HYDROGEOLOGY OF THE FAULTLESS SITE, NYE COUNTY, NEVADA

By William Thordarson

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METRIC CONVERSION FACTORS

For those readers who prefer to use inch-pound units rather than metric (International System) units, conversion factors for the terms used in this report are listed below:

Metric unit	*Multiply by*	*To obtain inch-pound unit*
centimeter (cm)	3.937×10^{-1}	inch
millimeter (mm)	3.937×10^{-2}	inch
kilometer (km)	6.214×10^{-1}	mile
meter (m)	3.281	foot
meter per day (m/d)	3.281	foot per day
meter squared per day (m^2/d)	$1.076 \times 10^{+1}$	foot squared per day
degree Celsius (°C)	1.8°C + 32	degree Fahrenheit
milligram per liter (mg/L)	[1]1.0	part per million
microgram per liter (µg/L)	[1]1.0	part per billion
picocurie per liter (pCi/L)	3.785	picocurie per gallon
liter (L)	2.642×10^{-1}	gallon
liter per day (L/d)	2.642×10^{-1}	gallon per day
gram (g)	3.527×10^{-2}	ounce

The following abbreviation also is used in this report:

microsiemens per centimeter at 25 degrees Celsius (µS/cm).

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

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[1]Approximate.

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ABSTRACT

The Faultless event was the detonation of an intermediate-yield nuclear device on January 19, 1968, at a depth of 975 meters below the surface of Hot Creek Valley, Nevada. This report presents details of the hydrogeology of the rubble chimney and radiochemical monitoring in re-entry hole UC-1-P-2SR.

The surface location of re-entry hole UC-1-P-2SR is about 91 meters north of the emplacement hole, UC-1. Re-entry hole UC-1-P-2SR was drilled to a total depth of about 1,097 meters. The hole penetrated Quaternary and Tertiary valley-fill sediments above the rubble chimney, as well as Quaternary and Tertiary valley-fill and Tertiary tuffaceous sediments within the chimney and rubble-filled cavity. The completion program (casing to a depth of 851 meters) was designed to permit monitoring the rate of water entering the chimney and concentration of radionuclides in the water.

Monitoring of the water level in re-entry hole UC-1-P-2SR indicated that, from 1970 to 1974, the water level was 695 meters below land surface. This water level probably represented a perched water level in clayey sedimentary rocks of minimal hydraulic conductivity. During filling of the rubble chimney from 1974 to 1983, the water level rose slowly to a depth of 335.1 meters. The 1983 level was about 167 meters below the pre-event level that was about 168 meters below land surface.

Water with temperatures ranging from 37 to 61 degrees Celsius occurred at the bottom of the re-entry hole at depths ranging from 728 to 801 meters. A temperature of 100 degrees Celsius at a depth of 820 meters was projected from temperature logs.

The hydraulic connection between the re-entry hole and the rubble chimney is considered poor to fair. The minimal transmissivity of the clayey sedimentary rocks, the large quantity of drilling mud used, and the possibility of plugged perforations are the probable causes of the limited hydraulic connection between the hole and the chimney.

A hydraulic injection test indicated that clayey sedimentary rocks in the interval from 691 to 802 meters have a transmissivity of 8.8×10^{-2} meter squared per day; the hydraulic conductivity was 7.9×10^{-4} meter per day. These values may be smaller than the actual values, because of a mud sheath around the hole and because the perforations may be partly plugged.

Chemical analyses of water samples indicate that the water predominantly was a sodium bicarbonate type. Chemical and radiochemical analyses indicated that, although the constituents generally increased with increasing depth, three distinct water-quality zones have lasted for more than 16 years, even during the rising water level. A statistical analysis of the mean values of selected water-quality properties and constituents in these zones indicated that the means were significantly different at the 99-percent probability level. The upper zone, above a depth of 594 meters, contained formation water that was characterized by specific-conductance values less than 280 microsiemens per centimeter at 25 degrees Celsius, temperatures less than 30 degrees Celsius, and near-background tritium concentrations of about 1×10^3 picocuries per liter. The lower zone, at depths from 728 to 801 meters, contained hot, more radioactive water from near the Faultless event that was characterized by specific-conductance values ranging from 300 to 440 microsiemens per centimeter, temperatures ranging from 37 to 61 degrees Celsius, and tritium concentrations of about 1×10^7 picocuries per liter. Water in the intermediate zone, at depths between 594 and 728 meters, had values of specific conductance and temperature, and concentrations of tritium that were between those in water from the upper and lower zones.

In general, the hot, radioactive water from the Faultless event apparently rose into the lower zone concomitant with the rising water level, as the rubble chimney was being filled. This general rise was interrupted by the apparently major dilution from colder water descending from the upper zone during 1975 and 1977.

INTRODUCTION

The Faultless event was the underground detonation of a nuclear device of intermediate yield at 1015 hours Pacific Standard Time on January 19, 1968, in Hot Creek Valley, Nye County, Nevada (fig. 1). The responsibility of the U.S. Atomic Energy Commission, since assumed by the U.S. Department of Energy, was to determine the suitability of using sites in Hot Creek Valley in central Nevada for underground testing of nuclear devices of higher yield than was possible at the Nevada Test Site, because of potential adverse seismic effects at Las Vegas, Nevada. The Nevada Operations Office, U.S. Department of Energy, acknowledges the responsibility of obtaining and having available for dissemination data adequate to:

1. Assure the public safety.
2. Inform the public, the news media, and the scientific community, if the need arises.
3. Document compliance with existing Federal, and possible future State and local, antipollution requirements.
4. Improve pre-event prediction capabilities.

These responsibilities can best be fulfilled by the establishment and maintenance of a long-term monitoring program. Investigations by the U.S. Geological Survey described in this report were performed under Interagency Agreement DE-A108-76DP00474.

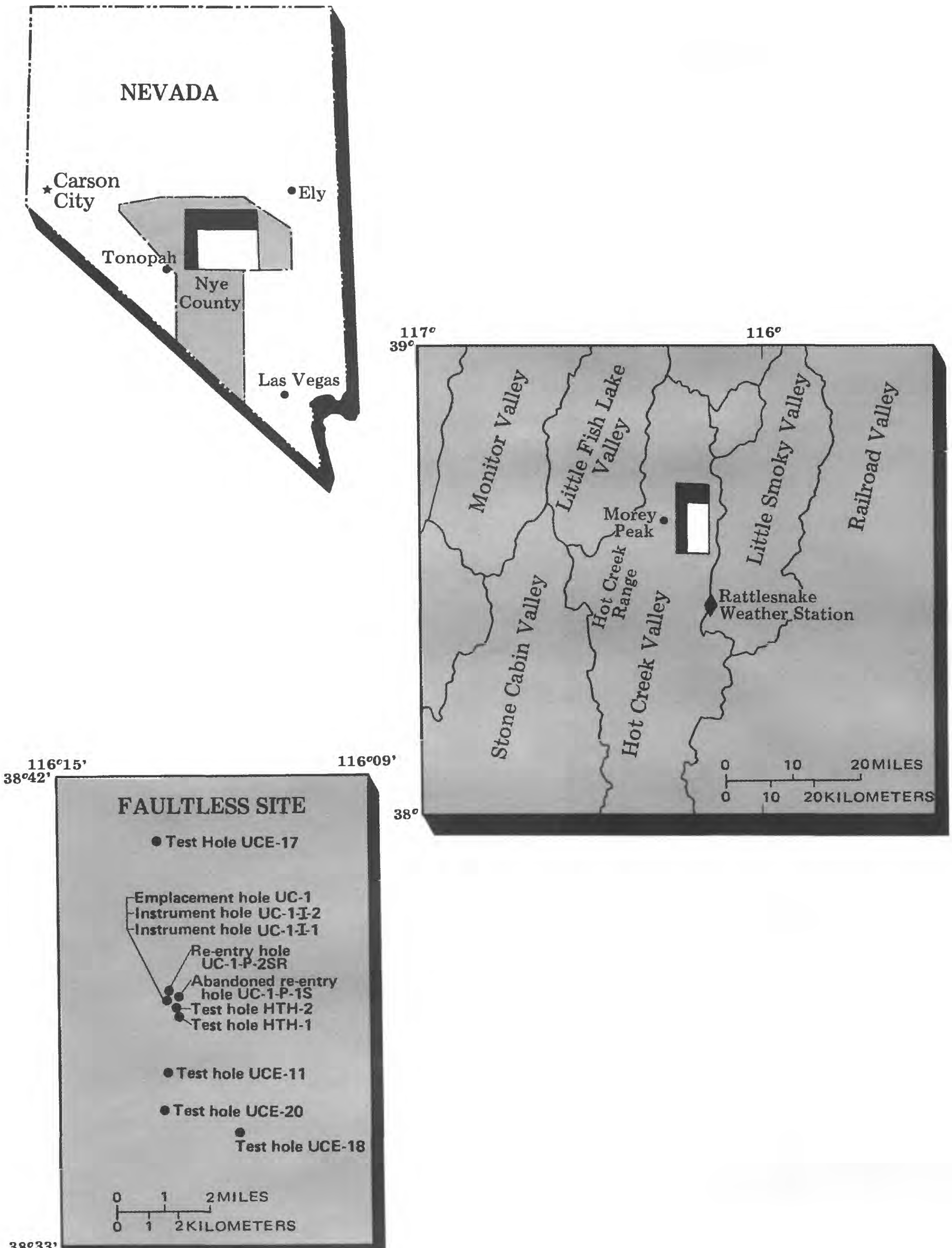

Figure 1.--Location of the Faultless site and boreholes in Hot Creek Valley.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, has been making hydrologic studies of sites of underground nuclear tests in order to provide data on the occurrence, quality, and quantity of ground and surface waters that might be affected by these nuclear tests. These site studies, such as this study of the Faultless event, provide data on the hydraulic properties of rocks near the site, the rate of water inflow to the rubble chimney caused by the event, the distribution of radionuclides within the chimney, and the capacity of ground water to affect initial transport of radionuclides away from the rubble chimney (West and Grove, 1969). The scientific objectives at the site of re-entry hole UC-1-P-2SR were to:

1. Obtain representative water samples from numerous chimney horizons between the current (1983) water surface and the lower cavity boundary, analyze these samples for radionuclide concentrations, and apply the resultant data in calculations of total radioactivity present and its zonal distribution.
2. Isolate a zone below the cavity and measure the hydraulic potential in that zone.
3. Measure the hydraulic potential in the alluvium "block" that overlies the chimney and determine its contribution, or lack of contribution, to chimney infill. Use this data for a more precise definition of the local hydrologic environment.
4. Use all data for evaluating the pre-event ground-water contamination prediction.

This report presents detailed hydrogeologic interpretations based on data collected predominantly from re-entry hole UC-1-P-2SR at the Faultless site, although some interpretations based on data collected from other wells are included. Only the infilling of ground water into the rubble chimney is discussed; discussion of the regional flow system before and after the Faultless event is beyond the scope of this report.

The hydrogeology was investigated jointly by the U.S. Geological Survey, Teledyne Isotopes, and the Desert Research Institute before the Faultless event. Since the event, the U.S. Geological Survey, Teledyne Isotopes, and the U.S. Environmental Protection Agency have monitored water levels and radiochemical quality of ground water at the Faultless site. After 1971, Teledyne Isotopes was no longer involved.

Location of Faultless site

The Faultless site is about 97 km northeast of Tonopah, Nev. (fig. 1); latitude is 38°38'3.4774" N.; longitude is 116°12'55.1936" W. (Nevada central-zone coordinates N. 1,414,339.91, E. 628,920.87) at the emplacement hole, UC-1. The re-entry hole, UC-1-P-2SR, is 91.1 m northeast of emplacement hole UC-1 and at latitude 38°38'06" N., longitude 116°12'59" W. (Nevada central-zone coordinates N. 1,414,632.50, E. 628,982.18). Instrument holes UC-1-I-1 and UC-1-I-2 are within 25 m of emplacement hole UC-1.

Previous Investigations

The data obtained from hydrogeologic monitoring of the Faultless site have been reported by Thordarson (1984). The general hydrology and chemical data in Hot Creek Valley were reported by Dinwiddie and Schroder (1971) and by Robinson and others (1967). Discussions of ground-water flow systems in Hot Creek Valley and vicinity were made by Fiero and others (1974), by West and Grove (1969), and by Rush and Everett (1966). Lithologies of test holes UCE-11, UCE-17, UCE-18, and UCE-20 have been presented previously (Barnes and Hoover, 1977; Corchary, 1969; Dixon and Snyder, 1977; Hoover, 1977; and Snyder, 1977). Geologic effects of the Faultless event have been described by McKeown and others (1970).

PHYSICAL SETTING OF STUDY AREA

Geography

Hot Creek Valley trends north for 110 km, and is 8 to 30 km wide, between north-trending ranges of the Basin and Range physiographic province. To the west, the Hot Creek Range rises to a maximum altitude of 3,111 m at Morey Peak, just west of the Faultless site. The floor of the valley ranges in altitude[1] from about 1,580 to 1,830 m above National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Climate is arid in the valley; precipitation averages 119 mm annually at the Rattlesnake weather station, 22 km south of the Faultless site in Hot Creek Valley, at an altitude of 1,802 m. Average yearly temperature at the station is 10.6 °C; the maximum recorded temperature was 39.4 °C and the minimum recorded temperature was -28.3 °C.

Geology

Hot Creek Valley is a large graben in which a sequence of Quaternary and Tertiary valley fill, approximately 1,200 m thick, is underlain by a thick sequence of volcanic rocks of Tertiary age. Flanking mountain ranges are large fault-block mountains in which volcanic rocks of Tertiary age generally overlie carbonate rocks of Paleozoic age.

At the site of emplacement hole UC-1, the valley fill is 732 m thick, and is underlain by tuffaceous sediment and zeolitized tuff to the total depth of the hole (998 m). The section penetrated by other test holes (UCE-17, UCE-18, UCE-20, and HTH-1) contains some densely welded tuff or rhyolite in the Tertiary volcanic rocks. Lithology, hydrology, and construction of test holes HTH-1, HTH-2, and UCE-18 were presented by Thordarson (1984, fig. 2). Temperature data for 1970 and 1971 in the lower part of re-entry hole UC-1-P-2SR were presented by Thordarson (1984, fig. 3).

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[1]Altitude, as used in this report, refers to the distance above or below the NGVD of 1929.

Lithology of Rocks Penetrated by Boreholes

Emplacement hole UC-1, instrument hole UC-1-I-1, and test hole HTH-1 penetrated alluvium and were bottomed in tuffaceous sediments (Thordarson, 1984). The alluvium consists of a matrix cemented by clay containing sand-size crystal grains and welded tuff, and some Paleozoic chert, siltstone, and carbonate-rock fragments. The matrix encloses pebble- to boulder-size fragments of welded tuff and some Paleozoic rocks. Some welded-tuff boulders are as much as 1.5 to 3 m in diameter, although the average size of fragments larger than sand size probably is less than 15 cm. The upper 150 to 300 m of the alluvium generally is unconsolidated. The degree of induration of the alluvium generally increases downward, possibly because of compaction. A few thin intervals that appear to be almost entirely clay or sand were penetrated, but not cored.

