HYDROLOGIC AND GEOCHEMICAL MONITORING IN LONG VALLEY CALDERA, MONO COUNTY, CALIFORNIA, 1982-1984

By C.D. Farrar, M.L. Sorey, S.A. Rojstaczer, C.J. Janik,
R.H. Mariner, and T.L. Winnett

U.S. GEOLOGICAL SURVEY

and

By M.D. Clark

U.S. FOREST SERVICE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4183

Sacramento, California
1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2235
2800 Cottage Way
Sacramento, CA 95825

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 236-7476

CONTENTS

CONTENTS (Continued) Page

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

CONVERSION FACTORS

For those readers who may prefer metric (SI) units rather than inch-pound units, the conversion factors for the terms in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
inch (in)	25.40	millimeter (mm)
pound (lb)	0.4536	kilogram (kg)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometers (km^2)
cubic mile (mi^3)	4.170	cubic kilometer (km^3)
micromhos per centimeter at 25 celsius (μmho/cm at 25°C)	1.000	microsiemens per centimeter at 25 celsius (μS/cm at 25°C)
foot of water	0.029	bar of air pressure at standard temperature and pressure
foot of water	2.945	kilopascal (kpa)

<u>National Geodetic Vertical Datum of 1929 (NGVD of 1929)</u>: 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. NGVD is referred to as sea level in this report.

HYDROLOGIC AND GEOCHEMICAL MONITORING IN LONG VALLEY CALDERA, MONO COUNTY, CALIFORNIA 1982-1984

By C.D. Farrar, M.L. Sorey, S.A. Rojstaczer, C.J. Janik, R.H. Mariner, and T.L. Winnett (U.S. Geological Survey) and M.D. Clark (U.S. Forest Service)

ABSTRACT

The Long Valley caldera is a potentially active volcanic area on the eastern side of the Sierra Nevada in east-central California. Hydrologic and geochemical monitoring of surface and subsurface features began in July 1982 to determine if changes were occurring in response to processes causing earthquakes and crustal deformation. Differences since 1982 in fluid chemistry of springs has been minor except at Casa Diablo, where rapid fluctuations in chemistry result from near-surface boiling and mixing. Ratios of $^{3}He/^{4}He$ and $^{13}C/^{12}C$ in hot springs and fumaroles are consistent with a magmatic source for some of the carbon and helium discharged in thermal areas, and observed changes in $^{3}He/^{4}He$ between 1978 and 1984 suggest changes in the magmatic component. Significant fluctuations in hot spring discharge recorded at several sites since 1982 closely followed earthquake activity.

Water levels in wells have been used as strain meters to detect rock deformation associated with magmatic and tectonic activity and to construct a water table contour map. Coseismic water-level fluctuations of as much as 0.6 ft have been observed but no clear evidence of deformation caused by magmatic intrusions can be seen in the well records through 1984. Temperature profiles in wells, which can be used to delineate regionally continuous zones of lateral flow of hot water across parts of the caldera, have remained constant at all but two sites.

INTRODUCTION

The Long Valley area lies within a region characterized by recent volcanism and seismic activity. Earthquakes with magnitudes near 6 occurred within the Long Valley caldera in May 1980 and January 1983. These earthquakes and related seismic activity within the Sierran block south of the caldera, along with changes in fumarolic discharge and detection of ground deformation during the period 1980-82 increased concern over the possibility of a volcanic eruption in the near future (Miller and others, 1982). Since January 1983, lower levels of seismic activity and reduced rates of ground deformation indicate a lessened likelihood of imminent volcanic activity. Nevertheless, the Long Valley area continues to exhibit significantly higher rates of microearthquake activity and ground deformation than other areas in California and is still recognized as having the potential for volcanic eruption.

The Long Valley caldera contains an active hydrothermal system within the area of increased seismicity and ground deformation, and changes in the hydrothermal system may be expected to accompany these other phenomena. Variations in the discharge characteristics of hot springs in the Long Valley caldera have been noted following, and possibly preceding, earthquakes of magnitude 5 or greater (Sherburne, 1980, p. 130; Sorey and Clark, 1981). Such observations suggest that monitoring of the hydrologic system in the Long Valley area could be used, along with a variety of geodetic and geophysical techniques, to predict future tectonic or volcanic activity or to detect the subterranean movement of magma. Consequently, the U.S. Geological Survey began a hydrologic monitoring program in August 1982. The program is funded as part of the Geological Survey's Volcanic Hazards Monitoring Program and is still in progress.

Purpose and Scope

The purpose of the hydrologic monitoring program is two-fold: 1) to determine to what extent the hydrologic system responds to volcanic processes, and 2) to establish baseline data that characterize the current hydrologic system prior to possible renewed volcanism. Determination of the response of the hydrologic system to volcanic processes involves identifying which aspects of the hydrologic system respond, quantifying the response, and offering an explanation of the relationship between volcanic processes and the hydrologic response observed.

The program conducted by the Water Resources Division of the U.S. Geological Survey includes the following activities:

> 1) Literature search for historic data concerning the discharge characteristics of hot springs and fumaroles, ground-water levels, and subsurface temperatures; 2) ground-water level measurements--continuous and periodic; 3) measurements of hot spring discharge by direct and indirect means; 4) collection and chemical analyses of water samples from hot springs, cold springs, wells, and surface waters; 5) isotopic analyses of waters; 6) subsurface temperature data--continuous at a point, and periodic temperature profiles; 7) meteorologic measurements--barometric pressure and precipitation; 8) exploratory drilling at selected sites.

This report summarizes the hydrologic and geochemical data collected under this program during the period 1982-1984, and includes descriptions of methods of data collection and preliminary interpretations of the results obtained. For comparison, selected data are also included from earlier hydrologic studies by the Water Resources Division and from chemical and isotopic studies being carried out by the Survey's Geologic Division and by other agencies and institutions.

These data collection activities have established baseline conditions in the ground-water system and levels of natural variability due to seasonal and periodic hydrologic processes. General patterns of flow of thermal and nonthermal ground water can be delineated from the ground-water level measurements, water chemistry, and subsurface temperature data. Analyses of continuously recorded water-level and spring discharge data at selected sites has provided initial estimates of the effects of recharge, barometric pressure, earth tides, and earthquakes on the ground-water system.

Description of the Study Area

The Long Valley area is located in southwestern Mono County in east-central California about 20 miles south of Mono Lake and 30 miles northwest of Bishop, California (fig. 1). The study area includes the Long Valley caldera and parts of the surrounding mountains.

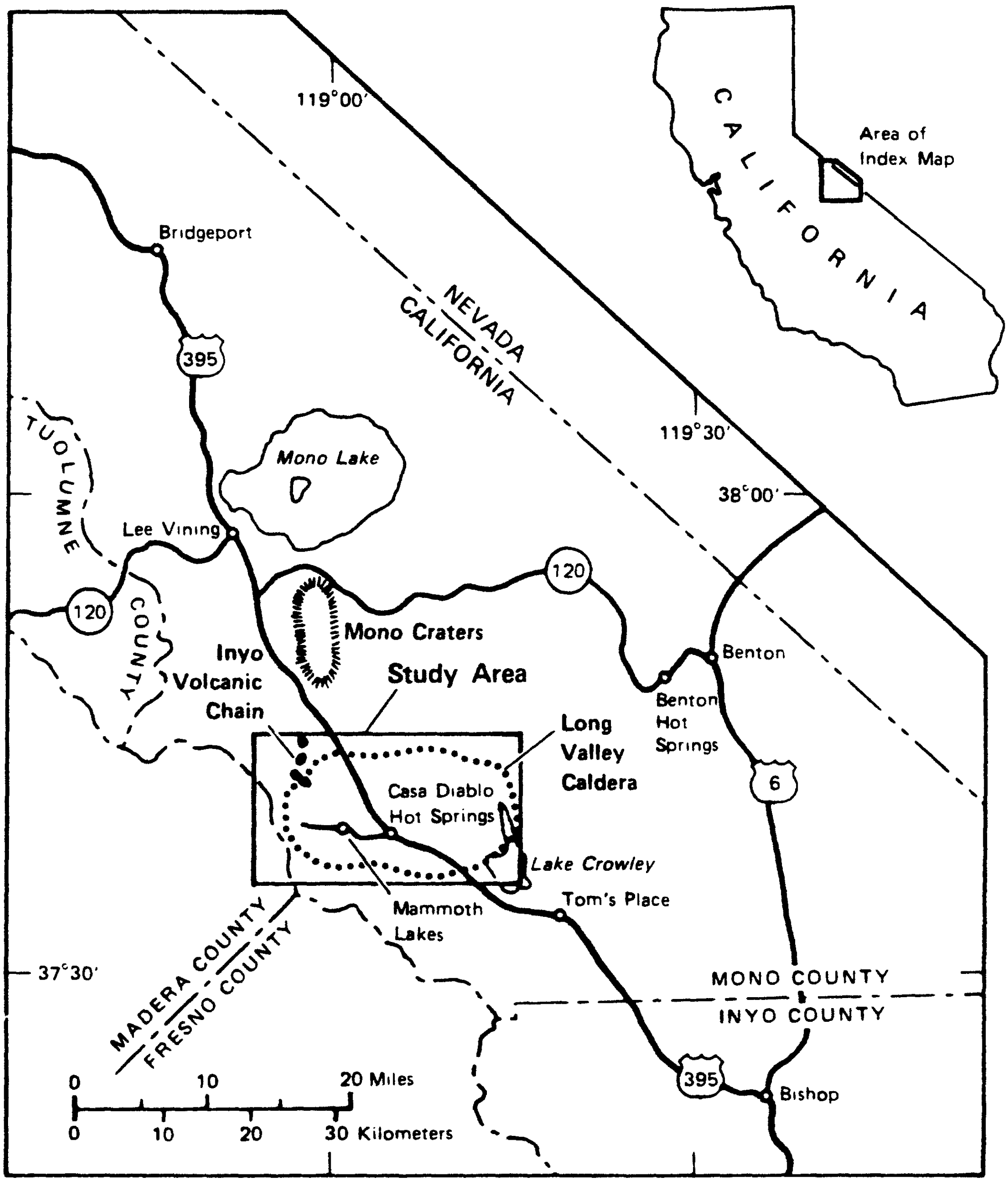


Figure 1. Index map showing location of study area.

The caldera floor is elliptical in plan, measuring about 18 miles east to west and about 10 miles north to south. The Sierra Nevada lies along the west and south margins of the caldera. A range including Bald Mountain and Glass Mountain forms the northern boundary; a dissected tableland lies to the east. Altitudes range from 6781 ft at the Lake Crowley spillway to 11,053 ft on Mammoth Mountain and 11,123 ft on Glass Mountain (pl. 1).

The caldera is drained by the Owens River which flows easterly across the northern part and then south into Lake Crowley. Major tributaries include Mammoth, Hot, Deadman, Glass, Sherwin, Convict, McGee, and Hilton Creeks.

The Long Valley caldera is at the base of the steep eastern escarpment of the Sierra Nevada. The western part of the caldera forms a reentrant in the range front. The topographic expression of the caldera is largely the result of structural collapse following the extrusion of an estimated 144 mi^3 of rhyolite ash about 0.7 m.y. ago (Bailey and others, 1976). As the magma chamber emptied, subsidence of the overburden occurred along arcuate ring faults. Later volcanic eruptions contributed flow rocks and pyroclastics of rhyolitic to basaltic composition. The post-subsidence eruptions built a resurgent dome in the west-central part of caldera, the rim rhyodacite complex of Mammoth Mountain, and several smaller domes and flows near or along the caldera margin (pl. 1).

Extending northward from the Long Valley caldera to Mono Lake are two chains of young volcanic features: the Inyo volcanic chain and the Mono craters (fig. 1). The islands in Mono Lake are also of volcanic origin. The eruptive activity at the Inyo chain took place during a geologically short interval of time about 550-650 yrs B.P. (Miller, 1985) and produced domes, rhyolite flows, and phreatic craters (pl. 1). Studies by Stine (1984) show evidence that volcanism on the Mono Lake islands may have been active as recently as 220 yrs B.P.

The injection of a dike has been postulated as the cause of recent seismicity and ground deformation observed in the south moat of Long Valley caldera (Savage and Cockerham, 1984). Because the volcanic features of the Inyo chain are likely the result of dike injection (Eichelberger and others, 1985) the style of volcanism at the Inyo Chain may be used as a model for possible future eruptions in the south moat.

During the Pleistocene pluvial period, the Long Valley depression filled with water to form Long Valley Lake. This caldera-lake rose to a level of about 7800 ft; subsequent overflow and downcutting of the southeast caldera rim caused the lake to drain over a period of 0.6 m.y., with complete draining occurring within the last 0.1 m.y. Lacustrine sediments deposited from the lake accumulated to varying thicknesses. The maximum thickness is greater than 1000 ft and occurs within the east moat of the caldera (Bailey and others, 1976).

Evolution of the hydrothermal system in Long Valley occurred after caldera formation; Bailey and others (1976) infer from the distribution of hydrothermal alteration that hydrothermal activity may have reached a maximum about 0.3 m.y. ago. Sorey (1984) and Smith (1976) infer from the stratigraphic record of evaporite deposits at Searles Lake (120 miles southeast of the study area) that hot-spring discharge during the past 40,000 years has been continuous at near present-day rates.

Geothermal energy development in Long Valley began in 1959 when Magma Power Company and its affiliates drilled about 20 exploratory wells in the Casa Diablo and Hot Bubbling Pool areas. Because of the engineering capabilities and economic considerations prevailing at the time, geothermal energy development was temporarily abandoned in the early 1960's. By the mid-1970's, renewed interest in the geothermal resources of Long Valley led energy companies to reactivate exploration programs. By 1983 two geothermal production sites had been picked and production plant designs were completed. The site at Casa Diablo was completed and tested in late 1984. Exploratory drilling at the second site, near Hot Bubbling Pool, began in April 1985.

Previous Hydrologic Studies

The hot springs in Long Valley have been visited since early times by Native Americans and travelers who frequented the springs because of their purported healthful properties and recreational benefits. One of the earliest hydrologic descriptions of the hot springs and other thermal features of Long Valley was included in an investigation of the water resources of Owens Valley (Lee, 1906). Further descriptions and data on the hot springs are presented in Waring (1915); Stearns and others (1937); and Waring (1965).

A more comprehensive treatment of the Long Valley hydrologic system was published by the California Department of Water Resources (1967). This investigation was concerned with the impact of waste waters from geothermal wells on the chemical quality of the water resources. The Mammoth Basin part of the Long Valley caldera was studied by the California Department of Water Resources (1973) to provide the information to develop management plans for protecting and preserving the water resources of the basin. Lewis (1974) presented data from the latter study and from U.S. Geological Survey investigations of the springs and wells in the Long Valley area.

Geochemical studies of the thermal waters in the caldera by Willey and others (1974) and Mariner and Willey (1976) were directed at determining chemical characteristics of hot-spring waters and geothermal reservoir temperatures in the hydrothermal system. The source of arsenic discharging into Lake Crowley was investigated by Eccles (1976). Setmire (1984) made a water-quality assessment of Mammoth and Hot Creeks that was primarily directed toward biological constituents.

A conceptual and mathematical model of the hydrothermal system based on a synthesis of much of the previously collected geologic and hydrologic information is given by Sorey and others (1978). Sorey and Clark (1981) reported on the changes in discharge characteristics observed at hot springs and steam vents following the earthquakes of May 1980, and annual reports presenting water resources data in the Long Valley area have been published since 1980 by the Mammoth Ranger District, Inyo National Forest, U.S. Forest Service. Finally, data from temperature measurements in wells, including several deep wells drilled in 1978 and thereafter, were used by Sorey (1984) and Blackwell (1984) to develop more detailed models of fluid flow within the present-day hydrothermal system.

Acknowledgments

This report, in part, provides a summary of hydrologic and related data collected by individuals outside the Geological Survey. A.F. White, Lawrence Berkeley Laboratory, provided data on water chemistry and isotopic composition; J.N. Vallete Silver, Carnegie Institute, analyzed the chemistry of samples she collected during May 1984; T.M. Gerlach, Sandia National Laboratory, provided results of gas analyses; H.A. Wollenberg, Lawrence Berkeley Laboratory, provided stable carbon-isotopic data for rock samples; and W. Rison, New Mexico Institute of Mining and Technology, provided results of helium isotope analyses.

The cooperation extended by many landowners in allowing access to data collection sites on private land is greatly appreciated. William Asper, manager of the Mammoth-Pacific Geothermal Power Plant at Casa Diablo, has cooperated by allowing long-term deployment of monitoring equipment at several sites and by providing data on wells located on plant property. Los Angeles Department of Water and Power has helped the monitoring effort by providing historic records of streamflow and chemistry and also by allowing use of the department's flume and gage house on Hot Creek. Gary Guacci, LeRoy Crandall and Associates, contributed data on wells and test holes drilled for the Mammoth Water District. Finally, Robert Islen, Hot Creek Fish Hatchery, enthusiastically cooperated with data collection from the source springs at the hatchery.

WATER CHEMISTRY AND ISOTOPIC COMPOSITION

Chemical and isotopic data for water from springs, streams, and wells are being collected to establish baseline conditions, detect changes that may be occurring in response to geologic processes, estimate maximum reservoir temperatures, determine the origin of selected constituents, and to obtain data for future geochemical modeling. These data are presented here along with data collected during earlier U.S. Geological Survey studies, data from the California Department of Water Resources, and data collected by other institutions concurrently with the Geological Survey monitoring program.

Sample Collection and Analysis

Water samples collected by U.S. Geological Survey personnel under this program were handled by the methods outlined by Wood (1976) and Brown and others (1970). In general, similar methods of collection and preservation were used for samples analyzed by non-Geological Survey laboratories. Sample volumes were collected by a variety of means depending on site conditions. For shallow streams, dip samples were collected downstream from reaches where good mixing occurred. For sites where water depth was generally greater than 1 foot, a depth-integrating sampler (DH-48) was used to collect volumes by the equal-width-increment method. Spring water samples were collected either by dipping a volume directly from the source or by using a peristalic pump to fill containers. The samples from two wells (CH-10A and CH-10B) were collected by air lifting the water using a drill rig compressor.

Regardless of collection procedure, all samples for chemical analysis were filtered through a .45 μ filter or a .22μ filter (after August, 1984) shortly after collection. One 500 mL aliquot of the filtered water was placed in a field-rinsed polyethylene bottle for analysis of anions. A second 500 mL aliquot was placed in an acid-rinsed polyethylene bottle and was acidified with concentrated nitric acid to a pH of 1.5 or less for analysis of cations. Where the silica concentration was expected to exceed about 50 mg/L, polymerization of silica was avoided by diluting to 1/10 concentration using deionized water.

Preservation of samples for mercury analyses presents special problems because mercury can diffuse through the walls of polyethylene sample bottles. To stabilize mercury in water samples collected after August, 1984, a 10 mL aliquot of 5 percent nitric acid and 0.05 percent potassium dichromate was added to about 250 mL of filtered sample contained in a glass bottle. Samples for chemical analysis were shipped to either the U.S. Geological Survey Central laboratory in Arvada, Colorado or the U.S. Geological Survey laboratory in Menlo Park, California under the direction of R. H. Mariner.

For oxygen and hydrogen isotopic analyses, field rinsed 200 mL flint glass bottles were filled with unfiltered sample water. For carbon isotope analyses, 50 mL of a saturated solution of strontium chloride in ammonium hydroxide was added to about 900 mL of raw sample in a 1-liter field-rinsed glass bottle. Isotopic analyses were done in Geological Survey laboratories in Reston, Virginia and Menlo Park, California.

Temperature, pH, and alkalinity were measured on site. Temperatures were measured using a variety of mercury-filled glass thermometers, or hand-held digital thermometers with RTD sensors. The pH was obtained using a digital meter calibrated in the field at a temperature near that of the sample source. Alkalinity was determined by titration aganist sulfuric acid either by the incremental method or by titration to a pH of 4.5. The analytical methods used in the Geological Survey's Central Laboratory to detect individual constituents are listed below and described by Skougstad and others (1979).

Constituent or Ratio	Analytical Method
Alkalinity	Titration
Arsenic	Atomic absorption
Boron	Emission DC plasma
Calcium	Atomic absorption or emission, Inductively coupled plasma
Chloride	Colorimetry, discrete analyzer
Fluoride	Ion selective electrode
Iron	Atomic absorption or emission, Inductively coupled plasma
Lithium	-do-
Manganese	-do-
Mercury	Atomic absorption
Potassium	-do-
Residue at 180°C	Gravimetric
Silica	Colorimetry, molybdate blue or emission, inductively coupled plasma
Sodium	Atomic absorption or emission, Inductively coupled plasma
Strontium	-do-

Constituent or Ratio	Analytical Method
Sulfate	Turbidimetric
Zinc	Atomic absorption or emission, Inductively coupled plasma
Carbon 13/12	Mass spectrometry
Deuterium/Protium	-do-
Oxygen 18/16	-do-

Sampling Program

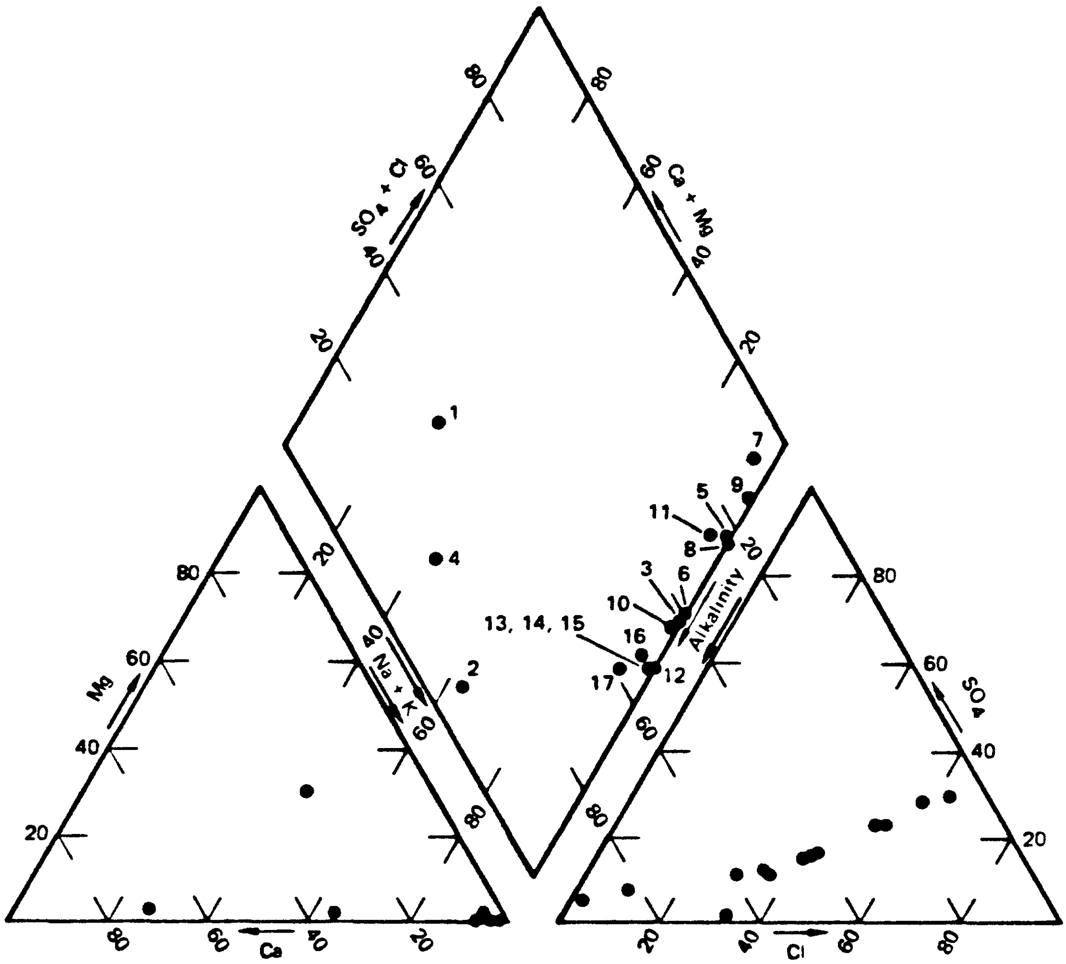
Sample sites include but are not restricted to each main hot-spring area (Casa Diablo, Hot Creek gorge, Little Hot Creek, and the Alkali Lakes) and cold springs representative of the nonthermal meteoric water. Because water chemistry varies locally and the location and quantity of discharge changes with time, more than one source was sampled at each hot spring area. Individual sample points were chosen to include those with the greatest discharge and highest temperatures. Selection of sample points within Mammoth Creek and Hot Creek was based on the location of good discharge-measuring sections and the proximity to inflow of hot-spring fluids.

Sampling frequency varied over time and from site to site. The variability in sampling frequency is due to limited access to some sites during winter months and in part to changes in the rates of fluid discharge. In general one or more springs were sampled in each hot-spring area at least four times during 1983 and in May and September 1984. Sampling of selected sites on a semiannual basis is planned to continue for an indefinite period.

Results of Water Chemistry Sampling

Ground water in Long Valley can be classified as thermal or non-thermal (meteoric). Non-thermal springs (such as Laurel spring) and wells tapping shallow aquifers discharge water low in dissolved solids with temperatures less than about 12°C. Hot springs and wells tapping the hydrothermal system discharge water containing 1000-1500 mg/L dissolved solids at temperatures near the boiling point at ambient pressure. Mixing of non-thermal and thermal waters results in water of intermediate temperature and ionic composition (such as in the Hot Creek Fish Hatchery springs). The results of chemical analyses from selected springs and wells are given in table 1. The table has subheadings grouping individual sites by geographic areas: Alkali Lakes, Casa Diablo, Fish Hatchery, Hot Creek gorge, Little Hot Creek, caldera margin, and outside the caldera.

Non-Thermal Waters--The chemical analyses of water samples from Laurel spring typify the chemistry of non-thermal waters discharging after a short travel path from the recharge area. The water is alkaline, with less than 100 mg/L dissolved solids and a temperature near the mean annual air temperature. Concentrations of elements characteristic of hot-springs such as fluoride, boron, and arsenic are all low. A trilinear diagram (fig. 2) shows that the relative concentrations of major ions for waters from Laurel spring are distinctly different from the relative concentrations in thermal waters. Calcium is the



PERCENTAGE REACTING VALUES, in milliequivalents per liter

1. Laurel spring (LS)
2. Reds Meadow Tub spring (RMT)
3. Colton spring (CS)
4. Fish Hatchery - AB Supply
5. Meadow spring (MS)
6. Casa Diablo Geyser (CDG)
7. Casa Diablo North spring (CDNS)
8. Casa Diablo Milky Pool 1 (MP-1)
9. Casa Diablo Milky Pool 2 (MP-2)
10. Hot Bubbling Pool (HBP)
11. Casa Diablo South spring (CDSS)
12. Well CH-10A
13. Well CH-10B
14. Hot Creek gorge spring (HC-2)
15. Hot Creek gorge spring (HC-3)
16. Hot Creek gorge spring (HC-1)
17. Little Hot Creek Flume spring (LHC-1)

Figure 2. Major ion composition of water from selected springs and wells in the Long Valley area.

dominant cation and bicarbonate the dominant anion in the non-thermal waters.

Thermal Waters--The thermal waters are generally near neutral to slightly alkaline (pH 6.5-8.5), sodium-chloride rich, and contain between 1000-1500 mg/L dissolved solids. The relative proportions of major ions can be seen on the trilinear diagram (fig. 2). Sodium is the dominant cation, ranging from about 250 mg/L in North spring at Casa Diablo to 400 mg/L in springs at Hot Creek gorge and Little Hot Creek. In terms of milliequivalents, sodium and potassium ions account for about 98 percent of the cations; calcium and magnesium account for only about 2 percent. Chloride and bicarbonate are the dominant anions, but sulfate constitutes as much as 30 percent of the total anions.

Silica is present in concentrations generally between 140-240 mg/L except at Little Hot Creek where the concentration is about 85 mg/L. The high concentrations of sodium, potassium, and silica result from water-rock reactions with highly silicic volcanic and intrusive rocks in the hydrothermal reservoir. Among the minor elements characteristic of hot spring waters are arsenic, boron, fluoride, and lithium. In unmixed thermal waters arsenic concentrations generally range from 0.5 to 2.0 mg/L, boron from 9 to 13 mg/L, fluoride from 8 to 12 mg/L, and lithium from 1.0 to 3.0 mg/L.

The variability of water chemistry between various spring vents in the Casa Diablo area is greater than differences between vents in other areas. The pH of spring water at Casa Diablo generally ranges from slightly acidic (6.2) to alkaline (8.4). The high chloride concentration in these waters is indicative of the chemical composition of water in underlying shallow thermal aquifers. A few spring vents at Casa Diablo (believed to be short-lived features) discharge acidic waters (pH=3.8) which may be steam-heated. By comparing alkalinity, calcium, and magnesium concentrations, two hot-water types can be identified. Alkalinity at North spring (CDNS) ranges between 45 and 61 mg/L; at Colton (CS) and Geyser Springs (CDG) alkalinity is greater than 300 mg/L. Calcium at North spring ranges between 8.7 and 10.0 mg/L; at Colton and Geyser spring calcium is less than 2 mg/L. Magnesium follows the same trend, higher at North spring, lower at Colton and Geyser. These differences in water chemistry may be caused by variations in the flux of carbon dioxide gas at each site.

Mixed Waters--The mixing of thermal and non-thermal waters results in springs discharging waters of intermediate temperatures and chemical compositions. Such springs are found in the Fish Hatchery area and the Alkali Lakes - Whitmore Hot Springs area. An estimate of the relative proportions of hot to cold water can be made by comparing temperatures and arsenic, boron, chloride, and fluoride concentrations with those in the hotter springs in the Casa Diablo area.

Consistency of Data--The maximum variance from the mean value of individual major constituents commonly exceeds 15 percent for samples collected at different times from the same site (table 1). For minor constituents (concentrations $\leq$ 1.0 mg/L) variance from the mean often exceeds 100 percent. The variability of data at one site may result from several factors: differences in field equipment, variability in the exact point of sampling, differences in methods and analytical accuracy at different laboratories, and actual variations in water chemistry.

Field equipment as simple as a thermometer can yield values varying by 4-5°C between instruments with purported accuracies of 0.5°C. To get consistent values, digital thermometers must be routinely calibrated and checked against an accurate standard. Temperatures given in table 1 for samples analyzed by the Geological Survey's Central Laboratory (USGS-C) are maximum temperatures measured to the nearest 0.1°C. These temperatures are accurate to within about 0.5°C. Some of the variability in temperatures between visits at a site result from the difficulty in measuring fountaining hot springs such as site HC-3 in Hot Creek gorge.

Some of the differences between ion concentrations reported by different laboratories may relate to sampling at slightly different locations by different field personnel. At Casa Diablo this could result in significant differences in reported chemistry. Use of the detailed location maps of Casa Diablo, Hot

Creek gorge, and Little Hot Creek areas included in this report may help to alleviate this problem.

To evaluate the effects of differences in methods and analytical accuracy at different laboratories on the reported data, future sampling will include analyses of duplicate samples run in different labs by different methods. The available data indicate, however, that actual variations in chemistry over time are probably minor at most sites except for Casa Diablo where rapid variations in chemistry have been noted in some spring vents. For example, in vents first noted to discharge acid waters ($pH<5$), the pH rose to near 7 over a period of 4-5 days and significant changes in ionic concentrations occurred (see Sulfate spring 2, Casa Diablo area, table 1). Such changes probably reflect processes associated with near-surface boiling and mixing rather than changes in underlying thermal-water reservoirs.

Isotopic Composition

Data defining the isotopic composition of ground waters are useful for determining recharge sources (hydrogen and oxygen isotopes), determining the source of selected elements (carbon isotopes), and age dating waters (tritium). The earliest isotopic data for waters in Long Valley are from geochemical studies done during the 1970's (Willey and others, 1974, and Sorey and others, 1978). The use of isotopic data in these earlier studies was directed toward determining recharge areas and ground-water circulation patterns by comparing hydrogen and oxygen isotopic ratios of hot spring and well waters with cold springs and snow samples.

Beginning in 1983 additional isotopic sampling began. This more recent sampling has been carried out by three different Geological Survey field teams and by Lawrence Berkeley Laboratory. Isotopic contents were determined by four different laboratories. In addition to hydrogen and oxygen isotopic ratios, the more recent sampling has included analysis for carbon 13/12 ratios and tritium concentrations at selected sites.

Table 2 summarizes the results of isotopic analyses. Data for hydrogen and oxygen are given in standard δ-units, parts per mil (o/oo) relative to SMOW (Craig, 1961); carbon 13/12 ratios are in δ-units, expressed in parts per mil, relative to the Peedee belemnite (Faure, 1977).

The data for isotopic ratios from any one site show some variability over time and between laboratories. On a percentage basis, the carbon ratios show the most variability, generally 20-25 percent; oxygen and hydrogen ratios are mostly within 10 percent. Within any one hot spring area, the greatest variability in hydrogen and oxygen ratios is observed from springs near Casa Diablo. At Casa Diablo, South, North, and Geyser springs are within 200 ft of one another but isotopic ratios vary by 11 δ-units for hydrogen and 2 δ-units for oxygen. At Hot Creek gorge three springs within about 1000 ft of one another give a range of values spanning 7.5 δ-units for hydrogen and oxygen 1.2 δ-units. At Little Hot Creek data for two springs about 100 ft apart span 6 δ-units for hydrogen and 1.2 δ-units for oxygen. The variability may result from a combination of one or more factors: actual isotopic variations, laboratory procedures, differences in sample points, the physical character of springs, or random errors.

The analytical methods have a precision of about 2.0 δ-units for hydrogen ratios, and 0.2 δ- units for oxygen and carbon ratios (T. Coplen, 1985, oral communication). No information is currently available on the comparability of results between laboratories.

Variability may be due in part to differences in sampling points for those sites where data from different analytical laboratories are given in table 2 (indicating different collectors). The physical characteristics of individual sample sites influence the quality of data. Evaporation may cause fractionation in springs with low discharge, high surface temperatures, or surface fountaining. Isotopic ratio determinations on samples collected at different times may vary due to changes in discharge, temperature, or fountaining between sample times. Although at the present time a thorough assessment of factors accounting for the observed variations in isotopic ratios at indiviudal sites cannot be made, some general conclusions can be drawn from the differences in ratios observed between sites.

Hydrogen and oxygen isotopes--Sorey and others (1978) recognized that significant differences existed in hydrogen and oxygen isotopic ratios for meteoric waters in and around the Long Valley caldera. Fractionation causes isotopically heavier precipitation to fall on the Sierra (example: Minaret spring $\delta D = -111$, $\delta^{18}O = -14.9$.) than on the mountains north and northeast of the caldera (example: Watterson Trough spring $\delta D = -131$ and $\delta^{18}O = -17.4$). Thus, ground-water recharge from different source areas may have distinct stable-isotope ratios.

Isotope ratios of thermal waters from springs and wells plot to the right of the meteoric water line (fig. 3). This relation has long been recognized as resulting from water/rock reactions at elevated temperatures that preferentially exchange rock ^{18}O for water ^{16}O with little change in hydrogen isotope ratios because of the paucity of hydrogen in rocks. The isotopic data for the thermal waters are consistent with the conceptual model that deep circulation of precipitation recharges the hydrothermal system and juvenile water does not contribute significantly to the flow of hot water.

