in the repository is calculated with the Bateman equations (a simultaneous system of linear, homogeneous, first-order, ordinary differential equations with constant coefficients). Dissolution rate of the waste matrix may either be explicitly defined or calculated as a first-order kinetic dissolution process.

Lithologic logs from wells in the Amargosa Desert are being compiled for correlation with geophysical data and determination of most likely paths of ground-water flow in the Amargosa Desert.

The flood potential of Fortymile Wash and its tributaries draining Yucca Mountain was evaluated by R. R. Squires and R.L. Young. Considered in the analysis were floods that would be expected in 100-yr and 500-yr recurrence intervals, and the maximum potential floods. In Fortymile Wash, the maximum potential flood would stay confined within the wash "canyon" in the Yucca Mountain area; depths of these floodwaters are estimated to be about 5-8 m.

An investigation to map Pliocene and Pleistocene rocks and geomorphic surfaces of the Ash Meadows quadrangle and vicinity, Amargosa Desert, was initiated under the direction of Dr. R. L. Hay, University of California. Included in the study area are widespread spring deposits and lakebeds, indicative of hydrologic conditions different from those of modern times. Determining the spring discharge and lacustrine history of the Amargosa Desert will contribute significantly to our understanding of the regional paleohydrology.

A report entitled "Vegetation and Climates of the Last 45,000 Years in the vicinity of the Nevada Test Site," by W. G. Spaulding, was prepared in fulfillment of a University of Washington contract to the USGS and approved for release as Open-File Report 83-535. It states that during the glacial maximum (about 18,000 yr B.P.), the following conditions prevailed in the region as compared to modern conditions: Average winter and summer temperatures were both lower, resulting in an average annual temperature about 6-7°C lower; summer precipitation was about 40-50 percent less, winter precipitation was about 60-70 percent greater, and average annual precipitation was about 30-40 percent greater.

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Waste Isolation Pilot Plant, New Mexico

The DOE has been investigating an area about 45 km east of Carlsbad, New Mexico, to determine its suitability as a site for the Waste Isolation Pilot Plant (WIPP), a geologic repository for nuclear wastes generated by defense activities. The geology and hydrology of the area have been studied in cooperation with Sandia Laboratories to provide the DOE with information on which to base an assessment of the site, particularly with respect to geologic stability, long-term isolation of waste radionuclides, and the potential for the hydrologic system to provide a barrier to radionuclide transport. The potential host rock is bedded salt of the Salado Formation of late Permian age.

Hydrology

By Jerry W. Mercer, Albuquerque, N.M

Objective: To evaluate the hydrologic systems on a regional and site-specific basis with regard to their potential for radionuclide transport.

Approach: Data are being acquired and assembled to define in detail the hydrology of the WIPP site including its relationship to regional ground-water systems. These data will be used to improve digital models simulating ground-water flow and solute transport. The models will be needed to predict rates and directions of movement of radioactive species and their concentrations in ground water if they should be released from a repository.

Progress: The evaluation of the WIPP site hydrology on a regional scale was completed and the regional interpretive report was submitted to DOE. Future site-specific studies will be conducted by Sandia National Laboratories.

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Mercer, J.W., 1983, The geohydrology of the proposed Waste Isolation Pilot Plant site, Los Medanos area, southeastern New Mexico: U.S. Geological Survey Water Resources Investigations Report 83-4016, 113 p.

Paradox Basin, Utah

The eastern Utah portion of the Paradox Basin is being explored by the DOE through its contractor, the Office of Nuclear Waste Isolation of Battelle Memorial Institute, to locate a potential repository site. Geologic investigations are being conducted by Woodward-Clyde Consultants and the U.S. Geological Survey; the Utah Geological and Mineral Survey is reviewing the mineral-resource potential of the area.

Geology

By Robert J. Hite, Lakewood, Colo.

The initial investigations focused on Salt Valley, one of a series of northwest trending diapiric salt anticlines along the northeast edge of the Paradox Basin in southeast Utah. In fiscal year 1980, the investigations were expanded to include study areas at Gibson Dome, Lisbon Valley, and Elk Ridge (figs. 9 and 10). Efforts in fiscal year 1982 were focused on the Gibson Dome study area.

Objective: To assist DOE and its contractors in the acquisition and interpretation of basic geologic data from drill cores in the Paradox Basin area.

Approach: The core is described and logged using visual and nondestructive optical aids. Bromine content, insoluble residues, water content, gas inclusions, hydrocarbon and kerogen contents, mineralogy and petrology of the marker beds, and various physical properties are determined on samples of the cores.

Progress: Weight percent organic carbon was determined for 60 samples from the Gibson Dome test hole (G.D. No. 1) (fig. 10). Some black shales from the Paradox evaporites contained as much as 7.68 wt. percent carbon. Eleven halite samples from Salt 6 [1/] had organic carbon contents ranging from 0.05-0.51 percent which demonstrates the organic-rich nature of the Paradox halite relative to most other salt deposits. These samples are also being analyzed by pyrolysis chromatography so that the amounts of hydrocarbons generated by additional heating will be known.

Data were obtained for the purpose of estimating the oxidation-reduction potential of rocks above the salt in G.D. No. 1. These data were obtained by visually estimating the organic carbon content, percent of the rock (redbeds only) where Fe^{+3} had been reduced to Fe^{+2}, and noting the presence of sulfide minerals. These data are being plotted as a redox log at the same scale as the gamma-ray log.

A previously unknown white nodular mineral in the insoluble residues from the carnallite zone in Salt 6 was determined to be the borate mineral szaibelyite $MgBO_2(OH)$.

1/ Stratigraphic nomenclature for the salt section in the Paradox Basin is described in Hite and Lohman (1973).

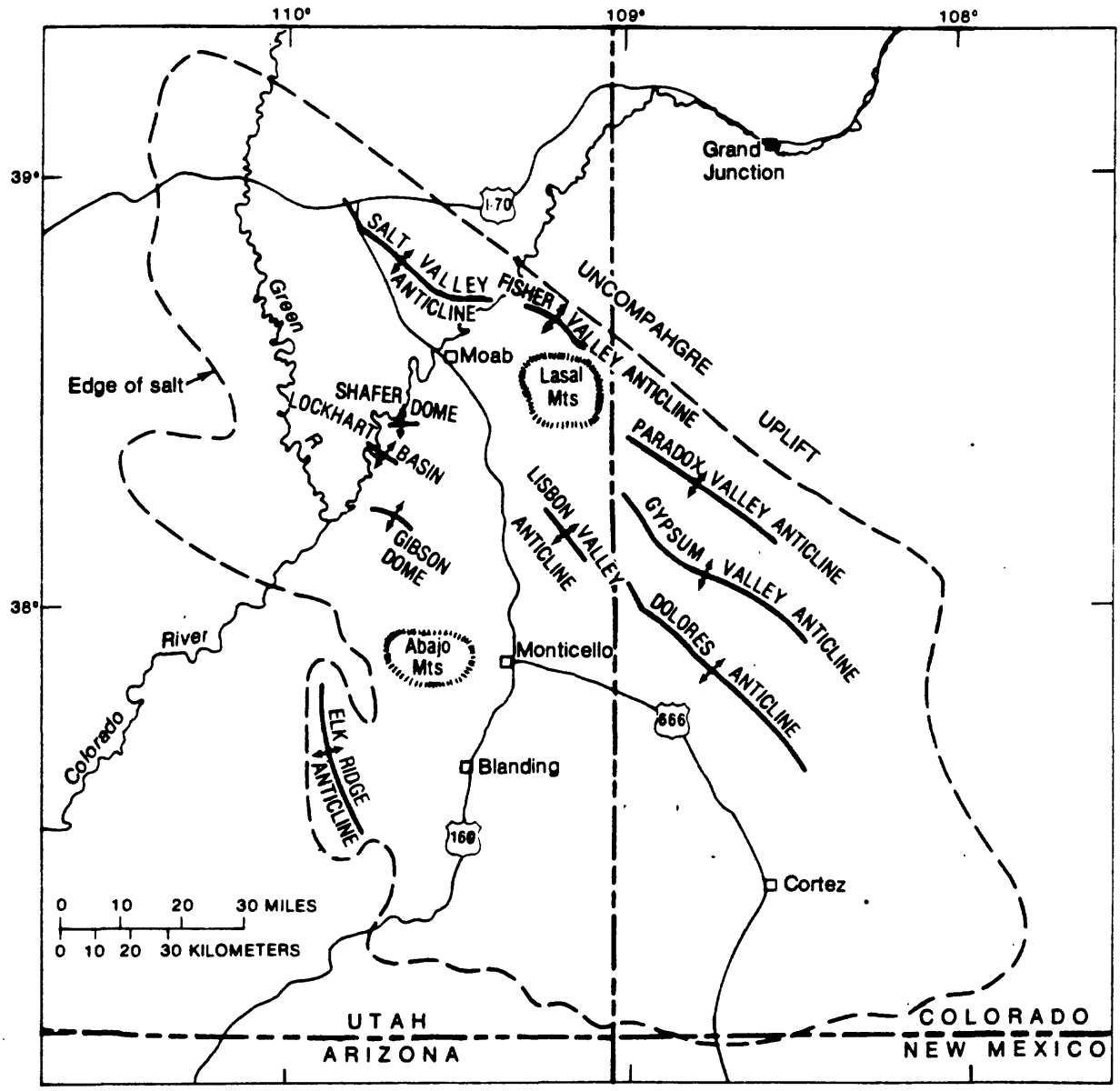


Figure 9.--Paradox Basin, Utah and Colorado

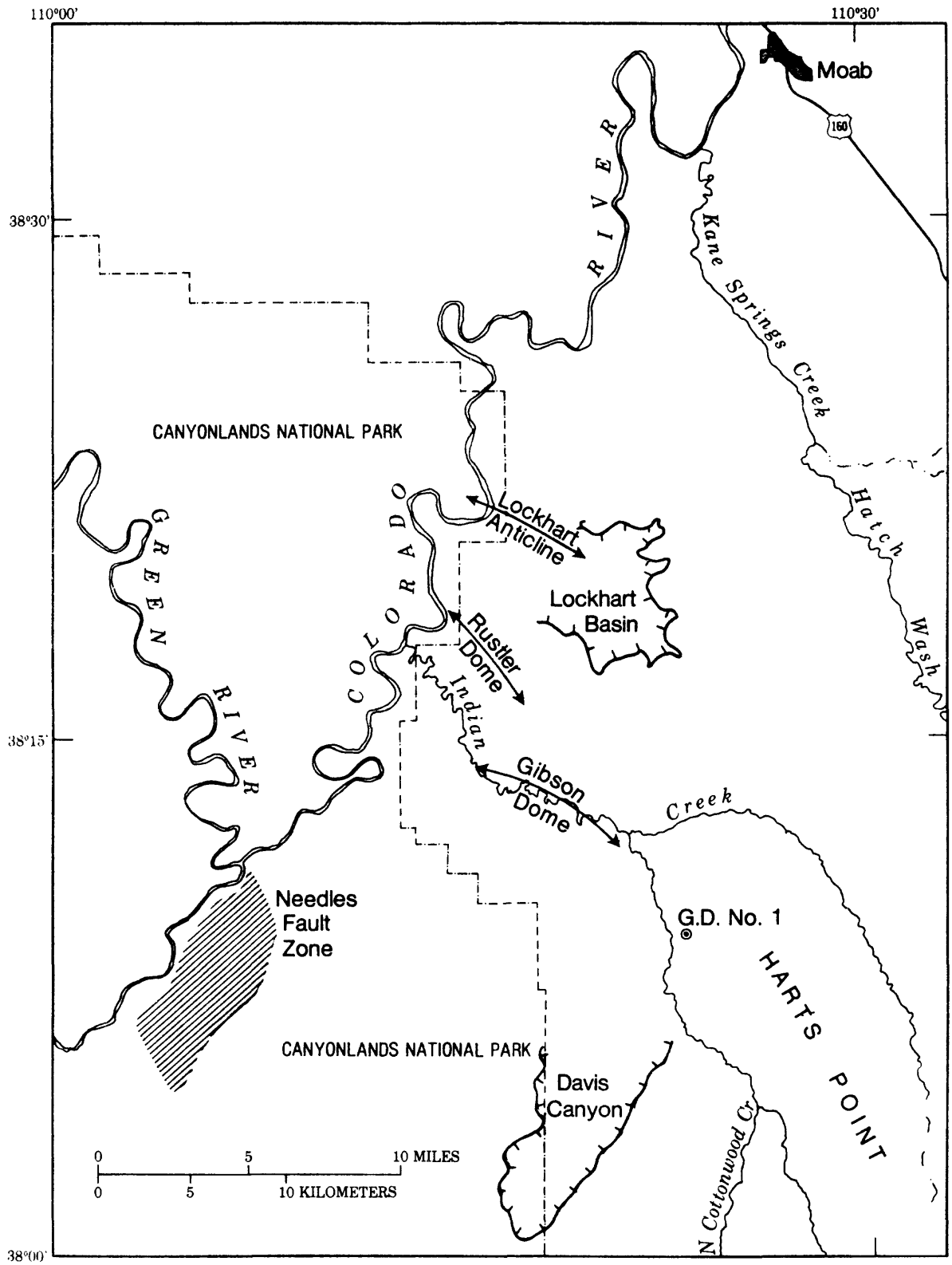


Figure 10.--West-Central part of the Paradox Basin, Utah.

Bromine distribution profiles have been finished for all halite beds in G.D. No. 1 through Salt 17. Only one of these profiles shows any evidence of solution and recrystallization of halite. Salt 10 has a 13-m-thick interval of low bromine halite (60-85 ppm) at the top of the bed. The interval, which is characterized by extremely coarse-grained halite, seems to be regional in extent because it has been observed in other coreholes in the basin. This suggests that the recrystallization was very early diagenetic and does not represent local entry of meteoric water into the deposit.

A pure concentrate of carnallite was obtained from Salt 6 in G.D. No. 1 using heavy liquid separation. This material will be used in an attempt at potassium-calcium dating. In addition, wet chemical analysis will be performed for rubidium and ammonia in solid solution. Ammonia release from carnallite as a result of heating might possibly create problems in a repository constructed beneath the carnallite marker in Salt 6.

The final run of water determinations for Salt 6 in G.D. No. 1 was made. Carnallite-free halite ranged from 0.196 to 0.530 wt. percent H_2O with an average of 0.224 wt. percent. Samples from the carnallite marker ranged from 0.575 to 2.148 wt. percent H_2O. These percentages, of course, include some bound water as well as inclusion water.

Nodules of the rare earth borate mineral braitschite were identified in cycle 5 interbed (overlies Salt 6). It does not appear that the mineral occurs in sufficient quantity to be considered a rare-earth source.

Chemical analyses of the two potash deposits in the Gibson Dome core were completed. The upper deposit (Cycle 13) is 1.51 m thick and averages 19.06 percent K_2O. This deposit consists of sylvite and halite. The lower deposit is in Cycle 18 and also consists of halite and sylvite. This deposit consists of an upper zone 1.19 m thick which averages 31.67 percent K_2O and a lower zone 0.78 m thick which averages 21.71 percent K_2O. These two zones are separated by a barren interval (0.55 m thick) which contains a 0.11-m-thick layer of anhydrite. The potash deposit in Cycle 18 is continuous over much of the Gibson Dome-Rustler Dome-Lockhart Anticline area (fig. 10). Where this deposit is at depths of less than 1,200 m, it constitutes a potential economic source of potash. At the G.D. No. 1 location, the deposit is too deep (>1,350 m) to be recovered by conventional shaft mining. The potash deposit in Cycle 13 does not have sufficient thickness and grade to constitute an economic deposit in this area.

The most recent published explanations of the origin of the Needles Fault Zone (fig. 10) invoke gravity sliding of post-salt strata over the Paradox evaporites (McGill and Stromquist, 1974). There is considerable evidence to suggest that the arcuate trend of graben faulting may have developed in response to a salt dissolution front which has moved southeast as much as 10.5 km from the vicinity of the Colorado River where downcutting exposed salt beds. Geomorphic relationships in the area suggest the faulting may be quite young, and thus, the potential rate of dissolution

advance may be very rapid. Regardless of the initial cause of faulting, there is little doubt that the fault system serves as a hydraulic connection between the upper aquifer and the salt deposits of the Paradox Member. Under such conditions, dissolution of salt would have to take place. It would seem essential to determine if dissolution is taking place, and if so, how long it will take to reach Davis Canyon (fig. 10).

Report

Hite, R.J., 1982, Potash deposits in the Gibson Dome area, southeast Utah: U.S. Geological Survey Open-File Report 82-1067.

Reference

Hite, R.J., and Lohman, S.W., 1973, Geologic appraisal of Paradox Basin salt deposits for waste emplacement: U.S. Geological Survey Open-File Report, 75 p.

McGill, G. E., and Stromquist, A. W., 1974, A model for graben formation by subsurface flow; Canyonlands National Park, Utah: University of Massachusetts, Department of Geology and Geography, Amherst, Massachusetts, Contribution No. 15.

Quaternary Geology of the Fisher Valley Area, Utah

By Steven M. Colman and Fred F. Hawkins, Lakewood, Colo.

The geology of the Fisher Valley area, Utah, (figs. 9 and 11) relates to a variety of factors that are significant in evaluating the potential of the Paradox Basin for locating a waste repository. The salt diapir and the contiguous Quaternary sediments in the Fisher Valley area provide the best record of Quaternary salt deformation in the Paradox Basin; in addition, the physical stratigraphy, buried soils, and fossil content of the Quaternary sediments provide the most complete record of Quaternary environments and climates in this region. Thus, the history of the Fisher Valley area has important implications for radioactive waste disposal anywhere in the Paradox Basin.

Objective: To determine the extent and timing of deformation of Quaternary sediments and attendant drainage modifications in the Fisher Valley area and the relation of this deformation to the adjacent salt diapir; to determine the paleoclimatic and geomorphic significance of the physical stratigraphy, buried soils, and fossil content of the Quaternary sediments; and to estimate possible future climatic and geomorphic changes.

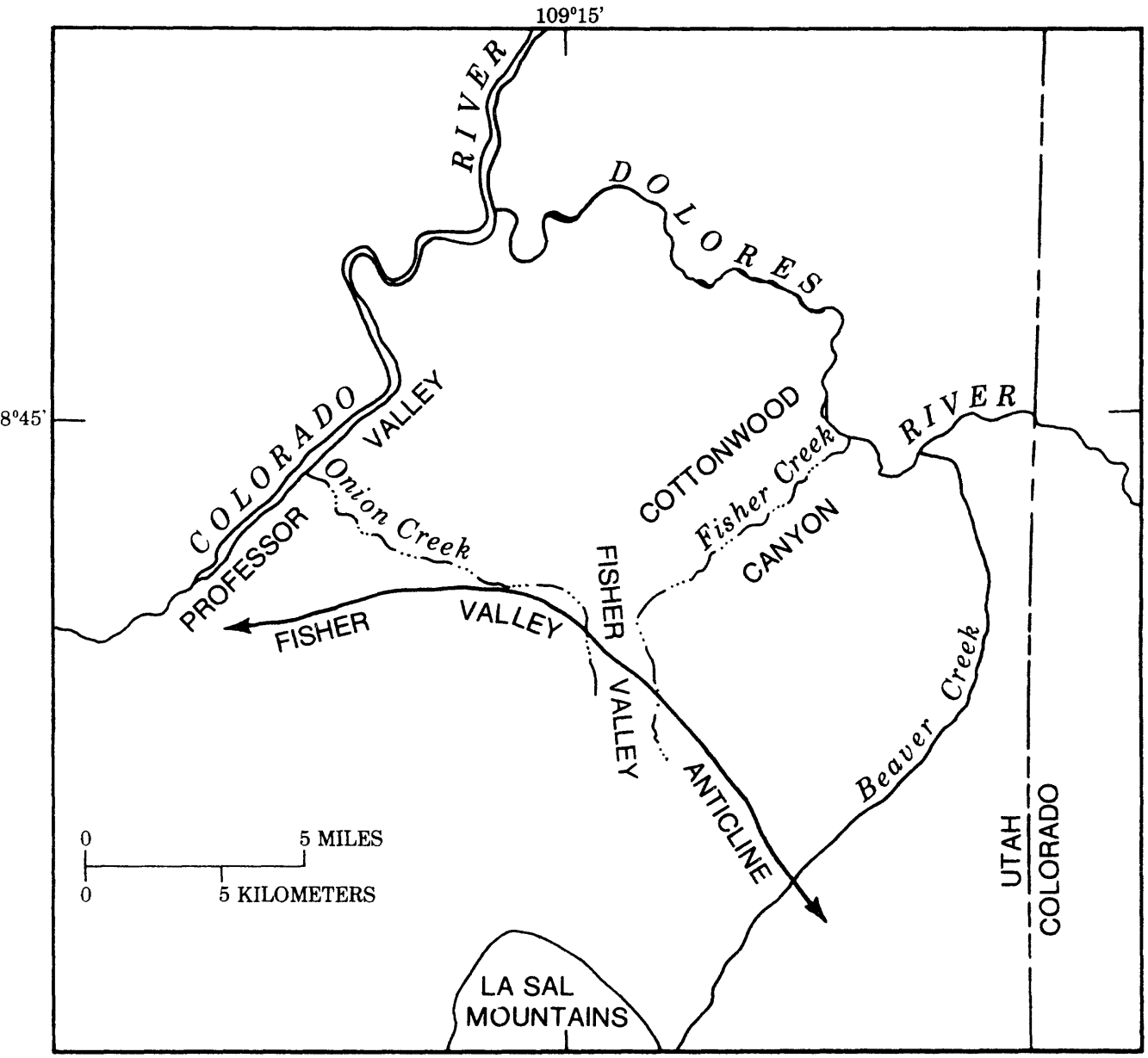


Figure 11.--Sketch map showing location of Fisher Valley anticline and geographic features in the vicinity of Fisher Valley, Utah.

Approach: The Quaternary geology of the area was mapped in detail, including the measurement of stratigraphic sections, to determine the pattern of deformation of the Quaternary sediments and the relation of this deformation to the salt diapir. The sediments and soils in the section were sampled for soils analysis, paleomagnetism, thermoluminescence, and uranium-series analysis. These samples will provide chronologic, paleo-environmental, and paleoclimatic information.

Progress: Most of the field work for the project has been completed including field mapping of the Quaternary sediments in Fisher Valley and of the terraces along the Colorado River in Professor Valley. Plane-table mapping of the ash bed stratigraphic markers in Fisher Valley was completed at a scale of 1:6,000. A preliminary map of the Fisher Valley and Professor Valley areas at a scale of 1:24,000 was completed (Colman and Hawkins, 1983). Detailed stratigraphic sections of the Quaternary sediments and soils in Fisher Valley were measured, and the soils of both Fisher and Professor Valleys were sampled. Grain-size, carbonate content, and bulk-density analyses of the soils were completed and the results compiled. The sediments in Fisher Valley were sampled and prepared for amino-acid, thermoluminescence, uranium-trend, and radiocarbon analyses. Also, samples were collected for paleomagnetic measurements. Preliminary analyses of the paleomagnetic and amino-acid samples have produced encouraging results, and these methods should prove useful for estimating the ages of the sediments. Micropaleontological analyses of the sediments indicated that most of the deposits are barren.

The results of this work suggest that both the Fisher Valley diapir and the Cache Valley structure (a westward extension of the Fisher Valley anticline) have been active in Quaternary time and that major geomorphic changes have occurred periodically in the Fisher Valley area.