WELL CONSTRUCTION OF RE-ENTRY HOLE UC-1-P-2SR

The post-shot re-entry hole UC-1-P-2SR (fig. 2) was spudded on February 19, 1968. Difficulty was experienced during drilling, including bridges, cave-ins, and loss of circulation. The hole was initially designated UC-1-P-2; from this hole, the first sidetrack hole (UC-1-P-2S) was unsuccessfully attempted at a depth of 823.0 m. A later, successful sidetrack hole, UC-1-P-2SR, was used as the monitoring hole. Large quantities of drilling mud and cement were lost during drilling; the quantity of mud and cement lost is not known, but it may be similar to the 1,060,000 L of mud that were lost during drilling of emplacement hole UC-1. The effects of lost drilling fluid on water levels and chemistry and radiochemistry of water may be appreciable. The hole was completed by installing 14.0-cm OD (outside diameter) casing that was hung on slips to a depth of 851 m. This casing was perforated from 349.9 to 850.4 m with three hundred thirteen 13-g shots, or one 0.952-cm hole every 1.5 m (fig. 2). Fill was tagged by the drill pipe and left inside the 14.0-cm OD casing at a depth of 833.3 m. Previously, the 24.45-cm OD casing that was cemented totally had been perforated from 349.9 to 592.8 m with one hundred forty-five 28-g shots, or one shot per 1.5 m. Finally, water from the decontamination pad was pumped down the tubing while water was pumped down the casing-tubing annulus; each joint of tubing was washed into the hole as the tubing was pulled from the hole. Drilling water used was obtained from test hole UCE-18. A directional survey of re-entry hole UC-1-P-2SR is presented in figure 3.

HYDROGEOLOGY OF RUBBLE CHIMNEY AND ADJACENT AREA

This section on hydrogeology principally is concerned with the rubble chimney that formed after collapse of the cavity created by the Faultless event. Data are chiefly from the re-entry hole, UC-1-P-2SR. Because the water table was depressed within the rubble cavity after the Faultless event, the unsaturated rubble chimney initially received water slowly by: (1) Condensation of water vapor in the chimney; (2) water percolating slowly downward from partly saturated alluvium in the upper part of the chimney; and (3) ground water flowing into the chimney from the surrounding alluvium (S.W. West, U.S. Geological Survey, written commun., 1971; Teller and others, 1968).

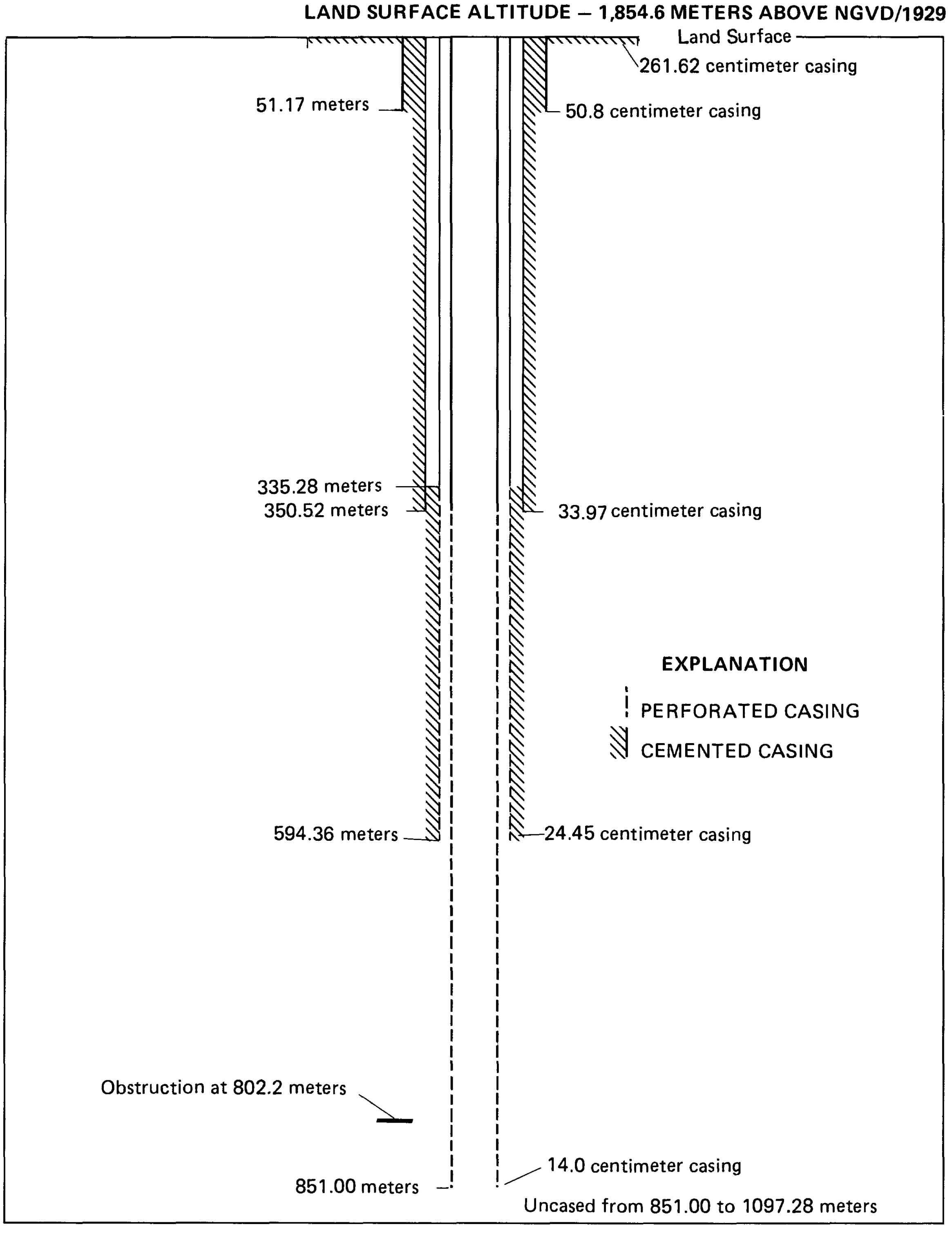
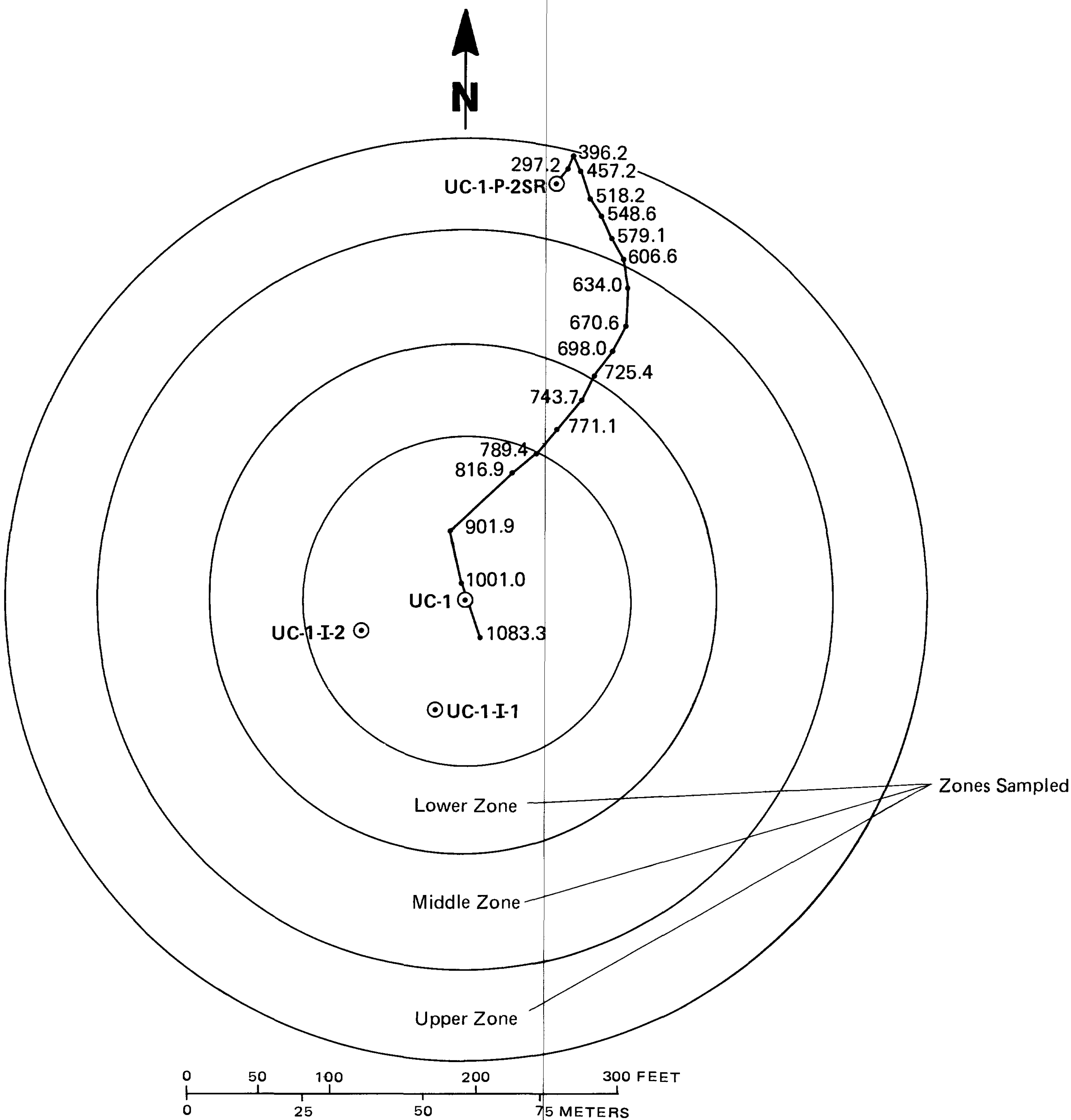


Figure 2.--Well construction of re-entry hole UC-1-P-2SR.



EXPLANATION

UC-1 ⊙ BOREHOLE AND NUMBER

1083.3• POINT ON DIRECTIONAL SURVEY SHOWING DEPTH (UNCORRECTED FOR HOLE DEVIATION), IN METERS BELOW LAND SURFACE

Figure 3.--Directional survey of re-entry hole UC-1-P-2SR.

Description of the Aquifer

Water in re-entry hole UC-1-P-2SR occurs within a rubble chimney of collapsed alluvium and tuffaceous sedimentary rocks. Down to the depth of the obstruction at 802 m, the casing probably is within collapsed alluvium, because the contact of alluvium and tuffaceous sedimentary rock at an original depth of 733 m probably has collapsed after the Faultless event to a depth far below the depth of this obstruction. Therefore, only collapsed alluvium yielded water to the re-entry hole. The alluvium and tuffaceous sedimentary rocks had minimal hydraulic conductivity except for thin beds of sand and gravel in the alluvium (Dinwiddie and Schroder, 1971).

Hydrogeologic Factors Affecting Data Obtained from Re-entry Hole UC-1-P-2SR

Several hydrogeologic factors, discussed in detail hereafter, affected the data obtained from the re-entry hole. These factors are: (1) Zone of perched or semiperched water; (2) downward drainage of water to the zone of perched water; (3) zone of hot water; (4) fault barriers; and (5) hole conditions.

Zone of Perched Water

An apparent perched water level was maintained at a depth of about 695 m during 1968 to 1974. This perched water zone did not represent the rise in water level resulting from infilling of the chimney until 1974. Possible perching of downward-percolating water in the rubble chimney may have resulted from the presence of an almost impermeable layer in the collapsed alluvium that separated the shallow ground-water system from the deeper, regional ground-water system (S.W. West, written commun., 1969). However, another explanation for the nearly unchanging depth to water of about 695 m from 1968 to 1974 may be the result of a small local body of water in the collapsed alluvium around the well bore (S. W. West, written commun., 1969). This body of water may have developed initially by the injection of the water used to clean the drilling pipe and decontamination pad at the end of drilling. Then, after drilling, this body of water may have been maintained either by drainage of water down the well bore or by downward percolation of water through the rubble chimney.

At the end of 1974, the water level rose above the nearly stationary water level of about 695 m. This rise signified the rise in water level above the perched zone as the rubble chimney continued to fill and the water level rose toward the original pre-event static water level, which was at a depth of about 168 m.

Downward Drainage of Water

Downward drainage of water through the borehole in the unsaturated zone above the perched water level was detected on September 23, 1971, within the 14.0-cm OD casing by a spiral meter with a water catcher (L. J. Schroder, U.S. Geological Survey, written commun., 1971). The spiral meter with water catcher initially was set at a depth of 589.5 m inside both the 14.0-cm OD and 24.45-cm OD casings for 1 hour; the catcher was dry. Then, the spiral meter with water catcher was set at a depth of 682.8 m inside only the 14.0-cm OD casing, where it collected 2.1 L in 1 hour. The water temperature was 31.7 °C when measured at the land surface; the air temperature was 31.7 °C at a depth of 615.7 m, suggesting that the water came from this depth. This water may represent slow condensation of water vapor in the chimney, slow drainage from partly saturated sedimentary rocks with minimal hydraulic conductivity in the chimney, or formation water flowing into the chimney.

Downward flow of water below the water level in the borehole was indicated by several tracer tests during 1971 (S.W. West, written commun., 1971). To evaluate the concept that water was entering re-entry hole UC-1-P-2SR at a high level and flowing out near the bottom of the hole, the U.S. Geological Survey added a lithium chloride tracer at the surface of the water on March 31, 1971. Background information on lithium concentration previously was obtained by sampling the water in December 1970. The water was resampled July 15, 1971. The concentration of lithium on July 15, 1971, was nearly the same as the background measured in December 1970 and March 1971; this concentration similarly indicated that all the added lithium was flushed from the well bore between March 31 and July 15.

A radioactive tracer survey using iodine-131 and a gamma detector was made July 15, 1971, by the Birdwell Division of Seismograph Service Corp. This survey indicated that vertical movement of water in the well bore was too slow to detect. Another gamma scan of re-entry hole UC-1-P-2SR was made on August 10, 1971, by Birdwell Division personnel to check the location of the iodine-131 injected into the hole on July 15; the iodine-131 was not detected.

Before leaving the site on August 10, Birdwell Division personnel injected three slugs of scandium-46 near the top, near the middle, and near the bottom of the water column in the hole. On August 24, 1971, Birdwell Division personnel checked for the location of the scandium-46 slugs. The upper slug had moved laterally out of the hole, above a depth of 754 m; the middle slug had moved downward in the well bore from 756 to 779 m; and the lower slug possibly had moved downward to a point below the obstruction in the hole at a depth of 802 m. These tests proved conclusively that water still was moving downward in the borehole and eventually out into the chimney in at least two zones (S.W. West, written commun., 1971). The rate of downward flow in the borehole above 754 m was about 4.6 m/d, and the rate below 754 m was about 1.5 m/d. These velocities are equivalent to 57 L/d in the borehole above 754 m and about 19 L/d in the borehole below 754 m, as the volume of the casing is about 12.4 L per linear meter.

Zone of Hot Water

The presence of a zone of hot water that was heated as a result of the Faultless event is indicated by the three temperature logs that were made by Birdwell Division personnel in December 1970 and in March and July, 1971 (Thordarson, 1984, fig. 3). These three temperature logs are similar; all show a marked increase in temperature gradient from 40 °C at a depth of 756 m to 75 °C at a depth of 801 m. A projection of this gradient indicates a temperature of 100 °C was reached at a depth of about 825 m. Temperatures of water samples measured in 1970-81 have indicated similarly high temperatures, ranging from 40 to 60 °C in the depth interval from 744 to 789 m. This zone of high temperature has been maintained for more than 12 years, because of the persistent heat in the lower part of the chimney. This zone of hot water, directly underlying the zone of perched water, may be partly responsible for perching the water by supplying hot water or condensed steam to the zone of perched water.

Fault Barriers

The faults that bound the graben (the downthrown block at the site) may interrupt the lateral hydraulic continuity, because of hydraulic barriers resulting from displacement of rocks of lesser hydraulic conductivity against rocks of greater hydraulic conductivity (S.W. West, written commun., 1969 and 1971). In addition, the alluvium within the graben probably was compressed, causing decreased hydraulic conductivity when the block slid downward as a wedge between the faults (S. W. West, written commun., 1971).

