UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

U.S. GEOLOGICAL SURVEY RESEARCH IN RADIOACTIVE WASTE DISPOSAL--FISCAL YEAR 1980

By Robert Schneider and N. J. Trask

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ILLUSTRATIONS

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 (n mi)
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)
$decimeter^3$ (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)
Volume per unit time (includes flow)—Continued			
$decimeter^3$ 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 1980

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

Since the advent of the Atomic Age, scientists have known that the release of radioactivity from nuclear activities could have harmful effects on the environment and on man. Also, it was recognized that the potential transport of this radioactivity from buried sources to the human environment would involve water. 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 waste 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 described 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 second report of progress of USGS research in radioactive waste, the first being by Schneider and others (1981)[3].

RELATION TO PROGRAMS OF OTHER AGENCIES

For about 30 years the USGS 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 a variety of regional and detailed geologic and hydrologic studies and generic research related to waste disposal 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

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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, Roseboom, E.H., Robertson, J. B., and Stevens, P. R., 1982, U. S. Geological Survey Research in Radioactive Waste Disposal--Fiscal Year 1979: U. S. Geological Survey Circular 847, 74 p.

are referred to collectively as cooperative programs in contrast to those activities supported by direct Congressional appropriations to the USGS[1].

With regard to high-level and transuranic wastes, the specific responsibility for selection of sites for waste repositiories, 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 which 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.

To improve the coordination between DOE and USGS, the USGS and the DOE Office of Nuclear Waste Management prepared an Earth Science Technical Plan (ESTP) for mined geologic disposal of radioactive waste (high-level and transuranic wastes)[2]. The objectives were to formally organize the earth-science research tasks directed toward licensing a geologic repository, to show how these tasks address the principal technical questions related to geologic disposal of nuclear waste, to identify technical questions that require additional attention, and to establish the basis for assigning priorities to future work.

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.

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[1] Schneider, Robert, 1980, USGS participation in the National Waste Terminal Storage Program, in Proceedings of the 1980 National Waste Terminal Storage Program information meeting: Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, Report ONWI-212, p. 5-6.

[2] Office of Nuclear Waste Management, U.S. Department of Energy, and U.S. Geological Survey, 1980, Earth Science Technical Plan for Disposal of Radioactive Waste in a Mined Repository: DOE/TIC-11033 (Draft) and USGS draft report, National Technical Information Service, Springfield, Virginia.

BUDGET SUMMARY -- FISCAL YEAR 1980
(in millions of dollars)

High-level and transuranic wastes and related generic research		
USGS appropriation	3.39	
DOE transfer of funds	5.50	
NRC transfer of funds	0.04	
		8.93
Low-level wastes and related research on geologic and hydrologic processes		
USGS appropriation	2.34	
DOE transfer of funds	0.56	
		2.90
Uranium mill tailings		
USGS appropriation	0.11	
		0.11
Total		11.94

HIGH-LEVEL AND TRANSURANIC WASTES

Geological Survey Program for Identifying Environments Suitable for Locating Disposal Sites

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, environmental 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 geologically stable environment, a host rock of low permeability in a flow system with slow ground-water velocity, rocks with high sorptive capacity in the flow sytem, and long flow paths to discharge areas downgradient from the repository. Previously, attention was focused almost exclusively on the potential repository 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.

The process of selecting potentially suitable sites for repositories is extremely complex, involving social and political factors in addition to those pertaining to hydrology and geology. In view of the fact that the DOE has the responsibility for selecting sites, this USGS study requires the coordination and concurrence of the DOE which has had site selection activities underway for some time. The DOE effort currently is focused primarily on salt, tuff, and basalt as the potential host rocks for the waste.

The study is part of the USGS high-level waste program, which was started in fiscal year 1979 with direct Congressional appropriations.

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 One of the approaches explored by a subgroup of the DOE-DOI Working Group that developed the Earth Science Technical Plan (U.S. Department of Energy and U.S. Geological Survey, Subgroup I of ESTP Working Group, 1980) is to be tested in a prototype area. As adapted by the USGS the approach stresses the concept of identifying environments with relatively independent multiple barriers to nuclide transport in order to overcome deficiencies in our ability to characterize adequately the masses of rock around a repository, and to predict accurately the nature and occurrence of future waste-rock-water reactions, natural events, and nuclide transport (Bredehoeft

and others, 1978; Interagency Review Group on Nuclear Waste Management, 1979). Eleven broad physiographic provinces, encompassing the 48 conterminous states, have been identified as the basic land units in the national screening process. During the screening, the provinces will be subdivided successively into regions, areas, and potential sites.

Progress The Basin and Range Province, which encompasses parts of eight states--Arizona, California, Idaho, Nevada, New Mexico, Oregon, Texas, and Utah--was selected for testing the screening process.

Work began on assembling a data base for the screening effort. Published data and data in the files of the USGS are being compiled by specific subjects for use in evaluating geohydrologic environments. National and regional overviews, useful for preliminary screening, exist for the occurrence of various rock types, mineral resources, seismic activity, and volcano-tectonic features. Data are being gathered, assimilated, and compiled on mining districts and their commodities, surface occurrences of potential host rocks including granite, tuff, argillaceous rocks, basalt and salt. Preliminary reports on seismicity and regional tectonics are nearly finished. A preliminary compilation of gravity data was made and magnetics data are now being assembled. Hydrology, the keystone for regional environmental assessments, appears to be less well suited to regional definition, and it is probable there are significant areas with an absence of information on deep water movement. The available hydrologic data and information useful for characterizing the hydrology and delineating ground-water flow systems of the Province are being assembled.

Efforts were directed toward identifying ways of recording and processing the large amounts of data needed for a national screening process. Progress in developing algorithms for digitizing, storing, and combining areal information of the type needed is well advanced, and the problem is to adapt the systems best suited for this particular application. Work also began on assessing the capabilities of and adapting ground-water models for use in interpreting regional flow systems and evaluating the transport of radionuclides in geohydrologic environments.

Report

Bedinger, M.S., 1980, The Geological Survey program for identification of suitable geohydrologic environments for the disposal of high-level radioactive wastes: in Proceedings of the 1980 National Waste Terminal Storage Program information meeting: Office of Nuclear Waste Isolation, Columbus, Ohio report ONWI-212, p. 280-281.

References

Bredehoeft, J.D., England, A.W., Stewart, D.B., Trask, N.J., and Winograd, I.J., 1978, Geologic disposal of high-level radioactive wastes--earth science perspectives: U.S. Geological Survey Circular 779, 15 p.

Office of Nuclear Waste Isolation Staff, 1980, NWTS criteria for the geologic disposal of nuclear waste--Site qualification criteria: ONWI-33 (2) Draft, 9 p.

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.

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 (NWTS) 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 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 geologic 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 Virginia M. Glanzman, Lakewood, Colo.

Objective To locate and characterize rock masses at the NTS and in southern Nevada suitable as host media for high-level radioactive wastes; to describe the areal and depth distribution and structural integrity of these rock masses; and to assess the potential for contaminant release by hydrologic transport, or as a result of tectonic, and (or) volcanic activity.

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 Field work in the Syncline Ridge and Calico Hills areas (fig. 1) was completed and reports on the geology, geophysical studies, and core analysis were released (Anderson and others, 1980; Daniels and Scott, 1980; Hagstrum and others, 1980a,b; Hoover and Morrison, 1980; Spengler and Rosenbaum, 1980). Field investigations on the geology of the Twinridge granitic pluton (fig. 1) were completed and a report on results is in press (Maldonado, 1981). A ground magnetic traverse was made of the area to acquire new data to help identify the magnetic source rock by relating the detailed anomalies of that traverse to known geologic units. This is important inasmuch as the source rock is buried and the small exposed mass of intrusive rock is nonmagnetic. Owing to its geologic complexity, the Twinridge area is no longer being investigated as a potential repository site. Geologic and geophysical investigations were conducted in the southwestern quadrant of NTS, principally the Yucca Mountain area.

Field work for geologic mapping of the tuff bedrock in the southwestern NTS region was completed and a map compiled. This map will provide a better understanding of the distribution, welding, and volume of the Crater Flat tuffs and genetically related silicic volcanic rocks. An analysis of aeromagnetic and ground magnetic data from the southwest portion of the NTS was completed.

Yucca Mountain: A deep stratigraphic drill hole (USW-G1), located in a major northwest-trending valley at the north end of Yucca Mountain, was drilled and cored to a depth of 1829 m. The rocks were identified as Crater Flat Tuff from about 549 to 1074 m, silicic lava-flow breccia from 1074 to 1196 m, and a thick lithic-rich tuff below 1196 m. A preliminary appraisal is that all the volcanic rocks below the Crater Flat Tuff are genetically related to it and about the same age. This tentative conclusion is based on the general similarity of these older tuffs to the Crater Flat Tuff. Preliminary testing indicates that all the tuffs below Crater Flat are magnetically normal. Only the volcanic rocks at Tram Peak that are part of the Crater Flat Tuff have reverse polarity. Based on petrologic and geophysical evidence, the depth to basement or pre-Cenozoic rock under the USW-G1 site may be on the order of 3,050 m.

Gravity measurements were made at Yucca Mountain. An area of low gravity is centered about 2 mi west of the USW-G1 hole and probably reflects a depression in the pre-Tertiary basement surface. The depth to the basement at the center of the low gravity area is estimated to be 3-4 km. Low-level aeromagnetic data collected over the area show small magnetic variations over the repository area being considered.

The effect of the near-surface volcanic rocks is filtered out in higher level aeromagnetic data which are thought to reflect the magnetic structure of the basement rocks. The horizontal extent of the maximum gradient of the major magnetic high over the north end of Yucca Mountain is about 2 1/2 km; this width of the gradient suggests that the depth to the basement just northeast of drill hole USW-G1 as determined from geomagnetic data is in rough agreement with the depth estimated on the basis of the gravity analysis.

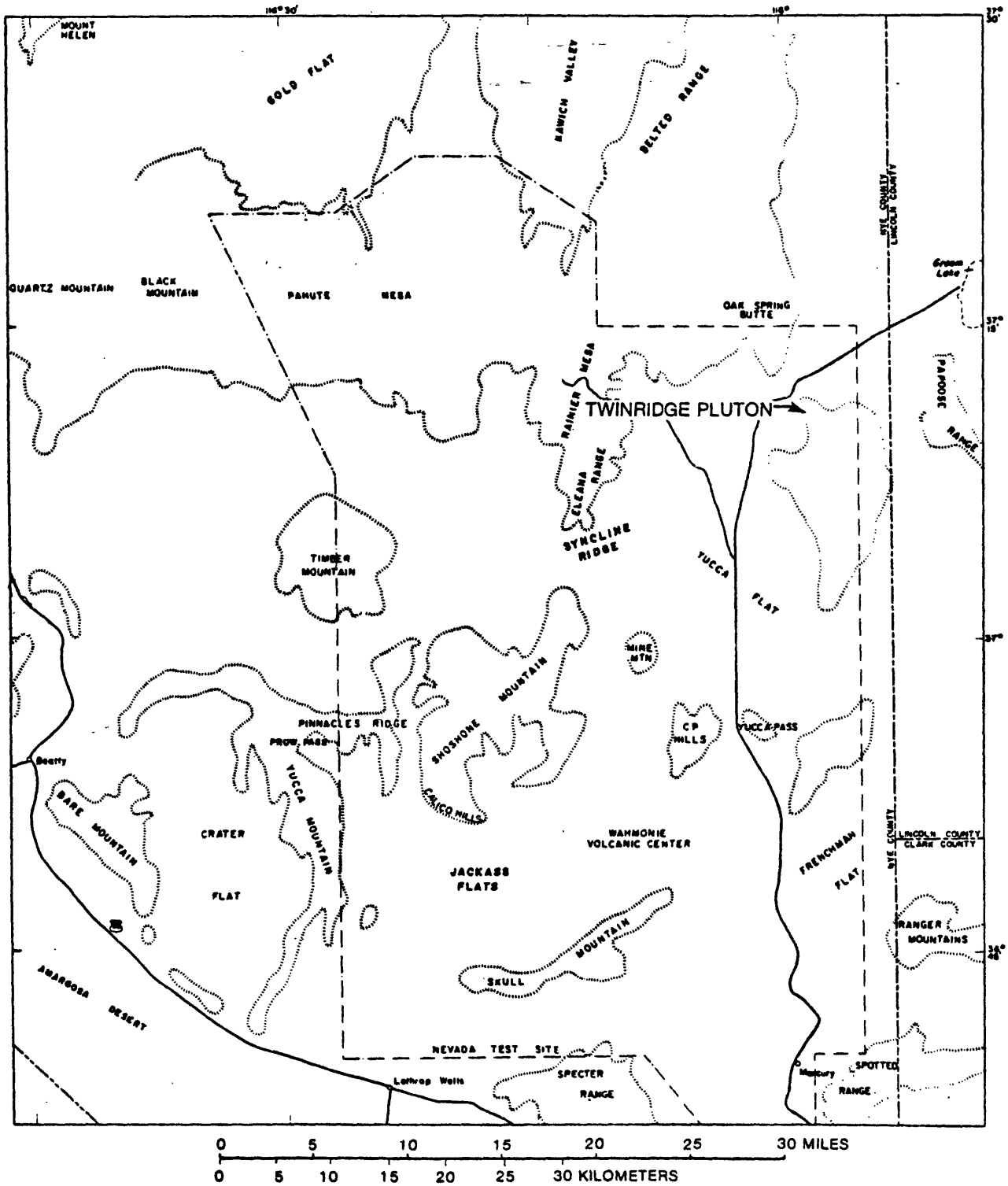

FIGURE 1.-Index map of the Nevada Test Site.

A preliminary temperature log made in USW-G1 indicates a temperature gradient of 15°C/km in the unsaturated zone (0 to 300 m) and 25°C/km between the depths of 1160 and 1980 m. The latter value leads to a heat flux of about 1HFU (40 kW/km^2). Additional temperature logs are planned.

A synthesis was made of all the electrical traverse data near the Yucca Mountain site identifying all principal electrically conductive zones. The conductive zones are inferred to be faults from the association of a number of them with known faults which have been mapped at the surface. These data were then integrated with the surficial geology to produce a map of inferred faulting in the site area.

Data from gravity and aeromagnetic surveys of the Timber Mountain region suggest that deformation caused by volcanism has been accommodated along straight line faults which combine to give the appearance of an arcuate pattern. The magnetic data suggest that rock units in the central graben of the Timber Mountain caldera and along the southeast margin of Timber Mountain have been thermally altered. Gravity data indicate the southern part of Timber Mountain is underlain by relatively dense, possibly intrusive rocks similar to those exposed on the southeast side. Gravity data also suggest that the Silent Canyon caldera which is centered just northeast of Timber Mountain may extend considerably south so as to underlie much of the Timber Mountain area. The Yucca Mountain area is separated from the southern part of Timber Mountain by a triangular shaped horst. Several linear terrain features in the southern part of the caldera are closely alined with features on geophysical maps, implying that terrain features are fault controlled.

Reports

Anderson, L.A., Bisdorf, R.J., and Schoenthaler, D.R., 1980, Resistivity sounding investigation by the Schlumberger method in the Syncline Ridge area, Nevada Test Site, Nevada: U.S. Geological Survey Open-File Report 80-466, 54 p.

Byers, F.M., Jr., and Dixon, G.L., 1980, Current geologic investigations in the southwest quadrant of the Nevada Test Site in support of the nuclear waste program (abs.), in Proceedings of the 1980 National Waste Terminal Storage Program Information Meeting: Office of Nuclear Waste Isolation Report ONWI-212 (addendum), p. 7-8.

Daniels, J.J., and Scott, J.H., 1980, Borehole geophysical measurements for hole UE25a-3, Nevada Test Site, Nuclear Waste Isolation Program: U.S. Geological Survey Open-File Report 80-126, 30 p.

Dixon, G.L., Carr, W.J., and Twenhofel, W.S., 1980, Earth science investigations for nuclear waste disposal at the Nevada Test Site (abs.): Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 414.

Hagstrum, J.T., Daniels, J.J., and Scott, J.H., 1980a, Interpretation of geophysical well-log measurements in drill hole UE25a-1, Nevada Test Site, radioactive waste program: U.S. Geological Survey Open-File Report 80-941, 32 p.

Hagstrum, J.T., Daniels, J.J., and Scott, J.H., 1980b, Analysis of magnetic suspectibility well log in drill hole UE25a-5, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 80-1263, 33 p.

Hoover, D.L., 1980, Tectonic geomorphology of valley-edge elevations in the Great Basin (abs.): Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 450.

Hoover, D.L., and Morrison, J.N., 1980, Geology of the Syncline Ridge area related to nuclear waste disposal, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Open-File Report 80-942, 70 p.

Maldonado, Florian, 1981, Geology of the Twinridge pluton area, Nevada Test Site, Nevada: U.S. Geological Survey Open-File Report 81-156, 13 p.

Spengler, R.W., and Rosenbaum, J.G., 1980, Preliminary interpretations of geologic results obtained from boreholes UE25a-4, -5, -6, and -7, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 80-929, 33 p.

Tectonics, seismicity, volcanism and erosion rates in the southern Great Basin

By W.J. Carr and A.M. Rogers, Lakewood, Colo.

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 The following approaches are being used: (1) investigating the rate, intensity, and distribution of faulting during approximately the last 25 m.y., with emphasis on the last 10 m.y.; (2) monitoring and interpreting present seismicity; (3) studying the history of volcanism; and (4) evaluating past rates of erosion and deposition.

Progress Tectonics--Mapping of the Quaternary deposits in the Yucca Mountain-Jackass Flats and Crater Flat areas has been completed and maps are being compiled for publication. The results of mapping and other work indicate a lack of youthful fault scarps in the Yucca Mountain area. A few faults in Crater Flat cut the surface alluvium; however, this alluvium is probably more than 100,000 years old and the scarps show considerable maturity. Trenching is planned to confirm these conclusions. Reports on the Quaternary stratigraphy of southwestern NTS and dating of Quaternary carbonate materials were completed. A preliminary study was made of a relatively young fault cutting the oldest Holocene alluvium along the northwest side of Bare Mountain (fig. 1). This is probably the youngest faulting in the southwestern NTS area. Detailed mapping of the northern Amargosa Valley is under way on new aerial photographs. A simplified computer program and mathematical model were completed in a study of erosion rates in the Great Basin. This model is the first step in an attempt to relate erosion and slopes to rates of tectonic uplift. A reconnaissance was made of the relations between alluvium and basalts in the Lunar Crater-Black Rock basalt field in the Pancake Range, north of the Nevada Test Site (fig. 2). A brief examination of the Pancake Range area indicates that

alluvial stratigraphy like that defined for the NTS can be used for approximate dating of basalts and faulting elsewhere in the Great Basin. Preliminary structure contour maps of the 11.5 m.y.-old Rainier Mesa Member of the Timber Mountain Tuff have been completed for the entire NTS area.

Interpretation of volcanism, seismicity, geophysics and geology for the southern Great Basin suggests the presence of a distinct structural-physiographic subprovince, here called the Lahontan subsection, in the western half of the Great Basin. The eastern margin lies near a north-south "axis of symmetry" (Eaton and others, 1978), but is arcuate and concave westward (fig. 2). East and west portions of the southern Great Basin are divided by a persistent septum that coincides closely with the "axis of symmetry" and consists of eastward-dipping Paleozoic rocks that separate volcanic fields of southwestern and central Nevada from those of eastern Nevada and western Utah. Portions of this magnetically "quiet" septum in southern Nevada are prominent areas of relatively high topography such as the Grant-Quinn Canyon Ranges, Sheep Range, and Spring Mountains.

During the Neogene, the eastern margin of the Lahontan subsection appears to have been a little more active tectonically than the septum to the east or areas in the center of the subsection, as evidenced by concentration of small basalt eruptions (medial basalt belt on fig. 2), Quaternary faulting, and seismicity. This marginal zone of slightly higher tectonic flux is somewhat diffused in the Walker Lane belt of dextral shear and the zone may curve southwestward from the Spring Mountains across the highly active areas of Death, Panamint, and Owens Valleys (fig. 2) where it includes relatively young volcanic areas such as the Greenwater and Coso fields. This southwestward curving may be related to a change in crustal thickness or composition, as suggested by a prominent east-west gravity gradient and seismic velocity changes at about lat 37° N. In northern Nevada, the eastern margin of the Lahontan subsection may follow the Oregon-Nevada lineament (Stewart and others, 1975). Mantle flow is suggested as a mechanism for this segmentation of the Great Basin.

New dates on rhyolite lavas associated with the Black Mountain caldera northwest of Timber Mountain agree fairly well with ages of associated ash-flow tuffs (Thirsty Canyon Tuff), but tend to push back ages obtained from samples collected earlier. The age range for Black Mountain caldera activity now appears to be between about 7 and 10 m.y. A zircon fission track date of 8.8 m.y. was also obtained on the small rhyolite plugs at Calico Hills. This suggests that at least some of the uplift and hydrothermal alteration of the Calico Hills occurred in connection with extrusion of the nearby rhyolite of Shoshone Mountain, rather than in earlier episodes of volcanism as previously thought.

Work by B. Crowe and D. Vaniman (Los Alamos National Laboratory) in cooperation with the USGS, is aimed at identifying significant petrologic and chemical differences between groups and subgroups of young basalts in the southern Great Basin. Trace elements support a division of basalts into two groups before and after about 4 m.y. ago. The older basalt group tends to be associated with bimodal silicic activity, whereas the younger is viewed as rift-related and apparently accompanied a switch in structural style to a concentration of Basin and Range faulting in narrower zones than

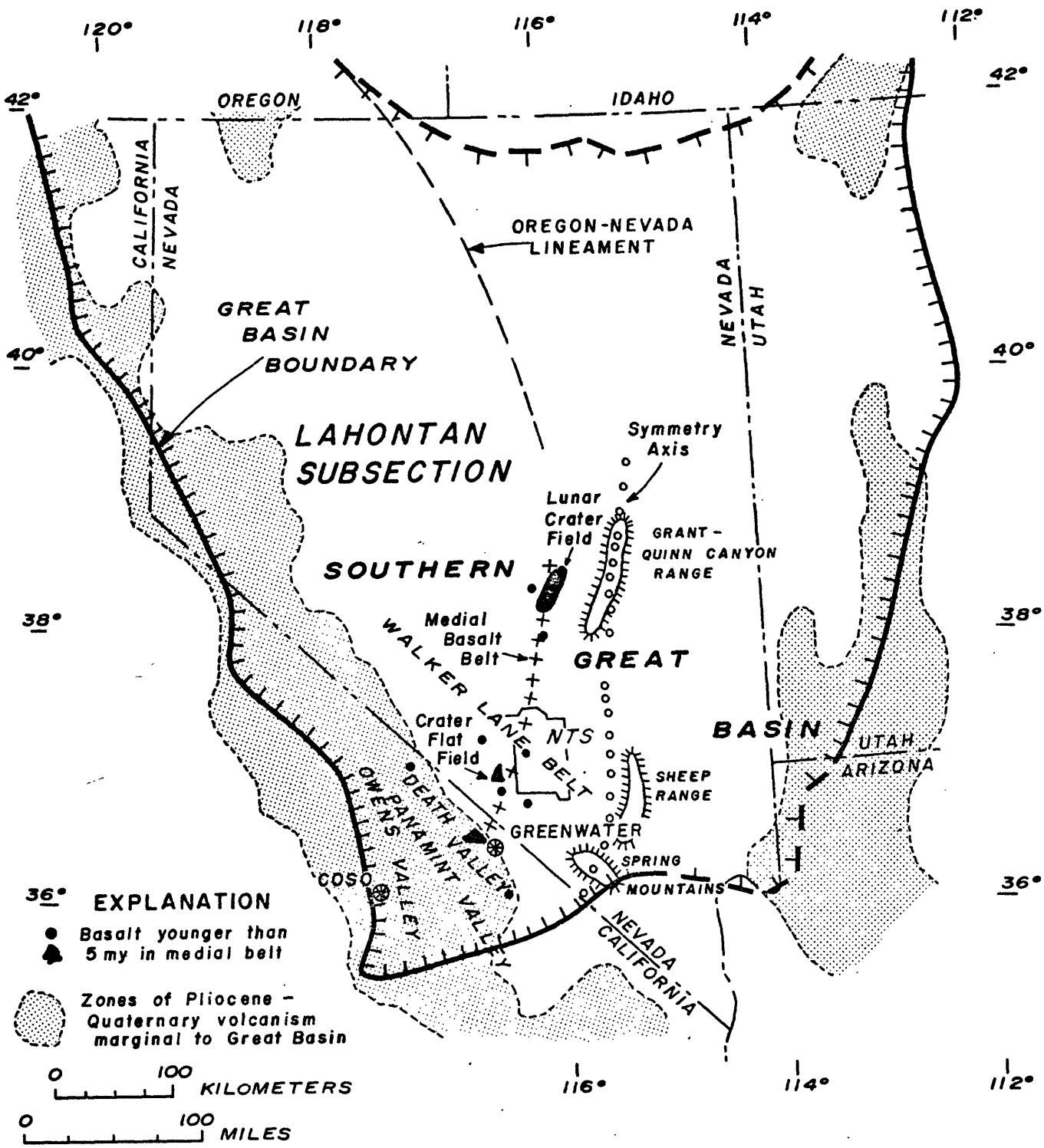

FIGURE 2.-The Southern Great Basin, showing selected volcanic, structural, and physiographic features.

had existed previously. The younger basalts appear to have relatively high Sr^{87}/Sr^{86} ratios.

Volcanism--The conclusion of a preliminary assessment of the risk of volcanism at a proposed repository at Yucca Mountain is that the annual probability of volcanic disruption of a potential waste storage site by an eruption located within 25 km of Yucca Mountain is 10^{-8}, or within 50 km, 10^{-9} (Crowe and Carr, 1980). These figures are based on very conservative data and reasoning. Future work will attempt to take into account structural controls and other factors affecting volcanism and how it might disrupt a repository.

Three distinct episodes of late Tertiary and Quaternary basaltic activity in the southern NTS region have been identified which are younger than 5 m.y.: one episode about 4 m.y. ago in the Crater Flat area and in the north end of the Greenwater Range; another about 1.1 m.y. ago in the Crater Flat area; and an episode northwest of Lathrop Wells and north of Beatty about 300,000 years ago. The virtually simultaneous eruption of basalts at different locations within the region strongly suggests that they were controlled by regional stress, although the locations of individual eruptions was probably controlled by local structures.

A brief reconnaissance was conducted of the Greenwater volcanic field, 50 km southwest of NTS, where there are good examples of local basaltic eruptive mechanisms. Available information indicates a period of strongly bimodal (basaltic and rhyolitic) volcanism occurred in the field in a relatively short time span between about 4 and 7 m.y. ago. The area contains the youngest (5 to 6 m.y. of age) known rhyolitic rocks in the NTS region. Two distinct episodes of basaltic activity, older and younger than the youngest rhyolite, were recognized in the study. The structural control for this volcanism is interpreted to be localization between right-stepping offset ends of the regional, right-lateral, strike-slip fault system.

Seismicity--Earthquakes are being monitored by the 45-station southern Great Basin seismograph network, and seismicity continues to occur in a diffuse but persistent east-west band just north of the NTS. Another broad feature of the seismicity pattern that has emerged is a U-shaped band of near-quiescence that encompasses the NTS on the south. Several focal mechanisms have been examined for some of the best recorded and located events. These mechanisms indicate normal and strike-slip movement on faults with trends ranging from approximately north to east, resulting in a tension axis that trends northwest. Focal mechanisms for five events in the southern NTS area indicate normal faulting on northeast-trending faults.

Report

Crowe, B.M., and Carr, W.J., 1980, Preliminary assessment of the risk of volcanism at a proposed nuclear waste repository in the southern Great Basin: U.S. Geological Survey Open-File Report 80-357, 15 p.

References

Eaton, G.P., Wahl, R.R., Prostka, H.J., Mabel, D.R., and Kleinkopf, M.D., 1978, Regional gravity and tectonic patterns: their relation to late Cenozoic epeirogeny and lateral spreading in the western Cordillera: Geological Society of America, Memoir 152, p. 51-92.

Stewart, J.H., Walker, G.W., and Kleinhampl, F.J., 1975, Oregon-Nevada lineament: Geology, May 1975, p. 265-268.

Hydrology

By W.E. Wilson, Lakewood, Colo.

Objective To determine present and past hydrologic regimes of the NTS area in order to predict the potential for ground-water transport of radioactive waste to the accessible environment.

Approach 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. Data will be assembled to define the regional hydrology of southern Nevada and to characterize in detail ground-water flow from prospective repository sites to points of present and possible future discharge.

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 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.