The sediments in Fisher Valley apparently were deposited over a considerable span of time, and probably record much of the Quaternary history and environment of the area.

A report entitled "Late Cenozoic movement of the Onion Creek salt diapir, southeastern Utah" was completed and is being reviewed.

Report

Colman, S.M. and Hawkins, F.F., 1983, Preliminary surficial geologic map of the Fisher Valley - Professor Valley area, southeastern Utah: U.S. Geological Survey Open-File Report 83-58.

Hydrology

By William E. Wilson, Lakewood, Colo.

Objective: To determine the geologic and hydrologic relationships between the bedded salt deposits and the regional ground- and surface-water flow systems in the Paradox Basin of Utah and Colorado. The results are intended to provide a regional hydrogeologic framework upon which to base more detailed investigations of potential repository sites for high-level radioactive wastes.

Approach: Regional hydrogeologic reconnaissance studies were conducted, primarily using available data and reports supplemented by data on existing wells and measurements of the specific conductance of streams. Test drilling and hydraulic testing were undertaken in Salt Valley near Moab, Utah.

Progress: In preparation are the following four reconnaissance reports that describe the regional surface-water and ground-water hydrology of subareas in the Paradox basin.

> Ackerman, D.J., Hydrogeologic reconnaissance of the San Miguel River Basin, southwestern Colorado.
>
> Whitfield, M.S., Jr., Thordarson, William, Oatfield, W.J., Zimmerman, E.A., and Rueger, B.L., Regional hydrology of the Blanding-Durango area, southern Paradox basin, Utah and Colorado.
>
> Weir, J.E., Jr., Maxfield, E. B., and Hart, I.M., Reconnaissance of the geohydrology of the Moab-Monticello area, western Paradox basin, Grand and San Juan Counties, Utah.
>
> Weir, J.E., Jr., Maxfield, E.B., and Zimmerman, E.A., Reconnaissance hydrology of the Dolores River Basin, eastern Paradox basin, Colorado and Utah.

The reports describe the regional characteristics of ground-water recharge, discharge, and water quality for the two major aquifer systems. Also included are flow and water-quality data for the major streams in the Paradox basin.

The upper aquifer system overlies the salt and discharges to major streams within the study area. It includes, from top to bottom, water-bearing units in the following stratigraphic units: Dakota Sandstone (Cretaceous), Entrada Sandstone (Jurassic), Navajo Sandstone (Jurassic and Triassic (?)), Wingate Sandstone (Triassic), and Cutler Formation (Permian). The lower system is in the Mississippian Leadville Formation which does not crop out in the Paradox Basin.

Reports

Rush, F.E., Whitfield, M.S., Jr., and Hart, I.M., 1982, Regional hydrology of the Green River-Moab area, northwestern Paradox basin, Utah: U.S. Geological Survey Open-File Report 82-107.

Wollitz, L.E., Thordarson, William, Whitfield, M.S., Jr., and Weir, J.E., Jr. 1982, Results of hydraulic tests in the U.S. Department of Energy's wells DOE-4, 5, 6, 7, 8, and 9, Salt Valley, Grand County, Utah: U.S. Geological Survey Open-File Report 82-346.

Geophysics

By Raymond D. Watts and F.H. Hildenbrand, Lakewood, Colo., and John H. Sass, Flagstaff, Ariz.

Objective: To use geophysical data to characterize and differentiate subsurface lithologic types, structural configurations, and inhomogeneities in areas of interest.

Approach: Surface, airborne, drill-hole electromagnetic, gravity, and temperature measurements are employed to obtain information on the geologic structure and the presence or absence of significant amounts of ground water.

Progress: Electrical Methods--The project was completed. Data from 43 vertical electrical soundings were processed and interpreted, and a report prepared (Watts, 1982).

The principal conclusions follow.

- Electrical conditions around the proposed repository location at Davis Canyon (fig. 10) are very uniform, and show no indications of anomalous lithologic, hydrologic, or structural conditions.

- A conductive zone was observed at approximately 14,000 m elevation above mean sea level in the vicinity of Gibson Dome. It is interpreted as a water table above the level of the Colorado River.

- A conductive zone was observed at approximately 1,100 m elevation above mean sea level in Lockhart Basin. It is interpreted as a water table below the level of the Colorado River. The possibility that water may flow from the Colorado river downward and eastward beneath Lockhart Basin is contrary to generally accepted concepts of flow in the hydrologic system for the area.

- A region of complex electrical conditions was observed at Harts Point. The causative structure is not known.

- Highly conductive zones were observed in the vicinity of the Lockhart Basin. There are two plausible explanations: (1) conductive brines resulting from dissolution of salt are present in or near the shear zone, or (2) conductive clay is present in the fault gouge. The extremely low interpreted resistivities are more consistent with the presence of brines than of clays.

Magnetic--A consistent magnetic data set was compiled. The anomaly maps of seven surveys were digitized at the intersections of flight-line traces and anomaly contour lines. The effects of the earth's ambient field were removed from the resulting data sets to obtain residual magnetic field values. An evaluation at 3,790 m above sea level was selected as the reduction datum level. The data sets were then merged using one-dimensional splining techniques, and a magnetic anomaly map was produced.

Gravity--A compilation of gravity data involved accessing a data bank and retrieving principal facts of 5,976 gravity stations between latitude 37° 15' and 39° 00'N and longitude 108° 30' and 110° 45'W. A preliminary editing of data from these stations was carried out, resulting in the elimination of stations having obvious gravity errors.

Temperature Measurements--Temperature data were obtained to a depth of about 1,900 m (6,300 ft) in well G.D. No. 1, Gibson Dome. Identical continuous temperature logs of the well were obtained in March 1981 and January 1982, indicating that the well is in thermal equilibrium.

Thermal conductivities were measured on 15 specimens representative of the major formations. These were used to calculate representative conductivities for each gradient interval, using the lithologic log to estimate the proportions of each rock in the intervals. The mean heat flow, weighted according to the length of the depth interval sampled, is 67 ± 2 mWm^{-2} if no anisotropy is assumed, and 65 ± 3 if anisotropy is assumed to account for the observed difference in conductivity in the xy and xyz directions. The mean observed heat flow from the Gibson Dome well is 66 ± 3 mWm^{-2}. Detailed consideration of thermal regional conductivity structure may well reduce this value by about 10 percent.

Excursions in the gradient profile correlated very well with changes in lithology. This was particularly apparent in the high-gradient "spikes" in the profile within the Paradox Formation (approximately 900-1,600 m), which correspond reasonably well to known shale and siltstone interbeds within the section which is composed primarily of evaporites.

Based on the internal consistency of heat-flow measurements in intervals above and within the Paradox Formation (that is, to a depth of nearly 100 m), vertical water movement with seepage velocities exceeding a few millimeters per year within the well or formation can be ruled out. Curvature in the temperature profile within the Pinkerton, Molas, and Leadville Formations is consistent with vertical water movement either in the hole or formation (or possibly with loss of drilling fluid), centered at about 1,780 m (about 5,850 ft). Some additional core samples would allow calculations of heat flow and help resolve the question of vertical water movement.

A report entitled "Thermal data from well G.D.-1, Gibson Dome, Paradox Basin, Utah," by J.H. Sass, A.H. Lachenbruch, and E.P. Smith was prepared and submitted for review.

Report

Watts, R.D., 1982, Application of deep dc electrical sounding surveys in exploration of a possible repository site in salt, southwestern United States, in Proceedings of a workshop on Geophysical Investigations in connection with Geological Disposal of Radioactive waste, Ottawa, Canada, September, 1982: Nuclear Energy Agency, Organization for Economic Cooperation and Development (OECD/NEA), Paris.

Gulf Coast Salt-Dome Region

North Louisiana

By G. N. Ryals, Alexandria, La.

The DOE is investigating the suitability of salt domes in the north Louisiana salt-dome basin as potential sites for the disposal of radioactive wastes. The Geological Survey, in cooperation with DOE, is studying the regional hydrogeology of the area. The north Louisiana salt-dome basin includes all or parts of 11 parishes, an area of about 7,800 km^2 (figs. 12 and 13). The basin is a structural depression bounded on the west by the Sabine uplift and on the northeast by the Monroe uplift. The strata of principal concern to this study are of Late Cretaceous and Tertiary age, dip generally southeast, and are less than 900 m below land surface. Hosman (1978) described the general geohydrology of the area based on available data and discussed the need for additional data and studies.

Objective: To describe the regional geohydrology and define the ground-water flow system of the north Louisiana salt-dome basin with particular attention to the potential for transport of radionuclides from a repository in a salt dome.

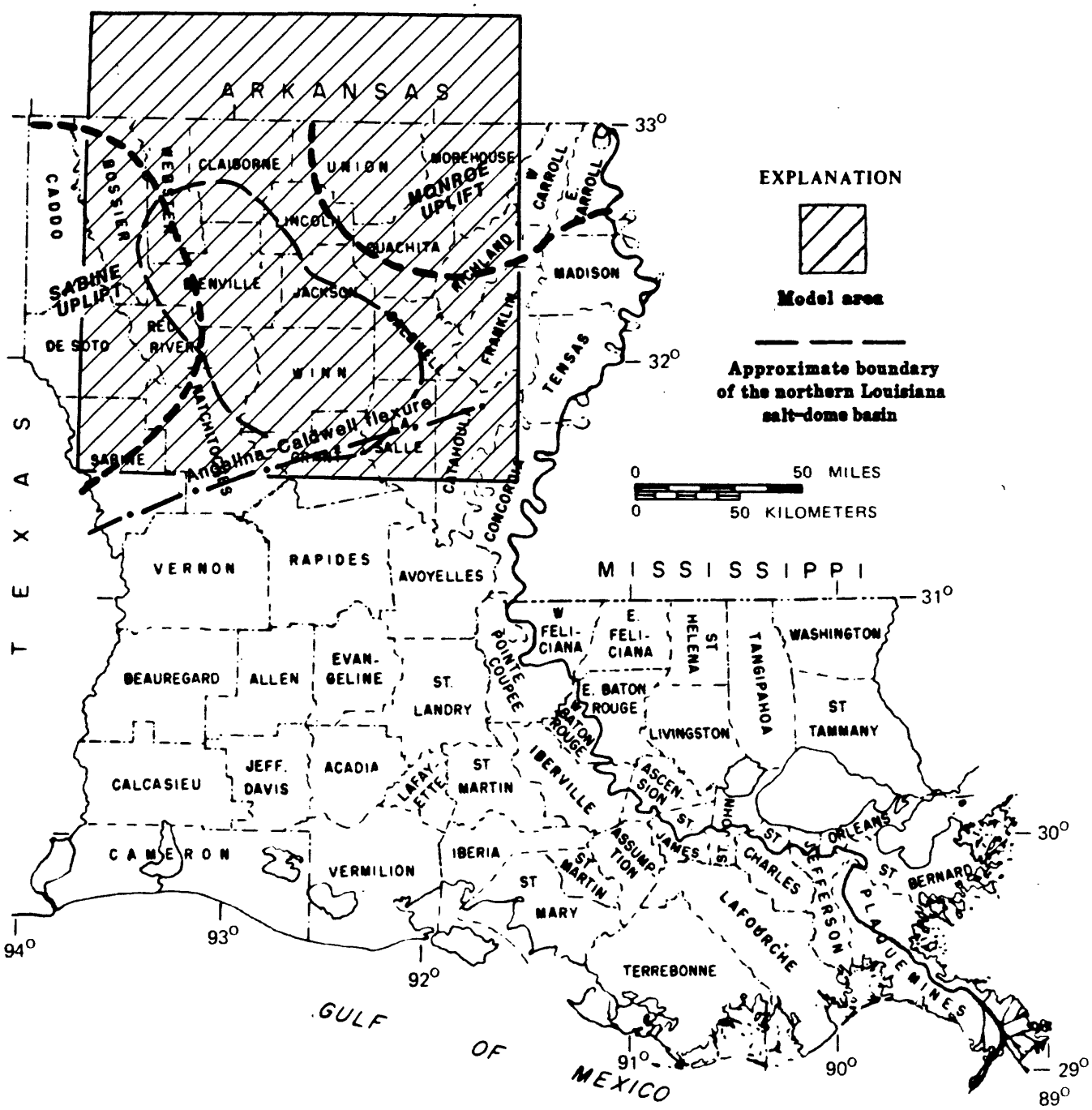


Figure 12.--Location of northern Louisiana salt-dome basin showing area to be modeled.

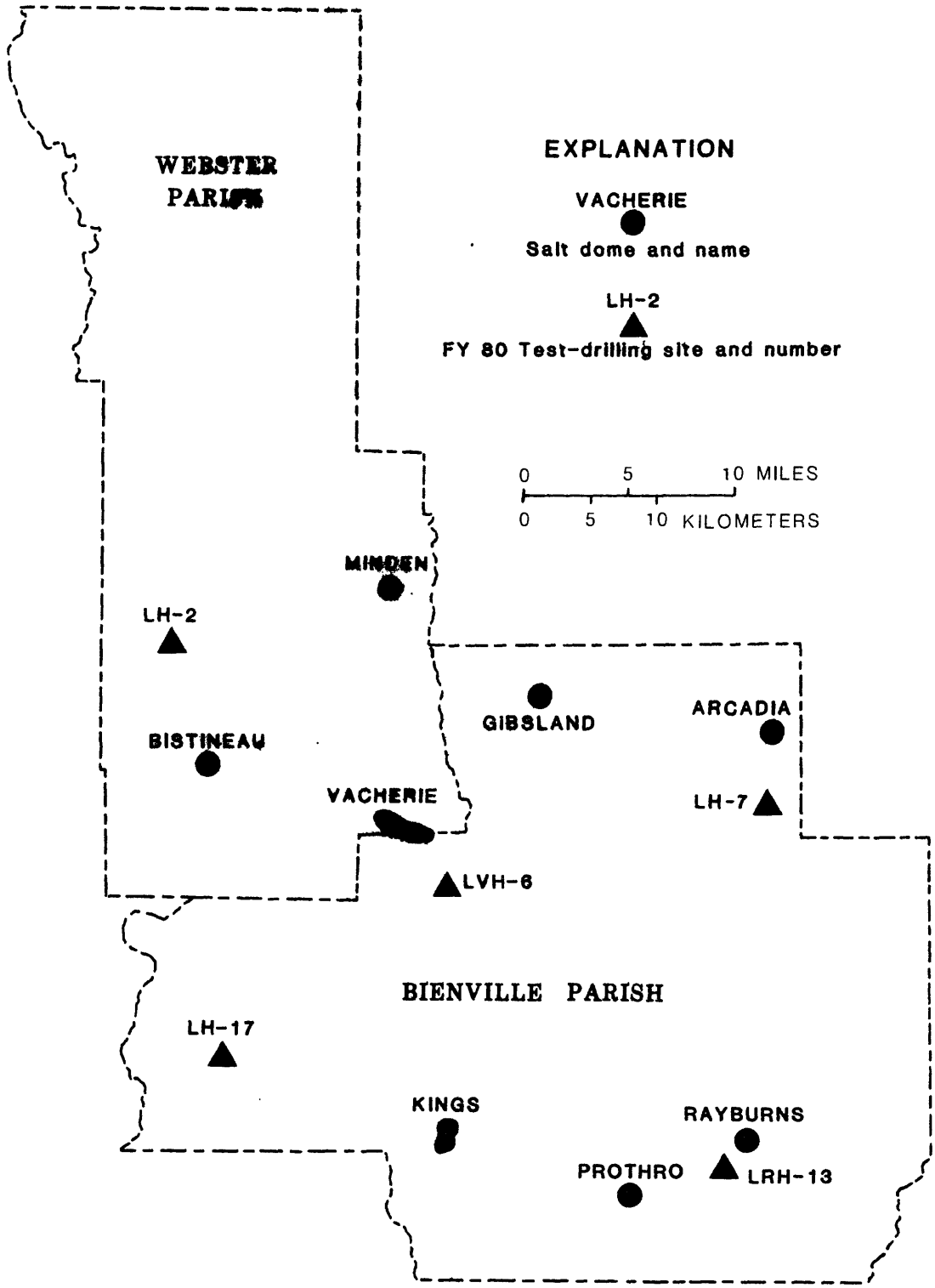


Figure 13.--Location of salt domes and fiscal year 1980 test-drilling sites, Bienville and Webster Parishes, Louisiana.

Approach: Construct a regional, three-dimensional digital model that will simulate flow in the multilayered ground-water system to depths of 900 m or more. The deepest water-bearing unit to be modeled is the Nacatoch Sand of Late Cretaceous age. Other principal units in the model will be the Wilcox Group, undivided, of Paleocene and Eocene age, and the Carrizo Sand, Sparta Sand, and Cockfield Formation of Eocene age.

A series of 17 regional geohydrologic maps depicting specific geologic and hydrologic properties of the aquifers and confining beds, needed for input to the model, has been completed. Other maps necessary for model input cannot be made without data from a regional test-drilling program.

Progress: A series of reports, Parts I, II, III, and IV (see Reports), on the regional geohydrology of the northern Louisiana salt-dome basin was completed. In addition, analysis of geohydrologic data from the fiscal year 1980 test-drilling program continued. The Part I report presents the regional geohydrologic framework and data needs, as well as data from the drilling program. Part II presents geohydrologic maps of the Tertiary aquifers and related confining beds; Part III, potentiometric levels of the Wilcox-Carrizo and Sparta aquifers; and Part IV, hydraulic characteristics of the Wilcox-Carrizo aquifer.

Progress toward the Geological Survey goal of developing a regional ground-water flow model has been delayed because needed data have not been available. The test-drilling program in fiscal year 1980 provided only a small part of the data needed to develop a regional model.

Reports

Ryals, G.N., 1982, Regional geohydrology of the northern Louisiana salt-dome basin, part I, conceptual model and data needs: U.S. Geological Survey Open-File Report 82-343.

_____ 1983, Regional geohydrology of the northern Louisiana salt-dome basin, part II, geohydrologic maps of the Tertiary aquifers and related confining beds: U.S. Geological Survey Water-Resources Investigations Report 83-4135.

_____ 1983, Regional geohydrology of the northern Louisiana salt-dome basin, Part III, potentiometric levels of the Wilcox-Carrizo and Sparta aquifers: U.S. Geological Survey Water-Resources Investigations Report 83-4131.

_____ 1983, Regional geohydrology of the northern Louisiana salt-dome basin, Part IV, hydraulic characteristics of the Wilcox-Carrizo aquifer: U.S. Geological Survey Water-Resources Investigations Report 83-4132.

Reference

Hosman, R.L., 1978, Geohydrology of the northern Louisiana salt-dome basin pertinent to the storage of radioactive wastes--a progress report: U.S. Geological Survey Water-Resources Investigations Report 78-104, 27 p.

Mississippi

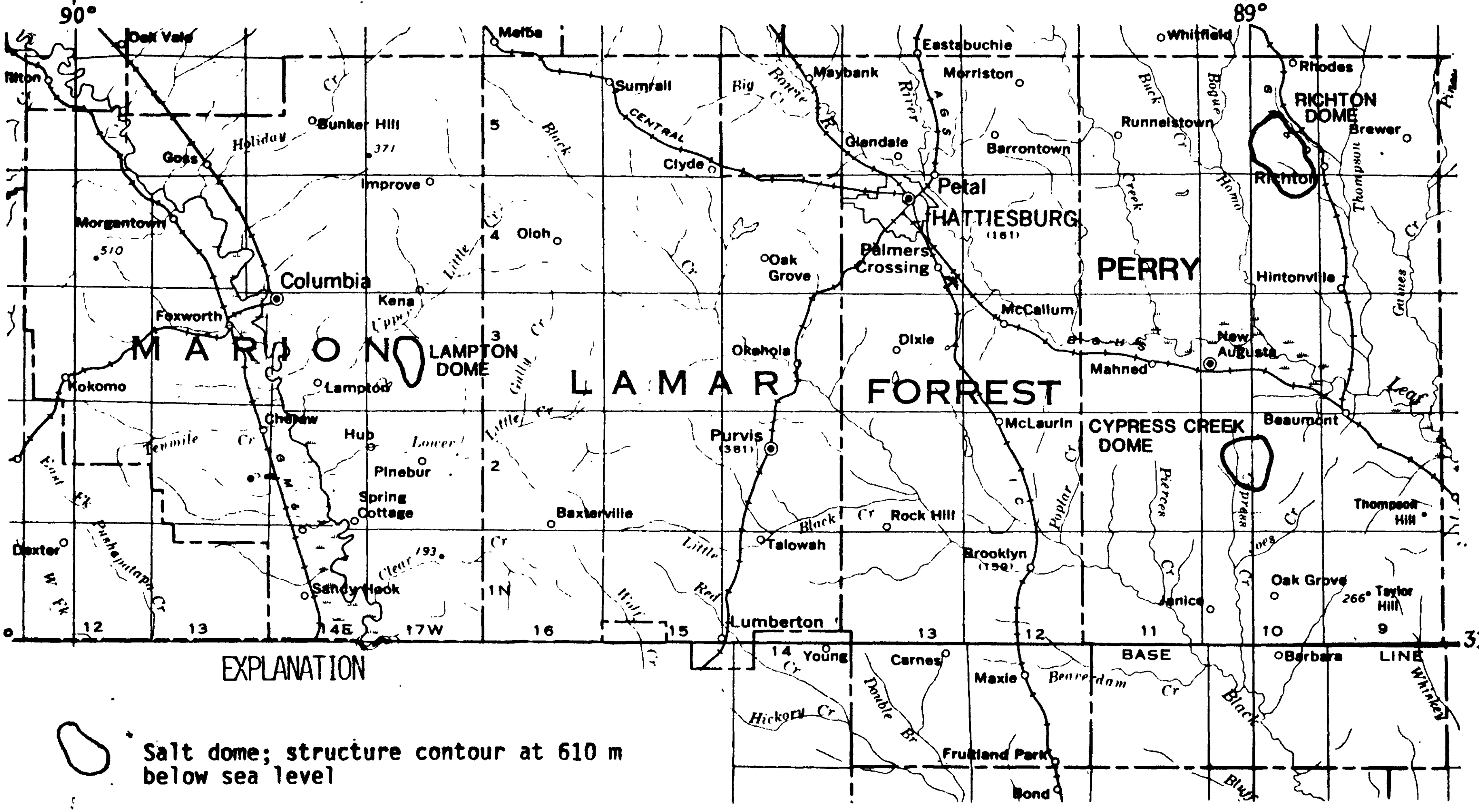
By C.B. Bentley, Jackson, Miss.

The DOE is conducting investigations in the Mississippi interior salt-dome basin to determine the suitability of salt domes as potential sites for the disposal of radioactive wastes. Knowledge of the geohydrology of the basin, especially of the ground-water-flow regimes peculiar to the 50 piercement-type salt domes within the basin, is very limited. Three domes in Mississippi are among those that were selected by the DOE for consideration in identifying a potential waste repository site. Cypress Creek, Lampton, and Richton domes (fig. 14) are among eight in the Gulf Interior Region of Louisiana, Mississippi, and Texas that the DOE evaluated on the basis of minimum geologic, hydrologic, environmental, and socioeconomic criteria for a waste repository. The domes intrude most of the Tertiary section, and the caprock of each occurs at a Miocene horizon. The Tertiary section is composed predominantly of sands and clays with minor units of marl and limestone. Regional dip is approximately 6m/km to the south-southwest. The Geological Survey, in cooperation with the DOE, is studying the regional ground-water hydrology of the basin and the local ground-water hydrology near each of the domes.

Objective: To describe the ground-water hydrology of the salt-dome basin, with emphasis on determining rates and directions of water movement.