Hole Conditions

The hole conditions that affected the data collected are: (1) Partly plugged perforations; (2) an obstruction at a depth of 802 m, and (3) the dogleg in the hole. The perforations probably were partly plugged with drilling mud and clay from the surrounding alluvium (S.W. West, written commun., 1971). However, data from hydraulic-injection and tracer-injection tests indicated that the perforations were not entirely plugged. An obstruction in the hole was encountered at a depth of 802 m. Therefore, the bottom part of the perforated casing from the depth interval of 802 to 850 m was not open to the borehole; but flow of water below a depth of 802 m may have been possible along the outside of the casing. The dogleg in the hole occurred below a depth of 426.7 m. Above this depth of 426.7 m, the hole was nearly vertical and near the edge of the rubble chimney, and about 90 m from the center of the rubble chimney (fig. 3). Below this depth, the hole was at a steeper inclination of 6° to 17° from vertical, and the obstruction at a depth of 802 m was about 35 m from the center of the rubble chimney (fig. 3). Thus, the dogleg was an important hydrogeological factor in the re-entry hole, causing the water-sampling zones and water-yielding zones to occupy different locations with respect to the axis of the rubble chimney.

Water Levels in Re-entry Hole UC-1-P-2SR

Water levels in re-entry hole UC-1-P-2SR are discussed in this section in reference to the apparent zone of perched water and the recovery of water level to the pre-event level within the rubble chimney of the Faultless event. A sketch of the rubble chimney showing water levels at various times is presented in figure 4. Water-level data for the re-entry hole has been presented in a previous report (Thordarson, 1984). An arithmetic graph of water levels in the re-entry hole is presented in figure 5; a semilogarithmic graph is presented in figure 6. In general, the water levels from 1968 to 1974 represent the top of the zone of perched water; the water levels from 1975 to 1983 represent the rise of water levels to the pre-event water level.

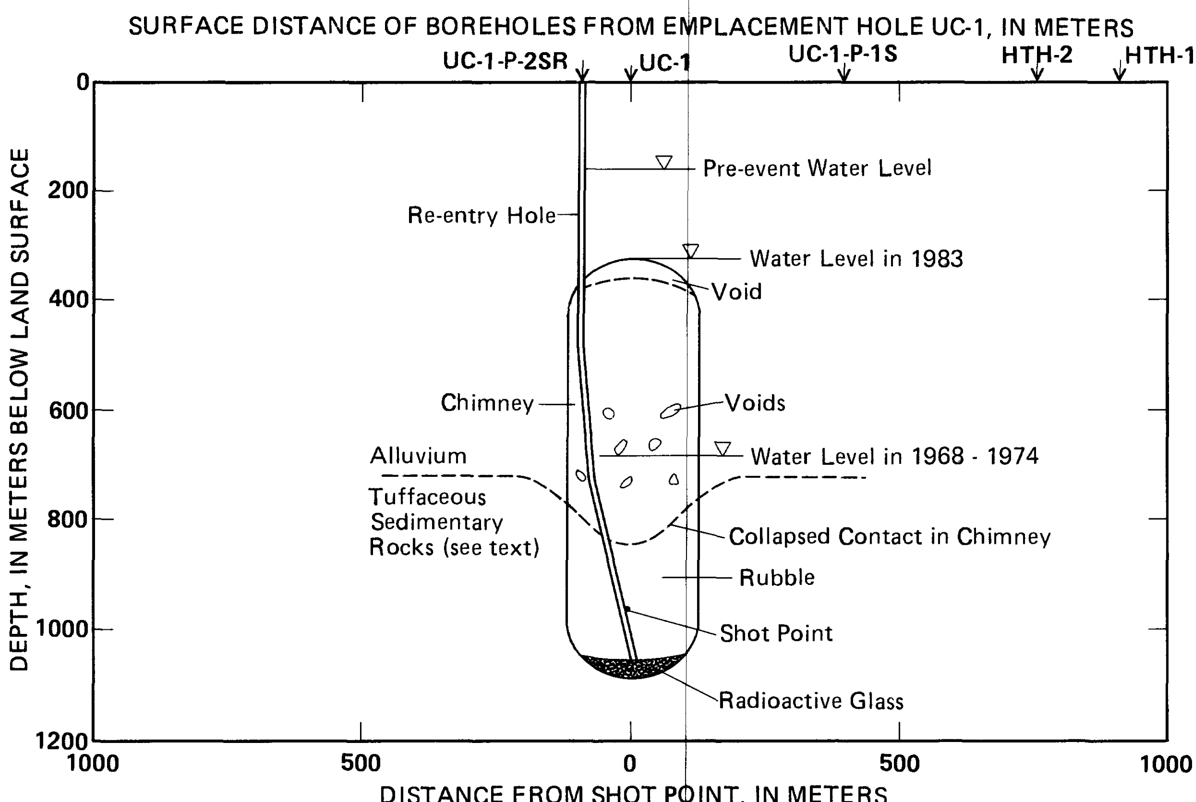


Figure 4.--Rubble chimney showing water levels at various times.

Water levels in the zone of perched water first were detected when the re-entry hole was completed on April 8, 1968, after 2 days of washing fluid from the decontamination pad and from the tubing down the hole. This wash water partly may have caused the higher water levels during the first months after the borehole was completed. The first depth to water level of 653.5 m was measured on April 9, 1968, followed by a rise to a depth of 646.2 m on June 5, 1968. This initial rise may have been principally the result of downward percolation in the rubble chimney, if faults were hydraulic barriers isolating the rubble chimney from the surrounding alluvium (S.W. West, written commun., 1969). Dilation of the alluvium that is commonly assumed to occur during collapse of the alluvium into the chimney may have caused the rubble to drain freely until it reached the value of specific retention in the alluvium. The rising water level indicated that water was yielded to the borehole at a faster rate than water was draining from the borehole (S.W. West, written commun., 1971).

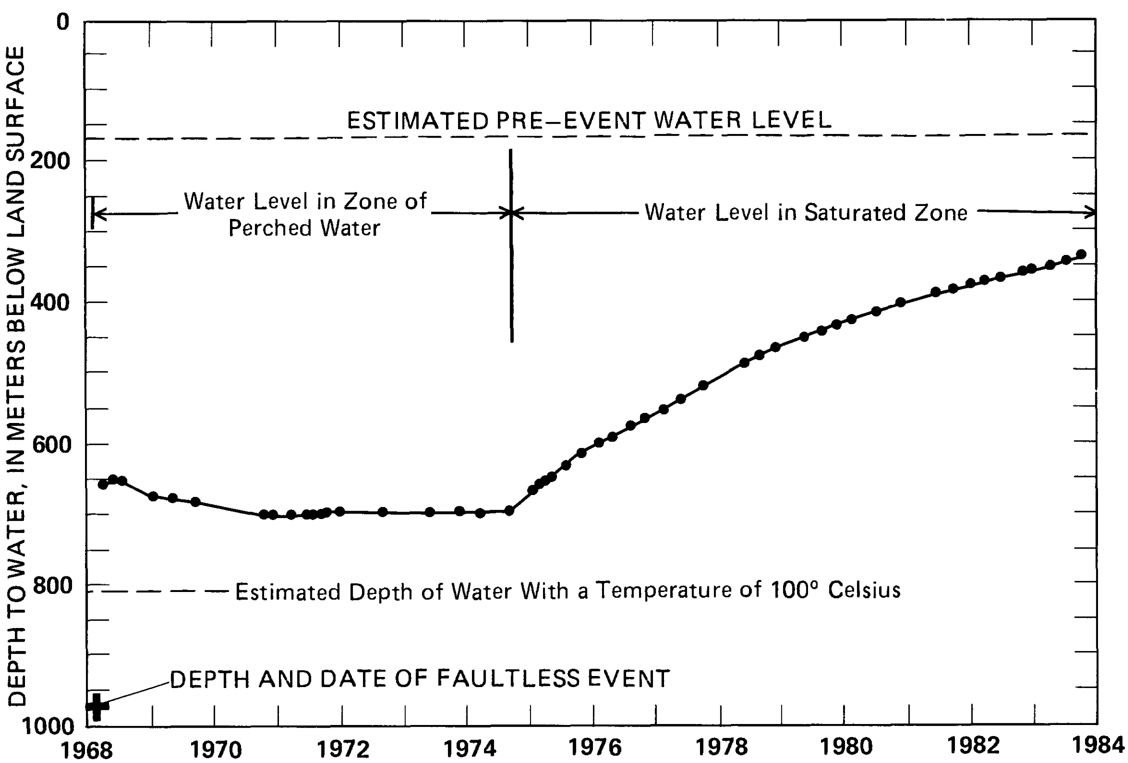


Figure 5.--Water levels in re-entry hole UC-1-P-2SR.

After the initial rise, the water level declined from a depth of 646.2 m on June 5, 1968, to a depth of 699.8 m on October 27, 1970 (fig. 5). This decline in water level may indicate that the rate of water entering the borehole decreased during this time and became less than the rate of outflow to the rubble chimney (S.W. West, written commun., 1971).

Between October 27, 1970, and September 24, 1974, the water level fluctuated slightly between depths of 699.8 m to 692.5 m, but generally was at a depth of about 695 m (figs. 5 and 6). This water level probably was the top of the zone containing perched water that was maintained even though the rubble chimney probably was being filled below this zone.

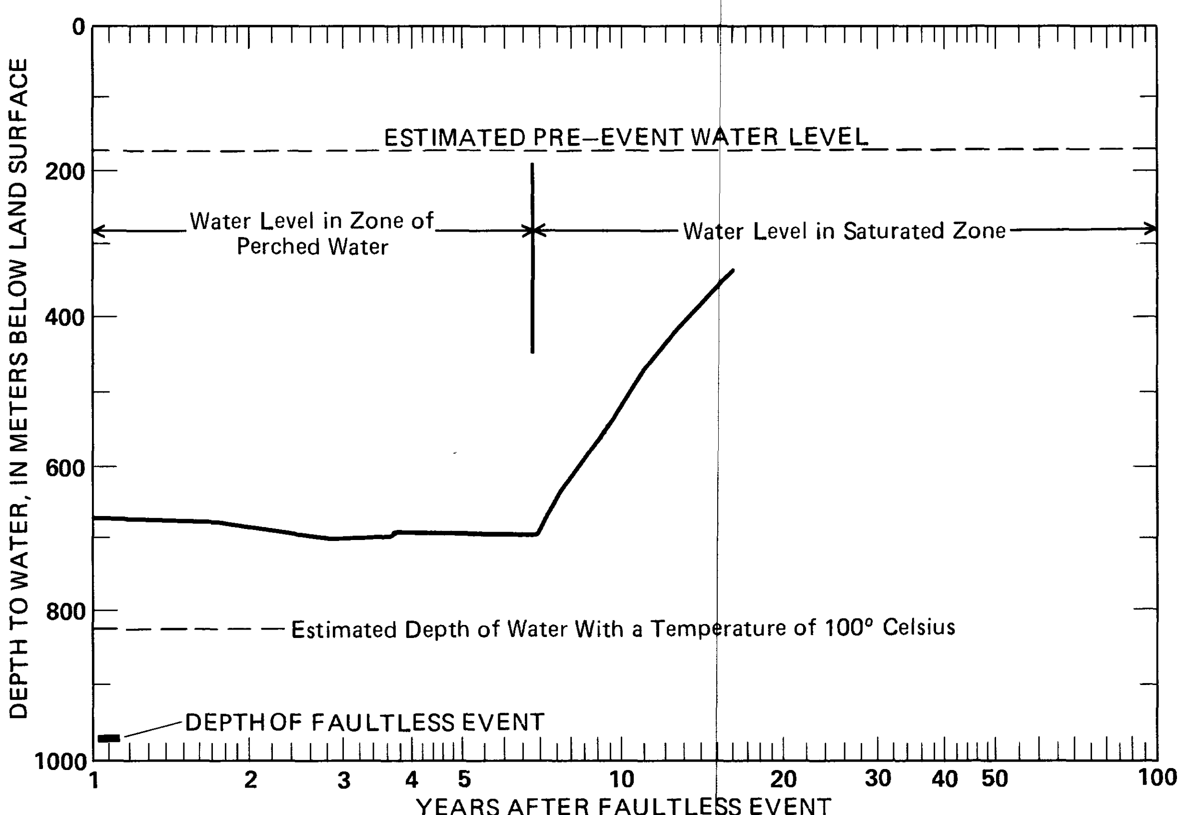


Figure 6.--Water levels in re-entry hole UC-1-P-2SR.

From September 1974 to October 18, 1983, the water levels rose continuously from a depth of 695.9 m to a depth of 335.1 m. The water level probably will continue to rise to the pre-event level at a depth of about 168 m. As indicated on the arithmetic and semilogarithmic graphs, the arithmetic graph is a gently curved line; during the last 4 years, the semilogarithmic graph is a straight line (figs. 5 and 6). Although these graphs of water level have a normal appearance, the rate of infilling of the borehole increased after the water level started to recover within the 24.45-cm casing (figs. 7 and 8). The bottom of the 24.45-cm casing was at a depth of 594.36 m, and this casing was close to the edge of the chimney (fig. 4). The reason for this increase in infill rate is not known; perhaps the rocks were more permeable toward the outer part of the rubble chimney, or the perforations may have been less plugged in the 24.45-cm casing than in the 14.0-cm casing.

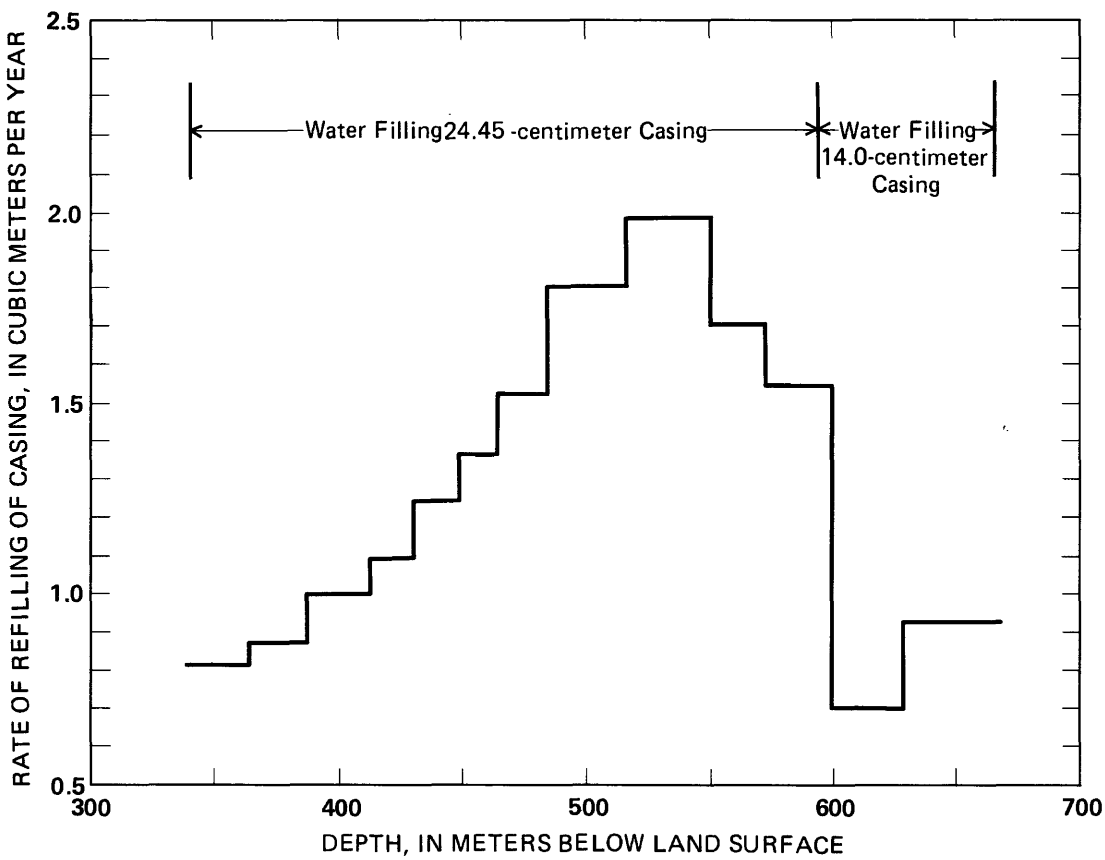


Figure 7.--Rate of water entry at depth intervals in re-entry hole UC-1-P-2SR.