The isotopically lightest water occurs in the fumarole CDF at Casa Diablo ($\delta D = -146.3$, $\delta^{18}O = -20.4$). Because both deuterium and oxygen-18 in these samples are depleted relative to local precipitation, water/rock reactions do not account for the observed data. A more likely explanation is that fractionation during steam separation accounts for the isotopic shift. At

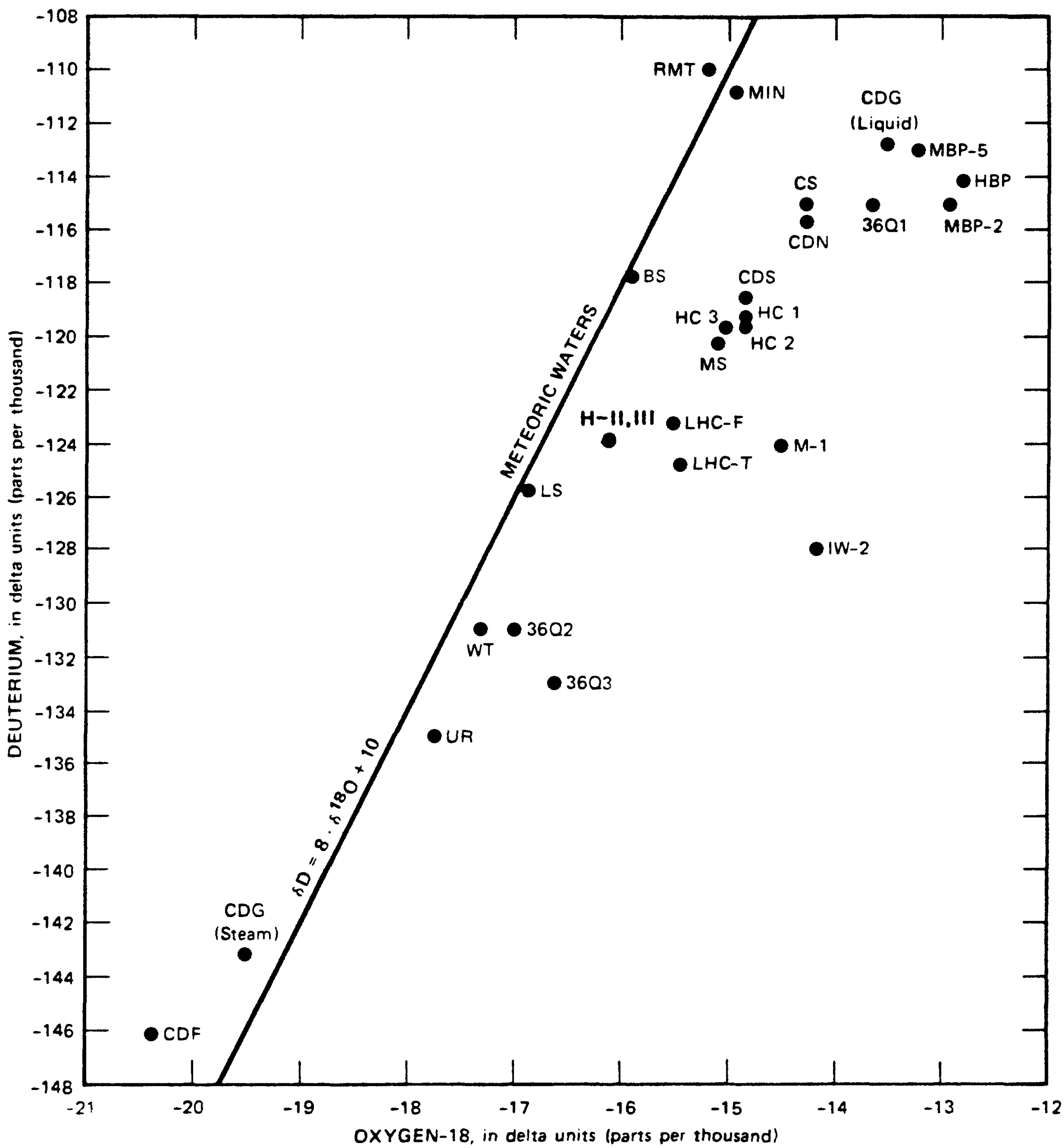


Figure 3. Deuterium versus ^{18}O in delta units for selected fumaroles, springs, and wells. Site abbreviations follow those used in table 2, locations are shown on Plate 1. Data points are mean values of data in table 2. For sites with three or more values, means do not include values accounting for greater than 50 percent of the range.

temperatures below 220°C isotopic fractionation between vapor and liquid tends to concentrate deuterium in the liquid phase and deplete it in the vapor phase; at temperatures at least up to 300°C oxygen-18 is concentrated in the liquid (Friedman and O'Neil, 1977). The isotopic ratios in steam from Casa Diablo vents may be an indication that fractionation due to steam separation is taking place at below 220°C.

Isotopic data from seven geothermal wells at Casa Diablo (table 2, excluding site SS-2) can be grouped into two classes. Samples from wells IW-2 and M-1 are more depleted in deuterium (δ D = -128 and -124) and oxygen-18 ($\delta^{18}O$ = -14.2 and -14.5) than wells End-5, MBP-1, MBP-2, MBP-4, and MBP-5 (δD = -111 to -115.8 and $\delta^{18}O$ = -12.9 to -14.2). Wells IW-2 and M-1 were completed to a depth of about 2000 ft and are used for injection of geothermal fluids. The other wells are for production and have depths of about 650 ft. The differences in isotopic ratios between deep and shallow wells may be indicative of recharge from the west for the shallow thermal aquifer and recharge from the south for the deeper injection zone.

Carbon Isotopes--Carbon 13/12 ratios are useful for explaining the origin of volatiles in hydrothermal systems. The importance of CO_2 in volcanic processes and earthquakes has been noted by Barnes and others (1978), and Irwin and Barnes (1980).

Carbon isotope ratios have been determined for samples from most of the thermal and non-thermal springs. The $\delta^{13}C$ ratios for thermal springs discharging waters above 70°C fall in the range -2.8 to -6.1, for non-thermal springs $\delta^{13}C$ ranges from -10.5 to -17.9, mixed waters have intermediate values (fig. 4). In eight gas samples from springs the $\delta^{13}C$ ratio ranges from -4.1 to -7.88; in samples from fumaroles the range is from -5.5 to -10.5.

The range of carbon isotope ratios for dissolved carbonate and CO_2 in the thermal waters is consistent with values obtained for mantle derived carbon (table 3; Taylor and Gerlach, 1984 a, b), but carbon 13/12 ratios from carbonate rocks collected within the study area by H. Wollenberg (written communication, 1985) also bracket this range. The ratios for carbonate rock samples from Sierran roof pendants (metamorphic rocks) range from 0.0 to -11.9 o/oo and from +2.6 to -0.3 o/oo for tufa and travertine samples (fig. 4). Because none of the water or gas samples showed $\delta^{13}C$ values in the range covered by the recent tufa and travertine, these deposits probably do not contribute carbonate ions to the hydrothermal system or to the nonthermal springs. In a system with aqueous carbonate species and carbon dioxide gas, fractionation processes tend to concentrate carbon-13 in the aqueous carbonates. This relation may explain why the gas samples are more depleted in ^{13}C than waters from thermal springs. The lowest ^{13}C values were measured in waters from cold springs and probably result from dissolution of carbonate ions enriched in carbon-12 derived from organic matter in recent sediments, or plant root respiration in soils.

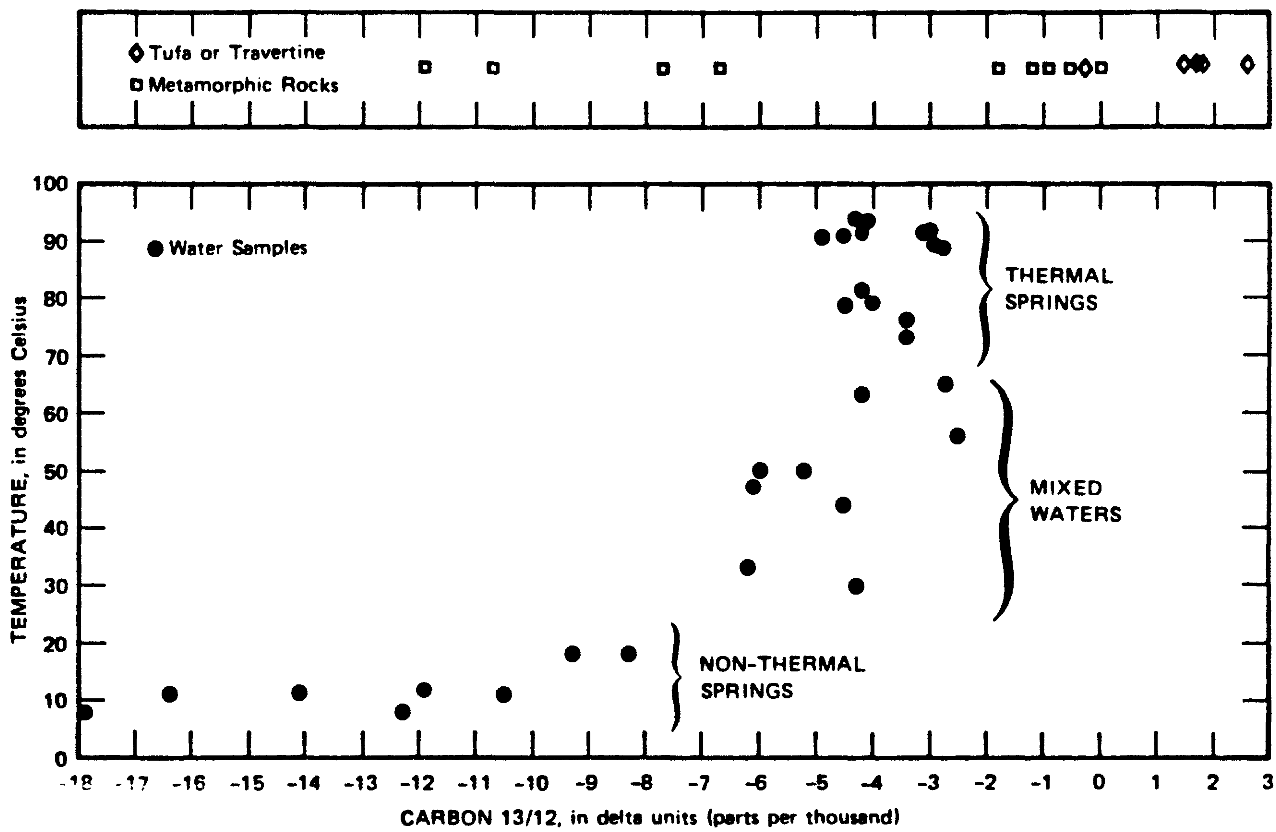


Figure 4. Carbon 13/12 ratios in selected rock samples and carbon 13/12 ratios for spring waters plotted against water temperature.

Tritium--The results of tritium analyses (table 2) made available through Lawrence Berkeley Laboratory (A. F. White, written communciation, 1985) show detectable concentrations of tritium in all samples from springs and wells. Concentrations are reported in tritium units (T.U.); 1 T.U. is defined as one atom of tritium (^3H) per 10^{18} atoms protium (^1H). Values range from less than 1 in several hot spring samples to 25 for the Big Spring sample.

The limit for age dating using tritium is about 50 yrs because it has a 12.3 yr half-life. Tritium is produced in the upper atmosphere as a by-product of cosmic-ray induced neutrons bombarding nitrogen. The natural concentrations of tritium were greatly disturbed by atmospheric thermonuclear bomb testing carried out between 1953 and 1969.

Waters with concentrations less than 5 T.U. are generally assumed to have entered the ground-water system sometime prior to 1953. Higher concentrations indicate that all or part of the water entered the ground-water system after 1953. Mixing of pre- and post-1953 waters can greatly complicate the interpretation of tritium data.

Radioisotopic data for Long Valley waters are rather limited and further sampling will be required before any firm conclusions can be drawn. However, the presence of tritium in all samples suggests that some mixing, probably at shallow depth, of post-1953 water with older water is an ongoing process at all sites.

GAS CHEMISTRY

Samples of gases from springs and fumaroles have been collected by various investigators from the U.S. Geological Survey and other agencies between 1976 and 1984. Although this work was not part of the current Water Resources Division monitoring effort, some chemical analyses from the gas sampling have been made available for inclusion in the report.

Sample Collection

Gas samples from springs and fumaroles have been collected by or under the supervision of R. H. Mariner, C. J. Janik, and T. Casadeval of the U.S. Geological Survey and by T. M. Gerlach of Sandia National Laboratory. Gerlach and Janik used evacuated bottles containing sodium hydroxide solutions to collect steam and noncondensible gases. Fumarolic gases were conducted to the sample bottles through insulated tubes inserted several feet into the vents, and gases from hot springs were collected through funnels and plastic tubing. Mariner and Casadeval used flow-through bottles containing no alkaline solutions. Each technique has advantages under different conditions of gas flow rate, temperature, and vent geometry. The analytical methods used by these investigators are not reported here.

Sampling Program

No consistent effort has been made to sample gases at regular intervals at particular sites. Only for the fumarole labled CDF at Casa Diablo (fig. 5) are gas data available for samples collected on different occasions by the same investigator. Hydrothermal features for which meaningful gas samples can consistently be collected are restricted to thermal areas at and to the east of Casa Diablo. With the exception of the fumarole on the north side of Mammoth Mountain (MMN), areas of steam and gas discharge west of Casa Diablo (pl. 1) have yielded samples which are too contaminated with air to be useful for gas analyses; therefore only data for MMN are given. Gas temperatures measured at the land surface at the sites west of Casa Diablo range from 75^{o} to 93^{o}C.

Results

Chemical analyses of gases sampled from hot springs and fumaroles with minimal air contamination are listed in table 4. Analyses are reported on a water-free volume-percentage basis, and a water to gas ratio is listed for most samples. As seen from the data in table 4, gases from each discharge feature sampled consist of over 90 percent CO_2 with minor amounts of N_2, O_2, H_2S, H_2, CH_4, NH_3, He, and Ar. In general, gas compositions appear to be controlled by near-surface processes in shallow thermal reservoirs and fault conduits rather than by interactions between the hydrothermal system and magmatic intrusions.

No consistent trends in the gas chemistry of the Casa Diablo fumarole are evident (table 4). There has been a general decline in the rate of discharge of steam and gas from this

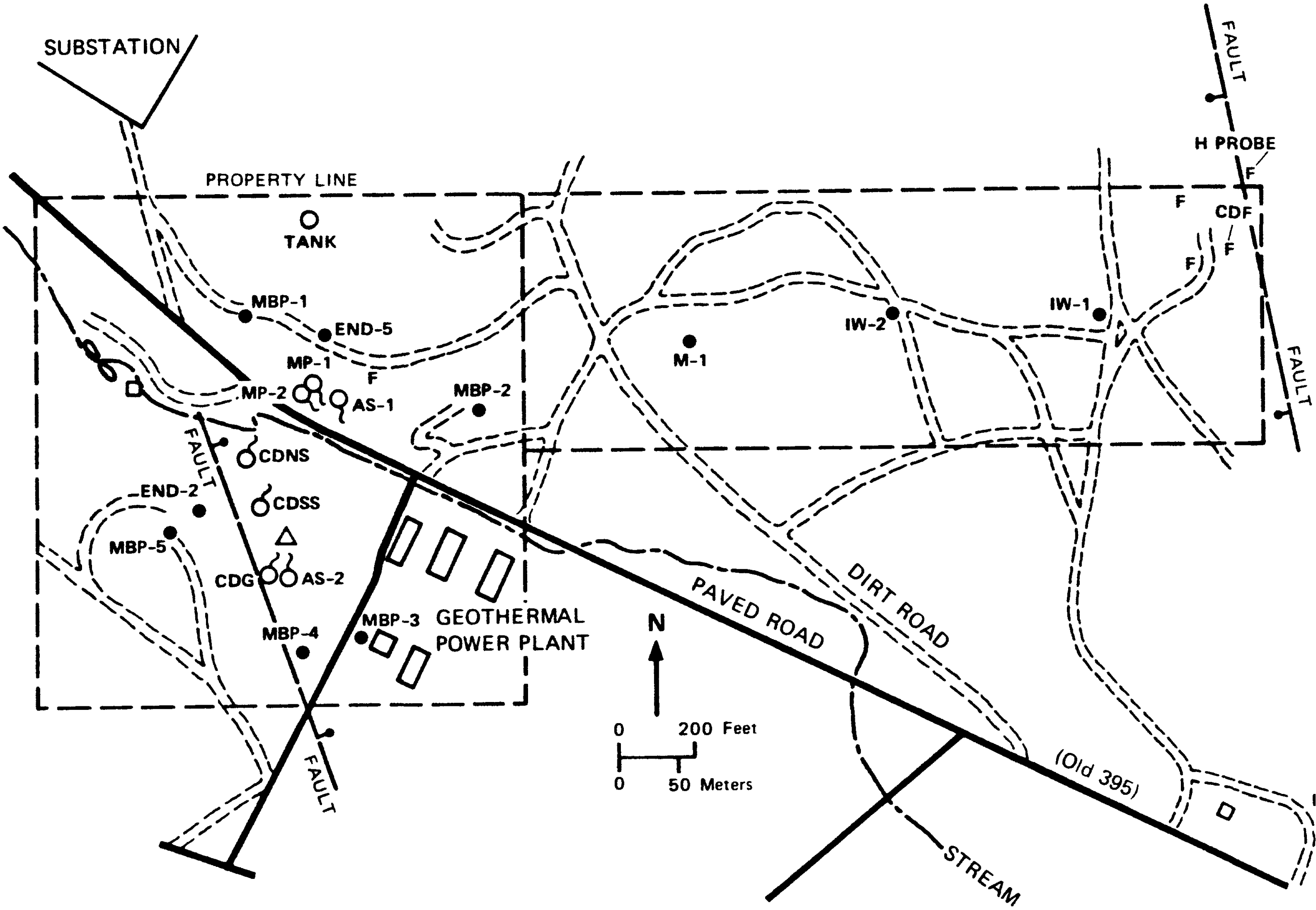


Figure 5. Map of the Casa Diablo area (T.3S., R.28E, sec. 32) showing locations of hot springs (open circles with tails), fumaroles (F), and wells (filled circles) labeled with abbreviations as used in text and tables. The site where a flume and recorder were in place during part of 1984 to measure the flow of water from the geysers (CDG) is shown by a triangle. Locations based on maps provided by the Ben Holt Company, Pasadena, California.

fumarole since it became active in 1982, as reflected by the 2^{o}-3^{o}C decline in measured surface temperatures. Calculations based on the gas geothermometer of D'Amore and Panichi (1980) applied to the Casa Diablo fumarole yield estimates near 170^{o}C for the reservoir temperature from which the gases were derived. This is close to the temperatures measured in nearby wells that penetrate the shallow thermal reservoir beneath the Casa Diablo area (see section on Changes in Temperature Profiles in Wells).

Other Gas Monitoring Programs

Changes in hydrogen concentration in gases discharging from a fumarole at Casa Diablo (labeled H PROBE in figure 5) and from soil gases near Laurel spring in the south moat (labeled LS in pl. 1) have been continuously monitored since May 1982 (McGee and others, 1983). Additional hydrogen probes were installed in 1984 near Sherwin Creek Campground and along the west side of Long Canyon. Such monitoring could be useful in detecting intrusive activity because hydrogen gas is present in magma and is relatively bouyant, mobile, and non-reactive. Hydrogen events at the Casa Diablo site, consisting of short-lived peaks and periods of rapid fluctuations in hydrogen concentration, have been observed to preceed every seismic swarm that has occurred in the south moat since January 1983 by a few hours to a few days (McGee and others, 1983). Precursory hydrogen activity at the Laurel spring site has been observed before seismic activity in the Sierra south of the caldera and beneath Mammoth Mountain, but not before the seismic swarms in the south moat (K. A. McGee, written communication, 1984).

Concentrations of helium, mercury, and radon in soil gas around the floor of the caldera and adjacent lands have been measured in 1975 (Hg), 1978 (He), 1982 (Hg, He), 1983 (Hg, He, Rn), and 1984 (Hg, He, Rn). Interpretations of the areal and temporal variation in concentrations of these gases in soil are discussed by Varekamp and Buseck (1984), Williams and others (1983), Williams (1985), and Reimer (written communication, 1984). In addition, results of monitoring radon-222 emanations from thermal and nonthermal springs since September 1982 are described by Wollenberg and others (1985).

Ratios of $^3He/^4He$ in helium gas from hot springs and fumaroles to the helium isotope ratio in air were reported by Rison and others (1983). These data, along with results furnished by W. Rison (New Mexico Institute of Mining and Technology, Socorro, New Mexico) for samples collected in 1984, are listed below.

Feature	10/78	8/81	6/83	8/83	10/84
HC-3	4.8	5.2	5.7	5.5	5.2
LHC-1			6.5		6.0
CDF			4.9		4.5
21P1					6.0
CS					4.5
RMT					2.5
MMN					4.5

Helium isotope ratios greater than 1 are indicative of a mantle component; crustal helium, dominated by radiogenic ^4He, has helium isotope ratios lower than 1. Helium isotope ratios are high for all features sampled but are highest for features located east of the resurgent dome (LHC-1 and 21P1). Rison and others (1983) considered the increase in the helium isotope ratio at HC-3 between 1978 and 1983 suggestive of an increase in the mantle helium component. By this same reasoning, the decrease in helium isotope ratio between 1983 and 1984 at sites HC-3, LHC-1, and CDF would imply a decrease in the mantle helium component.

HOT SPRING DISCHARGE

In this section of the report, average values of hot-spring discharge at various thermal areas are discussed and compared with values obtained in previous investigations. Periodic discharge measurements were obtained by both direct flow measurements and by indirect measurements of the chemical discharge from hot springs into streams. Data are also available since August 1983 regarding fluctuations in the total thermal-water contributed by hot springs located along Hot Creek and Mammoth Creek based on continuous monitoring of streamflow, specific conductance, and temperature at the flume on Hot Creek below the gorge (HCF in pl. 1).

Casa Diablo area

Hot spring activity in the Casa Diablo area was cited in the literature as early as 1889 (Russell, 1889). The springs were once used for bathing by Indians and travelers along the old highway between Bishop and Mono Lake, as photo-documented in Reed (1982). Waring (1915) describes one main spring at Casa Diablo forming a pool 15 ft in diameter, "in which water was in violent ebulition and thrown to a height of 12-18 inches." His estimate of the total discharge of hot water from this area was approximately 2 L/s. In about 1930 an attempt to stimulate the flow of the main spring by drilling into it apparently resulted in a short-lived jet of boiling water that reached a height of about 100 ft (Blake and Matthes, 1938, p. 82-83). The "steamy jet" was reactivated on December 21, 1937, without human intervention, and may have continued to discharge in this fashion at least until 1957, when a photographic record of its activity was made (Smith, 1976). Subsequently, hot spring discharge may have declined following periods of fluid production from geothermal wells drilled and tested in the 1960's by the Magma Power Company (McNitt, 1963). During the period June 1972 to June 1973, spring discharge from this area consisted primarily of steam-heated shallow ground water and total discharge ranged from 0 - 0.6 L/s (Sorey and Lewis, 1976).

Thermal fluid currently discharges at Casa Diablo in two separate areas, a lower area adjacent to old highway 395 and an upper area 0.3 miles northeast of the old highway (fig. 5). Discharge at the upper area occurs mainly as steam in fumaroles and steam-heated water seeps. These features include the fumarole labled CDF which has been periodically sampled for gas chemistry since 1982 (table 4) and the fumarole labled H PROBE in which emissions of hydrogen gas have been continuously monitored since 1982. Steam discharge from this upper area increased during 1981-1982 (Miller and others, 1982). Liquid discharge from the upper area is insignificant.

Discharge from the lower area occurs mainly from high-chloride neutral-pH hot springs with temperatures between 80° and 93°C (fig. 5). Low-chloride acid-pH hot springs also occur periodically in this area but their flow is minimal. Chemical analyses of waters from these hot springs are listed in table 1. The feature labled CDG corresponds with the main spring discharging high-chloride water and currently consists of several vents with pulsating discharges of water and steam. Although commonly referred to as the Casa Diablo geysers (as in this report), these features should be considered fountaining or jetting hot springs rather than true geysers.

Hot-spring discharge from the lower area may have increased during the 1981-82 period when fumarolic discharge from the upper area increased. Although the lower area was not inspected in 1980, hot-spring discharge in September 1981 appeared negligible. Since 1982, hot water has discharged on a continuous basis from the geysers and other springs on the west side of the old highway. Visual observations indicate that fluctuations in spring discharge have occurred since 1982 in response to earthquakes and other processes, such as erosion of the sides of the liquid-filled pools surrounding the geyser vents. No attempt had been made to quantify such changes until June 1984, when a flume was installed below the geysers (fig. 5).

A stage recorder was added to this site in September 1984. The stage record obtained at the flume below the geysers is plotted in figure 6 in terms of average daily discharge values. Part of the total liquid output from the geysers bypassed the flume, and this fraction generally increased during the period of record. Hence, the long term trend in the discharge record is difficult to intepret. Nevertheless, a significant increase in

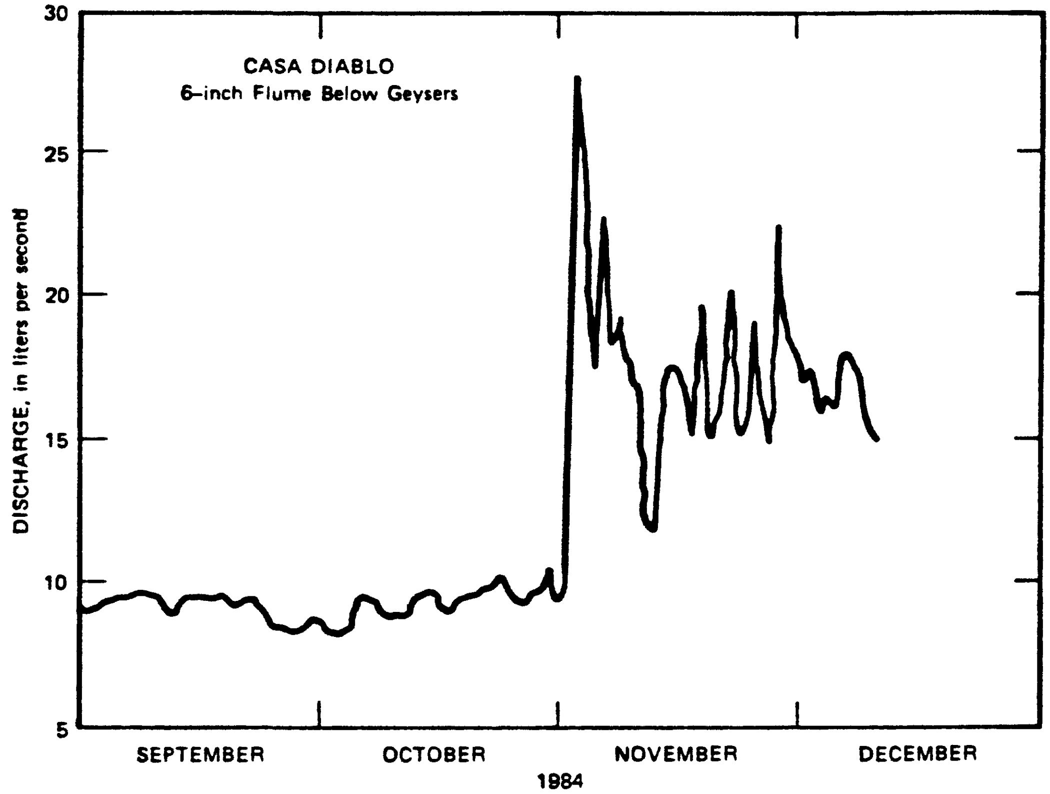


Figure 6. Plot of discharge of water through the flume located below the Casa Diablo geysers (CDF) for the period September - December 1984, based on gage heights recorded at 15-minute intervals and averaged over 24-hour periods.

liquid output from the geysers beginning on November 2, 1984 can be discerned. Although the cause of the increased flow is as yet unexplained, it preceeded by 3 weeks a M_L5.8 earthquake in the Sierran block to the south. Rates of discharge of steam from the geysers have also been greater since November 2, 1984, as has the level of variability in the output of both steam and water. The flume was removed in January 1985 when most of the flow of the geysers was bypassing the measuring site.

The total hot-spring discharge from the lower area at Casa Diablo was measured as 43 L/s on December 19, 1984. This measurement was made by gaging the flow of the unnamed tributary to Mammoth Creek at points upstream and downstream from where the drainage from the hot springs enters this tributary (fig. 5). Comparison with the discharge record plotted in figure 6 indicates that the total hot-spring discharge before November 2, 1984 may have been lower by a factor of about 2 than the value measured in December.

Five production wells (labeled MBP in fig. 5) and two injection wells (labeled IW in fig. 5) were drilled in the Casa Diablo area in 1983-84 for the Mammoth-Pacific Geothermal Power Plant. During this time an existing well (M-1) was converted into an injection well. The production wells supply hot water to a 7.5 megawatt geothermal power plant that is scheduled to begin full-scale operation in 1985. Chemical analyses of waters from the production wells (table 1), sampled during flow testing, are similar to analyses of water from nearby hot springs, indicating that the wells produce from the same shallow aquifer system that supplies water to the hot springs. Consequently, well production and injection in 1985 and thereafter can be expected to affect the discharge of hot springs and fumaroles in the Casa Diablo area.

Hot Creek Fish Hatchery

Springs at the Hot Creek Fish Hatchery (T.3S., R.28E., sec. 35) occur in four main spring groups (fig. 7) and discharge water at temperatures between 11° and 16°C along a basalt - alluvium contact. Previous studies (California State Department of Water Resources, 1967; Lewis, 1974; Sorey, 1975; Sorey and Lewis, 1976) have delineated the chemical characteristics of the hatchery springs, as indicated in table 1. Listed below are the total discharge and chloride concentration of water from each group of springs as measured in July 1984.

Spring group	Discharge (L/s)	Temperature (°C)	Cl (mg/L)
AB	360	16.0	8.0
CD	348	14.0	3.7
H-I	176	12.8	2.1
H-II,III	136	11.1	1.5
Total	1020	--	--
Weighted average	--	14.1	4.6

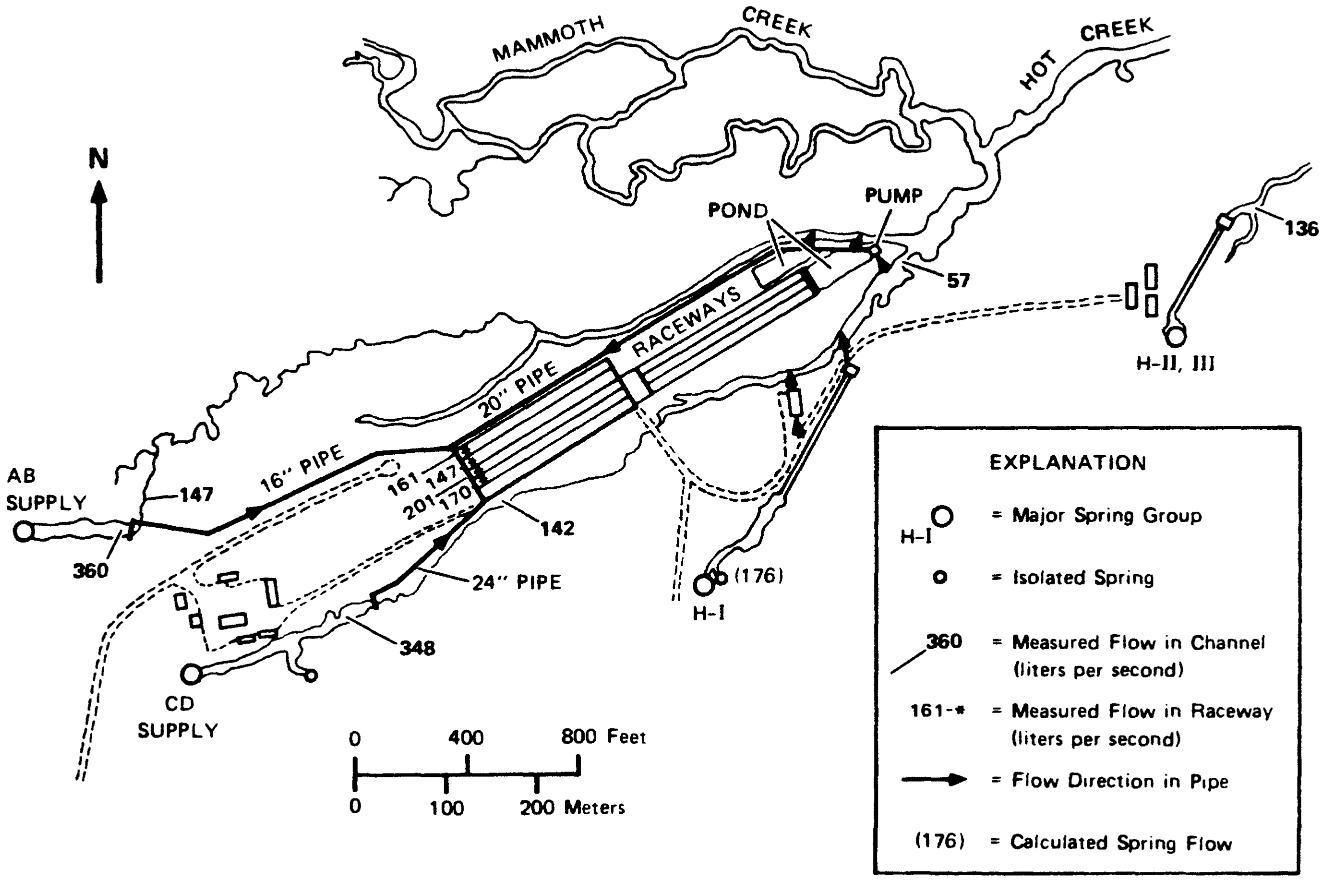


Figure 7. Map of the Hot Creek Fish Hatchery (T.3S, R.28E., sec. 35) as of July 1984 showing locations and flow rate of major spring groups that drain through the hatchery facilities and into Mammoth Creek and Hot Creek.

Discharge measurements made in 1973 averaged 964 L/s for the total flow of the hatchery springs (Sorey and Lewis, 1976, p. 788). The 5 percent difference between the 1973 and 1984 measurements is less than the probable error in this type of measurement. Additional flow measurements and chemical sampling are required to delineate the seasonal variations in discharge and chemistry that are expected to accompany the seasonal hydrologic cycle.

The weighted average temperature and chloride concentration of the hatchery spring waters are significantly greater than those of cold springs in the same area (for example, Laurel spring). This fact and the variation in chloride and temperature between different spring groups at the hatchery indicates that the hatchery springs contain mixtures of thermal and nonthermal ground waters. Temperature measurements in nearby wells CW, CM-2, and SS-2 (figs. 27, 28, and 37) and the chemistry of water obtained from well SS-2 at the Sheriff's substation support the concept that thermal waters underlie the shallow cold-water aquifer in the vicinity of the hatchery. Assuming that such thermal water contains chloride in concentrations similar to those measured in hot springs at Casa Diablo and Colton Spring (260 mg/L), an average thermal component of 2 percent is indicated for the hatchery springs, as originally suggested by Sorey (1975). For a 2 percent fraction, the total discharge of high-chloride thermal water at the hatchery would be 20 L/s.

Little Hot Creek

The springs of Little Hot Creek (T.3S., R.28E., sec. 13) are located in a small canyon near the head of the creek. Above the springs there is no perennial flow in the channel. Five main spring orifices discharge high-chloride water at temperatures of 76° - $82^{\circ}C$ (fig. 8). Analyses of liquid and gas chemistry and isotopic compositions for two of these springs are listed in tables 1, 2, and 4.

A weir plate and stage recorder were installed in Little Hot Creek in November 1979 at a site about 400 ft downstream from the hot springs. The continuous record of flow at this site is tabulated in terms of average daily discharge for the period January 1980 - December 1983 in unpublished Water Resources Data Reports by the U.S. Forest Service, Mammoth Ranger District, Inyo National Forest. Based on these records the average total flow of the hot springs above the weir is approximately 11 L/s.

Changes in spring flow at Little Hot Creek following earthquakes of magnitude 6 in May 1980 were delineated by Sorey and Clark (1981), who recorded increases in the total spring discharge of as much as 45 L/s following the magnitude 6 earthquakes on May 25, 1980. Spring flow returned to normal within a period of hours after the earthquakes, and a similar response has occurred following nearby earthquakes of magnitude $\geq$ 5 in subsequent years. In contrast, continuous records of temperature in the spring orifice labeled LHC-2 show no

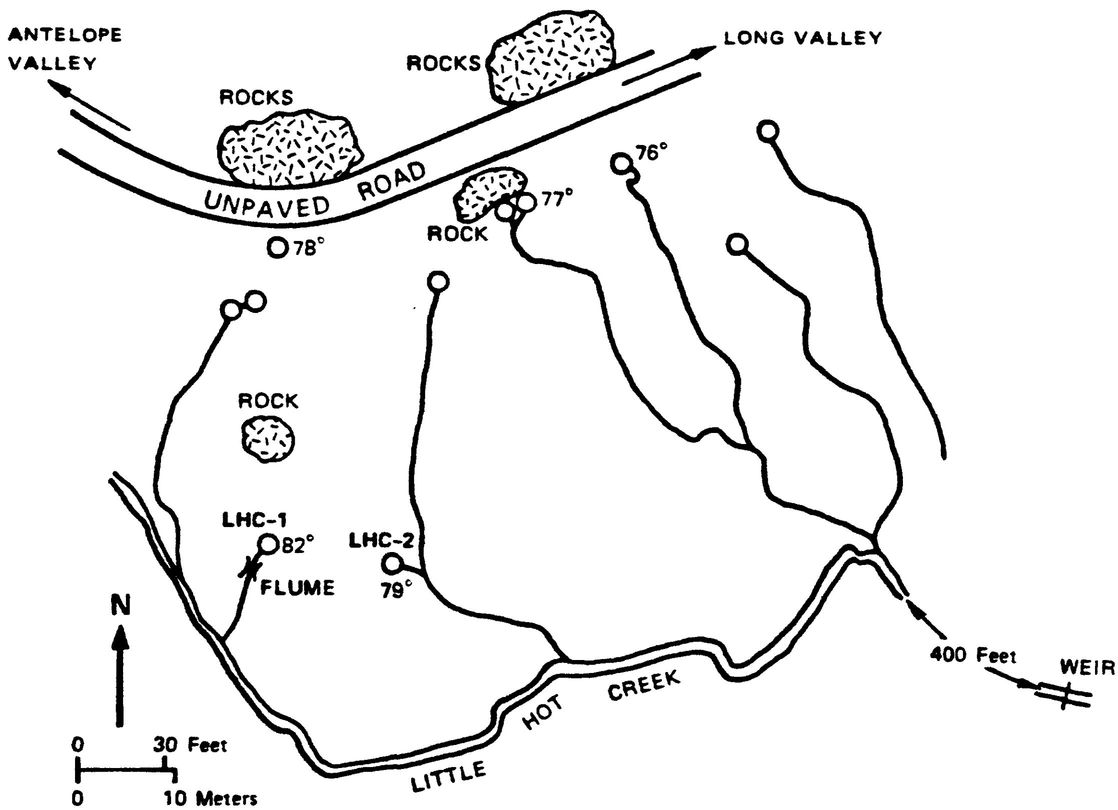


Figure 8. Map of the hot-spring area along Little Hot Creek (T.3S, R.28E, sec. 13) showing principal hot springs (open circles) and spring temperatures in degrees celsius, as measured in May 1984. Springs for which chemical and isotopic data are available are labeled with the abbreviation used in the data tables. Locations based on an unpublished map prepared by Frederick Wilson, U.S. Geological Survey, 1974.

significant coseismic changes. In July 1984 a flume and recorder were installed immediately below the spring orifice labeled LHC-1 to monitor fluctuations in discharge unaffected by periods when Little Hot Creek is flowing above the hot springs.