Approach: A drilling, testing, and sampling program was conducted in 1980-81 to gather data to describe the geologic and hydrologic conditions of a region within the basin that includes Cypress Creek, Lampton, and Richton domes. Future investigations may be focused on a yet smaller area close to one or more of these domes.

Progress: A preliminary report on the geohydrology of the area of Cypress Creek and Richton salt domes was prepared and was in review at the end of the year. The report summarized the results of the investigation and outlined needs for future investigations in the area. No field work was conducted.



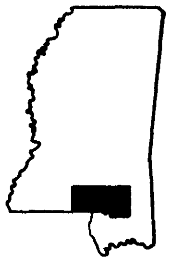
EXPLANATION

Salt dome; structure contour at 610 m below sea level

Base map from U.S. Geological Survey Map of Mississippi, 1972

10 0 10 Miles

10 0 10 Kilometers



LOCATION OF STUDY AREA IN MISSISSIPPI

GENERIC RESEARCH

The research described below is concerned with the properties of selected geohydrologic environments and rock types that may be suitable for the emplacement of high-level and transuranic wastes, how they may be explored and characterized, and how various geologic and hydrologic processes may affect the integrity of a repository.

As areas are identified where waste-disposal sites might be located, some of this research will become more site specific because generic studies must inevitably give way to detailed characterization of sites. However, much of the research will continue to have general applications to many geographic localities as well as to national needs other than disposal of radioactive wastes.

Studies of Rock Types and Environments for Emplacing Waste

Western Cretaceous Shales

By C.E. Neuzil, Reston, Va., and T.C. Nichols, Lakewood, Colo.

Owing to their relatively low permeability, the thick, extensive Cretaceous shales in the western United States serve as important confining layers for associated aquifers. There is also the possibility that their low permeability would make them useful for the disposal of radioactive wastes and other toxic materials.

A number of questions must be answered before the Cretaceous shales could be considered seriously as a site for a waste repository. Among these are:

(1) What is the nature of ground-water flow in the shales and how much leakage occurs through them?

(2) If fracture leakage is important, what is the distribution, geometry, and aperture size of the fractures? Are they densely spaced and small, or widely spaced and relatively large?

(3) What are the geotechnical problems associated with emplacing hot radioactive wastes in these highly montmorillonitic shales?

(4) Would high temperatures, resulting from the emplacement of high-level radioactive wastes, cause phase changes, the release of water, and changes in the physical properties of the shales?

Objective: The overall objective is to evaluate the geohydrologic and geotechnical behavior of the Cretaceous shales of the western United States with reference to their potential for isolating high-level radioactive wastes and other toxic materials. This will first require gaining an understanding of the behavior and properties of the shales under natural or undisturbed conditions. Secondly, the effects of disturbances caused by mining or excavation, and waste emplacement must be evaluated.

Approach: The approach will involved completing a regional aquifer-confining layer flow simulation as a basis for studying flow in the Cretaceous shales. Concurrently, core drilling and in situ testing will be done to obtain laboratory and field data on the hydraulic properties of the shale. Field measurements will also be made to obtain geotechnical data including state of stress and physical rock properties. Laboratory tests on the cores will be used to obtain hydraulic and geotechnical data under controlled conditions. Shallow (less than 200 m) test holes will be drilled to sample as much of the Cretaceous shale sequence as possible.

The mechanical effects on the shale of emplacing hot wastes will be analyzed by model studies. This will include developing a viscoelastic model for deformation. Laboratory testing will be required to provide the physical property data needed to support the model analysis. Based upon rock displacements calculated from this analysis, calculations will be made of the probability of producing joints and fractures which would change the virgin permeability values.

Progress: Hydrogeologic studies--A comprehensive study of the aquifer-confining layer system in South Dakota (Bredehoeft, Neuzil, and Milly, 1983), presents extensive determinations of hydraulic conductivity and specific storage for the Cretaceous shales. The data show that (1) local hydraulic conductivity of the shale ranges from 3×10^{-11} m/s to 2×10^{-14} m/s, decreasing with depth, (2) regional hydraulic conductivity at equivalent depths is 10 to 1,000 times larger and ranges from 5×10^{-12} m/s to 2×10^{-9} m/s, and (3) the specific storage is approximately 3×10^{-5} m^{-1}. The hydraulic conductivity data suggest that fracture leakage in the shales is important. This aspect of the problem is considered in Leakage and fracture permeability in the Cretaceous shales confining the Dakota Aquifer in South Dakota, by C.E. Neuzil, J.D. Bredehoeft, and R.G. Wolff. This paper, to be published in the Proceedings of the First Annual C.V. Theis Symposium by the National Water Well Association, develops the relation between fracture size and spacing in the shales in South Dakota, and discusses the evidence for the likely average spacing, which suggests a value on the order of 10^2 to 10^3 m.

Field investigations were carried out during the 1982 field season, involving drilling, coring, and hydraulic testing in the boreholes. A new approach was used to measure undisturbed pore pressure at depth in the shale; it involved permanent emplacement of transducers in a borehole backfilled with a

shale slurry. Results of this test, which suggest the occurrence of abnormally low pressures in the shale, are presented by Neuzil and Pollock (1983) together with a hypothetical mechanism for pore-pressure lowering. The data suggest that when the rock hydraulic diffusivity is small (as in the shales) erosional unloading can cause lowered pore pressures and possibly desaturation. The results are particularly interesting from a waste isolation point of view since long-term ground-water flow into the "tight" formation can result.

Cores will be used for laboratory permeability tests, mechanical tests (see section on Geotechnical studies), and tests which will aid in the interpretation of a suite of geophysical logs of the corehole.

Slug tests were conducted to determine permeability, but the tests failed to provide useful data because of a small leak in the test system. Hydraulic fracturing tests were run to estimate the state of stress, but the results were difficult to interpret.

Geotechnical studies--Essential to determining the feasibility of placing a waste repository in a Cretaceous clay-shale deposit, is a knowledge of the in situ material properties and geologic framework of the shale. The following evaluation of clay-shale properties is based on field and laboratory data obtained from the Pierre Shale at two upland plateau locations near Hayes, South Dakota, one on a divide and the other in an actively eroding drainage depression approximately 20 m lower than the other. These locations, although about 5 km apart, yielded data for approximately the same stratigraphic section of the Pierre Shale.

Investigations to depths of 183 m show the shale to be a fairly uniform, low-shear-strength, low-modulus, anisotropic rock mass, consisting mostly (60-100 percent) of dominantly mixed-layer, smectitic clays, and that it is totally saturated and partially underpressured. The shear strength is much lower in the direction of the bedding (approximately horizontal) than normal to the bedding.

The shale section in the lower actively eroding area had slightly different mineralogic characteristics than at the higher divide location. At the lower location, the shale consistently had a higher total clay content with more mixed-layer smectite that resulted in higher moisture content and a lower rock density. The thickness of the weathered zone at the lower location was much smaller than at the higher location even though the base of weathering occurred at nearly the same elevation at both locations. The deepest weathering on the divide location was about 20 m.

Locally, discrete natural fractures occur sporadically to the depths investigated, but they are very small, tight, randomly oriented, and mostly with well-developed slickensides. At present, there is no evidence to suggest that the fractures observed significantly affect the generally low permeability of the shale on a large scale. At the divide location, three fracture zones were present in which multiple fractures and brecciation were observed.

In each of these zones (up to 2 m thick), there was no significant gouge development and no free water. The breccia fragments were essentially the same as the undisturbed shale, showing no alteration or recrystallization and being 100 percent saturated. Based on drilling observations and laboratory data, it was concluded that the zones are not hydraulically transmissive. The zones have very low apparent dips and no lateral displacements nor well-developed thicknesses of gouge that would indicate significant faulting. The deepest brecciated zone was at a depth of about 90 m. No obvious normal faulting was observed such as the gravity faulting reported at the Oahe damsite, 45 km to the east (Underwood and others, 1964) in the Missouri River trench. These observations along with known low-shear strengths parallel to bedding (Fleming and others, 1970) and the in situ shear stress values determined above and below the breccia zones indicate the possibility that the brecciation may be a consequence of rebound deformation that resulted from erosional unloading.

The in situ state of stress in the shale, measured with a Menard pressuremeter, appears to be nearly lithostatic, equal to the weight of the overlying rock (Woodward Clyde Consultants, 1982). The maximum ratio of average horizontal to vertical stress, K_o, was 1.3 and the minimum was 0.90. The K_o values tended to decrease with depth but, nonetheless, indicated nearly equal horizontal to vertical components. As expected, the measurements also showed the shale to be highly overconsolidated near the surface with decreasing overconsolidation occurring at depth. The overconsolidation ratio (OCR) at 23 m was 11, and it decreased to 3.5 at a depth of 170 m. The bulk density in the fracture zones decreased approximately 0.10 g/cc, K_o dropped from 1.3 to 1.0, and the OCR changed from 5.3 to 4.0 indicating a relaxation and change of properties of the shale that may be related to the removal of overburden by erosion.

The measured thermal properties of the shale are quite variable depending on whether it is in the natural state or desiccated. At a constant pressure, the values of coefficient of thermal expansion (α) and specific heat (s) change significantly with changes of temperature and the degree of saturation. In the saturated shale, α values are approximately the same as those of water and, like water, increase in a nonlinear manner with temperature. In the desiccated state, α values increase linearly with temperature and are very small, smaller than those of many metals. On the other hand, values of s increase during desiccation but decrease again in the final stages of desiccation.

Values of s for the desiccated material appear to be linearly dependent on temperature change. The average conductivity (K) and thermal gradient were measured only in the saturated state (Sass and Galanis, 1983), but more than likely also change with desiccation and temperature. The mechanical anisotropy does not appear to influence the thermal conductivity significantly.

The creep properties determined upon loading and unloading can be significant. The maximum creep occurred in shale sections that appeared to be the most relaxed, that is, where the density was relatively low and the shale had the highest water content.

Maximum measured creep in 48 hours, about 1.73 percent, was caused by unloading. Savage (1982) applied the theory of three-dimensional consolidation to experimental, hydrostatic, consolidation data on the Pierre Shale in an attempt to model time-dependent deformation of the shale. An effort will be made to check the applicability of this model to field creep tests.

In addition to the above, the following laboratory investigations are continuing:

(1) Constant-strain-rate tests at 10^{-5} to 10^{-8} per second; temperature to 200°C; and pressures to 50 MPa. Includes studies of resulting mineralogic changes.

(2) One-dimensional consolidation tests.

(3) O^{18}/O^{16} and deuterium determinations in pore water, and pore-water chemistry.

(4) Study of chemical osmosis and its consequences on effective stresses and pore-fluid potentials.

(5) Pore-pressure studies in cores.

(6) Directional thermal properties.

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Water Flux in the Unsaturated Zones of Deserts

By Jacob Rubin, Menlo Park, Calif.

The unsaturated zone in deserts is one of the barriers to the movement of radioactive solutes which could be utilized in connection with designing repositories for high-level radioactive wastes. In order to predict the effectiveness of such a barrier, one should be able to estimate the prevailing long-term water fluxes at considerable depths for a specific location. Field data on fluxes of this type are extremely scarce.

Soil-water conditions in the uppermost (root zone) layers of arid, unsaturated zones are known to fluctuate widely with time. Theoretical considerations show that the effects of these fluctuations are transmitted downward but are rapidly attenuated with depth. As a result, at sufficient depths, near steady-state water fluxes may exist in unsaturated zones. Such fluxes reflect long-term trends. By studying profiles of selected water properties at appropriate depths in the unsaturated zone, it should be possible to find indications of whether an approximate steady state exists, and to measure the extant water fluxes.

Objective: To determine long-term averages of the downward water fluxes in the unsaturated zone for several types of desert conditions.

Approach: The approach involves studying water conditions in the unsaturated zone, with particular attention to determining sampling depths at which water fluxes are apt to reflect long-term trends. Using pressure-head and hydraulic-conductivity data, existing water fluxes will be computed from which estimates of long-term flux trends will be extracted. These estimates will be compared with analyses based on isotopic data and with simulation based predictions.

Progress: To evaluate long-term, average, downward water fluxes and obtain representative values for areally extensive unsaturated zones, a rapid, steady-flow method, which was developed earlier, for determining hydraulic conductivities of unsaturated, relatively dry sediment cores is being tested.

A series of tests of the method, using repacked, precompacted, unsaturated cores of a coarse-textured soil (Oakley sand), were completed. The lowest conductivities measured to date are 3.6×10^{-8} cm/s. These corresponded to 23.8 percent of soil saturation and soil water suction of 200 cm of water. To date, tests of the method using a fine-textured soil (Aiken Clay loam) have produced unrealistic water-content conditions.

Theoretical analysis has revealed that with the current size of the core holder, there may be significant transverse differences in water fluxes (and water contents) within the core during the steady-flow test. If this were the case, the previously measured fluxes would have been averages (rather than unique values). A series of experiments is being conducted to find out whether this is the case. Preliminary results suggest that there are no significant differences between fluxes within the soil core. More accurate tests, requiring changes in the design of the core holder, are now being implemented.

Plutonic Rocks of the Southeastern United States

By N.J. Trask and G.W. Leo, Reston, Va.

Crystalline rocks, including plutonic rocks, have been considered as potential host rocks for high-level radioactive waste repositories since 1955 because of their high strength and generally low permeability (National Academy of Sciences, 1957). Several countries including the United States, Canada, Sweden, France, the United Kingdom, and Switzerland are evaluating crystalline rocks and their surrounding terranes for suitability as host media for repositories.

In fiscal year 1982, the Department of Energy conducted regional literature surveys of crystalline rocks in the Northeast, North Central and Southeast Regions. Studies of specific rock masses, designed to collect data of relevance for high-level radioactive waste repositories, will be conducted during later phases of the DOE program. There are numerous crystalline rock masses with different ages and properties throughout the three regions under consideration. However, no one has developed a set of earth-science criteria for selecting the ones that are most suitable as host media.

Objective: To obtain an understanding of the basic field relations of representative plutonic rocks of the Southeast as related to radioactive waste disposal. To suggest criteria for evaluating such bodies as host media and participate with the DOE in initial planning and review of the screening process to select those that are most suitable.

Approach: Reconnaissance field investigations will be conducted of representative plutonic rock masses in the southeast Piedmont where the USGS has numerous working relationships with local earth scientists. Comparisons of fracture density, internal structure, age and relationship to potential host rocks will be made.

Meetings and workshops with the Department of Energy and with other investigators of crystalline rocks will be conducted and (or) attended as a means of arriving at useful criteria for screening.

Progress: Fifteen late-syn-metamorphic and post-metamorphic plutons in the southeast Piedmont were examined in reconnaissance fashion. The outcrops examined are not highly fractured. Most have an average density of fractures of 0.3/m and a maximum density of 4/m when the abundance of fractures is plotted according to the method of Thorpe (1979). Outcrops of some plutons have lower fracture densities than this, but the number of fractures is too small for meaningful measurements. There are no systematic differences in fracture density with pluton age or fracture orientation. The outcrops examined represent at most only 1 percent of the surface area of the plutons and may not be representative. However, the densities of fractures measured by a borehole televiewer in two holes in the Winnsboro complex, South Carolina (Zoback and Hickman, 1982) are comparable to the densities of near vertical fractures measured in surface outcrops of the pluton. It is also noteworthy that one large pluton with very few fractures in surface exposures has been extensively quarried and there are virtually no fractures in any of several quarries over an area of some tens of square kilometers.

The Cedar Rock pluton in the Inner Piedmont of southwest Georgia has been mapped recently in detail by Higgins and Atkins (1982). It is well-foliated in places and the foliation has been contorted into intricate folds in some outcrops. Despite this complicated internal structure, the pluton displays remarkably few fractures. Studies of this pluton were started. Samples were collected for isotopic and chemical studies, and studies of the few existing fractures were begun.

At a workshop sponsored by the Office of Nuclear Waste Isolation of Battelle Memorial Institute provisional criteria were developed for screening the crystalline rocks of the Southeast, much along the lines suggested by Trask (1982).

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Uranium Distribution in Igneous Rocks

By Robert A. Zielinski, Lakewood, Colo.

As investigations of waste-disposal sites in igneous rocks become more specific, geochemical studies will provide useful information on which to base judgments of site suitability. Studies of the distribution and mobility of naturally occurring uranium can be particularly informative because uranium is readily mobilized during the interaction of rocks with oxidizing water and because indications of uranium movement can be integrated with isotopic measurements that provide estimates of the timing of such movement. Observations of naturally "redistributed" uranium can also help to predict pathways and geochemical traps for uranium that is introduced by man into the same environment.

Objective: To identify the major sites of redistributed uranium in igneous rocks and to attempt to relate the relative amount of redistributed uranium to other measurable properties of the host rocks that influence radionuclide mobility.

Approach: Fission-track radiography of polished thin sections is used to identify mineralogical hosts of uranium. Redistributed uranium is identified by its association with secondary alteration products such as calcite, clay, zeolite, opal, or secondary oxides of iron and manganese. The amount of redistributed uranium is estimated by leaching of crushed, sized rock powders at 25°C with a mild acid-reducing solvent [1 M $NH_2OH \cdot HCl$ + 25% (V/V) CH_3COOH, pH ≈2] that selectively dissolves manganese oxides and calcite hosts and that removes weakly adsorbed uranium from mineral surfaces (Chester and Hughes, 1967). The relative amounts of leachable U, Mn, and Ca are

related to rock properties such as differences in the degree of welding, fracturing, devitrification or alteration, and to the degree of isotopic equilibrium between chemical and radiometric (radium-equivalent) uranium (RaeU); the latter determined by gamma-ray spectroscropy.

Progress: Forty-one core samples of Tertiary rhyolitic ash-flow tuff exhibiting varying degrees of welding, fracturing, devitrification or alteration were obtained from drill hole USW-G1 at Yucca Mountain, Nevada Test Site (fig. 5). Six lithologic units were sampled, four of which contain intervals of moderately-to-densely welded, devitrified, relatively unaltered ash-flow tuff, the potential host for the high-level radioactive waste.

Radiographic measurements of this group of samples indicate a common spatial association of uranium with secondary oxides of iron and manganese that fill microfractures and coat grains. Nonwelded, highly altered tuffs clearly contain more evidence of redistributed uranium because of a greater abundance of secondary iron and manganese oxides. In other samples, secondary oxides are too sparse and their distribution too irregular to allow quantitative ranking on the basis of thin-section observations.

The association of uranium and manganese oxides is supported by covariance of dissolved uranium and manganese in leachates. The leaching procedure also produces the expected order of leachability, i.e., nonwelded, altered tuffs > welded tuff > vitrophyre. The precision of the leaching procedure was estimated from duplicate measurements of fresh sample splits and analytical variation is generally small compared with the observed differences in leachability that occur within and between lithologic units.

The leaching results provide a relative ranking of similarly welded intervals from different lithologic units. The moderately-to-densely welded Topopah Spring Member of the Paintbrush Tuff shows the least evidence for incipient formation of manganese oxides and calcite and for uranium redistribution; a finding that is consistent with its location above the present static water level. Similarly welded intervals from more deeply buried rhyolitic units such as the Bullfrog Member and Tram units of the Crater Flat Tuff contain approximately twice the amount of leachable U and Mn in the Topopah Spring Member of the Paintbrush Tuff. In general, the relative abundance of manganese oxides and calcite, inferred from leaching of competent welded tuffs, mimics their observed relative abundance in macroscopically fractured intervals of the same tuff unit. For the entire subset of 21 samples of the most welded tuffs, respective leached amounts of Ca, Mn, and U average 18.3, 33.5, and 4.1 percent of the amount present.

In spite of differences in the amount of incipient alteration and of adsorbed (?) uranium, agreement of actual uranium concentrations with radiometric uranium concentrations (RaeU) in whole-rock samples indicates dominant closed-system behavior of uranium and its long-lived daughters and suggests that the extent of recent (<300,000 yr) uranium movement on the scale of a whole rock sample is minor or dominantly intergranular. Thus, the present physical-chemical environment of the studied rocks appears to restrict uranium mobility.

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Methods for Characterizing Environments for Emplacing Wastes

Identification of suitable repository sites requires that a body of rock and its local and regional geologic and hydrologic environment be well understood and characterized as to its physical and chemical properties and the potential for disrupting the containment properties of the environment by future geologic events or processes. At the same time, the characterization must be done with a minimum number of penetrations by drill holes and shafts. For some of this characterization, existing techniques are adequate or can be modified to provide the needed information. For other aspects, some new geophysical and geochemical techniques are being developed which can make the task easier, give more accurate results, or provide desirable information that is unobtainable at present.

In many respects geophysical studies of possible repository sites involve an unconventional use of geophysics. Usually geophysicists look for faults, hydrothermal alteration, secondary minerals, and other anomalies, rather than for the absence of such features. The research described below is aimed at better defining the capabilities and limitations of existing methods and improving these methods for the specific needs of the waste-isolation program. All geophysical techniques need to be assessed further and improved from the point of view of distinguishing from normal background variations, fine-scale inhomogeneities that may be of concern in evaluating the waste-isolation properties of the site.

The research in geochemistry involves the improvement of existing methods and development of new methods of isotopic dating of rocks, soils and minerals.

High Frequency Electromagnetic Methods

By David L. Wright, Lakewood, Colo.

Inhomogeneities and structural flaws in a rock mass are potential problems for its use as a host medium for radioactive wastes. Radio waves seem to offer a good means of finding such features. Unfortunately, radio probing of rock, at present, is comparable in its stage of development to seismic prospecting in the 1940's and 50's: some basic capabilities exist, but considerable improvement is needed in 1) instrumentation, 2) understanding of wave-propagation phenomena, and 3) interpretive tools and techniques.

Electrical properties of rocks are very strongly affected by the water in the rocks. Low porosity, unfractured rocks contain very little water and are quite resistive; porous rocks that contain more water are less resistive. Thus, a rock's electrical resistivity may be, in a gross way, proportional to its suitability as a host medium for wastes. Dry rock salt and granite are known to be excellent media for radio-wave probing. There is at present a lack of data on radio-wave propagation including absorption and scattering in various rock types. Because propagation involves bulk variations in the rocks, laboratory measurements are not entirely adequate.

To be useful in the early stages of repository exploration, radar must be functional from boreholes; mined openings will not be initially available for radio probing activities. Use of boreholes introduces many practical problems for radar work, such as the effects of the borehole fluids on antenna performance and interactions between the logging cable and the antennas.

Objective: To determine the capabilities and limitations of high frequency electromagnetic techniques for evaluating the homogeneity and continuity of granite, salt, and other low conductivity media, to develop and field-test prototype equipment, and to develop or enhance interpretive techniques.

Approach: Both theoretical analysis and experimental scale-model studies are being applied to answer some questions regarding propagation and antenna behavior in fluid-filled boreholes, particularly if the fluid is a highly conductive one like saturated brine. In order that an actual borehole radar might be tested and made available, along with other geophysical methods for site characterization, a full-scale prototype borehole radar system is being developed. Finally, data-acquisition and data-processing techniques are being developed appropriate to borehole radars.

Progress: Successful detection of an air-filled tunnel in mineralized granite was achieved by the USGS prototype monopulse borehole radar system. This demonstrates the ability of the radar to detect inhomogeneities in the dielectric properties of rock as predicted by theoretical calculation.

An important improvement to the radar itself was made by the addition of electronic gain switching. The radar operator can now set and change gains while the radar is operating, permitting rapid adjustment of the system to a wide variety of borehole situations.