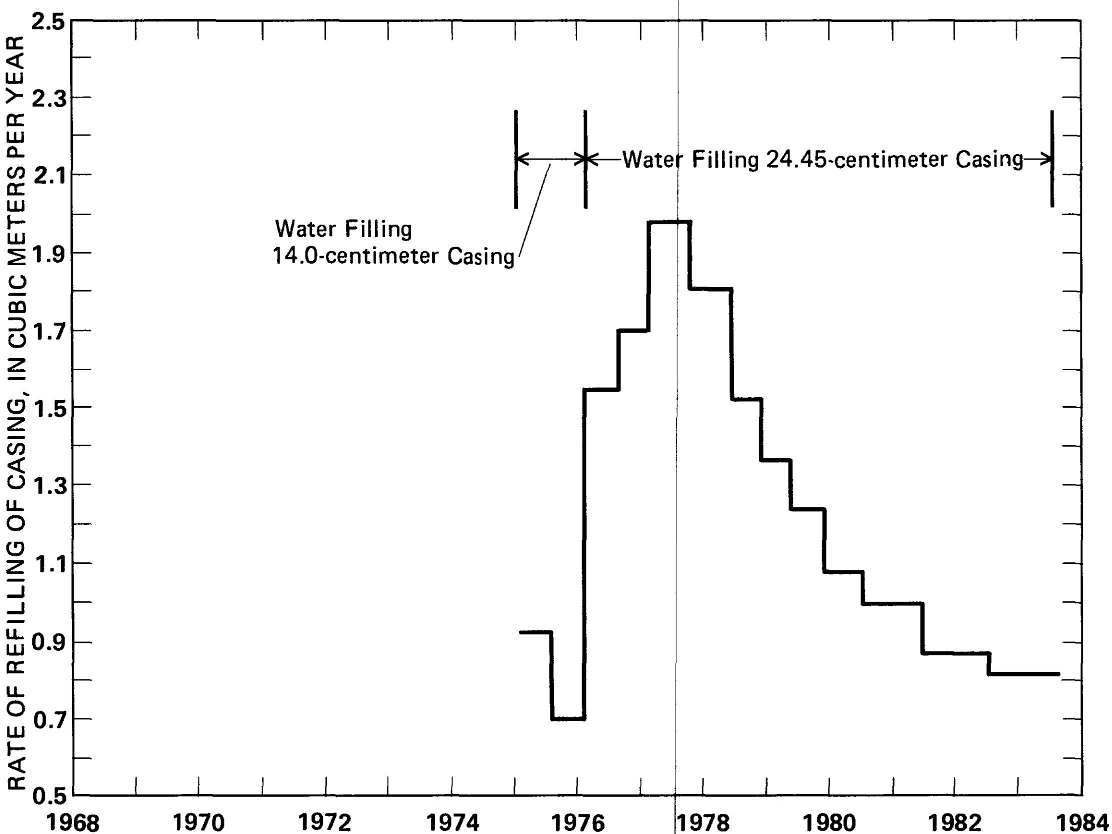


Figure 8.--Rate of water entry into re-entry hole UC-1-P-2SR, 1974-83.

An estimate of the year in which the rubble chimney may fill with water may be obtained by extending the last straight-line segment on the semilogarithmic graph (fig. 6) to 168 m, the estimated depth of the pre-event water level. This extrapolation indicates 1993 as the earliest estimated year when the pre-event water level could be reached. Extending the semilogarithmic graph on a curved line to the pre-event water level indicates 2018 as the latest estimated year when the pre-event water level would be reached. Since 1968, water levels in the rubble chimney have been much lower than the pre-event water level or the water levels in other boreholes completed in the surrounding alluvium. Therefore, ground-water movement away from the Faultless site does not seem to have been possible since 1968 (S. W. West, written commun., 1969 and 1971).

Hydraulic Testing

Hydraulic testing in re-entry hole UC-1-P-2SR consisted of several injection tests. Only the results of the last injection test, during which 5,680 L of water were injected into the hole on January 12, 1972, are presented. These injection-test data were analyzed by a method described by Cooper and others (1967). A graphical data plot and analysis of the injection test are presented in figure 9. Results of this injection test indicate that the transmissivity of the interval from 691 to 802 m is 8.8×10^{-2} m^2/d. The hydraulic conductivity is 7.9×10^{-4} m/d, corresponding to the minimum value for clayey sandstone (Freeze and Cherry, 1979); the calculated hydraulic-conductivity value probably is one or two orders of magnitude too small, based on a comparison to the hydraulic conductivity determined for tuffaceous sediments penetrated in test hole HTH-1 (Dinwiddie and Schroder, 1971). Perhaps the perforations are plugged by mud or clay from the formation, resulting in the anomalously small value of hydraulic conductivity. Another reason for the minimal hydraulic conductivity may be that some of the shots did not perforate the casing.

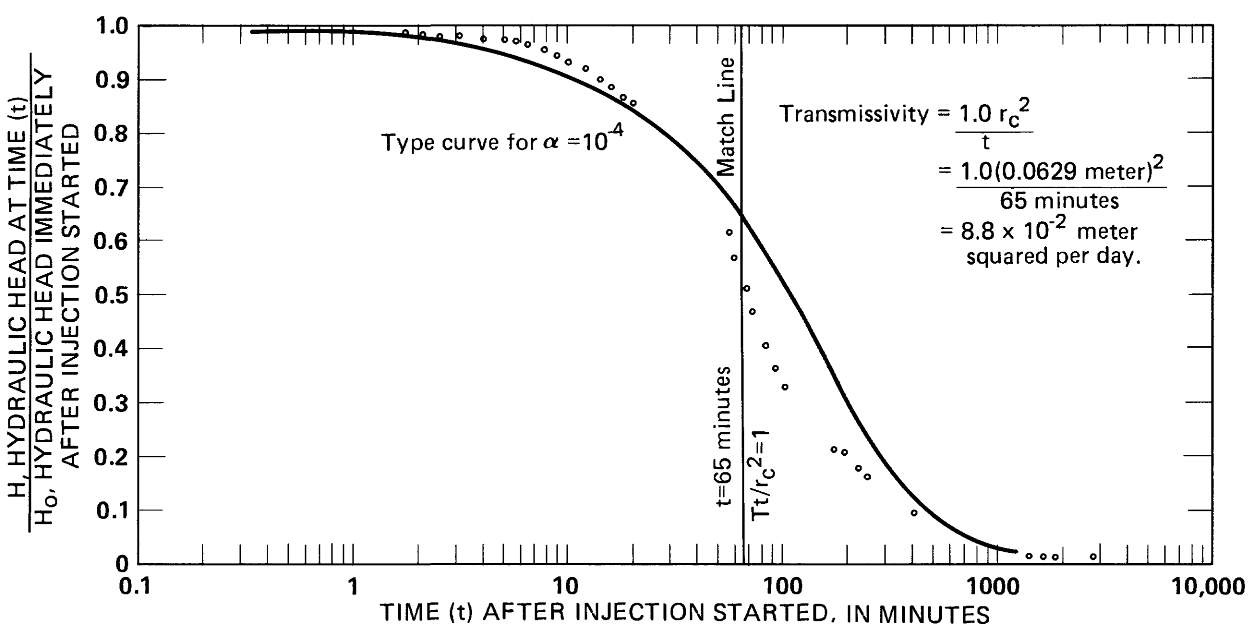


Figure 9.--Analysis of water-level recovery in re-entry hole UC-1-P-2SR during injection test.

Well-bore-storage effects within the casing were prominent during the water-level recovery following the Faultless event. This condition is shown by the full logarithmic graph of change in hydraulic head of the recovering water level from the perched water level of September 24, 1974, indicating that a unit slope (a one-to-one slope) occurred until about 1976 (fig. 10). This unit slope is indicative of well-bore-storage effects. Even after 1976, well-bore-storage effects were prominent, but the slope was lowered to 0.76 when the water level entered the 24.45-cm casing. The graph in figure 10 resembles the graph for increasing well-bore storage in Earlougher, 1977 (fig. 2.12). Because the well-bore storage is so prominent, the semilogarithmic recovery curve probably cannot be analyzed for transmissivity and hydraulic conductivity at the present time.

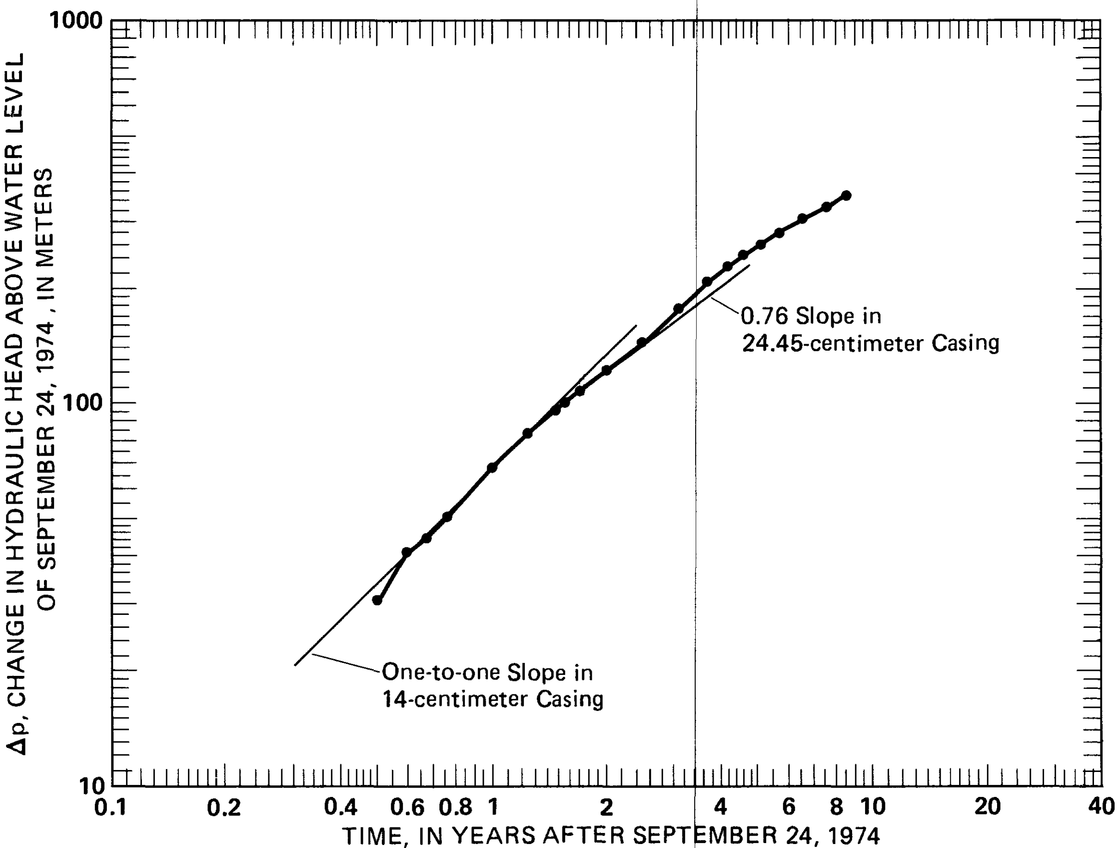


Figure 10.--Change in hydraulic head during water-level recovery in re-entry hole UC-1-P-2SR.

CHEMICAL AND RADIOCHEMICAL MONITORING

Chemical and Radiochemical Zones

Chemical analyses of the water from re-entry hole UC-1-P-2SR from 1968 to 1983 indicate that the water was very similar to the water in the valley fill, as represented by the water from test hole HTH-1, notwithstanding the very dissimilar water from test hole UCE-18 that was used to drill re-entry hole UC-1-P-2SR (Dinwiddie and Schroeder, 1971). Major-element, tritium, and gross beta concentrations indicate three zones of water in re-entry hole UC-1-P-2SR: (1) An upper zone above a depth of 594 m; (2) an intermediate zone from 594 to 728 m; and (3) a lower zone from 728 to 801 m. To analyze the chemical and radiochemical data, the three zones were studied with respect to: (1) Radial distance of the zone from the center of the rubble chimney; (2) well construction, and (3) ground-water temperature. The directional survey in figure 3 presents the location of the upper, middle, and lower zones. Because the lower zone is closest to the center of the rubble chimney, it may contain a greater concentration of radiochemical elements and may be subjected to less dilution from radial flow into the rubble chimney than the overlying zones. Well-construction data (Thordarson, 1984) indicate that the bottom of the 24.45-cm casing at depth of 594.36 m controls the location of the most diluted upper zone, partly because of the increased diameter of the casing that stores a greater volume of water than the underlying smaller casing. Thus, the rise in water from the smaller casing into the overlying larger casing should dilute the rising water, thereby resisting increases from more concentrated water below. High ground-water temperatures that are related to the hot water in the bottom of the rubble cavity control the upper limit of the lower zone. These zones have persisted for 16 years.

A statistical analysis of the upper, middle, and lower zones was conducted, using one-way analysis of variance (R.C. Averett, U.S. Geological Survey, written commun., 1977) on the specific conductance, pH, gross beta concentration, and tritium concentration for the data from each of the many times of sampling between 1975 and 1982. For these properties and radiochemical constituents, a statistically significant difference occurred in the sample means from most suites of samples in these zones at the 99-percent probability level, $p=0.01$. A logarithmic transformation of the tritium concentrations was needed to make an analysis of variance of the tritium data. The significant difference between the sample means at the 99-percent probability level attests to the permanence of these zones with respect to chemical and radiochemical constituents in the ground water as the rubble chimney filled with water.

Chemical Constituents and Physical Properties

The rocks penetrated by re-entry hole UC-1-P-2SR consist of acidic volcanic rocks or alluvium containing abundant fragments of acidic volcanic rocks. Water sampled from re-entry hole UC-1-P-2SR predominantly was a sodium bicarbonate type. The analyses for chemical constituents and physical properties for samples collected from re-entry hole UC-1-P-2SR are presented in Thordarson (1984). The water samples probably were contaminated to some degree by the large quantities of mud and cement used to drill the hole.

Chemical constituents generally increase with increasing depth; these depths may be divided into three zones, namely, above 594 m, 594 to 728 m, and 728 to 801 m. The upper zone, above a depth of 594 m, contains water that is similar to the sodium bicarbonate type water found throughout the region in the tuffaceous aquifer system (Winograd and Thordarson, 1975; Claassen, 1973). Water in the upper zone is characterized by specific-conductance values less than 280 μS/cm and temperatures less than 30 °C. Water in the lower zone is characterized by specific-conductance values of 300 to 440 μS/cm and temperatures of 37 to 61 °C. Although water in both the upper and lower zones contain the same major constituents of sodium and bicarbonate, water in the lower zone has about 1.5 times the dissolved solids as does that in the upper zone. Water in the intermediate zone, occurring between 594 and 728 m, contained concentrations of chemical constituents that were between the concentrations in water from the upper and lower zones.

Chemical analyses of water samples from test hole HTH-1 (Dinwiddie and Schroder, 1971) are presented for comparison with representative samples from the cooler water from the upper zone in re-entry hole UC-1-P-2SR in table 1; analyses of hot springs in Nevada that issue from formations containing acidic volcanic rocks are presented for comparison to hotter water from the lower zone in the re-entry hole in table 2. Water sampled from the upper zone in re-entry hole UC-1-P-2SR resembles formation water from test hole HTH-1 of meteoric origin; water sampled from the lower zone resulting from meteoric water that was heated only by the Faultless event resembles thermal water from hot springs. Analyses of thermal water from the hot springs indicate that the thermal water was derived from meteoric water that was recharged during times of colder climate, probably during the Pleistocene (Mariner and others, 1974 and 1983).