Test drilling is being conducted to characterize in detail the hydrologic regimes of candidate areas for a waste repository. Results will provide information on potential ground-water flow pathways, bulk hydrogeologic properties of potential host rocks and surrounding rock units, and ground-water chemistry and age.

Progress Under the direction of F. E. Rush and G. C. Doty, hydraulic testing was conducted on tuffs penetrated by a 1,969-m core hole in Yucca Mountain, an area at NTS being characterized to determine its suitability as a waste repository. The static water level was about 620 m below land surface. Preliminary results indicate the tuffs have very low hydraulic conductivities.

R.K. Waddell has completed a two-dimensional, steady-state model of a ground-water flow system in Nye and Clark Counties, Nevada, and Inyo County, California, using parameter estimation techniques. Characteristics of the flow system are determined by the locations of low-conductivity rocks (barriers); by the amounts of recharge occurring in

the Spring Mountains, Pahranagat, Timpahute, and Sheep Ranges, all of which lie from 60 to 100 km northeast, east and southeast of NTS and in Pahute Mesa (fig. 1); and by the amount of flow into the study area from Gold Flat and Kawich Valley (fig. 1). Analyses of sensitivity of head with respect to model parameter variations indicate that, for example, the flux term having the greatest impact is recharge on Pahute Mesa and underflow from Gold Flat and Kawich Valleys.

A sensitivity study was made of fluxes at selected sites in the western part of the model area using calculations of heads and the results of the head sensitivity analysis to determine the parameters that would most affect predictions of radionuclide transport from a hypothetical repository in the southwest quadrant of the Nevada Test Site. Additional geologic and hydrologic data from the Timber Mountain and Yucca Wash areas would greatly improve the quality of estimates of ground-water flux through the Yucca Mountain area.

A mineralogic study of borehole samples of alluvium is being made by B.F. Jones in an effort to identify features that would be diagnostic of formerly saturated conditions. Such a tool could be used to recognize the positions of higher water tables during Pleistocene time.

General X-ray diffraction examination of matrix fines in bulk and of fractions whose diameters are less than 1 m were completed for samples from well Ullg, in Frenchman Flat. Further data were also obtained from heat stage and solvation runs, but no evidence of "chain" clay, considered to be indicative of persistent ground-water saturation, has been identified. Compilation of the X-ray diffraction data on all samples from well Ullg suggests that a significant change in mineral composition may be present below about 240 m. Zeolite (clinoptilolite) becomes the most abundant phase (at least as suggested by peak intensities) and the dominant expandable clay may possess a larger basal spacing (>14Å). Further work is needed to demonstrate whether differences are attributable to a change in provenance or in hydrologic conditions. The clay properties could be related solely to the hydration state during examination, but if not, they may reflect different interlayer cations and a change in cation composition of associated waters.

Climatic changes over about the last 50,000 years in southern Nevada are being documented by analyses of vegetative remains in packrat middens, by W.G. Spaulding (University of Washington), on contract to the USGS.

A total of 24 radiocarbon dates on three type midden sections from the NTS provide the following information:

1) Documentation of climatic changes on the Eleana Range from the glacial maximum to the end of Wisconsin time; about 17,000 years before present (B.P.) to about 11,000 years B.P.

2) A record of vegetation change on the Specter Range from the late middle Wisconsin (about 28,000 years B.P.) to the glacial maximum (about 15,000 years B.P.).

3) Documentation of the impact of climatic change on the Eleana Range during the middle Wisconsin, from about 49,000 years B.P. to about 38,000 years B.P.

Preliminary interpretations indicate that during pluvial times mean annual temperature was about 5-8°C cooler and precipitation was less than 25 percent greater than modern conditions at NTS. These results suggest that the pluvial climate was probably not drastically different from today.

The potential for flooding is a factor in assessing the suitability of sites for the temporary surface storage of high-level radioactive wastes. To aid in evaluating potential sites in eastern Jackass Flats, NTS, the 100-yr, 500-yr, and maximum potential floods were evaluated for Topopah Wash (Christensen and Spahr, 1980). Results show that the areal extent of the 100-yr flood would coincide closely with most stream channels; the 500-yr flood would exceed the discharge capacities of all channels except Topopah Wash and some upstream tributaries; and the maximum potential flood would inundate the entire area of eastern Jackass Flats.

Report

Christensen, R.C., and Spahr, N.E., 1980, Flood potential of Topopah Wash and tributaries, eastern part of Jackass Flats, Nevada Test Site, southern Nevada: U.S. Geological Survey, Water-Resources Investigations Open-File Report 80-963, 22 p.

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) (fig. 3), a geologic repository for nuclear wastes generated by defense activities. The geology and hydrology of the area are being 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 WIPP site is located in the Delaware Basin a tectonically stable region. The potential host rock is bedded salt of the Salado Formation of Late Permian age.

Salt Dissolution and Deformation Studies

By R.P. Snyder and L.M. Gard, Jr., Lakewood, Colo.

Geologic studies in and near the WIPP site are concerned with the identification and evaluation of salt dissolution and salt deformation processes and phenomena to determine their possible effect on the geologic integrity of the area. Included in the features under study are breccia pipes, dissolution fronts and salt deformation structures.

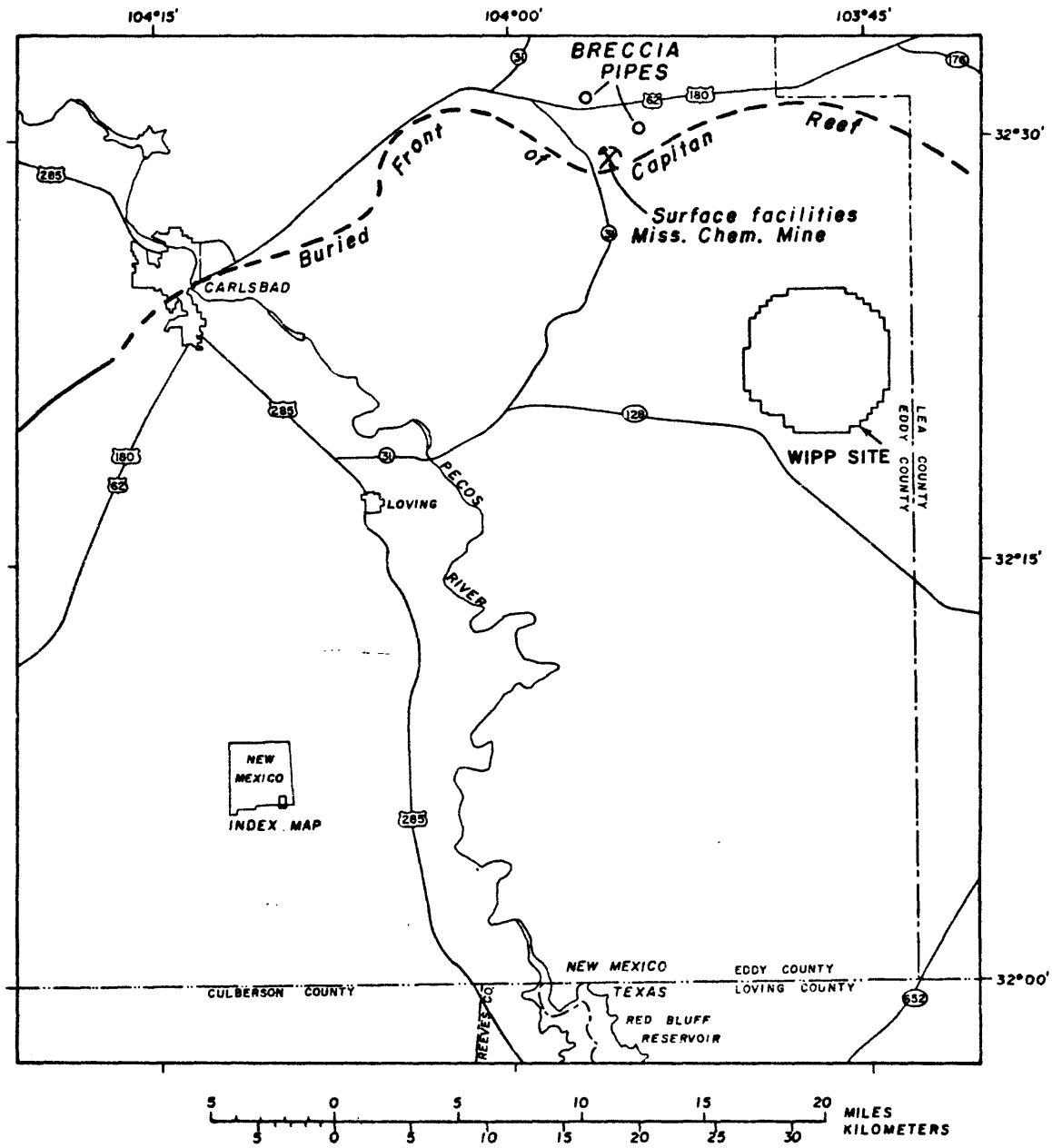

FIGURE 3.-Map showing location of the Waste Isolation Pilot Plant (WIPP) site, New Mexico.

Objective To characterize the salt dissolution and salt deformation features, and to determine whether they will have a negative effect on the integrity of the WIPP site.

Approach The geologic investigations involve the acquisition, analysis, and interpretation of subsurface data from (1) shallow core tests (<350 m) drilled to investigate dissolution phenomena in the Salado and Rustler Formations, and (2) deep wells (>500 m) drilled to determine the nature of geophysical anomalies, to investigate deep dissolution, or to explore for oil and gas. The work involves the examination and analysis of cores, cuttings, and geophysical logs from the drill holes, and it includes regional geologic reconnaissance, detailed mapping, and the analysis of geophysical data. Samples are selected for age determination to estimate the rate at which the "dissolution front" is advancing, and to date the formation of breccia pipes.

Progress The work focused primarily on exploration drilling in two structures identified as breccia pipes. These features lie north of the WIPP site (fig. 3) and overlie the buried Capitan Limestone, the bounding structure of the Delaware Basin.

The first breccia pipe to be explored by surface drilling was identified when mine workings of the Mississippi Chemical Co. (MCC) potash mine intersected the structure at a depth of about 360 m below the surface. The drill hole penetrated 350 m of brecciated Triassic Dockum Group and Permian Dewey Lake Red Beds and Rustler Formation. Below 350 m, the rock was broken, but stratigraphically in place and identifiable as the Rustler Formation. These rocks dip about 30° and have been downdropped about 180 m. The drill hole bottomed at 396 m, about 25 m below the mine workings (depths are not correlative because of surface elevation differences).

Detailed mapping of the MCC mine drifts in the vicinity of the breccia pipe revealed that the beds of the Salado Formation at mine level have been downwarped about 12 m toward the pipe for a distance of 60 m from the edge of the pipe. These strata are also downfaulted 1-2 m towards the pipe by a ring fault. Fragments of anhydrite in the pipe and adjacent to the boundary are believed to have been displaced downward about 100 m.

Oil seeps associated with the ring fault in the mine and found sporadically in core from the drill hole have been identified by J.G. Palacas, USGS, as similar to oil produced from the Yates Formation, which underlies the Salado Formation. There are nearby wells producing from this formation.

Drill hole exploration of the second pipe was done in two stages, 0 to 247 m, and later 247 to 604 m. Breccia of the Dockum Group and Permian Dewey Lake Red Beds, Rustler and Salado Formations was cored from the surface to a depth of 580 m. These breccia fragments showed no stratigraphic order. Only about 13 m of Salado halite was intersected. Below 580 m to the total depth a fractured anhydrite dipping about 45° was cored. This unit is believed to be the Fletcher Anhydrite Member of the Salado which overlies the Capitan Limestone at this location. At least one identifiable fragment of the Culebra Dolomite Member of the Rustler Formation was found, 30 m below its normal depth.

Oil from the Yates Formation (J.G. Palacas, oral commun., 1980) was also found on a few fragments in this hole, suggesting that upward migration may have occurred from the underlying Yates.

The collapsed breccia pipes are believed to have their roots in the Capitan Limestone, a formation known for its cavernous nature. The Carlsbad Caverns are the best example of this. Where the reef is buried (dashed portion of reef front on fig. 3), data from numerous drill holes also confirm the cavernous nature of the limestone.

Reports

Jones, C.L., and Gonzales, J.L., 1980, Geologic data, in Basic data report for drillhole WIPP 18 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND 79-0275, p. 6-16.

_____ 1980, Geologic data for borehole WIPP 19, in Basic data report for drillhole WIPP 19 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND 79-0276, p. 6-25.

_____ 1979, Geologic data for borehole WIPP 21, in Basic data report for drillhole WIPP 21 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND 79-0277, p. 6-16.

_____ 1979, Geologic data for borehole WIPP 22, in Basic data for drillhole WIPP 22 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND 79-0278, p. 6-19.

Snyder, R.P., and Drellack, S.L., Jr., 1979, Geologic data, in Basic data report for drillhole WIPP-30 (Waste Isolation Pilot Plant--WIPP): Sandia Laboratories Report SAND 79-0284, p. 4-19.

Snyder, R.P., and McIntyre, A.F., 1980, Geologic data, in Basic data report for drillhole WIPP-33 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND 80-1102, p. 6-25.

Cenozoic History of Pecos River Drainage System

By George O. Bachman, Albuquerque, N. Mex.

This project is concerned with the Cenozoic history of the Pecos River drainage system and the influence of this system on erosion and dissolution in the vicinity of the Waste Isolation Pilot Plant site.

Objective To determine if presently active geologic processes offer any potential hazards to confinement of wastes at the site.

Approach The approach is to identify and understand those geologic processes that have shaped the present land surface and to determine the relative and absolute ages of significant geologic features in the vicinity of the WIPP site.

Progress The Cenozoic history of the Pecos River drainage in the Delaware Basin has been summarized by Bachman (1980). The report incorporates an outline of dissolution and karst development in Permian evaporites of the region. Dissolution has been an intermittently active process in the Delaware Basin at least since Triassic time and it is impractical to attempt to calculate a steady rate of dissolution for the basin. Since the end of Permian time, the region has been above sea level (and presumably dissolution has been active) for a minimum of 154 m.y., and below sea level (when presumably dissolution was inactive or less active) for less than 71 m.y.

Complex karst features including collapse sinks, karst mounds (new term), karst domes (new term), and caves formed by solution of evaporite deposits have been described. Karst mounds are erosional remnants of regional breccia. Karst domes are structural features which have formed on a very irregular dissolution surface. Breccia pipes or breccia chimneys are collapse sinks which have formed over a deep seated aquifer system (the Capitan Limestone). These sinks probably are the result of water rising in the unsaturated zone under a strong hydraulic head, through fractures, into the evaporite sequence, creating a cavity by dissolution into which the overlying rocks collapse. The sinks appear to be restricted to areas overlying the Capitan Limestone reef around the periphery of the Delaware Basin.

Subsurface evidence suggests that deep dissolution is not presently an active process in the Castile Formation beneath the thick Salado Formation in the basin proper, and there is no evidence to suggest that breccia pipes pose a threat to the integrity of the WIPP site which lies in the basin inside the reef.

Report

Bachman, G.O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico: U.S. Geological Survey Open-File Report 80-1099, 116 p.

Fluid Inclusion Studies

By Edwin W. Roedder, Reston, Va.

The storage of radioactive waste in natural salt was originally suggested, in part, because salt mines are dry. However, microscopic fluid inclusions are known to be present in most salt deposits. Most of these inclusions will migrate toward a source of heat such as a waste canister and bring in proximity to it an amount and composition of brine whose consequences must be assessed. In addition, the inclusions are fluids that either were present when the salt was deposited or moved in later and became trapped (due to recrystallization of salt); in the latter case, they provide information on the previous movement of fluids through the rocks.

Objective To determine: (1) what information can be obtained from fluid inclusions that may help in determining if, when, and how fluids

moved through the salt in the past and whether this may occur in the future; (2) how much fluid is present in any given site, and what are its distribution, properties, and composition; and (3) what predictions can be made as to the behavior of these fluid inclusions following storage of waste.

Approach Specially prepared samples are examined by microscope for fluid inclusions and appropriately sized portions are removed for study on microscope with freezing, heating, and crushing stages. The temperature of first melting of a completely frozen inclusion provides a measure of the eutectic temperature of the chemical system within the inclusion. The temperature of disappearance of the last solid phase and the composition of that phase, when compared with appropriate phase diagrams, place some limits on the fluid composition.

In the heating stage, the temperature at which the inclusion formed can be inferred from the temperature at which the shrinkage vapor bubble disappears. In salt samples, this determination is somewhat ambiguous because of the possibility of post-entrapment flowage of the host salt crystal. Gas pressure within an inclusion is estimated from the volume of the bubble in an inclusion under the microscope before and after cracking the inclusion or dissolving the host crystal in water. Rate of migration of inclusions in a thermal gradient (by solution at the hotter and reprecipitation at the cooler end) is determined by measurements under the microscope before and after subjecting the sample to a controlled static thermal gradient at a constant ambient temperature for weeks.

Progress Previous work has been almost solely on samples from the WIPP site in New Mexico; in FY 80 salt from several other sources was studied.

Salt samples from the WIPP site have been studied particularly to determine the behavior of the fluid inclusions in thermal gradients on the order of those to be expected from a waste canister ($1.5°C \cdot cm^{-1}$). Rates of migration up the thermal gradient have been determined and some data have been obtained on the behavior when moving inclusions contact a grain boundary. For ambient temperatures in the range 108°-260°C, cubic inclusions 1 mm on an edge move 1.2-5.4 $cm \cdot yr^{-1}$. The rate of migration within single crystals increases with inclusion size, thermal gradient, and ambient temperature, but there are other unknown factors that may change the rate by a factor of 3. On contacting a grain boundary, most inclusions lost most of their fluid to the grain boundary, resealed themselves as a gas-rich inclusion, and reversed their direction of movement, going down the thermal gradient (Roedder and Belkin, 1980b). A general review of inclusions trapped during diagenesis was published (Roedder, 1979) and the possible origins of such fluids, and their significance in nuclear-waste storage siting, are discussed by Stewart and others (1980).

The results of these brine-migration studies have been used to reinterpret the data published by Lambert (1980) on the Salt Block II experiment (Roedder and Belkin, 1980b). The resulting differences in interpretation can only be resolved by actual examination of samples from Salt Block II.

Core samples from the Rayburns and Vacherie salt domes in Louisiana, obtained from the Louisiana State University Institute for Environmental Studies, were examined for inclusions. These samples were found to contain far less water than those from the WIPP site (certainly less than 0.1 volume percent and probably in the range 0.01 to 0.001 volume percent), but the inclusions are highly erratic in distribution (Roedder and Belkin, 1979a). Unlike those in many bedded salt deposits and other salt domes, the brine inclusions in the salt from these two domes contain fluids that are not far from simple $NaCl-H_2O$ solutions, with very few other ions. One possible explanation for the composition of such fluids is that fresh water penetrated the salt at some unknown time in the past and was trapped.

Samples were collected from various points in the Klodawa salt dome in west-central Poland, where severe mining hazards from "popping salt" have been encountered. Preliminary studies indicate that high pressure gas inclusions caused this phenomenon.

The analysis of the water content of salt samples has been considered a routine matter in the past, and frequently the resulting data are reported without even a statement of the method used. A cooperative study with R.L. Bassett of the University of Texas at Austin (manuscript submitted to Geology) has shown that most such determinations are not truly comparable, that many contain serious and, in part, systematic errors, and that the results are generally on the low side. These problems arise from a combination of the multiple modes of occurrence of water in the samples, and the sampling, sample preparation, and analytical techniques used.

Samples of bedded salt from the Palo Duro basin in Texas have also been studied as part of this cooperative project. Determinations of intergranular fluid have been made on whole 10-cm (4-inch) cores by careful drying at 35°C. The amounts obtained on 15 samples (0.0156 to 0.853 wt.%) are minimum values for intergranular inclusions and include essentially no intragranular fluid inclusions, and no water from hydrous minerals. Further analyses of these various types of water are in progress.

Arrangements have been made to investigate the inclusions in samples of salt from the Asse salt mine in the Federal Republic of Germany, where a cooperative brine migration test is planned with the United States. E.W. Roedder has been asked by ONWI to join the Brine Migration Task Group.

Reports

Roedder, E., 1979, Fluid inclusion evidence on the environments of sedimentary diagenesis - a review: Society of Economic Paleontologists and Mineralogists Special Publication 26, Symposium on determination of diagenetic paleotemperatures, p. 89-107.

Roedder, E., and Belkin, H.E., 1979a, Migration of fluid inclusions in Waste Isolation Pilot Plant site salt in thermal gradients (Abs.): Materials Research Society Symposium G, Scientific Basis for Nuclear Waste Management, Cambridge, Nov. 26-30, 1979, Abstracts volume, abstract J1-K.

Roedder, E., and Belkin, H.E., 1979b, Fluid inclusion study on core samples of salt from the Rayburns and Vacherie Domes, Louisiana: U.S. Geol. Survey Open-File Report 79-1675, 25 pp.

Roedder, E., and Belkin, H.E., 1980a, Thermal gradient migration of fluid inclusions in single crystals of salt from the Waste Isolation Pilot Plant (WIPP): Northrup, C.J.M., Jr., (ed), Scientific basis for nuclear waste management: New York, Plenum Press, v. 2, p. 453-464.

Roedder, E., and Belkin, H.E., 1980b, Migration of fluid inclusions in polycrystalline salt under thermal gradients in the laboratory and in Salt Block II (abst.): Proc. 1980 Natl. Waste Terminal Storage Program Information Meeting, ONWI - 212, p. 361-363.

Stewart, D.B., Jones, B.F., Roedder, E., and Potter, R.W., II, 1980, Summary of U.S. Geological Survey investigations of fluid-rock-waste reactions in evaporite environments under repository conditions, in Underground disposal of radioactive wastes: v. I, Proceedings International Atomic Energy Agency Symposium, Helsinki, 1979: Vienna, Internat. Atomic Energy Agency, p. 335-344.

Reference

Lambert, S.J., 1980, Mineralogical aspects of fluid migration in "Salt Block II" experiment: Sandia National Laboratories, Sand 79-2423, 24 p.

Geochronology and Isotopic Studies

By Barney Szabo, John Rosholt, John Obradovich, and M. Tatsumoto, Lakewood, Colo.; and James R. O'Neil, Menlo Park, Calif.

Objective To date the time of formation of various geologic materials, and by use of natural isotopes, determine and describe geologic processes pertinent to the geologic stability and integrity of a waste repository at the WIPP site.

Approach Samples of solids, liquids and gases are collected and isotopic ratios determined by various techniques involving mass spectrometry. The results are interpreted in terms of ages or descriptions of geologic processes.

Progress Geochronology and isotopic studies fall into three categories: hydration and solution of potash and anhydrite, dating the formation of breccia pipes, and stable isotope studies.

Hydration and Solution of Potash and Anhydrite, and other minerals (Barney Szabo and John Rosholt, Lakewood, Colo.)--This investigation is aimed at determining the time at which subsurface solution of potash and alteration of anhydrite and polyhalite to gypsum (which develops where shallow ground waters first interact with the anhydrite formation) have occurred near the WIPP site.

Uranium and thorium analyses of altered evaporites in the upper part of the Salado Formation from test hole WIPP-25 indicate a dissolution process older than 700,000 yr. Studies of the upper part of the Rustler Formation from test hole WIPP-27 suggest a dissolution period at approximately 90,000 yr b.p. Repeat analyses of these samples are in progress, and the results should be regarded as preliminary.

Dating the Formation of Breccia Pipes (John Obradovich and M. Tatsumoto, Lakewood, Colo.)--These studies are attempting to date the time of formation of breccia pipes and help to determine their origin, as well as date the times of diagenesis and deformation metamorphism of the evaporite deposits. This is being done through K-Ar and K-Ca dating of samples of sylvite, polyhalite, langbeinite, diagenetic silicates, or other appropriate minerals from breccia pipes.

The results for clay samples collected from the wall of a breccia pipe encountered in the Mississippi Chemical Co. (MCC) mine (approximately 3 m from header, entry no. 5) are preliminary. However, they indicate that the ages obtained (greater than the age of deposition of the Upper Permian formations, 230 m.y.) reflect a detrital origin rather than an authigenic one for the clays. X-ray analyses (in progress) will be used to identify and quantify the various clay species. The data are meaningless with regard to time of breccia pipe formation. Further dating of clays is not recommended unless there is some reason to believe the clays formed during or after pipe formation.

Ten K-Ar ages, determined on a variety of potassium salts from breccia pipes by O.K. Manuel (USGS and Univ. of Missouri), gave ambiguous results. Ages determined for sylvite were very young and variable, 5.04 to 19.3 m.y. Older ages were determined for one sample each of langbeinite (164 m.y.), halite (205 m.y., assuming 0.1 per cent K), and polyhalite (241 m.y.). These older ages are in closer agreement with the K-Ar age of 212 m.y. reported by Brookins and others (1980) for polyhalite from a breccia pipe in the Delaware Basin. One explanation for the young sylvite ages is diffusive loss of argon; however, these diffusive losses would range from 91 to 98 per cent and require rather high underground temperatures. While sylvite is known to lose argon by diffusion more readily than many of the minerals commonly used for K-Ar dating, a number of instances can be cited where the K-Ar ages reported for sylvite are in good agreement with the ages determined by other radiometric methods or with paleontologically determined ages (e.g., Polevaya and others, 1980). A second explanation is that the young K-Ar ages reflect the time of latest recrystallization and that the variability in ages is due to the presence of excess radiogenic argon in fluid inclusions. The young ages would then be maximum ages for the time of recrystallization.

Further information on the recrystallization history of these minerals may come from study of the potassium-calcium series. Professor Manuel was able to solve the chemical problems of separating and running calcium for K-Ca analyses. One K-Ca age of 34 m.y. has been determined on a single sylvite sample. This age contrasts with K-Ar ages of about 13 and 19 m.y. for sylvite fragments and 164 m.y. for langbeinite from the same hand sample. A better determination of the age of recrystallization of these samples may

come from simultaneous K-Ar, K-Ca, and Rb-Sr age determination on the same crystal. Toward this goal, we have recently rebuilt a gas mass spectrometer into a solid source mass spectrometer to analyze potassium and calcium.

Stable Isotope Studies (James R. O'Neil, Menlo Park, Calif.)--Oxygen and hydrogen isotope analyses have been made of (1) brines from several wells in the salt deposits of the Delaware Basin, (2) inclusion fluids in halite crystals from test hole ERDA No. 6, and (3) locally derived meteoric waters. A new interpretation of previously determined solute compositions is that the brines are genetically related and that they probably originated from the evaporation of ancient ocean waters. Although variable in solute contents, the brines have rather uniform isotopic compositions. The stable isotope compositions of both the brine and fluid inclusions from test hole ERDA No. 6 are variable but remarkably regular and show that (1) mixing with meteoric waters has occurred, the extent of mixing decreasing with depth, and (2) water in the ERDA No. 6 brine probably originated from the dehydration of gypsum. Stable isotope compositions of all the waters analyzed indicate that fairly extensive mixing with ground water has occurred throughout the area. These studies suggest that active ground-water circulation occurred in the Delaware Basin in the past.

Report

Szabo, B.J., Gottschall, W.C., Rosholt, J.N., and McKinney, C.R., 1980, Uranium series disequilibrium investigations related to the WIPP site, New Mexico: U.S. Geological Survey Open-File Report 80-879, 20 p.

References

Brookins, D.G., Register, J.K., Jr., and Kruger, H.W., 1980, Potassium-argon dating of polyhalite in southeastern New Mexico: Geochimica Cosmochimica Acta, v. 44, no. 5, p. 635-637.

Polevaya, N.I., Titov, N.E., Belyaev, V.S., and Sprintsson, V.D., 1958, Application of the Ca method in the absolute age determination of sylvites: Geochemistry, 1958 volume, p. 897-906.

Tremba, E.C., 1969, Isotope geochemistry of strontium in carbonate and evaporite rocks of marine origin: Ph.D. Dissertation, Ohio State University, 185 p.

Hydrology

By Jerry W. Mercer, Albuquerque, N. Mex.

Objective To evaluate the hydrologic systems in the area with regard to their potential for radionuclide transport.

Approach Data will be acquired and assembled to define in detail the hydrology of the WIPP site including its relationship to regional ground-water systems. Improvements in digital models, simulating ground-water

flow and solute transport, will be required to predict rates and directions of movement of radioactive species and their concentrations in ground water if they should be released from a geologic repository.

Progress Water-bearing zones above and below the proposed host formation for the waste, the Salado Formation, include the water-bearing dolomites in the Permian Rustler Formation above the Salado, the brines at the Rustler-Salado contact, and the brines in the Bell Canyon Formation below the Salado (see table below). The water-bearing zones in the Rustler Formation require the most detailed definition, followed, in turn, by the Bell Canyon Formation.