Hot Springs Between Casa Diablo and Hot Creek Gorge

In addition to the hot springs at Casa Diablo and the Hot Creek Fish Hatchery, thermal water is contributed to Mammoth Creek and Hot Creek (above the gorge) from Meadow spring (MS), Chance spring (CHS), and Colton spring (CS) (locations shown on pl. 1). No discharge was observed at Meadow spring and Colton spring prior to 1982, although evidence of previous periods of spring flow exists in the form of mineral deposits at CS and drainage channels at MS. The flow of Colton spring, which was first observed to flow in June 1982, was measured with a portable flume in February 1985 as 0.5 L/s. Two areas of weak steam discharge occur on the hillside above Colton spring and may be connected to the same upflow channel that feeds the hot spring. Meadow spring is along the northwest trending fault from which the fumaroles above Casa Diablo discharge; its flow was not measured but is estimated to be similar to that of Colton spring. The flow of Chance spring, which is a mixture of thermal and nonthermal waters at a temperature of 18°C, was estimated as 23 L/s by Sorey and Lewis (1976).

At Hot Bubbling Pool (HBP) no surface discharge occurs at the present time, and a description of this area by Waring (1915) indicates that a similar condition has existed for at least 70 years. However, upflow of hot water is required to maintain the surface temperature of the pool at about 60°C. Sorey and Lewis (1976) estimated the rate of upflow of hot water into the pool as 6 L/s. An unknown fraction of this upflow must seep into the shallow ground water system and eventually discharge into Hot Creek.

Continuous measurements of pool stage in HBP and water level in well CW located 200 ft west of the pool show diurnal fluctuations at both sites with a periodicity of about 7 hrs and an amplitude of about 0.5 ft. Rises in water level in the pool are accompanied by noticeable upwellings of hot water within the central part of the pool. Water-level fluctuations in well CW lag behind those in the pool by about 2 hrs. Such fluctuations may be related to the alternate buildup and release of fluid pressure adajacent to subsurface conduit(s) that transmit hot water laterally away from the pool. Superimposed on the periodic water-level fluctuations are longer-term changes in the average daily water level of as much as 1-2 ft.

Hot Creek Gorge

Hot Creek gorge (T.3S., R.28E., sec. 25) is an erosional feature with approximately 100 ft of relief cut by Hot Creek into the 0.28 m.y. old Hot Creek rhyolite (Bailey and others, 1976). Numerous hot springs discharge into the creek along a 1 mile section of the gorge bounded by northwest trending faults which form a small graben within the rhyolite flow. Temperatures of individual springs in this reach range from ambient to 94°C, generally being hotter near the graben faults. Most of the spring discharge occurs within about 500 ft of the bridge at the bathing area (fig. 9), including the flow from two large vents formed in the bed of Hot Creek.

The flow from individual spring vents in the gorge has been qualitatively observed to vary with time following the larger magnitude earthquakes that have occurred in the Long Valley area since 1973. New vents have frequently been activated while flow from other vents has decreased or disappeared. Data from chemical analyses and temperature measurements (table 1) indicate that the temperature of water from individual vents decreases as spring flow decreases, but that the chemical content of the water remains relatively constant. This implies that the temperatures of the non-boiling springs are controlled mainly by conductive heat losses from the upflow conduits. Seismically induced increases in spring flow presumably reflect increases in the permeability of fault conduits which cut across the gorge; subsequent decreases in permeability and spring flow could be due to mineral deposition and sediment clogging. As discussed below, however, the total discharge of hot water in the gorge has not as yet been significantly affected by these near-surface effects.

The total flow of the hot springs in the gorge was estimated by Eccles (1976) and Sorey and Clark (1981) from measurements of streamflow and chemical load in Hot Creek upstream and downstream

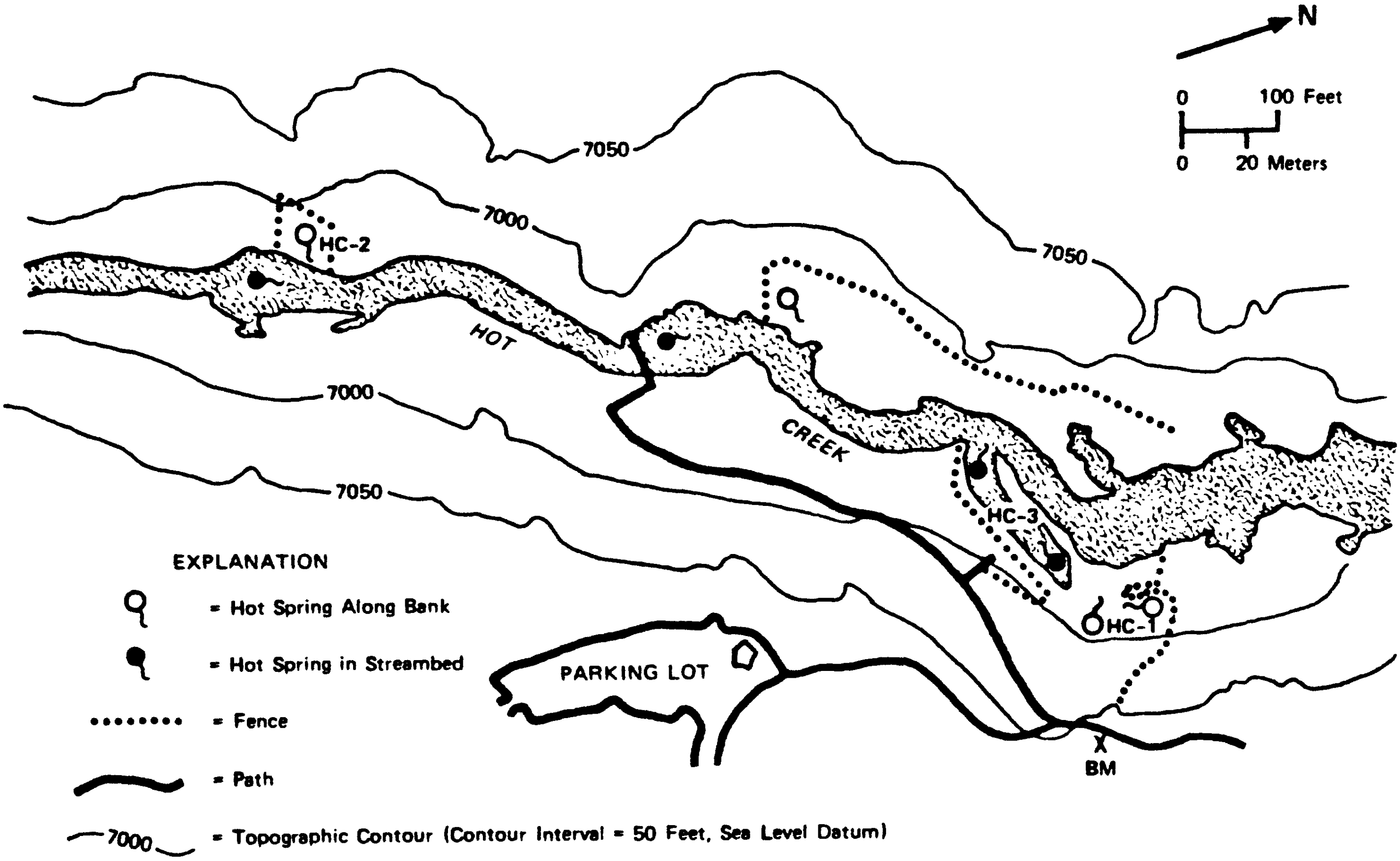


Figure 9. Map of a part of Hot Creek gorge (T.3S, R.28E., sec. 25) showing locations of hot springs referred to in text and tables and unnamed features that are conspicuous on the land surface. Locations and elevations based on an unpublished map prepared by Frederick Wilson, U.S. Geological Survey, 1974, and modified to include changes induced by subsequent seismic activity.

from the gorge made between 1972 and 1980. Hot spring discharge is calculated as the increase in flux of chloride or boron divided by the concentration of these elements in the gorge hot springs. Attempts to estimate hot-spring inflow from streamflow measurements alone would be of questionable value because such inflow is only about 10 percent of the average flow of the creek. Spring flow estimates from the studies noted above and from one additional measurement of chemical flux made during the course of this investigation are listed below.

Date (mo-day-yr)	Hot-spring discharge (L/s)
10-17-73	283
1-17-73	248
3-21-73	216
9-15-73	261
9-25-73	272
7-17-80	296
12-10-80	329
11-11-84	261

The values shown were calculated as the average of the difference between chloride fluxes upstream and downstream from the gorge divided by 215 mg/L and the difference between boron fluxes upstream and downstream from the gorge divided by 10 mg/L.

From these data the average discharge of hot springs in the gorge is calculated as 271 L/s. There is some indication that this discharge was greater following the earthquakes in May, 1980 (the average value for 1980 measurements is 312 L/s) and has subsequently returned to pre-1980 levels. However, the limited number of chemical flux measurements and the variability in individual measurements suggest that the apparently greater spring discharge between July and December 1980 may not be significant. Analysis of the continuous record of chemical flux at the Hot Creek flume (see below) which begins in August 1983 offers a better chance to discern changes in spring flow related to tectonic activity. From the data presented here and in previous sections it appears that hot springs above the gorge contribute 10 - 20 percent of the total flow of thermal water passing through the Hot Creek flume.

Flumes along Mammoth Creek and Hot Creek

Three sites for routine stream flow measurement and chemical sampling have been established along the Mammoth - Hot Creek drainage (pl. 1). Two of the sites are permanent stations with concrete flumes. At the Mammoth Creek flume site (MCF) a 7 ft modified parshall flume (built and operated by Los Angeles Department of Water and Power) is used to measure streamflow, which is recorded on an analog chart. At the Hot Creek flume site (HCF) a 10 ft modified parshall flume (built and operated by Los Angeles DWP, 1923-1979) is used to measure streamflow, which is recorded digitally at 15 minute intervals. A data logger (USGS minimonitor) at this site also records water temperature and specific conductance at 15 minute intervals. Discharge measurements at the third site (MC395) were made by wading with a current meter.

Data from 12 measurements of streamflow and chloride and boron concentrations at sites MCF and MC395 between May 1983 and October 1984 yield an average value of 11 L/s for the inflow of thermal water with chemical composition similar to that in the hot springs at Casa Diablo (Cl = 260 mg/L, B = 11 mg/L). Corresponding measurements of chemical fluxes at these sites on November 11, 1984 yield a calculated thermal-water inflow of 33 L/s. The difference (33 vs 11 L/s) is due to the increased flow of the Casa Diablo hot springs after November 2, 1984. Comparison of discharge measurements made at Casa Diablo with those made at sites MCF and MC395 indicates, however, that 25 - 50 percent of the hot-spring discharge at Casa Diablo is lost to evaporation and seepage into the shallow ground-water system upstream from the Mammoth Creek flume.

The continuous specific conductance and streamflow measurements recorded at HCF allow for estimation of hot spring discharge upstream from the flume for periods between the site visits. In order to calculate hot-spring discharge a relationship of specific conductance to the concentration of selected elements was developed. Based on 17 measurements made between November 1982 and October 1984 the following relations of boron (B) and chloride (Cl) concentrations in mg/L to specific conductance (SC) were established (fig. 10).

$$B = 0.00427 \ (SC) - 0.280$$

$$Cl = 0.098 \ (SC) - 7.5$$

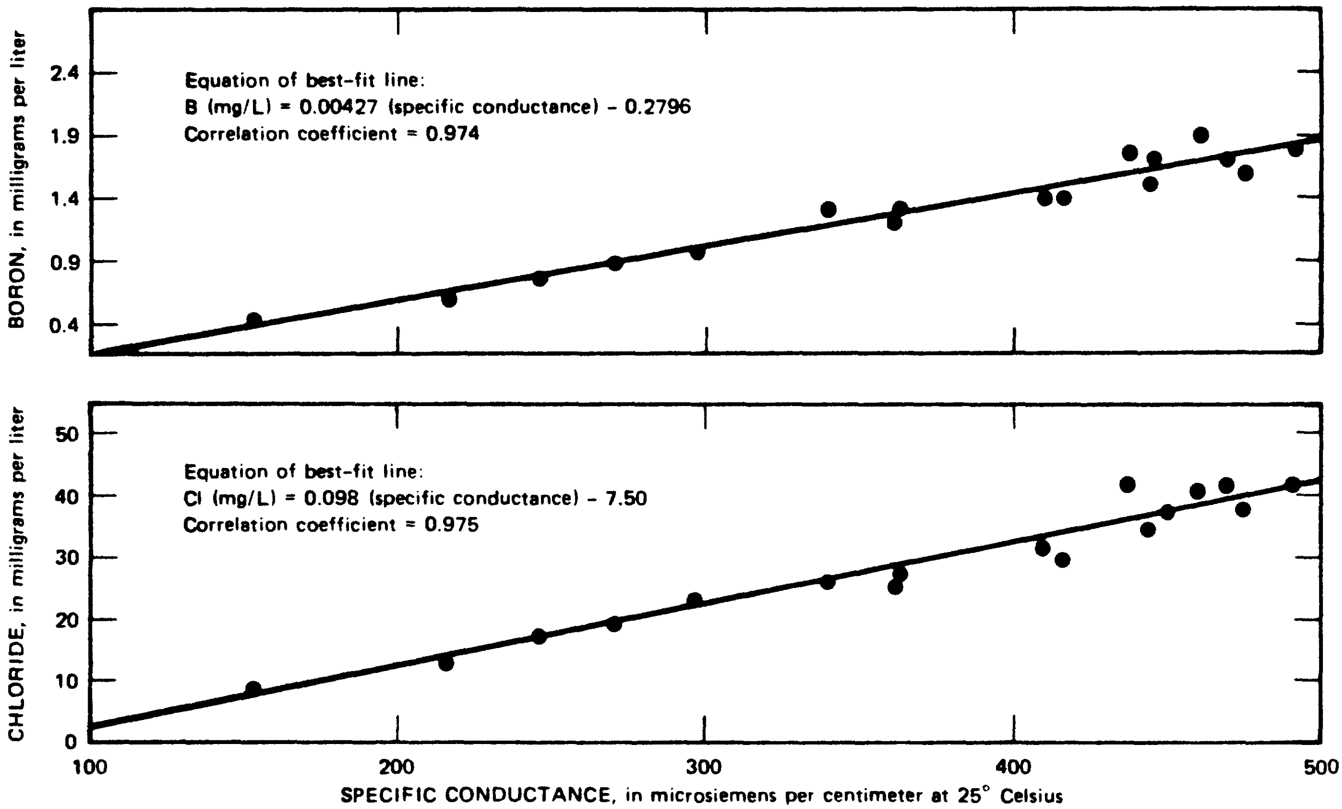


Figure 10. Plots of chloride and boron concentrations versus specific conductance for samples collected at the flume on Hot Creek.

Multiplication of the calculated chloride and boron concentrations times the measured streamflow yields the flux of each element past the flume. As noted in the previous section, estimates of hot spring inflow to the creek above the flume can then be obtained by dividing the chemical fluxes by the concentration of each element in the hot-spring waters.

Mean daily values of streamflow and chloride flux at HCF are plotted in figure 11 for the period January - December 1984. Comparison of the two records shows that while streamflow varies by as much as 150 percent in response to snowmelt-runoff and precipitation, the calculated chloride flux is relatively uniform. This is because it is derived primarily from hot-spring inflow. However, increased streamflow during the period May to August 1984 was accompanied by an increase of approximately 15 percent in chloride flux. Such an increase is significantly greater than the level of variability in this parameter during the winter months ($\pm$ 5 percent). Furthermore, the level of seismic activity in the May to August period was relatively low. Hence, the increase in chloride flux may be attributable to the release of chloride from storage within the drainage basin rather than to an increase in the discharge of hot springs. Changes in chloride flux attributable to this same mechanism appear to accompany increased streamflow following both snowmelt and rainfall events. Unfortunately, the mechanisms by which chloride is stored in and released from the drainage basin are not well

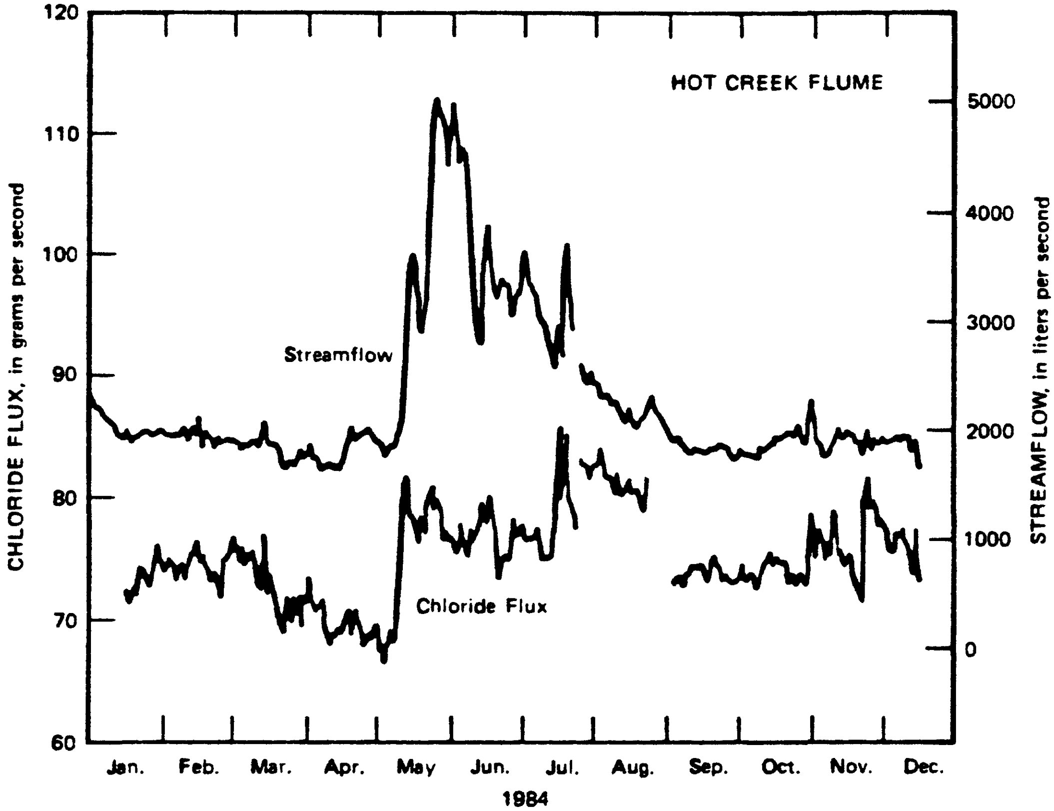


Figure 11. Plots of streamflow and chloride flux at the Hot Creek flume for 1984, based on values of river stage and specific conductance recorded at 15-minute intervals and averaged over 24-hour periods.

defined, and the rate of chloride release from storage does not appear to have a simple relationship to increased streamflow.

Analysis of the chloride flux record at the Hot Creek flume is still in progress. Preliminary checks show evidence of changes in hot-spring discharge following and possibly preceding large magnitude earthquakes such as the M_L5.8 event that occurred on November 23, 1984 within the Sierra 25 miles southeast of Mammoth Lakes. More detailed analyses of such effects requires comparisons of values of specific conductance, temperature, and streamflow averaged over time intervals shorter than 24 hours.

The chloride flux technique appears capable of detecting changes in hot-spring discharge as small as 25 L/s, or about 10 percent of the total spring flow in the gorge, during periods of relatively constant streamflow. To enable similar changes to be detected during periods of variable streamflow related to snowmelt or rainfall, more frequent stream gaging and sampling to measure chloride flux at sites above HCF will be required. Occasional malfunctions of the specific conductance probe have occurred, as for example during the period August 25 to September 2, 1984. Loss of record during such periods could be reduced by operating two conductance probes simultaneously.

GROUND-WATER-LEVEL FLUCTUATIONS AND GROUND WATER MOVEMENT

The ground-water system in the Long Valley area includes flows of thermal, nonthermal, and mixed waters in aquifers in various rock units at different depths. For the purposes of this report, the ground-water system is considered to consist of two major parts: a shallow, generally non-thermal part and a deeper thermal part. The deeper part is loosely referred to as the hydrothermal system and includes regions of ground-water downflow in recharge areas, ground-water upflow in discharge areas, and zones of lateral flow of thermal water at relatively shallow depths around the south and southeast sides of the resurgent dome.

Variations in pressure in aquifers are related to factors such as ground-water recharge and discharge, atmospheric pressure changes, and strain caused by earth tides or other geologic processes. Such variations are reflected in changes in the altitude of the water levels in wells which are open to one or more aquifers. Two types of ground-water-level data have been collected as a part of the hydrologic monitoring in Long Valley: 1) wide areal coverage--periodic measurement of water levels in a large number of wells distributed over the entire study area, all measured within a few days, and 2) site specific--continuous measurements of water levels at selected sites over periods ranging from a few weeks to more than one year.

Well Inventory and Test Drilling

The results of an inventory of wells are given in table 5. All inventoried wells, except those reported abandoned or destroyed, were field located to the nearest one second of latitude and longtitude. Township-range locations follow the numbering system shown in figure 12. The altitudes of most sites were determined by leveling from points of known altitude. Well construction information was obtained from published records (McNitt, 1963; California Department of Water Resources, 1967, and 1973; and Lewis, 1974), driller's reports, interviews with owners, and on-site observations. The inventory includes virtually all wells open or in use within the study area except for some of the shallow wells drilled for domestic water supply in the areas south and southwest of Lake Crowley and around Old Mammoth.

Three observation wells were drilled by the Geological Survey during July - August 1983. Two of the wells, CH-10A and CH-10B, were drilled near Hot Creek gorge, and the third well was drilled near Sherwin Creek Campground (locations shown on pl. 1 and schematic drawings of well construction in fig. 13). Drilling was by standard rotary methods using a combination of air, foam, and mud to remove cuttings.

The purpose of the drilling was to construct wells that tap confined aquifers in rocks of low compressibility. The water levels in such wells would be expected to fluctuate in response

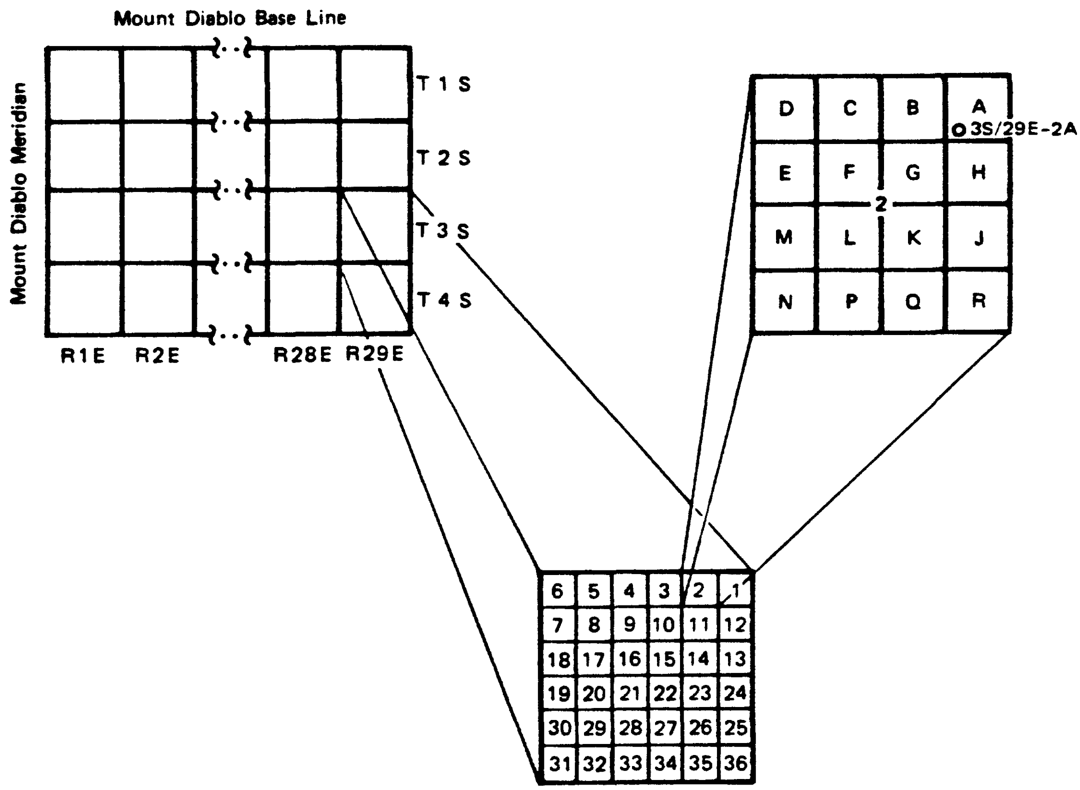


Figure 12. Well numbering system. Wells are asigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the well number 3S/29E-2A the part of the number preceding the slash indicates the township (T. 3 S.), the part between the slash and the hyphen indicates the range (R. 29 E.), the number between the hyphen and the letter indicates the section (sec. 2), and the letter indicates the 40-acre subdivision of the section.

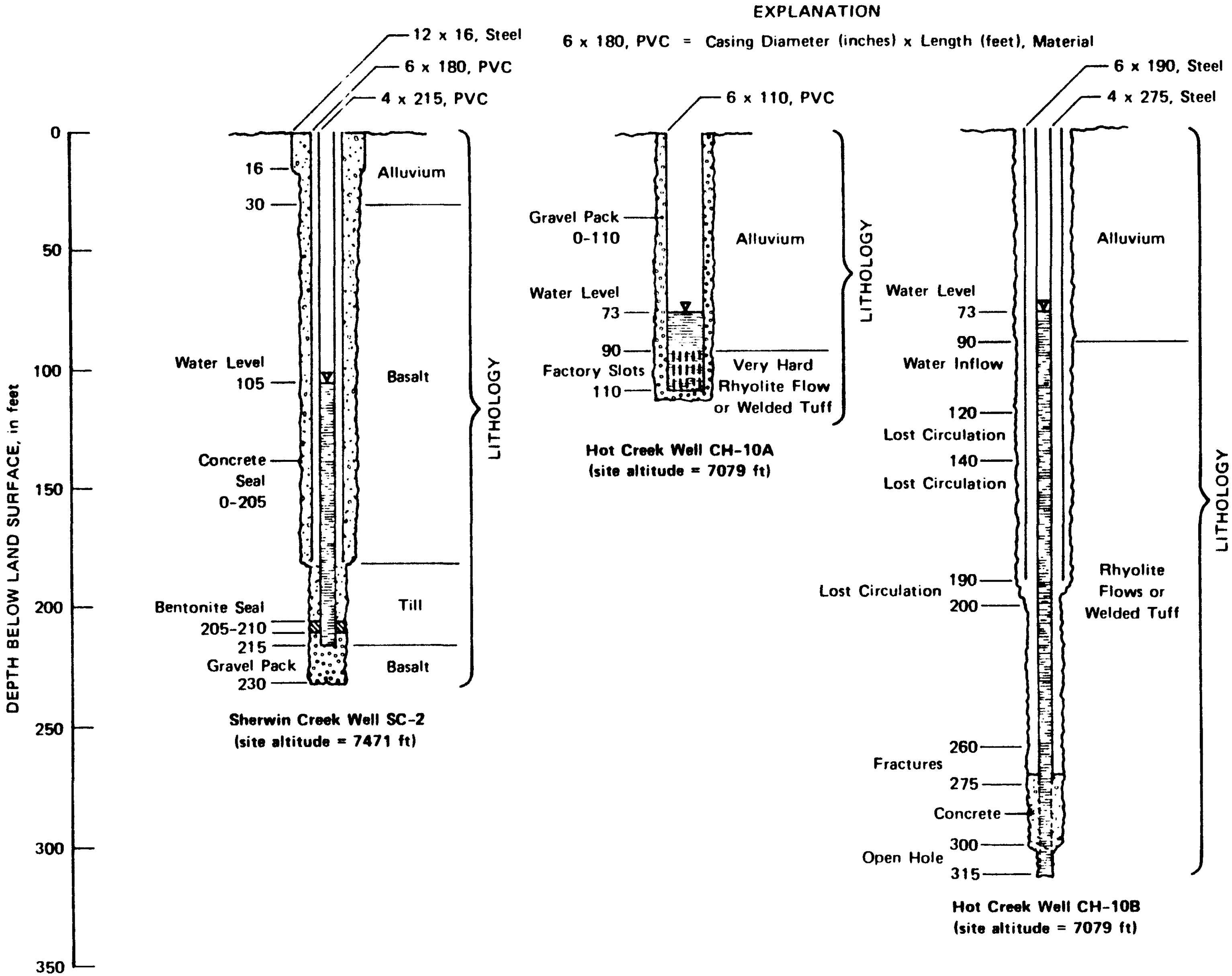


Figure 13. Schematic diagrams of the construction of wells SC-2, CH-10A, and CH-10B.

to strain events such as earth-tides, earthquakes, or ground inflation. These wells were also drilled to provide stratigraphic information, subsurface temperature measurements, and samples of ground water.

The site near Hot Creek was selected for exploration based on geohydrologic conditions. The rhyolite exposed in this area was expected to include a confined aquifer, and the site is within a graben containing springs that contribute approximately 80 percent of the hot water discharged to the surface in Long Valley (Sorey and others, 1978). The wells were drilled to 110 and 315 ft. Based on similar static water-level altitudes in CH-10A and CH-10B (table 5) and long-term continuous water-level records from CH-10B, neither well appears to tap a well-confined aquifer. The lack of confined conditions to a depth of 315 ft at this site probably results from fracturing associated with the nearby graben fault, which could provide paths of communication between aquifers at different depths.

The site near Sherwin Creek Campground was selected for an observation well (SC-2) because of the intense seismic activity in this area during the January 1983 sequence of earthquakes (Savage and Cockerham, 1984). A comparison of the static water-levels in SC-2 and in SC-1, a shallower well drilled in 1982, indicates that ground water is well-confined in the aquifer tapped by SC-2. Further discussion of the water-level record is included under the heading "Continuous Water-level Measurements".

Periodic Water-Level Measurements

Water-level data collected periodically since 1982 over a wide areal extent are listed in table 6. Additional water-level data for some of these wells prior to 1974 were given by Lewis (1974) and California Department of Water Resources (1973). These data are useful for analyzing long-term trends in ground-water levels and in the interpretation of directions of ground-water movement. Water-level data collected since 1982 have also been used in connection with repeat gravity measurements to estimate the fraction of observed changes in gravity resulting from addition or depletion of ground water beneath the measuring sites (R.C. Jachens, oral communication, 1984).

Fluctuations in water level observed during the course of this study ranged from less than 1 ft in some wells to as much as 10-20 ft in others. These changes appear to reflect primarily seasonal ground-water recharge and discharge cycles. No significant long-term trends in water level could be seen, either because no trends exist or because the data are too restricted in area or time to discern such changes.

Water-Table Contour Map

Water levels measured during the summer of 1984 have been used to construct a water-table contour map for the caldera. Both a plate-size version (pl. 2) and a page-size version (fig. 14) are included in the report. The altitude of the water level at each site was calculated by substracting the measured depth to

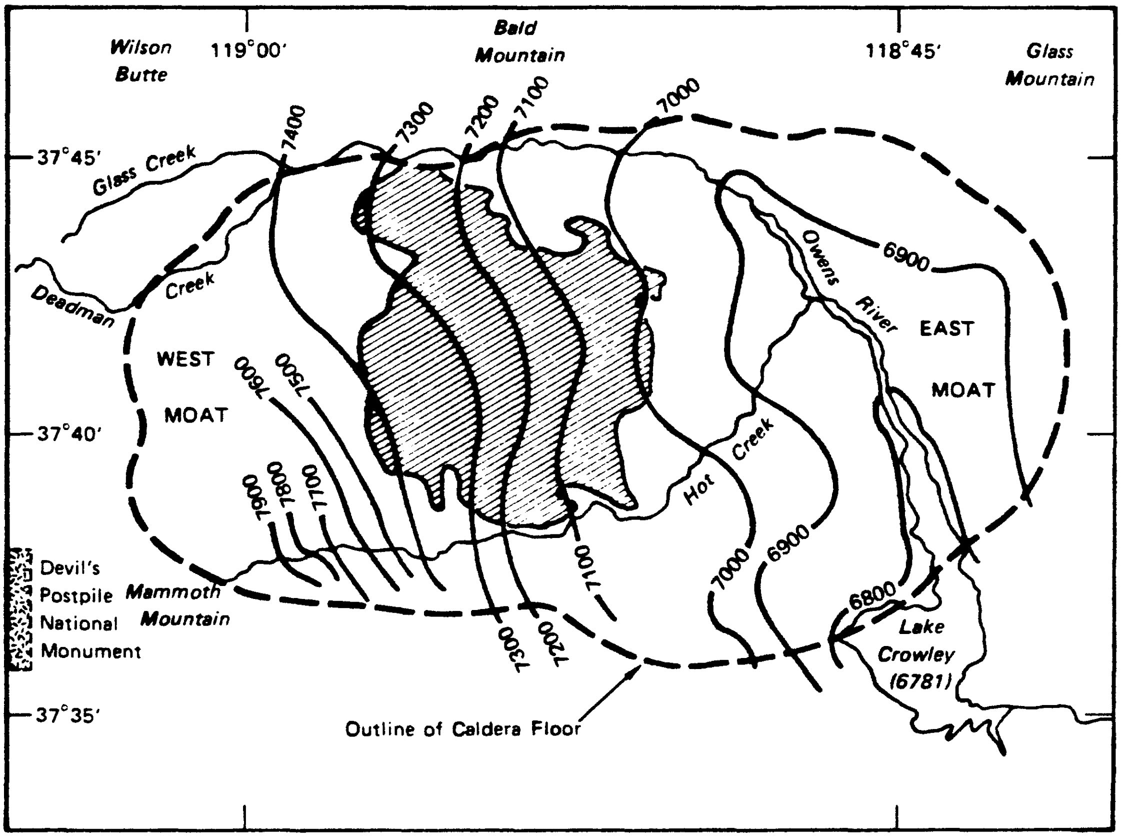


Figure 14. Water-table contour map for the Long Valley caldera. Altitude of water table given in feet above sea level, based on water levels measured during the summer of 1984 (table 6). Contour interval is 100 ft. Data points are shown on plate 2. Crosshatched pattern shows extent of volcanic rocks of the resurgent dome.

water from the altitude of the measuring point, which in most cases was close to the land surface. Measuring-point altitudes were determined either from leveling data or estimated from topographic maps (tables 5 and 6).

Data used to construct the contour map were collected from wells of varying depth that penetrate aquifers at different temperatures. In recharge areas, the hydraulic head (and hence the water-level in wells) tends to decline with depth, whereas in discharge areas it tends to increase with depth. In general, data from shallow wells (less than 1000 ft deep) were used to construct the map in order to minimize differences related to vertical ground-water flow. At several sites east of the resurgent dome measurements in adjacent wells at different depths indicate that hydraulic head is essentially constant with depth, at least above 1000 ft.

Within the western half of the caldera, where topography is more variable, significant differences in hydraulic head with depth have been observed at some sites. For example, in parts of the south moat underlain by alternating layers of basalt and glacial till, head differences of 5-10 ft have been measured in adjacent wells whose depths differ only by 50-100 ft. Within the west moat in areas of topographic highs, such as The Knolls north of Mammoth Lakes (pl. 1), significant head loss with downward flowing recharge is evidenced by depths to water as much as 1000 ft. below land surface. Consequently, locations of water-table contours within the west moat are less certain than elsewhere in the caldera.