The chemical reaction that probably dominates in the ground water within the rubble chimney is the hydrolysis of minerals (Hem, 1970; Krauskopf, 1979), especially alkali-silicate minerals. The result is an alkaline solution with a pH generally greater than 8.0 and large concentrations of alkalinity, sodium, potassium, and silica. This hydrolysis is well illustrated by the similarity of chemical compositions of the heated water from the lower zone in re-entry hole UC-1-P-2SR to the thermal water from springs issuing from acidic volcanic rocks where hydrolysis of silicate minerals takes place.

Table 1.--*Results of representative chemical analyses of water from the upper zone of re-entry hole UC-1-P-2SR and from test hole HTH-1*

[Dissolved constituents: Ca (calcium), Mg (magnesium), Na (sodium), K (potassium), CO_3 (carbonate), HCO_3 (bicarbonate), Cl (chloride), SO_4 (sulfate), SiO_2 (aqueous silica), Li (lithium), Sr (strontium), and F (fluoride) in milligrams per liter; pH in standard units; microsiemens, microsiemens per centimeter at 25 °Celsius]

Location	Sample Date	Sample Depth (meters)	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	SiO_2	Li	Sr	F	pH	Water temperature (degrees Celsius)	Specific conductance (microsiemens)	SO_4/Cl (molar ratio)
Re-entry hole UC-1-P-2SR.	7-20-83	485	2.3	0.02	47	1.2	11	100	4.8	15	15	0.05	0.30	0.8	9.3	--	225	1.2
Do--------------	7-20-83	576	2.5	.05	48	1.4	10	101	4.5	15	15	.06	.31	.8	9.4	--	215	1.2
Test hole HTH-1------	8-05-67	213-259	5.9	.9	58	6.7	0	137	7.5	18	18	.08	.16	1.4	7.9	22.0	285	0.89
Do--------------	8-05-67	290-350	8.7	.6	39	3.9	0	116	4.4	11	25	.05	.23	.9	7.7	24.5	218	.92
Do--------------	8-02-67	731-750	3.7	.8	144	7.9	122	47	13	44	44	.15	.14	12	10.2	27.0	663	1.2
Do--------------	8-01-67	805-826	4.7	2.0	107	2.7	1	225	15	36	42	.11	.12	8.2	8.7	33.0	482	.89
Do--------------	7-31-67	899-917	12	.4	110	1.2	5	247	20	34	68	.16	.33	2.6	8.4	33.0	567	.63

Table 2.--*Results of chemical and radiochemical analyses of water from the lower zone of re-entry hole UC-1-P-2SR and results of chemical analyses for selected hot springs issuing from sedimentary rocks that contain volcanic-rock fragments*

[Dissolved constituents: Ca (calcium), Mg (magnesium), Na (sodium), K (potassium), CO_3 (carbonate), HCO_3 (bicarbonate) Cl (chloride), SO_4 (sulfate), SiO_2 (aqueous silica), Li (lithium), Sr (strontium), and F (fluoride) in milligrams per liter; gross alpha, dissolved as natural uranium, in micrograms per liter; gross beta, dissolved as cesium-137, and tritium, in picocuries per liter; pH in standard units; microsiemens, microsiemens per centimeter at 25 °Celsius]

Sample			Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	SiO_2	Li	Sr	F	Gross alpha	Gross beta	Tritium	pH	Water temperature (degrees Celsius)	Specific conductance (microsiemens)	SO_4/Cl (molar ratio)
Number	Date	Depth (meters)																			
									RE-ENTRY HOLE UC-1-P-2SR												
1	12-02-70	786	0.7	<0.1	67	2.2	--	--	6.5	20	26	0.08	0.07	1.0	5.3	72	$2.4x10^6$	10.1	59.8	325	1.1
2	08-13-75	789	1.8	.8	62	.9	19	106	6.3	32	34	.05	.02	1.6	10	35	$9.6x10^6$	9.6	60.6	265	1.9
3	02-12-76	789	2.0	.2	79	1.3	26	115	11	48	51	.08	.07	2.0	<3.6	110	$3.7x10^8$	9.7	--	362	1.6
4	09-01-76	774	2.1	.1	98	1.6	9	138	19	82	64	.11	.13	2.2	<3.8	130	$7.6x10^8$	9.1	52.8	472	1.6
5	10-19-77	774	--	.1	79	.9	11	135	6.4	29	27	.07	.21	1.5	<2.3	22	$2.3x10^5$	9.2	49.0	223	1.7
6	06-15-78	789	--	.2	74	.9	9	138	6.7	30	27	.07	.17	1.6	3.8	30	$2.9x10^6$	9.1	56.0	320	1.7
7	12-13-78	789	2.7	.1	71	1.2	8	126	6.6	32	30	.06	.16	1.6	<2.5	6.3	$5.5x10^6$	9.1	55.0	300	1.8
8	05-31-79	789	5.2	<.1	75	.8	12	147	12	32	26	.08	.31	1.6	<3.3	3.7	$7.2x10^6$	9.2	42.0	315	.98
9	12-06-79	789	3.1	.2	74	.9	6	189	7.6	31	26	--	.16	1.6	23	34	$8.0x10^6$	8.7	54.0	290	1.5
10	07-19-80	789	2.2	.0	69	.9	9	138	7.1	31	26	.06	.13	1.8	3.7	4.0	$1.4x10^7$	9.1	53.5	339	1.6
11	07-01-81	789	2.7	.1	74	.7	9	138	6.8	35	29	.07	.13	1.6	<5.1	<2.3	$1.8x10^7$	9.1	55.0	340	1.9
12	07-21-82	789	3.2	.0	74	.8	4	151	12	34	28	.08	.14	1.8	<6.0	6.0	$2.1x10^7$	8.6	--	445	1.0
13	07-21-83	789	2.5	.04	72	.8	9	150	7.9	33	26	.08	.14	1.9	<7.0	6.1	--	9.0	--	300	1.5
									BOG HOT SPRINGS[1]												
--	--	0	.2	<.1	81	1.0	11	116	15	45	57	.03	--	1.7	--	--	--	9.0	54	356	1.1
									HOWARD HOT SPRINGS[2]												
--	--	0	3	<.1	88	1.7	--	127	10	62	85	--	--	--	--	--	--	9.2	56	400	2.3
									DAROUGH'S HOT SPRING[3]												
--	--	0	1.3	.1	110	2.6	3	146	12	53	98	.3	--	14	--	--	--	8.3	95	479	1.6
									KLOBE HOT SPRINGS[4]												
--	--	0	1	<.1	64	.7	--	144	6.3	18	85	--	--	--	--	--	--	9.2	54	295	1.1
									MINERAL HOT SPRINGS[5]												
--	--	0	1.6	<.1	75	2.2	--	108	15	45	83	<.2	--	8.9	--	--	--	9.1	60	344	1.1

[1]In Humboldt County, Nev., section 7, township 46 north, range 28 east.
[2]In Humboldt County, Nev., section 4, township 44 north, range 31 east.
[3]In Nye County, Nev., section 8, township 11 north, range 43 east.
[4]In Eureka County, Nev., section 28, township 18 north, range 50 east.
[5]In Elko County, Nev., section 16, township 45 north, range 64 east.

A time-series analysis of the chemical data was made, (Keely, 1982; Keely and Wolf, 1983). For this purpose, graphs of mean values of specific conductance, temperature, and pH versus time are presented in figures 11, 12, and 13; diagrams of specific conductance, temperature, and chloride related to depth and time are presented in figures 14, 15, and 16. The water samples probably were contaminated by drilling mud and cement, to some degree. This is well illustrated in figure 13 that indicates that the maximum values of pH generally were measured in water from the upper zone, above a depth of 594 m.

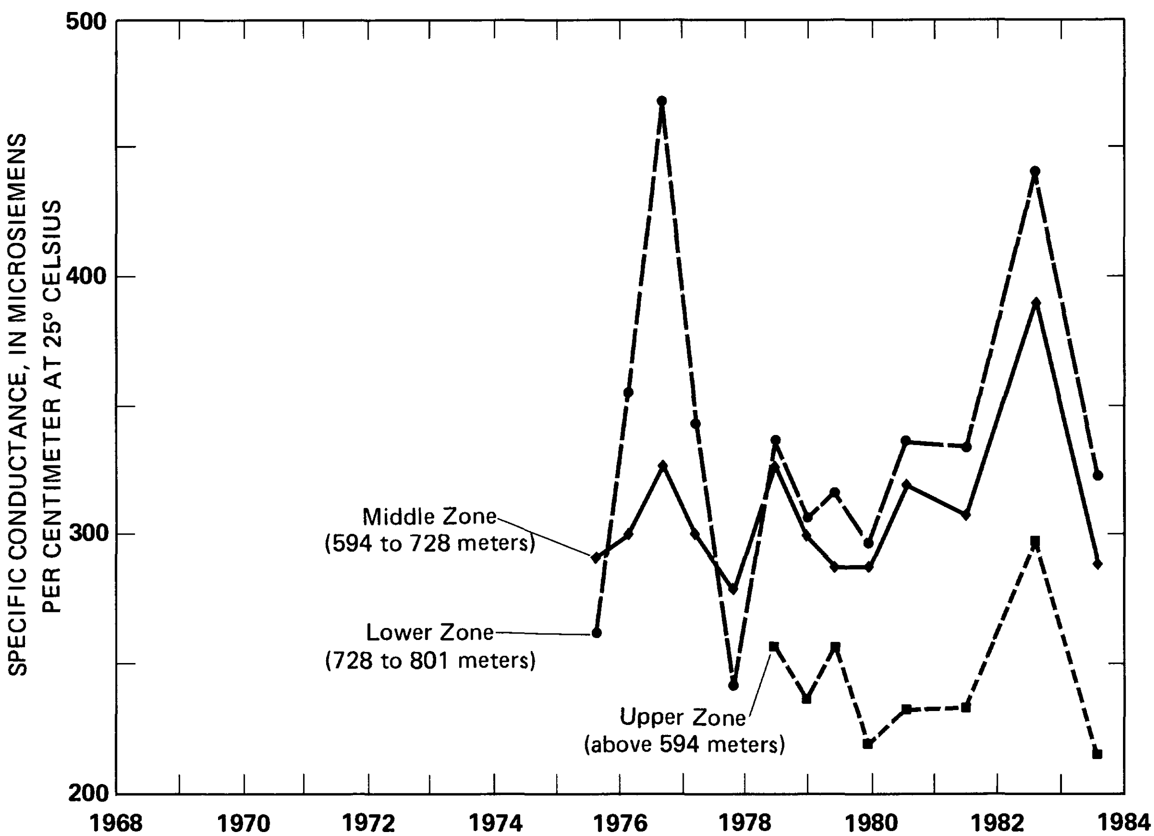


Figure 11.--Mean values of specific conductance in upper, middle, and lower zones in re-entry hole UC-1-P-2SR.

This possibly is due to contamination by drilling mud or cement behind the perforations of the 24.45-cm O.D. casing. Below a depth of 594 m, the casing is not cemented, resulting in less contamination by cement. Notwithstanding the contamination by cement, the data in figures 11, 12, and 13 indicate irregular, slow, transient changes in the chemical time-series patterns, that possibly are related to the rising water level in the chimney, rising hot water, and descending cooler water. In general, increasing values of specific conductance and temperature were measured in 1976, 1978, and 1980 to 1981;

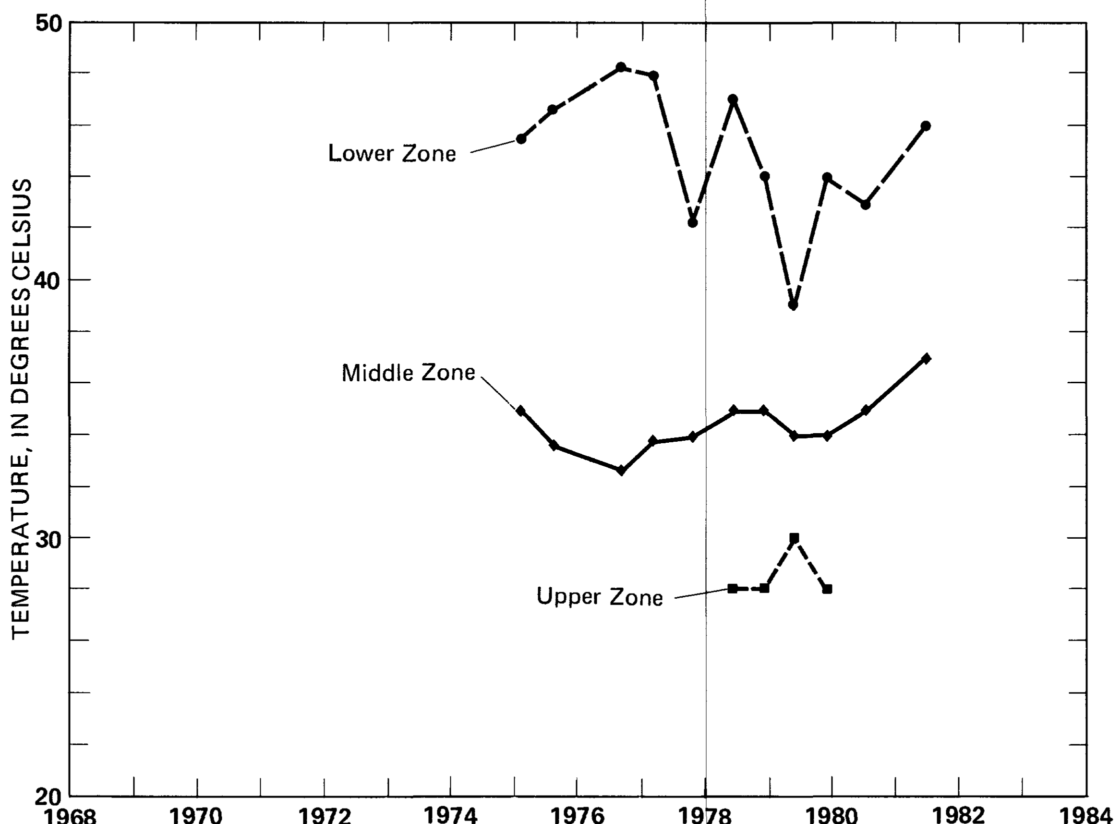


Figure 12.--Mean values of temperature in the upper, middle, and lower zones in re-entry hole UC-1-P-2SR.

decreases in these values were measured in 1977 and 1979. Increasing values were associated with either the initial rise of hot water, when the water level rose above the perched level, or were associated with later rises of hot water, resulting from convection or other unknown reasons. Decreasing values appeared to result from the descending colder waters from above, either from injection caused by higher hydraulic heads in the borehole than in the formation as the water level rose, or thermal convection. The occurrence of decreasing values generally persisted for shorter periods than the occurrence of increasing values. The striking zonation of the water into an upper zone above 594 m, a middle zone, 594 to 728 m, and a lower zone, 728 to 801 m, is indicated on the depth versus time figures (figs. 14, 15, and 16).