Permian stratigraphic formations associated with the Salado Formation in the WIPP area

Series	Formation	Lithology	Approximate Thickness (m)
Ochoan	Dewey Lake Red Beds	Siltstone and sandstone	30-170
	Rustler	Anhydrite, dolomite, and sandstone	85-130
	Salado	Rock salt; minor amounts of anhydrite, polyhalite, and potash ores	530-610
	Castile	Anhydrite with some limestone and salt	400-405
Guadalupian	Bell Canyon	Sandstone	305

Regional hydrologic studies at WIPP continued with the completion of 12 hydrologic test holes in the Rustler Formation. The holes range in depth from 47 to 469 m. The purpose of this effort and subsequent testing was to improve our knowledge of the regional flow system in the Culebra and Magenta Dolomite Members of the Rustler Formation and at the Rustler-Salado formational contact. As with previous testing, specially designed drill holes and testing equipment were utilized. Although testing is continuing, preliminary calculations of transmissivity for the Culebra Dolomite Member range from 3 m^2/d to 1 x 10^{-2} m^2/d, while the values for the Magenta Dolomite Member ranged from 1 x 10^{-1} m^2/d to 2 x 10^{-4} m^2/d. The variability in these values may be the result of variations in fracture distribution caused by local evaporite dissolution. Owing to the very low permeability of the Rustler-Salado contact zone, testing has been slow and difficult because water levels stabilize very slowly; consequently it has not been completed.

In addition to studies of the regional flow system, a major effort was undertaken to define the hydrology of Nash Draw, the nearest drainage course to the WIPP site (eastern edge about 8 km west of the center of the site). Nash Draw probably developed by a combination of dissolution,

resulting in subsidence and accelerated erosion. The testing program utilized six drill holes that had been drilled for stratigraphic evaluation and cased for later hydrologic testing. The objective was to determine the aquifer properties and chemical quality of water in the three water-bearing zones in the Rustler Formation. The field work, conducted in cooperation with Sandia National Laboratories, was almost completed.

Hanford Reservation Region, Washington

The DOE through its contractor, Rockwell Hanford Operations, is investigating the feasibility of and the technology for designing and constructing a repository for commercial high-level radioactive waste at the Hanford Reservation in basalt flows of the Columbia Plateau (fig. 4). In support of this effort, the USGS has been requested by the DOE to make reconnaissance geologic maps of the Columbia River Basalt Group and to conduct model studies of ground-water flow in basalt aquifers underlying the Plateau. Work by the USGS is being conducted in parallel with additional geologic and hydrologic studies by Rockwell within the Hanford Reservation and vicinity.

Geologic Mapping of the Columbia Plateau

By Donald A. Swanson, Vancouver, Wash.

Basalt flows of the Columbia River Basalt Group of Miocene age underlie most of the Columbia Plateau (fig. 4). Recent advances in knowledge of the basalt permit it to be subdivided into many mappable units (Swanson and others, 1979c). This has made possible the mapping of these units and evaluation of the amount and style of basalt deformation on a regional scale. Such information heretofore has been unobtainable except for local areas; for the first time a geologic overview of the entire Columbia Plateau is being achieved.

Objective To prepare a geologic map of the Columbia River Basalt Group in Washington, Oregon, and Idaho at a scale of 1:250,000. The map will be used in the DOE's evaluation of regional tectonic and stratigraphic relations for the underground storage of radioactive waste.

Approach The geology of the region is mapped on quadrangle maps or aerial photographs by standard field methods. Individual lava flows or several similar flows are traced in the field. The stratigraphy of the lava flows was worked out using physical characteristics supplemented by a large number of chemical analyses which demonstrated clear distinctions between otherwise similar flows. Use is also made of the fluxgate magnetometer to identify normal or reversed magnetic polarity of the flows (which indicates whether the earth's magnetic field was normal or reversed when the lava flow solidified).

Progress Most of the Columbia River Basalt Group (fig. 4) has now been mapped. Work in FY 80 concentrated on north-central Oregon and western Idaho south of lat 46°, and complements mapping of eastern Washington

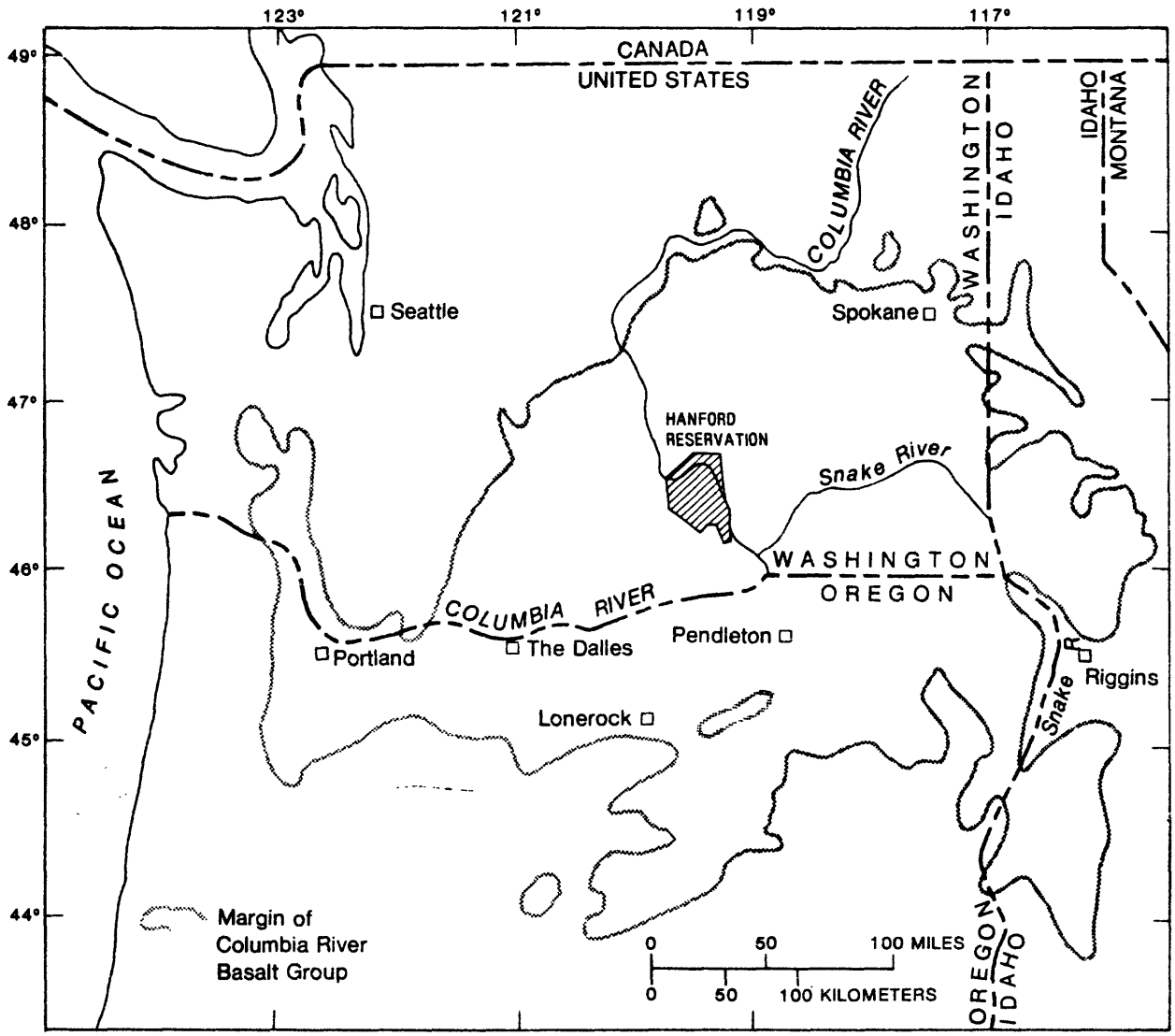

FIGURE 4.-Index map of Columbia Plateau.

and northern Idaho completed earlier. A team of six geologists has been involved in mapping in northern Oregon and western Idaho under the direction of Swanson: J.L. Anderson, V.E. Camp, P.R. Hooper, D.A. Swanson, W.H. Taubeneck, and T.L. Wright.

A pattern of northwest-trending dextral faults recognized from past work in Washington has been found to extend into the region around Pendleton and The Dalles, Oregon. Associated with these faults are sharp parallel anticlines. In places the faults are offset in a left-stepping fashion, the segments connected by small thrust faults. Conjugate northeast-trending sinistral faults occur less commonly than the dextral faults. Major thrust faults, with displacement of 1 or more kilometers, may occur in the Columbia Gorge west of The Dalles.

A prominent linear vent system for one or more flows of Grande Ronde Basalt was discovered near Lonerock, Oregon (fig. 4). This system, at about lat 45°08' N., long 119°55' W., is the westernmost vent system for Columbia River basalt yet known and again raises the possibility that other vents are hidden beneath the western part of the Columbia Plateau, including the Pasco Basin. Many flows of local derivation and limited extent have been found in northeast Oregon and southern Idaho. These flows complicate the local stratigraphy but do not alter the regional stratigraphic framework. West-northwest dextral faults and rarer northeast sinistral faults apparently cut the basalt near Riggins, Idaho, well north of the projected trend of the Olympic-Wallowa lineament (extends west-northwest south of the confluence of the Snake and Columbia Rivers), which is thought by some workers to form a boundary between a region of shear to the south and a region of little shear to the north.

Reports

Bentley, R.D., Anderson, J.L., Campbell, N.P., and Swanson, D.A., 1980, Reconnaissance geologic map of the Yakima Indian Reservation, emphasizing the Columbia River Basalt Group: U.S. Geological Survey Open File Report 80-200, 76 p.

Swanson, D.A., Anderson, J.L., Bentley, R.D., Byerly, G.R., Camp, V.E., and Wright, T.L., 1980, Newly completed geologic map of the Columbia River Basalt Group, eastern Washington and northern Idaho: Geological Society of America, Abstracts with Programs, v. 12, no. 3, p. 154-155.

Swanson, D.A., Wright, T.L., Camp, V.E., Gardner, J.N., Helz, R.T., Price, S.M., Reidel, S.P., Ross, M.E., 1980, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1139, scale 1:250,000.

Swanson, D.A. and Wright, T.L., 1981, Guide to geologic field trip between Lewiston, Idaho, and Kimberly, Oregon, emphasizing the Columbia River Basalt Group, p. 1-28 in Johnston, D.A. and Donnelly-Nolan, J. (eds.), Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U.S. Geological Survey Circular 838, 189 p.

Wright, T.L., Black, K.N., Swanson, D.A., and O'Hearn, Tim, 1980, Columbia River basalt: 1978-1979 Sample data and chemical analyses: U.S. Geological Survey Open File report 80-921, 109 p.

Ground-Water Model of Basalt Aquifer in Southeastern Washington

By David B. Sapik, Tacoma, Wash.

The Columbia River Basalt Group includes a complex system of aquifers of large areal extent. The principal aquifers have been stressed by pumping at several centers and models have been constructed for management purposes to simulate the effects of pumping. The complexity and large areal extent of the aquifers, however, have made it difficult to define the boundary conditions realistically.

Objective To determine if a three dimensional groundwater model could be constructed using available data to simulate flow in the confined basalt aquifers underlying the Columbia River Plateau in southeastern Washington.

Approach The work was subdivided into three tasks: (1) to select and verify a suitable computer program for the model, (2) to compile the available hydrogeologic and other necessary data; and (3) to construct a model of the ground-water flow system using these data and determine the sensitivity of the model's predictions to a reasonable range of hydraulic characteristics of the ground-water flow system and of initial boundary conditions.

Progress An attempt was made to calibrate the steady-state model using available data and the results of a sensitivity analysis of predicted water levels to variations in hydraulic parameters; also initial and boundary conditions were tested. Predicted water levels were found to vary greatly with relatively small changes in aquifer transmissivity and vertical conductivity of confining beds, and much less with changes in recharge. Owing to the inadequacy of the data, it was not possible to place reasonable limits on these parameters and it was decided that an acceptable calibration could not be achieved. Analysis of the available data on existing and historical pumpage distribution and pumping rates indicated that they were insufficient to calibrate a transient-flow model.

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 (fig. 5). In fiscal year 1980 the investigations were expanded to include study areas at Gibson Dome, Lisbon Valley and Elk Ridge (fig. 5). At Salt Valley, two drill holes (DOE-1 and DOE-2) had been drilled to depths of 393 and 374 m respectively; and DOE-3 (fig. 6) had been cored almost continuously to 1,242 m. In fiscal year 1980, a hole was drilled to a depth of 1946 m on the Gibson Dome.

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 The structural configuration of the complexly deformed evaporite sequence intersected by the three holes at Salt Valley (fig. 6) has been established. Both DOE-1 and DOE-2 penetrated the same halite bed which is overturned and nearly vertical. The distribution of trace bromine in halite from DOE-3 indicates this hole penetrated the same bed found in DOE-1 and -2 and that it is also overturned at this location. The determinations of water-insoluble material in the halite rock of DOE-3 show that it is very low; averaging about 1.5 weight percent. X-ray examination of these residues show that they generally consist of about 95 percent anhydrite with the remainder made up of quartz, dolomite, calcite, and trace amounts of illite. The H_2O content of the halite samples analyzed thus far has been much less than anticipated; the range in samples from DOE-3 is from 0.229 to 0.008 weight percent.

Samples from the Palo Duro basin, Texas, another area being investigated by the DOE, were submitted to the USGS laboratory for water analysis. These samples of halite have an H_2O content ranging from 3.027 to 0.247 weight percent. The samples with highest water contents also have the highest content of insoluble residues (up to 47 percent). An appreciable amount of this water is probably porewater in the clay matrix and is not inclusion water from halite. In general, however, samples with a relatively low content of insoluble residues still had much higher water contents than Paradox Basin halite.

The clay mineralogy of selected samples from Salt Valley has proved to be more complex than originally thought. However, all the clay has very low exchange capacity and no structural water.

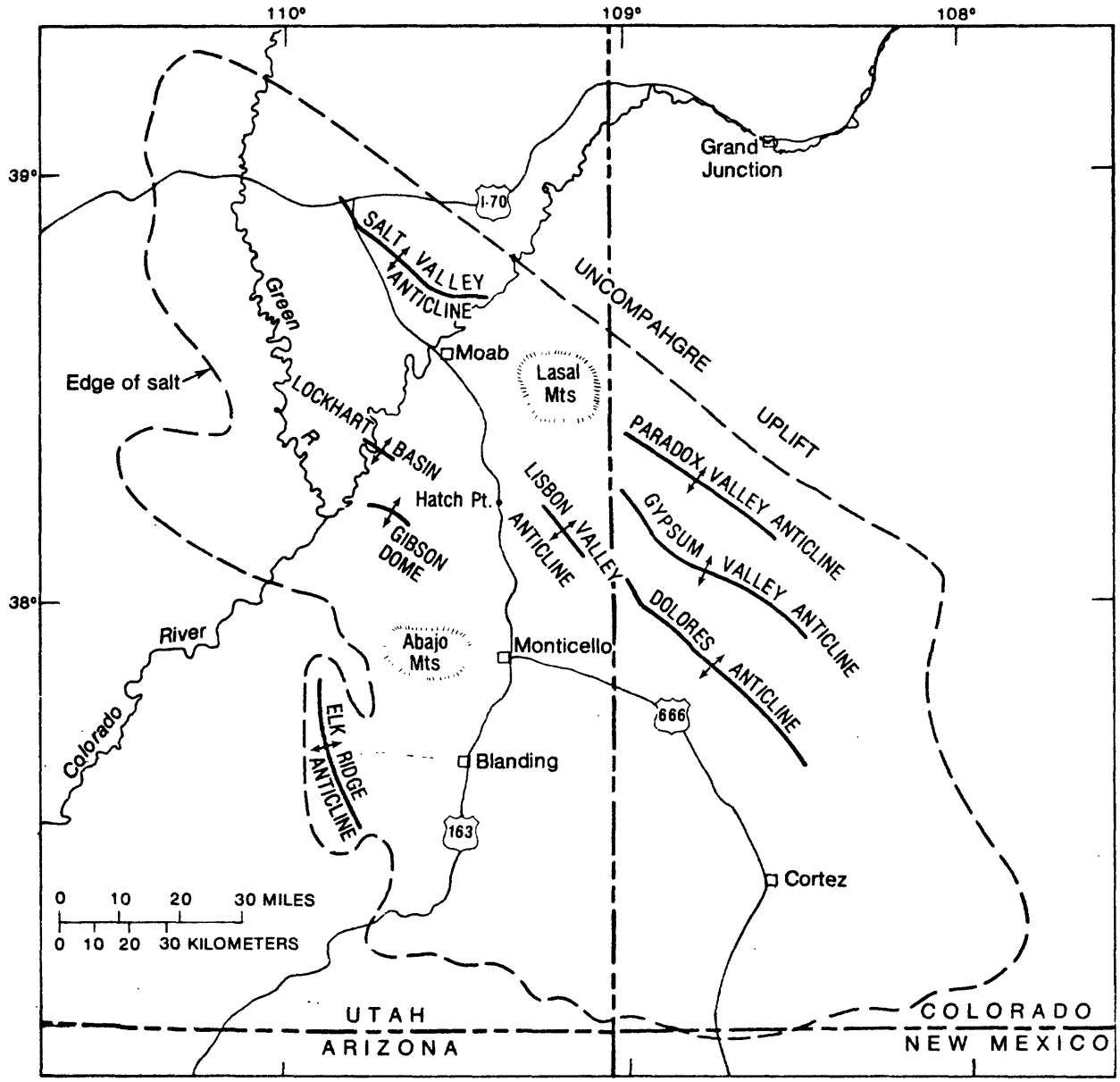

FIGURE 5.-Paradox Basin, Utah and Colorado.

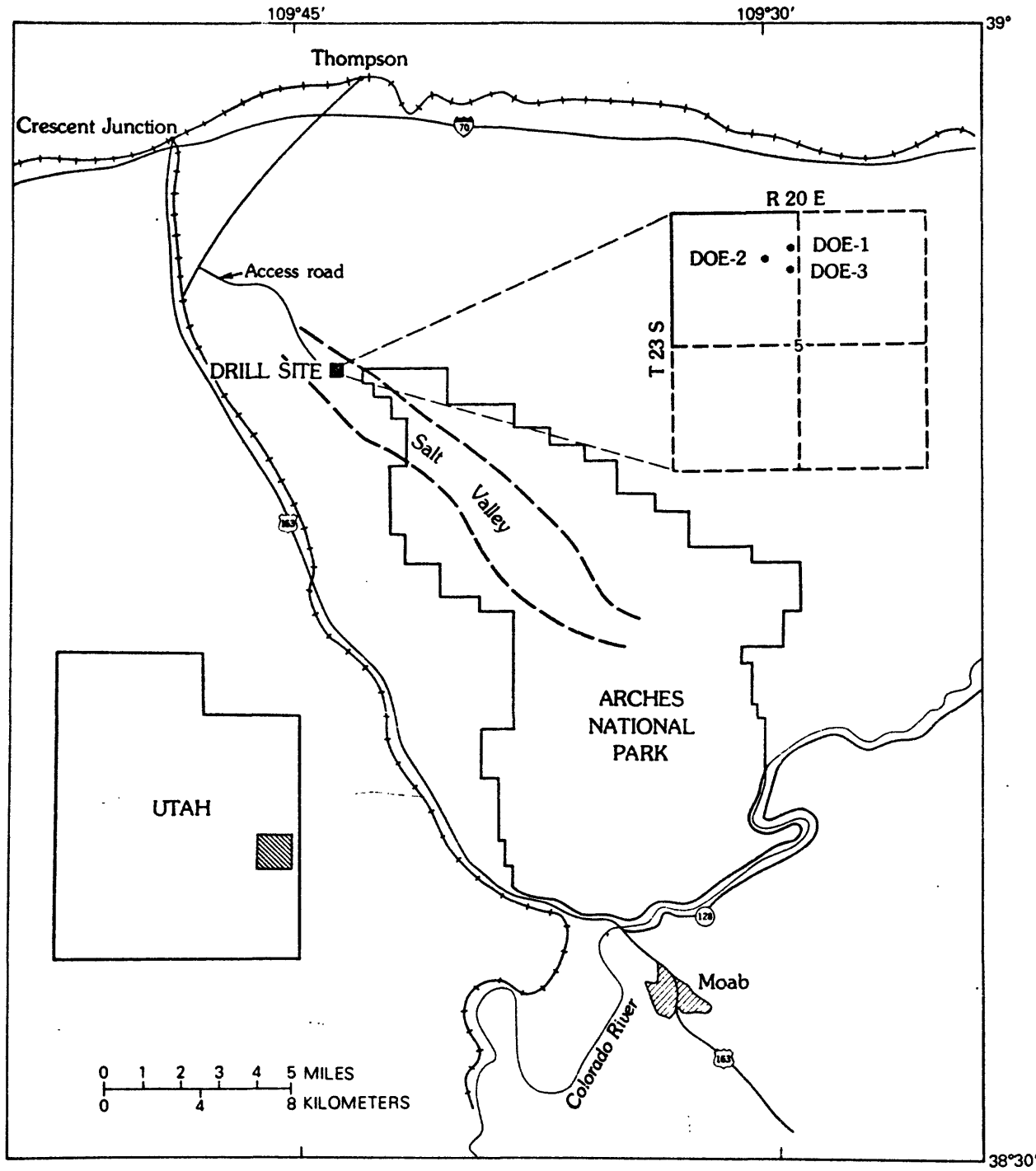

FIGURE 6.-Location of three-hole deep drilling project in Salt Valley, Utah.

A longitudinal section through Salt Valley anticline shows that the caprock overlying the salt is sealed off to the northwest by a thick cover of Mancos Shale. Additional barriers to ground-water flow from the caprock are the deep and structurally closed synclines flanking the structure.

Core from the Gibson Dome was received and placed in a USGS-DOE Core Facility in Lakewood, Colorado, where it will be analyzed.

Hydrology

By Merrick S. Whitfield, 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 (fig. 5). 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 at one prospective site, Salt Valley, to evaluate the geology and hydrology of the caprock and adjacent aquifer systems.

Progress Five reconnaissance reports and three site-specific reports have been written for subareas of the Paradox Basin. One of the site-specific reports (Rush and others, 1980) has been published and all the others are undergoing review.

The reconnaissance reports describe the regional ground-water flow for the two major aquifer systems in the basin. The upper system[1] overlies the salt and discharges to major streams within the study area. The lower system (Mississippian Leadville Limestone) does not crop out in the Paradox Basin, and both recharge to and discharge from this system occurs outside the study area.

Within the study area extensive, thick salt beds effectively separate the upper and lower ground-water systems hydrologically. However, the potential for some upward leakage between the two systems does exist locally where salt beds are thin or absent. Only two areas are known in the Paradox Basin where active dissolution of salt is taking place. Both these areas are in the northeastern parts of the basin where the salt is near land surface and dissected by streams. In most places the permeable beds within the two ground-water systems are separated from the salt beds by

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[1] 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).

confining beds of low permeability. As a result, most actively flowing ground water has no contact with the salt.

Water in the upper ground-water system is generally of good quality. Brackish or saline water generally occurs in the lower ground-water system.

Nine exploratory wells were drilled in Salt Valley, Utah, to obtain geologic and hydrologic data. The hydraulic conductivity of the caprock, as determined by pumping tests in six of the wells, ranged from 9×10^{-5} to 4.5×10^{-2} m/day, thus indicating very slow ground-water movement. Water levels in these test holes indicate a general flow direction toward the northwest. Chemical analyses of water from these wells indicate that the concentration of dissolved solids and the age of the water both increase toward the center of the valley, suggesting that recharge occurs along the faulted edges of Salt Valley. Carbon-14 specific activity for caprock water yielded an uncorrected age of about 17,000 years B.P. near the edge of the valley and 26,000 years B.P. near the center of the valley.

Report

Rush, F.E., Hart, I.M., Whitfield, M.S., Giles, T.F., and D'Epagnier, T.E., 1980, Results of Hydraulic Tests in Wells, DOE-1, 2, and 3, Salt Valley, Grand County, Utah: U.S. Geological Survey Open-File Report 80-205, 38 p.

Geophysics

By Raymond D. Watts, Jeffrey J. Daniels, and Alfred H. Balch, Lakewood, Colo.

Objective To utilize geophysical data to characterize and differentiate subsurface lithologies, structural configurations and inhomogeneities in areas of interest. To evaluate state-of-the-art down-hole seismic equipment for mapping interbeds in salt with vertical seismic profiles.

Approach Surface, airborne, and drill-hole electromagnetic and seismic refraction methods are employed to obtain information on the geologic structure and the presence or absence of significant amounts of ground water.

To test the applicability of computer processed vertical seismic profiling, which is essentially a new and untried technique, a seismic source is placed in one drill hole (source hole) and the waveform recorded at many depths in another (geophone hole). The data are then processed, analyzed, and interpreted to identify, resolve and profile-map lithologic units of the geologic section between the two holes.

Progress Slingram, a ground-based moderate penetration method, detected anomalies that appeared to be due to near-surface, perched water pods in the caprock at Salt Valley. The anomalies were drilled, and hydrologic measurements confirmed this interpretation.

Extremely Low Frequency (ELF) loop-loop soundings revealed no continuous conductor above or below the salt. The detection limit of the method is not precisely known, so there could be isolated areas of dissolution that are smaller than the detection limit.

DC resistivity soundings produced data that were disturbed by the inhomogeneity of the caprock unit (the insoluble residue left after dissolution of the salt from the top of the diapir). This method is probably of limited utility over breached diapiric anticlines due to the inhomogeneity of the caprock and the inability of DC currents to penetrate below the resistive salt. In any case, there was no evidence of a conductor that would indicate present-day dissolution at the top of the salt.

A helicopter-borne electromagnetic survey detected linear anomalies within Salt Valley that are probably controlled by caprock lithology, but may be generated directly by either lithologic or hydrologic variations. On the flanks of the anticline, anomalies were detected that appear to be expressions of splay faults or zones of extensive jointing. Further interpretations of these data are being made.

A vertical seismic profile experiment was conducted at the Salt Valley test site in January 1979. Due to numerous problems, only one complete, fair-quality profile was obtained. Based on the results of the first shoot, a second shoot was conducted with improved equipment in November and December 1979. The field data were plotted and each of the several thousand records was checked for quality and accuracy. Approximately 10 percent of the traces were discarded to improve overall data quality. Shots recorded under identical source-receiver conditions were summed, and composited, to improve signal-to-noise ratio. The results were subjected to a variety of filtering operations, to improve signal-to-noise ratio, with a minimal loss in resolution. The most important feature observed was a multiplicity of upward-traveling events, or reflections. These coherent events in several cases correspond to places in the hole where marker beds are known to intersect the hole. The consistency of the appearance of these events and their coherence give us a good deal of confidence that these events are true reflections. Two sets of reflections were selected for detailed interpretation. They are associated with two marker beds that intersect DOE-3 at the 431-449-m interval and the 496-539-m interval. A multiplicity of reflected modes are observed to originate at these levels. The apparent velocity of these reflected events has been analyzed. Data from shooting DOE-1 to DOE-3 and DOE-2 to DOE-3 have been used. The true dip of these two horizons has been calculated. The agreement between these dip values and those obtained from the cores is excellent. Further we have determined that the strike of the marker beds is about S 63° W. This information was not obtained on the core, since it was not oriented.

Gibson Dome--VLF (Very Low Frequency, 15-20 KHz) magnetic field tilt and ellipticity measurements appear to reliably locate faults. The method has been used to map continuations of the geologically-mapped faults of the Lockhart Basin onto part of Hatch Point which is covered by eolian deposits. It has also been used to detect parallel faults in the center of Shay Graben a 15-km-long system north of the Abajo Mountains and faults to the north of the Graben that have been newly mapped by Woodward-Clyde Consultants.

VLF has been used to investigate circular features on top of Hatch Point. The features have almost no VLF signature, so they are interpreted as being depositional or erosional rather than structural in nature.

Dipole-dipole resistivity surveys were done under contract in the vicinity of the Gibson Dome drill hole. They revealed remarkable uniformity of rock conductivity except for an anomalous conductor at the plunging east end of the Gibson Dome structure. This area is intensely jointed, so the high conductivity may be due to the presence of ground water; it is also possible that the anomaly is due to a fault at this site.

Magnetometric resistivity (MMR) measurements appear to be equally effective as VLF in mapping faults on Hatch Point and in Lockhart Basin. The penetration of the method is greater than that of VLF. Quantitative interpretation of these data is being made to see whether it is possible to estimate the depth of electrically anomalous conditions associated with the faults.