Significant progress was also made in the area of digital processing for radar data enhancement. A number of time-domain techniques such as stacking, normalizing, time-weighting, and average removal were used to enhance returns from geologic structures of interest when the desired signals are obscured by external or system-generated noise. Frequency domain filtering was also used and was quite successful in suppressing system-generated oscillations, allowing the desired data to be clearly observed.

Much of this work was reported at the Workshop on Geophysical Investigations in Connection with Geological Disposal of Radioactive Waste, sponsored by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD) held in Toronto, Canada, September, 1982.

Borehole Geophysical Logging

By W. Scott Keys, Frederick L. Paillet, and Ulrich Schimschal,

Lakewood, Colo.

Test drilling is essential for the investigation of potential host rock types and sites for the disposal of radioactive waste, and wells must be drilled at operating sites to monitor the movement of artificial radioisotopes. Borehole geophysical logging not only provides a synergistic suite of measurements to aid in the evaluation of sites, but these measurements permit the lateral and vertical extrapolation of data from hydrologic tests and core analyses. Borehole geophysical logging may also provide data on the location, orientation, and width of fractures which can be useful in determining their capability to transmit fluids. Gamma spectrometry in monitoring wells permits the identification and semiquantitative analysis of migrating radioisotopes behind well casings where sampling may be difficult or impossible.

Objective: The objective is to develop specialized well-logging equipment and log-interpretation techniques for application to the unique problems and conditions encountered in geohydrologic investigations of existing and potential sites for the disposal of radioactive waste.

Approach: The research is divided into borehole geophysical techniques for characterizing potential disposal sites and those techniques useful for monitoring waste migrating with ground water at existing sites. Site characterization methods include acoustic, nuclear, and resistivity logging that can provide data on the properties of rocks related to ground-water movement and solute transport. Temperature, fluid conductivity, and flowmeter logging can be used to analyze the spatial distribution of permeability when the system is hydraulically stressed. Special attention is focused on methods that provide information on fractures because they constitute a significant problem in evaluating fluid transfer conditions at proposed sites. The geophysical data are digitized in the field and computer methods are used for collation and interpretation in order to maximize the cost-benefit ratio.

Site monitoring techniques available for use in boreholes include gamma spectrometry, neutron activation, and temperature and fluid-quality logging. All of these can provide real-time data on the vertical and horizontal distribution of certain types of waste without sampling.

Progress: Research on borehole geophysical logs and hydrologic tests to characterize crystalline rocks for nuclear waste storage at two sites in Canada has been summarized (Davison, Keys, and Paillet, 1982). The work was carried out at Whiteshell Nuclear Research Establishment, Manitoba, and Chalk River Nuclear Laboratory, Ontario. The geophysical logs that are particularly useful to characterize rock type, alteration, and the location and character of fractures are the acoustic televiewer, acoustic waveform, acoustic velocity, neutron, gamma, resistivity, temperature, and caliper. In situ hydraulic tests of single fractures or fracture zones isolated by packers provided quantitative information on permeability, extent, and interconnection. The computer analysis of digitized acoustic waveforms has identified part of the waveform that has amplitude variations related to permeabilities measured in the boreholes by packer tests. Under specified conditions, the geophysical and hydrologic methods described in this report can largely substitute for continuous coring.

A report entitled, "Acoustic characterization of fracture permeability at Chalk River, Ontario," by F.L. Paillet, was accepted for publication by the Canadian Geotechnical Journal.

A large number of geophysical logs were made at the Underground Research Laboratory (URL) in Manitoba, Canada. Four deep, continuously cored holes and seven drill holes have been logged to date, and analysis of these logs has started. A large amount of core data and hydrologic test data will be available in the future, and mining of the underground chamber will begin in January 1984. This will provide direct access to part of the rock being investigated by geophysical logs.

Preliminary analysis of URL logs indicates that the compensated neutron porosity sonde will be effective for logging in crystalline rocks, and that a three-curie source can be used in such rocks instead of the much larger source required by design calculations. The standoff detectors on this sonde provide high-resolution fracture data. It appears that depletion and enrichment of uranium has taken place along some permeable fractures at the site and may provide a guide to such fractures.

Frederick L. Paillet has completed tests of the theory for acoustic propagation in shales using data from a site near Fort Pierre, South Dakota. The recorded waveforms for observed, trapped-fluid modes, and those predicted from theory, are almost the same. Tests have been carried out at three different frequencies and at various times after filling the holes with water. Acoustic velocity decreases with hydration, and it was possible to identify bentonite beds and fractures from the acoustic waveforms recorded in one hole.

Frederick L. Paillet prepared a report entitled, "A comprehensive theory for the interpretation of compressional and shear head waves in boreholes," which is to be published in the Bulletin of the Seismological Society of America.

Renee Kierstein has developed programs for both the computer and programmable pocket calculator to correct the orientation of fractures or other planar surfaces logged with the acoustic televiewer. Corrections are made for deviation of the hole from vertical and for the effect of the vertical component of the earth's magnetic field on the tilted magnetometer. Test results suggest that fracture orientation can be corrected to $\pm 5°$ provided there is no significant amount of magnetite in the rocks.

A.E. Hess has tested and modified a heat-pulse flowmeter that has excellent low velocity flow-measuring sensitivity. The flowmeter was tested using water velocities ranging from 0.35 to 250 millimeters per second and was found capable of measuring naturally occurring, thermally induced convection currents in boreholes. The flowmeter is being extensively modified in order to improve both field reliability and response through four-conductor logging cable.

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High Resolution Electromagnetic Sounding Methods

By Frank Frischknecht, Lakewood, Colo.

Electrical methods are very useful in the exploration and characterization of potential sites for nuclear waste repositories. Many features such as zones of abnormal fracturing or alteration, which are important in site selection, are good targets for electrical methods. Electrical methods are effective for locating both horizontal and steeply dipping boundaries, and

some rock types in the subsurface can be predicted from established relationships between rock type and resistivity.

Existing resistivity and electromagnetic methods work very well and are used on a routine basis for depth sounding when the earth can be represented approximately as a horizontally layered medium. However, to make a conventional resistivity or frequency domain loop-loop EM sounding, the electrode configuration or loop spacing must be two or three times the desired depth of investigation. The presence of major lateral boundaries or other inhomogeneities near an electrode or loop causes distortion of the sounding curve and interpretation of the results is difficult and very time consuming if the distortion is severe. An electromagnetic technique which employs concentric loops or a single loop should be less susceptible to the effects of lateral boundaries than conventional methods. However, to achieve the necessary sensitivity for deep probing with such a configuration, frequency domain measurements must be made with extreme accuracy or time domain wave forms must be employed.

Objective: The primary objective is to develop time domain electromagnetic (TDEM) sounding methods using the concentric or single-loop configurations. A secondary objective is to evaluate and demonstrate the method in areas where potential repository sites have been or are being investigated with other geophysical methods.

Approach: Initial tests of the concentric and single-loop domain techniques were carried out using a commercially available (SIROTEM) TDEM system designed for mineral prospecting. A larger system for sounding to depths as great as 2,000 m, which would be useful even in low resistivity rocks, is being developed. Methods for rapid display and computer inversion of the data are being developed. Three-dimensional model studies are being made to determine correction factors for such structures, if feasible, and to establish limitations and capabilities of the method.

Progress: Scale-model studies show that single loop TDEM data are more easily interpreted than separated-loop frequency-domain data when lateral boundaries are present. Of course, the method is not immune to the effects of lateral boundaries and scale studies have been made to determine the effects of some types of structural features. For instance, truncation of a horizontal conductive layer can cause a pronounced distortion of the TDEM sounding curve, but only when the loop is over the edge of the layer.

Programs to convert raw-voltage, transient data to apparent resistivities and to plot data in the field were developed for desk-top computers. Programs to invert data, assuming a one-dimensional model, were developed for both the coincident-loop and central-loop configurations using either transient voltages or apparent resistivities.

A new medium power TDEM transmitter was developed and used very successfully in the field, and development of a new high power (100 amp) transmitter is in

progress. A computer-based receiver system which will permit measurements at later times than the existing system has been assembled and is being tested.

Field measurements have been made at a number of localities including the Nevada Test Site (NTS) (Frischknecht and others, 1982). A comparison of central- and coincident-loop results obtained along a profile at NTS extending west from Yucca Mountain (fig. 2) indicate that basically the two configurations give similar results.

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Isotope Geochronology

By John F. Sutter, Reston, Va.

Improvements in the dating of past geologic events will allow better estimates of the rates at which changes have occurred and the likely consequences of such changes over the life of a repository; they also will allow us to place higher confidence limits on such estimates. Events that have occurred between about 30,000 to 1,000,000 years ago fall in a time range that is not now covered by standard dating techniques. In addition, reducing the size of sample needed for age determinations will allow the dating of materials that cannot be dated at present and thus expand the applicability of the techniques involved.

The research described below is supplemented by the Geological Survey's extensive activities in Quaternary research under its Earthquake Hazards, Climate, and Reactor Hazards programs. All of these programs include research on improving techniques for dating relatively recent geologic events and materials.

Objective: To develop new methods of determining the ages of rocks and geologic events and to improve the time range and sensitivity of several existing techniques.

Approach: A laser probe mass spectrometer has been assembled for dating the time for formation of rocks, minerals, and fluid inclusions by potassium/argon methods. This recently-developed technique reduces the sample size by several orders of magnitude and allows ages to be determined on microscopic samples. Its development should make it possible to date periods of shearing and faulting, rock alteration, metamorphism, and volcanism by looking at smaller domains within the rock mass than is currently possible.

Progress: Development work on the laser probe mass spectrometer continued with the testing of a laser sample chamber vacuum system and an argon purification system. Also, development work on sample holders resulted in the design of a multiple-sample laser system. Testing of argon isotopic background in both mass spectrometer and sample chamber was begun and sensitivity and detection limits were estimated. The result of this testing suggests that mineral sample sizes on the order of a few micrograms can likely be dated by this technique in our laboratory. For most samples, this means that individual mineral grains can be dated in situ without extracting them from the rock prior to analysis, as must be done for the conventional K-Ar dating method. Development work on the type of sample preparation necessary for this method was accomplished and characterization of a preliminary sample set and standards was begun. An unanticipated result of the testing was the recognition that the ability to measure K-Ar ages with the laser extraction system is not controlled by the ability to measure radiogenic ^{40}Ar, as was expected, but by the ability to measure ^{36}Ar with enough precision to make the necessary correction for atmospheric argon contamination. Our mass spectrometer has an inherent blank level at mass number 36 of about 1×10^{-16} moles; thus, our present detection limit for ^{36}Ar is about 1×10^{-17} moles.

In practical terms, any improvement in our blank level at mass number 36 reduces the sample size needed for measurement by a corresponding factor. Our goal is a sample size of 1 microgram or less (presently, it is about 5 micrograms) which will allow us to date single K-bearing mineral grains only a few million years old. To reach this goal, several modifications to our existing mass spectrometer system are likely to be necessary. The manufacturer of our mass spectrometer (VG-Isotopes Limited of Winsford, England) is now working on the development of modifications that would result in a significantly reduced background at mass number 36. Considering that the smallest sample sizes needed to calculate conventional K-Ar dates is on the order of tens to hundreds of milligrams; we have demonstrated that the laser-argon age probe is capable of reducing that sample size by at least 3-4 orders of magnitude.

Investigations and Modeling of Geologic and Hydrologic Processes

A major objective of the USGS research related to the disposal of high-level wastes is the identification and understanding of the critical geologic and hydrologic properties and processes involved in radionuclide migration from a repository to the biosphere. One group of properties and processes is related specifically to the thermal and mechanical stresses imposed by the emplacement of high-level wastes. The effects of these stresses on the underground flow of fluids (including vapor) and heat cannot be modeled at present for fractured rocks and unsaturated alluvium. To accurately describe the flow of fluids in these media requires an understanding of rock mechanics, heat transport, saturated ground-water flow in fractured rock, nonisothermal water fluxes in the unsaturated zone, and combined unsaturated-saturated zone flow in thick alluvium.

The research described below is supported from USGS appropriations.

Fluid Flow in Fractured Rocks

By P. A. Hsieh, Menlo Park, Calif.

The success of an attempt to predict the movement of fluids in a low-permeability, fractured rock mass will depend on the ability to (1) mathematically describe the physical laws that govern the movement of fluids in such an environment, and (2) quantitatively characterize the porosity and permeability of the rock mass and the flow system by meaningful and measurable quantities.

Objective: The objective is to examine the validity of characterizing a fractured rock mass as an anisotropic porous medium. Two questions are to be addressed: (1) Under what circumstances are the mathematical equations for fluid flow in anisotropic porous media applicable to an actual field site? (2) On what scale must the flow system be examined and measurements taken?

Approach: At present, two general approaches have been proposed to predict the movement of fluids in fractured rocks--the discrete approach which attempts to characterize fluid flow in individual fractures, and the continuum approach which characterizes the fractured rock mass as an anisotropic, and possibly "double," porous medium. The current research follows the continuum approach.

The approach to examining the validity of a mathematical model is to predict, by theory, the response of a flow system that is subjected to a known stress and then to compare the predicted behavior with the actual behavior observed in a field test conducted at a site where conditions are similar to those assumed in making the theoretical predictions. The effect of scale will be examined theoretically by computer simulations and experimentally by making measurements for different volumes of rock during field testing. Specifically, the approach involves (1) reviewing the literature on fluid flow in fractured rock, (2) deriving analytical solutions of equations for flow in

an anisotropic porous medium for various field testing schemes, and developing methods of computing the hydraulic conductivity tensor from field data, (3) conducting field tests at a site located on fractured crystalline rock of moderate permeability (i.e., about 10^{-6} cm/s), (4) comparing theoretical predictions and observed results, examining differences between the two, and possibly modifying the theory to account for discrepancies, (5) examining the effect of scale by analyzing field data taken for different volumes of rock and by computer simulations, and (6) obtaining additional data from other sites (e.g., Stripa, Sweden) for similar analysis, with emphasis on data from field tests on rocks of low permeability (i.e., 10^{-9} cm/s or less).

Progress: The past 3 years of research activity have culminated in the development of a comprehensive methodology of hydraulic testing in fractured rocks. The methodology utilizes geological and geophysical information as background. It consists of conventional single-hole packer tests in conjunction with a newly developed cross-hole packer test. The cross-hole method involves injecting fluid into a packed-off interval in one borehole and monitoring hydraulic head variations in packed-off intervals in neighboring boreholes. Borehole orientation is unrelated to the principal directions of relatively high hydraulic conductivity which, therefore, need not be known a priori. The method yields complete information about the directional nature of hydraulic conductivity in three dimensions on a scale comparable to the distance between the test boreholes. In addition to providing all six components of the hydraulic conductivity tensor, the cross-hole method also yields the specific storage of the fractured rock mass. While the theory behind this method treats the rock as a homogeneous, anisotropic, porous medium, the test provides detailed information about the degree to which such assumptions may actually be valid in the field. Details of this field-testing methodology are described by Hsieh (1983).

The proposed hydraulic testing methodology has been applied to a granitic site near Oracle in southern Arizona, which was provided by the Department of Hydrology and Water Resources, University of Arizona. Two series of single-hole pressure tests (constant-head injection and pressure-slug) have been conducted along the entire lengths of two boreholes. The injection and pressure-slug tests yielded similar hydraulic conductivity values ranging from 10^{-11} to 10^{-7} m/s. In each borehole, the arithmetic average of the hydraulic conductivities determined at different packed-off intervals was similar to the overall hydraulic conductivity obtained from open-hole tests. Preliminary cross-hole tests have been conducted in the same two boreholes. Although the hydraulic conductivity tensor and specific storage cannot be obtained without data from a third borehole, the results nevertheless suggest that the tested rock mass responds as a classical, anisotropic, porous continuum. Further tests in a three-dimensional array of boreholes are under way.

Report

Hsieh, P.A., 1983, Theoretical and field studies of fluid flow in fractured rocks: Ph.D. dissertation, University of Arizona, Tucson, Ariz.

Field Tests of Flow in Unsaturated Alluvium

By E. P. Weeks, Lakewood, Colo.

If unsaturated alluvium in arid regions is considered for the host medium in high-level waste repositories, models must be developed to estimate the flow of water that might leach radionuclides and transport them toward the water table, considering ambient thermal conditions and the presence of a heat source. These models will be useful also to evaluate effects of extreme climatic events and of climatic changes on the integrity of the repository.

Objective: To develop and field test operational models to simulate combined saturated-unsaturated flow under anisothermal conditions at a small scale and on a precise theoretical basis; also, to simulate saturated-unsaturated zone interactions at an areal scale on a more empirical basis.

Approach: Field, laboratory, and modeling studies will be used to achieve the objective. Field studies will include the measurement of subsurface moisture tension, temperature, and humidity to determine the flow of heat and water.

Data from field tests of unsaturated flow will be used to develop and test an operational small-scale model for combined unsaturated-saturated zone flow under anisothermal conditions. The model will permit the simulation of various conditions of infiltration and soil-moisture depletion by evapotranspiration. Results of the small-scale model studies will be used to develop a more empirical large-scale model that will include the approximate effects of the unsaturated zone.

Progress: The installation of thermocouple psychrometers has been completed at Jackass Flats on the Nevada Test Site with psychrometers installed at a distance of 4.0-4.3 m from the sidewall of the caisson along each of three rays 120° apart. The psychrometers, together with tensiometers and gas-sampling tubes, are installed at 60-cm intervals between depths of 1.5 to 12 m. Instruments along three rays will allow three experiments, including one with a heater and subsequent water flooding, one with flooding but no heater, and one for long-term monitoring. The heater experiment is now scheduled to start in the winter of 1983-84.

The heater experiment at Tryon, Nebraska at the University of Nebraska Sandhills Agricultural Laboratory has been in progress for almost 2 years, and will be halted in September 1983. Water collected in a depression and ran down the annulus of the heater hole in the summer of 1982, resulting

in a sharp drop in temperature in its immediate vicinity. The problem was identified, the heater hole was rebackfilled, and the surface mounded to prevent further ponding of water. Temperatures regained their pre-infiltration level and the test is progressing well.

Nonisothermal Water Fluxes in the Unsaturated Zone

by W. N. Herkelrath, Menlo Park, Calif.

In view of the low water flux usually found in the unsaturated zone in arid regions, this environment has been suggested as being worthy of further consideration for locating high-level waste repositories.

Initially, the wastes will be at higher temperatures than their surroundings and will probably be placed in a medium that is relatively dry and is approximately at atmospheric pressure. Therefore, assessments of plans for containing waste in the unsaturated zone must be based on models which use nonisothermal water-flow theory applicable to porous media with low water contents and air pressures. In addition, vapor as well as liquid water flow must be taken into account.

Currently, there exist two competing theoretical approaches to the flow of vapor and liquid in response to thermal gradients: one is based on hypotheses about the mechanism involved while the other is largely empirical and based on the principle of irreversible thermodynamics. Few critical experimental checks of these approaches are available, and almost none of them are for transient conditions. In those carried out, soil temperatures and water suctions are considerably lower than those anticipated near the high-level radioactive waste, at least for some time after burial. These tests and certain theoretical considerations have demonstrated significant shortcomings of the available theories.

Objective: To examine critically the adequacy of the available theories for nonisothermal liquid and water-vapor transport under various conditions of water content, temperature, and air pressure expected to be associated with the presence of high-level radioactive waste.

Approach: The approach will include conducting laboratory tests to examine the theoretical concepts. Laboratory measurements of relevant properties will be made for samples taken from field test sites to estimate parameter values for computer modeling of field transport conditions.

Progress: Work continued on the development of laboratory methods to measure the temperature dependence of flow properties in unsaturated soils and rocks. The submersible pressure outflow cell (SPOC) was developed to enable rapid and reliable measurement of water content and capillary pressure at temperatures from 4°C to 100°C. The SPOC was used to determine the isobaric (constant capillary pressure) temperature dependence of water content in

an unconsolidated sand. This unique experiment indicated large hysteresis in the relationship between water content and temperature. Furthermore, paths traversed in pressure-temperature-water content space were found to close only when main branch wetting or drying loops were encountered. The SPOC system was also used to determine the soil-moisture diffusivity at elevated temperature. Temperature-induced changes in measured parameters were found to be as much as ten times larger than predicted by the standard soil-physics theory. A miniaturized soil-moisture probe was also developed for use in vapor-flow and boiling-flow experiments. The probe was used to measure the dielectric constant of unsaturated porous media by time-domain reflectometry (TDR). The TDR probe was found to give reliable nondestructive measurement of the water-content distribution in laboratory soil cores.

Laboratory studies of transient water-vapor flow in soil also continued. We discovered previously that adsorption of water vapor on the surface of soil particles had a dramatic effect upon vapor transport. We found that the adsorbed water served as a large source of vapor, which buffered pressure changes in the porous medium. An analytical approach was developed to provide a solution to the modified flow equation which we proposed. Comparison between experimental results and the analytical solution was excellent, providing further support for the new adsorption-affected vapor-transport theory.

Reports

Constantz, J. and Herkelrath, W.N., 1982, The isobaric temperature dependence of water retention in a sand (abs.): Agronomy Abstracts, v. 74, p. 160.

Moench A.F. and Herkelrath, W.N., 1981, Analytical approach to the simulation of laboratory steam-flow experiments: Proceedings of the Seventh Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, Calif., Dec. 15-17, p. 179-181.

Modeling Fluid Flow and Energy Transport in Unsaturated Alluvium

By D. W. Pollock, Reston, Va.

The transport of water and energy in an unsaturated porous medium are strongly coupled. To adequately evaluate the thermal effects of high-level radioactive waste disposal in unsaturated alluvium, it is necessary to consider the simultaneous transport of water and energy.

When an unsaturated porous medium is exposed to a heat source (such as a container of high-level waste), water-vapor pressure increases with increasing temperature which causes vapor to move away from the heat source by a combination of diffusion and gas flow. Liquid flow toward the heat source occurs in

response to large gradients in liquid-water potential which develop as the material surrounding the heat source dries. The net result is the gradual formation of a dry zone that expands at a rate controlled by the net water flux.

Heat-conduction analyses can provide first-order estimates of temperature changes in an unsaturated porous medium. However, heat transport in an unsaturated medium is strongly affected by the movement of water vapor and the liquid water content. Latent heat transfer by vapor has the effect of increasing the apparent thermal conductivity of the porous medium. On the other hand, the thermal conductivity of an unsaturated porous medium decreases with decreasing liquid-water content. The temperature distribution in a repository will depend on the balance between these competing effects.

Objective: The objective is to develop mathematical models which can be used to (1) simulate the transport of water and energy near hypothetical repositories in a variety of unsaturated media, and (2) simulate field and laboratory experiments designed to reproduce conditions that will exist in a waste repository.

Approach: A numerical model of fluid flow and energy transport in unsaturated porous media will be developed and used to study the effects of relatively high temperatures on the movement of water and energy in the vicinity of a repository. A numerical model provides a means of studying the relative merits of a variety of repository designs and unsaturated hydrogeologic environments. Concurrent field and laboratory experiments will result in a much improved understanding of nonisothermal transport processes in unsaturated porous media. New information about the physics of the transport processes will be incorporated into the numerical model as it becomes available.

Progress: Work continued toward developing and refining numerical models of heat transport and fluid flow in unsaturated alluvium. Meaningful two-dimensional simulations are often impractical, if not impossible, because of the large amounts of computer time required to solve two or three simultaneous, nonlinear transport equations. To help alleviate that problem, the waste repository was considered to be an areally extensive array of closely spaced canisters. That assumption permits the thermal load to be approximated by a uniformly distributed heat source and the transport processes to be considered one dimensional in the vertical direction. Numerical simulations which assume two dimensional, axisymmetric transport around individual canisters in a repository indicate that one dimensional vertical transport is a good assumption above and below the repository and a satisfactory first approximation within the repository when the canisters are spaced on the order of 5 m apart or closer (Pollock, 1982).