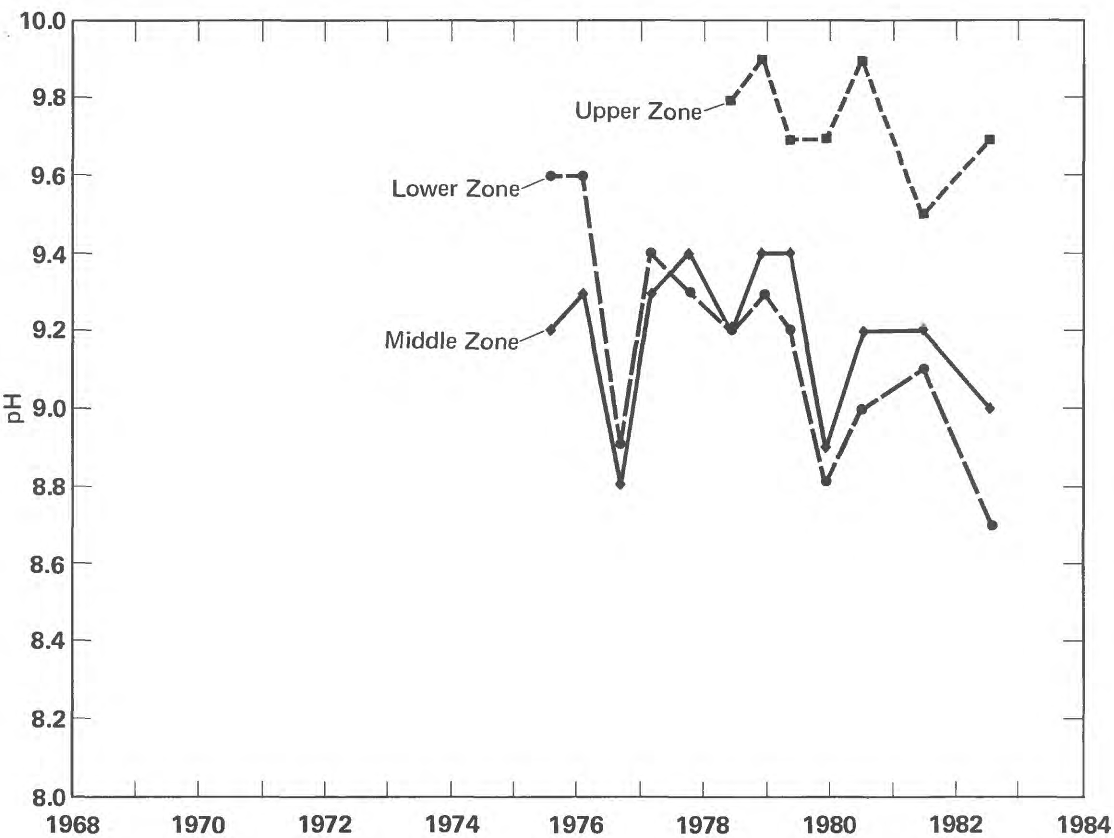


Figure 13.--Mean values of pH in upper, middle, and lower zones in re-entry hole UC-1-P-2SR.

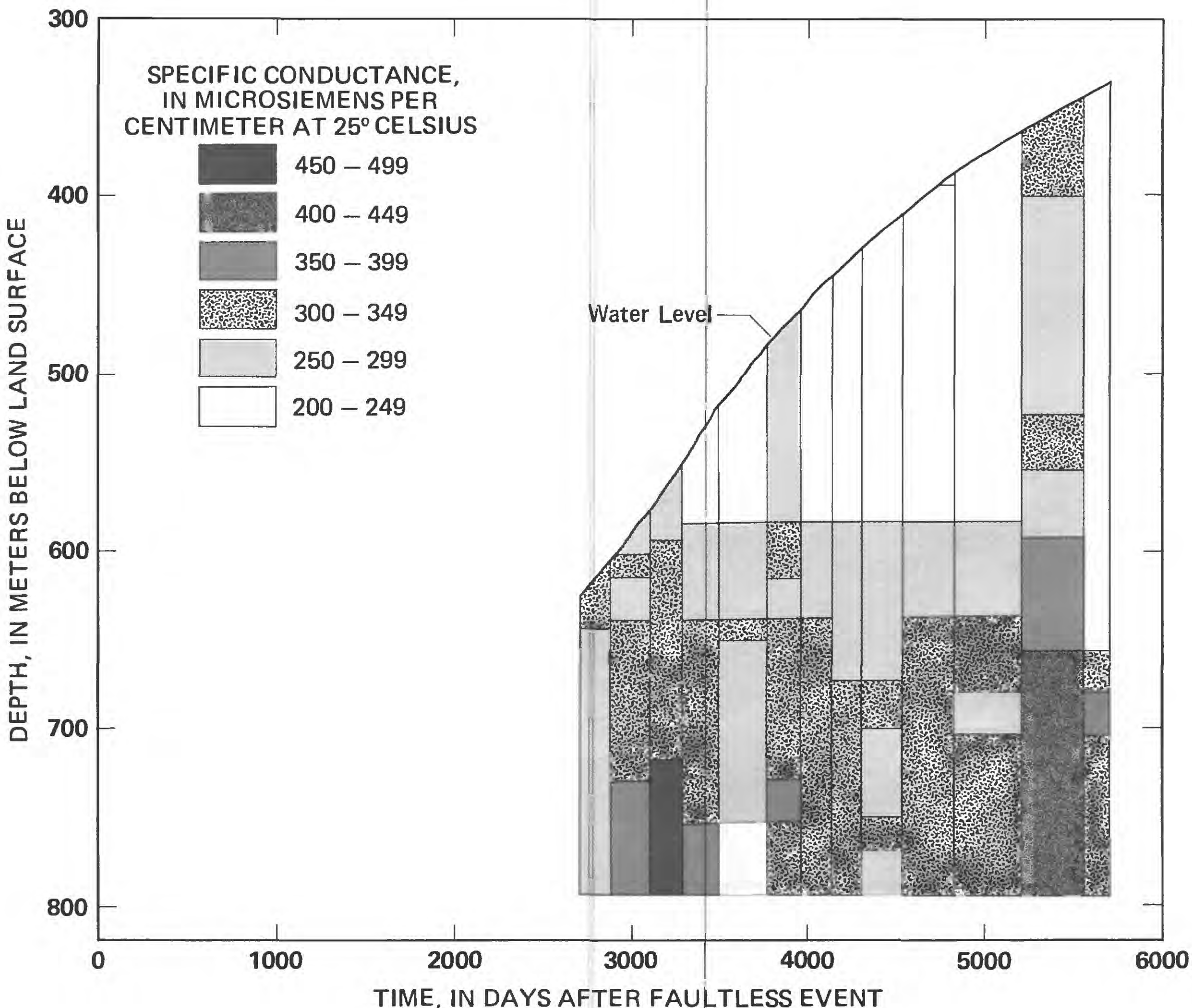


Figure 14.--Changes in specific conductance with depth in re-entry hole UC-1-P-2SR.

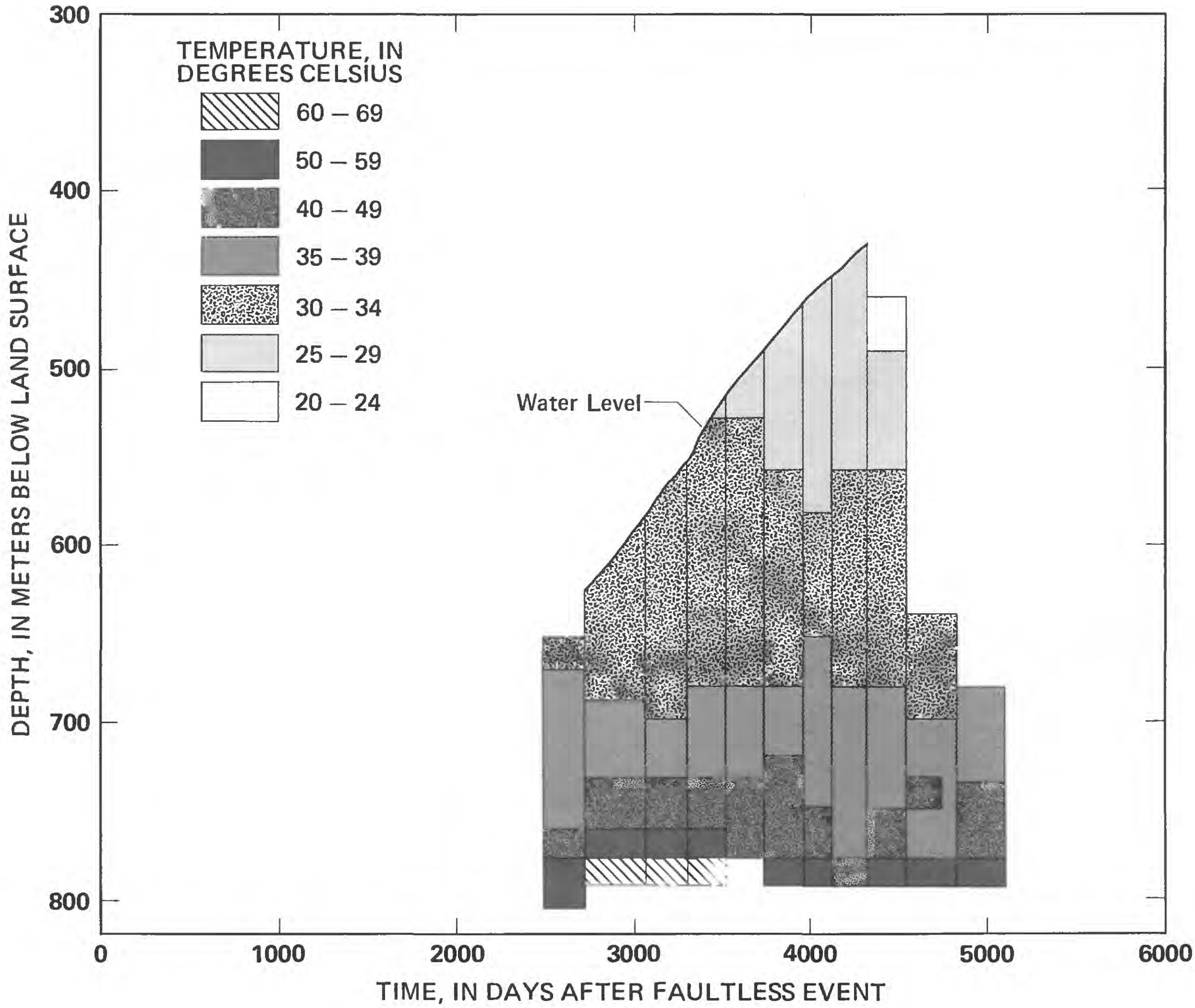


Figure 15.--Changes in temperature with depth in re-entry hole UC-1-P-2SR.

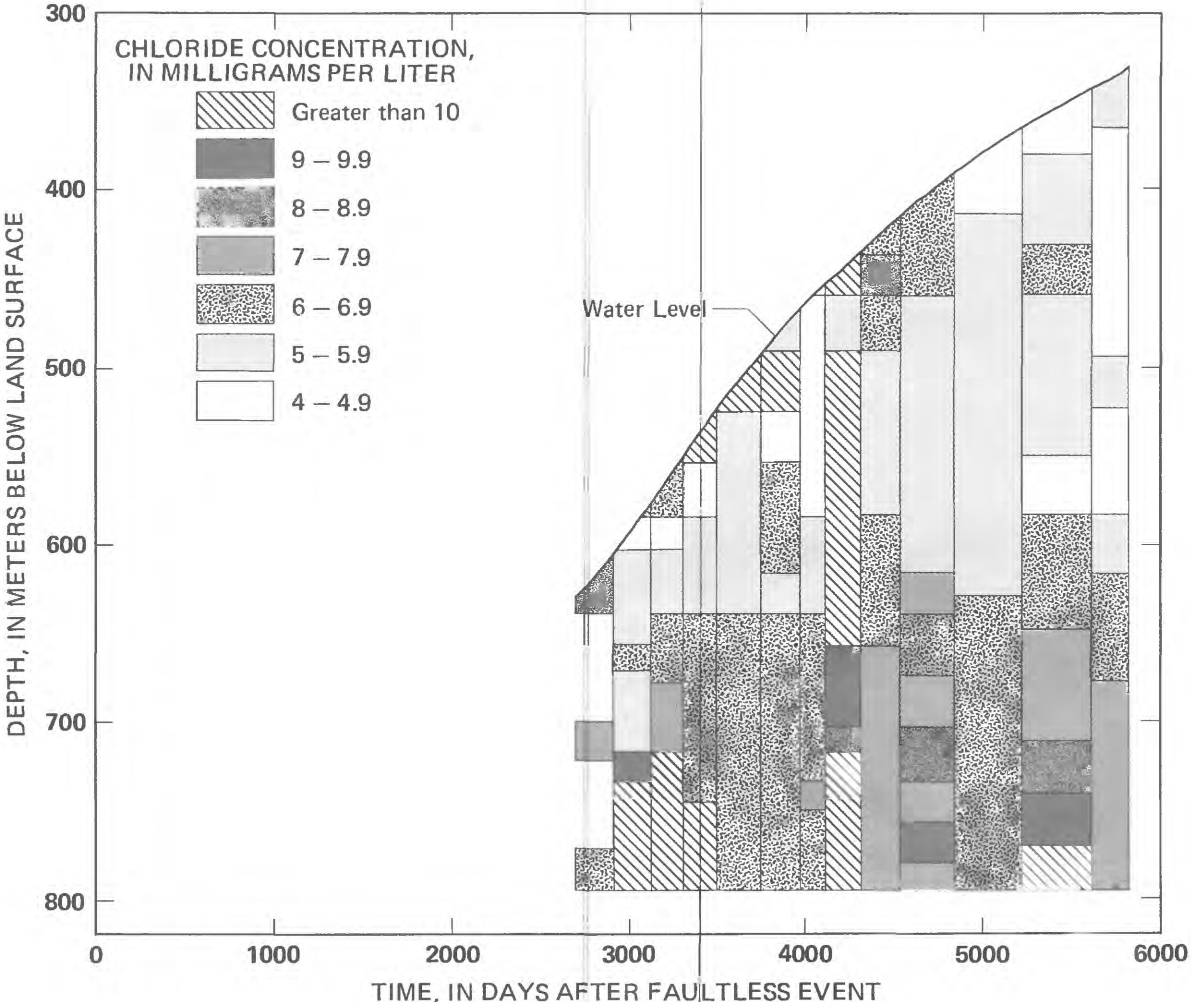


Figure 16.--Changes in concentration of chloride with depth in re-entry hole UC-1-P-2SR.