The contour map (fig. 14 and pl. 2) is similar to a previously published map (Sorey, Lewis, and Olmsted, 1978), but differs in detail because it is based on more data points. The movement of ground water in the shallow non-thermal system is generally from west to east; recharge occurs around the caldera rim, within the west moat, and beneath the resurgent dome. Ground water discharge occurs in springs located around the rim, along the south and east sides of the resurgent dome, at the land surface in the lowland meadows west of Lake Crowley, and subaqueously into Lake Crowley.

The water-level contour map could be used along with interpretations of stable isotope data discussed in a previous section of the report to infer that the hydrothermal system is also recharged around the western margin of the caldera, probably along the caldera ring fracture. Lithologic and thermal data from wells PLV-1 and PLV-2 indicate that within the west moat hot water flowing in the welded Bishop Tuff at depths below about 3000 ft may be isolated hydraulically (i.e. confined) from cooler ground water in the shallow volcanics by layers of nonwelded early rhyolite and moat rhyolite tuff. Thus hydraulic heads within the welded tuff may differ substantially from heads represented by water levels in wells completed in the overlying volcanics within the west moat. Farther to the east, however, water levels measured in wells which penetrate into the Bishop

Tuff appear to be similar to water levels in nearby shallower wells, indicating little difference in head with depth. Anomalous conditions do occur in the Little Antelope Valley area, where water-level measurements in well LAV-1 indicate that nonthermal ground water in the meadow area is perched above the regional water table beneath the resurgent dome, the altitude of which is indicated by water levels in wells CH-6 and FP-1.

Continuous Water Level Measurements

Water wells are commonly quite sensitive to rock dilatation (Bredehoeft, 1967; Bodvarsson, 1970) and the monitoring of rock deformation has proved to be a fundamental tool in predicting volcanic activity (Swanson et. al, 1981). In an effort to continuously monitor deformation within the Long Valley area, ten water wells at eight sites (pl. 1) have been instrumented with pressure transducers for periods of a few weeks to more than one year. Seven sites were active as of January 1985, four with telemetry platforms transmitting data collected at fifteen minute intervals and three with on-site digital recorders which record data at intervals of 15 minutes or one hour. Well construction information for each site is given in table 5. At each active site the water level in the well, the local atmospheric pressure, and the air temperature are monitored. At six of the active sites, water level is monitored with down-hole strain-bridge transducers which offer a resolution of approximately 0.003 ft of water-level change. At the other active site, CH-10B, water level is monitored with a nitrogen bubbler gage attached to an uphole strain-bridge transducer with a resolution of about 0.02 ft. This device is used at this site because it is far less prone to complete failure than down-hole devices in harsh environments.

Water-level data presented here are reported in feet of water above the transducer sensing element. The altitude of the sensing element (datum) was arbitrarily set because only the relative water-level fluctuations are needed for strain analyses. The atmospheric pressure sensors installed at selected sites provide a resolution of approximately 300 microbars (0.01 ft of equivalent water-level change at standard temperature and pressure. Data from these sensors was used to filter the water-level data to remove effects of atmospheric pressure fluctuations.

This part of the study formally began in January 1983 with the instrumentation of three sites: CH-10, CH-6 and SC-1. At CH-10 and CH-6 the water level was monitored with a nitrogen bubbler gage and recorded hourly on punch tape. The water-level data collected during 1983 from these two sites is shown in figure 15. At both sites the water-level record is contaminated by nearly uniform diurnal fluctuations which become very prominent in the spring. These diurnal fluctuations are apparently the result of temperature dependent leaks in the nitrogen line which developed over time. No air-temperature records were collected at these sites and as a result of this contamination, the water-level

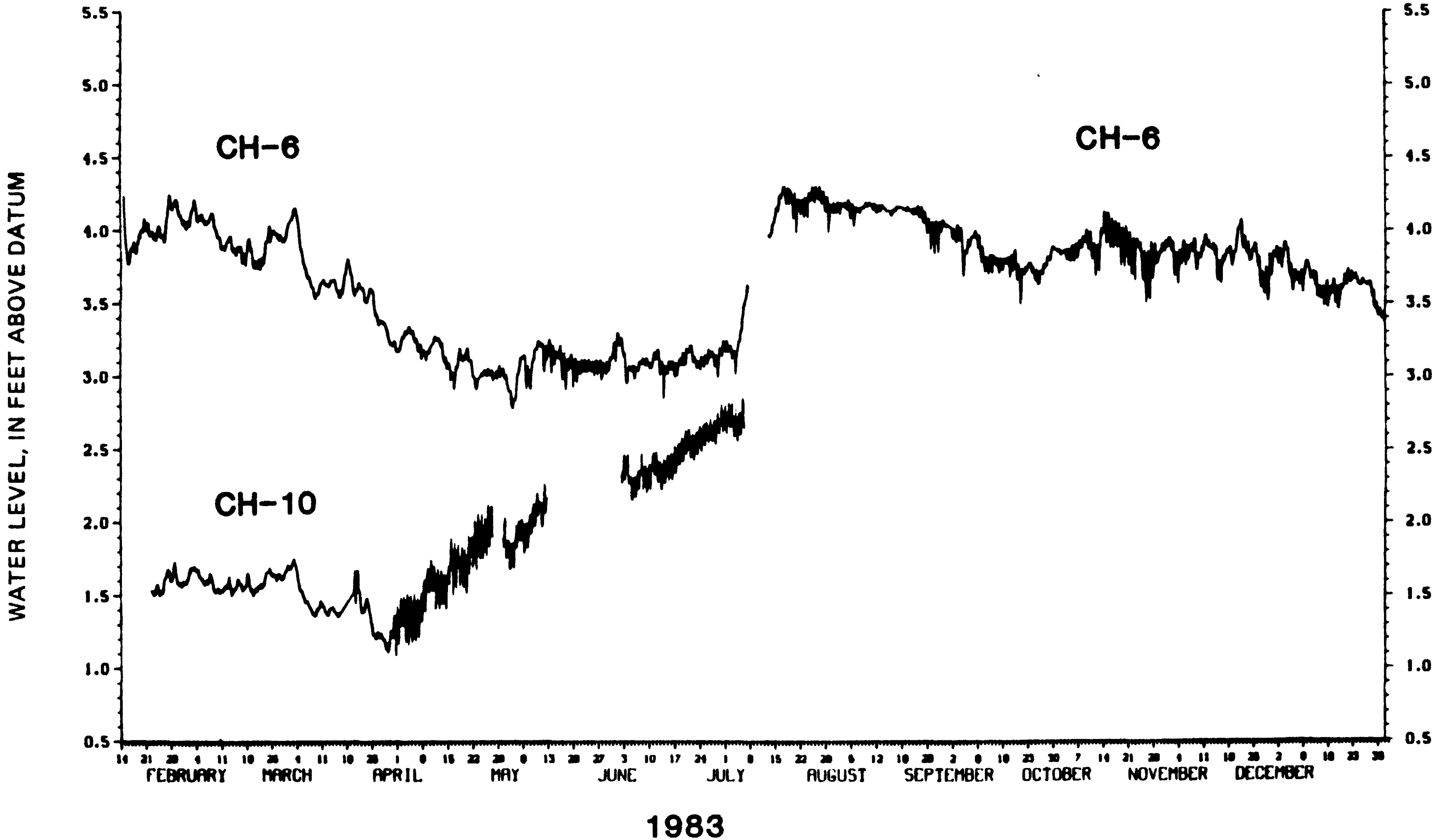


Figure 15. Water-level records for wells CH-6 and CH-10 during 1983. Gaps represent periods of missing record due to equipment problems. DATUM is altitude of transducer sensing element.

record is accurate only to within approximately 0.15 ft. While the water-level records at both sites are inadequate for monitoring deformation, they are useful as an indication of the seasonal variations in head which can be expected in the shallow- to medium-depth confined aquifers and aquitards present in the Long Valley area. At the other site installed in January 1983, SC-1, water level was monitored with a down-hole pressure transducer at 15 minute intervals and data was transmitted via telemetry. This site also proved troublesome as leaks frequently caused the downhole transducers to fail. The well proved to be poorly suited for monitoring rock deformation because it taps an unconfined aquifer. Monitoring was discontinued at this site in July 1983.

In August 1983 four new sites were selected for continuous monitoring: CH-1, CH-5, CH-10B and SC-2. Data collected from these sites during 1984 are shown in figures 16-19. While there are gaps in the data (these gaps are related to both platform and instrument failure) the data are highly accurate and largely free from noise except at CH-10B. Monitoring the water level at CH-10B has been problematic. The 90-100°C water in the well rapidly corrodes conventional down-hole water-well instruments causing them to fail. The nitrogen bubbler gage system currently used to monitor the water level at this well displays the same inadequacies which were present at CH-6 and CH-10. Monitoring at this well is being continued for the purpose of identifying the

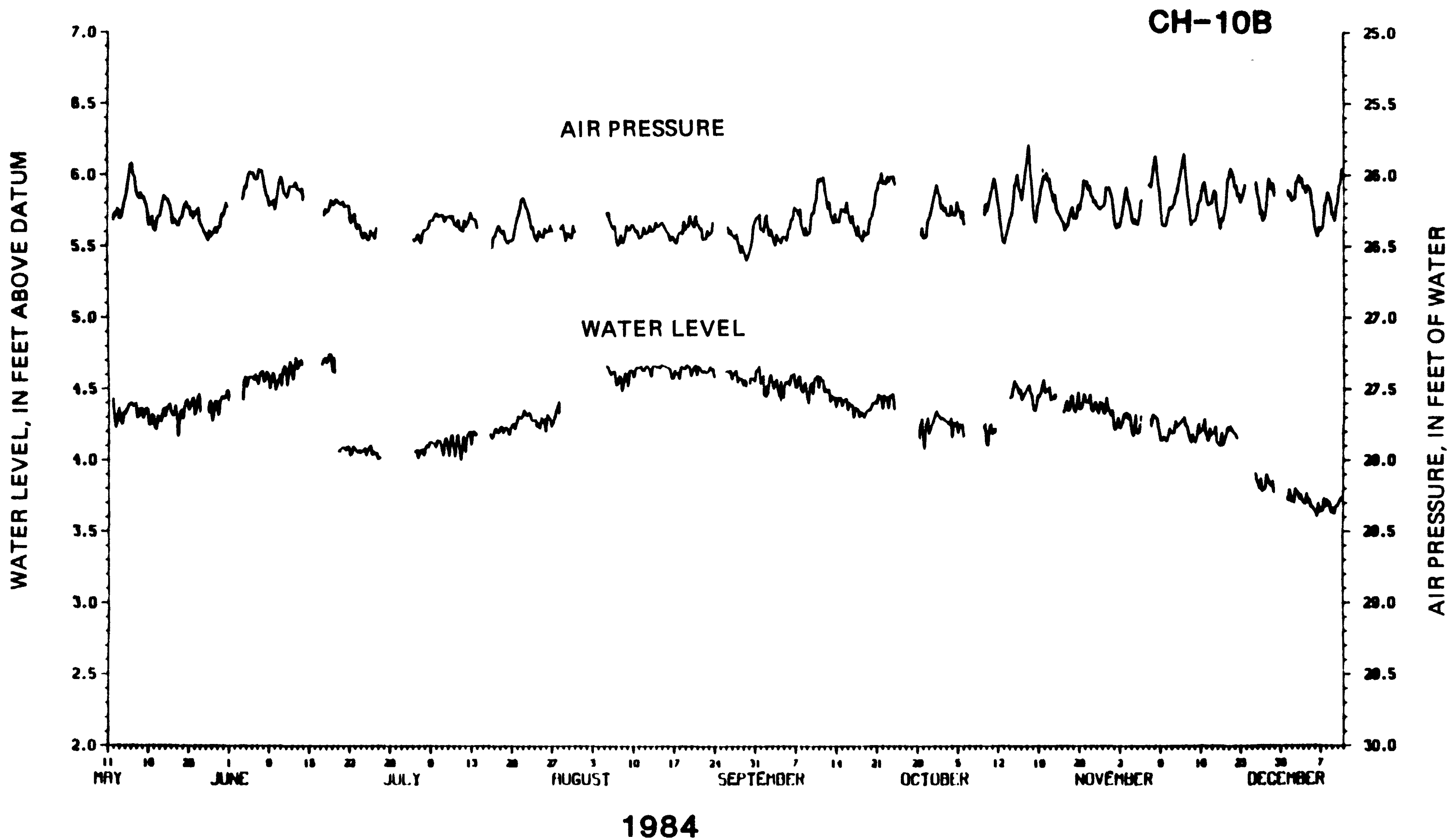


Figure 16. Water-level and barometric-pressure records for well CH-10B during 1984. Gaps represent periods of missing record due to equipment problems. Units of feet of water for barometric pressure apply to standard temperature and pressure. DATUM is altitude of transducer sensing element.

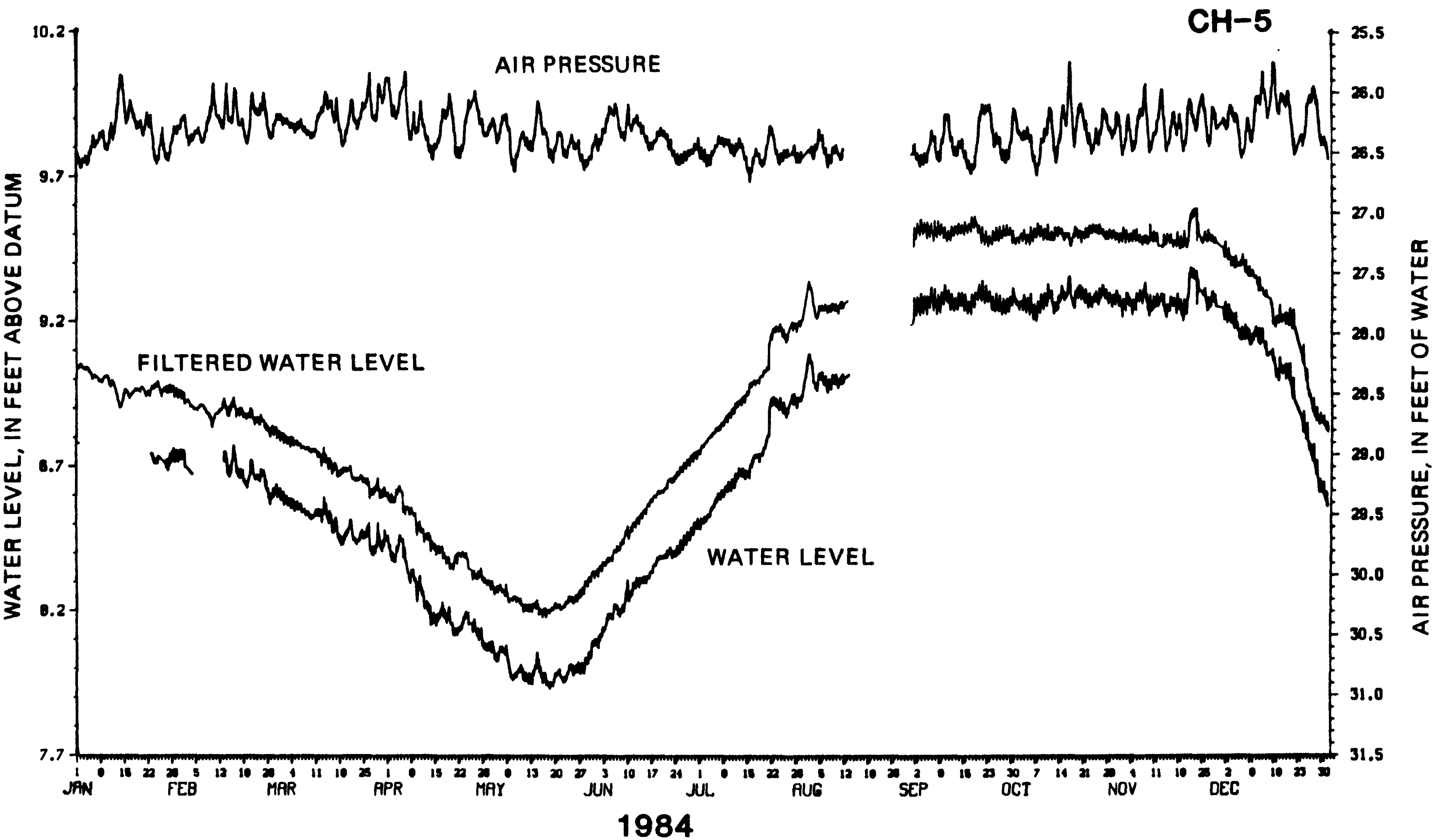


Figure 17. Water-level and barometric pressure records for well CH-5 during 1984. Filtered water level represents the water level with effects of air-pressure fluctuations removed. Gaps represent periods of missing record due to equipment problems. Units of feet of water for barometric pressure apply to standard temperature and pressure. DATUM is altitude of transducer sensing element. Filtered water level curve shifted upwards by 0.2 ft.

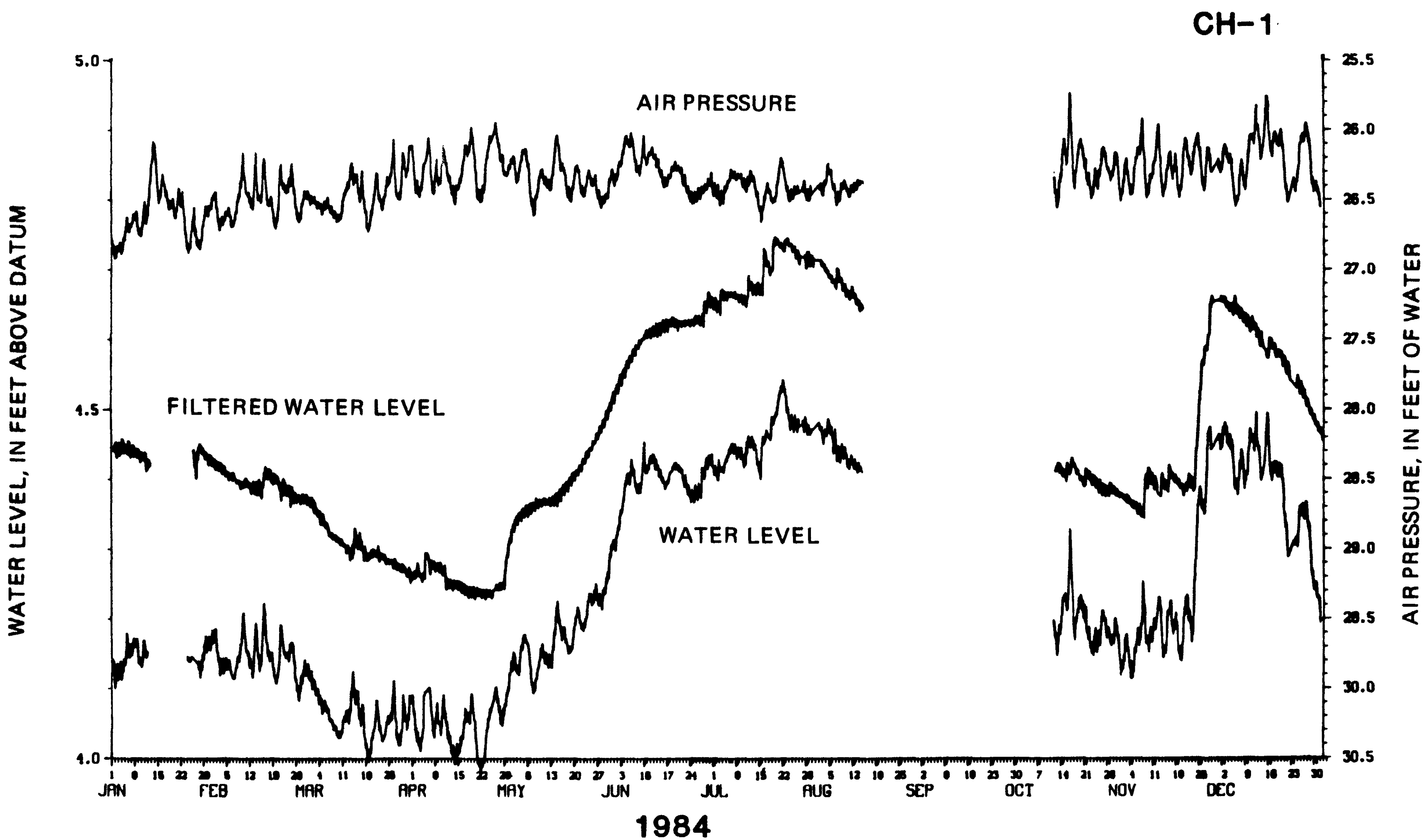


Figure 18. Water-level and barometric-pressure level records for well CH-1 during 1984. Filtered water level represents the water level with effects of air-pressure fluctuations for removed. Gaps represent periods of missing record due to equipment problems. Units of feet of water for barometric pressure apply to standard temperature and pressure. DATUM is altitude of transducer sensing element. Filtered water level curve shifted upwards by 0.3 ft.

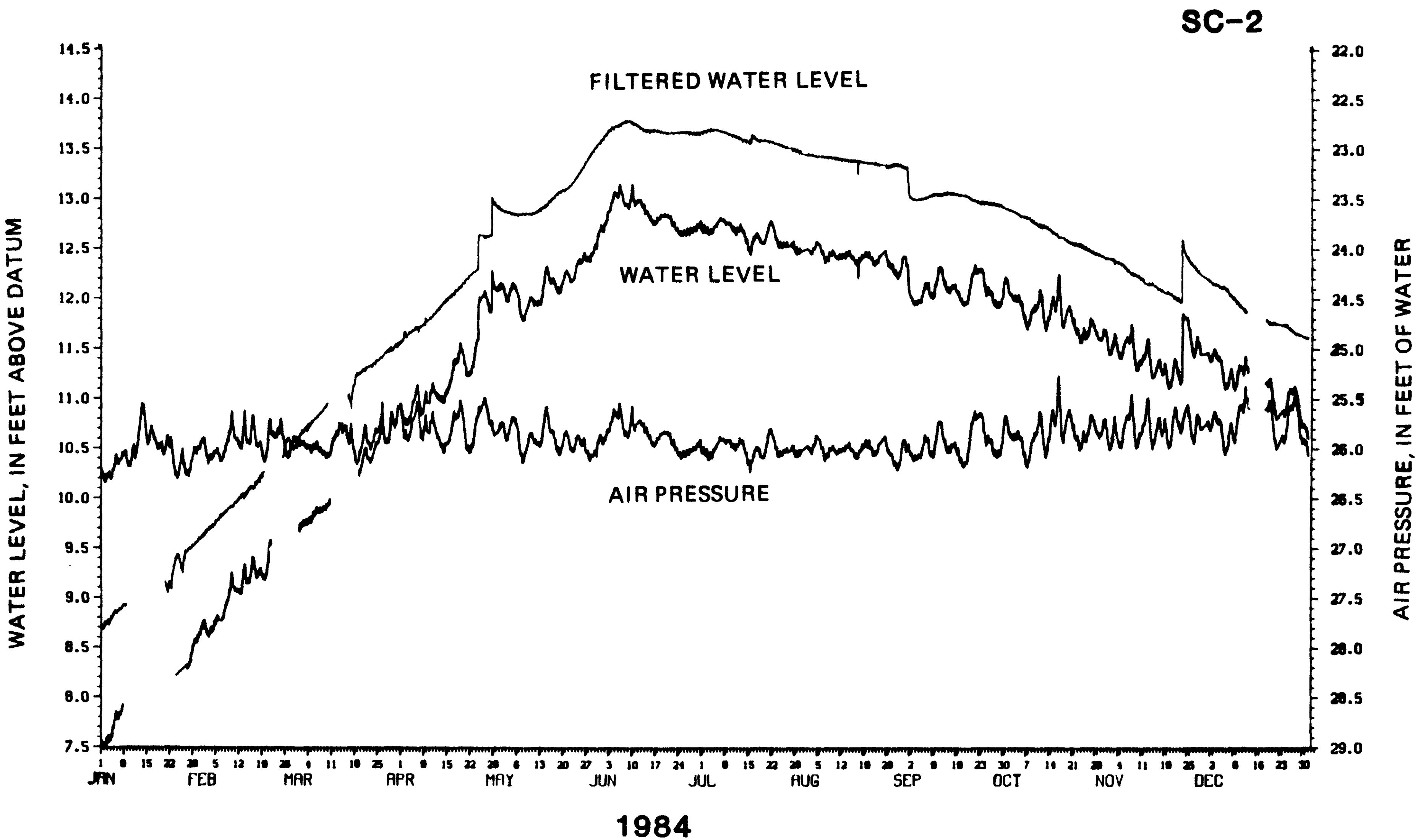


Figure 19. Water-level and barometric-pressure records for well SC-2 during 1984. Filtered water level represents the water level with effects of air-pressure fluctuations removed. Gaps represent periods of missing record due to equipment problems. Units of feet of water for barometric pressure apply to standard temperature and pressure. DATUM is altitude of transducer sensing element. Filtered water level curve shifted upwards by 1.0 ft.

effects of future geothermal development on hot springs in Hot Creek gorge. The other sites installed during the fall of 1983 have been far less prone to failure than CH-10B. They are also sensitive to rock deformation; at all three sites water-level fluctuations in response to earth tides can be discerned. Listed below are the magnitude of the response of these three wells to the M2 tide (main component of the solid-earth tide) and the low frequency barometric efficiency of each well.

SITE LOCATION	AMPLITUDE OF RESPONSE TO M2 EARTH TIDE (FEET)	LOW-FREQUENCY BAROMETRIC EFFICIENCY
CH-1	0.01	0.26
CH-5	0.01	0.16
SC-2	0.02	0.78

Figures 17-19 show the unfiltered and filtered hydrographs at CH-1, CH-5, and SC-2. In the filtered hydrographs, the effects of atmospheric pressure fluctuations on the water level were removed using a simple linear filter based upon a regression analysis of the response of the wells to low frequency (two cycles per day or less) atmospheric-pressure fluctuations. The filtering was done because the response of wells to air-pressure fluctuations can easily mask the response of wells to tectonic deformation. The response of water wells to low-frequency air-pressure fluctuations in confined aquifers has been understood for decades (Jacob, 1940) and the filters developed for these wells display a standard error of approximately 0.005 ft.

The filtered hydrographs for these three wells show that major fluctuations in water level were mostly seasonal in nature until late November 1984. There were minor fluctuations in water level prior to this time that apparently are not related to seasonal recharge but to seismic events and aseismic rock deformation. Water levels dropped 0.03 ft on April 10 and 0.07 ft on April 9 at CH-1 and CH-5 respectively. Rapid rises in water level of 0.34 and 0.37 ft occurred at SC-2 on April 24 and April 28 respectively. The April 24 rise was in response to a distant earthquake with the epicenter located in Morgan Hill, California; the April 28 rise was in response to a magnitude 4.2 earthquake within the Long Valley caldera near Laurel Creek (pl. 1). Rapid rises in water level in SC-2 also occurred in response to moderate-size (magnitude 3.5-5.0) local earthquakes during the fall of 1983. Water levels rose 0.07 ft on July 16 at SC-2, 0.05 ft on July 18 at CH-1 and 0.09 ft on July 21 at CH-5. The water-level rise at SC-2 was in response to a magnitude 3.6 earthquake within the caldera which occurred 8 hours after the onset of a earthquake swarm. This earthquake swarm lasted for two weeks and the water-level rises at CH-1 and CH-5 during the second half of July may be indirectly related to this seismic activity.

A magnitude 5.8 earthquake that occurred on November 23 outside the boundary of the Long valley caldera (25 mi southeast of Mammoth Lakes, CA) caused water-level changes at all three sites and was preceded and followed by anomalous water-level fluctuations at two of the sites (fig. 20). Immediately following the earthquake, water levels rose 0.63 ft at SC-2 over a two and one-half hour interval and dropped 0.01 ft and 0.08 ft over less than a 7 minute interval at CH-1 and CH-5 respectively. At CH-5 water levels rose 0.1 ft over a 30 hour period between November 20 and 21; this water-level rise was followed by a cummulative 0.1 ft drop in water level from November 23 to 25. Water levels rose 0.05 ft on November 7 at CH-1. Subsequent to the November 23 earthquake water levels rose 0.24 ft. at CH-1 over a 5 day period (November 23-28).

The water-level fluctuations described above may be related to strain events within the caldera. Rapid changes in water level of less than about 0.1 ft could result from elastic deformation accompanying local earthquakes, whereas rapid fluctuations of 0.1 ft or more probably reflect inelastic deformation induced by seismic waves. Inelastic deformation would occur during compaction of unconsolidated sediments or closing of fractures in shallow volcanic rocks. Slow changes (on the order of several days) in water level may reflect aseismic fault creep. The response of wells CH1, CH5, and SC-2 to earth tides and local seismic activity indicate that these wells can be used to detect small strain events and should be useful in detecting strain which would accompany rapid (on the order of weeks or less) igneous activity at depth.

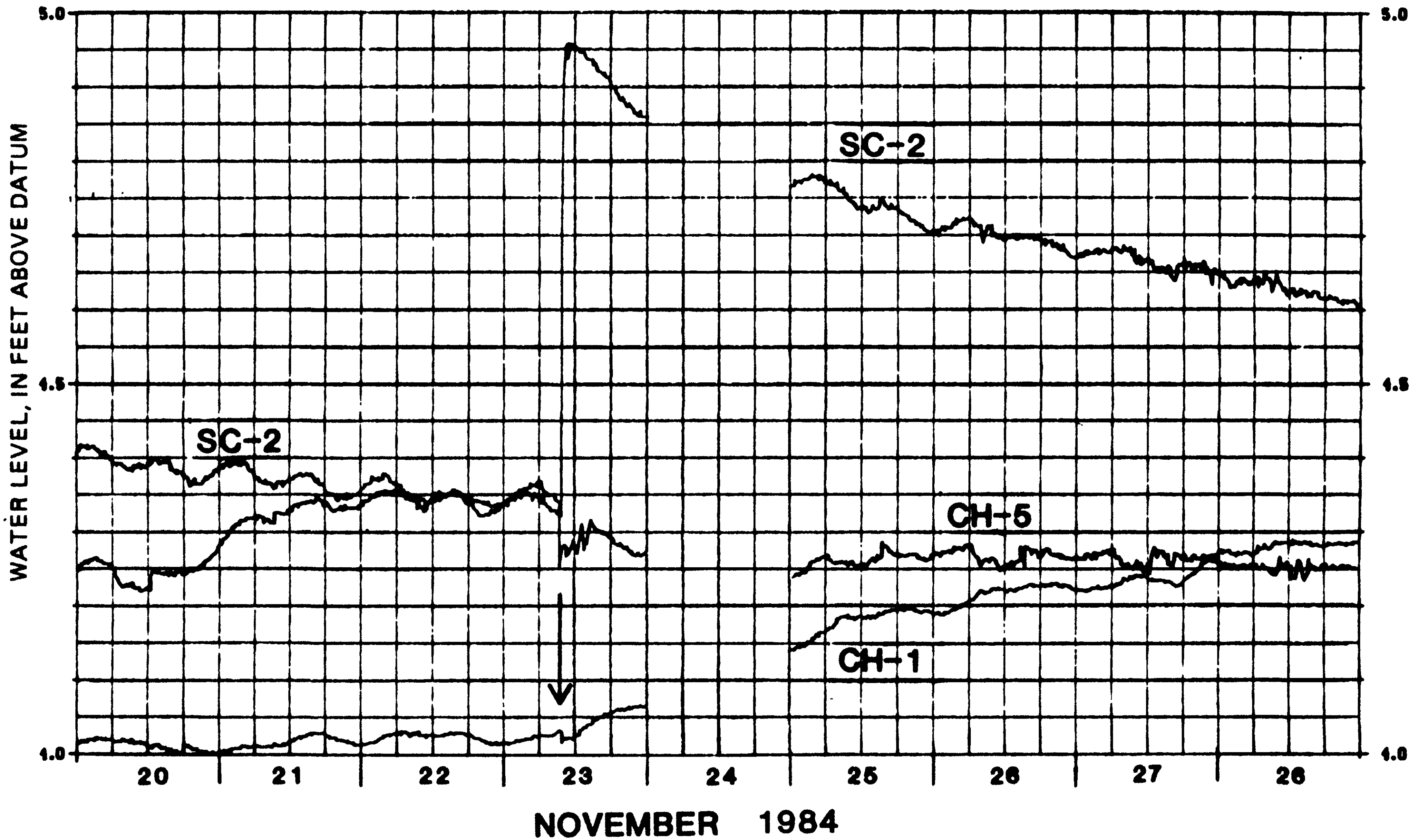


Figure 20. Filtered water-level records for wells SC-2, CH-1, and CH-5 during November 1984. Filtered water level represents the water level with effects of air pressure fluctuations removed. Data for November 24 lost due to computer operator failure. Arrow indicates the occurrence of a M_L 5.8 earthquake 25 mi. southeast of Mammoth Lakes on November 23, 1984. DATUM is altitude of transducer sensing element.

In the fall of 1984, water-level monitoring began at two deep core holes drilled within the west moat of the Long Valley caldera, PLV-1 and PLV-2 (pl. 1). These wells were completed with small-diameter steel tubing that was gun-perforated at depths of 1755 ft (in moat rhyolite) for PLV-1 and 1850 ft (in early rhyolite tuff) for PLV-2. The hydrograph at PLV-2 during the fall of 1984, shown in figure 21, contains many rapid rises, some of which can be related to local earthquakes. The water level dropped 9.0 ft over the period of monitoring. The effects of air pressure on water level are not removed from the record because the response of this well to long term (several days) cycles in air pressure apparently differs from the shorter term response. No hydrograph is shown for PLV-1 because its perforations apparently became clogged and its water level does not fluctuate significantly.

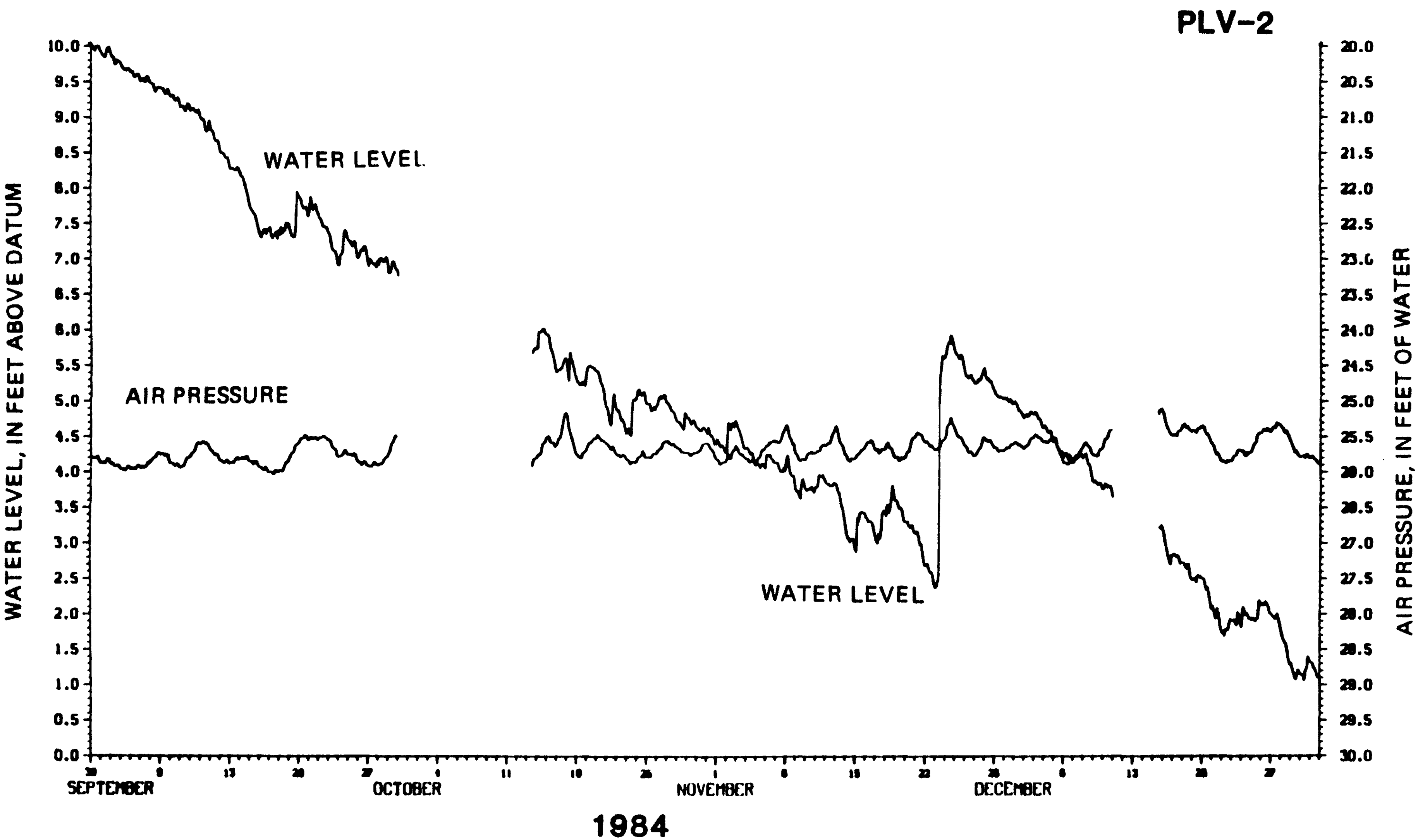


Figure 21. Water-level and barometric pressure records for well PLV-2 during 1984. Gaps represent periods of missing record due to equipment problems. Units of feet of water for barometric pressure apply to standard temperature and pressure. DATUM is altitude of transducer sensing element.