Hole-to-surface resistivity measurements were made from the Gibson Dome drill hole. Surface measurements were made along radial lines at 20° intervals around the drill hole out to a distance of 2000 m. Measurements were made with the source at depths of 518 m and 760 m. Approximately 1000 measurements were made (in less than 2 days) with the help of Woodward Clyde personnel. Preliminary interpretation of these data indicates a very uniform distribution of the electric field away from the drill hole. This implies uniform layering of the geologic strata above 760 m.

Reports

Daniels, Jeffrey J., 1980, Hole-to-surface resistivity measurements at Salt Valley, Utah: U.S. Geological Survey Open-File Report 80-981, 36 p.

Daniels, Jeffrey J., Hite, Robert J., and Scott, James H., 1981, Geophysical well-log measurements in three drill holes at Salt Valley, Utah: U.S. Geological Survey Open-File Report 81-36, 67 p.

Remote Sensing

By Jules D. Friedman, Lakewood, Colo.

Objective To acquire, process and interpret geologically a variety of satellite and aircraft image products of the Paradox Basin region in order to detect and delineate previously unmapped structures which might significantly affect the suitability of a waste repository site.

Approach Small-scale multispectral images recorded from satellites and large-scale multispectral data obtained from airborne instruments are used to identify regional and sub-continental scale fault and fracture zones, intrusive and extrusive magmatic centers, collapse structures, buried stream channels, and recent erosional and depositional features that would not be readily detectable through field studies and interpretation of aerial photographs. Features so identified are compiled and digitized. Maps and overlays are prepared at various scales showing the areal distributions of linear features as a function of trend and (or) length; contour maps are made of the areal density of linear features and their intersections, and diagrams prepared of the azimuthal and length-weighted azimuthal distributions. The origin and significance of the features identified are interpreted.

Progress Preliminary uncontrolled slant-range X-band radar image mosaic of the northern Paradox Basin and accompanying report was prepared. Field investigations of lineaments and landforms were continued. A draft of a report, intended for open-file release, entitled, Uncontrolled X-band radar-image mosaic of the western part of the 2° Moab Quadrangle, Utah, was completed. This mosaic is useful for making geomorphic interpretations and identifying fracture traces, although azimuthal bearings of the fracture traces mapped from the uncontrolled mosaic are only approximate. The mosaic shows many previously unreported fracture traces and adds to our understanding of the fracture pattern of the region.

Joan Heller and Diane DeLillio carried out a field investigation and mapping in the Moab 2° Quadrangle to relate the content of the X-band radar mosaic and Landsat images to the geology, topography, and landforms of the region. Emphasis was placed on the contrast between halokinetic and other landforms.

Computer plots were completed of hierarchical lineament categories and total lineament concentrations for a set of maps showing tectonic lines and lineaments of the Moab 2° Quadrangle at a scale of 1:250,000, registered to a topographic base.

An analysis was made of Ektachrome Aerographic aerial photographs and field investigations were made to evaluate geomorphic evidence for Holocene movement within salt diapirs.

A color composite Landsat scene of the Paradox basin was synthesized from spectral band ratios 4/5, 4/6, and 6/7, and a geological interpretation undertaken.

Report

Friedman, J.D., and Simpson, S.L., 1980, Lineaments and geologic structure of the northern Paradox basin, Colorado and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1221; two sheets, 1:250,000 and 1:500,000.

Gulf Coast Salt Dome Region

North Louisiana

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 (fig. 7). 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.

Objectives 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.

Approach A regional, three-dimensional digital model that will simulate flow in the multilayered ground-water system to depths of 900 m or more is to be constructed (fig. 7). The deepest water-bearing unit to be modeled is the Nacatoch Sand of the Upper Cretaceous Series. 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 Formations 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 The Geological Survey analyzed geohydrologic data from 16 test wells completed at 5 sites in the northern Louisiana salt-dome basin (fig. 7). The drilling program was planned and managed by Law Engineering Testing Co. (LETCO) for the Office of Nuclear Waste Isolation (ONWI) of Battelle Memorial Institute, Columbus, Ohio. The intent of the program is to characterize a study area of 2,600 km^2 around two salt domes (Rayburns and Vacherie) which are currently being considered as potential repository sites in northern Louisiana. Wells were screened in the Sparta Sand, Carrizo Sand, Wilcox Group (undivided), Nacatoch Sand, and in the equivalent of the Austin Group (Upper Cretaceous Series).

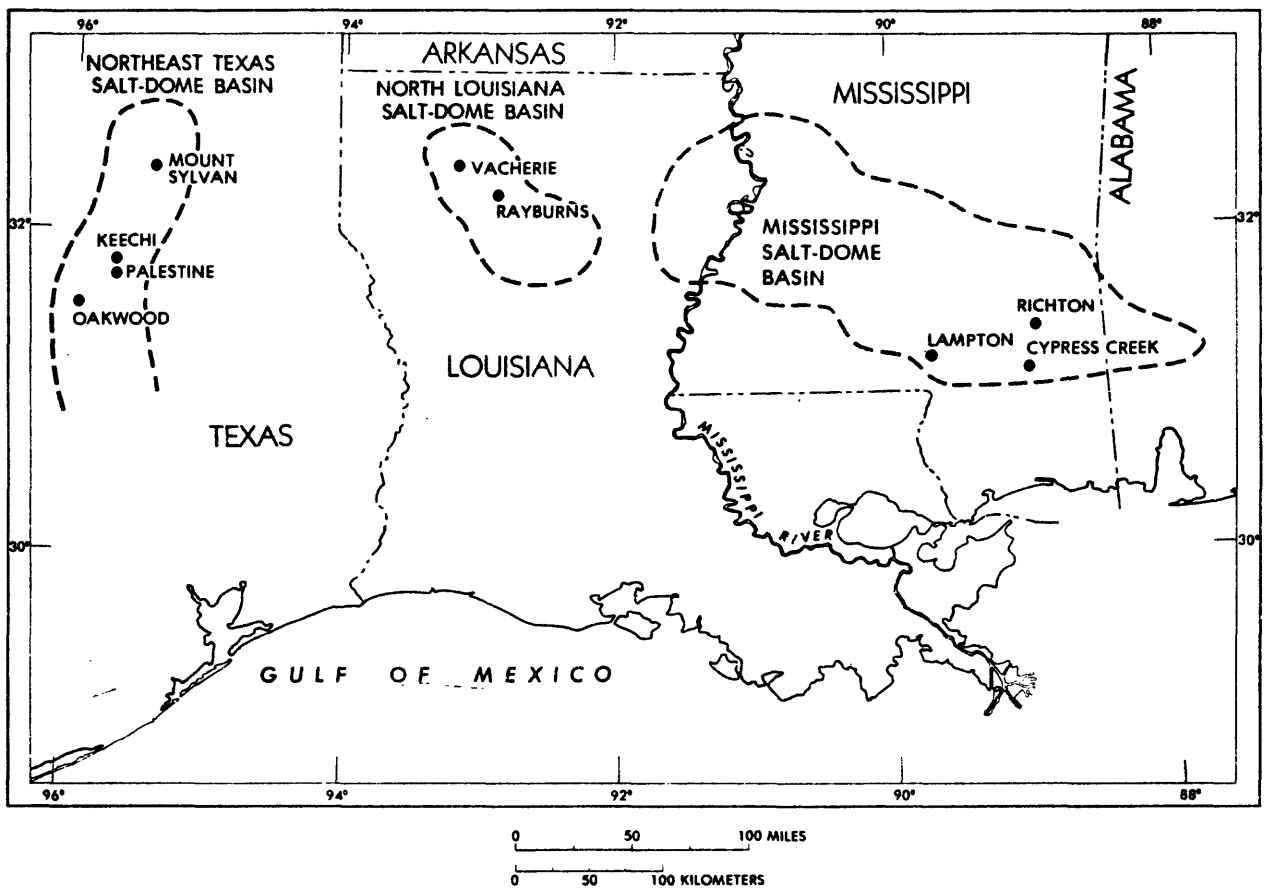

FIGURE 7.-Gulf Coast area showing locations of salt domes being studied.

The Geological Survey served as a technical advisor during the drilling program with regard to the selection of sidewall cores and screened intevals, analysis of aquifer-test data, and the collection of water samples for analysis by the Geological Survey Central Laboratory, Denver, Colo.

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

Three geohydrologic maps and a data report were completed and released to the open file (See "References"). Water levels in observation wells in the vicinity of Vacherie and Rayburns domes and the flow and water quality of certain key streams in the area of the domes were monitored.

Reports

Ryals, G. N. 1980, Potentiometric surface of the Wilcox-Carrizo aquifer; Bienville, Red River, northern Natchitoches, and southern Webster Parishes, Louisiana: U.S. Geological Survey Open-File Report 80-117 (map).

___1980, Potentiometric maps of the Sparta Sand, northern Louisiana and southern Arkansas, 1900, 1965, 1975, and 1980: U.S. Geological Survey Open-File Report 80-1180 (4 maps).

___1980, Base of fresh ground water, northern Louisiana salt-dome basin and vicinity, northern Louisiana and southern Arkansas: U.S. Geological Survey Open-File Report 80-2038, 5 p.

Ryals, G. N., and Hosman, R.L., 1980, Selected hydrologic data for the vicinity of Rayburns and Vacherie salt domes, northern Louisiana salt-dome basin: U.S. Geological Survey Open-File Report 80-217, 17 p.

References

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 78-104, 27 p.

Mississippi

By P. A. Dooley, 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 hydrology 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 the southeastern part of the basin were selected by the DOE as being

acceptable by various minimum criteria for further consideration in identifying a potential waste repository site. Cypress Creek, Lampton, and Richton domes (fig. 7) 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 and local ground-water hydrology of the basin.

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

Approach Following the preparation of a preliminary summary of the geohydrology of the salt-dome basin (Spiers and Gandl, 1980), a drilling, testing, and sampling program was conducted in order to more accurately describe the geologic and hydrologic conditions of a region including 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 During the drilling program the following Tertiary formations were hydrologically tested and sampled: the Wilcox Group, the Sparta Sand, the Cook Mountain formation, and the Miocene Series. The caprock units above the salt stocks at Cypress Creek and Richton domes were also tested. Order-of-magnitude estimates of permeability were made for each of these aquifers. Potentiometric maps were constructed and an analysis was made of the vertical distribution of head in the major aquifer systems. The highest potentiometric heads are in the Wilcox Group and successively lower heads occur in the overlying aquifers. Horizontal hydraulic gradients were determined and a conceptualized model of ground-water flow near Cypress Creek and Richton domes was developed. Water quality data were used to more accurately define the base of freshwater in the study area and then to identify near-dome saline anomalies and areas of brine pooling. Local empirical relations were established between formation water resistivity and concentrations of dissolved solids. Such relations can be used in conjunction with geophysical logs to estimate specific features of the quality of water in the tertiary formations investigated.

Reference

Spiers, C. A., and Gandl, L. A., 1980, A preliminary report of the geohydrology of the Mississippi salt-dome basin: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-595, 45 p.

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 wastes, how they may be explored and characterized, and how various geologic and hydrologic processes may affect the integrity of a repository. Some of the work is being done at localities described in the preceding section because they provide convenient and suitable

locations and needed supporting studies and data, but the results obtained should be applicable to other localities.

As additional areas are identified where waste disposal sites might be located, some of this research will become more site specific since 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.

With two exceptions, the projects described below were supported by the Geological Survey's direct appropriation; the work described in the section entitled, "Salt-brine-waste-canister interactions", was funded by the DOE and that under "Computer simulation of geologic stability of a repository" was funded by the NRC.

Studies of Rock Types and Environments for Emplacing Wastes

Western Cretaceous Shales

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

Previous studies of the Dakota regional aquifer system (Dakota Sandstone and equivalent rocks) suggest that the overlying Cretaceous shales, which act as a confining layer for the aquifer, are low in permeability. These investigations indicate that the shales could isolate wastes for long periods of time.

A number of questions remain to be answered before a repository could be considered seriously. Principal among these questions are:

1. Does the low permeability suggested by the hydrologic model analysis indicate flow through the rock matrix; flow through small, closed joints and fractures; or flow through widely-spaced, large fractures?

2. What are the problems, particularly rock mechanics problems, associated with putting hot wastes in highly montmorillonitic shales? High temperature wastes would cause a phase change in minerals with an associated release of water. Would the physical properties of the shale change during this process?

Objective The general objective is to evaluate the geohydrologic conditions and physical properties of the thick Cretaceous shales of the western United States in relation to their potential use as a host rock in high-level radioactive-waste repositories. Concerning the physical properties, a specific objective is to evaluate, in situ, the state of stress and mechanical properties of the Pierre Shale.

Approach The approach will involve completing a hydrologic model analysis of a large region as a prototype for studying the Cretaceous shales. Concurrently, core drilling and in situ testing will be done to obtain

laboratory and field data on the permeability of the Pierre Shale. In addition, field measurements will be made to determine in situ stress and other physical and engineering properties of the rock. Constant-strain rate and creep tests will be conducted on the cores under pressure and temperature conditions to be expected in repositories. Four shallow test holes will be strategically located to sample the entire stratigraphic sequence of Cretaceous shales above the Dakota aquifer.

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.

The sorption properties of the shales will be determined in the laboratory. The results will be incorporated into a transport model to obtain insight into nuclide transport processes in these shales. Initial transport predictions will be made at ambient ground-water temperatures without the influence of heat.

Progress Laboratory tests to determine the hydraulic properties of the Pierre Shale were conducted with equipment developed and built by Terra Tek of Salt Lake City. A general analytical solution for the transient flows in the test and a resulting methodology for test analysis were developed (Hsieh and others, 1981; Neuzil and others, 1981) and applied to the test data. This analysis gave good results which were consistent with the consolidation tests, strengthening our confidence in the consolidation analyses.

The tests yielded values for matrix conductivity ranging from approximately 10^{-12} m/s at 1 MPa effective stress to approximately 5×10^{-14} m/s at 25 MPa effective stress.

Modeling of the flow system in the Cretaceous shales above the Dakota aquifer indicates that the regional average permeabilities of the shales decrease with depth, ranging from approximately 10^{-9} m/s (Pierre Shale) to 10^{-11}m/s (Mowry and Belle Fourche Shales). These results further enforce the hypothesis that flow through the shale is primarily through fractures.

One consolidation test on the Pierre Shale has been analyzed using a modified consolidation theory (Gibson and Lo, 1961). This analysis indicates that in one dimension the shale is decidedly viscoelastic and can be described using a simple linear viscoelastic model.

The U.S. Water and Power Resources Service generously donated approximately 3 m of a 17-cm-diameter core, obtained within what is thought to be the Mobridge Member of the Pierre Shale. The cores were taken between depths of 35 and 65 m. A portion of these samples has been prepared for laboratory testing, some of which is completed. Clay mineralogy, Atterberg limits, natural moisture content, density, and organic content have been determined

for the samples tested to date. The results show the samples to contain over 65 percent clay-size particles, with montmorillonite being the dominant clay mineral. The organic content ranged between 2 and 4 percent. The University of Colorado, under contract to construct consolidation cells to test the deformation properties of the Pierre Shale, experienced difficulties in constructing a non-flow pore pressure measurement device and in-cell deformation gages. These problems are being overcome and the consolidation cells are completely assembled.

Preparation of a laboratory van for use in the field was completed. The van is equipped for electronic and mechanical core deformation monitoring, refrigerated core storage, precision testing of physical properties, and precision sample preparation.

Applying a continuum mechanics approach and using data of rocks loaded under various temperatures and pressures at various strain levels, Savage and Swolfs (1980) produced theoretical master curves depicting relaxation moduli and creep compliance versus time for various rock types. The significance of these curves for shales lies in the fact that measurements made at short times can be extrapolated to predict behavior at very long and geologically significant times.

Reports

Hsieh, P.A., Tracy, J.V., Neuzil, C.E., Bredehoeft, J.D, and Silliman, S.E., 1981, A transient method for determining the hydraulic properties of 'tight' rocks, Part I - Theory: International Journal of Rock Mechanics and Mining Science, v. 18, no. 3, p. 245-252.

Neuzil, C.E., Cooley, C., Silliman, S.E., Bredehoeft, J.D., and Hsieh, P.A. 1981, A transient method for determining the hydraulic properties of 'tight' rocks, Part II - Application: International Journal of Rock Mechanics and Mining Science, v. 18, no. 3, p. 253-258.

Savage, W.Z. and Swolfs, H.S., 1980, In situ geomechanics of crystalline and sedimentary rocks, pt. 1 of The long-term deformation and time-temperature correspondence of viscoelastic rock--An alternative theoretical approach: U.S. Geological Survey Open-File Report 80-708, 21 p.

Reference

Gibson, R.E, and Lo, K.Y., 1961, A theory of consolidation in soils exhibiting secondary compression, Norwegian Geotechnical Institute, Publication No. 41, Oslo, 16 p.

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 at appropriate depths in the unsaturated zone, profiles of selected water properties, it should be possible to find indications of whether an approximate steady state exists, and to measure the extant water fluxes.

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

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 will be extracted estimates of long-term flux trends. These estimates will be compared with analyses based on isotopic data and with simulation based predictions.

Progress In order to evaluate long-term average downward water fluxes and obtain representative values for areally extensive unsaturated zones, it was necessary to develop a rapid method for determining hydraulic conductivities of unsaturated cores of sediments. A method was designed whose capabilities and limitations are being tested. The first tests of the feasibility of the method involved theoretical studies. The appropriate differential equation of flow was solved numerically for three different soils using experimentally determined unsaturated hydraulic conductivities. The mathematical solutions obtained demonstrated the theoretical feasibility of the proposed method and suggested certain experimental conditions which would improve the technique's performance. In addition, these solutions are being used to test the theoretical sensitivity of the method to possible experimental errors.

It is planned to utilize the technique eventually in a mobile, field laboratory, so that sediment cores can be tested immediately after removal. In order to do this, the test conditions for a given core will have to be estimated. To aid in arriving at these estimates it will be necessary to make rapid measurements of core-water suction, to appraise very approximately certain sediment properties, and to prepare suitable type-curves which describe possible test results. It was found that suitable type-curves can be computed.

The method required that it be possible to establish rapidly a steady flow of water through the sediment cores. Appropriate instrumentation was designed and constructed, and in a series of laboratory experiments, it was demonstrated that it was possible to achieve steady-state flow

sufficiently rapidly to obtain the desired results. The experiments revealed the need for modifications and improvements of the prototype apparatus. This has been done and the instrument is ready for further testing.

Granite and Related Crystalline Rocks

By Zell E. Peterman, Lakewood, Colo. and
James D. Byerlee, Menlo Park, Calif.

Crystalline igneous rocks such as granite and some metamorphic rocks such as gneiss are abundant in the Earth's crust and have great strength, structural and chemical stability, heat tolerance, and low porosity. Their water content generally is low and is contained in fractures and in hydrous silicate minerals. Fractures are commonly filled with clays, hydrous oxides, and other minerals with good sorptive properties. In view of these properties, several countries including the United States, Canada, Sweden, and the United Kingdom are evaluating these types of crystalline rocks and their terranes for their suitability, respectively, as host media for emplacing wastes and as areas to locate potential repository sites.

A major problem presented by these crystalline rocks is that of characterizing their hydrologic properties. Near the surface of the earth, granites and other crystalline rocks have been fractured through cooling and stresses in the crust. Intercrystalline permeability is generally low, but water flows through interconnecting fractures. At shallow levels, fracture permeability decreases markedly with depth, but the distribution and hydrologic properties of fractures at anticipated repository depths are poorly known. Isotopic studies of the timing of geologic events and the occurrence and transport of fluids may provide criteria for making an initial selection of study areas where suitable repository sites might be located.

Objectives To apply isotope geochemical techniques to the evaluation of properties of crystalline rocks with respect to their suitability for long-term containment of radioactive wastes. To determine the timing of geologic events on regional and local scales for assessing long- and short-term geologic stability. To determine the effects of repeated tectonism on the integrity of crystalline rocks. To determine the source and residence time of fluids and gaseous species in crystalline rocks with the ultimate aim of evaluating the past migration of fluids and gaseous species, and their communication with the biosphere.

Approach Undertake laboratory investigations, including the study of naturally occurring isotopic systems to identify the effects on permeability of rock-water interaction, geochronologic studies to determine the nature and timing of geologic events that may have affected the permeability of rocks in particular terranes, and permeability measurements at temperatures and pressures anticipated at repository depths.

Progress Sherman Granite, southeast Wyoming--An isotopic and petrologic study of the Sherman Granite has been completed. Samples from two 65-m drill holes have been the subject of studies to evaluate the extent and nature of rock-water interaction as recorded by various isotopic systems. Three unfractured, 30-cm intervals were selected from each hole at different depths. A 3-cm interval was also selected because it contains a 1.25 cm-wide shear zone containing microbreccia and parallel fractures away from the shear. U-series analyses of the unfractured samples show equilibrium, or in the shallowest samples, near-equilibrium values. Such equilibrium values from relatively near-surface samples of granitoids are the exception rather than the rule.

To determine whether or not the granite contained uranium in sites from which it could be readily removed by ground water, laboratory leaching studies were conducted on coarsely crushed material. Generally, 1 to 5 percent of the total U was removed by these short-term experiments. In contrast with the whole-rock determinations, the U isotopic compositions of the leachate is strongly out of equilibrium ($^{234}U/^{238}U$ activity ratios of 1.39 to 2.22 in contrast with equilibrium values of 1.00). Fission-track mapping identified a major association of U with biotite especially where it is rimmed and veined with hematite. U also occurs in iron-stained fractures and in various accessory minerals such as allanite, zircon, and sphene.

Rb-Sr analyses have been completed on two unfractured samples from each hole and on the fractured material. Four data points for unfractured samples define an isochron age of 1.43 b.y. with an intercept value of 0.7029. The age is in good agreement with previous determinations on the Sherman Granite. The fractured samples show a loss of about 13 percent of their Rb which is readily correlated with more intense chloritization of biotite. Plagioclase is much more severely altered to sericite and clay minerals, and hornblende is altered to talc(?) and hematite.

The results of the study completed thus far suggest that rock-water interaction was limited to the fracture zones. The nature of the isotope systems and mineralogical integrity in the unfractured intervals indicate that interaction with water in these zones has been minor if not insignificant.

Vermilion Granite Complex, northern Minnesota--U-Pb analyses of microcline and whole-rock samples from cores from two 60-m drill holes in the main phase of the Vermilion Granite Complex have been completed. The granite is a major unit of a late Archean greenstone-granite terrane that developed in a relatively short time span about 2.65 ± 0.05 b.y. ago. Late Archean stabilization is reflected in K-Ar and Rb-Sr biotite ages of 2.5 ± 0.1 b.y., and the region last cooled below 100°C in the early Paleozoic as indicated by fission-track ages of apatite (C.W. Naeser, USGS, personal commun., 1980).

The average fracture spacing in one core hole (CR-17) is 5 m with intervals up to 15 m in which no natural fractures occur. The average spacing in the other core (CR-19) is 1.7 m with one unfractured interval of 15 m. CR-19 is more severely altered than CR-17 and shows protoclastic textures.

Samples at 58 m (CR-17) and 54 m (CR-19) were selected for analyses. On a $^{206}Pb/^{204}Pb$--$^{207}Pb/^{204}Pb$ diagram the two whole-rock samples and their constituent microclines are colinear with a slope corresponding to an age of 2.69 b.y. Previous radiometric ages on the unit include a Rb-Sr whole-rock isochron of 2.64 b.y. and U-Pb zircon and sphene ages of 2.68 b.y. All of these are in agreement within experimental error. On a discordia plot, the whole-rock samples define a chord with intercepts at 2.69 and 0.22 b.y. The data for CR-19 lie above concordia indicating loss of U relative to Pb and the CR-17 data lie below the chord. Mobility of U in recent geologic time is indicated.

These data add to an increasing data base for U-Pb systems in Precambrian granitoids. Commonly, ages derived from Pb-Pb relations are in good agreement with those determined by independent methods. In contrast, U-Pb ages are commonly discordant and reflect mobility of U relative to Pb late in the history of these rocks. A plausible scenario, especially in stable terranes of relatively simple geologic histories, is that the isotopic systems remained closed during a major part of the crustal residence time of these rocks. As the units were uplifted to shallower levels, fracturing induced by unloading and relaxation of horizontal stresses allowed ingress of water that resulted in mobility of U. Data for the two samples of the Vermilion Granite Complex indicate that this process has occurred at depths of at least 56 m below the surface. An important goal of such studies is to provide information on the maximum depth of uranium mobility, hence rock-water interaction, in different tectonic environments. Obviously, deeper holes are required although some deductions can be made by combining the U-Pb data with age data and establishing time-temperature (hence depth) histories of these granitoids. High precision isotopic data are required to make meaningful comparisons with independent age data and to evaluate the times of latest disturbance. Further work is not planned immediately on samples of the Vermilion Granite Complex.

Precambrian basement rock, northeastern Wyoming and southern Montana--A report has been completed on a study of Precambrian basement rock cores obtained from test wells through the Madison Limestone. Rb-Sr and U-Pb data identify the basement in this region as being related to the Archean terrane of the Wyoming age province. Isotopic systems in minerals have been disturbed indicating a Proterozoic thermal event. In spite of this disturbance, the Rb-Sr systems in whole-rock samples are reasonably coherent and define Archean ages of the terranes penetrated in the drilling. Petrographic studies have identified the effects of rock-water interactions immediately below the unconformity at the base of the Cambrian and along fractures in deeper parts of the cores. Fractures are filled with secondary, low temperature minerals including gypsum, anhydrite, chlorite, and carbonate. Alteration of plagioclase is most pronounced within narrow zones adjacent to these fractures. Rb-Sr data from a highly altered gneiss from Madison #1 (northeast Crook Co. Wyo.), near the unconformity shows the effects of severe alteration in this zone. U-series analyses of two samples show disequilibrium values in the altered gneiss but equilibrium values in the fresh granite obtained from Madison #2 (southeast Custer Co., Mont.).

Laboratory study of fluid movement in granite--The changing permeability of a typical granite, the Westerly granite of southern New England, in a temperature gradient with confining and pore pressure, was measured in the laboratory over time. Permeability decreased in all cases, at a rate which increased at higher temperatures. Near 300°C, permeability dropped sharply within a few days to around 5 percent of the initial value regardless of the stress applied to the rock mass. The dissolution and redeposition of quartz and feldspar minerals within cracks and channelways was found to be the major cause of permeability reduction. The results suggest that if similar processes of solution and redeposition occur around a waste canister, the migration of radionuclides may be suppressed.

Reports

Morrow, C., Lockner, D., Moore, D., and Byerlee, J., 1981, Permeability of granite in a temperature gradient, Journal of Geophysical Research, v. 86, no. B4, p. 3002-3008.

Morrow, C., Lockner, D.A., Moore, D.E., and Byerlee, J.D., 1980, Fluid flow through granite in a temperature gradient: I. Permeability (Abs.), EOS, v. 61, no. 46, November 11, 1980, p. 1112.

Moore, D.E., Morrow, C., and Byerlee, J.D., 1980, Fluid flow through granite in a temperature gradient: II. Fluid chemistry (Abs.), EOS, v. 61, no. 46, November 11, 1980, p. 1112.

Peterman, Zell E., 1979, Geochronology of the Archean of the United States: Economic Geology, v. 74, p. 1544-1562.

Peterman, Zell E., 1981, Dating of Archean basement in northeastern Wyoming and southern Montana: Geological Society of America Bulletin, Part I, v. 92, p. 139-146.

Smedes, H.W., 1980, Rationale for geologic isolation of high-level radioactive waste, and assessment of the suitability of crystalline rocks: U.S. Geological Survey Open-File Report 80-1065, 57 p.

Anhydrite

By Walter E. Dean, Lakewood, Colo.

Anhydrite has been suggested as a possible host medium for emplacement of radioactive wastes. It occurs in thick, relatively homogeneous beds of low permeability in several areas west of the Mississippi River. The thermal conductivity of anhydrite is as high as that of rock salt, both rock types having values near the high end of the range observed in rocks. The thermal expansion of anhydrite is similar to that of most common rock types and is only 1/3 that of rock salt. It contains very little intercrystalline water and, although more soluble than most rocks, is much less soluble than rock salt.

Objective To inventory the geologic and hydrologic properties, and specific physical and chemical characteristics of anhydrite in the United States, and to identify apparently favorable areas for more intensive investigation to determine the possibility of locating potential repository sites.

Approach Based on a survey of available data, all major evaporite deposits within the conterminous United States were evaluated in terms of the stratigraphic relationships of anhydrite units to the entire deposit, the thickness of the entire deposit, and the relative abundance of anhydrite.