Radiochemical Constituents

Graphs of gross alpha, gross beta, and tritium concentrations (uncorrected for radioactive decay) versus time are presented in figures 17, 18, and 19; a graph of tritium concentrations (uncorrected) related to depth and time is presented in figure 20. The data in these figures generally illustrate the distinct zonation in the same upper (above 594 m), middle (594 to 728 m), and lower (728 to 801 m) zones as were prominent in the zonation of the chemical data. Gross alpha concentration does not indicate much zonation in the middle and lower zones; because only less than values of gross alpha concentration in the upper zone were available, calculations of mean values for inclusion in figure 17 were not possible. Gross beta and tritium concentrations illustrate

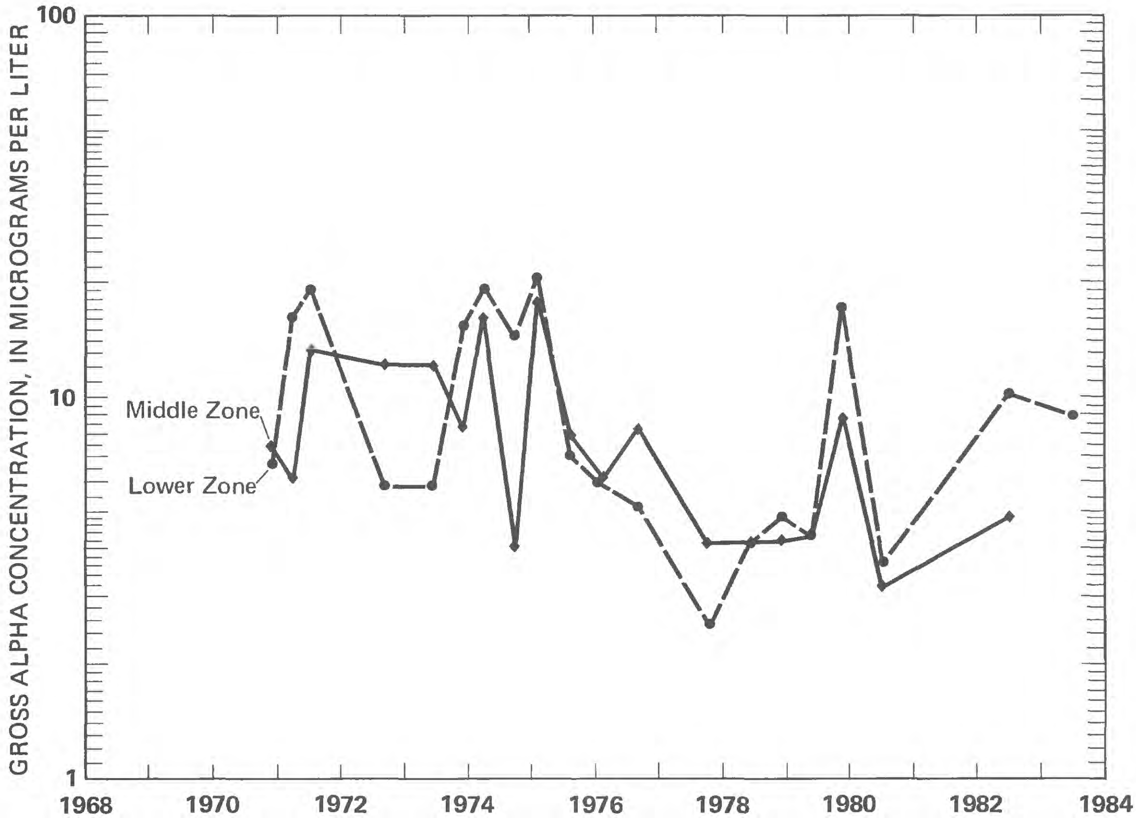


Figure 17.--Mean values of gross alpha concentration in middle and lower zones in re-entry hole UC-1-P-2SR.

the best zonation of the radiochemicals; an obvious correlation of gross beta and tritium concentrations occurs with the hot lower zone from 1970 to 1977. However, after 1977, gross beta concentrations fluctuate, and tritium concentrations increase steadily. Gross beta concentration appears to have decreased from radioactive decay and decreased about one log cycle in 10 years in the middle and lower zones. In general, peak concentrations of gross alpha, gross beta, and tritium were measured in 1971, 1974, 1976, and 1982;

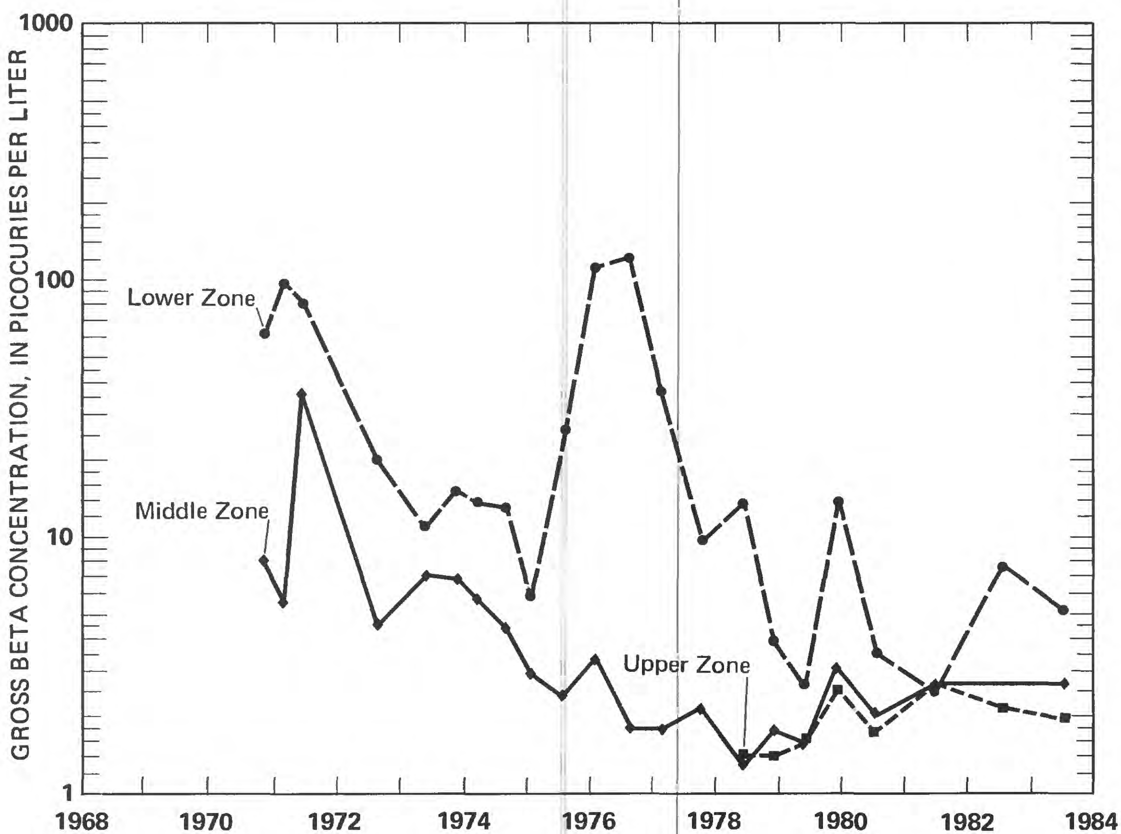


Figure 18.--Mean values of gross beta concentration in upper, middle, and lower zones in re-entry hole UC-1-P-2SR.

minimum concentrations were measured in 1972, 1975, and 1977. The minimum values in 1977 support the concept that there is flow from the upper to the lower zone. These graphs show irregular, slow, transient changes in the radiochemical time-series patterns, similar to those in the chemical time-series patterns; they possibly are related to the same rising hot water or descending cold water that affected the chemical time-series patterns. The peak in tritium concentration in 1976 was much higher in the lower zone than in the middle zone (fig. 19), which indicates possible vertical movement of hot water containing large concentrations of tritium into the lower zone, and that the hot water did not reach the middle zone.

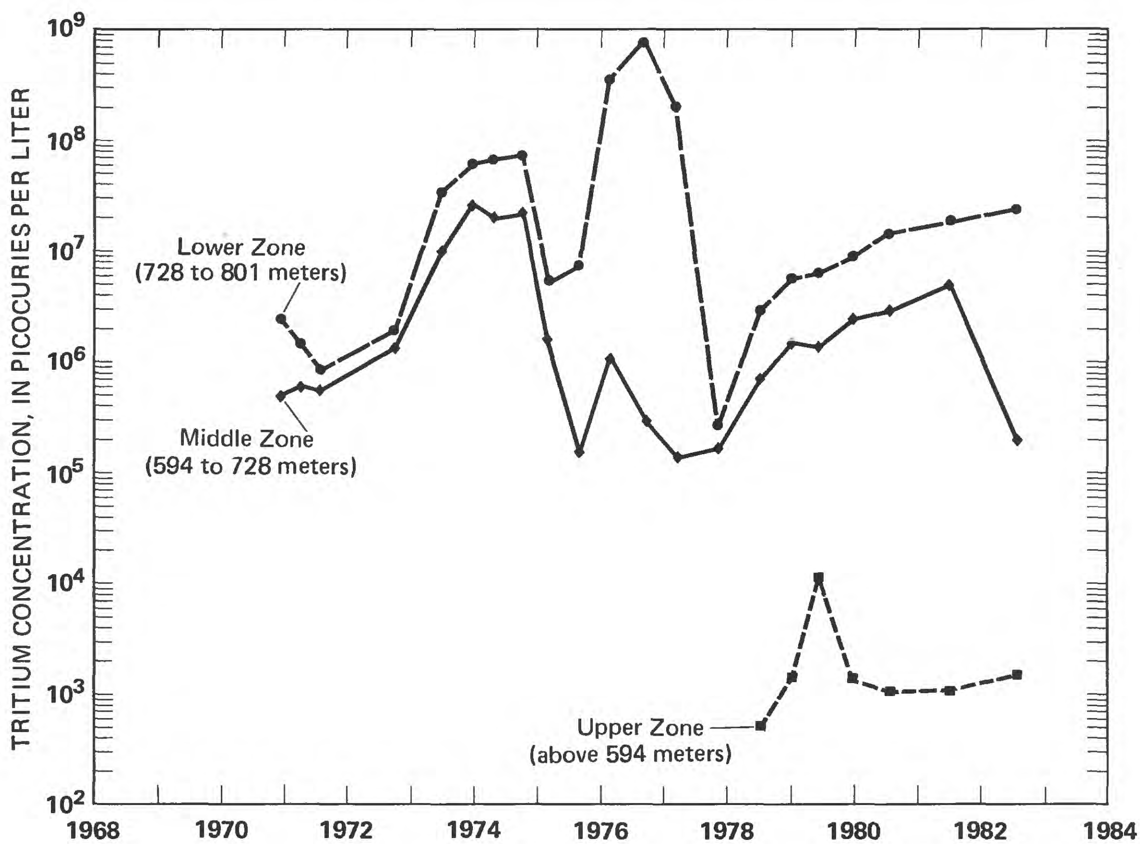


Figure 19.--Mean values of tritium concentration in upper, middle, and lower zones in re-entry hole UC-1-P-2SR.

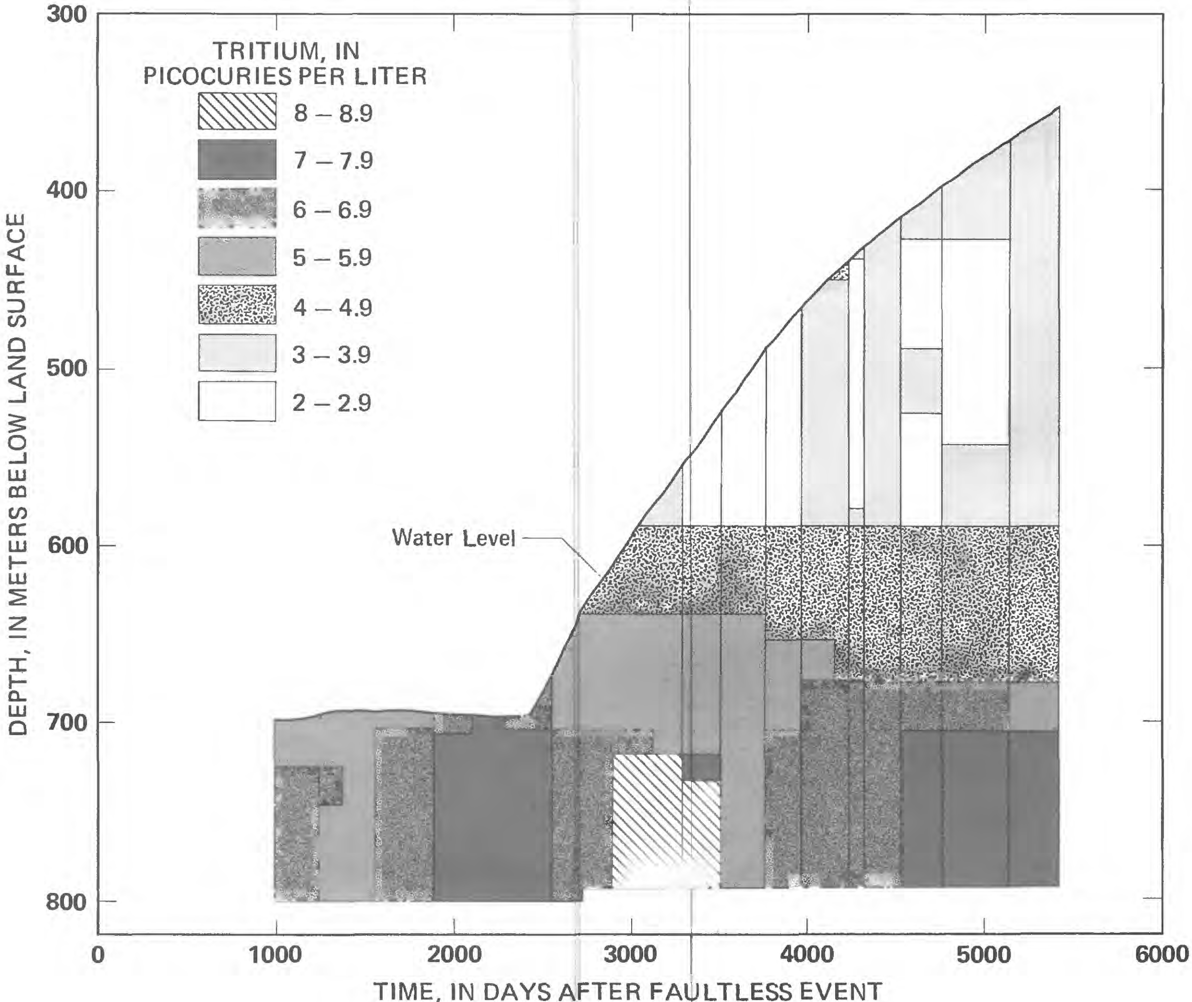


Figure 20.--Changes in concentration of tritium with depth in re-entry hole UC-1-P-2SR.

Monitoring at Bottom of Hole

The bottom sampling point at a depth of 798 m in re-entry hole UC-1-P-2SR was considered most representative of the ground water from near the Faultless event, because it contained the largest concentration of radiochemicals. Hot water from the Faultless event at the bottom sampling point has persisted for more than 13 years; this persistence has allowed chemical and radiochemical monitoring of the ground water just above the former cavity of the Faultless event. Sampling of deeper zones in the bottom of the chimney would have been desirable, but, because of the obstruction in the hole at a depth of 802 m, this was not possible; therefore, some of the scientific objectives were not accomplished.

Chemical and radiochemical analyses of water samples from the bottom sampling point are presented in table 2; the samples are numbered in a time sequence to correspond with numbers in figures 21-24. Although the bottom sampling point in reentry hole UC-1-P-2SR is considered to be at a depth of 789 m, in a few cases, water analyses were available only from slightly lower depths of 774 m and 786 m (table 2).