CHANGES IN TEMPERATURE PROFILES IN WELLS

Equilibrium temperature-depth profiles have been recorded on more than one occasion at 14 sites in wells ranging in depth from 150 ft to 6970 ft. At 10 of these sites, temperature profiles were recorded both before and after May 1980. These data, along with temperature measurements in 9 other wells drilled after 1978, provide information on the hydrothermal system in Long Valley caldera not discussed in earlier reports.

Equipment and Well Construction

Temperature profiles were obtained for the most part from measurements of the resistance of glass-bead or platinum-wire thermistors as a function of depth. Resistance values were converted to temperature using calibration data obtained for the glass-bead probes under laboratory conditions by R. J. Munroe (U.S. Geological Survey, Menlo Park, California), and calibration data supplied by the manufacture for the platinum-wire thermistors. In general, profiles for relatively shallow wells were determined from discrete-point measurements of resistance made with portable equipment, whereas profiles for deeper wells were determined using continuously recording systems. Temperature data for wells CP on 8-30-79, M-1 on 8-29-79, MBP-1,2,4,5 on 12-15-83, PLV-1 on 10-26-82, and PLV-2 on 1-3-82 and 1-21-82 were obtained from discrete-point measurements using clock-driven Kuster gauges. All data were collected by

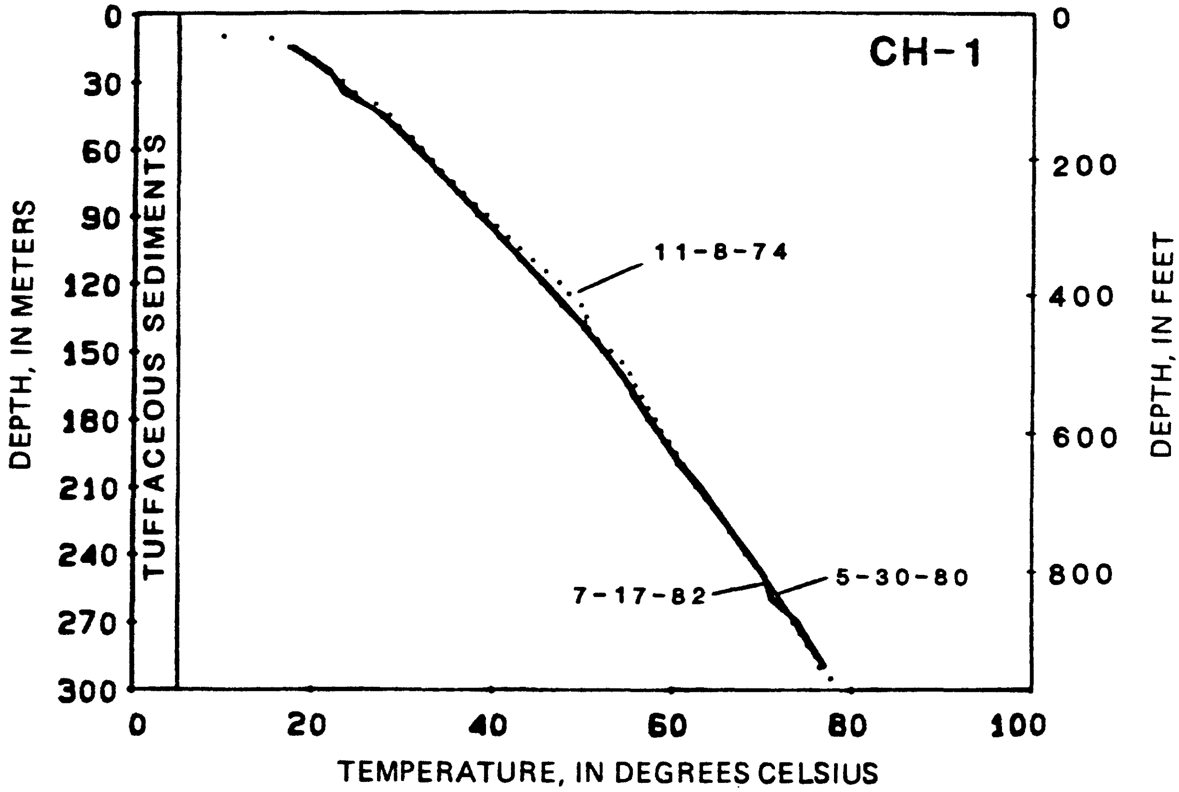
Geological Survey personnel, unless otherwise indicated.

In most cases, the temperature profiles were measured at times such that disturbances due to drilling should be minimal. Exceptions include profiles for wells CP on 8-30-79 (45 days after completion), M-1 on 8-29-79 (2 days after completion), PLV-1 on 10-26-82 (6 days after completion), PLV-2 on 10-3-82 and 10-21-82 (0 and 18 days, respectively, after completion), and RG on 6-10-76 and 6-13-76 (1 and 4 days, respectively, after completion). Completion dates and Township/Range locations for each well are listed in table 5.

Methods used to complete these wells included (a) installation of casing to total depth with a cemented annulus to total depth, (b) installation of tubing or slotted liner to total depth with no cement below surface casing(s), and (c) installation of surface casing with open-hole conditions below to total depth. Method (a) was used to complete the USGS heat-flow holes (DC, DP, and holes labled CH, except for CH-10A and CH-10B and well CM-2). Method (b) was used to complete wells CP, M-1, MBP-1,2,4,5, PLV-1, PLV-2, RM, and SS-2. Method (c) was used on wells CW, END-2, and RG. Details of construction for wells SC-2, CH-10A, and CH-10B, drilled in 1983, are shown in figure 13.

Data and Discussion

Temperature profiles of individual wells and plots comparing different well combinations are shown in figures 22-38. The level of detail shown on each plotted profile is dependent on



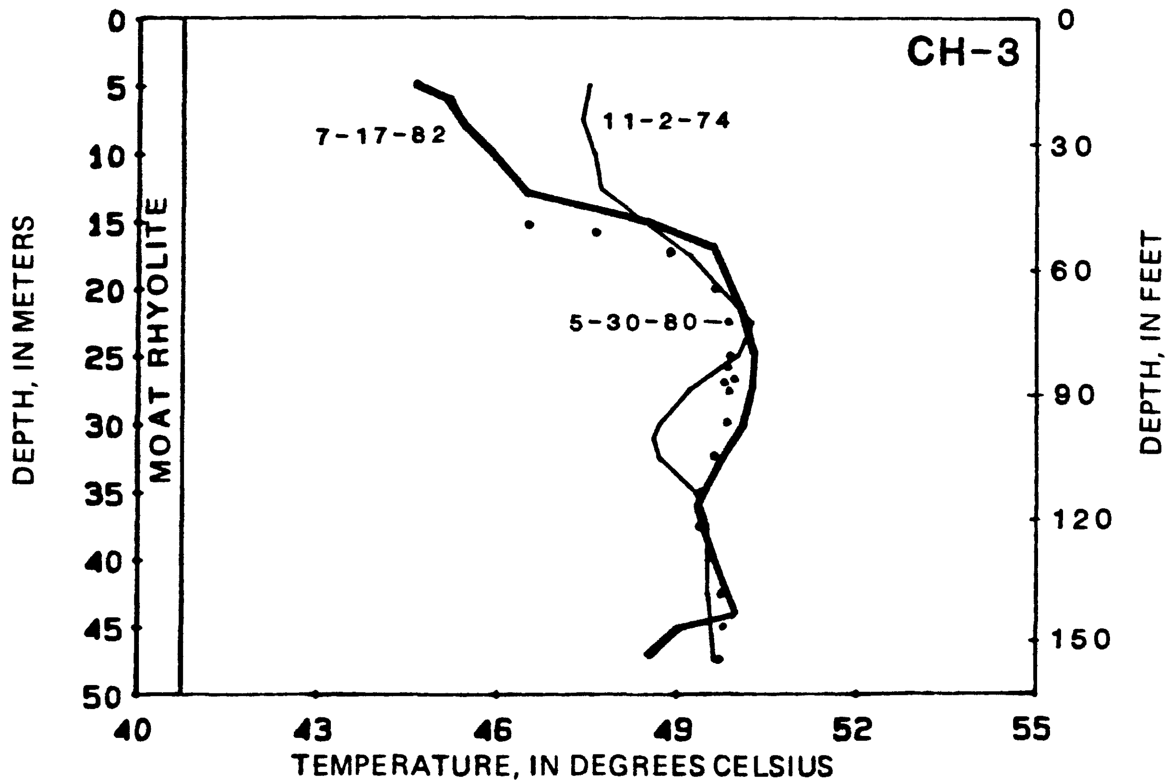


Figure 22. Temperature profiles and lithology for wells CH-1 and CH-3.

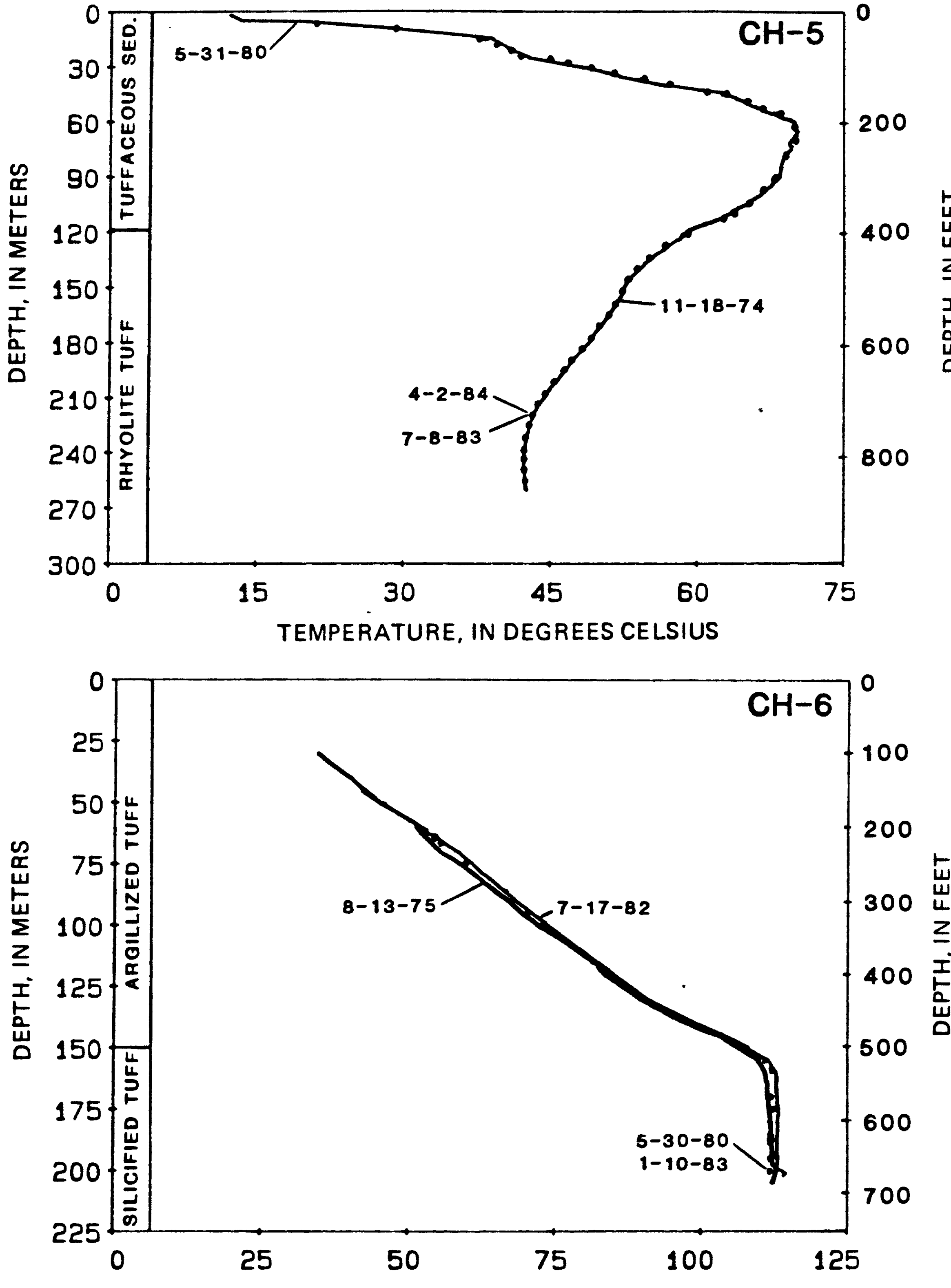


Figure 23. Temperature profiles and lithology for wells CH-5 and CH-6.

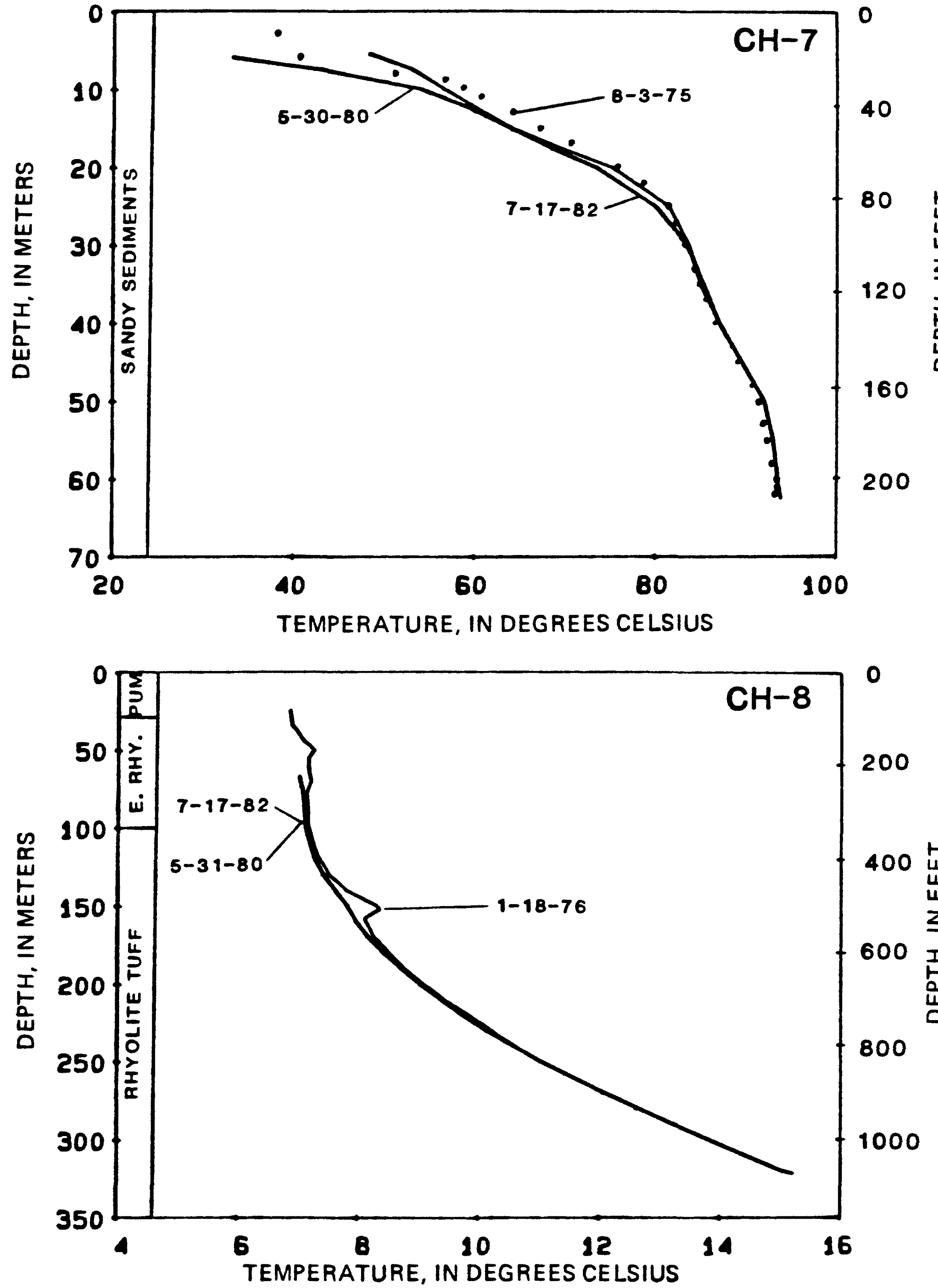


Figure 24. Temperature profiles and lithology in wells CH-7 and CH-8. E.RHY. stands for Early Rhyolite of the resurgent dome. PUM stands for pumice.

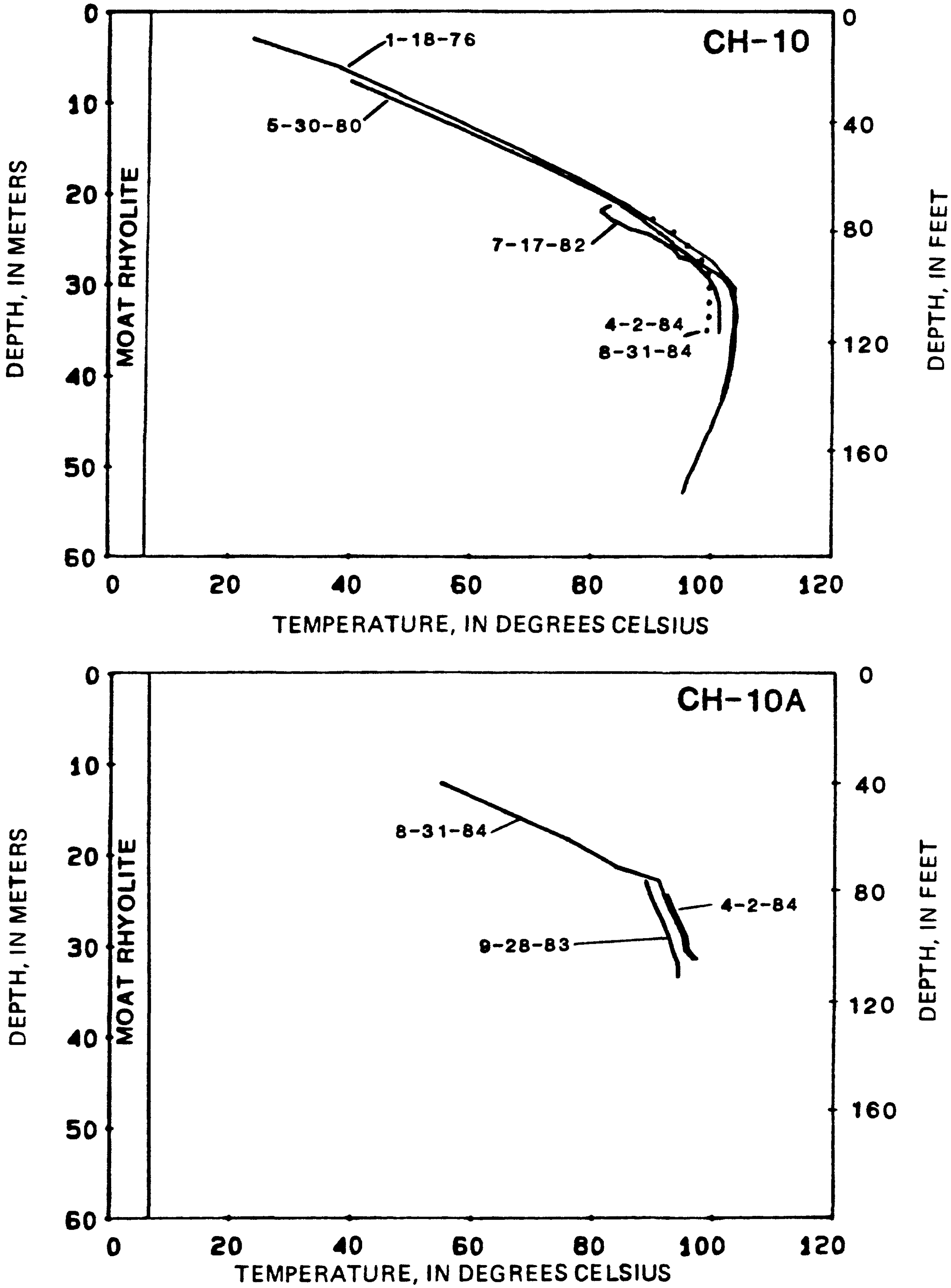


Figure 25. Temperature profiles and lithology for wells CH-10 and CH-10A.

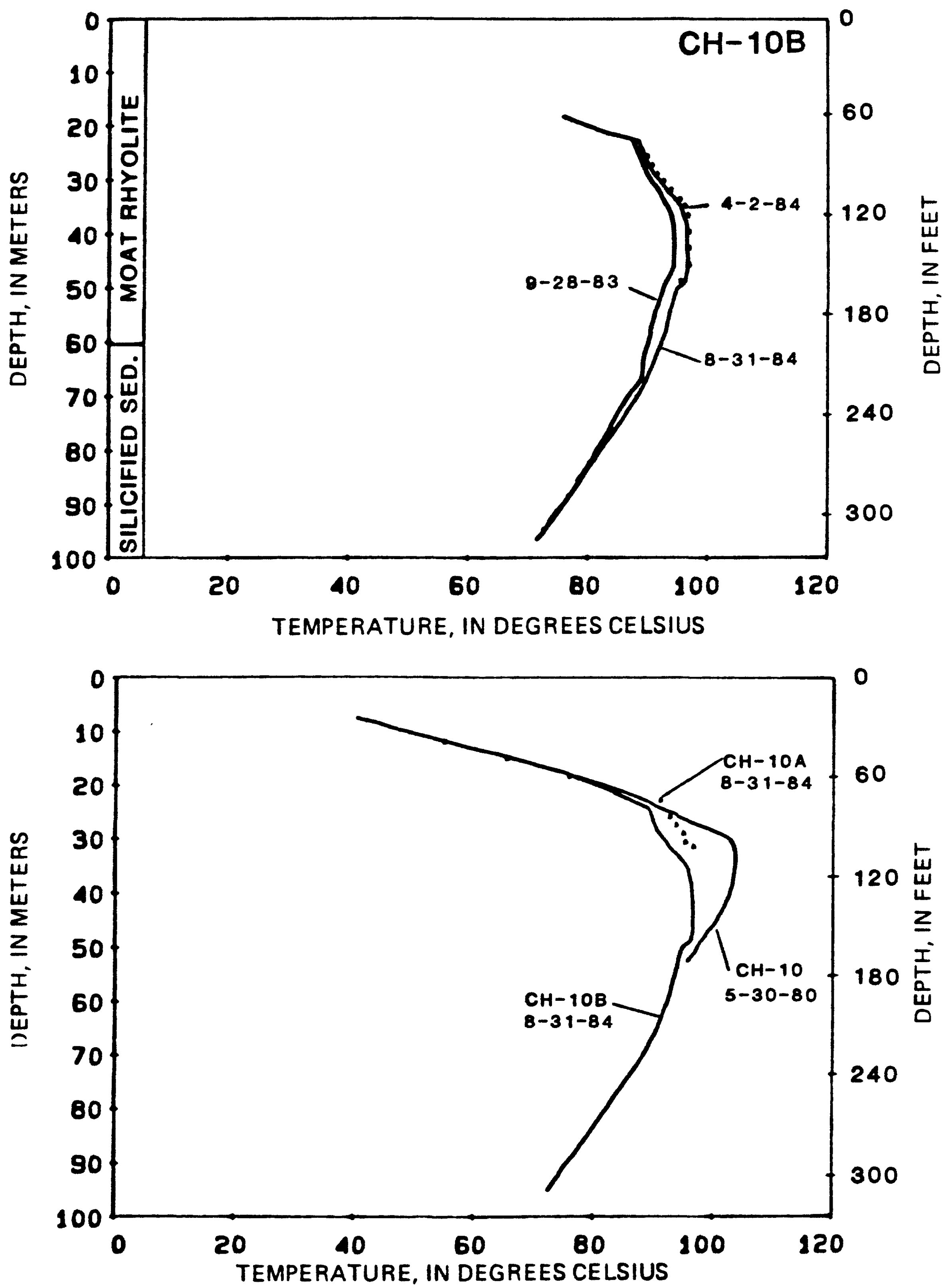


Figure 26. Temperature profiles and lithology for well CH-10B and comparison of recent temperature profiles in CH-10, CH-10A, and CH-10B.

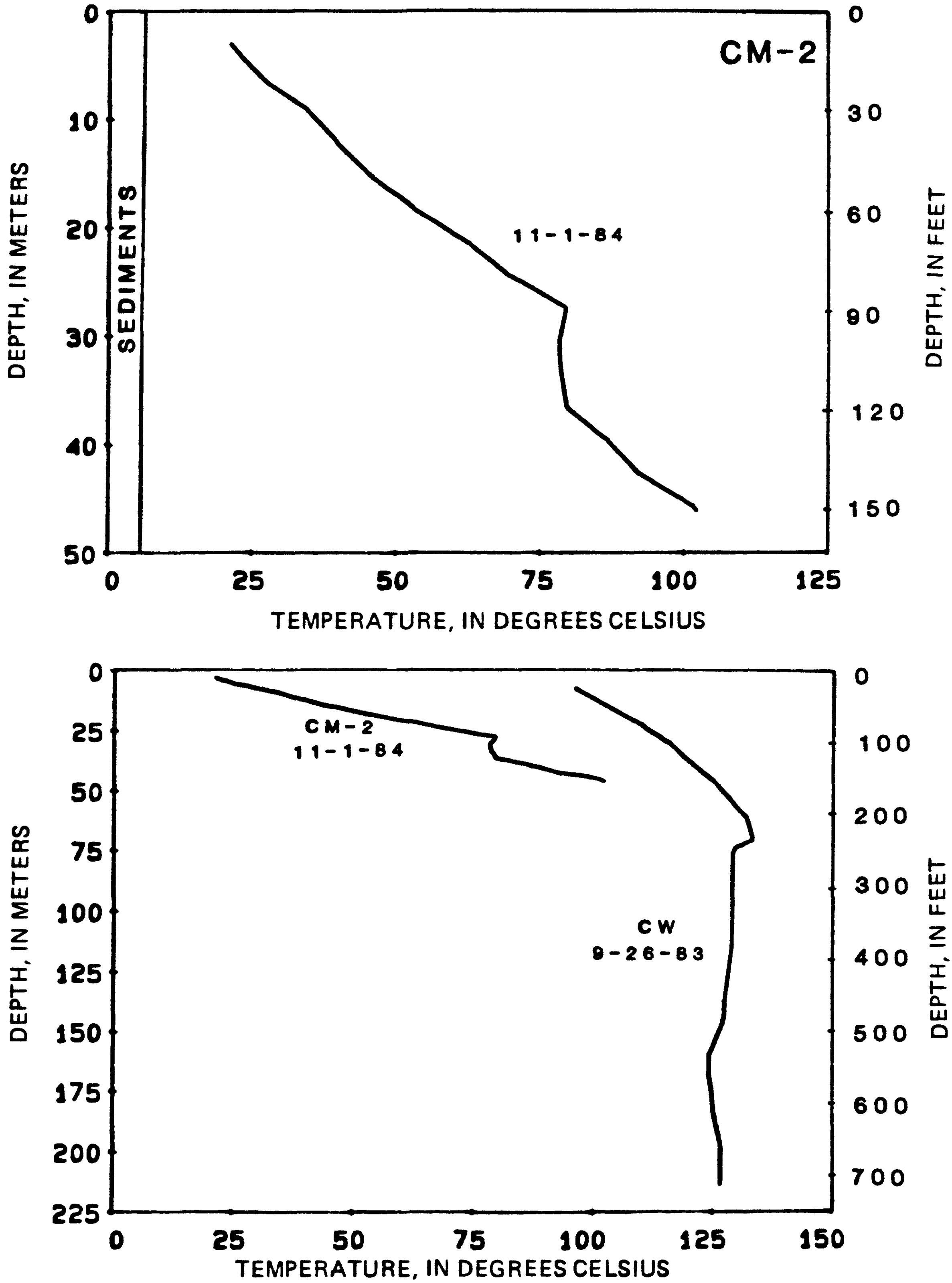


Figure 27. Temperature profile and lithology in well CM-2 and comparison of recent temperature profiles in wells CM-2 and CW.

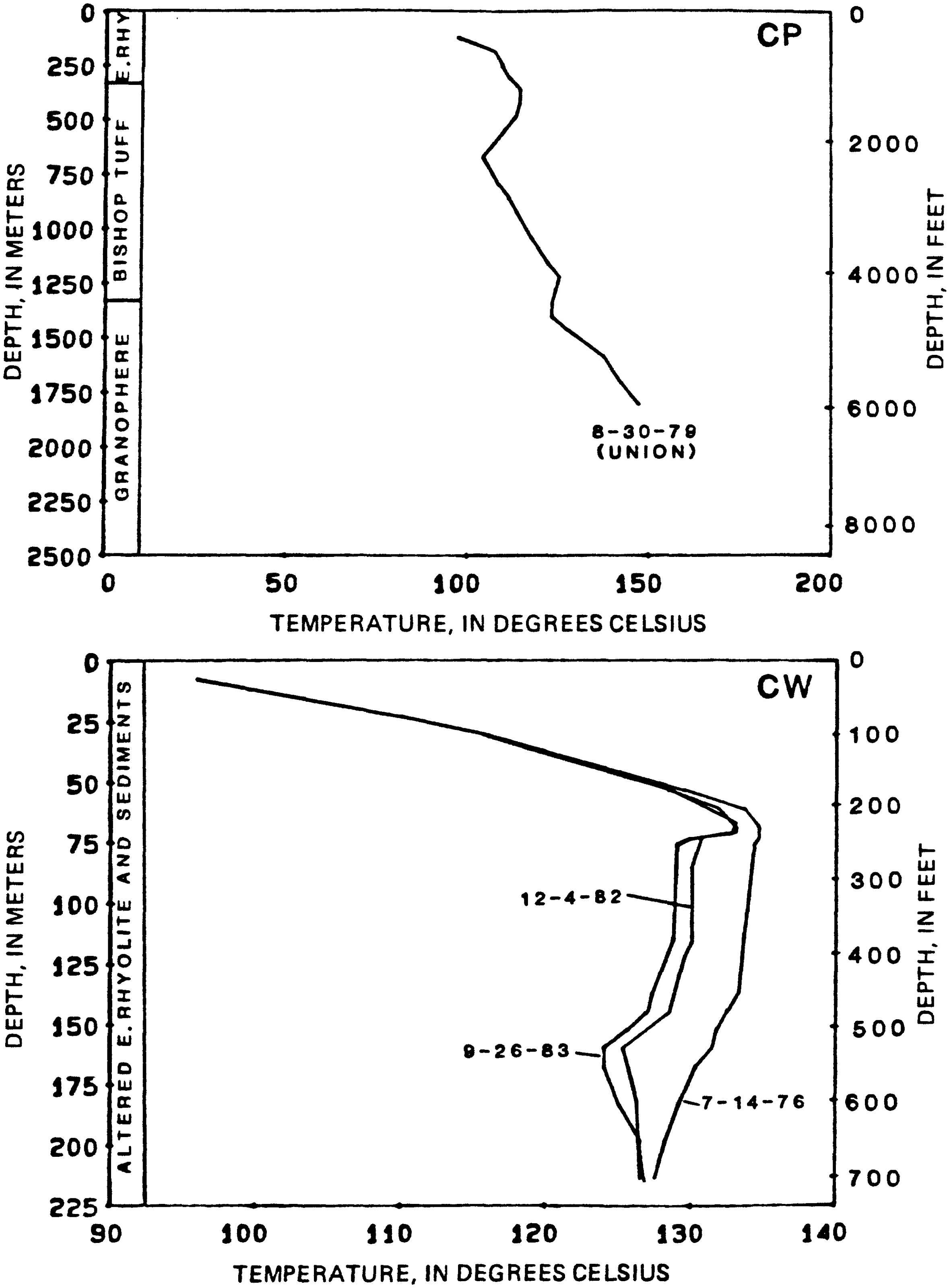


Figure 28. Temperature profiles and lithology for wells CP and CW. GRANOPHERE represents the intrusive equivalent of rocks of the moat rhyolite of the resurgent dome. E.RHY stands for Early Rhyolite.

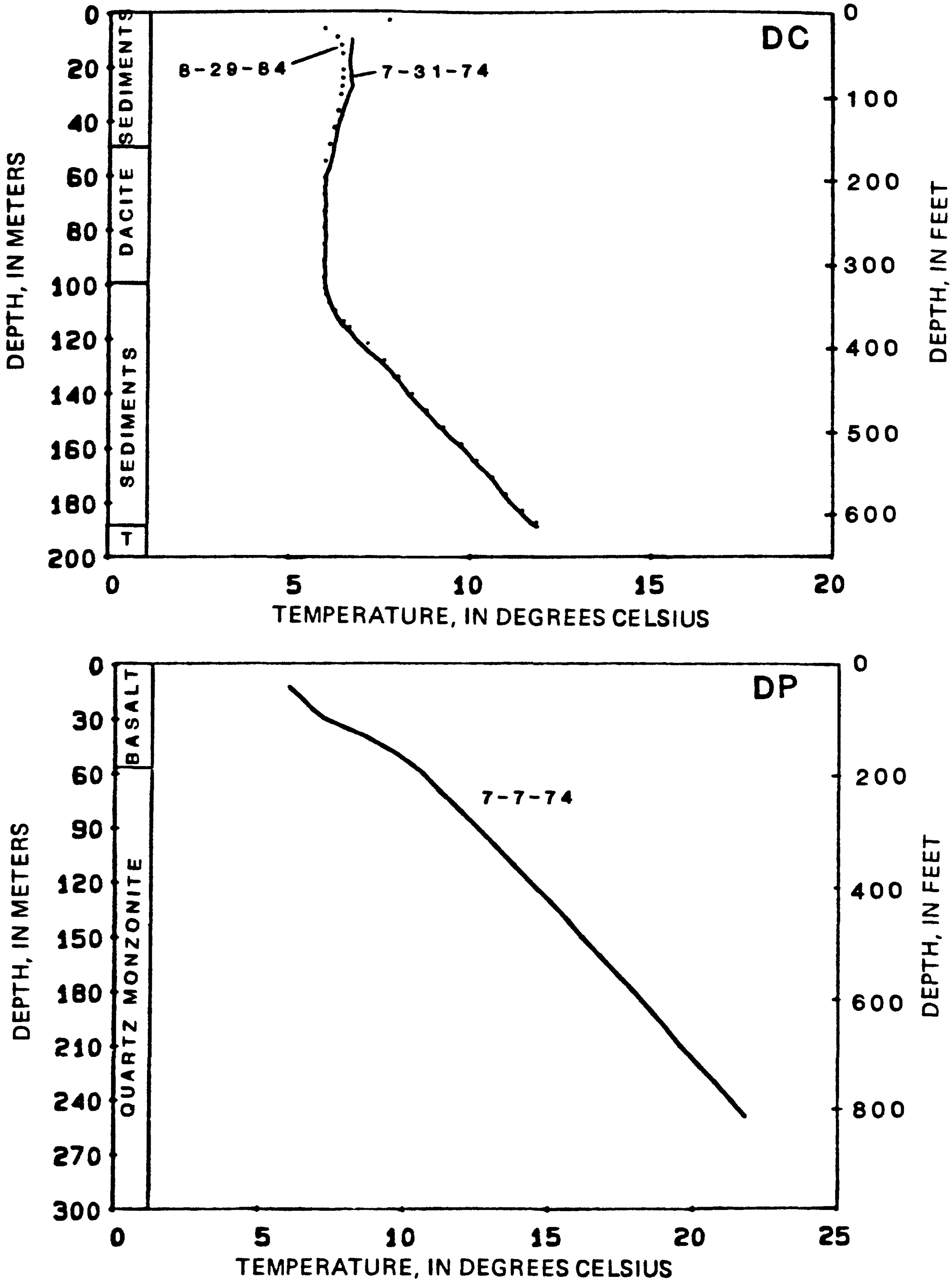


Figure 29. Temperature profiles and lithology for wells DC and DP. T stands for tuff, DACITE represents rocks similiar in composition to the rhyodacite of Mammoth Mountain.