Progress A report on the occurrence and properties of anhydrite was prepared for publication: Dean, W.E., and Johnson, K.S. (eds.), Anhydrite deposits of the United States and characteristics of anhydrite important for storage of radioactive wastes.

Salt-Brine-Waste-Canister Interactions

By I.M. Chou, Reston, Va.

Brines in rock salt tend to be mobilized by an increase in temperature, by fracturing due to thermal expansion, by the migration of fluid inclusions, and by dehydration of hydrous minerals. The presence of brines can be expected to increase the possibility of corrosion of canisters and leaching of waste, decrease the rock strength, and decrease sorptive properties of the host rock. One or more of these factors could affect the retrievability of wastes, and at the worst might threaten the integrity of waste containment.

A thermal pulse peaking many tens of years after waste emplacement and lasting hundreds of years is currently being anticipated in the design of repositories. The maximum temperature to be attained over tens of meters of salt in which wastes have been buried will probably be kept below 100°C by the choice of canister spacing or thermal output. However, surface temperatures of the canisters may be as high as 300°C.

The focus of this project is to characterize the physico-chemical properties of the fluids and solids in the system Na, K, Ca, Mg/Cl, SO_4, Br, and reaction products formed by interaction of these components with those of the integrated waste-disposal system. These data will help in the design of the waste-disposal system, water getters, and radionuclide adsorbers.

Objective To determine the likely interactions among salt, brine, canisters, and waste at a range of temperatures and pressures that may be anticipated in disposal of high-level radioactive waste or spent fuel. To determine the properties of the resultant reaction products at temperatures up to 300°C.

Approach The system Na, K, Ca, Mg/Cl, SO_4 is being investigated at temperatures up to 300°C. These are the major components in natural salt-brine systems including the brine fluid inclusions in bedded salt which tend to migrate to a heat source. A multi-component system simulates to some extent the effects of adding waste components to the brines. The resulting brines will be characterized as to (1) solubility and phase equilibria, (2) vapor pressure, boiling points and freezing points, (3) volumetric

properties of the brines, and (4) hydrolysis reactions in bitterns.

Interactions among brines, salt, canister materials, and "waste" are also being investigated up to 300°C. Canister reactions to be studied include (1) Ti + NaCl + $CaSO_4$ + bittern brines, (2) Cu + $CaSO_4$ + bittern brines, (3) Zr alloy + NaCl + $CaSO_4$ + bittern brines, (4) Steel (ss) + NaCl + $CaSO_4$ + bittern brines. Studies simulating the effects of high-level wastes include (1) effect of Cs, Sr, and U on solubilities and phase equilibria, (2) effect of Cs, Sr, and U on vapor pressure, (3) partitioning of Cs, Sr, and U between the brine and potential solid phases.

Processes involving salt, brine, and waste reactants will be modeled at temperatures up to 300°C. Processes examined will include solution and mass transport, fluid inclusion migration and decrepitation, and hydrogen evolution.

Progress (1) Any brines that might come in contact with nuclear waste would tend to dissolve ^{90}Sr and ^{137}Cs as chlorides. Such a fluid would thus contain its own energy source and by migrating could change the thermal evolution of the repository from designed values. In order to define the problem, the solubility of Sr and Cs in complex brines must be known. The solubilities of $SrCl_2 \cdot 6H_2O$, $SrCl_2 \cdot 2H_2O$, and halite in the system NaCl-$SrCl_2$-H_2O have been determined from 18° to 115°C with NaCl contents fixed at 0, 5, 10, 15, and 20 weight percent. The presence of NaCl in the solution reduces the $SrCl_2$ content and the solution is readily saturated with halite as well as the solid $SrCl_2$ hydrates. In the system KCl-$SrCl_2$-H_2O a similar reduction of $SrCl_2$ solubility occurs but the content of total dissolved solids is higher at comparable temperatures. $CaCl_2$ and $MgCl_2$ are more soluble than $SrCl_2$ and bitterns high in either of these components limit $SrCl_2$ solubility to a few weight percent. In solutions with significant SO_4^{2-}, Sr is soluble only to about 0.0005 weight percent. Therefore, addition of a soluble SO_4^{2-} bearing phase, e.g., Na_2SO_4 in a waste canister overpack, would limit Sr mobility in the event of canister breaching.

The solubility relations in the system CsCl-NaCl-H_2O have been determined between 20° and 95°C for solutions containing $\lesssim$50 weight percent CsCl. The solutions containing $\gtrsim$50 weight percent CsCl are found to be stably coexisting with CsCl-NaCl solid solution and(or) a "new phase" which is anisotropic. The composition and crystal structure of this "new phase" remain unknown.

(2) Models and equations for calculating the migration rate of fluid inclusions under a thermal gradient in rock salt have been developed previously by several workers. The results obtained from these calculations vary widely. Part of the cause for the scatter in the results is that much of the data required for the calculations is not available and the various workers have had to estimate the requisite parameters. Three of these parameters are (1) Soret coefficient of NaCl; (2) concentration of NaCl (mole/liter) in halite saturated brine (C_E); and (3) $\partial C_E/\partial T$.

The compositions of natural fluid inclusions are complex, and the data on Soret coefficient of NaCl in mixed electrolyte solutions do not exist. The experimental techniques used previously by others, such as conductivity and

optical methods, are not applicable to obtain these data. A "Soret cell" designed for the direct sampling method has been assembled and some preliminary results have been obtained for NaCl in 1 m to 6 m NaCl solutions from 20° to 60°C.

Measurements of the concentration of NaCl (in weight percent) in halite saturated WIPP-A (a synthetic brine used to simulate those at the WIPP site in New Mexico) and NBT-6 (a synthetic brine containing 5 weight percent NaCl, 5 weight percent KCl, 10 weight percent $MgCl_2$, 10 weight percent $CaCl_2$, and 70 weight percent H_2O) brines have been completed for the temperature range from 20° to 100°C. In order to convert these data from weight percent or molar units (mole/1000g H_2O) to molal units (mole/liter), density data for halite saturated solutions of these brines are needed. These density data have been obtained by direct measurement and also from calculations based on the model of Potter and Haas (1978). The differences between the calculated and the measured densities were less than 0.2 percent for both brines. This result indicates that the Potter-Haas model can be satisfactorily used to predict the density of a brine with known composition in weight percent or molar units.

Values for $(\partial C_E/\partial T)$ have also been calculated for WIPP-A and NBT-6 brines. When all these parameters were used in Anthony and Cline's (1971) model for migration velocity of brines, it turned out that the Soret coefficient contributes the largest uncertainty in the migration velocity estimations.

(3) To support the Avery Island, Louisiana, heater experiments conducted by the DOE, a detailed study of the brines and bitterns present in the salt dome has been completed. Analytical data includes Na, K, Mg, Ca, Sr, Li, Cl, SO_4, Br, δD, $\delta^{18}O$, and Zn. The bittern brines at Avery Island probably are connate evaporite waters that reacted with sediments and then were incorporated into rising salt domes without major dilution by normal ground water. NaCl brines probably originated either (a) by bittern brines becoming diluted by ground water and then dissolving more NaCl, or (b) above the Zn-bearing strata. Intermediate brines probably were produced by mixing of bitterns with NaCl brines.

Steam condensate samples from the brine migration experiment at Avery Island have been analyzed for deuterium contents (for details of experimental set up, see Krause and Gnirk, 1979). Samples from TEST NB (Natural Brine Movement Under Elevated-Temperature Conditions) have $\delta D \approx 0\%$ SMOW, while those from TEST SB (Synthetic Brine Movement Under Elevated-Temperature Conditions) have δD as high as 47,790% SMOW. This result indicates a significant amount of brine had migrated from brine borehole to heater borehole within a period of three months. However, the mechanisms for the migration are still not known.

Reports

Clark, J.R., Evans, H.T., Jr., and Erd, R.C., 1980, Structure of tachyhydrite: Acta Cryst. B36, p. 2736-2739.

Clynne, M.A., Chou, I.M., and Haas, J.L., Jr., 1980, $SrCl_2$ solubility in complex brines (Abs.): Scientific Basis for Nuclear Waste Management Symposium, Materials Research Society Annual Meeting, p. D127-128.

Clynne, M.A. and Potter, R.W., II, 1979, Solubility of some alkali and alkaline earth chlorides in water at moderate temperatures: J. Chem. Eng. Data, p. 338-340.

Clynne, M.A., Potter, R.W., II, and Thurmond, V.L., 1980, The application of the physicochemical properties of boiling bitterns to the interpretation of brine migration experiments related to salt repositories, in Northrup, C.J.M., Jr., Scientific Basis for Nuclear Waste Management: New York, Plenum Press, v. 2, p. 465-470.

Erd, R.C., Clynne, M.A., Clark, J.R., and Potter, R.W., II, 1979, Crystal data for tachyhydrite $CaMg_2Cl_6 \cdot 12H_2O$: J. Appl. Cryst., v. 12, p. 481-482.

Potter, R.W., II, 1979, Computer modeling in low temperatures geochemistry: Rev. Geophys. Space Phys., v. 17, no. 4, p. 850-860.

Stewart, D.B., Jones, B.F., Roedder, E., and Potter, R.W., II, 1979, Summary of U.S. Geological Survey Investigations of fluid-rock-waste reactions in evaporite environments under repository conditions: International Atomic Energy Agency Symposium on the Underground Disposal of Radioactive Wastes, IAEA-SM-243/97.

References

Anthony, T.R., and Kline, H.E., 1971, Thermal migration of liquid droplets through solids: J. Appl. Physics, v. 42, p. 3380-87.

Haas, J.L., Jr., 1976, Physical properties of the coexisting phases and thermochemical properties of the H_2O component in boiling NaCl solutions: U.S. Geological Survey Bulletin 1421-A, 73 p.

Krause, W.B., and Gnirk, P.F., 1979, Dome-salt brine-migration experiements at Avery Island, Louisiana, in Proceedings of the National Waste Terminal Storage Program Information Meeting, October 30-November 1, 1979, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, ONWI-62.

Potter, R.W., II, and Haas, J.L., Jr., 1978, Solubility of highly soluble salts in aqueous media: Part I, NaCl, KCl, $CaCl_2$, Na_2SO_4, and K_2SO_4-Solubilities to 100°C: Jour. Research, U.S. Geological Survey, v. 6, no. 2, p 247-257.

Potter, R.W., II, and Stewart, D.B., 1979, Physical properties of bitterns in rock salt applied to the design of nuclear waste repositories: Proceedings of the National Waste Terminal Storage Program Information Meeting, ONWI-62, p. 45-46.

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 are 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 1) developing a method to measure the water content in salt beds indirectly by means of a borehole probe, and 2) improvement of existing methods and development of new methods of isotopic dating of rocks, soils and minerals that will allow dating of geologic events and features not possible at present. Improvements in the accuracy of dating geologic events and features will help to refine our knowledge of the geologic history of an area, and improve our ability to make extrapolations into the future.

Surface Seismic Methods

By Hans Ackermann, Lakewood, Colo.

Controlled-source seismic methods, both reflection and refraction, are useful tools in exploring for suitable sites for nuclear waste repositories in areas of layered sedimentary rocks with relatively simple structures; these methods generally offer better resolution of subsurface variations in structure and lithology than other geophysical techniques. While surface seismic techniques have been used for many years in petroleum exploration and a variety of equipment and techniques are readily available, the emphasis has been on deep penetration whereas exploration for waste repository sites will require higher resolution at much shallower depth-from a few hundred to one or two thousand meters.

Although data processing techniques may be readily scaled to shallower targets, data acquisition techniques may not because of the difficulty in scaling the frequency of the seismic pulse and the surface wave which is

a major source of noise. Some improvement has been made during the past few years by using the higher frequency portion of the seismic pulse.

Presently used methods of interpreting seismic refraction data assume seismic layers of constant velocity for calculating the depth to these layers. This assumption is invalid and not only results in incorrect depth values but does not permit the delineation of lateral velocity changes which are indicative of lateral changes in physical properties within the layers. However, refraction data contain all the information necessary to calculate both depth variations and lateral velocity changes and this can be done by means of interactive ray-tracing computer programs.

The value of shear-wave velocity for determining the physical properties of subsurface materials is well known. However, shear waves are seldom used in seismic refraction surveys because (1) high energy shear waves are difficult to generate, (2) they attenuate more rapidly than compressional waves, and (3) interfering noise trains are generated due to conversion from shear to compressional energy. The use of shear waves, particularly in shallow cross-hole engineering studies and reflection surveys, is becoming more common and these methods may also be applied to refraction surveys.

Objective To devise modifications to standard seismic data acquisition methods for obtaining information applicable to the depth and levels of resolution of interest in identifying and characterizing potential sites for nuclear waste repositories.

Approach Various techniques will be tested which are aimed at removing the noise created by low frequency surface effects from reflection surveys using the close seismometer spacings necessary to obtain high resolution. Interactive ray-tracing computer programs will be developed to calculate both depth variations and lateral velocity changes from refraction data.

Progress A 48-channel system for recording high resolution seismic reflection data at potential nuclear waste disposal sites was purchased. Initial testing is planned for FY 1981.

Interactive ray-tracing computer programs, which will improve the interpretation of seismic refraction data, have been written and tested with both theoretical data and a large amount of field data. A manuscript on this subject has been accepted for publication by the Society of Exploration Geophysicists. It will be published in the monograph series pending some revisions of the computer program so it can be run on small machines.

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 inhomogeneities and flaws. 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 the 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. Rock salt and granite are known to be excellent media for radio probing, largely due to their dryness. There is at present a lack of understanding of the fundamentals of radio wave propagation in geologic media. A suitable radar operating frequency cannot be selected without first characterizing radio wave propagation, absorption, and scattering in the various rock types. Because these measurements involve bulk variations in the rocks, the measurements cannot be made in the laboratory.

To be useful in the early stages of repository exploration, radar must be functional from boreholes (Nickel and others, 1981); 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 salt and other low conductivity media, to develop and field-test prototype equipment, and to develop or enhance interpretive techniques.

Approach Preliminary experiments were conducted above ground with the borehole simulated by a plastic tube filled with brine in which the antenna was placed. The strength of the transmitted radio signal was measured after passing through the wall of the tube by an appropriate receiving antenna, amplifier, and oscilloscope. Various combinations of antennas, baffles and frequencies were tested to reduce attenuation to a minimum and determine useful operating frequency ranges.

Progress The design work necessary for the mechanical portion of the borehole radar was completed. Materials were obtained and machining of all major mechanical parts of the prototype radar was completed. The electrical design work followed two approaches, a pulsed system, and a swept frequency continuous wave system. A number of subassemblies have been tested. Based on the progress made, it appears that initial field tests of a complete prototype borehole radar will be possible in fiscal year 1981.

Reference

Nickel, H., Sender, F., Thierbach, R., and Weichart, H., 1981, High frequency electromagnetic tools for the prospection of saltdome

structures from boreholes: 50th Annual International Society of Exploration Geophysicists Meeting, Houston, Texas, November 16-20, 1980: Geophysics, v. 46, no. 4, p. 432-433.

Borehole Geophysical Logging

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

Test drilling is one of the most useful exploration methods for the identification and characterization of waste-disposal sites and for determining the extent of subsurface migration of radionuclides in ground water. Borehole geophysical logging and measuring devices are an essential part of test drilling.

Of all the factors involved in site characterization, fluid (and waste) flow in rock fractures is one of the most significant and least understood. Borehole geophysical logging can be useful in determining the water transmitting capability of fractures intersected by boreholes.

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

Approach The research is divided into those borehole geophysical techniques useful in characterizing potential repository sites, and those useful for monitoring possible waste migration in ground water after a repository site has been developed. Site characterization methods involve resistivity, acoustic, and nuclear logging devices to provide more detailed information about potential ground-water motion and radioisotope transport than is normally obtained in ground-water studies. Special effort has been focused on the identification of fractures that may be hydraulically conductive. The possibility of such zones remaining undetected by currently available site characterization methods constitutes one of the greatest problems in evaluating proposed repository sites. Future site selection studies will probably involve large quantities of geophysical data, and rapid data reduction schemes such as well log digitization will be needed to help obtain the most subsurface information at the least cost. Site monitoring applications include methods for the quantitative identification of radioisotopes in ground water, such as natural gamma-ray spectral log interpretation and neutron activation analysis, and methods for the characterization of subsurface flow in the repository area using flow-meter, temperature, and fluid conductivity logs.

Progress Research was continued on fracture identification and characterization with the acoustic televiewer (a borehole wall imaging device). The research included the development of new equipment and data analysis techniques to improve televiewer resolution and enhance the televiewer interpretation process. Televiewer data are also being used to evaluate new approaches to data analysis whereby direct and indirect manifestations of fracture properties can be recognized in conjunction with other types of geophysical

measurements. It was found that specific types of acoustic waveform anomalies could be associated with fractures that appear open on the televiewer image. A theoretical understanding of the effects of fractures on the individual modes of acoustic propagation within the digitized waveform data has lead to the definition of attenuation parameters that can be correlated with independent measurements of fracture permeability. The significance of these results lies in the prospect of being able to extrapolate a few expensive and time-consuming measurements of fracture permeability in one core hole to many more exploratory boreholes at little additional expense. These methods were tested in a series of boreholes at waste-disposal study sites on the Canadian Shield (Paillet, 1980). Figure 8 indicates the correlation of acoustic waveform data and fracture permeability measurements made by isolating individual fracture sets with inflation packers and performing pressure injection tests on the isolated sections of the borehole. These measurements, made by Environment Canada, are given in terms of the theoretical response of an infinite planar opening with a specified uniform effective width (fracture aperture).

Work continued on the development of methods to interpret quantitatively gamma-ray spectral logs. Theoretical models were developed of the quantitative effects of finite detector geometry, borehole diameter, bed thickness, and other lithologic parameters influencing gamma spectral measurements. The model studies suggested methods whereby experimental data may be corrected to account for these important effects (Schimschal, 1980a, 1980b, and 1981a). Continuing research in this area is now addressing the effects of finite logging speed and probe decentralization on spectral measurements, and it includes the field testing of analysis procedures formulated on the basis of previous theoretical models.

A study was made of the use of methods for quantitative flowmeter analysis for recognizing zones of fracture permeability (Schimschal, 1981b). Additional studies of flowmeter logging involved the testing and modification of a pulsed-thermal flowmeter system which has the potential for making low-velocity flow measurements an order of magnitude lower than those that can be made with impeller flowmeters. This should give greatly improved results in measuring the very low flow rates that are to be expected in test wells at proposed waste disposal sites.

Reports

Paillet, F.L., 1980, Acoustic propagation in the vicinity of fractures which intersect a fluid-filled borehole: Society of Professional Well Log Analysts, 21st Annual Logging Symposium, Transactions, Lafayette, Louisiana, June 1980, p. DD--DD33.

Schimschal, Ulrich, 1980a, Scintillation detectors in gamma spectral logging: geometry, absorption, and calibration: U.S. Geological Survey Open-File Report 80-688, p. 1-29.

_____1980b, Quantitative effects of lithology, borehole environment, and probe design in gamma spectral logging with scintillation crystals: The Log Analyst, September-October 198, p. 3-10.

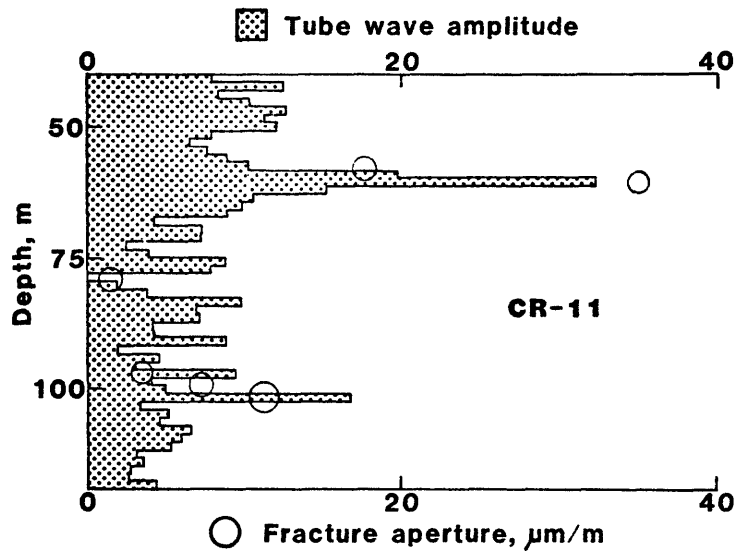

FIGURE 8.-Comparison of acoustic amplitude anomalies with measured permeabilities of selected fracture zones in a borehole. Permeabilities given in terms of effective total width (aperture) of fractures per meter of borehole. Hole CR-11 at Chalk River, Ontario.

_____1981a, A mathematical model of gamma ray spectrometry borehole logging for quantitative analysis: U.S. Geological Survey Open-File Report 81-402, 23 p.

Schimschal, Ulrich, 1981b, Flowmeter analysis at Raft River, Idaho: Ground Water, v. 19, no.1, p. 93-97.

Acoustic and Electric Techniques

By Jeffery J. Daniels, Lakewood, Colo.

Objective To develop and test new borehole geophysical techniques for locating geologic inhomogeneities that are beyond the range of detection of conventional well-logging probes.

Approach Hole-to-surface, direct-current resistivity systems are being developed together with field systems capable of operating to depths of up to 2,000 m.

Hole-to-hole acoustic surveys have the potential capability of detecting vertical as well as horizontal, structural, and lithologic features such as faults, fracture zones, lenses, alteration zones, and cavities. Multiple sources and receivers are positioned at various depths in vertical holes spaced a few tens of meters to a kilometer apart to detect transmitted and refracted acoustic events originating from a high power, repetitive, non-explosive source. The results are interpreted by means of specialized computer modeling procedures.

New techniques for making and interpreting borehole geophysical measurements needed for hole-to-hole applications will be tested in appropriate deep holes as they are available. New instrumentation for measuring magnetic properties will be developed.

Progress A technique was developed and tested to measure the surface distribution of the total electric field vector (magnitude and direction) caused by a current source that is located in a drill hole. These measurements in conjunction with resistivity well logs and hole-to-hole resistivity measurements can be useful for locating buried geologic features (with anomalous resistivities) away from a drill hole.

Neutron Activation Methods to Measure Water Content in Salt Deposits

By Frank E. Senftle, Reston, Va.

Water in salt deposits occurs in cracks and vacuoles and tends to move toward a source of heat because the solubility of salt in water is directly proportional to temperature. The composition of such fluids and the amounts that would ultimately move into contact with the canister and backfill are important factors to be considered in the design of a repository system. Because of the difficulties of measuring the true water content in cores of salt, a method to measure the moisture content in the range of 0.1 to

1.5 percent H_2O in salt deposits with a borehole probe would be useful.

Objective To test the feasibility of measuring the water content of salt deposits by means of neutron activation and high resolution gamma-ray spectrometry using a borehole probe.

Approach The USGS has previously developed for mineral exploration a neutron activation borehole probe which is now being applied to the problem of measuring the water content in salt. The probe, which is 7 cm in diameter and 2 m long, contains a ^{252}Cf neutron source and a high-resolution gamma-ray detector. Depending on the energy of the neutrons, the range of penetration and detection into a relatively dry salt bed will be about 60 cm from the borehole. Measurements could be made every 50 to 60 cm down a borehole to log the distribution of water. The plan is to test in the laboratory several possible neutron activation techniques which might be used to determine water content. The techniques would be evaluated for their sensitivity, possible gamma-ray interferences, and lower limits of detection. The borehole probe would be calibrated in a laboratory borehole facility, and finally tested in the field in a salt deposit.

Progress The ratio of the 439-keV peak from inelastic neutron scattering on sodium to the 789 keV peak from neutron capture by chlorine was found to be a suitable index of water concentration. Source-to-detector measurements show that the sensitivity cannot be significantly improved by proper choice of source-to-detector distance, but that some improvement in counting statistics and sensitivity can be achieved by choosing a source-to-detector distance of about 90 cm. There is a significant decrease in sensitivity when the borehole is filled with water. By constructing the sonde with non-hydrogeneous material, particularly between the source and detector, the sensitivity when the borehole is filled with brine can be enhanced due to the displacement of the fluid. The laboratory experiments to date indicate that the 439-keV/789-keV ratio method is suited for the measurement of water at low concentrations in salt deposits, and might be useful in monitoring relative changes in water concentration of less than 1 percent.

This preliminary study suggests a need for field studies in boreholes in salt deposits. The use of higher energy neutrons such as can be obtained with an accelerator-type neutron source would substantially increase the number of gamma rays produced by inelastically scattered neutrons. The higher neutron flux from such a source would also enhance the capture of gamma rays. It is therefore apparent that by use of a borehole accelerator the sensitivity of the method could be enhanced.

Report

Senftle, F.E., Mikesell, J.L., Doig, N.G., and Brown, F.W., Water analyses in salt deposits used for radioactive waste depositories, International Journal of Applied Radiation and Isotopes (in press).

Isotope Geochronology

By Meyer Rubin, and Joseph G. Arth, Reston, Va.; and
Carl Hedge, Lakewood, Colo.

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 us to date 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 The present limit of the carbon-14 technique of dating ground water and carbonaceous materials is about 30,000 years. Measuring carbon isotopes with the tandem-Van de Graaff mass spectrometer has the potential to extend this limit to 70,000 years and reduce the sample size needed by a factor of 100 to 1,000. A group at the University of Rochester has been pioneering this technique and Meyer Rubin is collaborating with them; equipment dedicated to this technique will be obtained if the results warrant it.

Work at a number of institutions has suggested that ground waters may be datable up to 200,000 years by chlorine-36 and krypton-81, and sediments and sedimentation rates up to 1 million years by beryllium-10, aluminum-26, and silicon-32. Like carbon-14, these isotopes are generated by cosmic rays in the upper atmosphere; they become incorporated in sediments or ground water and slowly decay with half lives somewhat longer than carbon-14. In order to make use of these isotopes, very small amounts of them must be measured and current research efforts are focused on use of cyclotrons or Van de Graaff accelerators. In addition, little is known about the geochemistry of these isotopes and the extent to which they may be selectively fractionated or adsorped through natural processes, which could alter the isotope ratios finally observed. Carl Hedge is closely following the development of these techniques and assessing their usefulness for work on radioactive waste problems. If and when a particular technique becomes sufficiently developed, consideration will be given to acquiring the necessary equipment to apply it.

Joseph G. Arth and his colleagues are in the process of assembling a laser probe mass spectrometer for dating the time of formation of rocks,

minerals, and fluid inclusions by potassium/argon methods. This technique, which is of very recent development, reduces the sample size by several orders of magnitude and allows ages to be determined on microscopic samples. Its development should enable us 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 The USGS continued cooperating with the University of Rochester and University of Toronto, in the operation of the Rochester van de Graaff accelerator as a tool for measuring various radiogenic isotopes useful in measuring ground-water flow and residence times. The 10 MEV tandem-van de Graaff mass spectrometer has been plagued with troubles this past year including belt breakage, release of insulation gas accidentally to the atmosphere, instability of voltages, and fractionation at the terminal. In spite of these problems, the rare radioactive isotopes ^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl and ^{129}I have been detected at or near natural levels without isotope enrichment by using negative ions, molecular dissociation, atom counting and isobar identification. Ratios of $^{14}C/^{12}C$ and $^{36}Cl/Cl$ near 10^{-16} have been measured during the development of radiocarbon and ^{36}Cl dating of small samples on the order of milligrams. The half-life of ^{32}Si has been determined to be 108 ± 18 years, in significant disagreement with the previously accepted value of 330 ± 40 years. All three of these radioactive isotopes have application to measurement of ground-water movement.

Meyer Rubin has been testing various methods of presenting the sample to the cesium sputter source to produce the largest possible beam current. Cracking of C_2H_2, CO_2, CO, and CH_4 has been achieved with a tesla coil and amorphous carbon produced gives a useable beam. Attempts to make graphite by a high pressure-temperature piston press are being made. Graphite is the material that produces the highest beam current. A dedicated accelerator, called the Tandetron, which will eliminate many of the problems of instability and fractionation is scheduled to be delivered to the University of Toronto in fiscal year 1981.

John F. Sutter, a K/Ar geochronologist from Ohio State University, was hired to develop the capability for K/Ar dating at Reston, Va. A high-resolution, ultra-high sensitivity mass spectrometer was delivered, as was a Nd-YAG Laser and a binocular microscope. Development of the laser K/Ar dating facility is proceeding and preliminary experimental results are expected during fiscal year 1981.

Reports

Gove, H.E., Elmore, D., Rubin, M., and others, 1980, Radiocarbon dating with tandem electrostatic accelerators: Radiocarbon v. 22, No. 3, p. 785.