The one-dimensional transport model was used to analyze a number of hypothetical repositories located in unsaturated alluvium with the hope of developing a better intuitive understanding of the effects of an intense heat source on the movement of water and energy in and around a repository. It was assumed for the simulations that the repository contained 10-year-old spent nuclear fuel and was located at a shallow depth which varied from 25 m to 100 m below land surface. Boundary conditions and material properties were designed to represent as closely as possible those of the arid alluvial fan environments at the Nevada Test Site. Results indicate that during the first 100 to 200 yr after burial a dry zone develops which, in some cases, may extend several meters above and below the repository. The development of the dry zone is followed by a recovery period lasting several hundred to a few thousand years, during which time decreased vapor transport and continued liquid flow toward the repository cause moisture conditions to approach initial levels once again. An effort was made to adjust the strength of the heat source to keep the maximum temperature near 150°C; a value of 15 W/m^2 produced good results for the systems considered. The simulations also showed that latent heat transfer by vapor can significantly affect the temperature distribution near the repository even under very dry initial conditions. As the temperature approaches 100°C in those parts of the system where the moisture content is large enough that vapor transport is not inhibited by adsorption effects, latent heat transport by vapor becomes so large that temperatures are held at or near 100°C. Temperatures in the immediate vicinity of the repository rise above 100°C only after the porous medium has dried sufficiently for adsorption to effectively cut the rate of vapor transport. Finally, the simulations confirm that even though a large fraction of the vapor transport near 100°C is due to gas flow (rather than diffusion, which dominates at lower temperatures), the alluvium is sufficiently permeable that significant changes in gas pressure do not occur, even when the thermal stress is extreme.

Report

Pollock, D.W., 1982, Fluid Flow and Energy Transport in a High-Level Radioactive Waste Repository in Unsaturated Alluvium: Ph.D. thesis, Department of Geology, University of Illinois, Urbana-Champaign.

Transuranium Elements in Ground Water

By J.M. Cleveland, Lakewood, Colo.

In view of the long half lives of many of the transuranium elements (plutonium, neptunium, and americium) and uncertainties regarding their chemical speciation, it is difficult to predict their transport and distribution characteristics. In particular, it is fruitless to attempt to make distribution measurements of the transuranium elements or to model their ground-water transport without first determining their chemical forms

and solubilities in the ground waters of interest. This speciation is relatively straightforward for monovalent elements such as americium, but is somewhat more complex for the multivalent elements plutonium and neptunium.

Research in this area is included in the high-level waste program because of its significance in evaluating the far-field consequences of disruption of a high-level waste repository.

Objective: To define the chemical speciation and the chemical and hydrologic behavior of transuranium elements in ground waters.

Approach: The current approach is along three different lines involving both phenomenological and thermodynamic studies:

1) Speciation of plutonium, neptunium, and americium in ground waters from rock types of actual or potential interest as repository host rocks.

2) Speciation of plutonium leached from cubes of vitrified radioactive waste.

3) Determination of accurate thermodynamic data for complexes of the transuranium elements (especially plutonium) with anions common in ground water.

The ground-water speciation studies (item 1) involve the addition of dissolved plutonium, neptunium, or americium to measured volumes of water samples from the rock types of interest. After standing for periods ranging from 1 to 30 days, the waters are shaken, sampled, and subjected to analysis for total plutonium concentration both before and after filtration through 0.05-μm Nuclepore filters. From these results, the percentages of the three elements remaining in solution are calculated. In addition, the filtrates undergo a series of carrier precipitation and solvent extraction experiments to establish the oxidation-state distribution of the plutonium, americium, and neptunium remaining in solution. These experiments are run at 25° and 90°C.

In the leaching speciation studies (item 2), plutonium-containing waste-glass cubes (obtained from Battelle Pacific Northwest Laboratory) are subjected to static leaching (using a variation of the Battelle MCC-1 procedure) with the same ground waters studied in item 1 for periods up to 360 days and at temperatures of 25° and 90°C. After standing for the specified period, the waters are sampled before and after filtration, and analyzed both for total plutonium concentration and oxidation-state distribution, using the procedures described in item 1.

Thermodynamic studies (item 3) have centered, thus far, on complexes of plutonium (IV) with sulfate and fluoride ions. The variation in distribution of plutonium in solvent extraction and ion exchange systems as a function of

the complexing ion enables the stability constant(s) and free energies of the complex(es) to be calculated; from the variation of these parameters with temperature the enthalpies and entropies are determined.

Progress: Following are statements of progress for the three areas of research.

(1) Studies were completed on the speciation of plutonium, neptunium, and americium in ground waters from four rock types of interest, and significant conclusions were reached regarding the influence of ground water on speciation. The four ground waters studied - namely, from basalt in the Hanford reservation in Washington, from Climax stock granite and tuff at the Nevada Test Site, and from Cretaceous shale from the Northern Great Plains - varied greatly in chemical composition and in ability to retain plutonium in solution. Plutonium was most soluble and, hence, most mobile in the basalt ground water, and least soluble in the shale ground water. From these results and others using synthetic solutions containing specific ions, it was possible to draw the following conclusions:

    a) Plutonium was most soluble in ground water containing a relatively high concentration of fluoride, a strongly complexing anion.

    b) In the absence of complexing ions, plutonium is least soluble in reducing waters because of the lower solubilities of the lower oxidation states [Pu(III) and Pu(IV), especially the latter].

    c) The solubility of plutonium is further diminished in reducing waters containing high concentrations of sulfate ion. Detailed results and conclusions of this study are given in a report by J.M. Cleveland, Terry F. Rees, and Kenneth L. Nash: Ground Water composition and its relationship to plutonium transport processes; to be published in a book entitled, "Plutonium Chemistry"; Proceedings of American Chemical Society Symposium at the 184th National ACS Meeting, September 12-17, 1982.

    Neptunium is generally soluble in all these ground waters except that from the Cretaceous shale at 90°C after 30 days. The insoluble neptunium in the shale water was Np(IV), again indicating the role of the strongly reducing properties of this water in immobilizing multivalent transuranium elements. Fluoride had little effect in solubilizing neptunium. Americium, which normally exists only in the trivalent state, was also generally soluble in all but the shale ground water. Since reduction would not be a factor in this case, the lower solubility is unexplained, but may result from the high sulfate concentration in this water. A report describing the neptunium and americium speciation results is in preparation.

(2) Preliminary results from the studies of leaching of vitrified radioactive waste indicate that ground-water composition has a major influence on leachability. Using the four ground waters mentioned above, the order of leachability, by rock source, was basalt >> tuff > granite > shale. The high degree of leaching in the basalt water is undoubtedly the result of its high fluoride concentration; visible evidence of attack was observed only in glass cubes exposed to this water. The relatively small degree of leaching by the granite and shale ground waters may result from surface passivation of the glass by ions, such as sodium or magnesium, which are present in greater concentrations in these two waters. The interim results of this leaching study are described in the above-mentioned report on ground-water composition and its relationship to plutonium transport processes.

(3) Thermodynamic data for complexation in the plutonium(IV)-sulfate system have been obtained and are given in a report by Kenneth L. Nash and Jess M. Cleveland, entitled, "Free energy, enthalpy, and entropy of plutonium(IV) sulfate complexes," to be published in Radiochimica Acta. The results indicated that two complexes are formed, according to the following reactions:

$$Pu^{4+} + HSO_4^- \rightleftharpoons Pu(SO_4)^{2+} + H^+ \quad (1) \quad K_1 = 585 \text{ at } 25°C$$

$$\Delta H = 18.5 \text{ kJ/mole} \quad \Delta S = 115 \text{ J/mole - deg}$$

$$Pu(SO_4)^{2+} + HSO_4^- \rightleftharpoons Pu(SO_4)(HSO_4)^+ \quad (2) \quad K_2 = 23$$

$$\Delta H = -17.6 \text{ kJ/mole} \quad \Delta S = -33 \text{ J/mole-deg.}$$

The high positive value for ΔS in reaction (1) was interpreted to indicate the formation of an inner-sphere complex, whereas the negative ΔS in reaction (2) suggests the formation of an outer-sphere complex.

Reports

Cleveland, Jess M., and Rees, Terry F., 1982, Characterization of plutonium in ground water near the Idaho Chemical Processing Plant: Environmental Science and Technology, v. 16, p. 437-439.

Cleveland, Jess M., Rees, Terry F., and Nash, Kenneth L., 1983, Plutonium speciation in selected basalt, granite, shale, and tuff ground waters: Nuclear Technology, v. 62, no. 3, p. 298-310.

Redox Potentials in Natural Waters

By D. C. Thorstenson, Reston, Va.

To model the chemical behavior of the actinides, particularly as it relates to their transport in ground water, it is necessary to know (among many other properties) the redox potential and factors affecting it in the natural environment as well as the redox chemistry of the actinides. Errors in measuring the redox potential can be large enough to result in incorrect predictions of mineral occurrences and order-of-magnitude errors in solubility or chemical speciation calculations.

Objective: To improve our understanding of and ability to determine redox potentials and reactions in ground-water systems and to evaluate the response of the actinides to these potentials.

Approach: As a result of the findings of the study of the theory of redox reactions, which were summarized in the Fiscal Year 1981 report (Schneider and Trask, 1983, p. 84-85), increased emphasis is now being placed on the use of modeling techniques to evaluate redox processes in natural systems, and significantly less work is being done on the electrode characteristics. Future efforts will be directed to studies of the distribution and reactions of the redox-controlling species in natural systems, and of the thermodynamics of microbially mediated redox reactions.

Progress: Development of modeling capability for aqueous redox reactions is continuing, with emphasis on the integration of aqueous speciation, mass balance, and reaction-path modeling techniques. A computer program for mass-balance calculations has been published (Parkhurst and others, 1982).

A major problem in reaction modeling lies in the fact that, for a given set of analytical data, chemical models are, in general, non-unique--that is, more than one set of reactions will be consistent with the available data. In systems for which abundant analytical data are available, the most useful modeling approach appears to be the use of mass-balance calculations in conjunction with saturation indices provided by aqueous speciation calculations. The utility of reaction-path calculations increases as the available data decreases. A paper presenting the results of these modeling studies is in preparation.

Report

Parkhurst, D.L., Plummer, L.N., and Thorstenson, D.C., 1982, BALANCE - A computer program for calculating mass transfer for geochemical reactions in ground water: U.S. Geological Survey Water Resources Investigations Report 82-14, 29 p.

References

Schneider, Robert, and Trask, N.J., 1983, U.S. Geological Survey research in radioactive waste disposal--Fiscal Year 1981: U.S. Geological Survey Water Resources Investigations Report 83-4105, 122 p.

Thorstenson, D.C., 1982, The concept of electron activity and the redox potential of aqueous solutions: American Chemical Society Symposium on Geochemistry of Nuclear Waste Disposal, National Meeting, March, 1982.

Solute Transport in the Unsaturated Zone

By Ronald V. James, Jacob Rubin, and Catherine Willis, Menlo Park, Calif.

If the unsaturated zone is to be considered a host medium for the emplacement of radioactive wastes, the medium must act as an effective barrier to radionuclide transport. The design of a suitable repository depends on our capability to predict the effectiveness of this medium as a barrier. Predictive models have been proposed, and others are being developed for solute transport in unsaturated porous media. The usefulness of these models is in question, however, and will remain so until they are based on laboratory and field data that relate solute-transport properties to water content. Also, these data must be compared against model predictions.

Objective: To develop data-based, laboratory, and field-tested mathematical models useful for predicting transport of waste radionuclides in the unsaturated zone.

Approach: The types of mathematical solute-transport models needed will require, in the early stages of the project, a combination of laboratory and theoretical work. The models to be developed and tested must be capable of simulating the most significant physical and chemical conditions characteristic of the unsaturated zone. These include wide variations in water content and in water-flow rates as well as a multiplicity of chemical reactions.

Progress: The broad, theoretical analysis of solute-transport mathematics has been supplemented by several new proofs and examples, all of which were published (Rubin, 1983). The proofs establish and explain, in a general manner, the fact, that the "algebraic option" formulations are applicable to two (and only to two) of the three solute-transport classes with equilibrium controlled reactions. The "algebraic option" is important because, when applicable, it leads to very efficient numerical methods of analyzing solute-transport problems with multicomponent reactions. The new examples demonstrate that the conclusions reached previously by considering relatively simple solute-transport cases may be applicable to many more complex cases (e.g. ones in which solute concentrations are too high to allow an assumption that each activity coefficient is equal to unity).

In order to utilize the "algebraic option" for a transport problem to which such an option is applicable, a set of interdependent non-linear and linear algebraic equations must be solved. The algebra of such equation-sets was studied. The sets investigated corresponded to multicomponent, equilibrium-controlled, classical, heterogeneous reactions. They involved most of the relevant reaction-segment types of current geochemical interest. One of the findings was that for each multiple reaction studied it was possible to reduce the relevant algebraic system (which usually contained many non-linear equations) to a system consisting of one, non-linear, single-variable, algebraic equation (usually a polynomial) and several linear equations. Each one of the latter equations could be solved independently when the solution of the nonlinear equation was available.

The study discussed above dealt with multiple reactions, the segments of which belonged to the same reaction class. Transport equations for problems involving hybrid, multicomponent reactions (i.e. ones with segments belonging to different reaction classes) were formulated taking advantage of the "algebraic option" whenever possible. Methods for solution are being devised.

Solute-transport analysis may require solution of partial differential equations subject to moving boundaries. It was demonstrated (Rubin, 1983) that such a situation may arise when transport is influenced even by a simple, non-hybrid, heterogeneous, equilibrium-controlled reaction of the classical chemical type. Two numerical methods have been tested for solving problems of this type. These methods are based on different theoretical approaches to solving the moving-boundary problem. One-dimensional equations with constant coefficients have been solved by the two methods, and the results obtained are in good agreement with each other. Experiments have been done to test the effect of varying the magnitude of the water flux and of the dispersion coefficients. The results agree with physical expectations. For instance, greater water flux increases the speed of the moving boundary. This cannot be seen from the equations alone. More efficient and versatile methods for solving moving-boundary problems are being studied.

A series of laboratory experiments designed to study certain aspects of solute transport in an unsaturated soil was completed. Solute profiles were developed in 50-cm-long, cylindrical, vertical columns of Delhi sand. Three steady-state flow rates were employed yielding darcy fluxes of 1.1×10^{-4}, 2.8×10^{-5}, and 1.1×10^{-5} cm/s which resulted in volumetric water contents of 0.22, 0.19, and 0.17 respectively (the saturated water content of Delhi sand is 0.40).

Ion-exchange processes were investigated using Ca^{2+} and Sr^{2+}. Each soil column was initially leached with a solution having a Sr/Ca concentration ratio of 0.067. This solution was displaced with a calcium solution containing no Sr^{2+} until the desired concentration profile was obtained. Chloride ion was used as a non-reactive tracer in this study. The two experiments having the faster flow rates were carried out in duplicate, with an excellent degree of reproducibility of results.

At the conclusion of each experiment, the columns were sliced into 27 segments which were analysed for water content and total concentration of each solute present. The cation-exchange capacity for each segment was obtained from the total concentration of cations in the segment and was found to vary less than 5 percent throughout the columns. The selectivity coefficient for Ca^{2+} and Sr^{2+} was obtained from the lower portion of the column below the solute dispersion zone. This region was used because it remained in equilibrium with the initial leaching solution which contained both Ca^{2+} and Sr^{2+} and had constant concentrations with depth.

Comparison of the cation-exchange capacity and the selectivity coefficient obtained at each of the three flow rates and corresponding water contents, with previous results from water-saturated experiments, failed to indicate any dependence of these parameters on water content. Analysis of individual solute profiles is continuing in order to determine the effects of water content on hydrodynamic dispersion, reaction rates, and the applicability of the local equilibrium assumption.

Report

Rubin, J., 1983, Transport of reacting solutes in porous media: relation between mathematical nature of problem formulation and chemical nature of reactions: Water Resources Research, v. 19, no. 5, p. 1231-1252.

Predictive Models of Radionuclide Transport in Ground-Water Systems

By David B. Grove, Lakewood, Colo.

It is generally agreed that leaching and transport of radioactive wastes by ground water are the most likely mechanisms by which waste radionuclides might enter the biosphere. Mathematical techniques to describe the transport and reactions of these dissolved radionuclides during their flow are necessary to the prediction of resulting chemical changes in ground water.

Objective: The objective is to develop and evaluate numerical modeling techniques to predict changes in water quality during the transport of radioactive solutes below the water table.

Approach: The approach is to solve the mass-transport equation using finite-difference and finite-element methods to produce a model that will predict the effects of perturbations of the ground-water system caused by the introduction of radionuclides.

Progress: Technetium-99 was identified as the major beta particle emitter in the contamination plume at the site of the uranium scrap recovery plant near Wood River Junction, Rhode Island (see section on Wood River Junction, Rhode Island under Low-Level Wastes). Strontium-90 was the only nuclide

present at concentrations above drinking water standards. Boron and potassium were new cations recently found in the plume. Electromagnetic conductivity surveys were successful in helping to delineate the plume of contaminated ground water. The sediments at this site appear to have little potential for solute-sediment interaction, showing a very low cation-exchange capacity.

Work was initiated on the new heat and solute transport numerical simulation model which is a complete revision of the Survey Water Injection Program (SWIP2 code of Intera). Reduction in computer storage requirements of about 20 percent was achieved by array space sharing. Several errors in the SWIP2 code were discovered and corrected. The first test problem was executed successfully.

Column and batch experiments were initiated to evaluate the uptake of Cr^{6+} by alluvium from a field site at Telluride, Colo. where ground waters have been contaminated with hexavalent chromium from mining operations. Results show that a significant quantity of Cr^{6+} is removed from solution. After achieving breakthrough with respect to Cr^{6+}, continued leaching with ground water free of Cr^{6+} removed most of the Cr^{6+} from the alluvium. Field sampling continued at Telluride and analysis of data indicated that contamination of the upper part of the aquifer has substantially decreased while the deeper part, that is the potential source for the city water supply, still contains a considerable concentration of chromium.

In connection with the modeling of contaminant transport at specific sites, laboratory techniques were evaluated and implemented for the low-level detection of strontium-90 and the determination of cation-exchange capacity of geologic materials. Successful use was made of inductive coupled plasma (ICP) to determine metal concentrations.

Report

Grove, D.B., 1982, Modeling the movement of contaminants in saturated ground water systems, in The impact of waste storage and disposal on ground-water resources, Ithaca, New York, June 28-July 1, 1982: Symposium Proceedings, Center for Environmental Research, Cornell University, Ithaca, New York.

Geomechanics

By H.S. Swolfs, Lakewood, Colo.

Within a mined repository for nuclear wastes, a thermal pulse will be generated by the radioactive decay of the shorter-lived fission products. The magnitude of the temperatures will be dependent primarily upon the isotopic composition of the waste, its age, concentration in the waste

form, and spacing of the canisters; the maximum temperatures can be controlled by appropriate manipulation of these variables. The principal mechanical effect will be the development of thermal stresses superimposed on existing stresses (of geologic or mining origin) in the rock mass containing the repository. Heating is expected to increase the compressive stress in the mass adjacent to the repository but to reduce it at a somewhat greater distance. Such additional stress changes could produce slippage on pre-existing fractures in the rock mass and changes in the permeability.

Modeling the thermally induced stress requires knowledge of the initial stress conditions prior to mining. In the absence of such information, it has been necessary to assume a non-differential or lithostatic stress (the increase in pressure with depth resulting from the weight of the overlying rocks); this assumption has resulted in considerable modeling errors. Some information on the initial stress can be obtained from measurements in boreholes in mined excavations. However, it would be desirable to have data from a large number of locations as far removed from the effects of mining as possible. Existing borehole instruments could make such measurements in advance of mining and during the exploration stages, but the significance of the measurements obtained must first be evaluated.

Objective: To test existing borehole instruments that provide information on the state of stress in rocks under controlled conditions; to evaluate such equipment in the field in areas where stress is known or can be evaluated independently; and to develop the use of such techniques for application to mined repositories.

Approach: Site characterization is a fundamental prerequisite in the identification and selection of geologic repositories. Specifically, the problems that still require satisfactory resolution include the definition of geologic structure (i.e., structural discontinuities on all scales), physical and thermo-mechanical material properties, and in situ initial stress, temperature, and hydraulic conditions in brittle rocks. To this end, a testing facility has been constructed and made operational in an experimental mine near Idaho Springs, Colo., and a surface site on South Table Mountain near Golden, Colo., has been chosen that allows the development of a theoretical model of the stress distribution in the rock mass. The borehole instruments already evaluated at the testing facility underground will be used to determine the mechanical properties at the surface site, and such determination of stress, strength, deformation and various moduli will be compared with similar information obtained from tests on core samples or derived by analytical methods. Thus, the geomechanics observatory near Golden serves as an additional proving ground to test and evaluate existing instrumentation and to develop modifications, improvements, or new techniques as required.

Progress: The state of stress has been successfully modeled at the experimental site near Golden, Colo. It consists of a constant gravitational (topographic) component and a seasonally varying thermal component. Verification experiments using three independent methods of stress

measurement have been carried out: two of these methods confirm the modeling results; the third method failed because of an inherent design problem in the instrument (Swolfs, 1982; Smith, 1982). A variety of other on-site experiments have been conducted to determine the thermal, deformational, and hydraulic properties of the host rock (Swolfs and Kibler, 1982). A significant problem in characterizing rocks at a repository site involves the delineation and quantitative description of the fracture population in the rock mass. As a result of preliminary mapping and geophysical surveys, it is now apparent that the lava flow capping the mesa consists of tabular rafts of rock (approximate volume 14×10^4 m^3) separated from each other by fracture zones about 30 m wide. These fracture zones, as well as the intensely fractured basal zone of the flow, appear to be the primary hydraulic conduits.

The fracture zones are most likely the result of the steady pull or tension applied to the basalt flow by lateral spreading of the weak sediments beneath. This particular stress condition is consistent with the modeling and field measurements.

Reports

Smith, W.K., 1982, Two BASIC computer programs for the determination of in-situ stresses using the CSIRO hollow-inclusion stress cell and the USBM borehole deformation gage: U.S. Geological Survey Open-File Report 82-489, 40 p.

Swolfs, H.S., 1982, First experiences with the CSIRO hollow-inclusion stress cell: U.S. Geological Survey Open-File Report 82-990, 17 p.

Swolfs, H.S. and Kibler, J.D., 1982, A note on the Goodman Jack: Rock Mechanics, v. 15, no. 2, p. 57-66.

Swolfs, H.S., 1983, Aspects of the size-strength relationship of unjointed rocks: 24th U.S. Symposium on Rock Mechanics, 8 p.

Synthesis of Neotectonic Conditions in the United States

By K.L. Pierce, S.M. Colman, and M.N. Machette, Lakewood, Colo.

The recent tectonic history of the country provides a basis for predicting and evaluating changes that could occur in the geologic setting, over the next few thousand years, in broad regions containing potential repository sites. The tectonic regime or setting determines: (1) the rates at which uplift and erosion may unroof a repository or the rates at which downwarping and sedimentation may bury it deeper, (2) the potential for developing new faults or movement on old ones that might intersect the repository or adversely affect the ground-water flow system, and (3) the likely frequency and severity of earthquakes in the region.