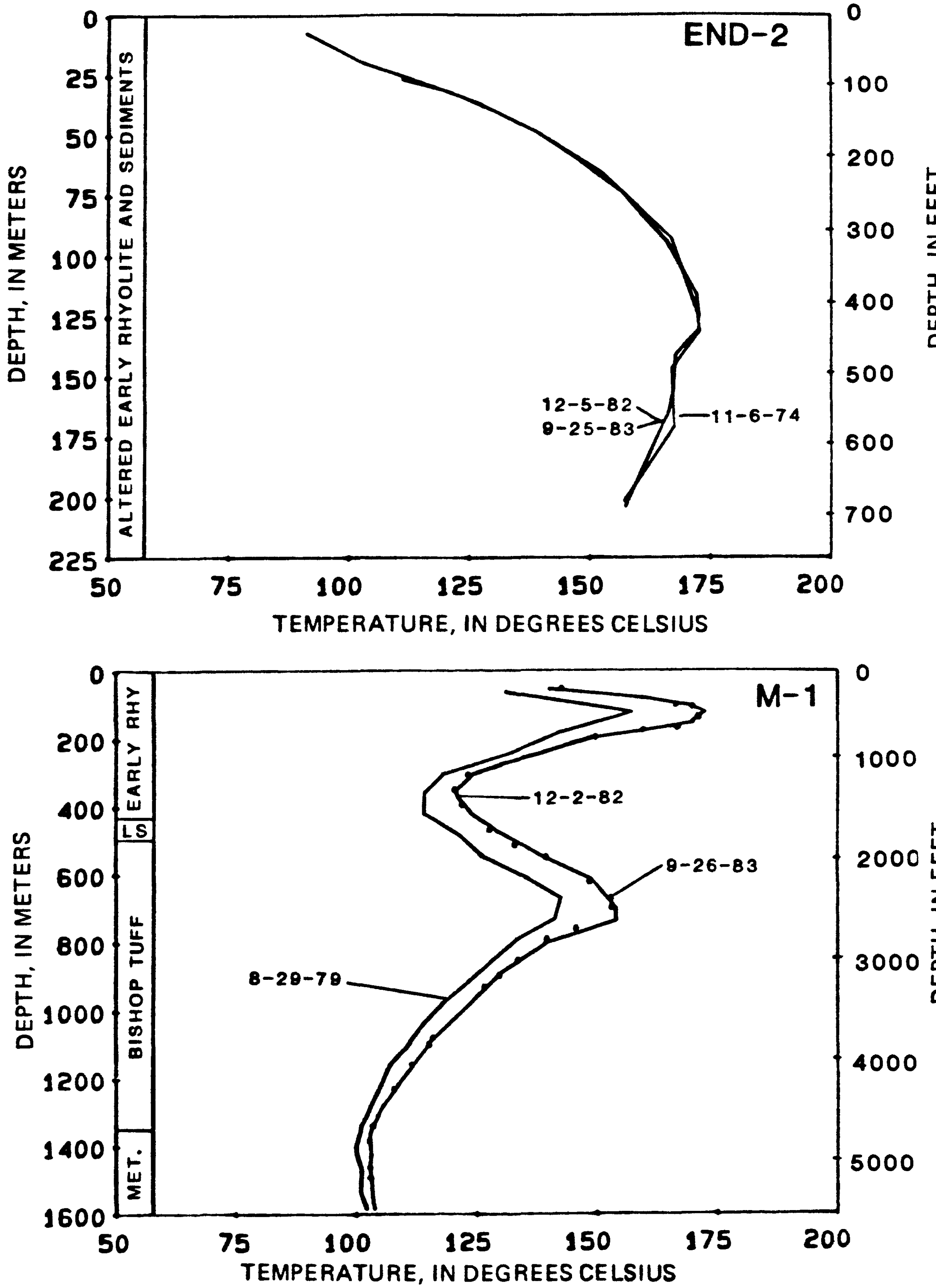


Figure 30. Temperature profiles and lithology for wells END-2 and M-1. LS stands for landslide block (granodiorite). MET stands for metasedimentary rocks of the Sierran roof pendant.

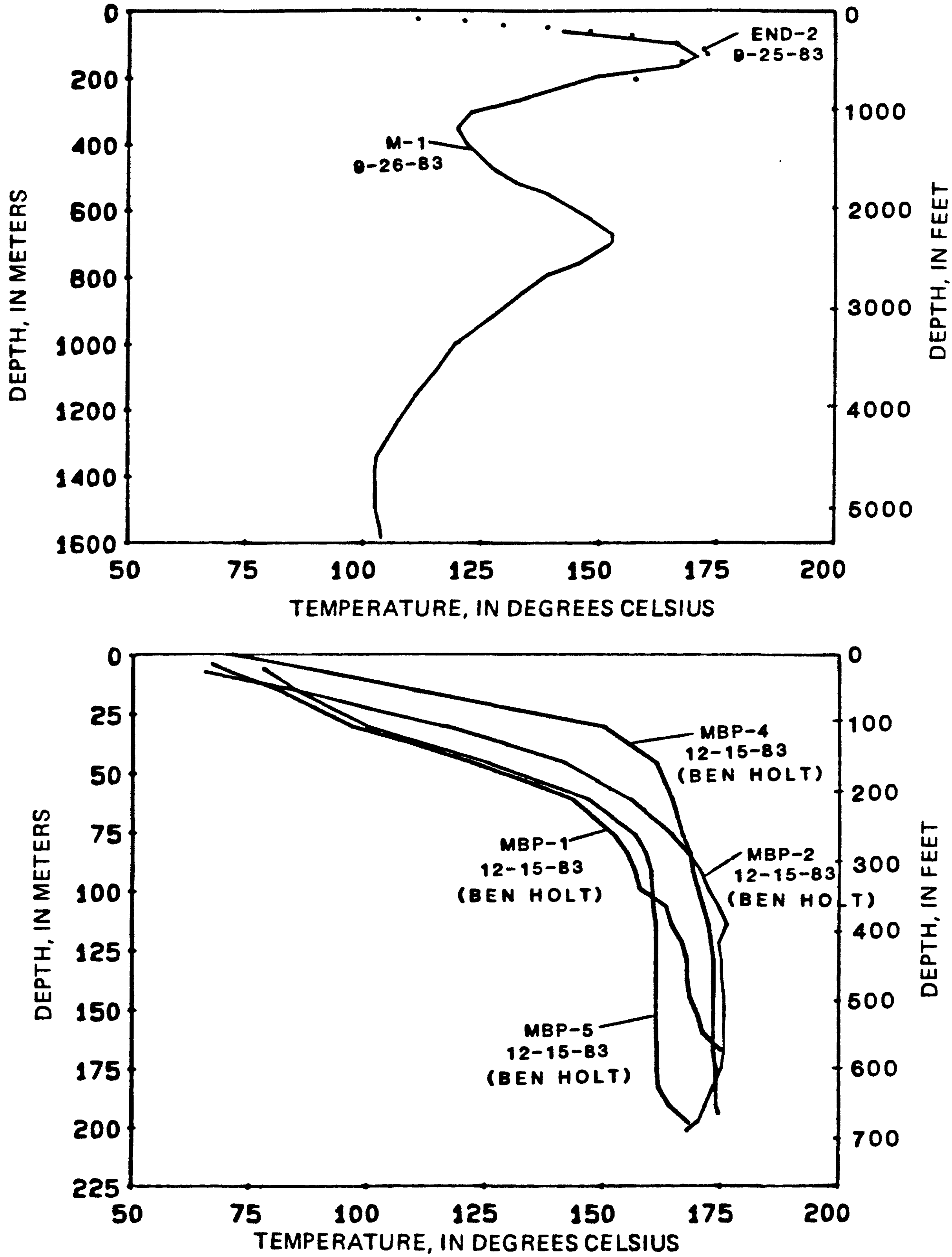


Figure 31. Comparisons of recent temperature profiles in wells End-2 and M-1, and profiles in wells MBP-1,2,4, and 5 run shortly ater completion.

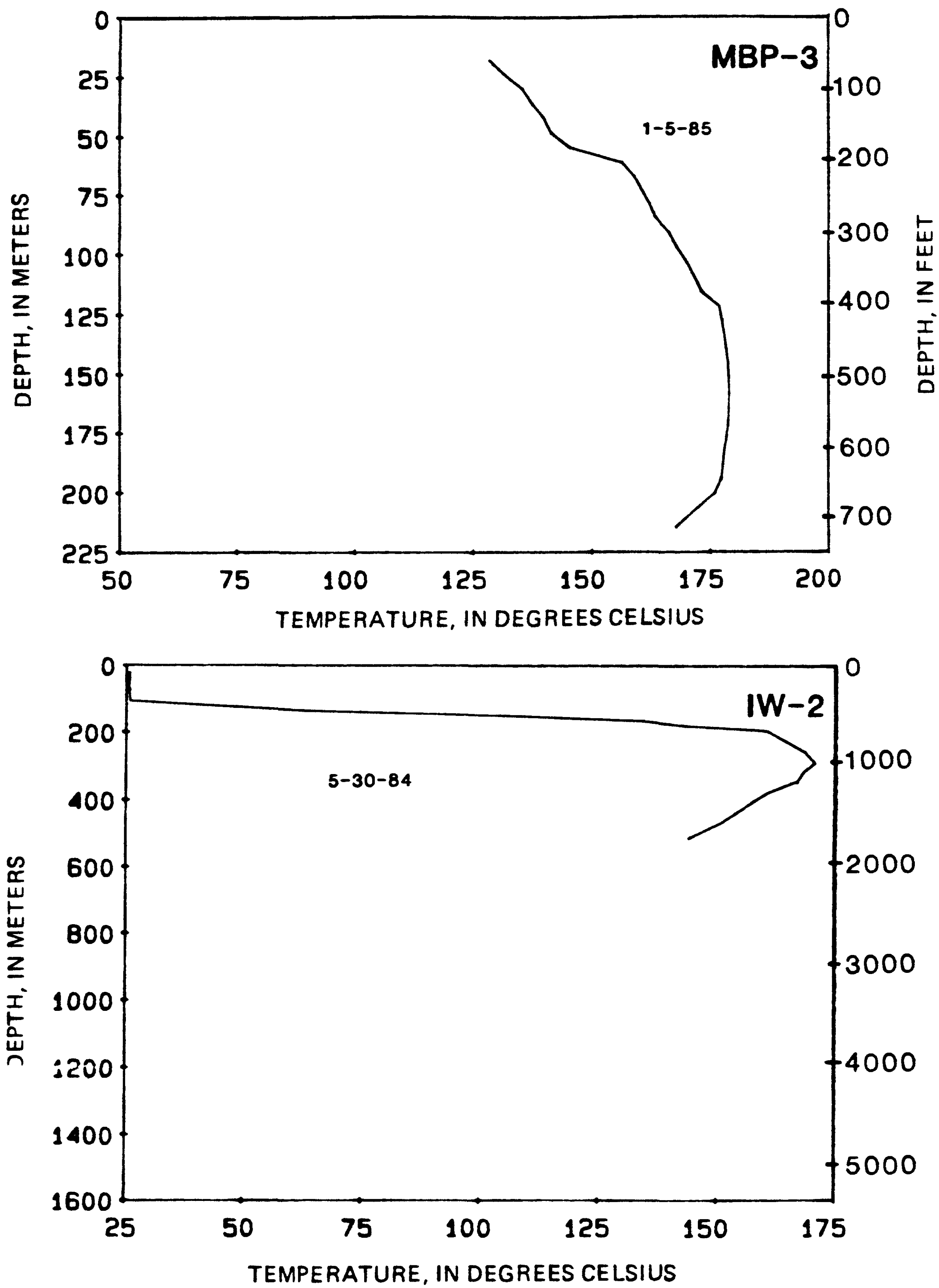


Figure 32. Temperature profiles for wells MBP-3 and IW-2.

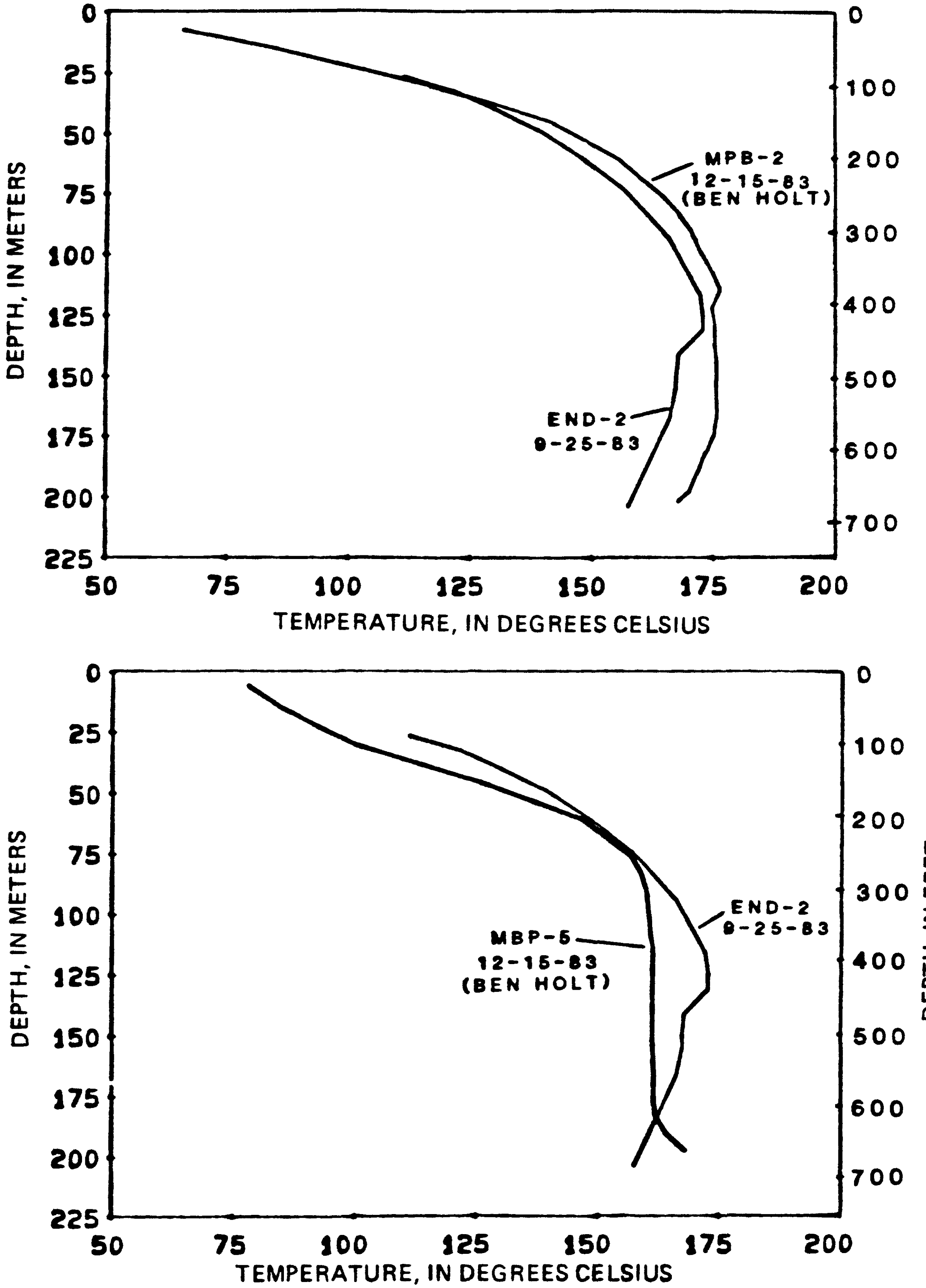


Figure 33. Comparisons of recent temperature profiles run in wells End-2, MBP-2, and MBP-5.

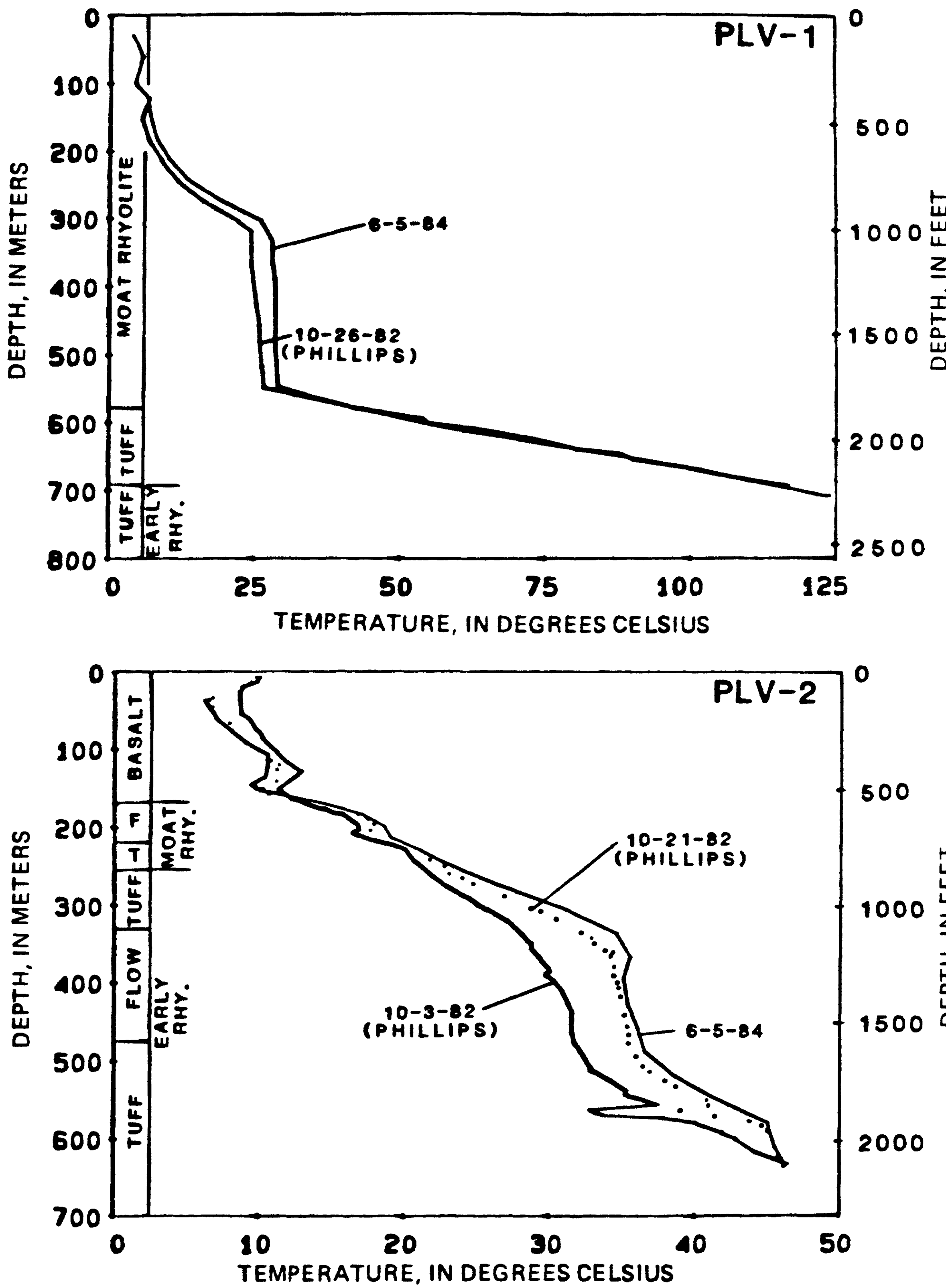


Figure 34. Temperature profiles and lithology for wells PLV-1 and PLV-2. F stands for flow and T for tuff in moat rhyolite rocks encountered in PLV-2.

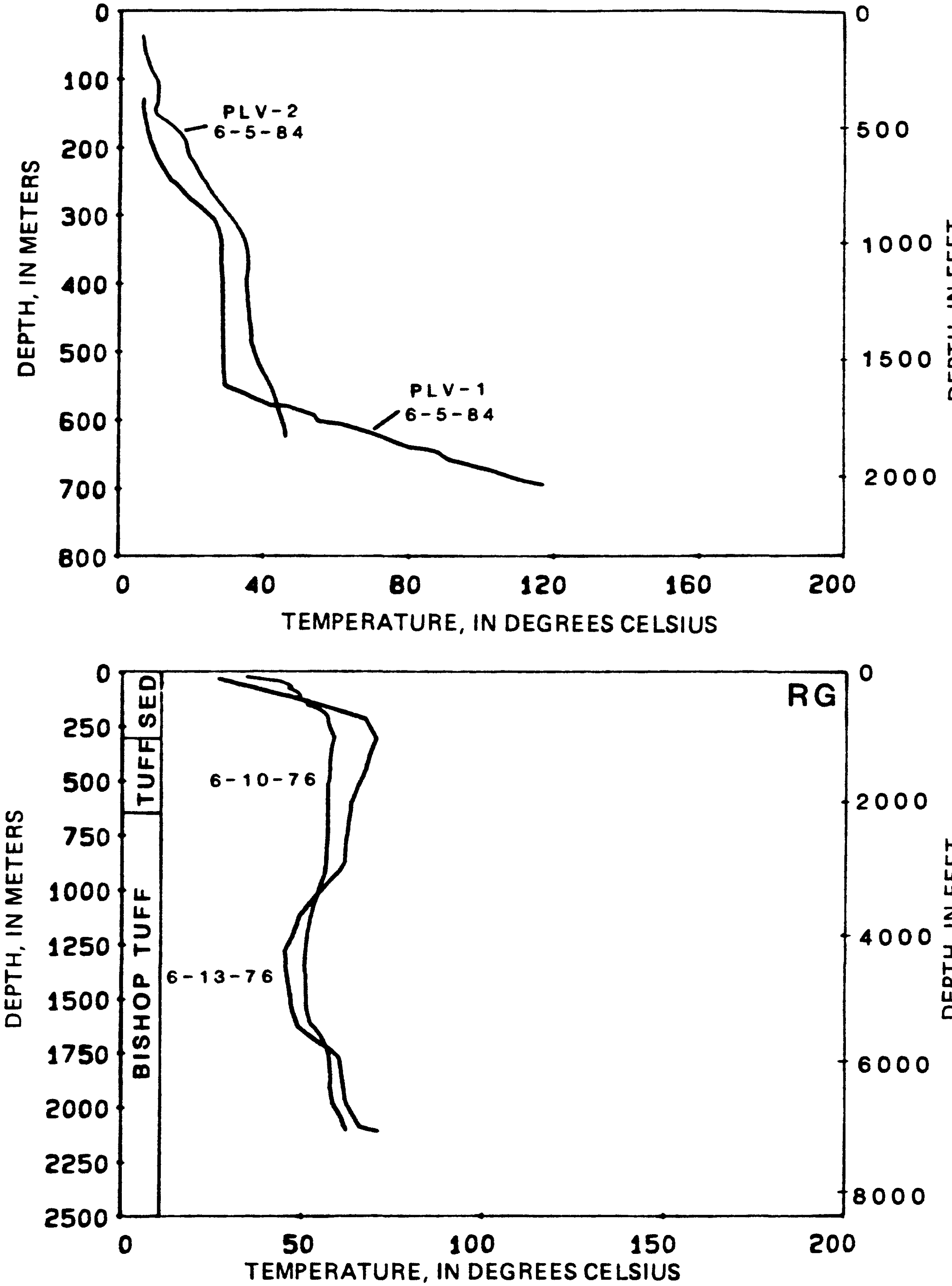


Figure 35. Comparison of the latest temperature profiles run in wells PLV-1 and PLV-2 and temperature profiles and lithology in well RG. SED. stands for lakebed sediments.

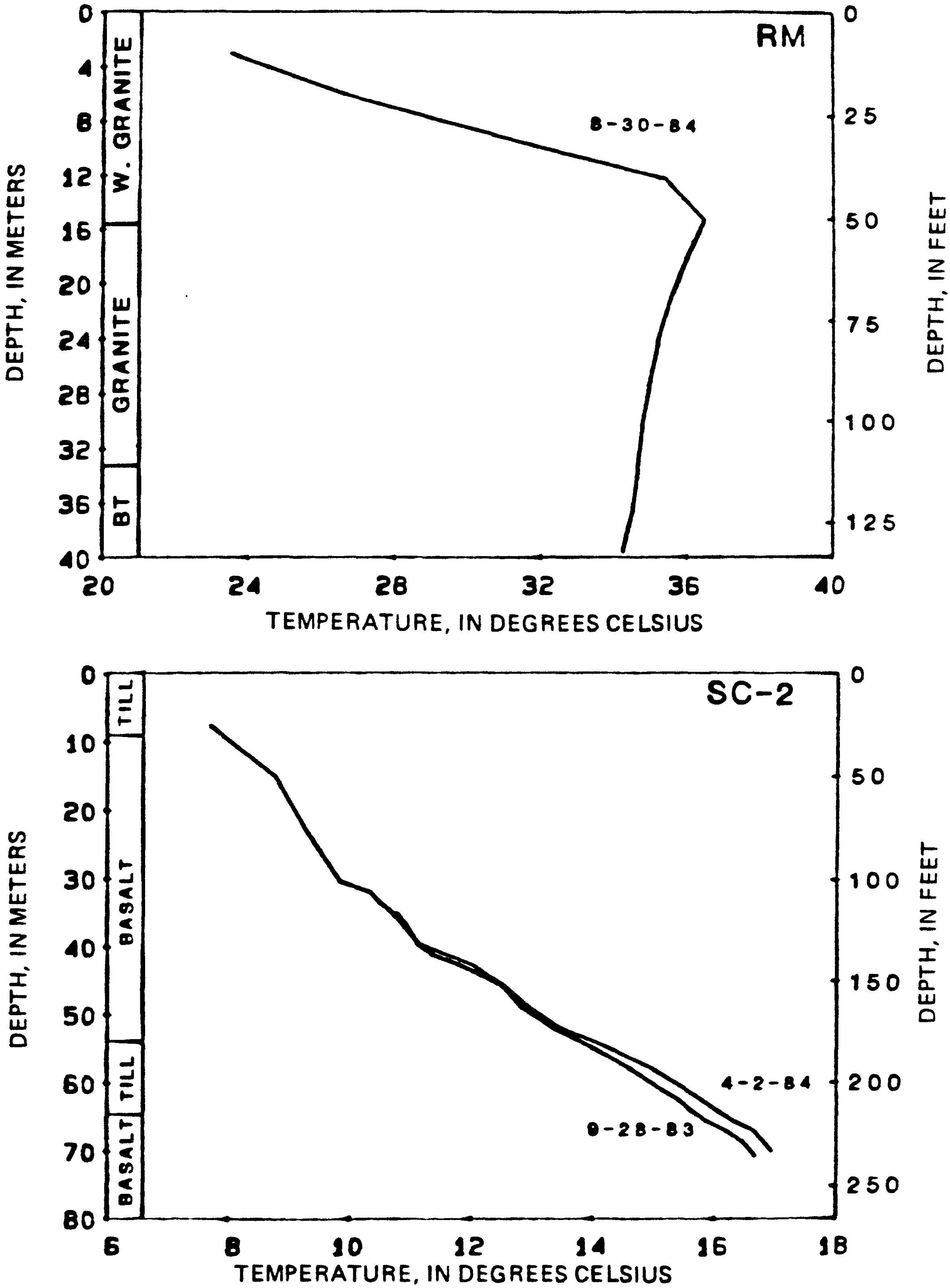


Figure 36. Temperature profiles and lithology in wells RM and SC-2.

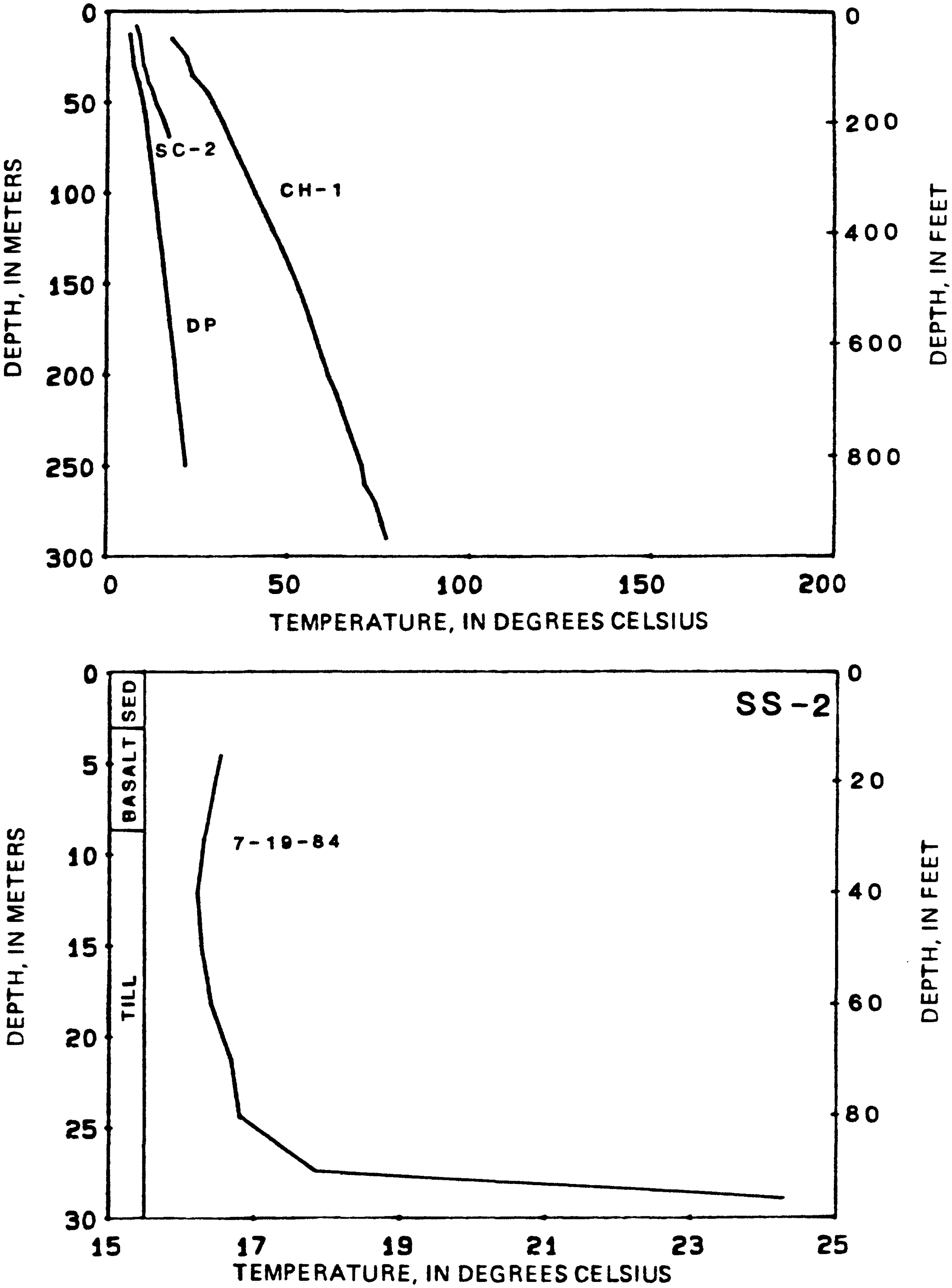


Figure 37. Comparison of the latest temperature profiles run in wells SC-2, DP, and CH-1, and temperature profiles and lithology in well SS-2.

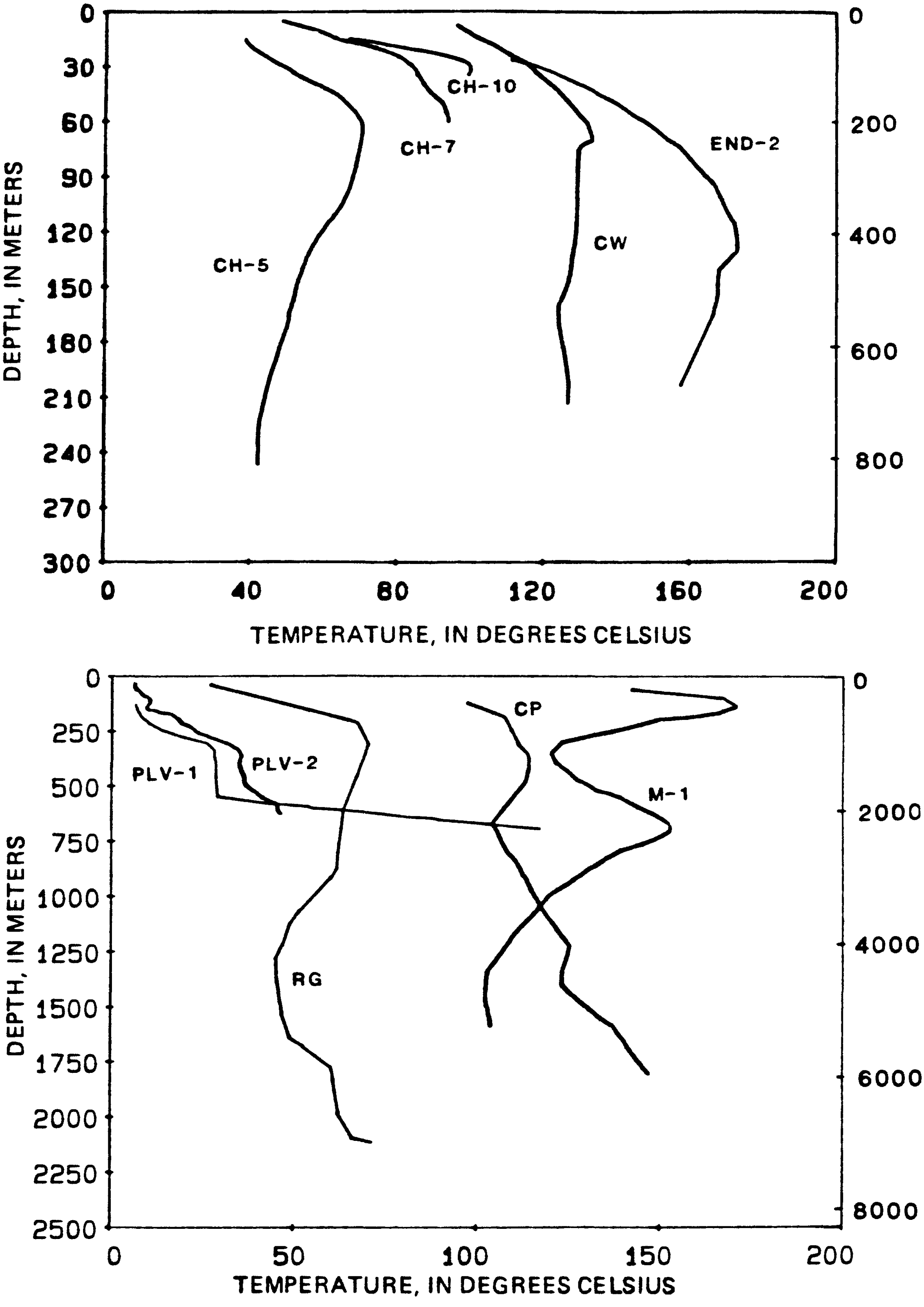


Figure 38. Comparison of the latest temperature profiles run in shallow wells located around the south side of the resurgent dome (top) and deep wells in various parts of the caldera (bottom).

whether it is based on discrete-point field measurements (for example, profiles for well SC-2, fig. 36) or on data digitized manually from plots of continuously recorded field measurements (for example, profiles for well CW, fig. 38). In cases where individual profiles within a set of profiles on the same graph could not be distinguished, the data points are left unconnected, as for the temperature profile for well M-1 on 9-26-83 (fig. 30).

In general, temperature differences between profiles run at different times in the same well are not significant, provided that sufficient time had elapsed for effects of drilling to have dissipated (roughly 10 times the drilling period). In cases where significant temperature differences are observed at relatively shallow depths, as for wells CH-3, CH-7, CH-10, and DC (figs. 22, 24, 25, and 29), such differences are probably caused by seasonal hydrologic processes. For wells CH-1, CH-5, CH-7 (below 100 ft), and END-2 (figs. 22, 23, 24, and 30), temperature profiles run before and after May 1980 are essentially identical. For wells CH-8 and M-1 (figs. 24 and 30) profiles run after 1980 are identical whereas the pre-1980 profiles show effects of drilling disturbances.

The data for wells CH-6 (in Little Antelope Valley, fig. 23) and CW (near Hot Bubbling Pool, fig. 28) do show significant temperature differences between profiles run before and after May 1980. In well CW there is a consistent decrease in temperature with time below the depth of casing at 230 ft. These changes and the shapes of the temperature profiles in this well indicate that cooler water is flowing up the uncased section of the bore hole from a depth of 520 ft and exiting just below the casing. The rate of upflow may have been enhanced by rock deformation accompanying seismic activity. Profiles in well CH-6 show differences of a few degrees within the nearly isothermal zone below a depth of 500 ft. In this case there is no consistent trend with time, and differences of similar magnitude are also found at shallower depths.

Although the available temperature profile data show little evidence of ongoing magmatic or tectonic processes, they do provide considerable information that can be used to delineate zones of thermal water flow within the hydrothermal system in Long Valley caldera. Temperature profiles in wells located around the south and east sides of the resurgent dome (for example, fig. 38) show steep temperature gradients and temperature reversals caused by lateral flow of thermal and nonthermal water. The data for these wells show a consistent trend of decreasing temperature within the zone or zones of thermal water flow between depths of 100 to 500 ft that suggests a general eastwardly direction to this flow from Casa Diablo toward Lake Crowley. These temperature data, along with chemical analyses of waters from shallow wells and hot springs in this area (table 1), indicates that hot spring waters discharging around the south and east sides of the resurgent dome are derived from localized upflow from these shallow lateral flow zones.