Rubin, Meyer, 1979, Problems of sample selection and preparation for geologists and archaeologists in using a new accelerator method of ^{14}C dating (Abs.): Geological Society of America, Abstracts with Programs, v. 11, no. 7, p. 507.

Rubin, Meyer, 1982, Sample preparation for electrostatic acceleration dating of radiocarbon, in Curry, Lloyd H., Nuclear and Chemical Dating Techniques: Interpreting the Environmental Record: American Chemical Society Symposium Series 176, p. 89-93.

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 potential 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, Tucson, Ariz.

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 current research effort is centered about step (2) and preparation for step (3) of the approach described above. Analytical solutions, in terms of the six components of the hydraulic conductivity tensor, have been derived for the cases of constant or variable discharge from point or line sources in a three-dimensional anisotropic porous medium of infinite extent. Image-well theory for an anisotropic flow system has been developed so that constant-head and impermeable boundaries can be taken into account. These solutions give the transient changes in hydraulic head at any point in a flow system due to prescribed rates of water injection into a packed-off interval in a borehole. Thus, applications of these solutions will require a field setup whereby water is injected into a packed-off interval in one borehole while head changes are measured in packed-off intervals in adjacent boreholes. A graphical method has been developed to compute the hydraulic conductivity tensor from field data for simple flow systems. For complicated flow systems, computer matching techniques will be needed. The case of prescribed head, rather than prescribed flow, in the injection interval is also being examined.

Plans were made to conduct a series of hydraulic tests, using straddle-packer equipment, in four boreholes, each about 90 m deep, in fractured granitic rock at a field site near Oracle, Arizona. The test site will be provided by the Department of Hydrology and Water Resources of the University of Arizona.

Nonisothermal Water Fluxes in Unsaturated Alluvium

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 principles 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 Development of experimental systems to investigate transient, nonisothermal flow in unsaturated soil was continued. Systems were built to determine the temperature dependence of unsaturated hydraulic conductivity and soil-moisture potential at temperatures up to 60°C. Results indicated that these important variables are much more temperature dependent than predicted by simple theory. The results implied that the rate of moisture movement in the soil in response to temperature gradients was as much as 10 times greater than predicted.

Experiments investigating the transient flow of water vapor in soil at temperatures up to 150°C were also continued. Because the equilibrium vapor pressure of water is less than steam-table values, results disagreed with standard gas-flow theory. Experiments were run to determine the dependence of vapor pressure in the soil on the extent of liquid saturation and temperature at temperatures up to 150°C. A vapor-flow theory which was modified to take vapor-adsorption and vapor-pressure lowering into account was developed. The experimental results were successfully

simulated using a finite-difference computer model based on the new vapor-flow theory.

Reports

Constantz, J.E., 1979, Temperature dependence of soil water movement during steady evaporation: Ph.D. dissertation, Univ. of California, Berkeley.

Herkelrath, W.N., 1980, Comment on "Analysis of water and heat flow in unsaturated-saturated porous media" by Marios Sophocleous: Water Resources Research, v. 17, no. 1, p. 255.

Herkelrath, W.N. and Moench, A.F., 1980, Transient steam flow in porous media - theory and experiment: Proceedings of the Sixth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, Calif., Dec. 16-18.

Herkelrath, W.N., and Moench, A.F., 1978, Laboratory investigations of steam pressure-transient behavior in porous materials: Proceedings of the Fourth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, Calif., Dec. 13-15, p. 54-59.

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 field test site at Jackass Flats on the Nevada Test Site was partially instrumented. Thermocouple psychrometers were placed in holes drilled in the sidewall of the caisson using a masonry core drill, and data collection on background moisture content and hydraulic head was started.

Data collection was started at the site in the Sandhills of Nebraska where it is planned to conduct generic tests of the laboratory and theoretical aspects of flow under anisothermal conditions. Prior to starting the electrical heater experiment, data are being obtained on the natural-moisture and thermal regimes.

Data collection is in progress for a laboratory bench-scale experiment to test the effects of heat on the moisture regime in a uniform unsaturated porous medium under controlled conditions. This experiment has enabled the debugging of the data acquisition systems needed for the field experiments.

A two-dimensional (r - z) finite-difference model of anisothermal vapor transfer has been developed and tested against existing laboratory data and against other models. More complete testing will be done using results from the bench-scale laboratory experiment and from the field sites in Nebraska and Nevada.

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 and physical speciation, it is difficult to predict their transport and distribution characteristics over the long term. In particular, it is fruitless to attempt to make distribution measurements of the transuranium elements without first determining their chemical forms in the ground waters of interest. This speciation is relatively straightforward for all elements except plutonium, which is most subject to hydrolysis, polymerization, and complexation.

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 and physical speciation, and the chemical and hydrologic behavior of transuranium elements (particularly plutonium) in contaminated ground waters.

Approach The approach is to sample leachates from selected shallow land disposal sites where there is sufficient plutonium to permit the necessary separations and analyses. The leachate is passed through a sequence of submicron membrane filters of successively smaller pore sizes to determine the distribution of plutonium among the various particle sizes and to establish the fraction in true solution. Only the plutonium passing through the smallest pore-size filter can be in true solution; therefore,

chemical studies are limited to this fraction. These studies include ion exchange to determine the charge of the plutonium species, and various carrier precipitation and solvent extraction procedures to establish the oxidation state of the plutonium.

Progress Sampling and analysis of trench leachates from the Maxey Flats, Kentucky, radioactive waste-disposal site have been concluded, and a paper by J.M. Cleveland and T.F. Rees which has been accepted for publication in Science, describes the speciation results, conclusions and recommendations from this study. Among the nine trenches sampled, some general trends were noted. The great majority (more than 80%) of the plutonium in the leachates was in true solution or in very small (less than 0.05μm) particles, and hence could be quite mobile in the environment. The predominance of plutonium in true solution suggested that it was complexed, and this suspicion was corroborated by ion-exchange data indicating that most of the plutonium was anionic, based on its low physical sorption, and on the failure of the plutonium to coprecipitate quantitatively with the $Fe(OH)_3$. It was concluded that the plutonium was complexed by organic ligands because the leachates had a high organic content, and because no inorganic ligands form complexes stable enough to account for the observed behavior. The presence of EDTA was established in a number of leachates and it is likely that much of the plutonium was complexed by this ligand. Oxidation state determinations indicated that most of the plutonium in the leachates was in the tetravalent form. On the basis of these findings it was recommended that all organic matter in radioactive waste be destroyed; and that it is unwise to have radioactive waste disposal sites in juxtaposition to chemical waste disposal sites because of the potential for radionuclide mobilization through formation of organic complexes.

Ground waters from the Nevada Test Site (NTS) and the Idaho National Engineering Laboratory (INEL) were also sampled and analyzed. Water from Well CN2, which penetrates the cavity of the "Bilby" nuclear weapon test at NTS, was found to contain plutonium concentrations of less than 40 fCi/L (femtocuries per liter), too low for our speciation analyses. Four wells were sampled near the Idaho Chemical Processing Plant waste injection well at INEL, and the results, although not yet complete, indicate ground-water concentrations of plutonium of about 50 fCi/L. One of the wells contains plutonium at a concentration sufficient to permit speciation analyses, which are currently underway.

A procedure has been developed for the sequential separation and analysis of thorium, uranium, neptunium, plutonium, and americium from a single water sample.

Redox Potentials and Chemistry of Actinides in 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. For many environments electrode measurements of redox potential are very inaccurate, and attempts to estimate redox potentials by other techniques are only slightly better. The measurement errors 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 In the absence of an innovative breakthrough in measurement techniques, the approach to be followed will consist of one or more of the following: (1) use of electrode materials other than the usual inert metals. For reducing environments, possibilities would include iron, iron oxides or hydroxides, or iron sulfides incorporated in the electrodes; (2) a wide variety of chemical redox indicators are available whose applicability to natural waters is untested; (3) equilibration with large volume samples with a small volume of a solution containing a known electroactive, and thus measurable, redox couple; (4) analysis of electrode responses to electrical or chemical perturbations on the sample. Since one of the major problems in making standard electrode measurements is the slowness of reaction at the electrode, the more rapid response to initial disequilibrium conditions might provide a more accurate estimation of the true redox potentials; or (5) further work on the estimation of pe, the negative $\log_{10}$ of electron activity, from analytical data for multiple redox couples in the same water.

Progress A computer program PHREEQE (Parkhurst, Thorstenson, and Plummer, 1980) has been developed, having the capability of modeling reactions among a large number of aqueous species and mineral phases. If the data base in the program is not sufficient for a particular problem, the program will accept as input, chemical species and mineral phases of the user's choice, with thermochemical data also provided by the user. An earlier version of this program has been used to model redox and ion-exchange reactions in a natural system (Thorstenson, Fisher, and Croft, 1979). The current program is being tested by modeling reactions in shallow ground waters and in two regional aquifer systems in the Northern Great Plains.

A study of the theory of redox reactions in geochemistry has been completed in collaboration with J.D. Hostettler. This study provides the bases for a general reevaluation of the theoretical concept of pe as an electron activity, and for a more fundamental interpretation of Eh measurements. This work also demonstrates the inherent inability to define a unique redox potential in a disequilibrium system and points

up the need for in-situ testing in field studies of redox-active contaminants in natural water systems.

Report

Parkhurst, D.L., Thorstenson, D.C., and Plummer, L.N., 1980, PHREEQE - A computer program for geochemical calculations: U.S. Geological Survey Water Resources Investigations 80-96, 210 p.

Reference

Thorstenson, D.C., Fisher, D.C., and Croft, M.G., 1979, The geochemistry of the Fox Hills-basal Hell Creek aquifer in southwestern North Dakota and northwestern South Dakota: Water Resources Research, v. 15, no. 6, p. 1479-1498.

Solute Transport In The Unsaturated Zone

By Jacob Rubin, Menlo Park, Calif.

If the unsaturated zone is to be considered as 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 models needed will require, in the early stages of the project, a combination of laboratory and theoretical work. In later stages, these models will be field tested.

The solute transport 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 Two different experimental approaches were used in the laboratory to assess the influence of water content and waterflow rate on the transport of reacting solutes in unsaturated sediments. One of these approaches employed short (5 cm) and the other utilized longer (49 to 75 cm) sediment columns. Each of these two approaches has different advantages and

limitations. For instance, the two approaches are applicable under significantly different water-content conditions although a narrow range of overlap does seem to exist.

Owing to the fact that the short-column approach is new, it was necessary to conduct a theoretical (computer simulation) study to test its theoretical feasibility. For instance, it was necessary to determine, at least for certain sediments, whether an instrumental system based on such an approach can create an ample zone of approximately constant water content within the experimental sediment columns. This theoretical study gave encouraging results and was followed by the design and construction of two special instrumental systems. One of these was a miscible displacement appartatus for solute transport experiment with sediments of relatively low water content. This apparatus was designed to enable the investigator to determine the separate effects of water content and water flux. The second instrument was a sediment-core slicer. The experimental systems were tested for their capability to produce and measure the desired physical conditions such as steady waterflow and relatively uniform water content in much of the core. The systems were tested also to determine if it was possible to uncouple the effects of water content and waterflow rate. The tests gave positive results.

A set of solute transport experiments was carried out with the aid of the new instrumental systems, using Oakley sand as the porous medium. A nonreacting solute (Cl^{-1}) and the two reacting solutes (Sr^{+2} and Ca^{+2}) were used in the experiments, the chemical reaction being cation exchange. Two water fluxes (1.3×10^{-4} and 1.3×10^{-5} cm/sec) were used with a sediment water content of 9 percent (by volume). Very promising results were obtained and the theoretical analysis is in progress.

The second approach to the study of transport of reacting solutes involved relatively long sediment columns and the use of special equipment that had been designed and built previously. Several solute transport experiments which were carried out with the aid of this equipment revealed that evaporation from the sediment core was sufficient to affect very significantly the results obtained. Thus, in order to make the desired long-column experiments possible, the evaporation rates had to be decreased by at least two orders of magnitude. Experiments were carried out to develop the design of equipment which would make such a decrease possible. On the basis of these experiments the needed equipment was designed, fabricated, and is now being assembled.

It was planned to compare the above-mentioned studies of solute transport in water-unsaturated sediment columns with solute transport, under similar water-flux conditions, in water-saturated sediment columns. At present, it is possible to carry out, for a variety of conditions, experimental testing of mathematical models for transport of solutes affected by surface reactions which are sufficiently fast to be considered equilibrium-controlled. On the other hand, the state of knowledge is not as adequate for testing models of transport systems with equally fast chemical reactions of the classical type (e.g., precipitation-dissolution and redox reactions). The

mathematical formulation of models for such transport systems had been devised previously. In 1980, numerical methods needed for the utilization of this formulation for predictive purposes were developed. These methods are being tested using, as an example, solute transport influenced by dissolution and precipitation. The mathematical problem involves the search for solution of partial differential equations with moving boundaries and with singularities at these boundaries. Removal of singularities proved to be a difficult task. Several approaches to removing the singularities were studied, one of which yielded promising results.

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 radionuclides might enter the biosphere. The partial differential equations that describe the movement of dissolved chemical species through the ground-water system are difficult to solve. Numerical solutions using high-speed computers presently seem to be the most attractive means to solve such equations. When such equations describe solute movement with little or no dispersion, a "shock front" phenomenon results which is even more difficult to analyze with existing techniques. The method of characteristics (MOC) is one rather primitive method of solving such equations and efforts are now underway to provide more attractive techniques from the standpoint of both accuracy and decreased computer costs.

Objective The objective is to develop and evaluate numerical modeling techniques to predict changes in water quality during the transport of radioactive solutes through saturated ground-water systems.

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 Two professionals, a senior hydrologist and a geochemist, have been added to the staff. The hydrologist will do research on radionuclide movement in saturated porous media and the geochemist will operate the support laboratory and conduct research concerning the application of precipitation and dissolution processes to ground-water contamination.

The computer program SWIP (Survey Waste Injection Program) which had been modified to account for radioactive decay and adsorption, has received increased attention from other government agencies, from consultants, and from researchers outside of the USGS. Efforts continued to improve the efficiency of the program. Specifically, a critical analysis was made of the numerical stability of the radial transport portion of the code.

Work continued on the investigation of field sites where the movement and reaction of solutes can be studied. In this connection, study continued of ground-water contamination from mining operations in Telluride, Colorado where both ground and surface waters have been contaminated by hexavalent chromium. Recent analyses of water samples indicated that the chromium concentration is decreasing and the contaminant is moving slowly down the valley.

The contamination of ground-water by radionuclides from a uranium reprocessing plant in Rhode Island is being investigated to determine the site's suitability as a potential case study for model verification. Contacts with USGS personnel in Rhode Island and operating plant personnel have resulted in a technical exchange of data and interchange of ideas that should benefit the investigation.

Report

Kipp, Kenneth L., 1980, Mathematical modeling of chemical transport in soil columns: EOS, v. 61, no. 17, p. 234.

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 zero or lithostatic stress (the increase in weight of the overlying rocks with depth); 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 by such instruments 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 A large variety of borehole instruments has been developed and marketed during the last several decades that reportedly convey direct information on the state of stress, strength, deformation, various moduli and other essential properties of the rock mass. Many investigations of individual instruments have been published in the literature, but there have been very few attempts to compare the measurements from such instruments or examine them under laboratory conditions where the imposed stress is known and the significance and reliability of the measurements can be evaluated. To this end, a testing facility has been constructed in an experimental mine operated by the Colorado School of Mines near Idaho Springs, Colorado. This facility consists of a rectangular block (3 m long, 1 m wide, and 1.7 m deep) of gneiss partially excavated in the floor of the mine. Flatjacks inserted, cemented and pressurized in narrow, vertical slots peripheral to the block will subject it to known stress levels up to $3x10^4$ KPa. Holes of different diameters have been drilled vertically into the isolated block to accommodate the various instruments to be tested. From the measurements obtained in this manner, the theoretical basis of the instruments will be critically re-examined to determine whether or not the constitutive laws of rock behavior that they invoke are realistic. In addition, attempts will be made to simplify data reduction procedures, many of which are clumsy and tedious.

To develop an efficient site-characterization methodology, a site near Golden, Colorado, has been chosen that allows the development of a theoretical model of the stress distribution in the rock mass. The borehole instruments already tested in the block will be used to determine the mechanical properties at this 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 from analytical methods. Thus, the test site serves as an additional proving ground to test and evaluate existing instrumentation and to develop modifications, improvements, or new techniques as required.

Progress The borehole instrument testing facility near Idaho Springs, Colorado, has been completed and is operational. A complete suite of tests are planned for fiscal year 1981. Some of the borehole instruments and recording devices have been purchased and others are borrowed on a short-term basis from other Federal agencies.

Work on the test site near Golden, Colorado, is well underway. The site consists of a 6-m-thick lava flow that caps the southeastern part of

South Table Mountain. A temperature probe has been constructed and installed at the site to monitor the rock-temperature distribution in the flow; nine months of data have been collected to date and will be used to model the thermal-stress field in the flow as a function of time (Savage and Swolfs, 1980). The first attempts at measuring the stress distribution in the flow were made in November 1980 using two different overcoring techniques; i.e., the U.S. Bureau of Mines deformation gage and the Australian hollow-inclusion cell. The Australian device was found to be particularly sensitive to the temperature changes that accompany the overcoring operations, leading to mixed results. A second attempt will be made in June 1981 using a modified approach.

Tests with the Goodman Jack, a borehole device designed to measure the deformation modulus of the rock mass, have been completed (Swolfs and Kibler, 1981). Thorough calibration tests on the device in the laboratory were necessary to empirically obtain correction factors required to account for a factor-of-three discrepancy between the measured and true modulus.

Additional measurements completed at the test site include shallow-refraction, resistivity, depth to water table, and joint distribution surveys. Laboratory measurements have been made to obtain depth profiles of thermal-expansion coefficients, sonic velocities (both P and S), and whole-rock chemistry.

Reports

Savage, W.Z., and Swolfs, H.S., 1980, The long-term deformation and time-temperature correspondence of visco-elastic rock: U.S. Geological Survey Open-File Report 80-708, 21 p.

Swolfs, H.S., and Kibler, J.D., 1981, A note on the Goodman Jack: Rock Mechanics, Springer-Verlag, New York (in press).

Synthesis of Neotectonic Conditions in the United States

By Carl M. Wentworth, Menlo Park, Calif., and others

The recent tectonic history of the country provides a basis for predicting and evaluating changes in the geologic setting of broad regions or potential repository sites over the next few hundred thousand years. The tectonic regime or setting determines: (1) the rates at which uplift and erosion may unroof a repository or change its hydrologic regime, or the rates at which downwarping and sedimentation may bury it deeper, (2) the potential for changes in geologic structural setting, including fracture density and permeability, new faults or extension of old ones that might cut the repository, and (3) the likely frequency and severity of earthquakes in the region. Tectonic factors conceivably can produce significant changes in hydrologic conditions such as elevation of the water table, shortening of ground-water flow paths, and acceleration of rates of flow.

Objective 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. To improve our ability to analyze and predict the tectonic behavior and seismicity of the United States over the next few hundred to one 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 kinds of geologic evidence. 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.

Because the results of this project provide basic scientific information useful for a variety of purposes, it is supported jointly by the Radioactive Waste Disposal, Earthquake Hazards, and Reactor Hazards Programs of the Geological Survey.

Progress The whole of the eastern seaboard east of the Appalachian Mountain front from Georgia to Maine should be viewed as a single neotectonic domain undergoing northwest-southeast compression, based on continued study of geologic, geophysical and earthquake data (Wentworth and Mergner-Keefer, 1980 and 1981). Sporadic movements on northeast-trending reverse faults inferred to be scattered throughout the region have produced 100 m or less of vertical offset per fault over the past 100 m.y. Stratigraphic relations across the Stafford fault in north-central Virginia (Mixon and Newell, 1977) and the Cooke fault near Charleston, South Carolina (Behrendt and others, 1981) indicate decreasing offset rates since mid-Cretaceous time, and probably since Middle Jurassic time, with late Cenozoic rates of only 1/2 m per m.y. or less. Focal-mechanism solutions of recent earthquakes in coastal New England, northern New Jersey and farther southwest indicate that such deformation is still underway.

Damaging earthquakes and associated deformation like the intensity X Charleston earthquake of 1886 should be possible almost anywhere in the eastern seaboard region. This earthquake produced a northeast-trending meizoseismal area that contains a northeast-trending early Mesozoic fault in the basement and a related Cretaceous and Cenozoic reverse fault. Some modern earthquakes in the area indicate east-northeast-trending reverse faulting. A long recovery time for the regional stress field, following the strain released in large earthquakes, is suggested by the relatively

low frequency of large earthquakes in the region and the long and complex sequence of 1886 aftershocks (A.C. Tarr and Susan Rhea, unpublished data).

The Stafford fault zone has been mapped for about 60 km southwest of Washington, D.C., and may extend at least another 35 km southwestward through the North Anna Reservoir at the site of Virginia Electric and Power Company's North Anna reactors. Statistical analysis of geomorphic parameters of drainage basins on either side of the Stafford zone and the Spotsylvania aeromagnetic lineament on strike to the southwest of Fredericksburg indicates differences that are consistent with Stafford-sense reverse faulting. Microearthquakes at North Anna Reservoir (Dames and Moore, 1976) yield composite focal-mechanism solutions with one reverse focal mechanism in common, which on the average is similar to the attitude of the Stafford faults.

Study of Atlantic Coastal Plain stratigraphy, especially in the Continental Offshore Stratigraphic Test wells off Georgia and New Jersey, indicate the existence of periods of rapid subsidence superimposed on the thermal subsidence of the continental margin since Atlantic rifting (Heller and others, 1980). These intervals of rapid subsidence occurred during the Coniacian and Santonian, Eocene, and, off New Jersey, during late Cenozoic. Removing the effects of isostatic loading due to changing water depths (bathymetry) and increasing sediment thickness with time, yields a curve representing the tectonic--sealevel component of total subsidence. Episodic anomalies in this curve cannot be accounted for solely by sea-level changes, and are best attributed largely to tectonics. The tectonic cause is unknown, but may be related to contemporaneous changes in plate behavior.

To the west in the eastern midcontinent region, study of geomorphology and the altitude and distribution of Cretaceous rocks and comparison with curves of sea-level change indicate modest post-Cretaceous vertical deformation with maximum rates on the order of 1 m/m.y. This is similar in scale to the embayment-arch deformation along the eastern seaboard. The stratigraphic record is inadequate to resolve any faults of small offset, such as the Stafford zone in Virginia.

Study of Landsat images shows only weak agreement between photo-lineaments and faults mapped in Precambrian basement west of Lake Michigan. Isostatic response to early Pleistocene excavation of the 45,000 km^3 Lake Superior basin is sufficient to explain the 120-m highland rim surrounding the basin, using a crustal stiffness radius of 125 km.

Small-scale analysis of topography may aid neotectonic evaluation in regions lacking late Cenozoic stratigraphic control. A digital terrain map of the eastern United States showing over 3 minutes of latitude and longitude shows several very large features of possible neotectonic significance, as well as much finer structure. The Appalachian Highland, for example, extends from Alabama to Maine with a nearly constant width of about 225 km. Neither border follows mapped bedrock features for any great distance.

Statistical investigation has been carried out into the use of drainage-basin parameters to assess differential uplift rates at mountain fronts, using areas in the Transverse Ranges, California, along the Wasatch front

in Utah, and in southwest Arizona for control. Multivariate analysis of variance and linear discriminant analysis suggest that channel geometry parameters and drainage-basin shape are sufficient to characterize tectonic activity in 52 of 54 watersheds. After normalization for climate, three classes of uplift rate seem distinguishable: greater than 1 m/1000 yr, less than 1 m/1000 yr, and zero.

Study of neotectonic conditions in Colorado shows that the Rio Grande Rift and its northward extension to Wyoming is the principal neotectonic feature in the state, both in terms of total late Cenozoic displacement and of youthfulness of activity. Significant displacements and(or) relatively recent activity also occur, however, in the Paradox Basin and Uncompahgre region to the west, and to some degree in the Front Range and Plains to the east. There, evidence of recent deformation seems to die out northward across the state.

Research on methods of dating soils is being carried out to aid in the dating of neotectonic features. Studies of the chronologic sequence of calcic soils in New Mexico show that the rate of carbonate accumulation through time has been relatively constant over intervals of 50,000 years or more. The morphology of calcic soils can indicate whether or not carbonate in the soil has undergone episodes of dissolution and removal, and thus indicate times of greater soil moisture. Mapping of pedocal-pedalfer boundaries on different aged surfaces also indicates the location of critical differences in soil moisture at different times. Non-calcic buried soils in areas of calcic soils would indicate wetter conditions in the past. Upper limits could thus be placed on downward percolation of soil water, and hence ground-water recharge, in arid basins during the wetter times of the Pleistocene.

The Sonoran zone of western Arizona and southeastern California has been internally stable for several million years, based on study of young faults, mountain fronts and late Cenozoic volcanics. The region is almost barren of young faults, in contrast to surrounding areas, and is marked by stable, pedimented, sinuous mountain fronts.

The possibility of a widespread Quaternary increase in the rate of tectonism is raised by a review of the Cenozoic history of northern Honshu, Japan, stimulated by the magnitude 7.4 (Richter) Miyagi-ken-oki earthquake of 1978 (Wentworth, 1980). A similar change in the rate of Hawaiian hot-spot migration is suggested by Shaw and others (1981). In most parts of the United States the possibility of any such change will be very difficult to resolve.

Reports

Heller, P.L., Wentworth, C.M., Poag, C.W., and Mergner-Keefer, Marcia, 1980, Episodic post-rift subsidence of the eastern U.S. continental margin (Abs.): Geological Society of America, Abstracts with Programs, v. 12, p. 445.

Wentworth, C.M., 1980, The tectonic and geologic setting (of the June 12, 1978 Miyagi-ken-oki earthquake, Japan), in Ellingwood, Bruce, ed., An investigation of the Miyagi-ken-oki, Japan earthquake of June 12, 1978: National Bureau of Standards Special Publication 592, p. 12-35.

Wentworth, C.M., and Mergner-Keefer, Marcia, 1980, Atlantic-coast reverse fault domain: probable source of east-coast seismicity (Abs.): Geological Society of America, Abstracts with Programs, v. 12, p. 547.

_____, 1981, Regenerate faults of small Cenozoic offset as probable earthquake sources in the southeastern United States: U.S. Geological Survey Open-File Report, 81-356, map scale 1:2,500,000.

References

Behrendt, J.C., Hamilton, R.M., Ackermann, H.D., and Henry, V.J., 1981, Cenozoic faulting in the vicinity of the Charlston, South Carolina, earthquake zone: Geology, v. 9, no. 3, p. 117-122.

Dames and More, 1976, Summary report on the in-progress seismic monitoring program at the North Anna site, January 21, 1974, through May 1, 1976: report submitted to Virginia Electric and Power Company (Vepco), representing results of the seismographic study required of Vepco by the Nuclear Regulatory Commission (then Atomic Energy Commission) in 1973 as Question 2.28 to the Preliminary Safety Analysis Report for North Anna 3 and 4 power reactors, 117 p.

Mixon, R.B., and Newell, W.L., 1977, Stafford fault system: structures documenting Cretaceous and Tertiary deformation along the Fall Line in northeastern Virginia: Geology, v. 5, p. 437-440.

Shaw, H.R., Jackson, E.D., and Bargar, K.E., 1981, Volcanic periodicity along the Hawaiian-Emperor Chain: American Journal of Science, Jackson Volume 280-a, part II, p. 667-708.

Computer Simulation of Geologic Stability of a Repository

By Herbert R. Shaw, Menlo Park, Calif.

Mathematical models are being developed to analyze the long-term risks of placing radioactive wastes in an underground repository. Starting from a particular geometric picture of a repository in its geologic and hydrologic setting and physical properties such as porosity, density, thermal expansion coefficient, effective viscosity of bedded salt (host medium for the wastes), and discharge rates of the aquifers, various parameters such as the area of the repository and thermal output of the waste can be varied and various possible causes of release of radionuclides examined in terms of their probability of occurrence with time.

The work described below was done in collaboration with Sandia Laboratories, Albuquerque, New Mexico, with funds transferred from the Nuclear Regulatory Commission.

Objective To establish the role of feedback behavior in the analysis of the geologic stability of any generic environment considered as a candidate for disposal of radioactive waste materials; and to demonstrate the effectiveness of geological simulation methods in describing the ranges of possible release times and transport times of radionuclides from a hypothetical reference repository in a bedded salt environment.