Objective: To improve the ability to analyze and predict tectonic behavior and seismicity of parts of the conterminous United States during the next few hundred to one million years. To prepare a neotectonic map of parts of the conterminous United States that will show the patterns, styles, amounts, and rates of deformation (faulting, and broader horizontal and vertical movements) over the past few million years.

Approach: Evidence of neotectonic deformation and the deformation history through Quaternary time will be gathered and compiled from existing literature and with the help of regional and topical specialists. This information will be synthesized into a coherent depiction of the neotectonic behavior of parts of the United States in terms of relative movements and their amounts and rates.

Evaluations at scales as large as 1:500,000 will be prepared for key areas of the country. Faults, folds, uplifts, downwarps, and tilts will be shown together with horizontal shortening, extension, and sheer, where resolvable, and the kinds of geologic evidence for these tectonic features. Evidence to be used includes local indication of fault offset, variations in local and regional datums such as unconformities and old shore lines, sedimentary evidence of upland erosion and basin subsidence and deformation, and geomorphic evidence of change or stability. Methods of approximation, particularly those based on geomorphic arguments, will be sought. Limits on deformation from negative evidence will be included. Effective means of portrayal and analysis will be designed.

Progress: M.N. Machette and S.M. Colman have mapped and studied the morphology of about 50 prominent fault scarps in unconsolidated sedimentary formations of Holocene to early Pleistocene age within the Rio Grande rift of Colorado, New Mexico, and Texas. Most of the maps have scales of 1:125,000 to 1:1,000,000. Two are nearly through the review stage--"Map showing tectonic features of late Cenozoic origin in Colorado," by Colman, and "Map showing upper Cenozoic rocks and deposits and Quaternary faults, Rio Grande rift, south central Colorado," by Colman and others. By comparing the morphology of these fault scarps with those of several dated scarps in the western United States, they were able to distinguish faults with single, segmented, or compound movement and to discriminate between faults of Holocene, late Pleistocene, or middle Pleistocene age. Within the Rio Grande rift the following faults have demonstrable Holocene movement: the Sawatch and Sangre de Cristo fault zones in Colorado; the Coyote Springs, Socorro Canyon, La Jencia, Caballo, Cox Ranch, and Peloncillo faults in New Mexico; and the Van Horn and Mayfield faults in West Texas. The Peloncillo and Van Horn faults mark the west and east margins of the southern part of the rift.

Quaternary faults in the Rio Grande rift display several patterns: (1) they increase in number from north to south, (2) the cumulative displacement in east-west transects across the rift increases from north to south, and (3) they form a slightly radiating pattern that opens to the south. Both the age and the pattern of Quaternary faulting suggest that southward-radiating

extension of the rift is continuing, possibly as a result of a postulated clockwise rotation of the Colorado Plateau. Concentrated Holocene movement along most of the Sangre de Cristo and Sawatch fault zones may be related to the narrow and relatively simple basin geometry of the northern part of the rift, whereas Holocene faults of the central and southern parts of the rift are distributed over broader and more complex basins.

S.M. Colman (1983) has used a diffusion-equation model to estimate the ages of fault scarps. His analytical solution for the model allows direct calculation of ages of single-event scarps if the diffusion coefficient, which depends on lithology and climate, is known. The model has been tested for two scarps in Utah, one whose known age was used to calculate the diffusion coefficient, and the other whose unknown age was calculated. The model is also useful for qualitative comparisons of the histories of multiple-event scarps.

Reevaluation by K.L. Pierce of the amount of Pleistocene cooling in the northern Rocky Mountains, based on differences between Pleistocene and modern snowlines, suggests that either Pleistocene temperature departures were twice as great as the commonly estimated 6°C difference, or that precipitation increased significantly (Pierce, 1982a, 1982b).

Considering the conflict between the need for immediate estimates of the likelihood of faulting and earthquake activity at potential repository sites, and the fact that the accumulation of information on neotectonic conditions is a slow process, N.J. Trask (1982) reviewed available information on the rates of neotectonic processes. He estimated upper bounds for future rates of movement on a single fault to range from 10^{-6} to 8×10^{-5} events per year for regions east of the active western margin of the North American Plate. These upper bounds possibly can be lowered in future iterations of performance assessments, as additional data on neotectonic processes become available.

Reports

Machette, M.N., 1982, Morphology, age, and rate of accumulation of pedogenic $CaCO_3$ in calcic soils and pedogenic calcretes of the southwestern United States: Geological Society of America, Abstracts with Programs, v. 14, no. 4, p. 182-183.

Machette, M.N., 1982, Guidebook to the Late Cenozoic Geology of the Beaver Basin, South-Central Utah: U.S. Geological Survey Open-File Report 82-850, 42 p.

Machette, M.N., 1982, Quaternary and Pliocene faults in the La Jencia and southern Albuquerque-Belen basins, central New Mexico, in Grambling, J.A., and Wells, S.G., eds., Albuquerque Country, pt. 2: New Mexico Geological Society, 33rd Field Conference, Guidebook, p. 161-169, 14 figs.

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Machette, M.N., and McGimsey, R.G., 1983, Pliocene and Quaternary faults in the Socorro and western part of the Fort Sumner 2° x 1° quadrangles, New Mexico: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1465-A with pamphlet, scale 1:250,000.

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Pierce, K.L., 1982b, Pleistocene glaciation threshold, modern snowpack, and Pleistocene glacier activity, transect across the western U.S.: Geological Society of America, Abstracts with Programs, v. 14, no 7, p. 588.

Pierce, K.L., and Scott, W.E., 1982, Pleistocene episodes of alluvial gravel deposition, southeastern Idaho, in Bonnichsen, W., and Breckenridge, R., M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26.

Trask, N.J., 1982, Performance assessments for radioactive waste repositories: the rate of movement of faults: U.S. Geological Survey Open-File Report 82-972, 23 p.

LOW-LEVEL WASTES

The principal method of disposal for low-level wastes in the United States has been, and continues to be, shallow-land burial in pits and trenches. Wastes from private and commercial sources are generally buried in commercially operated disposal sites, while government-generated wastes are disposed of in sites operated by the DOE.

In 1975, the USGS received direct appropriations to assume a new mission in the area of disposal of low-level wastes. The general purpose of this mission is to develop geohydrologic guidelines that can be used to establish technical criteria for selecting, evaluating, licensing, and operating new low-level waste-disposal sites. The initial phase of this program included field studies at disposal sites at Sheffield, Illinois; Maxey Flats, Kentucky; Beatty, Nevada; West Valley, New York; and Barnwell, South Carolina. Final reports on the hydrogeology of the Barnwell and Maxey Flats sites will be

published in calendar year 1983, with the remaining three scheduled for 1984. To broaden the range of conditions under investigation, field studies were started in 1978 at the abandoned Argonne National Laboratory burial Site in Illinois. The report of that investigation is scheduled for publication early in calendar year 1984.

A second phase of the program was designed to address specific aspects of the geohydrologic controls on radionuclide waste containment at Barnwell, Sheffield, and Beatty; this activity will be continued for several more years. Included in this phase is the Wood River Junction, R.I., site where a contaminant plume developed in the ground-water system downgradient from a recovery plant for processing cold uranium scrap.

Investigations of Disposal Sites

The general approach is to utilize the sites as field laboratories for long-term studies of the fate of buried wastes in relation to the unique geohydrologic, climatic, and waste-disposal conditions that prevail at each. The range and variety of conditions represented make this segment of the program particularly useful for deriving guidelines useful to the regulatory and operational agencies in establishing technical criteria for licensing new sites.

The studies involve the following specific tasks:

- defining the geologic and hydrologic conditions at disposal sites that are pertinent to the subsurface leaching and migration of waste radionuclides in ground water
- defining the extent, rate of movement, and concentration of migratory radionuclides in ground water

In addition, a variety of conventional and innovative techniques are employed for sample collection and analysis, geophysical exploration, geochemical exploration, and numerical simulation.

Idaho National Engineering Laboratory

By J. T. Barraclough, Idaho Falls, Idaho

The Idaho National Engineering Laboratory (INEL), formerly the National Reactor Testing Station, was established in 1949 to test and develop peaceful uses of atomic energy in a remote location on the Snake River Plain in southeastern Idaho (fig. 15).

About 98 percent of the low-level aqueous radioactive waste and about 75 percent of the aqueous industrial chemical (non-radioactive) waste is discharged to two on-site disposal facilities. Liquid wastes are discharged

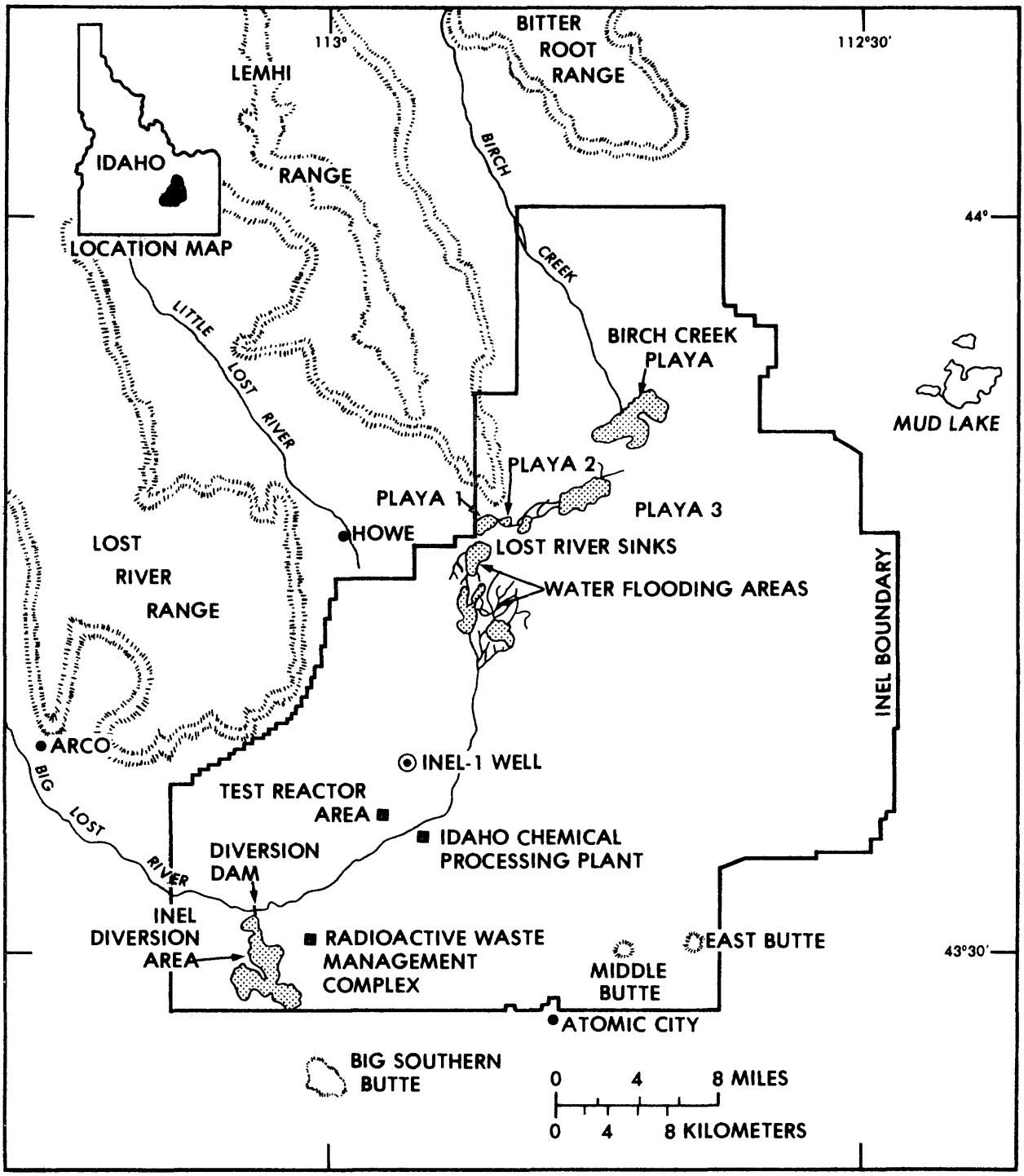

Figure 15.--Map showing selected facilities at the Idaho National Engineering Laboratory.

in the southern part of the reservation to ponds at the Test Reactor Area (TRA) and to a 183-m well at the Idaho Chemical Processing Plant (ICPP) which is open to the Snake River Plain aquifer. The aquifer, whose top is 137 m below these plants, is composed predominantly of basalt with some interbedded sedimentary layers. Solid radioactive wastes are buried at the Radioactive Waste Management Complex (RWMC) in the southwestern part of the reservation.

Seven radioactive waste products can be identified in the aquifer; tritium, strontium-90, iodine-129, cobalt-60, cesium-137, ruthenium-106, and plutonium isotopes. Although it had been known that ruthenium-106 was among the waste products, it was only recently that a more intensive effort was made to determine the extent of its migration in the aquifer. Tritium has migrated the farthest. Plumes of the other waste products have migrated smaller distances because they are subject to sorption reactions. There are seven indicators of chemical waste migration in the aquifer; chloride, sodium, specific conductance, nitrate, chromium, heat, and sulfate.

Objective: To describe the effects of liquid and solid radioactive waste and liquid chemical wastes on the Snake River Plain aquifer; to verify principles of the movement of waste solutes in a fractured-rock aquifer; to determine the effects of dispersion, dilution, sorption, and radioactive decay on waste-solute migration; to develop digital models to predict future waste migration; and to provide consultation to the DOE on a wide variety of geohydrologic problems.

Approach: The geologic, hydraulic, and geochemical characteristics of the system and the migration of radionuclides in the aquifer are defined by periodic sampling of wells together with special analyses, various types of drilling, coring, sampling, and borehole geophysical logging, and digital modeling.

Progress: The waste plumes of various constituents in the aquifer were mapped periodically. The most mobile constituents have migrated downgradient (south) 13 km from the ICPP and TRA, covering an area of about 80 km^2 since disposal began in 1952.

Continuing studies of the distribution and migration of radioactive and chemical products in the Snake River Plain aquifer are being used in revising and updating digital models which provide better waste-movement prediction capabilities. The hydraulic segment of the solute-transport model approximates the solution to the standard, transient, partial differential equation of ground-water flow in a bounded, two-dimensional, one-layered aquifer by finite-difference techniques. The approximation uses an iterative, alternating-direction implicit method. The second segment of the model simulates solute transport in flowing ground water. This transport is described by a partial differential equation representing a flow system that is subject to the effects of convective transport; velocity divergence; two-dimensional hydrodynamic dispersion; instantaneous equilibrium, linear isotherm, reversible adsorption, and, where applicable, radioactive decay. The

transport equation is approximated by an adaptation of the method of characteristics and its approximated solution must be correlated simultaneously with that of the hydraulic flow equation. The aquifer properties to which the solute-transport model is most sensitive are effective porosity, hydraulic conductivity, aquifer thickness, and the longitudinal and transverse dispersivities. Values for these parameters together with a range of assumed disposal and recharge rates will be incorporated in the model to simulate waste-plume positions by the year 2000. To support solute transport modeling at the INEL and at other DOE waste-disposal sites, data sets from two cases of radionuclide migration are being compiled. The data will be used to test and compare solute transport models and predict ground-water contamination at arid and humid disposal sites.

The waste migration data sets available at the INEL are very comprehensive. Over 20,000 water-quality data records from over 200 wells have been collected since 1949 and are now available on computer tape. Water-level data, waste-disposal data, and well-construction data are also available for modeling purposes. Hard copy documentation of the INEL data set is being prepared. A data set from a waste-disposal site at the Savannah River Plant, S.C. is also being prepared.

A new geophysical well logging truck with downhole TV camera and spectral logging capabilities is being equipped. This instrumentation is being used to study subsurface lithology and to support USGS studies and DOE operations both on the INEL and surrounding areas.

A detailed program plan to study waste migration in the unsaturated zone beneath the RWMC has been prepared. The study will attempt to verify, with field data, the digital-model predictions of radionuclide migration.

Report

Goldstein, Flora J., and Weight, Willis D., Subsurface information from eight wells drilled at the Idaho National Engineering Laboratory, Southeastern Idaho: U.S. Geological Survey Open-File Report 82-644, 29 p. (IDO-22063).

Sheffield, Illinois

By James B. Foster, Richard W. Healy, and John R. Gray
Urbana, Ill.

The Sheffield low-level radioactive-waste burial site, an 8-ha area located in northwestern Illinois, was operated from August 1967 to April 1978. The climate ranges from warm and humid in summer (average temperature 22.2°C) to quite cold in winter (average temperature -7.5°C). Average annual precipitation is 890 mm.

A hydrogeologic study of the site was conducted from 1976 to 1980. Additional studies were started in October 1980 to develop an understanding of the properties of glacial materials that are related to the containment of waste. One segment of the study is concerned with the hydrogeology of an area extending east of the site to a discharge boundary. A second part is an investigation of soil-moisture movement through the unsaturated zone and, in particular, through the waste trenches. A third segment is an investigation of the effects of trench construction on soil erosion and landform modification at the site. The research is supported in part by the NRC.

Objective: To define the stratigraphy and hydrology of the pebbly-sand unit extending eastward from the site to a discharge boundary in the shallow hydrologic system consisting of a strip-mine lake about 230 m northeast of the northeast corner of the site, and a creek about 660 m from the east side of the site.

To develop a ground-water flow model of the pebbly-sand unit from the site to the discharge boundary.

To determine the manner in which tritium is being released to the ground water from waste trenches and the rate of movement through the pebbly sand, including the development of a solute transport model for the tritium migration.

To define the mechanisms that control the movement of water and transport of radionuclides from disposal trenches through the unsaturated zone to the water table.

To quantify runoff and sediment yields at the site, and to determine the relations among rainfall, runoff, and sediment transport so as to provide a data base for assessing changes in site-management practices.

Approach: The investigation of the pebbly-sand unit will involve construction of test holes to define the stratigraphy of the glacial formations and the hydrology of both the confined and semi-confined strata. Hydraulic testing will be used to determine the hydraulic conductivity of the strata. Numerical modeling, initiated as a part of the previous site study, will be extended into the area east of the site. Water samples will be collected from test wells and analyzed for inorganic constituents and radionuclide content. An earth resistivity survey of a part of the area will be run to aid in delineating the extent of the pebbly sand. Tracer tests will be used to determine rates of ground-water flow.

Soil-moisture data on the unsaturated zone are obtained by the use of a soil-moisture probe, suction lysimeters, and core samples. Soil suctions are obtained from tensiometers and soil temperatures from thermocouples. Rates of soil-moisture flow are calculated from data obtained from tensiometers installed vertically and horizontally.

Radionuclide migration in the unsaturated zone is monitored by radiometric analysis of soil-moisture samples collected at points throughout the system. Moisture samples are collected at the interface between the bottoms of waste trenches and the subsoil and analyzed for radionuclide and other chemical content. Natural-gamma and gamma-spectral logging are used to monitor radionuclide migration in monitoring wells.

Evapotranspiration is computed from data obtained at a micrometeorological station. The relation between infiltration and intensity and duration of rainfall will be determined from comparison of rainfall and soil-moisture data.

Numerical modeling of moisture flow in the unsaturated zone is used to guide the data collection and to evaluate the mechanics of the system.

Runoff and sediment discharges are monitored in three watersheds comprising two-thirds of the land area of the site, and in a 1.10-ha watershed in undisturbed terrain 0.5 km south of the site. The effects of slope and land use on infiltration, runoff, and sediment yield are being evaluated at four test plots ranging in size from 10.2 to 11.0 m^2, two of which are at the disposal site and two in the undisturbed watershed. Land-surface altitudes are measured at fixed locations at the site to quantify settling and compaction. Periodic photographic surveys from stable reference points are used to study changes of vegetation and other surficial features. Surveys of ground-cover density are also made for assessment of variables affecting the relation between rainfall and runoff.

Progress: The final report, "Hydrogeology of a low-level radioactive-waste disposal site near Sheffield, Illinois," by J.B. Foster, J.R. Erickson, and R.W. Healy, has been approved for publication as Water-Resources Investigations Report 83-4125.

Twenty observation wells were constructed to determine the areal extent, source, distribution and concentration of tritium along a specific ground-water flow path.

Seven observation wells were drilled on private property southeast of the site to provide hydrogeologic data for developing a ground-water flow model. Tritium was detected in ground water in one well located about 125 m east of the nearest waste trenches.

All instrumentation for the unsaturated zone study has been installed in the tunnel that underlies four of the waste trenches, in the trench cap, and at the micrometeorological station. A report detailing instrumentation at the site has been prepared, and is being reviewed. Analyses of data collected to date indicate: (1) Where the compacted clay layer is present in the trench cap, moisture is effectively inhibited from entering the trenches; (2) Infiltration into the trenches occurs predominantly during spring. Only very intense storms will produce infiltration into trenches during summer

and fall; (3) Moisture movement in the vicinity of the tunnel is complex due to the large variability in material properties. Recharge to the saturated zone during the spring is characterized by small changes in soil tension (13 to 25 cm of water) over a short period of time (1 to 3 days).

Preliminary results indicate that peak suspended-sediment concentrations measured in 1981, (>54,000 mg/L) were 80 percent greater than peak concentrations measured in 1982, following the implementation of erosion control measures and the establishment of a denser ground cover on the site. Runoff and sediment yields from the site, however, remain significantly greater than yields from the undisturbed watershed. A 17.8-mm rain on July 21, 1982, for example, resulted in a sediment yield of about 200 kg/ha from a 1.32-ha portion of the site, whereas no runoff resulted from the same storm at the undisturbed watershed. Data collected from the test plots indicate that slope is a significant factor in the relation of rainfall to runoff and sediment transport in the undisturbed watershed. However, storm sediment yields obtained from plots of different slope on the site suggest the rainfall to runoff and sediment transport relations are less dependent on slope than on other factors, such as soil composition and compaction, land-surface characteristics, or the height of vegetation. Analyses of samples for particle-size distributions show that silt- and clay-size particles comprise over 95 percent of the sediment load in the site.

Argonne National Laboratory Site, Illinois

By James R. Nicholas, Urbana, Ill.

Low-level radioactive waste was buried during 1943-49 on the former grounds of the Argonne National Laboratory, in the Palos Forest Preserve, about 22 km southwest of Chicago, Illinois. The burial site was decommissioned and capped with concrete in 1956.

Radiometric analyses of unconsolidated glacial deposits and ground water beneath the burial site show that concentration levels in a tritium plume, or contaminated zone, in the drift range from $1x10^3$ to $1x10^7$ pCi/L. The plume extends at least 50 m north from the burial site and 40 m vertically downward to dolomite bedrock. Tritium concentrations in water from bedrock wells 360 m downgradient from the burial site range from $2x10^2$ to $1.8x10^4$ pCi/L[1/] annually. Samples from these wells have not contained detectable concentrations of any other waste nuclides. Tritium concentrations in an ephemeral stream adjacent to the burial site range from $2x10^2$ to $2x10^6$ pCi/L.

[1/] The upper limit of this range was reported erroneously as 1,400 pCi/L in Schneider and Trask (1983, p. 109), Schneider and Trask (1982, p. 98), and Schneider and others (1982, p. 65).

Objective: Because of the apparent opportunity at this site to learn more about the long-term mobility of waste isotopes in geohydrologic environments similar to those in many other areas of the United States, a study was initiated to define the hydrologic and geologic properties that control ground-water flow and solute transport in the drift and bedrock, and to determine the distribution and concentrations of tritium.