At somewhat greater depths, the temperature profile in well M-1 (figs. 30 and 38) at Casa Diablo indicates that there are additional zones of lateral flow of thermal and nonthermal water within the Bishop Tuff. The degree of continuity of these deeper flow zones east and west of Casa Diablo cannot be adequately delineated with the temperature data currently available. However, the temperature profile in well PLV-1 (figs. 33 and 38) shows evidence that the thermal reservoir within the Bishop Tuff does extend under parts of the west moat. Such evidence, along with calculations based on geochemical geothermometry applied to the hot spring waters, fits the model proposed by Sorey (1984, 1985) for circulation within the present-day hydrothermal system in Long Valley caldera. This model involves recharge along the caldera ring fracture in the west moat and heat input from recent intrusive bodies to produce a reservoir at about 240°C in the Bishop Tuff, through which water moves eastward toward the resurgent dome. Part of this flow apparently moves upward along fault conduits located at or west of Casa Diablo to supply thermal water at temperatures near 175°C to the shallow thermal reservoir(s) that extend from Casa Diablo eastward to Lake Crowley.

SUMMARY

This report contains data collected through 1984 in a hydrologic monitoring program conducted by the U.S. Geological Survey in the Long Valley caldera. Principal elements of the monitoring program include measurements of ground-water levels in wells, discharge rates of hot springs, and temperature profiles in wells, as well as the collection of water samples from springs and streams for chemical and isotopic analyses. In addition, the report contains data on chemical and isotopic analyses of gases from hot springs and fumaroles.

The goal of the monitoring program is to detect changes in the caldera's hydrothermal system caused by ongoing crustal processes such as magmatic intrusions and tectonic strain. Interpretations of changes observed in the hydrologic and chemical parameters being monitored are limited to some extent by the short period of detailed record (1982-84), by errors in the chemical and isotopic results reported by different laboratories, and by variations caused by sampling different discharge features within each thermal area. Therefore, the results discussed here should be regarded as a progress report.

A general pattern of increased discharge of hot springs and fumaroles was established by the summer of 1982, following the initiation of increased levels of seismicity in the Long Valley area in May 1980. Discharge measurements at or near several hot spring areas show temporary coseismic increases in spring flow

associated with earthquakes of relatively large magnitude (>M_L5) and close proximity. Although analysis of the spring discharge records is still in progress, there does not appear to be any evidence of precussary changes caused by magmatic intrusions that may have accompanied intra-caldera earthquakes in January 1983.

No changes in spring chemistry or isotopic content can be attributed directly to deep-seated crustal processes. Changes that have been recorded probably relate to near-surface variations in quantities of upflowing liquid and gas. The spring data along with temperature profiles in wells indicate that hot springs and fumaroles that discharge around the south and east sides of the resurgent dome are fed by upflow along fault conduits from relatively shallow hot-water aquifers in which water is moving from west to east. In contrast, values of helium and carbon isotopic ratios in hot spring and fumarolic gases show evidence of mantle or magmatic components in surficial discharges; and in the case of ratios of $^3He/^4He$, changes between 1978 and 1983 at Hot Creek gorge suggest an increase in helium derived from a recent magmatic intrusion.

Measurements of water levels in shallow wells were used to construct a water-table contour map and to delineate seasonal fluctuations in water level ranging from less than 1 ft to 20 ft. Continuous water-level measurements in selected wells during 1984 show diurnal fluctuations due to barometric pressure fluctuations and earth tides and coseismic water-level fluctuations of as much as 0.6 ft. However, additional water-level record in deeper wells that show less seasonal variation and greater response to tidal strain will be required to adequately delineate rock strain associated with earthquakes and magmatic intrusions.

Temperature-depth measurements in wells made before and after May 1980 show little evidence of change with time, except at the Chance Well near Hot Bubbling Pool where inner borehole circulation may have been enhanced by seismic activity. Taken together, the well temperature data are useful in delineating zones of lateral flow of thermal water at relatively shallow depths that appear to be regionally continuous across the southern part of the caldera.

REFERENCES CITED

Barnes, I., Irwin, W.P., and White, D.E., 1978, Global distribution of carbon dioxide discharges, and major zones of seismicity: U.S. Geological Survey Water-Resources Investigation Report 78-39, 12 p.

Bailey, R.H., Dalrymple, G.B., and Lanphere, M.A., 1976, Volcanism, structure, and geochronology of Long Valley caldera, Mono County, California: Journal of Geophysical Research, v. 81, no. 5, p. 725-744.

Bailey, R.A., and Koeppen, R.P., 1977, Preliminary geologic map of Long Valley Caldera: U.S. Geological Survey Open-File Report 77-468.

Blackwell, D.D., 1984, A transient model of the geothermal system of the Long Valley caldera: U.S. Geological Survey Open-file Report 84-939, p. 659-707.

Blake, A.H., and Mathes, F.E., 1938, The new Casa Diablo geyser: Sierra Club Bulletin, v. 23, no. 2, p. 82-83.

Bodvarsson, G., 1970, Confined fluids as strain meters: Journal of Geophysical Research, v. 75, p. 2711-2718.

Bredehoeft, J. D., 1967 Well-aquifer systems and earth tides: Journal of Geophyscial Research, v. 72, p. 3075-3087.

Brown, E., Skougstad, M.W., and Fishman, M.J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques in Water-Resources Investigations, Bk. 5, Ch. A1, 160 p.

California Department of Water Resources, 1967, Investigation of geothermal waters in the Long Valley area, Mono County, 141 p.

----------------------, 1973, Mammoth basin water resources environmental study (final report), 70 p.

Craig, H., 1953, The geochemistry of the stable carbon isotopes: Geochimica et Cosmochemica Acta, v. 3, p. 53-92.

Craig, H., 1961, Standard for reporting concentrations of deuterium and oxygen-18 in natural waters: Science, v. 133, p. 1833.

D'Amore, F. and Panichi, C., 1980, Evaluation of deep temperatures of hydrothermal systems by a new gas geothermometer: Geochimica et Cosmochimica Acta, v. 44, p. 549-556.

Eccles, L.A., 1976, Sources of arsenic in streams tributary to Lake Crowley, California: U.S. Geological Survey Water-Resources Investigation Report 76-36, 39 p.

Eichelberger, J.C., Lysne, P.C., Miller, C.D., and Younker, L.W., 1985, Research drilling at Inyo Domes, California: 1984 results: EOS Transactions, American Geophysical Union, v. 66, no. 17, p. 186-187.

Faure, G., 1977: Principles of Isotope Geology: John Wiley and sons, New York, 464 p.

Fournier, R.O., Sorey, M.L., Mariner, R. H., and Truesdell, A.H., 1979, Chemical and isotopic prediction of aquifer temperatures in the geothermal system at Long Valley, California: Journal of Volcanology and Geothermal Research, v. 5, p. 17-34.

Friedman, I., and O'Neil, J.R., 1977, Compilation of stable isotope fractionation factors of geochemical interest; in Data of Geochemistry: U.S. Geological Survey Prof. Paper 440KK, 60 p.

Irwin, W.P., and Barnes, I., 1980, Tectonic relations of carbon dioxide discharges and earthquakes: Journal of Geophysical Research, v. 85, no. 6., p. 3115-3121.

Jacob, C. E., 1940, The flow of water in an elastic artesian aquifer: Transactions of the American Geophysical Union, v. 2, p. 574-586.

Lee, W.T., 1906, Geology and water resources of Owens Valley, California, U.S. Geological Survey Water Supply Paper No. 181, 28 p.

Leroy Crandell and Associates, 1981, A review of available information on ground water conditions in Mammoth Valley: Consultants report to Mammoth County Water District May 14, 1981, 22 p.

------------------ 1984, Exploratory drilling in the vicinity of Mammoth Lakes, California: Consultants report to Mammoth County Water District, 53 p.

Lewis, R.E., 1974, Data on wells, springs, and thermal springs in Long Valley, Mono County, California: U.S. Geological Survey Open-File Report 52 p.

Mariner, R.H., and Willey, L.M., 1976, Geochemistry of thermal waters in Long Valley, Mono County, California: Journal of Geophysical Research, v. 81, no. 5, p. 792-800.

McGee, K.A., Sutton, A.J., Sato, M., and Casadeval, T.J., 1983, Correlation of hydrogen gas emissions and seismic activity at Long Valley caldera, California: EOS Transactions American Geophysical Union, v. 64, no. 45, p. 891.

McNitt, J.R., 1963, Exploration and development of geothermal power in California: California Div. of Mines and Geology Special Report 75, 45 p.

Miller, C.D., 1985, Holocene eruptions at the Inyo volcanic chain, California: Implications for possible eruptions in Long Valley caldera: Geology, v. 13, p. 14-17.

Miller, D.C., Mullineaux, D.R., Crandell, D.R., and Bailey, R.H., 1982, Potential hazards from future volcanic eruptions in the Long Valley - Mono Lake Area, east - central California and southwest Nevada - A preliminary assessment: U.S. Geological Survey Circular 877, 10 p.

Moore, J.G., Batchelder, J.N., and Cunningham, C.G., 1977, CO_2-filled vesicles in mid-ocean basalt: Journal of Geophysical Research, v. 2, p. 309-327.

Pineau, F., Javoy, M., and Bottinga, Y., 1976, $^{13}C/^{12}C$ ratios of rocks and inclusions in popping rocks of the Mid-Atlantic Ridge and their bearing on the problem of isotopic composition of deep-seated carbon: Earth and Planetary Science Letters, v. 29, p. 413-421.

Reed, Adele, 1982, Old Mammoth: Genny Smith Books, Palo Alto, Caifornia, 194 p.

Rison, W., Welhan, J.A., Poreda, R., and Craig, H., 1983, Long Valley: Increase in the $^{3}He/^{4}He$ ratio from 1978 to 1983: EOS Transactions American Geophysical Union, v. 64, no. 45, p. 891.

Russell, I.C., 1889, Quaternary history of Mono Valley, California: Eigth Annual Report of the U.S. Geological Survey, 1886-87, compiled by J.W. Powell, U.S. Geological Survey, Reston, Virginia, p. 261-394.

Savage, J.C., and Cockerham, R.S., 1984, Earthquake swarm in Long Valley caldera, California, January 1983: Evidence for dike inflation: Journal of Geophysical Research, v. 89, no. B10, p. 8315-8324.

Setmire, J.G., 1984, Water-quality appraisal of Mammoth Creek and Hot Creek, Mono County, California: U.S. Geological Survey Water-Resources Investigation Report, 84-4060, 50 p.

Sherburne, R.W., 1980, Mammoth Lakes, California earthquakes of May 1980: California Div. of Mines and Geology Special Report 150, 141 p.

Skougstad, M.W., Fishman, M.J., Friedman, LC., Erdmann, D.E., and Duncan, S.S., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey, Techniques of Water-Resources Investigations Bk. 5, ch. A1, 626 p.

Smith, G. I., 1976, Origin of lithium and other components in the Searles Lake evaporites, California; in Vine, J.D. ed., Lithium resources and requirements by the year 2000: U.S. Geological Survey Professional Paper 1005, p. 92-103.

Smith, G.S., ed., 1976, Mammoth Lakes Sierra: Genny Smith Books, Palo Alto, California, 148 p.

Sorey, M.L., Lewis, R.E., and Olmsted, F.H., 1978, The hydrothermal system of Long Valley Caldera, California: U.S. Geological Survey Professional Paper 1044-A, 60 p.

Sorey, M.L. and Lewis, R.E., 1976, Convective heat flow from hot springs in the Long Valley caldera, Mono County, California: Journal of Geophysical Research, v. 81, no. 5, p. 785-791.

Sorey, M.L. and Clark, M.D., 1981, Changes in the discharge characteristics of thermal springs and fumaroles in the Long Valley caldera, California, resulting from earthquakes on May 25-27, 1980: U.S. Geological Survey Open-File Report 81-203, 22 p.

Sorey, M.L., 1975, Potential effects of geothermal development on springs at the Hot Creek Fish Hatchery in Long Valley, Mono County, California: U.S. Geological Survey Open-File Report 75-637, 10 p.

Sorey, M.L., 1984, Evolution and present state of the hydrothermal system in Long Valley caldera: U.S. Geological Survey Open-File Report 84-939, 617-658 p.

Sorey, M.L., 1985, Evolution and present state of the hydrothermal system in Long Valley caldera: Journal of Geophysical Research (in press, 1985).

Stearns, N.D., Stearns, H.T., and Waring, G.A., 1937, Thermal springs in the United States: U.S. Geological Survey Water Supply Paper 679-B, p. 59-206.

Stine, S., 1984, Late Holocene Lake level fluctuations and Island volcanism at Mono Lake, California; in Stine, Wood, Sieh and Miller, Holocene paleoclimatology and tephrochronology east and west of the central sierran crest: Field trip guidebook for the Friends of the Pleistocene, Pacific Cell, October 1984 p. 21-49.

Swanson, D.A., Lipman, P.W., Moore, J.G., Heliker, C.C., and Yamashita, K.M., 1981, Geodetic monitoring after the May 18 eruption, in Lipman, P.W. and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 157-168.

Taylor, B.E., and Gerlach, T.M., 1984a, Chemical and isotopic composition of Casa Diablo Hot Spring: magmatic CO_2 near Mammoth Lakes, California: EOS Transactions, American Geophysical Union, v. 65, no. 7, p. 58.

Taylor, B.E., and Gerlach, T.M., 1984 b, Mantle CO_2 degassing at Long Valley, Steamboat Springs, and the Coso Range: EOS Transactions, American Geophysical Union, v. 65, no. 45, p. 1153.

United States Forest Service, 1980-1983, Water Resources Data for Mammoth Ranger District Inyo National Forest, California: Annual Reports.

Verekamp, J.C., and Buseck, P.R., 1984, Changing mercury anomalies in Long Valley, California: Indication for magma movement or seismic activity: Geology, v. 12, p. 283-286.

Waring, G.A., 1915, Springs of California: U.S. Geological Survey Water Supply Paper 338, 310 p.

Waring, G.A., 1965, Thermal springs of the United States and other countries of the world, a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Williams, S.N., Hudnut, K.W., Lawrence, E.A., and Little, J.N., 1983, Soil Hg distribution patterns and response to magmatic resurgence at Long Valley caldera, California: EOS Transactions American Geophysical Union, v. 64, no. 45, p. 891.

Williams, S.N., 1985, Soil radon and elemental mercury distribution and relation to magmatic resurgence at Long Valley caldera: Science, vol. 229, p. 551-553.

Willey, L.M., O'Neil, J.R., and Rapp, J.B., 1974, Chemistry of thermal waters in Long Valley, Mono County, California: U.S. Geological Survey Open-File Report, 19 p.

Wollenberg, H.A., Smith, A.R., Mosier, D.F., and Flexser, S., 1985, Radon-222 in ground water of the Long Valley caldera, California: Pure and Applied Geophysics, Special issue on earthquake predictors (in press).

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques in Water-Resources Investigation Bk. 1, Ch. D2, 24 p.

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California

Results in milligrams per liter except iron (Fe), mercury (Hg), manganese (Mn), and zinc (Zn), which are in micrograms per liter.
Feature: Name of sample site, with abbreviation used in figures and Plate 1 given in parenthesis.
Laboratory: BABC: Babcock and Sons, Riverside, CA; DWR: California Department of Water Resources; LBL: Lawrence Berkeley Laboratory (A. White); USGS-c: U.S. Geological Survey Central Lab, Arvada CO; USGS-m: U.S. Geological Survey Menlo Park (R. Mariner); USGS-s: U.S. Geological Survey Lab, Salt Lake City, Utah (discontinued); CIW: Carnegie Institute of Washington D.C. (N. Valette-Silver).
pH: pH measured in the field except for laboratory measurement noted by "L".
Alkalinity: Calculated as the equivalent concentration of calcium carbonate.
Dissolved Solids: Residue on evaporation at 180° except calculated values indicated by "c".

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Alkali Lakes-Whitmore Hot Springs area - springs and wells in T. 3S., R. 29 E. and T.4S., R.29E.																					
Unnamed spr. T.3S, R.29E sec. 21P1	05-22-72	USGS-m	56.0	7.9	25	0.60	310	37	679	68	150	4.6	250	1,262[c]	0.46	7.7	1.5	---	---	---	---
	11-11-83	LBL	50.0	6.9	27	0.71	338	34	334	160	160	4.7	171	1,164[c]	0.76	6.1	2.0	219	---	---	---
Unnamed spr. T.3S, R.29E. sec. 28H1	05-22-72	USGS-m	49.0	6.5	22	0.60	400	43	693	69	170	4.8	240	1,376[c]	0.34	8.8	1.7	---	---	---	---
	11-18-83	LBL	44.0	6.9	26	1.04	354	36	674	70	142	3.4	159	1,206[c]	0.86	7.0	2.2	93	---	---	---
Unnamed spr. T.3S, R.29E. sec. 31A1	05-20-72	USGS-m	58.0	6.6	15	0.40	310	22	424	81	170	7.5	150	1,021[c]	0.84	7.9	2.0	---	---	---	---
	11-17-83	LBL	50.0	7.9	17	0.45	279	20	424	85	147	5.5	119	939[c]	1.43	8.1	2.2	8	---	---	---
Unnamed spr. T.4S, R.29E. sec. 6Q	04-25-84	LBL	6	7.1	73.4	2.9	5.7	3.3	135	12.7	2.6	---	35.0	217[c]	0.021	0.15	0.01	0	---	---	---
Whitmore Hot springs (WS)	05-12-66	DWR	37	8.2	21	3.0	140	9.0	226	41	74	3.2	---	510[c]	0.46	3.70	---	---	---	---	---
	11-17-83	LBL	33	7.6	21.8	1.9	100	8.2	197	443	52.5	2.9	68.7	820[c]	0.51	2.54	0.8	11	---	---	---
Core Hole 7 (CH-7)	01-09-75		---	8.2[L]	55	2.2	470	21	---	82	200	5.4	160	---	---	8.5	2.1	---	---	---	---

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Casa Diablo area - springs in sections 15, 31, 32, 33, T. 3 S., R. 28 E.																					
Chance spr. (CHS)	03-26-63	DWR	17.0	7.4	23	7	50	8	96	28	55	0.4	54	255	0.060	1.85	---	---	---	---	---
	04-25-84	LBL	18.0	6.3	48.2	9.5	46	7.8	130	20.9	31.5	0.14	63.7	---	0.088	1.35	0.16	---	---	---	---
Colton spr. (CS)	08-26-82	USGS-c	93.0	9.1^{L}	1.4	0.20	390	25	354	140	270	12.0	240	1,310	1.6	12.	---	---	---	---	---
	12-04-82	USGS-c	95.0	8.4	1.2	0.07	370	25	367	140	250	11.0	240	1,290	1.5	12.	---	---	---	---	---
	01-14-83	USGS-c,m	93.0	---	---	---	---	---	---	---	260	---	---	---	1.7	---	2.9	---	0.1	---	10
	03-15-83	USGS-c	91.5	8.3	---	---	---	---	---	---	260	12.0	---	---	1.7	12.	2.9	---	0.2	---	10
	05-01-83	USGS-c	91.5	8.4	---	---	---	---	---	---	260	12.0	---	---	1.5	12.	---	---	---	---	---
	06-03-83	USGS-m	93.0	8.3	1.2	0.01	385	25	370	135	250	10.0	240	---	---	11.	2.8	---	---	---	---
	08-14-83	USGS-c	92.0	8.4	1.3	0.3	380	28	355	130	260	12.0	---	---	1.4	11.	---	---	<0.1	---	10
	10-06-83	USGS-c	91.5	8.3	1.3	---	370	24	355	140	260	11.0	240	1,280	1.6	11.	2.8	5	0.1	6	3
	12-15-83	USGS-c	89.1	8.4	1.7	<0.01	370	23	359	140	270	12.0	---	1,280	1.5	11.	2.9	20	0.5	10	10
	04-25-84	LBL	70.0	8.4	1.4	0.02	384	32	390	129	258	9.6	315	$1,376^{c}$	1.4	11.4	2.9	---	---	---	---
	05-09-84	USGS-c	91.4	8.3	1.3	<0.01	370	28	353	150	270	12.0	230	1,340	1.3	11.	3.3	5	0.3	6	5
	05-09-84	CIW	91.4	8.3	1.3	<0.01	378	---	---	---	---	---	234	---	2.0	11.4	---	2	---	5	<3
	09-04-84	USGS-c																			
Little Antelope Valley spr. (LAV)	10-11-84	LBL	10.0	5.2	3.8	0.8	8.3	4.8	25	1.4	0.5	---	---	---	0.006	0.02	0.0	0	---	---	---
Meadow spr. (MS)	08-27-82	USGS-c	60.0	7.5^{L}	3.8	0.8	230	37	132	110	210	8.7	210	910	2.2	9.1	---	---	---	---	---
	12-05-82	USGS-c	61.0	5.9	3.5	0.6	220	39	134	120	200	8.0	200	894	2.2	9.4	---	---	---	---	---
	03-15-83	USGS-c	61.0	6.2	---	---	---	--	---	---	200	8.8	---	---	2.4	9.0	0.16	---	0.1	---	<10
	05-01-83	USGS-c	61.0	6.6	---	---	---	--	---	---	180	8.3	---	---	2.0	8.1	---	---	---	---	---
	06-03-83	USGS-c	63.0	6.9	3.1	0.46	200	31	127	100	170	7.8	---	---	2.0	7.5	1.4	---	0.1	---	200
	08-14-83	USGS-c	62.3	6.4	3.2	0.53	200	39	135	100	180	7.6	180	---	2.1	7.8	1.4	---	0.9	---	4

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Casa Diablo area - springs in sections 15, 31, 32, 33, T. 3 S., R. 28 E. (Continued)																					
	10-06-83	USGS-c	64.4	6.2	4.1	0.57	210	36	122	120	190	7.2	190	844	2.0	8.5	1.3	9	0.1	15	17
Meadow spr.	12-15-82	USGS-c	56.0	6.2	4.4	0.60	200	32	119	120	190	7.5	180	824	1.8	8.0	1.4	8	0.2	14	5
(MS)	04-05-84	USGS-c	60.0	6.2	3.5	0.60	200	39	109	120	200	7.5	190	881	2.0	8.5	1.4	5	0.3	8	11
	05-10-84	USGS-c	63.3	6.3	3.4	0.60	210	39	115	120	200	7.7	190	865	1.8	8.6	1.5	6	0.3	14	18
	05-10-84	CIW	63.3	6.3	3.1	0.57	205	---	---	---	---	---	191	---	2.3	8.1	---	5	---	10	<3
	10-11-84	LBL	64.0	6.7	4.6	0.13	220	43	115	134	199	6.8	235	855[c]	2.2	9.1	1.6	7	---	---	---
Milky Pool 1 (MP-1)	08-19-83	USGS-c	87.3	7.6	2.4	0.04	330	37	206	160	270	14.0	170	1,120	1.6	13.0	---	---	---	---	---
Milky Pool 2	05-09-84	USGS-c	91.2	6.8	2.4	0.04	230	33	73	160	240	10.0	210	967	1.5	9.8	1.0	96	0.7	45	27
(MP-2)	05-09-84	CIW	91.2	6.8	2.3	0.37	232	---	---	---	---	---	220	---	2.0	9.8	---	107	---	43	13
North spr.	03-15-83	USGS-c	88.5	6.7	---	---	---	---	---	---	270	9.8	---	---	2.0	13.0	---	---	---	---	---
(CDNS)	06-03-83	USGS-m	92.5	6.8	8.7	1.2	235	24	---	155	260	10.0	216	---	---	13.0	1.2	---	---	---	---
	08-18-83	USGS-c	91.5	6.7	---	---	---	---	---	160	260	9.6	130	---	2.1	12.0	---	---	---	---	---
	10-04-83	USGS-c	91.5	6.8	9.1	1.2	240	23	47	160	260	9.3	220	971	1.9	12.0	1.1	15	0.3	36	53
	12-15-83	USGS-c	89.5	7.1	10.0	1.5	240	22	45	170	270	12.0	210	1,010	1.6	12.0	1.1	17	---	34	9
	05-09-84	USGS-c	89.5	6.9	10.0	1.4	250	25	61	190	270	9.1	200	1,020	1.5	11.0	1.3	16	0.5	31	8
	05-09-84	CIW	89.5	6.9	9.7	1.4	250	---	---	---	---	---	211	---	2.1	10.6	---	20	---	30	<3
	09-04-84	USGS-c	92.8	7.2	10.0	1.4	240	26	58	160	280	9.2	220	1,010	1.5	---	1.2	10	0.5	33	5
	11-11-84	USGS-c	89.8	6.8	10.0	1.3	240	24	36	170	270	8.0	220	1,000	1.2	13.0	1.2	9	0.3	46	9

Table 1. -- Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Casa Diablo area - springs in sections 15, 31, 32, 33, T. 3 S., R. 28 E. (Continued)																					
South spr. (CDSS)	08-27-82	USGS-c	93.0	8.4^{L}	11.0	2.2	290	27	186	150	260	8.1	210	1,090	1.5	11.0	---	---	---	---	---
	11-17-82	USGS-c	93.5	7.8^{L}	9.9	2.2	280	27	175	160	250	8.8	200	1,080	1.6	11.0	---	---	---	---	---
	01-14-83	USGS-c	86.0	---	---	---	---	---	---	---	250	---	---	---	1.5	---	1.7	---	0.2	---	20
	02-04-83	USGS-c	81.0	---	---	---	---	---	---	---	240	11.0	---	---	1.4	11.0	1.7	---	0.3	---	10
	03-15-83	USGS-c	80.0	6.6	---	---	---	---	---	---	240	8.5	---	---	1.5	11.0	1.8	---	0.1	---	20
	05-03-83	USGS-c	80.5	6.5	---	---	---	---	---	---	230	6.9	---	---	1.6	---	---	---	---	---	---
	06-03-83	USGS-m	84.0	6.7	23	3.3	320	31	281	225	205	8.2	200	---	---	9.6	1.8	---	---	---	---
Geyser (CDG)	11-19-83	LBL	92.0	9.4	1.5	0.53	389	40	469	152	269	10.1	341	$1,212^{c}$	2.5	12.7	3.7	5	---	---	---
	05-09-84	USGS-c	90.1	8.2	0.8	0.1	410	38	382	160	300	12.0	---	1,480	1.8	12	3.2	110	1.2	<10	<10
	05-09-84	CIW	90.1	8.2	1.2	0.8	416	---	---	---	---	---	268	---	2.1	12.4	---	230	---	<3	<3
	09-04-84	USGS-c	90.8	8.2	1.3	<0.1	410	40	388	160	310	13.0	---	1,470	1.8	13.0	3.0	40	0.1	20	<10
Sulfate spr.1 (AS-1)	08-06-73	USGS-s	93.0	3.7	19	41	27	17	0	1,500	20	0.4	160	1,820	0.005	0.05	---	7,400	---	---	---
Sulfate spr.2 (AS-2)	10-09-84	LBL	93.0	4.5	11.2	3.2	230	21	2.5	1.4	0.5	0.0	160	437^{c}	0.753	7.12	1.2	725	---	---	---
	10-13-84	USGS-c	88.0	6.8	5.1	2.3	230	16	62	190	210	8.5	120	857	0.73	7.6	1.1	130	---	120	11
Sulfate spr.3 (AS-3)	11-09-84	USGS-c	91.8	3.9	18.0	9.4	100	16	0	370	95	0.1	170	878	0.022	3.0	0.2	69,000	---	1,200	160
Casa Diablo area - wells in sections 32, 33. T. 3 S., R. 28 E.																					
Endogenous 5 (END-5)	05-19-72[1]	USGS-m	94.0	9.2	0.9	0.1	390	45	368	130	280	12.0	340	$1,217^{c}$	2.2	14	2.8	---	---	---	---
IW-2	01-04-83[2]	LBL	---	9.7^{L}	3.5	.008	401	10	464	118	132	23.7	91	$1,072^{c}$	0.181	10.8	0.22	64	---	---	---
MBP-1	01-04-83[2]	LBL	---	8.8^{L}	5.1	0.04	431	47	405	132	300	12.1	63	$1,248^{c}$	0.205	10.6	3.48	438	---	---	---

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Casa Diablo area - wells in sections 32, 33. T. 3 S., R. 28 E. (Continued)																					
MBP-2	01-04-83[2]	LBL	---	9.1[L]	1.8	0.03	430	45	410	133	288	12.8	65	1,236[c]	0.232	10.8	3.52	93	---	---	---
MBP-4	01-04-83[2]	LBL	---	8.8	1.4	0.02	453	52	425	135	300	13.6	188	1,414[c]	0.242	11.7	3.98	226	---	---	---
MBP-5	01-04-83[2]	LBL	---	9.2[L]	2.6	0.02	435	34	389	172	267	14.7	75	1,248[c]	0.202	10.3	3.98	159	---	---	---
Union (M-1)	01-04-83[2]	LBL	---	9.4[L]	0.9	0.02	422	18	415	172	180	14.5	61	1,126[c]	0.139	7.57	0.82	34	---	---	---
SS-2	11-17-84	LBL	12.0	6.8	22	6.4	23	5.1	130	10	7.4	---	60	---	0.130	0.40	0.10	3	---	---	---
Fish Hatchery area - springs in sections 34, and 35, T. 3 S., R. 28 E.																					
AB Supply	07-26-73	USGS-s	14.5	7.3	10.0	8.4	21	4.8	91	12	6.5	0.3	56	175	0.05	0.27	---	20	---	---	---
	05-25-82	USGS-c	14.5	6.8	10.0	10.0	30	---	---	---	---	---	50	---	---	.30	0.07	5	---	1	9
	06-21-84	USGS-c	16.0	7.1[L]	13.0	9.7	24	5.1	111	10	8.0	0.4	57	187	0.02	.37	0.08	7	0.1	1	4
CD Supply	06-14-66	DWR	16.0	7.2[L]	9	7	22	5	88.5	7	5	0.3	---	150	0.05	.17	---	---	---	---	---
	05-25-82	USGS-c	14.8	6.8	10	10	30	---	---	---	---	---	50	---	---	.30	0.07	5	---	1	10
	06-21-84	USGS-c	14.0	7.1[L]	11	8.1	20	4.2	97	9.7	3.7	0.4	53	155	0.03	.19	0.06	5	0.1	1	3
H-I	06-14-66	DWR	12.0	7.5[L]	11	6	19	5	83	7	4	0.3	---	135	0.03	.13	---	---	---	---	---
	05-25-82	USGS-c	13.0	6.8	10	7	10	---	---	---	---	---	50	---	---	.10	0.05	5	---	1	9
	06-21-84	USGS-c	12.8	7.2[L]	11	6.9	17	3.7	88	9.3	2.1	0.3	50	136	0.02	.13	0.05	6	0.1	1	3
H-II, III	06-14-66	DWR	12.0	7.3[L]	12	5	16	4	75	8	3	0.3	---	120	0.02	.08	---	---	---	---	---
	05-25-82	USGS-c	11.0	7.1	10	5	10	5	---	---	---	---	---	---	---	.10	0.05	5	---	1	9
	11-16-83	LBL	11.0	7.2	12.7	5.1	12	3.2	71	---	---	---	34	---	---	---	0.04	7	---	---	---
	06-21-84	USGS-c	11.1	7.3[L]	13.0	4.7	12	2.9	70	11	1.5	0.2	39	104	0.02	.09	0.04	<3	<0.1	<1	<3

Table 1. -- Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Fish Hatchery area - springs in sections 34, and 35, T. 3 S., R. 28 E. (Continued).																					
Hot Bubbling Pool (HBP)	05-24-72	USGS-m	60.0	7.2	3.3	0.1	380	25	382	120	250	11.0	300	1,532[c]	0.34	13.0	2.5	---	---	---	---
	02-04-83	USGS-c	56.0	8.1[L]	7.6	0.21	368	22	374	120	250	9.2	---	---	1.5	11.0	2.8	---	0.6	---	3
	11-17-83	LBL	55.0	8.0	11	0.23	335	23	399	110	238	10.3	207	1,188[c]	.248	10.8	3.4	55	---	---	---
Chance Meadow spr (CMS)	10-13-84	USGS-c	52.2	5.9	3.8	1.2	230	8.2	251	87	150	5.7	150	815	0.36	5.9	1.5	28	4.0	160	7
Hot Creek Gorge area - springs in section 25, T. 3 S., R. 28 E.																					
Morning Glory Pool (HC-1)	08-29-73	USGS-m	90.0	6.6	1.6	0.1	400	24	---	100	225	9.6	150	---	---	10.5	2.3	---	---	---	---
	05-29-80	USGS-m	92.0	7.8	2.4	0.08	395	23	484	94	220	10.0	142	---	---	10.0	---	---	0.2	---	---
	06-03-83	USGS-m	94.0	8.2	1.3	0.09	390	23	461	92	215	10.0	140	---	---	10.0	2.6	---	---	---	---
	12-13-83	USGS-c	73.3	6.8	1.4	0.29	380	22	495	110	230	9.5	140	1,210	0.9	11.0	2.5	5	0.3	25	23
Spring above bridge (HC-2	05-29-80	USGS-m	92.0	8.2	1.5	0.1	370	21	433	92	210	9.6	133	---	---	9.6	---	---	---	---	---
	01-11-83	USGS-c	90.0	7.6	---	---	---	---	---	---	210	---	---	---	0.96	---	---	---	---	---	---
	05-01-83	USGS-c	79.0	7.2	---	---	---	---	---	---	220	8.1	---	---	0.6	10.0	---	---	---	---	---
	06-03-83	USGS-m	82.0	7.3	7.0	0.26	375	23	441	98	210	10.0	140	---	---	10.0	2.5	---	---	---	---
	08-19-83	USGS-c	82.0	7.2	6.6	0.29	370	24	449	99	220	9.2	140	1,150	1.3	10.0	2.4	---	1.1	---	21
	10-04-83	USGS-c	79.1	7.2	6.4	0.22	370	21	450	100	220	9.7	140	1,140	0.98	10.0	2.4	3	0.3	10	5
	12-13-83	USGS-c	76.3	7.3	13.0	0.43	360	17	439	98	220	9.1	140	1,130	0.9	9.6	2.4	8	0.2	17	33
	05-08-84	USGS-c	79.2	7.3	6.5	0.20	360	24	435	100	220	9.8	130	1,150	0.9	9.5	2.7	6	0.1	12	20
	05-08-84	CIW	79.2	7.3	6.4	0.20	364	---	---	---	---	---	135	---	1.3	10.1	---	<3	---	10	<3
	09-03-84	USGS-c	78.7	7.4	6.7	0.20	360	26	430	100	220	9.4	140	1,160	0.92	9.9	2.6	<3	<0.1	14	6
Geysers (HC-3)	03-16-83	USGS-c	89.0	8.4	3.6	0.30	380	23	475	95	220	11.0	---	---	0.99	11.0	2.6	---	0.4	---	50
	05-01-83	USGS-c	90.0	7.9	---	---	---	---	---	---	230	10.0	---	---	0.8	11.0	---	---	---	---	---

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Hot Creek Gorge area - springs in section 25, T. 3 S., R. 28 E. (Continued)																					
Geysers (HC-3)	08-19-83	USGS-c	91.5	8.0	2.4	0.22	380	24	473	96	230	9.9	140	1,180	1.1	10.0	2.5	---	0.2	---	6
	11-18-83	LBL	90.0	8.2	2.9	0.22	353	23	475	105	176	6.9	165	1,131[c]	1.62	9.8	2.8	13	---	---	---
	12-13-83	USGS-c	88.3	8.2	3.7	0.20	380	24	471	94	230	10.0	140	1,150	0.9	11.0	2.5	40	0.2	10	10
	05-08-84	USGS-c	91.4	8.1	2.3	0.20	380	24	490	96	230	10.0	130	1,190	0.9	9.8	2.9	7	0.2	1	79
	05-08-84	CIW	91.4	8.1	2.3	0.18	382	29	---	---	93	---	138	---	1.3	10.8	---	<3	---	<3	<3
	09-03-84	USGS-c	91.0	8.1	2.2	0.18	380	28	477	96	230	10.0	140	1,190	0.93	9.9	2.7	<3	0.2	3	8
	11-12-84	USGS-C	90.2	---	---	---	---	---	---	---	220	10.0	---	---	---	10.0	---	---	---	---	---
Hot Creek Gorge area - wells in section 30, T. 3 S., R. 29 E.																					
CH-10	01-27-81	USGS-c	---	8.4[L]	7.0	---	---	---	---	---	220	---	---	---	---	8.9	---	---	---	---	---
CH-10A	08-09-83	USGS-c	82.0	8.8[L]	2.2	0.4	360	24	440	87	210	8.5	130	1,096[c]	0.77	9.6	---	---	---	---	---
	11-09-84	USGS-c	93.3	7.2	---	0.4	340	21	463	93	200	8.4	230	1,120	0.62	9.9	2.3	37	0.2	120	11
CH-10B	08-16-83	USGS-c	83.0	8.4	6.7	0.3	360	22	435	90	200	9.5	130	1,090[c]	1.2	9.0	---	---	---	---	---
Little Hot Creek area - springs in section 13, T. 3 S., R. 28 E.																					
Flume spr. (LHC-1)	02-03-83	USGS-c	82.0	---	---	---	---	---	---	---	200	3.5	---	---	0.63	9.0	2.9	---	0.1	---	10
	03-16-83	USGS-c	82.0	6.7	---	---	---	---	---	---	200	8.6	---	---	0.68	9.4	---	---	---	---	---
	04-29-83	USGS-c	82.0	---	---	---	---	---	---	---	200	8.9	---	---	0.50	9.0	---	---	---	---	---
	08-19-83	USGS-c	82.2	6.7	23	0.7	400	28	546	100	210	8.6	---	---	0.6	8.9	2.9	---	0.1	---	.3
	10-04-83	USGS-c	81.8	6.7	23	0.7	400	---	593	100	210	8.6	85	1,220	0.54	9.3	---	---	0.1	---	6
	11-18-83	LBL	80.0	7.4	13	0.67	377	27	625	101	173	5.5	84	1,170[c]	1.14	9.0	3.3	8	---	---	---
	01-17-84	USGS-c	80.0	6.7	23	0.61	370	27	610	100	210	9.2	78	1,210	0.58	9.1	2.6	35	1.3	200	19
	05-09-84	USGS-c	81.2	6.8	22	0.60	400	29	579	100	210	8.3	82	1,230	0.59	8.6	3.3	47	0.3	200	17
	05-09-84	CIW	81.2	6.8	22	0.55	398	---	---	---	---	---	81	---	.78	8.6	---	44	---	195	<3