Approach Feedback relationships between physical phenomena that may influence the geologic stability of a nuclear waste repository are studied in relation to geometric studies of hydrologic transport paths through the repository environment. The approach uses the simulation language DYNAMO to explore mechanisms that will be adapted to the development of a network flow model by Sandia Laboratories. Conditions of instability, like creation of solution cavities in salt or regimes of high chemical transport rates, are identified.

Progress Data on faulting statistics in the conterminous United States have been systematized. It is found that faulting corresponds to general laws of branching processes analogous to laws of stream branching and lunar cratering. Numbers of faults follow an inverse power law of fault length with exponents around -2. Rate data also have been systematized and used to calculate diagrams of earthquake magnitudes versus frequency. There are several alternatives for magnitude-frequency relations based on faulting data, so the results are nonunique. The results, however, are also very sensitive to assumptions about numbers and lengths of faults, so comparison with observed magnitude-frequency plots can be used to infer possible slip distributions. In the absence of faulting data, the process can be reversed; and spectra of possible, though nonunique, fault patterns can be inferred.

New work on geologic systems simulation includes an overview of the geologic-technologic interaction between energy systems and regional or global processes of tectonics, volcanism, and heat flow.

Report

Shaw, H.R., Gartner, A.R., Sontag-Eng, C., and Casey, L., 1980, Methods of simulation analysis applied to questions of geological stability of a radioactive waste repository in bedded salt: U.S. Geological Survey Open-file Report 80-705, 69 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 simple 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 DOE operated sites.

In 1975 the Survey received direct appropriations to assume a new mission in the area of low-level wastes. The general purpose of this mission is to develop geohydrologic guidelines which can be used to establish technical

criteria for selecting, evaluating, licensing, and operating new low-level waste-disposal sites. This program was designed initially to be a 5-year endeavor, including field studies at disposal sites at Sheffield, Illinois; Maxey Flats, Kentucky; Beatty, Nevada; West Valley, New York; and Barnwell, South Carolina. To broaden the range of conditions under investigation, field studies were started in 1978 at the abandoned Argonne National Laboratory burial site in Illinois. A second phase of the program was designed to address specific aspects of the geohydrologic controls on radionuclide waste containment at some of these sites, and this activity will be continued for several more years.

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:

- o defining the geologic and hydrologic conditions at disposal sites that are pertinent to the subsurface leaching and migration of waste radionuclides in ground water
- o defining leach rates and source terms for modeling the transport characteristics of buried radionuclides
- o 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. 9).

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

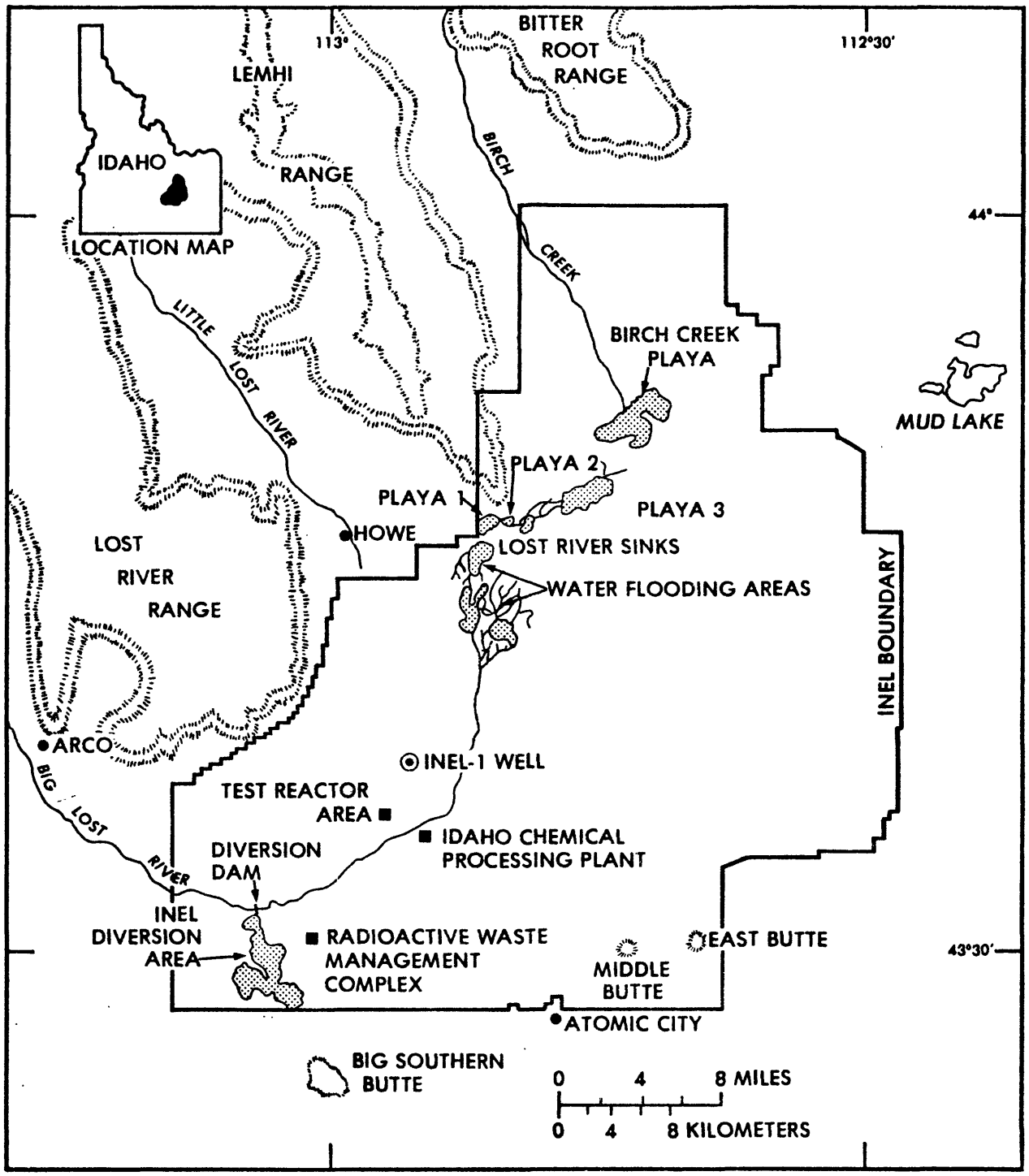

FIGURE 9.-Map showing selected facilities at the Idaho National Engineering Laboratory.

open to the Snake River Plain Aquifer. The aquifer, whose top is about 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.

Objective To describe the effect 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; and to provide consultation 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.

Progress The waste plumes of various constituents in the aquifer have been mapped periodically. The most mobile constituents have migrated downgradient (south) 12.2 km from the ICPP and TRA, covering an area of about 78 km^2 since disposal began in 1952.

Six radioactive waste products can be identified in the aquifer; tritium, strontium-90, iodine-129, cobalt-60, cesium-137, and plutonium. Tritium has migrated the farthest. The other waste plumes have migrated much smaller distances because they are subject to sorption reactions. For example, cesium-137 has migrated only 700 feet in 27 yr. There are five indicators of chemical waste migration in the aquifer; chloride, sodium, specific conductance, nitrate, and chromium. Comparisons of the plumes of various waste constituents indicate how hydrologic and geochemical processes control solute transport in a fractured basalt aquifer.

Aquifer parameter values that would result in a conservative simulation of waste solute transport were used to construct a digital mathematical model in 1974. Verification of the model is needed in the southern part of the INEL where waste products could eventually leave the INEL site. Eight new wells were drilled to monitor the movement of waste products in this part of the aquifer. The waste products have not moved quite as far as the model predicted. Although the simulation of transport is essentially correct, the model needs to be modified to incorporate new information on field conditions. This refinement will result in an improvement in the accuracy of predictions of future waste movement.

A Ground-Water Data Acquisition System (GWDAS) was developed to make rapid repetitive, remote measurements of a variety of properties related to waste transport in the aquifer near a disposal well for radioactive and chemical wastes.

This system provides an independent means of monitoring waste quantities injected and traces the movement of pulse concentrations of waste products through the aquifer. The information obtained should improve our concepts of solute transport.

In conjunction with the GWDAS, an automatic tritium monitoring system was designed and built. This surface monitor will analyze the tritium content of samples collected from a pumped well and provide detailed information on the movement of tritium bearing waste products in the aquifer. Both of these systems will be useful in studying subsurface waste transport in other areas.

Four wells were drilled to the Snake River Plain aquifer around the RWMC where solid radioactive wastes have been buried and stored since 1952. The wells are used to monitor the downward migration of radioactive waste products in the aquifer. Special precautions were taken to ensure that surface contaminants did not enter the wells by water, wind, or from contaminated equipment. A submersible pump and a continuous water-level measuring device (differential-pressure transducer) were installed in each well. After the equipment was installed, the well heads were sealed permanently to prevent the influx of contaminants. Windmill-charged storage batteries provide power, and the system is reliable and sensitive.

A reconnaissance survey of organic solutes was made in selected wells penetrating the Snake River Plain aquifer and perched bodies of ground water. The survey was aimed at evaluating the extent of organic chemical contamination. Water from wells was sampled for dissolved organic carbon (DOC), pesticides, herbicides, and for volatile and semi-volatile organic compounds. The DOC analyses indicated no high levels (>20 mg/L) of organic chemical contamination. No significant amounts of pesticides or herbicides were found. The analyses for volatile and semi-volatile compounds did not indicate the presence of hazardous organic contaminants.

Reports:

Bagby, J.C., Jensen, R. G., and Barraclough, J.T., 1981, a wind-powered, ground-water monitoring installation at a radioactive waste disposal site in Idaho, Open-File Report 81-493, 28 p. (IDO-22059).

Barraclough, J. T., 1979, Geohydrology of the eastern Snake River Plain, Idaho, as shown by a two-mile-deep well (Abs.), American Geophysical Pacific Northwest Regional meeting, Bend, Oregon, September, 1979.

Barraclough, J.T., 1980, Distribution of radioactive waste in the Snake River Plain aquifer at the Idaho National Engineering Laboratory (Abs.), American Water Resources Association Conference on Groundwater, November, 1980.

Barraclough, J.T., Lewis, B.D., and Jensen, R.G., 1981a, Hydrologic conditions at the Idaho National Enginering Laboratory, Idaho, emphasis: 1974-1978: U.S. Geological Survey Water-Resources Investigations 81-526, 77p (IDO-2060).

Barraclough, J.T. Lewis, B.D., and Jensen, R.G., 1981b, Hydrologic conditions at the Idaho National Engineering Laboratory, Idaho, emphasis: 1974-1978: U.S. Geological Survey Water-Supply Paper 2192, 131 p.

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 of by burial in shallow trenches since the early 1940's. To date, six burial grounds (solid waste disposal areas) have been used (fig. 10). 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; 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.

Progress During the early years of this investigation, field efforts were devoted to obtaining data that describes water movement at the four largest burial grounds, inasmuch as most data from previous studies was unavailable. Much of the effort during fiscal year 1980 was to prepare reports containing well data and ground-water-level data in and near these four areas. Problems in developing a computer program to display the data graphically, initially delayed publication of the reports, but the problems now have been partially overcome.

Secondary emphasis has been on field work, principally in Burial Ground 5. Slug tests were made of a number of shallow wells in the disposal site to obtain transmissivity coefficients of the weathered material overlying bedrock. A comparison of the results with transmissivity coefficients of the bedrock determined by aquifer pumping tests in one part of the site, indicates that most of the residuum has a moderately higher transmissivity. However, the values for the residuum would still be described as "low", indicating that ground water moves relatively slowly through the undisturbed parts of the residuum.

Water levels continued to be monitored in a small number of wells, including a multidepth piezometer cluster in the bedrock below Burial Ground 5. The year-long record shows that only minor differences in water levels--or hydrostatic pressures--were measured between the shallow wells in the residuum and the piezometers at depths of 30 and 43 m. The water level in the 61-m piezometer, however, stands about 2.4 m below that of the other wells. This indicates that ground water has the potential to move

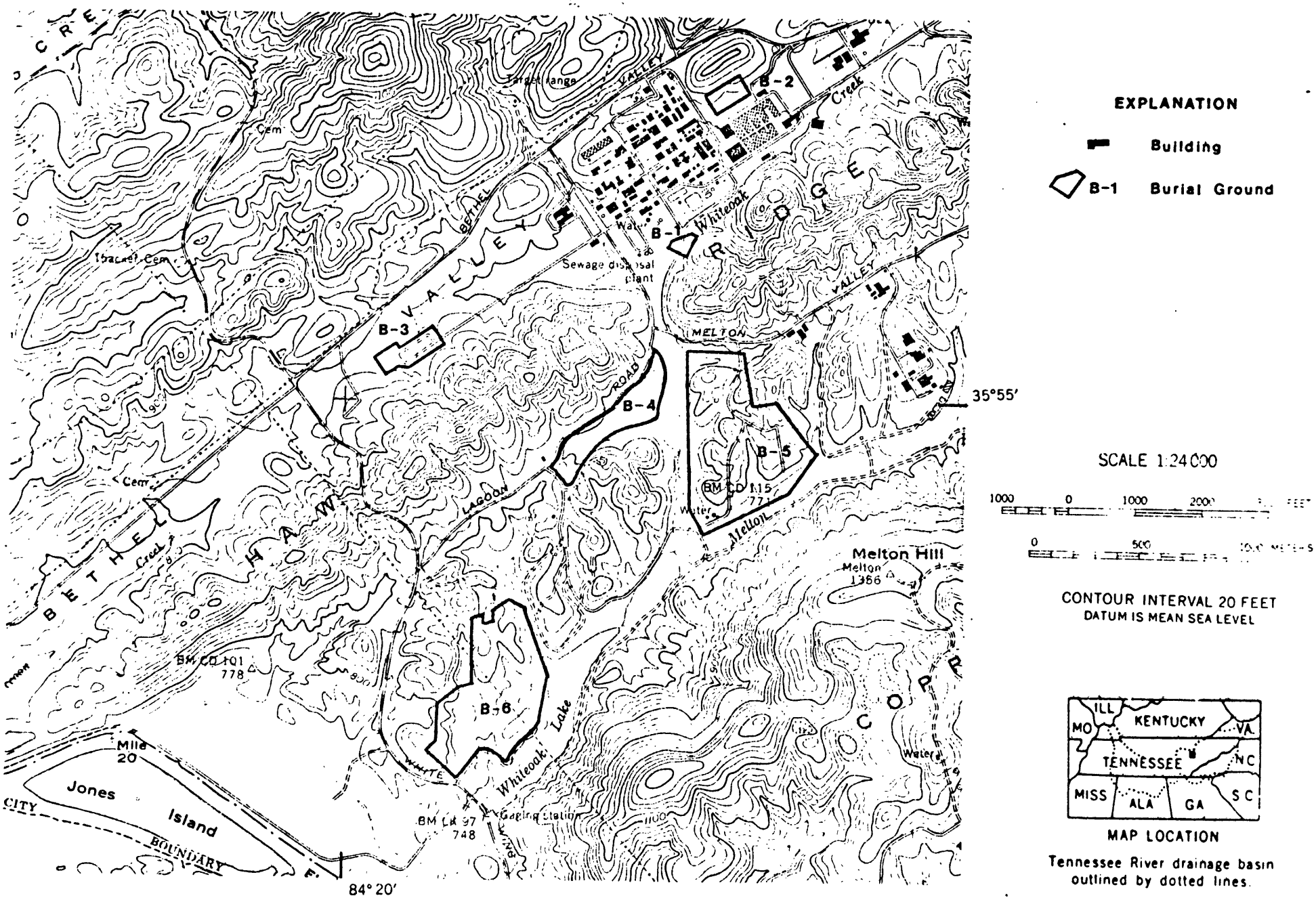

FIGURE 10.-Location of waste-burial grounds at Oak Ridge National Laboratory, Tennessee.

to the bedrock from the overlying materials, provided that flow pathways exist through the bedrock. The record also shows that the annual range in water-level fluctuations in the piezometers is less than that of the shallow wells and the changes are more gradual than those of the shallow wells. These characteristics suggest that flow pathways exist in the bedrock but they tend to be quite narrow and few in number.

To provide supplemental information on potentials at another point, a single packer was installed in an older well in Burial Ground 5. Cesium-137 had been identified previously in, or very close to, the well bore at a depth of about 43 m. At each of four packer settings the hydrostatic pressure below the packer is less than that above it, at least to a depth of 37.5 m, the deepest point at which the packer could be set. As with the previously mentioned site, ground water in the residuum has the potential for downward movement into the bedrock, and the well, which is uncased below the top of bedrock, serves to transfer water from the upper to the lower strata. Although it would be difficult if not impossible to prove the specific path taken by the cesium-137, the data also demonstrate that if the contaminant had entered the well in the upper part of the uncased section, conditions within the well would encourage downward movement through the well bore. Thus, the presence of the radionuclide at a depth of 30 m or more below the top of bedrock does not in itself prove that the contaminant was transported through bedrock. The possibility for making ambiguous interpretations of this type could be avoided by sealing the annulus between the casing and borehole wall of observation wells used for sampling water or measuring water levels.

Additional information about the bedrock character in the waste-disposal areas was obtained from a complete suite of geophysical logs of a newly constructed well south of the south end of Burial Ground 5 at a site for the injection of grout-waste slurries into hydraulically fractured shale. The well, 301 m deep, penetrates the same formations of the Conasauga Group (Cambrian age) that underlie the nearby burial grounds. The logs are particularly useful when used in conjunction with similar logs of other wells in the disposal areas, for they offer for the first time a means of correlating the bedrock strata from one well to another.

Report

Webster, D.A., Beatty, J.S., Benjamin, P.M., and Tranum, W.M., 1980, Water-level data for wells in Burial Ground 6, Oak Ridge National Laboratory, Tennessee, 1975-1979: U.S. Geological Survey Open-File Rept. 81-0057, 102 p.

Sheffield, Illinois

By James B. Foster, Champaign, Ill.

This commercially operated low-level disposal site is located in northwestern Illinois near the town of Sheffield. It covers about 8 ha of rolling terrain with well established drainage and is bordered on the east, north,

and west by strip mined land. The climate ranges from warm and humid in the summer (average temperature 22.2°C) to quite cold in the winter (average temperature -7.5°C). Average annual precipitation is 890 mm.

Waste burial in the first trench began in August 1967. Twenty-one trenches, comprising all of the usable space, were filled through April 1978. As of March 1978, 83,147 m^3 of waste had been buried.

Objective To study the hydrology and geology of the site in sufficient detail to provide the means of appraising the suitability of this type of hydrogeologic environment for disposal of low-level radioactive waste.

Approach The investigation has been divided into several phases, starting with the use of numerous test wells to define in detail the stratigraphy of the unconsolidated formations and the hydrology of the unconfined formations. Hydraulic well testing was used to determine hydraulic conductivity of the strata. Numerical modeling is being used to analyze the three-dimensional ground-water flow system. Detailed analysis of geologic and hydrologic conditions directly beneath burial trenches is being accomplished through studies in a specially constructed tunnel. Other approaches being used include special borehole geophysical logging techniques and geochemical analyses.

Progress The lithologically complex glacial deposits underlying the site are generally of low permeability, but they contain bodies of relatively high permeability which could provide avenues for migration of radionuclides. One such potential flow route is the saturated section of the pebbly sand unit which underlies most of the site. A ground-water flow model indicated that this unit was the principal control on ground-water flow from the site. The unit extends off site near the center of the east boundary. Tritium from the waste was first detected in water samples from a well in the unit after the high water-level period in the spring of 1979.

One other permeable unit of less importance has been identified. It is located near the southeast corner of the site and is composed of loess and clayey silt. Tritium, apparently from one trench in this part of the site, has been detected in water from observation wells located in the flow path.

Report:

Foster, J.B., and Erickson, J.R., 1980, Preliminary report on the hydrogeology of a low-level radioactive-waste disposal site near Sheffield, Illinois, Open-File Report 79-1545, 87 p.

Maxey Flats, Kentucky

By Harold H. Zehner, 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.

Streamflow and water-quality data will be used to describe the surface and near-surface hydrologic system at a depth of 1 to 2 m. Water from trenches is also being analyzed for standard and radiometric water-quality properties. Ground-water-flow models are being used to test and refine concepts of the flow system.

Progress Ground-water flow at the burial site is probably controlled by topography and ground-water mounding in the trench area, so that flow is away from the topographic axis of the site toward the adjacent valleys (Zehner, 1980). The rocks contain alternating saturated and unsaturated intervals, which probably result from the fact that many fractures terminate at bedding planes. The result is that the lower (saturated) parts of the fractured rock units form perched water bodies which flow to discharge areas.

A two-dimensional, cross-sectional flow model of the burial site shows that about 70 percent of the water entering the top of the plateau discharges to the hillsides through the upper 24-m section of rock (Pollock and Zehner, 1981). Water infiltrating the deeper, less active, part of the flow system also eventually discharges to the adjacent hillsides. Hillsides are largely covered with colluvium, and alluvium covers the valley bottoms. Mean annual base flow is 6.8 m^3/s in the drainage basin below the burial site. At least 95 percent of the base flow originates from infiltration, to a shallow depth, of rainfall and runoff into the colluvium and alluvium. A maximum of 5 percent of base flow is from bedrock in the drainage basin, and only about 0.6 percent is from bedrock underlying the trench area. The small discharge from bedrock underlying the trench area is considerably diluted by overland flow. The

ratio of mean monthly discsharge from bedrock to mean monthly stream discharge is about 1/10,000.

Water-quality data from shallow trenches and wells indicate that radioactive materials have moved from trenches, primarily through the lower sandstone marker bed. Cobalt-60 and manganese-54 have been detected in this bed at a maximum distance of 82 m from the nearest burial trench. Tritium was the only radionuclide detected in water from wells in alluvium and was probably due to air transport from the trench-water evaporator (Montgomery and others, 1977). Several radionuclides were detected in stream water and, most probably, originated from overland runoff carrying contaminated soil from the surface of the burial site.

Reports

Pollock D.W., and Zehner, H.H., 1981, A conceptual analysis of the groundwater flow system at the Maxey Flats radioactive waste burial site, Fleming County, Kentucky, in Little, Craig, Modeling and Low Level Waste Management: An Interagency Workshop: Oak Ridge National Laboratory, p. 197-213.

Zehner, H.H. 1980, Preliminary hydrogeologic investigation of the Maxey Flats radioactive waste burial site, Fleming County, Kentucky: U.S. Geological Survey Open-File Report 79-1329.

Reference

Montgomery, D.M., Kolde, H.E, Blanchard, R.L., 1977, Radiological measurements at the Maxey Flats radioactive waste burial site-1974 to 1975: U.S. Environmental Protection Agency, EPA-520/5-76/020.

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.

Objective The objective was to determine the downward flux (recharge rate) of moisture through the extremely dry unsaturated zone beneath the burial trenches of the site.

Approach Determination of soil-moisture movement requires data on soil-moisture content, soil-water suction, and unsatureated hydraulic conductivity. Although the coarse texture of the alluvial deposits makes it difficult

to obtain any reliable measurements of hydraulic conductivity, reasonable estimates can be made from data obtained in other research. Data on soil-moisture content and soil-water suction are being collected on a continuing basis, and are being compiled for an analysis of infiltration based on field measurements. Volumetric soil-moisture content is measured to depths of 6 m using a neutron soil-moisture meter. Soil-water suction, between depths of 3 to 10 m, is being measured indirectly using psychrometric methods. Estimates of long-term infiltration are also being made using an evaporation/infiltration model.

Progress Volumetric soil moisture to depths of 4 m varied from 4-10 percent but commonly was in the range of 6-8 percent. Soil-water potential, measured to depths of 3-10 m using thermocouple psychrometers, ranged from -13 bars to -70 bars. Unsaturated hydraulic conductivity computed from laboratory analyses of representative samples ranged from 2.1×10^{-4} to 4.5×10^{-13} cm/d.

Data from evaporation studies over a 2-yr period were used to calibrate a numerical model of long-term precipitation data that was used to estimate annual water budgets for a 15-yr period (1962-76). This analysis demonstrated that there is a potential for deep percolation despite the high annual evaporative demand, and it was used to predict the time of the year and the preceding soil-moisture and precipitation conditions required for such deep percolation. Soil-moisture profiles obtained monthly over an 18-mo period demonstrated that deep percolation occurred. The observed preceding conditions of soil moisture and precipitation and the time of year when the percolation occurred, support the interpretation of the model analysis which was made on the basis of long-term records.

Calculation of downward moisture movement through the waste-trench-backfill material, based on highly simplifying assumptions, suggests that moisture penetration may have been as deep as 6 m from 1963-80, but moisture requirements for this depth of penetration far exceed the availability. Steady-state downward moisture movement below a depth of 20 m, computed for an unsaturated conductivity of 1×10^{-5} cm/d, would be on the order of 4 cm/1000 yr.

West Valley, New York

By David E. Prudic, Carson City, Nev.

About 50 km south of Buffalo, New York, near the hamlet of West Valley, are the facilities of the Western New York Nuclear Service Center. Among these facilities is a State licensed burial ground for commercial low-level radioactive waste. The burial area (4 ha) contains a series of burial trenches that average 6 m deep, 10 m wide, and 180 m long.

The site is situated on glacial till and related fluvial-lacustrine deposits range in grain size from clay to gravel and average about 30 m in thickness at the burial ground. The waste-burial trenches are excavated in a clay-rich till with relatively low hydraulic conductivity.

In addition to the USGS study of geohydrologic factors controlling the subsurface movement of radioisotopes, the New York State Geological Survey, under contract with the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, began a complementary study in 1975 to evaluate all other factors related to radioisotope migration at the site.

Objective The objective was to describe the three-dimensional characteristics of the ground-water flow system and determine the extent, rate, and concentration of waste radionuclide movement from the trenches.

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

Progress The hydraulic conductivity of the unfractured clay-rich till at the burial site was evaluated with field and laboratory techniques. In general, horizontal hydraulic conductivity values measured from core samples agreed with values calculated from slug tests of piezometers. Slug tests were analyzed by two methods; one assumed horizontal flow to the piezometer screen (Cooper and others, 1967), the other assumed spherical, isotropic flow (Hvorslev, 1951). The average value of horizontal hydraulic conductivity, determined from slug tests of 12 piezometers, was 6×10^{-8} cm/s by the first method and 2×10^{-8} cm/s by the second.

Nine core samples were analyzed for horizontal and vertical hydraulic conductivity; horizontal values averaged 3.8×10^{-8} cm/s, vertical values averaged 6.2×10^{-8} cm/s which suggests little anisotropy. Consolidation tests were run on four core samples and, in general, the vertical hydraulic conductivity decreased by 40 percent at a pressure increase from near atmospheric to that which would prevail at a depth of 30 m. This suggests that the hydraulic conductivity of the till decreases with overburden pressure.

In general, ground water moves downward through the 30-m-thick sequence of clay-rich till, then laterally northeast about 0.6 km to Buttermilk Creek through lacustrine sands and silts whose upper portion is unsaturated. A two-dimensional finite-element model developed by Reeves and Duguid (1975) was used to evaluate factors controlling ground-water flow in the till along three vertical sections at the burial ground. The most accurate computer simulations of measured heads in piezometers were obtained by subdividing the model sections into four geologic units, each internally isotropic but differing in hydraulic conductivity to reflect fracturing near land surface and increased consolidation at depth (Prudic, 1981).

The best computer simulations suggest that fractured till near land surface is 3 to 10 times more permeable than the unfractured till at depth, and that the hydraulic conductivity of the unfractured till decreases 15 to 20 percent with depth because of consolidation by overburden pressures. The rate of ground-water flow through the till average 1 to 3 cm/yr. The model accurately simulated the changes in head that followed removal of water from one of the trenches. Specific storage values required to cal-

ibrate the model for transient conditions agreed well with values derived from four consolidation tests of till samples (Prudic, 1981).

All the trenches contain standing water, and water levels have risen persistently in most trenches. Computer simulations suggest that water leaving the trenches would not reach nearby intermittent streams bordering the burial ground unless the trench water level rose into the reworked till that covers the trenches. Deformed thin lenses of silt and sand constitute about 7 percent of the till mass but rarely exceed a few meters in lateral extent; simulations suggest that under prevailing hydrologic conditions, even a laterally extensive lens whose presence was unsuspected would not conduct trench water to the nearby streams.

Tritium migrated less than 3 m laterally and downward from the trenches in the firsr 7-11 yr after the trenches were completed (Prudic, 1979). Calculations of the extent of tritium migration beneath the trenches, using analytical and numerical techniques, suggest that hydrodynamic dispersion controls the migration of tritium and is approximately 200 cm^2/yr. The maximum distance tritium would migrate beneath the trenches, assuming a constant trench-water level and a constant flow velocity of 2 cm/yr would be about 11 m and it would take about 200 yr to reach a steady-state flow condition. Other radionuclides have migrated less than 1 m downward.