Approach: Measured water levels and tritium concentrations of water samples from a network of drift piezometers and bedrock wells are being used to determine the areal and vertical distribution of tritium. Discharge and tritium concentration are measured in the ephemeral stream to determine the role of surface water in tritium transport from the site. A variable-saturation ground-water flow model is being used to predict water (tritium) movement in the drift beneath the site. Spacing and size of bedding-plane openings in the dolomite are being studied in wells using geophysical logs. Spacing and orientation of vertical joints are being studied at quarries and by lineament identification on aerial photographs.

Progress: Joint orientations measured in quarries near the site and lineaments mapped on aerial photographs show that joints trend N 45° E and N 45° W. Joints observed in quarries evidence little solutional enlargement, however, the published results of studies indicate joint openings can be a few meters wide at locations within only a few miles of the study area. Joint width and frequency decrease with depth. Acoustic televiewer and caliper logs show solutionally enlarged bedding-plane openings of up to 20 cm in width. Bedding-plane openings can be correlated between wells at distances of up to 460 m. The widest openings are usually at or near the drift-dolomite contact. Geophysical log interpretation suggests that laterally continuous bedding-plane openings and porous zones transmit more water than do vertical joints.

Five bedrock wells were drilled 220 to 340 m north (downgradient) of the burial site. The locations are south and east of a Forest Preserve well which contains water with tritium concentrations ranging from 2×10^2 to 1.4×10^4 pCi/L. Although the wells are located to intercept joint sets and are connected hydraulically to bedding-plane openings at the drift-dolomite contact, only two wells contain water with tritium concentrations above a background level of 2×10^2 pCi/L. Concentrations range from 2×10^2 to 1.8×10^4 pCi/L. Both wells are located east of the Forest Preserve well.

Seepage runs in the ephemeral stream adjacent to the site show a losing reach east of the bedrock wells that contain tritium. The character of the drift at this location is not known. Tritium concentrations in this reach of the stream range from 7×10^3 to 5×10^4 pCi/L.

Preliminary study of water levels in the dolomite suggests ground-water mounding beneath the stream after prolonged periods of streamflow. The ground-water mound drives tritium westward toward the wells containing tritium. Comparison of stream-discharge records with tritium-concentration

changes in the Forest Preserve well indicate a travel time of 6-7 months from the stream to the well, a vertical distance of about 20 m and a horizontal distance of about 200 m.

Currently, the hydrogeologic conditions governing movement of tritium from beneath the burial site to the stream are not well understood. Several thin sand lenses, 3-15 cm thick, are present in the clay- and silt-rich drift. Their relation to the occurrence of tritium in the stream is being investigated.

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Maxey Flats, Kentucky

By Robert J. Faust, Louisville, Ky.

Low-level radioactive wastes were buried in a commercially operated facility in northeastern Kentucky, on a plateau called Maxey Flats, from 1963 to 1977. The burial site is about 104 m above surrounding valley bottoms. Wastes were buried in trenches 5 to 12 m deep, over an area of about 7.77 ha. Infiltrating water has accumulated in the trenches and is presently being removed and evaporated.

The ground-water system consists of at least eight rock units, each of which has different hydraulic properties, and all of which are fractured. Most ground water flows through the fractures. The lower boundary of the flow system is about 98 m below the top of the plateau. Most of the rocks are shale, including those in which waste is buried. The bottoms of most burial trenches are formed by a 0.5-m-thick sandstone interbed called the lower sandstone marker bed.

Objective: To describe the subsurface hydrology of the site in terms of volumes, rates, and pathways of ground-water flow from burial trenches. Also, to relate the hydrology to the migration of leached radionuclides so that generalizations can be drawn regarding the fate of buried waste in this type of geohydrologic environment.

Approach: The description of the ground-water system is based primarily on the collection of water-level and water-quality data from two recently constructed clusters of wells. Supplementary information from wells drilled in 1962 and 1973 is also used.

Progress: The study was completed and a draft of the final report was submitted. All significant findings were reported by Zehner (1979) in a progress report, and a conceptual analysis of the flow system was presented in a report by Pollock and Zehner (1981).

Water-level data are being collected from about 20 wells and about 5 trenches by the Louisville District Office of the U.S. Geological Survey.

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Beatty, Nevada

By William D. Nichols, Carson City, Nev.

A commercial low-level radioactive-waste disposal site has been operating near Beatty, Nevada, about 150 km northwest of Las Vegas, since 1962. The 32-ha site is situated in a desolate region of the Amargosa River Valley, sometimes referred to as the Amargosa Desert. Average annual precipitation is only about 114 mm. The site is underlain by 175 m of unconsolidated, generally coarse-grained, alluvial-fan and flood-plain deposits. The water table is at a depth of 90 m.

Field investigations at the site were suspended in June 1980, and data analysis and report preparation were continued into calendar year 1981. As a result of the analysis, it was decided to resume field investigations, and to continue the study for several years.

Objective: The objective is to investigate the geohydrology of the shallow, extremely dry, unsaturated zone at the site, with emphasis on determining the downward flux (recharge rate) of moisture through the alluvial deposits beneath the burial trenches.

Approach: Determination of soil-moisture movement requires data on soil-moisture content, soil-water suction, soil temperature, and unsaturated hydraulic conductivity. An instrumentation shaft, 14 m deep and 1.6 m in diameter, will contain removable work platforms at 3-m intervals. Psychrometers, thermocouples, and moisture sensors will be installed at selected depths at distances of as much as 4 m from the shaft. Soil-water tension, soil temperature, and soil-moisture content will be collected on a daily basis using digital data loggers.

Meteorological data will be collected at the site to study evaporation processes from bare soil.

Progress Plans were made to resume field investigations at the site. Much of the work consisted of designing a new instrumentation shaft to replace the 10-m-deep shaft which was rendered unusable because of operational activities at the waste-burial facility in late 1980.

The plans include detailed investigations of the hydraulic characteristics of the unconsolidated deposits containing the waste. Considerable effort was expended to acquire and install laboratory facilities in Carson City to support the field study.

West Valley, New York

By Marcel P. Bergeron, Ithaca, N.Y.

About 50 km south of Buffalo, New York, near the hamlet of West Valley, are the facilities of the Western New York Nuclear Services Center. Among the facilities are a nuclear-fuel reprocessing plant (currently inactive) with associated storage of highly radioactive liquid waste and spent fuel rods; a U.S. Nuclear Regulatory Commission (NRC)-licensed burial ground used by the site operator for burial of contaminated hardware and materials from the reprocessing operation; and a State-licensed burial ground (currently inactive) for commercial low-level radioactive waste.

The burial grounds are situated on glacial till and related fluvial-lacustrine deposits which range in grain size from clay to gravel and in thickness from 20 to 30 m at the burial grounds. The waste burial pits and

trenches are excavated in a clay-rich till with relatively low hydraulic conductivity. Near the reprocessing plant and related storage facilities, the clay-rich till is mantled by alluvial-fan and fluvial silty sand and gravel. These deposits are moderately permeable and range in thickness from 0 to 11 m.

From 1975-79, two complementary studies of the commercial burial ground focused on determining the extent of radioisotope migration from the site and the factors controlling the migration. One study was undertaken by the USGS and the other, funded initially by the U.S. Environmental Protection Agency (EPA) and later by the NRC, was done by the New York State Geological Survey (NYSGS). The present studies by USGS and NYSGS, both funded by NRC, are to evaluate the extent and potential for radionuclide migration near the remaining two facilities of the site: the reprocessing plant and related storage facilities (referred to as the North Plateau area) and the NRC-licensed burial ground.

Descriptions of the USGS study conducted from 1975-79, are given in Schneider and others (1982) and Schneider and Trask (1982).

Objective: The objective is to define the geologic framework and three-dimensional characteristics of the ground-water flow system in the North Plateau area and at the NRC-licensed burial ground, and to determine the extent and(or) potential for radionuclide migration from the two facilities.

Approach: A variety of standard and innovative hydrologic techniques are being applied in this study. Included are the installation of four surface-water stations, the installation and testing of specially constructed wells, the collection and analyses of core and water samples, digital modeling of ground-water flow and radionuclide transport, geophysical borehole logging, geologic mapping, and other techniques.

Progress: Nine test holes and wells were drilled in the North Plateau area to define the thickness and head relationships within the alluvial-fan and fluvial gravel deposit. In general, ground water in the reprocessing plant area moves laterally through the surficial gravels to points of discharge east of the plant. Some ground water is discharged through evapotranspiration from wetland areas and ponds occupying lower portions of the North Plateau. The remainder of the discharge sustains base flow to drainage channels or appears as spring discharge and seepage faces along steep stream channel banks bordering the North Plateau.

Hydraulic conductivity of the surficial gravels in the North Plateau area was evaluated with slug tests performed on eight wells. The tests were analyzed using methods described by Cooper and others (1967). Resultant values of hydraulic conductivity range from about 6 to less than 0.3 m/day. A finite difference model developed by M.G. McDonald and A.W. Harbaugh (in review) is being used to evaluate factors controlling ground-water flow in the surficial gravels of the North Plateau.

Seventeen test holes were drilled in the vicinity of the NRC-licensed burial ground to define in detail the geology of the site. Data from piezometers installed in each test hole indicate that ground water moves downward through a 20- to 30-m sequence of clay-rich till. Prudic (1979) stated that ground water beneath the till would subsequently move laterally northeast to Buttermilk Creek through lacustrine sands and silts whose upper portion is unsaturated.

Vertical hydraulic conductivity of the clay-rich till has been evaluated by laboratory analyses of nine core samples. Resultant hydraulic conductivities were closely grouped within the range from 2×10^{-8} cm/s to 4.3×10^{-8} cm/s with the exception of one shallow core sample for which the value was 1.2×10^{-7} cm/s.

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Wood River Junction, Rhode Island

By Barbara J. Ryan, Providence, R.I. and
Kenneth L. Kipp, Jr., Lakewood, Colo.

A recovery plant for processing cold uranium scrap was in operation at Wood River Junction, Rhode Island (fig. 16) from 1964 to 1980. Acid digestion with hydrofluoric and nitric acids and organic separation with tributyl phosphate and kerosene were used in the process. Solid wastes were shipped off-site and liquid wastes were discharged to the Pawcatuck River through a buried drain pipe from 1964 to 1966 and to lined "evaporation" ponds and trenches from 1967 to 1980. The "evaporation" ponds did not function as intended because average annual precipitation (1,150 mm) exceeds average annual evaporation (750 mm). Leakage from the ponds and trenches occurred

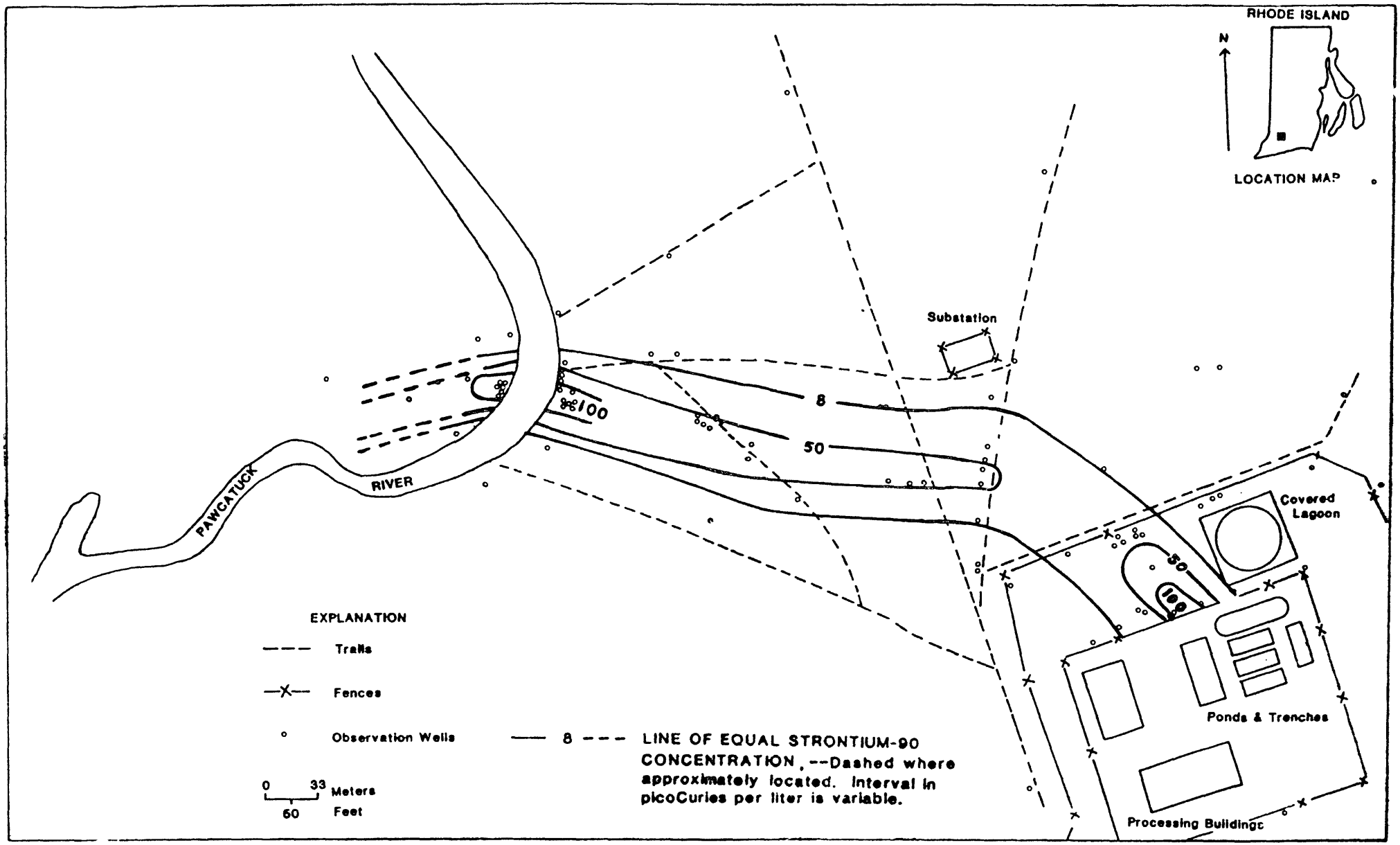

Figure 16.--Strontium-90 concentrations in ground water at the site of the uranium scrap recovery plant, Wood River Junction, Rhode Island, October 1982.

at least as early as 1967, resulting in a plume of contaminated ground water. Apparently, some irradiated materials were processed along with the cold uranium scrap, accounting for the presence in the wastes of strontium-90 and technetium-99. The U.S. Geological Survey began a 3-year study of the ground-water contamination in June 1981.

Objective: (1) To determine the nature and extent of interaction of radionuclides and solutes with aquifer materials, (2) To develop and calibrate numerical models of ground-water flow and radionuclide and solute transport, (3) To use the model to predict the residence time of selected contaminants in the aquifer, and (4) To use the model to predict the effect of the contaminants on the quality of water in nearby existing and proposed supply wells.

Approach: Observation wells are installed to define the lithology, the direction of ground-water flow, and the horizontal and vertical dimensions of the contaminant plume. Monthly water-level measurements are made and water samples are collected from the observation wells to measure concentrations of radiochemical and selected inorganic constituents in the contaminated water. Hydraulic conductivity is estimated from the lithology and from aquifer tests at nearby sites. Vertical distribution of porosity is determined from borehole geophysical logs. Seismic refraction is used to determine depth to bedrock. Interaction of sediments and radionuclides is determined from analyses of sediment and water samples taken at the same depths in boreholes.

Progress: Surface electromagnetic techniques were used to delineate the approximate areal extent of the plume and to design the monitoring well network. Approximately 100 wells were installed for water-level and water-quality measurements. Data from these observation wells indicate that the plume extends northwestward from the pond and trench area to the Pawcatuck River and adjacent swamp (fig. 16), is approximately 450 m long, 100 m wide, and is confined to the upper 5-20 m of saturated, medium-to-coarse sand and gravel. Zones of highest contamination occur at both ends of the plume, separated by a zone of less contaminated water. Fine sands and silts below the coarse sediments have not been penetrated by the plume. Split-spoon samples were collected from both the coarse-sand and fine-sand units. Piezometric-head and water-quality data from wells screened at multiple depths on both sides of the river indicate that contaminants discharge both to the river and to a swampy area northwest of the river. Water samples were collected from the Pawcatuck River where discharge of contaminants was suspected. The contaminants were not detected in the river samples, however, presumably because of dilution.

Radiochemical and common chemical constituents in the contaminated water were identified. Strontium-90, technetium-99, boron, nitrate, and potassium exceed background concentrations by at least an order of magnitude. Concentrations of gross beta emitters range from 5 to 500 pCi/L. No gamma emitters above detection levels have been found. Electrical conductivity of the

water ranges from 100 to 4,500 umhos/cm (at 25°C). Laboratory tests for porosity, grain-size distribution, and exchangeable cations were performed on the split-spoon samples. Tests for exchangeable cations indicate little capacity for uptake on the coarse sediments. Seismic refraction surveys were conducted to determine depth to bedrock.

Barnwell, South Carolina

By James M. Cahill, Columbia, S.C.

The Barnwell burial site is a State-licensed burial ground for commercial, low-level radioactive waste, and is located 8 km west of Barnwell, S.C. The burial area (130 ha) presently contains about 41 trenches that average about 7 m deep, and are 15 to 30 m wide, and 152 to 305 m long.

The trenches are excavated in unconsolidated coastal sedimentary formations that range in texture from clay to coarse sand. The clay fractions are mostly quartz with some kaolin.

The water table is generally at a depth of about 9 to 13 m. Ground-water recharge occurs locally from precipitation. Average precipitation is about 1,200 mm of which about 40 percent recharges the ground-water system.

Objective: The objectives are to describe the three-dimensional characteristics of the ground-water flow system and determine the extent and rate of movement from the trenches of waste radionuclides. In addition, it is intended to describe quantitatively soil-moisture migration in the unsaturated sediments and to assess the principal factors affecting this movement in humid environments.

Approach: A variety of conventional and innovative field methods and analytical techniques are being applied in this study. Special soil-moisture monitoring techniques are used to determine moisture behavior in unsaturated sediments at and near the burial trenches. Salt (NaCl) tracers are used to define the extent of moisture movement at selected trenches. Air samples above the trench covers are passed through cold traps, and the condensed water is analyzed for radionuclide activity. Meteorological data are collected at the burial site to make quantitative estimates of evaporation from the grass-covered surface. A digital model of ground-water flow beneath the trench area is used to predict possible solute migration.

Progress: Analyses of sediment cores, soil moisture, ground water, and atmospheric samples indicate that tritium has migrated downward, laterally, and upward from the buried waste. Tritium activity of about 240,000 pCi/L has been detected in water from a monitoring well 21 m deep. This well is located about 3 m south of the trench area and is screened in the permeable sands beneath the clayey sediments at a depth of about 18 m.

Tritium activity in water condensed from air samples collected 20 mm and 600 mm over a trench completed in 1975 ranged from about 3,000 to 6,000 pCi/L. The upper limit of this range was much lower than that for the previous year when the range was 2,400 to 17,500 pCi/L.

To study the mechanism of infiltration to the pit, sodium chloride tracers were placed near selected waste trenches and specific-conductance measurements were made of the partially saturated backfill sediments in the pits and of nearby undisturbed sediments. Preliminary results indicate that infiltration is occurring largely in the backfill materials rather than in the undisturbed sediments adjacent to the pits.

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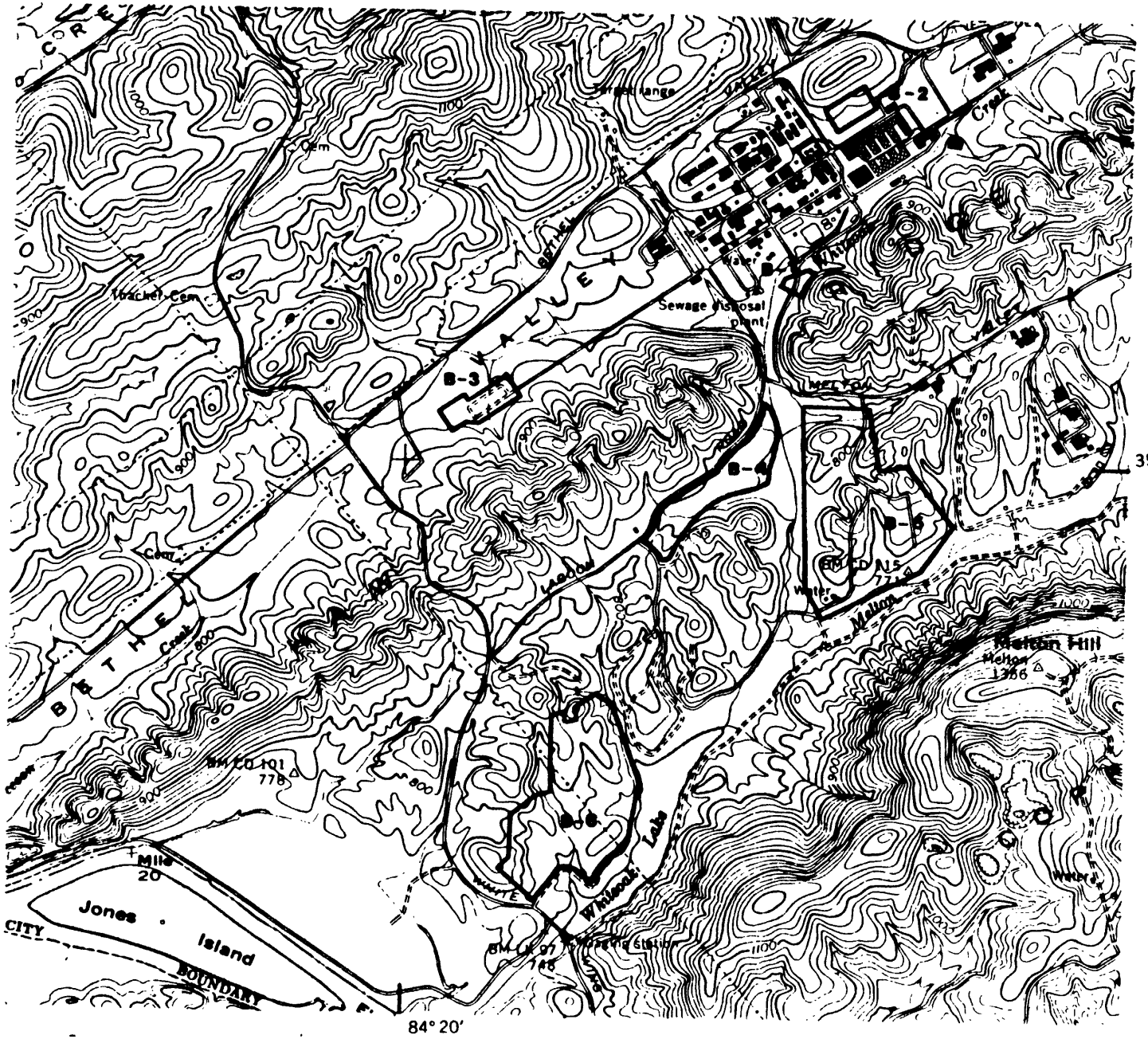
Oak Ridge National Laboratory, Tennessee

By D.A. Webster, Knoxville, Tenn.

At the Oak Ridge National Laboratory (ORNL), solid low-level radioactive wastes have been routinely disposed by burial in shallow trenches since the early 1940's. To date, six burial grounds (solid waste disposal areas) have been used (fig. 17). Small but measurable concentrations of radionuclides have been detected in the streams in and near the four largest disposal areas, leading to the belief that radionuclides are being leached from the waste, transported in ground water, and discharged to those streams.