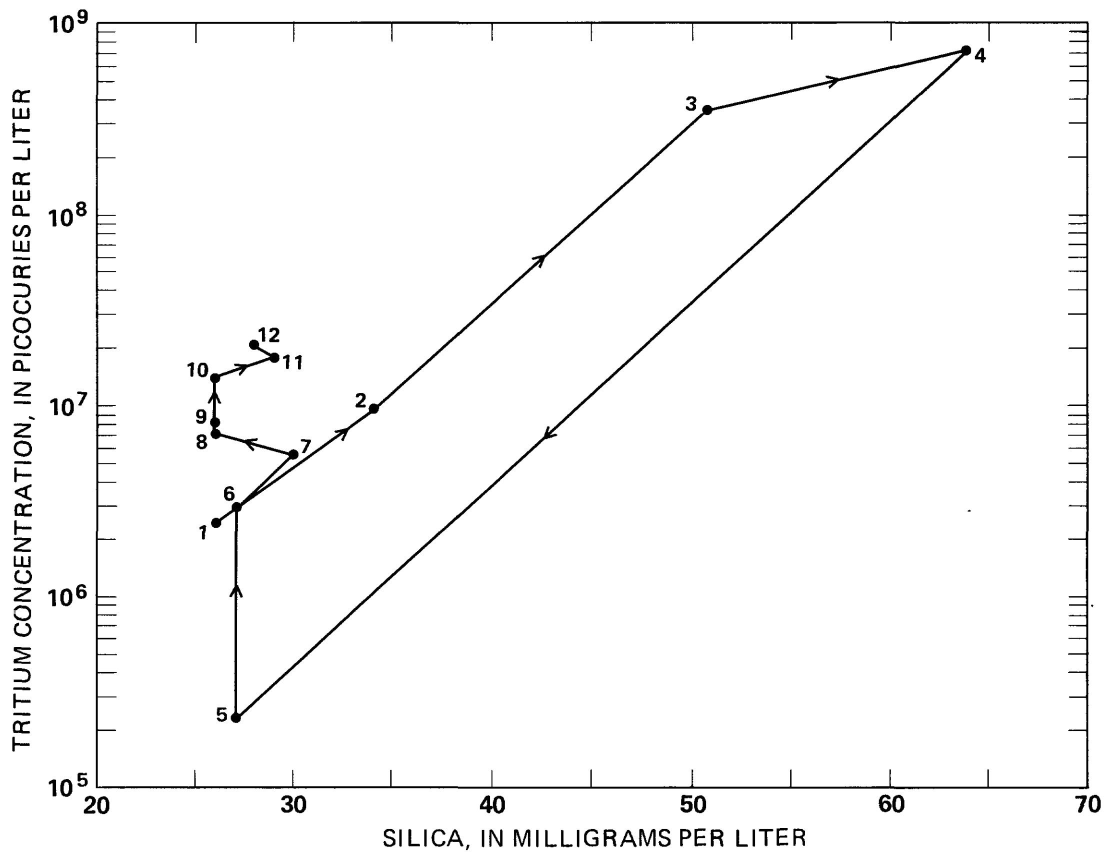


Figure 21.--Concentration of tritium versus silica at bottom of re-entry hole UC-1-P-2SR.

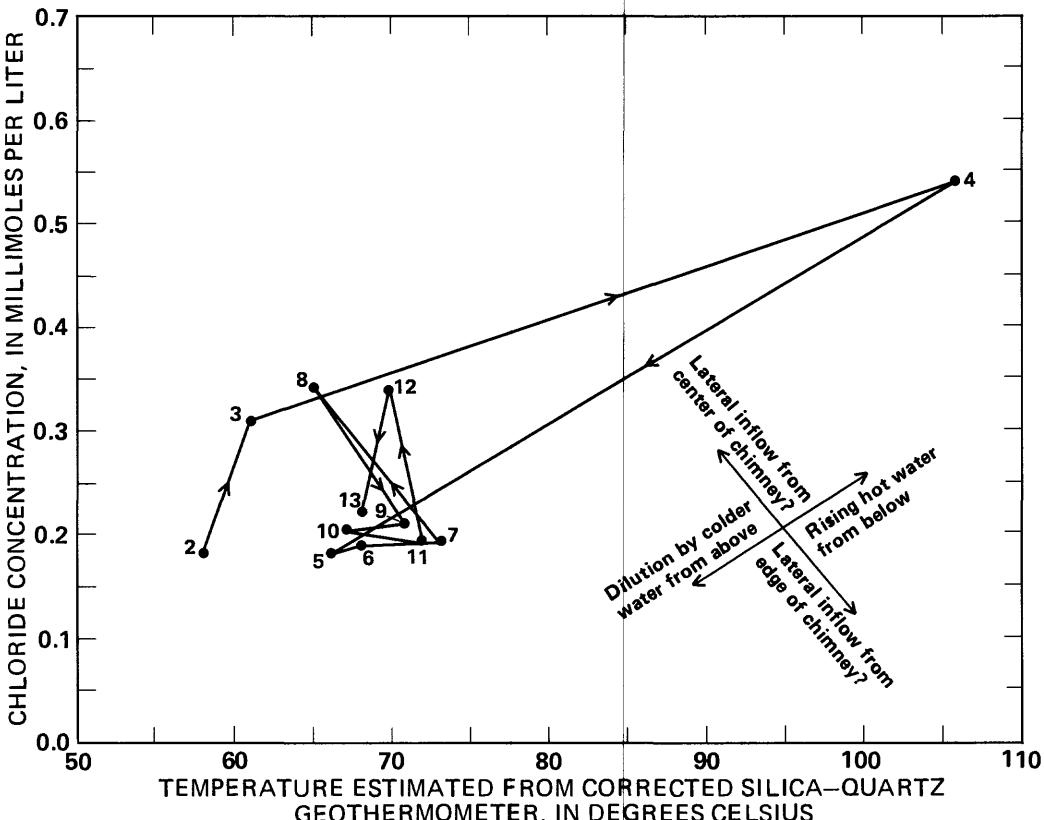


Figure 22.--Concentration of chloride versus temperature from corrected silica-quartz geothermometer at bottom of re-entry hole UC-1-P-2SR.

Estimated reservoir temperatures based on measurements obtained using a geothermometer of silica quartz, or corrected silica quartz, or sodium-potassium-calcium are presented in table 3 from calculations described by Rush (1983). For example, calculations from the silica-quartz geothermometer indicate that reservoir temperatures just below the bottom of the hole increased to a peak of 114 °C in 1976, as hotter water moved upward, along with the general rise in water level above the perched water level, that was formerly at a depth of about 695 m. In 1977, cooler water from above appears to have descended, so that calculations from the silica-quartz geothermometer indicated that reservoir temperatures just below the bottom of the hole were 80 °C or less from 1977 to 1983.

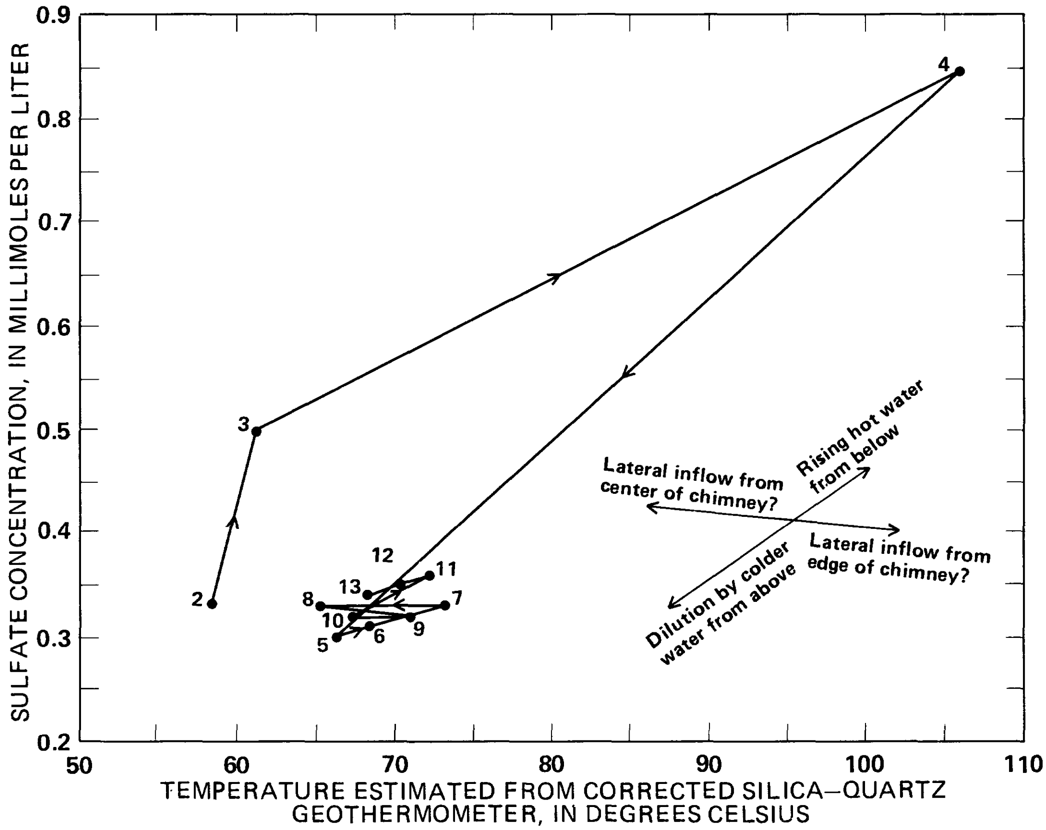


Figure 23.--Concentration of sulfate versus temperature from corrected silica-quartz geothermometer at bottom of re-entry hole UC-1-P-2SR.

To examine the changes in chemical and radiochemical constituents with changes in temperature, graphs of tritium versus silica and chloride, sulfate, and the sulfate-to-chloride ratio plotted versus temperature estimated using the corrected silica-quartz geothermometer (figs. 21, 22, 23, and 24) were made using the method suggested by Ellis and Mahon (1977), the numbers being in the time sequence listed in table 3. These graphs indicate that, from 1970 to 1976, tritium, chloride, and sulfate apparently increased as the temperature increased because of rising hot water from below. Then in 1977, dilution by cold water from above caused tritium, chloride, and sulfate to decrease. Then from 1978 to 1982, the tritium increased, but the chloride and sulfate only changed slightly. The tritium was approaching a long, broad peak from 1978 to 1982, probably because of continued upward movement of tritiated water, but the chemical composition was not changing too much.

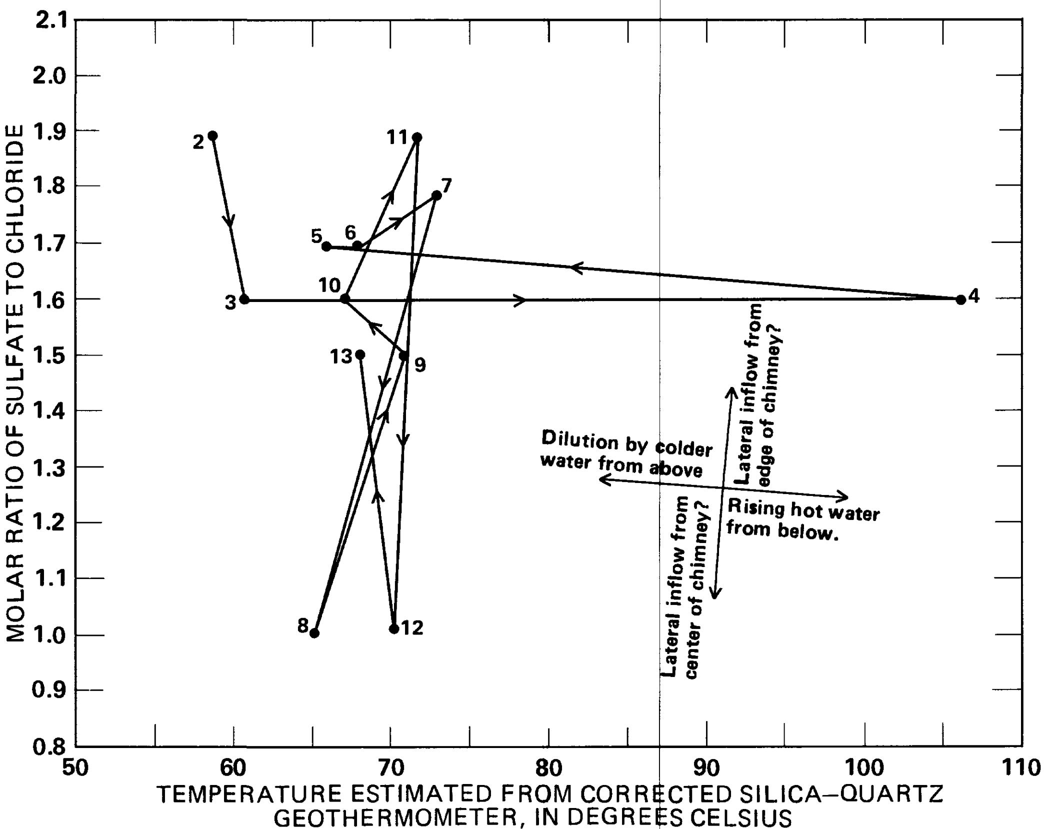


Figure 24.--Molar ratio of sulfate to chloride versus temperature estimated from corrected silica-quartz geothermometer at bottom of re-entry hole UC-1-P-2SR.

Table 3.--*Estimated reservoir temperatures*

Sample			Water temperature (degrees Celsius)	Estimated reservoir temperature, in degrees Celsius, based on indicated geothermometer		
Number	Date	Depth (meters)		Silica quartz (conductive)	Silica quartz (conductive, H_3SiO_4-corrected)	Sodium-potassium-calcium
1	12-02-70	786	59.8	74	---	138
2	08-13-75	789	60.6	85	58	67
3	02-12-76	789	----	103	61	79
4	09-01-76	774	52.8	114	105	88
5	10-19-77	774	49.0	75	66	---
6	06-15-78	789	56.0	75	68	---
7	12-13-78	789	55.0	80	73	69
8	05-31-79	789	42.0	74	65	46
9	12-06-79	789	54.0	74	71	58
10	07-19-80	789	53.5	74	67	64
11	07-01-81	789	55.0	78	72	54
12	07-21-82	789	----	77	70	54
13	07-21-83	789	----	74	68	59

SUMMARY

Re-entry hole UC-1-P-2SR was drilled to a total depth of 1,097 meters in the rubble chimney resulting from the Faultless event, using rotary drilling equipment and mud as the circulating medium. The hole penetrated 732 meters of alluvium and 365 meters of tuffaceous sediments; it was cased to a depth of 851 meters. An obstruction occurred at a depth of approximately 802 meters.

Monitoring of the water-level in re-entry hole UC-1-P-2SR indicates that, from 1970 to 1974, the water level was about 695 meters below land surface. This water level may represent a perched water level in clayey sedimentary rocks with minimal hydraulic conductivity. During filling of the rubble chimney from 1974 to 1983, the water level rose slowly to a depth of 335.1 meters. The 1983 level was about 167 meters below the pre-event water level of about 168 meters in depth.

Water with temperatures ranging from 37 to 61 degrees Celsius was detected at the bottom of the re-entry hole from depths of 728 to 801 meters. A temperature of 100 °Celsius at a depth of 820 meters was estimated by projection from temperature logs.

The hydraulic connection between the re-entry hole and the rubble chimney is considered limited. The minimal transmissivity of the clayey sedimentary rocks, the large volume of mud used during drilling, and the possibility of plugged perforations are the probable cause of the limited hydraulic connection between the hole and the chimney.

A hydraulic injection test indicated that the interval from 691 to 802 meters had a transmissivity of 8.8×10^{-2} meter squared per day; the hydraulic conductivity was 7.9×10^{-4} meter per day. These values may be too small because of a drilling-mud sheath around the hole, and because the perforations may be partly plugged.

Chemical analyses of water samples indicate that the water predominantly is a sodium bicarbonate type. Chemical and radiochemical analyses indicate that, although the chemical constituents and physical properties generally increase by increasing depth, three persistent zones have lasted for more than 16 years during the rising water level. A statistical analysis of variance of the mean values in these zones has indicated that the mean values are significantly different at the 99-percent probability level. The upper zone above 594 meters that contains formation water is characterized by specific-conductance values less than 280 microsiemens per centimeter, temperatures less than 30 °Celsius, and near-background tritium concentrations of about 1×10^3 picocuries per liter. The lower zone from 728 to 801 meters that contains hot, more radioactive water from near the Faultless event is characterized by specific-conductance values of 300 to 440 microsiemens per centimeter, temperatures of 37 to 61 °Celsius, and tritium concentrations of 1×10^7 picocuries per liter or more. Water in the intermediate zone, occurring between 594 and 728 meters, had values of specific conductance and temperature, and concentrations of tritium between those in water from the upper and lower zones.

In general, the hot, radioactive water from the Faultless event apparently has risen into the lower zone, concomitant with the rising water level as the rubble chimney was being filled. This general rise was interrupted by the apparent major dilutions from colder water descending from above, during both 1975 and 1977.

Because of the obstruction at 802 meters, the deeper zones near the former cavity of the Faultless event were not monitored. Therefore, some of the scientific objectives of the study were not accomplished.

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