Reports

Prudic, D E., 1980, Permeability of covers over low-level radioactive waste burial trenches, West Valley, Cattaraugus County, New York: U.S. Geological Survey Water-Resources Investigations 80-55. 41 p.

Prudic, D.E., 1981, Computer simulation of ground-water flow at a commercial radioactive waste landfill near West Valley, N.Y., in Little, Craig (ed), Modeling and Low Level Waste Management: An Interagency Workshop: Oak Ridge National Laboratory, p. 215-248.

Randall, A. D., 1980, Glacial stratigraphy in part of Buttermilk Creek valley, in LaFleur, R. G. (ed), Late Wisconsin stratigraphy of the upper Cattaraugus basin: Guidebook, 43rd Annual Reunion, Northeast Friends of the Pleistocene, p. 40-62

References

Cooper, H.H., Jr., Bredehoeft, J. D. and Papadopulos, S.S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, p. 263-269.

Hvorslev, M. J., 1951, Time lag and soil permeability in ground-water observations: Vicksburg, Miss., U.S. Army Corps of Engineers Experiment Station, Bulletin 36, 50 p.

Prudic, D.E., 1979, Core sampling beneath low-level radioactive-waste burial trenches, West Valley, Cattaragus County, New York: U.S. Geological Survey Open-File Report 79-1532, 55 p.

Reeves, Mark, and Duguid, J. O., 1975, Water movement through saturated-unsaturated porous medis--a finite-element Galerkin model: Oak Ridge National Laboratory, ORNL-4927, 232 p.

Barnwell, South Carolina

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

The commercially operated radioactive waste burial site near Barnwell, South Carolina continues to be the only operating burial site in the eastern United States. As a result of an Executive Order by the Governor to gradually reduce the monthly volume of waste buried in South Carolina to 2,832 m^3 by October 1981, only about 50 percent of the country's waste is currently being shipped to South Carolina. The solid waste is buried in the upper 6 to 7 m of unconsolidated clayey sand of Miocene age.

The water table is generally at a depth of about 9 to 13 m. Ground-water recharge occurs locally from precipitation. Precipitation averages about 119 cm/yr and it is estimated that about 40 percent recharges the ground-water system.

Objective The objective was to describe quantitatively soil-moisture migration and ground-water flow at the disposal site and assess the principal geohydrologic factors affecting radionuclide migration in unconsolidated coastal plain strata.

Approach Conventional field methods and numerical modeling techniques are being used to analyze the hydrologic system at the burial site. Special soil-moisture monitoring techniques will be used to determine soil-moisture behavior in the unsaturated deposits at and near the burial trenches.

Progress A digital model was used to simulate ground-water flow. The model is a three-dimensional representation of the flow system, and it uses a finite-difference technique to solve the ground-water flow equation. The model was calibrated primarily by means of a steady-state analysis in which discharge to streams was simulated, and recharge was assumed to be areally distributed. Calibration consisted of adjusting values of transmissivity and interlayer flow throughout the model until the observed configuration and position of the potentiometric surfaces and stream base flows were duplicated.

The calibrated model was used to construct potentiometric contours for part of the deepest saturated strata (50-150 m) where data were insufficient; this aided in defining better the flow patterns from the waste-burial site to points of discharge. Based on data obtained from the hydrologic model, it was calculated that the average water velocity in the saturated clayey sediments in the depth interval 9-18 m was about 12 mm/d and that it would take about 220 yr for water to travel from the burial site to the nearest point of discharge (986 m). The average water velocity in the upper most permeable sands (from about 18-50 m) was computed to be about 76 mm/d for a travel time of about 40 yr from the burial site to the nearest stream (1,097 m). The deepest saturated strata are recharged by precipitation.

Ground water in these strata flows laterally about 4,880 m to a stream discharge area. The average water velocity in the permeable sands was computed to be about 130 mm/d for a travel time of about 100 yr to the discharge area.

Argonne National Laboratory Site, Illinois

By J.C. Olimpio, Champaign, Ill.

One of the world's first low-level radioactive waste-disposal sites is located on former grounds of the Argonne National Laboratory, in the Palos Forest Preserve, about 22 km southwest of Chicago, Illinois.

Radiometric analyses of unconsolidated glacial deposits and ground water beneath the burial ground (Golchert and Sedlet, 1977) show that tritium has migrated downward through 40 m of drift to an underlying dolomite aquifer. Tritium concentrations in water from the Palos Forest Preserve bedrock wells, 360 m downgradient from the burial site, range from 200 to 1,400 pCi/l annually. Samples from these wells have not contained detectable concentrations of any other waste nuclides.

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 areas of the United States, a study was initiated to define the hydrologic and geologic properties of the drift which control ground-water flow and solute transport, and to determine the distribution and concentration levels of tritium beneath the site.

Approach The study, which was started in 1978, is based on conventional drilling, sampling, well testing, and geochemical analyses. Drilling and construction of a network of monitoring piezometers is completed. Periodic collection of water samples from the piezometers is under way. A simplified digital ground-water flow model has been used to help evaluate factors controlling flow near the site (Olimpio, 1980).

Progress The glacial drift beneath Plot M is a stratified sequence of clay- and silt-rich sediments that contain thin, interstratified sand lenses. The upper strata are clay-rich, contain numerous sand lenses and sand partings, and are infrequently fractured. In contrast, the lower strata are silty and sandy, do not contain sand lenses, and are not fractured. Numerous field- and laboratory-derived values of hydraulic conductivity of the drift (vertical and horizontal) vary little, ranging from 1.0×10^{-6} to 1.0×10^{-8} cm/s. However, the variation in geologic properties of the drift suggests that the bulk hydraulic conductivity of the upper strata is higher than that of the lower strata.

A tritium plume, a contaminated zone in the drift in which tritium concentration levels exceed 1,000 pCi/L. extends northward from the burial ground at least 50 m and vertically downward to bedrock. The center of the plume is approximately 15 m beneath the burial ground and the size, shape, and concentric pattern of tritium concentration values of the plume indicate that:

(1) the burial ground is no longer releasing tritium to the drift

(2) the plume moves as a single slug

(3) the primary direction of plume movement is vertically downward.

Sorption experiments to determine the distribution coefficient (Rd) of tritium on samples of drift indicate that tritium travels with ground water. The results also show that tritium is not significantly retained by these clay- and silt-rich sediments. A small amount of tritium may be reacting and exchanging with bound H or OH ions in the clay and silt.

Report

Olimpio, J. C., 1980, Low-level radioactive waste burial at the Palos Forect Preserve, Illinois, Part I. Preliminary finite-difference models of steady state ground-water flow: U.S. Geological Survey Open-File Report 80-774, 40 p.

Reference

Golchert, N.W., and Sedlet, Jacob, 1977, Radiological Survey of Site A and Plot M: Argonne National Laboratory Open-File Report, prepared for the U.S. Energy Research and Development Administratin, 89 p.

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.

Objective The objective was to (1) define the limitations of current chemical models, and (2) improve the reliability of current models to predict precipitation, dissolution, complexation, and bioavailability of elements in both contaminated and uncontaminated natural waters.

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, compilation and evaluation of thermodynamic data used in speciation calculations, and investigations of field sites where water-mineral reactions can be observed directly and analytical and theoretical calculations can be tested.

Progress Occurrences of aluminum precipitation in stream waters have been found which can be used to test our modeling capability. These precipitates are amorphous and composed primarily of aluminum, sulfate, and water. They provide very large surface areas for the coprecipitation of radioisotopes and other trace elements. Thermodynamic data on major forms of aluminum have been compiled and partially evaluated for chemical equilibrium computations. Solubility and stability relations have been derived from published data to show the conditions of formation of aluminum sulfate minerals.

The SKBF/KBS (Swedish Nuclear Fuel Supply Company/Nuclear Fuel Safety Project) operated for the Swedish Nuclear Power Utility Industry, has requested assistance on its hydrochemical investigations of deep groundwaters at the Stripa Mine site. This is an experimental site for studying the suitability of the crystalline igneous rock environment for developing a radioactive waste repository. Information on the major- and trace-element geochemistry of these ground waters is critical for making decisions concerning the suitability of this environment for a repository. Methodologies have been developed for sampling and analysis of major, minor, and trace elements in ground waters from granitic rocks, to be sampled from vertical and horizontal boreholes. The results of this study will be coordinated with those of isotope geochemists from Canada, England, Switzerland, and Sweden to develop an overall picture of the age, source, and geochemical evolution of these ground waters. The methodology and concepts developed should be transferable to similar studies in the United States.

Reports

Ball, J. W., Nordstrom, D. K., and Jenne, E. A., 1980, Additional and revised thermochemical data and computer code for WATEQ2--A computerized chemical model for trace and major element speciation and mineral equilibria of natural water: U.S. Geological Survey Water Resources Investigations 78-116, 109 p.

Nordstrom, D. K., 1980, The effect of sulfate on aluminum concentrations in natural waters: some stability relations in the system Al_2O_3-SO_3-H_2O

at 25°C and 1 atm, in Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 492.

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 Results of continuing studies on manganese oxide precipitation were presented at the 3rd International Symposium on Water-Rock Interaction, Edmonton, Alberta, Canada, and at the American Chemical Society National Meeting in Las Vegas, Nevada. A method for evaluating the rate of managanese oxide precipitation in open natural systems was described, which uses rate data obtained in laboratory simulations. Past studies of this type have used batch techniques that are not realistic models of real-world situations. A paper summarizing this work has been accepted for 1981 publication by Geochimica et Cosmochimica Acta.

Manganese oxidations occurring at low temperature (less than 10°C) produce a different form of oxide than those occurring near 25°C. The low temperature oxide had not been prepared in pure form before, and it has been shown to be less stable thermodynamically than the higher temperature species. The initial oxide in these systems is an unstable intermediate form which spontaneously oxidizes to a final stable form in open laboratory systems that simulate natural ones. The stability of the intermediate form is important because the forms of lower stability provide a stronger thermodynamic driving force for metal ion coprecipitation mechanisms. An understanding of these mechanisms will aid in evaluating manganese oxides as possible scavengers of radionuclides.

An evaluation of experimental and theoretical determinations of smectite clay mineral stabilities was presented in a paper given at the American Chemical Society National Meeting in Las Vegas, Nevada. Accurate quantitative expressions of smectite stability, as the Gibbs free energies of formation for particular minerals, would be useful in modeling the formation and persistence of this important class of cation exchangers in soil and sediment systems. A manuscript comparing methods for evaluating free energies of smectites is being submitted for publication.

Reports

Hem, J.D., 1980, Rates of manganese oxidation in aqueous systems (Abs.): Proceedings, 3d International Symposium on Water-Rock Interaction, July 12-24, 1980, Edmonton, Alberta, Canada, p. 57.

Hem, J.D., Roberson, C.E. and Fournier, R.B., 1980, Stability of beta-manganite and manganese oxide deposition from spring water (Abs.): American Chemical Society, Division of Environmental Chemistry, 180th National Meeting, August 24-29, 1980, p. 473-475.

May, H.M., Helmke, P.A. and Jackson, M.L., 1980, Aqueous solubility and thermodynamic stability of montmorillonites (Abs. GEOC 39): American Chemical Society, Division of Geochemistry, Chemical Congress of the North American Continent, Las Vegas, Nevada, August 25-28, 1980.

Geochemical Kinetics

By Hans C. Claassen, Lakewood, Colo.

The interaction of the solid and liquid phases in natural ground-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. Values for all the above properties can be estimated with existing techniques except for the effective surface area of rock material in the aquifer. Quantitative information on the surface area is required, however, to model mass transport (including pollutants) in a realistic fashion.

Objective To develop a means for estimating the effective surface area of rock material in aquifers through analysis of its influence on geochemical reactions and to apply the results to improve our understanding of the functional characteristics of selected hydrologic regimes.

Approach The approach was to apply the results of research, previously reported, to two ground-water systems, one in New Mexico and the other in southern Nevada. In both cases, geochemical-kinetic calculations were made in order to simulate the observed ground-water quality. The particular set of assumptions that was made for the simulation closest to observed ground-water quality was then used to deduce valuable new information about the flow regime.

Progress The principles of geochemical kinetics were applied in studies of two-ground water systems, one in New Mexico composed of soluble calcium sulfate and the other in southern Nevada composed largely of tuffaceous alluvium. Results of the first study (Claassen, 1981) showed that solution channels were the primary conduits by which surface water recharged the aquifer, and that these conduits were growing at the rate of a few tens of millimeters per year. This information will be valuable in estimating the amount of surface area available for sorption or ion exchange in the ground-water system. The methodology employed in the study should be applicable to studies of the radionuclide retention characteristics of rock systems

associated with potential radioactive waste repository sites. The specific information obtained will be valuable in evaluating the potential for leakage at a damsite being planned on the Pecos River upstream from Carlsbad, New Mexico.

The second study demonstrated the importance of flood runoff in recharging alluvial aquifers in arid environments. Initially, the quality of ground water in tuffaceous alluvium was expected to be the same regardless of whether the water had originated from direct local recharge through the alluvium or from underlying tuff which had been recharged in more distant upland areas. However, analysis of ground water known to have been derived from recharge in the highlands showed that this water had undergone a greater extent of reaction than the water in the alluvium. Thus it was concluded that water in the alluvium could not have flowed from the highlands, as previously hypothesized, but rather had originated as local recharge.

Radioactive and stable-isotope data support the new hypothesis of direct recharge from runoff and help to determine the times during which climatic conditions in southern Nevada were favorable for ground-water recharge. This analysis will be useful in the evaluation of potential radioactive waste repositories at the Nevada Test Site.

Reports

Claassen, Hans C., 1981, Estimation of calcium sulfate solution rate and effective aquifer surface area in a ground-water system near Carlsbad, New Mexico: Ground Water, v 19, no. 3, p. 287-297.

White, A.F., and Claassen, Hans C., 1980, Kinetic model for the short--term dissolution of a rhyolitic glass: Chemical Geology, v. 28, p. 91-109.

White, A.F., Claassen, Hans C, and Benson, Larry V., 1980, The effect of dissolution of volcanic glass on the water chemistry in a tuffaceous aquifer, Rainier Mesa, Nevada: U.S. Geological Survey Water-Suppy Paper 1535-Q, 34 p.

Modeling Mineral-Water Reactions

By L. N. Plummer, Reston, Va.

Objective The migration of dissolved waste radionuclides or any other solutes in ground water is controlled in part by chemical reaction in the mineral-solution system. The principal objectives of this study are to understand the kinetics of chemical reaction systems.

Approach A weight-loss method has been adapted to study dissolution rate of single crystals suspended by platinum wires in known solutions. The solution pH is kept constant using automatic titrations. Numerical simulation techniques are being used to model thermodynamic chemical reactions in aqueous-mineral systems. Glass electrodes are used in thermodynamic

studies of aqueous solutions. Carbonate reactions are investigated as a function of CO_2 partial pressures and temperature at 1 atm total pressure. Weight loss is measured to within 0.2 μm using an electronic balance. This method has proved far more reliable than batch experiments using a suspension of stirred particles.

Progress A report describing the computer code PHREEQE was published. This computer code is capable of predicting the outcome of hypothetical mineral-water reactions. The program has a wide range of potential applications, for example in predicting controls on actinide chemistry in ground-water environments.

In another study (with D.C. Thorstenson and D.L. Parkhurst), the logic of evaluating chemical reactions from available ground-water chemical and isotopic data was critically evaluated. An electron transfer equation was combined with mass-balance equations so that amounts of minerals dissolved and precipitated in ground water involving multiple oxidation states (such as with the actinides) could be predicted. An application of the reaction identification logic to ground-water chemical and isotopic data from Florida indicates a net reaction of de-dolomitization (dolomite dissolution with calcite precipitation) driven irreversibly by gypsum dissolution with minor sulfate reduction, ferric hydroxide dissolution, and pyrite precipitation. The results indicate the Floridan aquifer is open to both CO_2 and organic matter in central Florida.

The kinetics of aragonite ($CaCO_3$) dissolution were investigated by E. Busenberg using the weight-loss method. The reaction mechanisms are identical to those found for calcite ($CaCO_3$) dissolution. A significant backward reaction involving HCO_3^- on $CaCO_3$ surfaces was quantified.

Other work with (E. Busenberg) involved the thermodynamics of the chemical system $CaCO_3$-CO_2-H_2O at 1 atm total pressure and temperature to at least 90°C. The thermodynamic literature on the CO_2-H_2O system was critically evaluated to approximately 300°C and temperature-dependent expressions for the pertinent carbonate equilibria derived. The association constant for formation of the ion pair $CaHCO_3^+$ was measured potentiometrically at 4° and 25°C and from aragonite solubility as a function of PCO_2 between 4° and 80°C. The solubilities of calcite, aragonite, and vaterite were measured in CO_2-H_2O solutions between 0 and 90°C. As a result of these studies calcium carbonate reactions in a wide variety of environments ranging from uranium mill tailings to ground water to geothermal reservoirs may be reliably evaluated and predicted over a wide range of temperatures. Thermodynamic calculations in the carbonate system were further tested by comparing the thermodynamic equilibrium constants for calcite and aragonite with the apparent constants measured in sea water. The comparison, made possible by calculation of total individual ion activity coefficients of calcium and carbonate in sea water, shows good agreement between thermodynamic and apparent constants of calcite and aragonite at 25°C.

Reports

Parkhurst, D. L., Thorstenson, D.C., and Plummer, L. N., 1980, PHREEQE-A computer program for geochemical calcuations: U.S. Geological Survey, Water Resources Investigations, 80-96, 210 p.

Plummer, L. N., and Back, William, 1980, The mass balance approach: Application to interpreting the chemical evolution of hydrologic systems: American Journal of Science, v. 280, p. 130-142.

Chemical Reactions at Mineral Surfaces

By John D. Hem, Menlo Park, Calif.

Adsorption mechanisms are particularly important controls on the rate at which solutes may be transported in water moving through soils and rocks, and must therefore be understood and evaluated in planning radioactive waste storage and disposal strategies.

Objective To determine the effects of the surfaces of common minerals (oxides, silicates, etc.) on reaction rates and on dissolved concentrations of metal ions related to cation exchange and other adsorption phenomena.

Approach Current studies entail the development of a theoretical model for quantifying adsorption effects based on the concept of the electrical double layer (EDL) and testing refinements of the existing models in the laboratory. Mathematical fitting is done by means of a computer program.

The EDL theory postulates that an electrically charged solid surface that is immersed in water is covered with a layer of immobilized water molecules and that solute ions with electrical charges opposite in sign to the surface charge accumulate outside the water layer. This system is somewhat analogous to an electrical capacitor.

Progress A research hydrologist who has made substantial contributions previously to the refinement and application of EDL theory was added to the project staff late in the fiscal year. Work has been started on two phases of this project that are aimed at applying EDL theory to predict and determine adsorption behavior of natural mineral surface. One of these deals with the characterization and determination of actual locations of charged sites on plate and edge surfaces of kaolinite, a common clay mineral. The other phase deals with application of EDL theory in systems where organic material is present. All near-surface natural materials, including soils and sediments, contain organic matter and the realistic utilization of EDL models requires that the effects of such material be considered.

Work has continued on competitive adsorption of lead by a natural streambed sediment using solutions containing various amounts of Na^+ and H^+. Results of recent studies have been summarized in Geological Survey Water-Supply Paper 2187 (in press), entitled "Development of a model to predict the adsorption of lead from solution on a natural streambed sediment."

Microbial Reduction of Iron

By Garry G. Ehrlich, Menlo Park, Calif.

Leachates from shallow burial sites containing low-level radioactive wastes often have significant concentrations of dissolved ferrous (FeII) and manganous (MnII) ions. These ions are derived from materials contained in the wastes and from iron and manganese minerals in the soil. The metals in the precursor materials are usually in higher oxidation states such as Fe(III) and Mn(IV). Typically, compounds of iron and manganese in the higher oxidation state are only slightly soluble under the ambient conditions of a burial site; therefore, reduction is a necessary part of the solubilization process.

It is now commonly recognized that microbes are responsible for the reductive solubilization of these metals, but certain misconceptions about the mechanism of the process are widespread.

The reduced state of the environment in a shallow burial site is a result of microbial activity. Solubilization is not caused by the reducing condition in itself but because some microbially produced reductant reduces the metal compounds. Fe(II) and Mn(II) ions do not appear under sterile conditions unless powerful chemical reducing agents are present. Under low Eh conditions and at neutral pH, Fe(II) and Mn(II) are stable, and the presence or absence of potential ligands is immaterial.

Alexander (1977) lists several mechanisms to account for microbial iron reduction. Increases in acidity accompanying fermentation promote iron dissolution. Another possible mechanism is the direct reaction of fermentation products with ferric hydroxides and oxides. Alternatively, iron reduction may involve a direct enzymatic reaction between the oxide and the bacterial electron donor. The iron functions as an electron acceptor in cell respiration in a manner analogous to the reduction of nitrate by denitrifying bacteria.

It is not known whether the organic acids are reductants and the cells merely catalyze the process in some way, or whether iron reduction is a direct enzymatic process during which the intracellular production of the organic acids is inhibited.

Objective To determine quantitatively the role that microorganisms play in solubilization and mobilization of iron and managanese. This information will help to clarify the most significant chemical processes affecting the solubilization and mobility of many radionuclide and other substances of concern in waste-disposal sites.

Approach Microbial metabolism, biochemical reaction rates, and related quantitative studies are carried out in carefully controlled laboratory reaction vessels and flow columns. These laboratory studies are closely coordinated with field studies of actual disposal sites.

Progress A strain of Clostridium butyricum (American Type Culture Collection, No. 19398) that reduces Fe^{3+} in hematite (Fe_2O_3) to yield

up to 0.02 M Fe^{2+} when grown in 0.05 M glucose-mineral salts solution supplemented with trace amounts of vitamins was used in the experiments described below. It was found that hematite reduction occurred only if the cells were grown in the presence of hematite. Ferrous ions were not produced if vegetative cells were mixed with powdered hematite and held together for one month, or if spent, cell-free culture medium was mixed with hematite. The reduction process occurred only under conditions that allowed intimate contact between actively dividing cells and the mineral surface.

A complex mixture of organic acids including formic, acetic and butyric acids as major products and transiently appearing pyruvic and lactic acids was produced by C. butyricum from glucose. Hydrogen ions from the acids lowered medium pH under weakly buffered conditions and limited growth. At 0.02M phosphate concentration only about 0.04 moles of glucose per liter were converted before the pH dropped to 4.2-4.4 and growth stopped. Ferrous concentrations were less than 0.002M under these conditions. If calcite ($CaCO_3$) was added to neutralize excess acid, up to 0.12 moles of glucose per liter was converted before cell growth stopped. If calcite and hematite were present simultaneously, up to 0.16 moles of glucose per liter was converted, and Fe^{2+} concentrations of up to 0.02M were achieved.

By removing samples of culture fluid during growth and measuring glucose and Fe^{2+} concentrations, it was found that Fe^{2+} ions did not appear in solution until glucose was nearly exhausted and did not reach their maximum concentration until 48-96 hr after the final disappearance of glucose. Analysis of fermentation product mixtures using HPLC (high performance liquid chromatography) techniques showed that yields of acetate and butyrate were comparable in the presence or absence of hematite but that yields of formate were less if hematite was present. In the absence of hematite about 10 percent of the reacted glucose was converted to formate but formate yields were about 33 percent less in the presence of hematite. Molar yields of Fe^{2+} were slightly less than half of the difference between the formate concentrations of cultures grown in the absence and presence of hematite. These results suggest that formate might be involved in hematite reduction as follows:

$$4H^+ + Fe_2O_3 + H_2CO_2 \rightarrow 2Fe^{2+} + CO_2 + 3H_2O.$$

Direct reduction of hematite by formate present in cell-free spent culture medium, in the presence of a mixture of hematite and vegetative cells, or by direct reaction in boiling solution could not be demonstrated. A buildup of formate during glucose dissimilation followed by a slow loss of formate as Fe^{2+} concentration slowly increased, was not seen in sequential samples taken during an ongoing reaction. These results indicate that formate, either by itself or in the presence of C.butyricum cells, is not the reducing agent.

Thauer and others (1974) showed that certain Clostridium species, using reduced ferredoxin as a reducing agent, synthesize formate by reducing CO_2. Ferredoxin is an iron and sulfur-containing protein that is used by many species of obligate anaerobic bacteria as an electron transferring agent.

$$CO_2 + H_2 \text{ FERREDOXIN (red)} \rightarrow H_2CO_2 + \text{FERREDOXIN (ox)}$$

This reaction is catalyzed by an enzyme, Ferredoxin: CO_2 oxidoreductase. In the presence of hematite, electrons that would normally be used to reduce CO_2 are apparently diverted to Fe_2O_3 to produce Fe^{2+}. The identity of the electron carrier and the mode of transfer are still unknown.

Reference

Thayer, R. K., Fuchs, G., and Jungermann, K., 1974, Reduced ferredoxin: CO_2 oxidoreductase from Clostridium pasteurianium: its role in formate metabolism: Journal of Bacteriology, v. 118, no. 2, p. 750-758.

Influence of Benthic Geochemical Processes on Nutrient and Metal Cycling in Natural Waters

By E. Callender, Reston, Va.

Benthic sediment exchange processes may strongly influence the concentration of nutrients and metals in natural waters. Degradation of recently deposited organic matter and desorption-dissolution of precipitated iron and manganese oxyhydroxides result in pore-water concentrations that are significantly greater than those in overlying waters. Transport of pore-water-nutrient and metal ions may be accomplished by molecular diffusion and several advective processes including resuspension and bioturbation (sediment disturbance by benthic macroinvertebrates).

Objective To determine quantitatively the rates of nutrient and metal exchange from benthic sediment and the effect benthic exchange processes have on geochemical cycling in natural waters.

Approach Studies are divided into three basic approaches: the mass balance approach where the effects of sedimentation and sediment regeneration are determined from input-output data; laboratory studies of adsorption/desorption of ions by suspended sediment and advection/diffusion of ions from incubated cores to overlying water; and field studies to measure ion concentration-depth profiles and estimate benthic fluxes directly.

Progress Application of Fickian diffusion models to an extensive set of interstitial water data have resulted in the calculation of diffusion rates of nutrient and major ions from estuarine benthic sediment to overlying water. These have been compared to measured in situ benthic flux rates which have been determined with experimental chambers emplaced on the bottom. In areas where bioturbation is prevalent, in situ fluxes are several fold greater than diffusive fluxes.

Another method for estimating long-term benthic fluxes utilizes the sediment accumulation rate and the change in total concentration of any particular sedimentary constituent from the water-sediment interface to some depth in

the sediment. One major assumption of this method is that the sedimentation rate has remained relatively constant over the length of core analyzed.

References

Callender, E., Schultz, B.I., and Hammond, D.E., 1980, Nutrient exchange across the sediment-water interface in the Potomac River Estuary: Transactions American Geophysical Union, v. 61, no. 46, p. 1000.

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.

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

Approach The distribution of radium-226 in the sediments of a coastal marsh receiving radium-bearing oil brines is being investigated in a cooperative study with the U. S. Navy and the University of New Orleans.

Samples of ore and the derived tailings were collected at an active, acid-leach uranium mill, and are being studied by a sequential, selective extraction method to determine the effect of the milling process on the distribution and leachability of radium-226, thorium-230, and uranium.

Samples collected from a site in Denver, Colo. which had previously been occupied by several radium processing plants from 1915-25 are being studied by a selective extraction scheme to determine the distribution and leachability of the constituents mentioned above.

Progress The brine study is nearing completion. The areal and depth distribution of radium-226 in the brine-receiving marsh has been determined under the leadership of investigators from the University of New Orleans and the U. S. Navy. We have focused on factors influencing the retention of radium by these and other sediments. The brine has been analyzed for major and minor constituents. Sediments from the brine-receiving marsh, from a control marsh, and from sediments from other areas have been characterized with respect to particle size, carbon content, and cation exchange capacity. The particle size distribution of radium-226 in sediments from the brine-discharge site and the control site has been determined. The removal of radium-226 from brine-exposed and control-site sediments by various solutions has been examined, as has the sorption of radium-226 from

the brine by the control-site sediments and by sediments with a range of properties from other areas of the Nation. The kinetics of sorption and the effect of brine dilution have been investigated. To this date, about half of the radium-226 analyses have been completed.

The selective extraction method being used with the ore/tailings samples and the Denver site samples will partition the radionuclides and other constituents into water-soluble, exchangeable, acid-soluble, and resistate fractions. About 80 percent of the radiochemical analyses for the Denver site samples are completed. Radiochemical analyses of all of the extracts from the ore/tailings study have been completed, and a manuscript is in preparation.