Objective: To define the movement of water from the disposal areas so that an integrated ground-water--surface-water monitoring system can be developed, and to provide some of the hydrogeologic data necessary for the design of remedial measures to abate contaminant migration.

Approach: The approach involves the collection and analysis of areal and transient water-table data from many shallow wells; installation and testing of clusters of piezometers of varying depths to measure vertical head gradients and vertical distribution of hydraulic conductivity; the use of tracer tests to measure ground-water flow rates and directions; and the use of borehole geophysical logging, rock-core analysis, and hydraulic tests to determine some of the subsurface hydrologic characteristics of the rocks.



EXPLANATION

Building

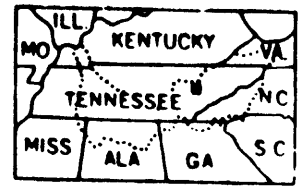
B-1 Burial Ground

SCALE 1:24 000

1000 0 1000 2000 3000 FEET

0 500 1000 METERS

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL



MAP LOCATION

Tennessee River drainage basin outlined by dotted lines

Figure 17.--Location of waste-burial grounds at Oak Ridge National Laboratory, Tennessee.

Progress: Near Burial Ground 3, five wells were cored over a lineal distance of about 670 m to provide both geologic and hydrologic information pertaining to ground-water flow from that site. The cores were taken primarily for examination of Unit F of the Chickamauga Limestone which has been described previously (Stockdale, 1951) as a 7.6-m-thick calcareous siltstone that probably is a barrier to ground-water flow. Examination of the core shows that in this area Unit F actually consists of a silty shale/shaley siltstone member, a limestone member, and a second silty shale/shaley siltstone member. Each member is laterally continuous across the area, but both the core and the geophysical logs indicate variability in thickness and composition. The presence of a continuous limestone unit sandwiched between two siliceous units is significant, for the common boundary area has potential for the development of solution cavities. Indeed, even though the core would indicate that the rock is dense and relatively impervious, weathered zones in the core and the presence of small solution openings in the well bore, found by acoustic televiewer logging of the wells, indicate that Unit F is slightly permeable. During the coring operation, Shelby tubes were used to recover the weathered material overlying the bedrock. Samples of that material just above the bedrock contact with Unit G, the thick limestone unit that underlies most of the disposal site, were submitted for ^{137}Cs analyses; the results were negative.

To help further define the hydrologic relationship of Unit F to adjacent Units E and G, both of which contain small transmissive solution cavities, a unique instrumentation network was designed by the USGS staff at the Idaho National Engineering Laboratory to continuously record water levels in each zone of the six wells of the area that penetrate all three stratigraphic units. The instrumentation system includes straddle packers, multiple transducers, micro-loggers, data recorders, and nearly a mile of cable connecting the instrumentation in the wells to a central data processing station. The straddle packers, while of small diameter in order to fit into NX-size core holes, are designed to also permit hydraulic tests of each unit. By year's end, the instrumentation had been installed and was undergoing minor modification and shakedown tests before being activated for data collection.

A core was cut previously of a 5.5-m-thick deposit of sediment that had accumulated over a 30-yr period in Well 41, about 140 m northeast of the boundary of Burial Ground 3. The well is known to penetrate a solution cavity in the limestone member of Unit F. The sediment core was dissected into 20-mm sections, and each section analyzed for ^{137}Cs. The results show a contaminant profile trending from no detectable activity at its base to as much as 335 ± 5 pCi/g through much of its mid-section, and then declining to about 100 to 200 pCi/g in its upper section. These analyses further confirm a prior interpretation that the well intercepts a major flow path from the disposal site, and suggest that in terms of concentration the translocation of cesium from the site is now in a declining phase. About 5 L of sediment, too liquid to core, was recovered from Well 43, about 400 m northeast of the boundary of

Burial Ground 3. Analyses of five samples of the recovered material indicate a range of ^{137}Cs activity from 0.11 ± 0.04 to 0.83 ± 0.21 pCi/g, suggesting that the well intercepts only a minor flowpath, but also illustrating how far the contaminant can travel through underground channels.

To obtain data on hydraulic conductivity, slug tests were made of a small number of old wells in Burial Ground 4, which is developed on the residuum of the Pumpkin Valley Shale of the Conasauga Group. Although the wells used for the test were not completely satisfactory, the test data indicated that the conductivities are low and significantly less than those characteristic of the residuum of Burial Ground 5, most of which is underlain by the Maryville Limestone of the Conasauga Group.

The USGS provided daily monitoring of the technical aspects of a year-long contract drilling program for the construction of four clusters of piezometers in Burial Ground 5. The piezometers are of telescopic design to minimize the potential for the translocation of any radioactivity down the borehole during the construction process, and are intended to yield information about ground-water movement through the bedrock underlying the site. Each cluster consists of a water-table well (a shallow well that varies in depth from cluster to cluster), and three wells drilled to depths of 30, 46, and 61 m. Geophysical logs were made of each piezometer to obtain additional geologic and hydrologic information, and to detect any anomalous levels of gamma activity. It is of interest that no contamination of the bedrock was found that could be measured by field instrumentation, and the three piezometers in the cluster beside Melton Branch resulted in flowing wells, confirming the interpretation that the watercourse is a discharge area for the ground-water system beneath the disposal site. Before installation of the casings in the bedrock wells, slug tests were made of the then 15-m open intervals in the wells. Preliminary data from these tests indicate a range of hydraulic conductivities as follows:

4.2×10^{-7} to 7.1×10^{-8} m/s for the 15- to 30-m interval,

2.9×10^{-7} to 3.5×10^{-9} m/s for the 30- to 46-m interval, and

4.9×10^{-8} to 3.5×10^{-9} m/s for the 46- to 61-m interval.

Geophysical logs were made of several existing bedrock wells in Burial Grounds 5 and 6 and in the area surrounding the pits and trenches previously used for the disposal of intermediate-level radioactive liquid wastes (ILW)[1/], and of

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[1/] The term intermediate-level waste is no longer in general use. It has been used at ORNL for wastes with a specific activity of less than 6×10^3 uCi/mL, consisting mainly of radionuclides, such as strontium and cesium, having half-lives of less than 50 yr.

some new wells near ILW Trench 7 west of Burial Ground 5. The objectives were to obtain data for correlating the stratigraphy between Burial Grounds 4, 5, and 6, to determine if the wells contained discrete localized peaks of activity in the bedrock that would indicate flow through fractures or small cavities, and to ascertain if cesium-contaminated mud was present in the bottoms of the wells as has been found in two of the deeper wells of similar vintage in Burial Ground 5. The gamma-ray logs of several wells showed anomalous levels of activity, amounting to as much as 1.8×10^4 cps in new wells near ILW Trench 7. Generally, where such large amounts of activity are present, it is only in the recently constructed wells that discrete zones of contamination appear. In the older wells there is a tendency for the dissolved contaminants in water to be sorbed by the strata exposed to the well and, as the open borehole ages, the activity profile of the well then becomes diffuse along much of the borehole wall. Spectral logging of wells having high gamma activities identified the man-made radioisotopes present as ^{60}Co and ^{137}Cs.

Eight of the wells logged in the ILW disposal area were found to have anomalously high amounts of gamma activity (^{137}Cs and ^{60}Co) at the bottoms of the wells. No attempt was made to sample the materials at the bottoms of the wells, but it is presumed that the activity is sorbed on very fine grained material that has accumulated in a manner similar to that in wells in Burial Ground 5 and near Burial Ground 3. The question remains unresolved whether the contaminated material is entering the borehole behind the casings that extend only to the top of bedrock, or whether the contaminants are entering the well bore at some lower point, thereby indicating transport through the bedrock.

Continuing an annual sampling of 16 wells used 5 years ago for ground-water tracer tests in two areas (north of Burial Ground 4 and in Burial Ground 6), it was found that not all of the tritium used as a tracer has been flushed from the ground-water system even though the distances involved are relatively short (3.5 m and 9 m, respectively). Recent sampling shows that concentrations of tritium in the well water range from background to as much as 0.5×10^{-4} Ci/L. This suggests that even though tritium is among the most conservative of tracers, a very inefficient retardation mechanism does exist in fine-grained geologic materials.

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Investigations and Modeling of Geologic and Hydrologic Processes

Geochemistry of Trace Elements in Natural Waters

By D.K. Nordstrom, Menlo Park, Calif.

The movement of radioisotopes, major elements, and trace elements through the hydrogeologic environment depends upon both biological and chemical as well as hydrodynamic processes. The chemical form of an element in an aqueous environment often determines which chemical or biological process is operating, e.g., adsorption on solids, precipitation, dissolution, uptake by biota, ion exchange, degassing, or oxidation-reduction. Chemical forms can be predicted from water analyses by simultaneous equilibrium calculations; however, there are several major uncertainties with this approach to chemical modeling.

Current limitations on chemical modeling include: (1) lack of adequate testing of speciation calculations against experimental and field data; (2) absence of a quantitative assessment of the redox status of natural waters; (3) absence of quantitative assessments of temperature, ionic strength, and compositional limits for use in specific models; (4) lack of adequate testing of adsorption model subroutines; (5) lack of an evaluation of available thermodynamic data; and (6) inadequate testing of equilibrium calculations against analytical determinations for specific forms of dissolved constituents.

Another aspect of hydrogeochemical processes of significance to the characterization of radioactive-waste repository environments is the evolution of ground-water chemistry in granitic terranes at great depth. Data on trace-element concentrations and trace-element geochemistry in deep granitic ground waters is almost non-existent. Such data would be valuable in assessing the hydrogeologic characteristics of granitic rock masses in relation to their suitability for repository purposes.

Objective: The objective was to (1) define the limitations of current chemical models, (2) improve the reliability of current models to predict precipitation, dissolution, complexation, and bioavailability of elements in both contaminated and uncontaminated natural waters, and (3) to improve our knowledge of trace-element behavior in deeply buried granitic rock masses.

Approach: A variety of laboratory, field, and theoretical techniques are being developed or adapted to overcome deficiencies in models and to test the reliability of models. These techniques include development of analytical methods for direct determination of free ion or bound species, and redox species, the compilation and evaluation of thermodynamic data used in speciation calculations, and the investigation of field sites where water-mineral reactions can be observed directly and analytical and theoretical calculations can be tested. Water samples from the Stripa Mine in Sweden, an experimental site for studying the suitability of the crystalline igneous rock for developing a repository, will be used to develop concepts and methodology for studying trace-element behavior in granitic rock masses and their application to the origin and evolution of granitic ground waters.

Progress: Preliminary interpretations of chemical properties of samples from deep (300-900 m) granitic ground waters at Stripa, using analyses by an international consortium of geochemists, indicate that the general increase in salinity with depth might be due to the leakage of fluid inclusions from the granitic rock mass to the zones of water-bearing fractures. These tentative conclusions are based on the Ca/Mg, Mg/Cl and Br/Cl ratios which do not match those of seawater or derivatives from "ancient seawater." Analysis of the Br/Cl ratio from fluid inclusions extracted from the Stripa granite are nearly identical to the ratio found in the deep ground waters. The anomalous Ca/Mg and Mg/Cl ratios match those of geothermal waters, rather than those from low-temperature seawater-derived sources, which suggests a fluid-inclusion origin. These preliminary findings are being further investigated with more fluid-inclusion leaching experiments, fluid-inclusion measurements, and evaluation of Holocene seawater known to be entrapped in central Sweden.

A method has been developed for the analysis of mixtures of sulfoxy anions (thiosulfate, sulfite, polythionate, and sulfate) based on ion chromatography (Moses, Nordstrom and Mills, 1982). The method has been shown to be effective in analyzing products derived from pyrite oxidation and sulfide oxidation in sulfur-rich springs.

Reports

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Nordstrom, D.K., Fritz, P., Donahoe, R.J., and Ball, J.W., 1982, Recent investigations of the major element, trace element, and isotopic geochemistry of deep granitic groundwaters at the Stripa Test Site, Sweden: Geological Society of America, Abstracts with programs, v. 14, no. 7, p. 577.

Chemistry of Hydrosolic Metals and Related Substances in Water

by John D. Hem, Menlo Park, Calif.

Objective: To understand the chemical processes that control solubility and movement in surface and ground water of metals such as iron, manganese, aluminum, and others which form hydroxides of low solubility and which may be adsorbed by or coprecipitated with such hydroxides.

Approach: From published literature, chemical, thermodynamic, and other basic data are obtained and used to formulate quantitative models to predict metal solubilities in conditions like those of natural water systems. These models are tested by laboratory experiments and, where any additional solubility equilibria or kinetic data are required, they are experimentally determined. After laboratory work has indicated the hypotheses to be valid, the models are tested by field observations using published water and mineral composition data when available. Special site studies may be made if published data are lacking or are inadequate.

Progress: The crystal form and thermodynamic stability of manganese oxyhydroxide precipitates are strongly influenced by relatively subtle differences in the conditions under which the initial oxidation occurs. These conditions also influence the form of the final precipitate which in natural systems has a composition closely approaching MnO_2, with all the manganese in the 4+ oxidation state.

The least stable initial precipitate that has been synthesized in our work to date is β MnOOH, which forms thin hexagonal platelets, identifiable by electron microscopy and X-ray diffraction. This material can be precipitated in pure form from solutions of manganous chloride, nitrate, or perchlorate by aeration at pH 8.0 to 9.5, if the temperature is held below about 5.0°C. At 25°C, under these conditions, the precipitate is hausmannite, Mn_3O_4. Both forms of the oxide spontaneously alter to more stable species on aging in solution in contact with air. The aging process involves disproportionation of Mn^{3+} and oxidation and reprecipitation of Mn^{2+} released during the disproportionation. This rearrangement is slow in laboratory systems at near neutral pH, but in natural systems oxidation and disproportionation steps probably occur at similar rates. A manganese oxide surface in an aerated aqueous system promotes oxidation and co-precipitation of many metal ions, especially iron, cobalt and other transition metals. Two other manganese oxyhydroxides have been identified in precipitates from solutions of manganous sulfate at temperatures below 5°C. These are γMnOOH, manganite, and αMnOOH, groutite. Both occur as elongated needle- or rod-shaped crystals. Manganite is more stable than the other Mn^{3+} oxides. This is significant because the less stable oxides undergo disproportionation more readily and, therefore, produce a stronger oxidation and co-precipitation regime for immobilizing and co-precipitating other solutes.

Lind (1982) identified the Mn^{3+} oxides by transmission electron microscopy and associated electron diffraction patterns.

Reports

Lind, C.J., 1982, Identification of manganese precipitates by electron diffraction (Abs.): American Geophysical Union, Fall Meeting, San Francisco, California, December 7-15, 1982.

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Geochemical Kinetics

By Hans C. Claassen, Lakewood, Colo.

The interaction of the solid and liquid phases in natural ground- and surface-water systems results in a water quality which is a function of the chemical characteristics of rock and water, the temperature, the effective surface area of rock in contact with the water, and the interaction time. Differences in lithology and climatic conditions result in a range of water qualities which is surprisingly narrow when the broad range of variables is considered. This would suggest that chemical controls are operant, but it is not presently known whether they are thermodynamic (equilibrium) or kinetic (rate process).

Objective: The primary objective is to study the rate and equilibrium processes controlling water quality in two model study areas in the San Juan mountains, southwest Colorado, where two types of silicate rock occur respectively: dacite-andesite tuff (Snowshoe Mountain Tuff of Oligocene age) and shale (Mancos Shale of Cretaceous age). Part of this study will include determining the influence of environmental factors such as precipitation quantity, quality, and time distribution; vegetative cover; and temperature; as well as the role of the soil zone; on water quality. A secondary objective is to develop a means for estimating the effective surface area of rock material through analysis of its influence on geochemical reactions.

Approach: Temporal changes in water quality in the two model study areas are correlated with environmental factors to develop a mechanistic hypothesis of the chemical processes which control the dissolved species in ground water and surface water. This hypothesis is refined and verified by controlled kinetic laboratory experiments and tested against future changes in water quality brought about by changes in the environmental conditions in the model study areas.

Progress: A major-ion mass-balance model of recharging precipitation was used to interpret the hydrologic and geochemical properties of the dacite-andesite tuff terrane in the central Rocky Mountains.

A simple hydrologic model of recharge resulting only from the September-June precipitation has been validated by naturally-occurring deuterium and tritium tracers. Evaporation of the snowpack under high-altitude (>3000 m) conditions has a significant impact on the concentrations of precipitation-derived constituents found in soil water. The greatest impact occurs in years of low precipitation, when evaporation may result in loss of more than 50 percent of the precipitated moisture.

Some soil-moisture constituents are probably derived entirely from precipitation, e.g., Cl and SO_4, whereas other major ions are contributed in lesser amounts.

In the soil zone and the underlying colluvium, chemical reactions occur between plant-respiration-derived carbon dioxide and (primarily) augite and plagioclase feldspar. This reaction proceeds under open-system conditions for a significant fraction of the reaction time, becoming a closed-system reaction when sufficiently removed from the soil zone. The closed-system reaction conditions persist as the ground water is discharged to surface-water systems.

The reaction-process model can be used to predict the effect on ground-water quality of changes in precipitation quality and quantity, in vegetative cover, and in other factors.

Although the model system employed was chosen to be hydrologically typical of Rocky Mountain conditions, it is likely that the geochemical processes are similar in regions with other hydrologic regimes. A report entitled, "Sources and mechanisms of recharge for ground water in the West-Central Amargosa Desert, Nevada--A Geochemical Interpretation" was approved for publication as a U.S. Geological Survey Water Resources Investigations Report.

Chemical Reactions at Mineral Surfaces

By James A. Davis, Menlo Park, Calif.

Physiochemical reactions at mineral surfaces are an important control on the rate at which some solutes are transported in water moving through soils, sediments, and rock formations. A detailed knowledge of the reaction mechanisms is being sought to aid in the selection of appropriate disposal strategies for specific hazardous wastes such as radioactive wastes.

Objective: To determine the effects of mineral surfaces (oxides, silicates, etc.) on the partitioning of solutes between dissolved and solid phases. To develop a thermodynamic data base that can describe the partitioning of specific elements or compounds between water and particular classes of solid phases.

Approach: Current studies include the development of a theoretical model for quantifying adsorption reactions based on the concepts of surface complexation modified by corrections from electrical double-layer theory. A model exists for well-characterized, clean hydrous oxides (Davis and Leckie, 1979), but this model needs to be extended to consider more complex solid phases such as aluminosilicate minerals, minerals with secondary surface coatings, or films of adsorbed organic material. Extension of the existing model will be based on experimental studies of these complex surfaces in the laboratory. Refinement of the model is accomplished by means of a chemical equilibrium computer program (MINEQL; Westall and others, 1976) which has been modified to include surface reactions in the computation of equilibrium.

The surface complexation model is based on the coordination chemistry of surface -OH groups which are present at many surfaces. The surface hydroxyl groups act as amphoteric Lewis acids or bases which can, thus, bond to either cations or anions. The current approach is to assess whether the surfaces of aluminosilicate minerals exhibit chemical behavior similar to hydrous oxides in their reactions with anions and cations, after making corrections for electrical effects with the theoretical model. Similarly, the chemical behavior of surfaces coated with natural organic matter of related model compounds is being studied. All soils and sediments contain natural organic material (fulvic and humic acids), and their influence on the surface chemistry of mineral phases needs to be determined.

Progress: The work was focused on a study of the mechanism of adsorption for natural organic matter (NOM). To estimate the chemical component of adsorption, the surface reactions of simple organic acids with alumina were studied as a function of pH and organic acid concentration. The organic acids included phthalic, salicylic, and several aliphatic dicarboxylic acids. The free energy of adsorption for these compounds can be divided into chemical and physical components using the surface complexation model developed earlier for inorganic anions (Davis and Leckie, 1980). Microelectrophoresis experiments show that the organic acids are probably not ionized after complexation with surface hydroxyls.

Research on the adsorption of natural organic material has revealed the following trends: The weak acidic functional groups of NOM form surface complexes with relatively basic surface hydroxyls, such as those on hydrous aluminum oxides, hydrous iron oxides, or edge sites of clay minerals. The complexes are sufficiently energetic to cause a significant coverage of those surfaces under conditions typical for lakes and rivers. Relatively acidic surface hydroxyls, e.g. those of silica, form weaker complexes, and

under natural conditions these surfaces may not be covered with organic material. The complex formation cannot be explained by a simple electrostatic attraction model; specific adsorption must be invoked to account for the free energy of adsorption and changes observed for the isoelectric pH.

An empirical model is being developed to describe NOM adsorption using the results for phthalate and salicylate and estimates for NOM functional groups. The assumptions necessary to apply the model make it semi-quantitative, but the results allow an initial estimate of the extent of mineral surface covered by NOM in natural waters.

Report

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URANIUM MILL TAILINGS

Radium Geochemistry

By Edward R. Landa, Lakewood, Colo.

In recent years, there has been increasing awareness among scientists and the general public of the radiological hazards resulting from natural radioactivity in the environment and from activities such as the mining and milling of uranium ores which increase the likelihood of exposure to the associated radiation. Another activity which has introduced radioactive materials into the environment is the management of residual products from

radium-extraction industries. Although these industries were most active in the early 20th century, officials in several states are presently concerned about the health hazards of these materials whose nature is often poorly understood.

Objective: To characterize some of the physical, chemical, biological, and mineralogical factors that may influence the mobility of radium and other uranium-series radionuclides in the surficial environment, with particular attention to uranium mill tailings.

Approach: Samples of the following earth materials are being studied:

(1) uranium ore,
(2) uranium mill tailings,
(3) soils containing residual-radioactive materials from radium extraction operations during the early 20th century,
(4) soils and sediments which have mixed with oil-production brine containing an elevated concentration of Ra-226.

Investigation techniques employed include selective leaching and particle sizing. Other techniques may be used and other samples studied as research progresses.

Progress: The sorption of Ra-226 from an oil-production brine (176 pCi/L) by soils and sediments was investigated. Sorption was rapid, and the percentage sorbed increased with brine dilution. Greatest removals of Ra-226 from sediments in the laboratory occurred with alkaline DTPA, HCl, and $BaCl_2$, with lesser removals occurring with the use of $CaCl_2$ and NaCl solutions. Removals of radium by digestion of sediments with sodium hypochlorite (NaOCl) indicate that most of the native and sorbed Ra-226 is associated with the mineral rather than with the organic fraction of the sediments. Correlation analysis based on 14 soils indicates that the retention of Ra-226 may involve precipitation reactions associated with sulfate-bearing minerals, as well as ion-exchange reactions with the clay-mineral fractions of surficial earth materials.

Soil samples collected from a site in Denver, Colorado, formerly occupied by several radium-extraction plants, were separated into particle-size fractions by sieving. The fractions were analyzed for Ra-226 and U by gamma-spectroscopic and delayed-neutron techniques respectively. Ra-226 contents ranged from about 1 to 8,200 pCi/g. Uranium concentrations ranged from about 5 to 7,500 ppm. Highest contents of both were generally found in the finest (<45μm) fraction, but the pattern was not always of progressive increase in radionuclide content with decreasing particle size. In some samples, Ra-226 and U contents in the 0.5- to 2.0-mm fraction approached or exceeded those of the <45-μm fraction. Ra-226/U-238 activity ratios ranged from about 1 to 28, indicative of contamination by ores and processing residues.

A report, "Sorption of ^{226}Ra from oil-production brine by sediments and soils," by E.R. Landa and D.F. Reid, was accepted for publication by Environmental Geology.

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