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Little Hot Creek area - springs in section 13, T. 3 S., R. 28 E. (Continued).																					
Flume spr. (LHC-1)	09-03-84	USGS-c	82.7	6.8	24	0.60	390	31	595	100	210	8.4	86	1,240	0.62	8.9	3.0	38	---	210	9
	11-12-84	USGS-c	82.6	6.8	23	0.60	390	27	576	100	200	8.1	84	1,230	0.45	8.8	2.7	42	0.4	200	<3
Thermograph spr. (LHC-2)	05-18-72	USGS-m	79.0	6.5	50	0.60	410	30	602	96	200	8.4	110	1,260	0.74	10.6	2.8	150	---	240	---
	07-12-76	USGS-m	---	---	---	---	---	---	---	---	200	---	88	---	---	8.9	---	---	---	---	---
	06-24-80	BABC	80.0	6.8^{L}	27	1.0	400	15	570	98	189	---	---	1,185	---	---	---	---	---	---	---
	07-17-80	USGS-c	79.0	7.9^{L}	---	---	---	---	---	---	210	---	---	---	---	10.0	---	---	---	---	---
	06-03-83	USGS-m	79.5	6.8	23	0.66	410	27	---	96	200	8.9	84	---	---	9.1	2.9	---	---	---	---
Springs along caldera margin																					
Big Spring (BS)	05-21-72	USGS-m	11.0	6.8	5.1	5.9	23	4	74	8.1	5.7	0.5	58	155^{c}	0.02	0.37	0.4	---	---	---	---
	11-18-83	LBL	11.0	7.3	4.6	5.7	24	4.3	84	8.9	4.2	---	51	---	.770	0.33	0.06	3	---	---	---
Laurel spr. (LS)	06-19-66	DWR	12.0	7.6	16	0	5	1.0	37	13	1.0	0.2	---	65	0.01	---	---	---	---	---	---
	06-03-83	USGS-c	12.0	8.6	16	0.6	5.9	1.3	40	18	0.5	0.1	---	---	0.003	0.02	.004	---	0.1	---	43
	11-17-83	LBL	10.0	8.8	14	0.6	5.3	1.2	37	17	0.4	---	20	---	.130	0.05	---	5	---	---	---
	01-17-84	USGS-c	11.8	7.8	16	0.6	5.7	1.3	40	19	0.5	0.1	20	81	0.004	0.02	.005	10	0.1	1	7
	05-10-84	USCG-c	12.0	8.9	15	0.6	5.8	1.4	39	20	0.5	0.1	19	81	0.004	0.02	.006	3	0.1	1	3
	05-10-84	CIW	12.0	8.9	15	0.59	5.7	---	---	---	---	---	20	---	<0.2	<0.02	---	2.7	---	<3	<3
	09-02-84	USGS-c	12.0	8.8	17	0.6	5.4	1.5	38	19	0.2	0.1	21	86	0.003	0.03	.005	<3	<0.1	3	17
Springs near Lake Crowley in T. 3S., R. 29 E.																					
Unnamed spr. sec. 34K1	05-23-72	USGS-m	41.0	7.5	23	1.2	320	28	570	59	150	4.6	205	1,142^{c}	0.36	8.1	1.6	---	---	---	---
Unnamed spr sec. 36Q1	04-24-84	LBL	18.0	8.6	11	0.61	56	4.8	120	16	13	1.2	67	242^{c}	0.064	0.37	0.13	---	---	---	---
Unnamed spr. sec. 36Q2	06-11-66	DWR	28.0	8.4	5	0	83	6	---	16	22	1.9	---	210	0.13	0.58	---	---	---	---	---
	04-24-84	LBL	30.0	8.8	4.4	0.21	83	6.7	160	18	21	1.8	74	306c	0.130	0.42	0.20	21	---	---	---

Table 1. -- Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Springs near Lake Crowley in T. 3S., R. 29 E. (Continued).																					
Unnamed spr. sec. 36Q3	04-24-84	LBL	25.0	8.1	3.8	0.03	83	6.4	150	17	18	1.8	78	299^c	0.100	0.40	0.19	4.5	---	---	---
Springs outside Long Valley caldera																					
Alpers Canyon spr. (AC)	08-03-84	LBL	15	6.5	9.0	6.8	8.6	6.2	75	0.36	1.1	---	61.6	---	0.0	.18	0.0	4	---	---	---
Bald Mtn spr. (BM)	08-03-84	LBL	11	6.8	9.3	1.9	6.5	3.4	37	0.65	0.4	---	47.3	---	0.0	.08	0.0	14	---	---	---
Clark Canyon spr. (CC)	08-03-84	LBL	10	7.1	8.2	1.3	10.8	4.3	42	0.88	0.8	---	52.3	---	0.0	.05	0.01	0	---	---	---
Hartley Springs (HS)	08-01-84	LBL	8	6.7	2.7	0.2	4.7	4.1	17	0.0	0.3	---	48.5	---	0.0	.04	0.01	---	---	---	---
Minaret spr. (MIN)	08-02-84	LBL	8	7.4	49	0.5	1.7	1.2	107	8.8	0.3	---	11.5	---	0.0	.04	0.01	5	---	---	---
Reds Meadow Tub spr. (RMT)	07-25-74	USGS-m	45.5	7.3_L	61	2.5	140	6.2	423	33	6.7	4.8	150	661^c	---	1.8	0.89	20	0.2	540	110
	08-19-80	BABC	46.0	6.6	62	2.	130	8	---	29	8.	---	---	---	---	---	---	---	---	---	---
	06-21-84	USGS-c	47.6	6.6	60	2.3	130	5.6	409	31	6.9	6.0	140	640	0.21	1.60	0.86	<3	<0.1	540	3
	08-02-84	LBL	45.0	6.8	72	1.8	142	8.4	427	28	4.	3.8	127	647^c	---	1.63	1.94	10	---	---	---

Table 1. — Chemical analyses of waters from selected springs and wells in the Long Valley area, Mono County, California (Continued)

Feature	Collection date	Laboratory	Temperature (°C)	pH	Ca	Mg	Na	K	ALK	SO_4	Cl	F	SiO_2	Dissolved solids	As	B	Li	Fe	Hg	Mn	Zn
Springs outside Long Valley caldera (Continued)																					
Upper Round Valley spr. (UR)	04-25-84	LBL	6	8.1	8.1	0.7	8.2	0.8	39	4.0	1.2	---	19.0	---	0.004	0.12	---	2	---	---	---
Watterson Trough spr. (WT)	04-25-84	LBL	13	7.7	7.9	3.0	13.2	3.6	52	4.7	2.8	---	64.6	---	0.12	0.11	0.01	0.0	---	---	---

1/ Total flow of steam and water condensed.

2/ No correction made for steam fraction lost (approximately 20 percent).

Table 2.— Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California

Results represent ratios of deuterium to hydrogen (δD) in water, oxygen 18 to oxygen 16 ($\delta^{18}O$) in water, and carbon 13 to carbon 12 ($\delta^{13}C$) in water (superscript w) and gas (superscript g), expressed in standard delta notation in parts per thousand (0/00). Tritium concentration is expressed in tritium units (TU).

Feature: Name of sample site with abbreviation used in figures, other tables, and Plate 1 given in parentheses.

Analytical lab: USGS-ml, U.S. Geological Survey, Menlo PARK, CA (C. Janik); USGS-m2, U.S. Geological Survey, Menlo Park, CA (R. Mariner); USGS-m3, U.S. Geological Survey, Menlo Park, CA (J. O'Neil); LBL, Lawrence Berkeley Laboratory (A. White); USGS-r, U.S. Geological Survey Laboratory, Reston, VA (T. Coplen).

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Alkali Lakes-Whitmore Hot Springs area-springs in T.3S, R.29E., and T.4S., R.29E.						
Unnamed spr.	05-22-72	USGS-m2	-123.9	-16.17	---	---
T.3S, R.29E	11-11-83	LBL	-127	-15.8	-6.0^{w}	0.48
sec. 21P1	10-06-84	USGS-ml		-16.1	-4.7^{w}	
Unnamed spr.	05-22-72	USGS-m2	-123.4	-15.85	---	---
T.3S, R.29E	11-18-83	LBL	-128	-15.8	-4.5^{w}	1.52
sec 28H1						
Unnamed spr.	05-20-72	USGS-m2	-121.2	-15.23	---	---
T.3S, R.29E.	11-17-83	LBL	-123	-15.7	-5.2^{w}	0.71
sec. 31A1						
Unnamed spr.	09-00-75	USGS-m2	-120.3	-15.26	---	---
T.4S, R.29E.	04-25-84	LBL	-116	-14.7	---	---
sec. 6Q						
Whitmore Hot Springs (WS)	11-17-83	LBL	-129	-16.1	-6.2^{w}	4.06
Casa Diablo area - springs in sections 32, 33, T.3S, R.28E.						
Chance spr. (CHS)	04-25-84	LBL	-113	-14.7	-8.3^{w}	---

Table 2.-- Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California (Continued)

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Casa Diablo area - springs in sections 32, 33, T.3S, R.28E. (Continued)						
Colton spr.	03-15-83	USGS-m2	-112.5	-14.3	---	---
(CS)	06-03-83	USGS-m2	-115.4	-14.3	-3.6[w]	---
	06-26-83	USGS-m1	-118.5	-14.4	-3.58[w]	---
	08-14-83	USGS-m2	-113.3	-14.2	---	---
	12-15-83	USGS-r	-114	-14.3	-2.8[w]	---
	05-09-84	USGS-r	-115	-14.3	-3.1[w]	---
	06-27-84[1/]	USGS-m1	-116.3	-14.3	-3.4[w], -10.5[g]	0.19
	08-03-84	LBL	---	---	-3.0[w]	2.0
	09-04-84	USGS-r	-114	-14.2	-4.1[w]	---
	10-05-84	USGS-m1	---	-14.3	-3.8[w]	---
Meadow spr.	03-15-83	USGS-m2	-117.2	-15.3	---	---
(MS)	06-03-83	USGS-m2	-119.8	-15.2	---	---
	08-14-83	USGS-m2	-120.3	-15.0	---	---
	12-15-83	USGS-r	-120	-15.0	-2.5[w]	---
	05-10-84	USGS-r	-121	-15.1	-4.2[w]	---
North spr.	06-03-83	USGS-m2	---	-14.2	---	---
(CDNS)	06-26-83	USGS-m1	-110.9	-12.8	---	0.39
	12-15-83	USGS-r	-115	-14.3	-2.9[w]	---
	05-09-84	USGS-r	-116	-14.3	---	---
	08-00-84	USGS-m2	---	---	-3.8[w]	---
	09-04-84	USGS-r	-114	-14.2	-6.1[w]	---
South spr.	02-04-83	USGS-m2	-115.0	-14.3	---	---
(CDSS)	03-15-83	USGS-m2	-118.4	-14.7	---	---
	06-03-83	USGS-m2	-122.0	-14.8	---	---
Geyser (liquid)	06-26-83	USGS-m1	-111.6	-13.5	-3.45[w]	0.39
(CDG)	11-18-83	LBL	-118	-13.2	-3.0[w]	0.34
	06-29-84	USGS-m1	-113.7	-13.6	---	---
	09-04-84	USGS-r	-113	-13.5	-4.9[w]	---
	10-05-84	USGS-m1	---	-13.3	-3.0[w]	---
(steam)	06-26-83	USGS-m1	-143.2	-19.6	-7.88[g]	0.26
	10-05-84	USGS-m1	---		-4.1[g]	---
Fumarole	11-82 to 9-83	Sandia	---	---	(-5.6 to -5.7)[g]	---
(CDF)	06-26-83	USGS-m1	-146.3	-20.4	-7.39[g]	---
	10-10-84	USGS-m1	---	-18.9	-5.66[g]	---

Table 2.-- Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California (Continued)

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Casa Diablo area - wells in sections 32, 33, T. 3S, R. 28E.						
Endogenous 5 (End-5)	05-19-72	USGS-m2	-115.8	-14.2	---	---
IW-2	01-07-84	LBL	-128	-14.2	---	3.06
MBP-1	01-07-84	LBL	-114	-13.2	---	---
MBP-2	11-15-83	LBL	-115	-12.9	---	1.30
MBP-4	01-05-84	LBL	-114	-13.4	---	0.30
MBP-5	01-05-84	LBL	-111	-13.4	---	---
Union (M-1)	01-05-84	LBL	-124	-14.5	---	---
SS-2	11-17-83	LBL	-116	-15.1	---	---
Fish Hatchery area - springs in section 34 and 35, T. 3S, R. 28E.						
Fish Hatchery sprs. H-II,III	09-00-75	USGS-m2	-121	-16.2	---	---
	11-16-83	LBL	-128	-15.8	---	15.6
	04-16-84	LBL	-124	-16.3	---	---
Hot Bubbling Pool (HBP)	05-24-72	USGS-m2	-111.2	-12.4	---	---
	06-26-83	USGS-m1	-114.6	-13	-2.7[w],-5.8[g]	0.03
	11-17-83	LBL	-114	-11.7	---	1.73
	06-28-84	USGS-m1	-113.7	-13.1	---	0.59
	10-05-84	USGS-m1	---	-13.1	-3.3[w],-5.7[g]	---
Chance Meadow Spring (CMS)	10-13-84	USGS-r	-120	-15.4	-4.8[w]	---
Hot Creek Gorge area - springs in section 25, T.3S, R. 28E.						
Morning Glory Pool (HC-1)	08-29-73	USGS-m2	-120.3	-14.8	---	---
	04-00-75	USGS-m2	---	---	-4.4[g]	---
	05-29-80	USGS-m2	-119.9	-14.8	-1.7[w],-6.0[g]	---
	06-03-83	USGS-m2	-118.4	-14.9	-4.3[w]	---
	12-13-83	USGS-r	-118	-14.2	-3.4[w]	---
	08-00-84	USGS-m2	---	---	-4.4[g]	---

Table 2.-- Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California (Continued)

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Hot Creek Gorge area - springs in section 25, T.3S, R. 28E. (Continued).						
Spring above bridge (HC-2)	05-29-80	USGS-m2	-123.8	-15.0	---	---
	05-01-83	USGS-m2	-116.7	-14.7	---	---
	08-19-83	USGS-m2	-117.1	-15.0	---	---
	06-03-83	USGS-m2	-119.4	-14.2	---	---
	12-13-83	USGS-r	-117	-14.8	-3.4^{w}	---
	05-08-84	USGS-r	-121	-14.7	---	---
	09-03-84	USGS-r	-119	-14.6	-4.5^{w}	---
Geysers (HC-3)	03-16-83	USGS-m2	-118.3	-15.2	---	---
	05-01-83	USGS-m2	-120.3	-15.4	---	---
	06-27-83	USGS-m1	-120.6	-14.4	-4.0^{w}, -5.2^{g}	0.36
	08-19-83	USGS-m2	-119.1	-15.1	---	---
	05-08-84	USGS-r	-121.5	-15.0	-4.2^{w}	---
	09-03-84	USGS-r	-119	-14.8	-4.5^{w}	---
	10-06-84	USGS-m1	---	-14.9	-4.1^{w}, -6.3^{g}	---
Little Hot Creek area - springs in section 13, T.3S, R. 28E.						
Flume spr. (LHC-1)	02-03-83	USGS-m2	-121.0	-15.3	---	---
	03-16-83	USGS-m2	-122.8	-15.5	---	---
	04-29-83	USGS-m2	-122.7	-15.9	---	---
	08-19-83	USGS-m2	-121.5	-15.8	---	---
	11-18-83	LBL	-125	-15.2	-3.4^{w}	0.17
	12-00-83	USGS-r	-120.5	-15.7	-4.3^{w}	---
	05-09-84	USGS-r	-123.5	-15.7	-4.2^{w}	---
	06-28-84	USGS-m1	-124.7	-15.6	-4.2^{w}, -6.7^{g}	0.00
	09-03-84	USGS-r	-124	-15.6	-4.2^{w}	---
	11-12-84	USGS-r	-126	-15.6	-4.8^{w}	---
	10-05-84	USGS-m1		-15.6	-4.7^{w}	---
Thermograph spr. (LHC-2)	05-18-72	USGS-m2	-121.8	-15.3	---	---
	07-12-76	USGS-m2	-123.8	-16.4	---	---
	05-20-82	USGS-m3	-123.0	---	---	---
	06-17-82	USGS-m3	-124.3	---	---	---
	07-15-82	USGS-m3	-124.7	---	---	---
	08-12-82	USGS-m3	-126.6	---	---	---
	09-09-82	USGS-m3	-125.8	---	---	---
	10-12-82	USGS-m3	-126.0	---	---	---
	11-19-82	USGS-m3	-126.3	---	---	---
	06-03-83	USGS-m2	-126.0	-15.7	-4.4^{w}, -6.3^{g}	---

Table 2.-- Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California (Continued)

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Cold springs along caldera margin						
Big Spring	05-21-72	USGS-m2	-115.4	-15.9	---	---
	11-18-83	LBL	-120	-15.9	-10.5[w]	25
Laurel spring (LS)	06-03-83	USGS-m2	-123.7	-16.8	---	---
	11-17-83	LBL	-128	-16.7	-14.3[w]	8.2
	01-17-84	USGS-r	-123	-17.1	-11.7[w]	---
	05-10-84	USGS-r	-126	-17.1	-11.9[w]	---
	09-02-84	USGS-r	-126	-16.9	-14.1[w]	---
Springs near Lake Crowley in T.3S., R. 29E.						
Unnamed spr sec. 36Q1	04-24-84	LBL	-115	-13.7	-9.3[w]	1.2
Unnamed spr. sec. 36Q2	04-24-84	LBL	-131	-17	-4.3[w]	1.7
Unnamed spr. sec. 36Q3	04-24-84	LBL	-133	-16.7	---	---
	10-05-84	USGS-m1	---	-17.2	-6.7[w]	---
Springs and fumaroles outside Long Valley caldera						
Bald Mtn. spring (BM)	08-03-84	LBL	---	---	-16.4[w]	---
Hartley springs (HS)	06-00-76	USGS-m2	-126.3	---	---	---
	08-01-84	LBL	---	---	-17.9[w]	---
Mineret spring (MIN)	09-00-75	USGS-m2	-110.7	-14.9	---	---
	08-02-84	LBL	---	---	-12.3[w]	---
Reds Meadow Tub spr. (RMT)	07-00-74	USGS-m2	-111.2	-15.2	---	---
	06-21-84	USGS-r	-110	-15.1	-6.1[w]	---
	06-27-84	USGS-m1	-109	-14.4	---	---
	08-02-84	LBL	---	---	-3.6[w]	8.4
	10-09-84	USGS-m1	---	-15.0	-5.9[w]	---
Upper Round Valley spr (UR)	04-25-84	LBL	-135	-17.7	---	---

Table 2.-- Isotopic analyses of water and gas from selected springs, fumaroles, and wells in the Long Valley area, Mono County, California (Continued)

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	δD o/oo	$\delta^{18}O$ o/oo	$\delta^{13}C$ o/oo	Tritium T.U.
Springs and fumaroles outside Long Valley caldera (Continued).						
Wattersson Troughs spr. (WT)	06-00-76	USGS-m2	-135	---	---	---
	04-24-84	LBL	-131	-17.4	---	---
Mammoth Mt. fumarole (MMN)	06-00-82	USGS-m2	---	---	-5.5[g]	---

1/ Gas sample from Colton spring was collected from steam vent 100 ft above hot spring.

Table 3. Range of carbon isotope ratios in nature. Values are given in delta notation relative to the PDB standard.

Material	$\delta^{13}C$
Fresh water carbonates[1]	-14.1 to +9.8
Marine carbonates[1]	-3.3 to +2.4
Carbonatites and colorless diamonds[2]	-10 to -2
Colored diamonds[2]	-32.3 to -5
CO_2-fluid inclusions, oceanic basalts[3]	-8 to -5
Atmospheric carbon dioxide[2]	-10 to -7
Aquatic plants--terrestrial[2]	-19 to -6
Basalts-whole rock[1]	-26 to -19
Organic matter in recent sediments[2]	-30 to -10
Rocks from Long Valley area:	
Tufa and travertine[4]	-0.3 to +2.6
Sierran metamorphic carbonates[4]	-11.9 to 0
Bishop Tuff-fluid inclusions[5]	-40 to -15

[1] Data from Craig, 1953
[2] Data from Faure, 1977
[3] Data from Pineau and others, 1976, and Moore and others, 1977
[4] Data from H.A. Wollenberg, written communication, 1985
[5] Data from T. Gerlach, written communication, 1984

Table 4. Chemical analyses of gas from springs and fumaroles in the Long Valley area, Mono County, California.

Results in percent, on a water-free basis, except for values of H_2O/gas, which are expressed as a volumetric ratio. nd indicates no laboratory determination was made.
Feature: Name of sample site with abbreviation used in figures, other tables, and Plate 1 given in parentheses.
Analytical lab: USGS-m1: U.S. Geological Survey, Menlo Park, CA (C. Janik); USGS-m2: U.S. Geological Survey, Menlo Park, CA (R. Mariner); Sandia: Sandia National Laboratory (T. Gerlach), results shown are average values for samples collected on same date.
H_2S: Total sulfur calculated as H_2S.
O_2: For samples with nd shown for Ar, O_2 = O_2 + Ar.

Feature (abbrev.)	Collection date mo-day-yr	Analytical lab	T °C	CO_2	H_2S	H_2	CH_4	NH_3	He	N_2	O_2	Ar	H_2O/gas
						(volume percent-water free)							(volumetric)
Casa Diablo area - springs and fumaroles in sections 32 and 33, T.3S, R.28E.													
Colton spring[1] (CS)	06-27-84	USGS-m1	96	95.36	0.76	0.0623	0.0656	0.00	0.006064	3.53	0.0	0.084	---
Geyser (CDG)	06-26-83	USGS-m1	94	95.44	1.69	0.0142	0.0116	1.13	0.000119	1.75	0.00262	0.0321	830
	10-05-84	USGS-m1	--	98.06	0.095	0.0218	0.0326	0.004	0.000629	1.47	0.2895	0.0337	15
Fumarole (CDF)	11-11-82	Sandia	96	93.2	5.5	0.028	0.016	nd	nd	0.56	0.013	nd	195
	01-14-83	Sandia	94	95.8	0.37	0.021	0.021	nd	nd	3.1	0.39	nd	190
	04-25-83	Sandia	95	96.9	0.69	0.47	0.047	nd	nd	1.7	0.13	0.012	255
	04-28-83	Sandia	94	96.7	0.65	0.22	0.044	nd	nd	1.6	0.17	0.02	242
	06-26-83	USGS-m1	94	89.78	0.66	0.031	0.026	0.387	0.000377	7.62	0.80	0.0974	260
	09-23-83	Sandia	94	96.7	0.93	0.30	0.06	nd	nd	1.6	0.07	0.032	237
	05-31-84	Sandia	93	97.7	0.78	0.055	0.031	nd	nd	0.80	0.03	nd	285
	10-10-84	USGS-m1	94	98.2	0.65	0.045	0.045	0.095	0.00104	0.96	0.0	0.023	191
Fish Hatchery area - springs in section 35, T.3S, R.28E.													
Hot Bubbling Pool (HBP)	06-26-83	USGS-m1	64	97.25	0.0132	0.0403	0.0694	0.0114	0.000498	2.42	0.177	0.00168	0.27
	10-05-84	USGS-m1	--	94.35	0.1138	0.0308	0.0305	0.0	0.0	4.73	0.575	0.1231	0.0
Hot Creek Gorge area - springs in section 25, T.3S, R. 28 E.													
Morning Glory Pool (HC-1)	05-31-84	Sandia	93	96.1	0.13	nd	nd	nd	nd	3.03	0.74	nd	nd
Geysers (HC-3)	06-27-83	USGS-m1	79	96.69	0.0338	0.0123	0.0741	0.0053	0.0024	2.98	0.0747	0.0758	0.67
	10-06-84	USGS-m1	--	96.43	0.0582	0.0018	0.0087	0.0	0.0	2.93	0.4256	0.0811	1.74
Little Hot Creek area - springs in section 13, T.3S, R. 28 E.													
LHC-1	05-31-84	Sandia	80	96.5	0.05	nd	nd	nd	nd	2.77	0.66	nd	nd
	06-28-84	USGS-m1	80	91.0	0.18	0.0004	0.031	0.019	0.0	7.05	1.48	0.104	52
Mammoth Mountain area - fumaroles in section 31, T.3S, R. 27E.													
MMN	06-00-82	USGS-m2	80	91.22	0.02	0.01	0.008	nd	0.005	8.27	0.01	0.11	nd

[1] Sample from Colton Spring was collected from a steam vent 100 ft above the hot spring.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID: Name or number abbreviation used on figures and tables throughout report.
Location: Township, range, section and quarter section all referenced to Mount Diablo baseline and meridian.
Site description: Describes well where two or more wells are located in same general area.
Date drilled: Date original drilling completed.
Altitudes: Referenced to NVGD, 1929 and rounded to nearest foot. Altitude of M.P. (measuring point - generally top of casing) surveyed July-August 1984, except values in parenthesis which were picked from topographic maps with 80 or 40 ft. contour interval and values for wells in Casa Diablo area which were surveyed by Ben Holt Co. Altitude of W.L. (water level); values with asterisk used to prepare water-level contour map.
Casing: Diameter in inches x length in feet.
Logs: C, caliper; D, drillers; G, geophysical; K, core; L, lithologic; T, temperature.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
DC	2S/27E-34A		08/00/73	7515/7343	633	3.0 x 560 1.25 x 633		L,T	Drilled by USGS for heat-flow measurement. Water level measured outside 1.25 in. pipe.
27R1	2S/28E-27R	USFS windmill 50 ft. SW. of old well		7041/7005	125	6			
28P1	-28P	windmill		7110/7034	125	6			
30N2	2S/29E-30N	unused well near entrance gate		6914/6905	32	8			Depth sounded 08/05/82.
31P1	-31P	unused well near windmill		6916/6912	8	30 x 8			
35N1	-35N	windmill		(6914)/(6912)	75	6			
36P1	-36P	windmill		(6980)/(6907)		6			
PLV-2	3S/27E-3K		10/03/82	7734/7336	2330	1.75 x 2330	1845-1855	K,L,T	Geothermal test hole drilled by Phillips Petroleum Co., perforated 8/1/84 by Schlumberger.
PLV-1	-22J		10/20/82	8509/7523	2347	1.75 x 2347	1750-1760	K,L,T	Geothermal test hole drilled by Phillips Petroleum Co., perforated 8/1/84 by Schlumberger.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
MMI	-31C	well at Ski Lodge	00/00/58	(8920)/(8901)	120				Water level altitude 08/27/71.
MWD-9B	-33F	destroyed	7/22/84	(8350)	801	none	open hole	L	Municipal water-supply well. No water encountered in well.
34R	-34R	J. Haddaway	11/07/72	(7920)/(7815)	115			D	Depth plugged back from 130 ft Water level altitude 11/7/72.
35E	-35E	supply well for Manzanita Trailer Park	00/00/56	(7880)/(7872)	52		27-52	D	Water level altitude 10/29/66. Destroyed; insufficient yield.
LM	3S/28E-6L	SE of Lookout Mt. along Dry Creek		(7330)/(7260)	3000	x 500	500-3000 open hole		Geothermal test hole drilled by Occidental Geothermal.
FP-1	-15A	Freeport mineral ventures test hole LV-34	00/00/83	(7300)/(7023)		none	open hole		Uncased 6 in. diameter hole at Clay Pit.
LAV-1	-15P	Former windmill site		7205/7203	15	30 x			Unused stock well in Little Antelope Valley.
SF	-20B	Near head of Long Canyon graben	00/00/84	(7758)/(7280)	890				Drilled by Santa Fe International as water supply well for future deep hole.
LC	-20H	do.	00/00/82	7683/7260	4000				Geothermal test hole drilled by Union Oil Co.
CH-6	-22C	Little Antelope Valley	11/07/74	7249/7045	685	1.25 x 677	535-540	K,L,G,T	Drilled by USGS for heat-flow measurement. Perforated 08/04/82.
LV-15	-30R	well nearest Antelope Valley Rd.	05/31/72	(7324)/(7320)	58	2 x 57	55-57	K,L,T	Drilled by USGS for shallow temperature and water-level measurements.
END-2	-32E	Location shown on detailed map of Casa Diablo	08/31/60	7352/7306	810	13 x 220 9 x 400	400-810 open hole	T	Drilled by Magma Power Co. 90 ft. of drill string at bottom of hole.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
END-5	-32E	Location shown on detailed map of Casa Diablo	00/00/60	7343	405	x 250	250-405		Drilled by Magma Power Co. (destroyed).
M-1	-32F	do.	08/00/79	7316/7258	1900	13 x 210 9 x 0-1070 7 x 1015-1090	1055-1900	G,T	Originally drilled by Union Oil Co. Well plugged back from 5200 to 1900 for injection.
MBP-1	-32E	do.	11/16/83	7343	650	22 x 100 16 x 300 13 x 250-650	300-650	L,G,T	Drilled by Ben Holt Co. as production well.
MBP-2	-32E	do.	11/5/83	7302	650	22 x 100 16 x 300 13 x 250-650		L,G,T	Well plugged and abandoned.
MBP-3	-32E	do.	11/29/84	7310	704			L,G,T	Drilled by Ben Holt Co. as production well.
MBP-4	-32E	do.	10/9/83	7334	650	22 x 100 16 x 300 13 x 250-650	300-650	L,G,T	Drilled by Ben Holt Co. as production well.
MBP-5	-32E	do.	10/10/83	7364	650	22 x 100 16 x 300 13 x 250-650	300-650	L,G,T	Drilled by Ben Holt Co. as production well.
IW-2	-32F	do.	12/1/83	7292	1800	20 x 100 13 x 1000 10 x 900-1800	1270-1800	L,G,T	Drilled by Ben Holt Co. as injection well.
IW-1	-32F	do.	09/30/84	7295	2200			L	Drilled by Ben Holt Co. as injection well.
SS-1	-33P	Sheriff Sub-station old well	00/00/61	7179/7161	75	8 x 75	51-75	D	Unused
SS-2	-33P	Sheriff Sub-station new well	10/17/78	7180/7172	100	10 x 35 6 x 100	34-60 80-100	D,T	Domestic supply
CR	-33Q	Chance (Lacey) Ranch	00/00/63	7162/7151	80	6			Well filled in with sand to 25 ft.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
CM-2	-34C	Chance meadow	10/30/84	(7085)	152	4 x 152		D,T	Drilled by USGS for borehole seismicity measurement.
ES	-34R	well 40 ft east of school building	00/00/49	(7090)/(7072)	47	8 x 47		D	Old well at unused elementary school
CW	-35E	Near Bubbling pool	00/00/61	7089/7078	680	14 x 230	230-TD	C,T	Depth measured 12/82, originally 804 ft deep.
2A	3S/29E-2A	windmill		(6922)/(6917)	32	8		T	Stock well northeast of Benton Crossing.
LV-25	-7A	PVC pipe	06/09/72	6875/6867	18	2 x 18	16-18	L,T	Drilled by USGS for shallow temperature and water-level measurement.
LV-21	-13C		00/00/72	(6855)/(6847)	22	2 x 20	20-22	L,T	do (destroyed).
LV-30	-18G	PVC pipe	00/00/72	6896/6892	9	2 x 9	7-9	L	do.
CH-1	-19C		11/02/73	6972/6931	973	1.25 x 973	470-475	G,K,L,T	Drilled by USGS for heat-flow measurement. Original depth 997 ft. Perforated 08/03/82.
CH-7	-19R		11/20/74	6957/6952	210	1.25 x 210	198-203	G,T	Drilled by USGS for heat-flow to 543 ft; caved to 210 ft. Perforated 08/03/84; obstruction at 93 ft.
CH-3	-27L		09/20/74	(6882)/(6874)	160	1.25 x 160	none	D	Drilled by USGS for heat-flow measurement.
RG	-29K	covered over	06/10/76	(6970)	6920			G,T	Republic Geothermal test well. Plugged, abandoned, and covered.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
LV-18	-29M	PVC pipe	06/02/72	6966/6948	71	2 x 71	69-71	L,T	Drilled by USGS for heat-flow measurement.
LV-45	-29R	PVC pipe	05/17/73	6985/6957	96	2 x 96	none	T	do.
CH-10	-30E	well nearest access road	00/00/75	7076/7006	175	1.25 x 175	115-120	L,T	Drilled by USGS for heat-flow measurement. Perforated 1/27/81, Obstruction at 116 ft.
CH-10A	-30E	well 20 ft. south of gage house	08/10/83	7080/7006	110	6 x 110	90-110	L,T	Detailed diagram of well construction and lithology on Figure 13.
CH-10B	-30E	well in gage house	08/00/83	7080/7006	315	6 x 192 4 x 275	300-315 open hole	C,L,T	do.
LV-28	3S/30E-19M		00/00/72	(6950)/(6881)	87	2 x 85	85-87	L,T	Drilled by USGS for shallow temperature and water-level measurements (destroyed).
DP	4S/26E-2D	Dump	00/00/73	(7760)	820			D,T	Drilled by USGS for heat-flow measurement (destroyed).
RM		Reds Meadow Campground	00/00/84	(7640)/(7636)	130			D,T	Drilled for USGS as water supply well.
MWD-2	4S/27E-3A		11/23/79	(7888)/(7723)	632	16 x 12 x 8 x	200-350 500-600	L	Municipal well; unused, low yield. Water level measurement 11/79.
MWD-3	-3B		09/13/80	(7920)/(7741)	354	16 x 330		L	Water level measurement 9/80, unused.
MWD-1	-3C		07/23/76	(7940)/(7802)	382	14 x 12 x	200-370	L	Municipal supply well. Water level measurement 7/76.
MWD-5	-3E	destroyed	10/14/82	(7980)/(7975)	---	none	open hole	L	Test well drilled for Mammoth Water District (filled in). Water level measurement 7/84.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
MWD-4C	-3J	destroyed	07/02/84	(7880)/(7872)	518	none	open hole	L	Test well drilled for Mammoth Water District (filled in) Water level measurement 7/84.
MWD-6B	-3R	destroyed	07/18/84	(7900)/(7900+)	407	none	open hole	L	do. Water level measurement 7/84 (artesian flow).
MWD-7C	-12D	destroyed	07/20/84	(7910)/(7694)	425	none	open hole	L	do. Water level measurement 7/84.
LV-19	4S/28E-1F	PVC pipe	06/05/72	(7090)/(7051)	99	2 x 99	97-99	L,T	Drilled by USGS for shallow temperature and water level measurements. As of 1982 filled with rocks.
AP	-1M	well 0.3 miles E. of airport terminal	05/00/84	7090/7068	70	x 66	52-66	D	Water supply well for County Airport. Water level altitude 10/9/84.
SQ	-3J	outside SW corner of shed	10/26/79	7102/7089	125	8 x 125	27-125	D	Deepest of three wells at Sierra Quarry.
LV-2	-4P	PVC pipe	05/17/72	7168/7139	44	2 x 42	40-42	D	Drilled by USGS for shallow temperature and water level measurement.
SC-1	-6L	2.5 in. pipe	07/00/82	7471/7377	132	2.5 x 40	40-132 open hole	K,L,T	Drilled by Sandia National Lab.
SC-2	-6L	well in shelter	08/00/83	7472	230	12 x 16 6 x 180 4 x 215	215-230	G,L,T	Detailed diagram of well construction and lithology in Figure 13.
LP	-10D	near infiltration pond	00/00/84	7126/7115	50	6 x			Drilled by Mammoth Water District.
LV-34	4S/29E-4J	PVC pipe	00/00/73	(6855)/(6846)	96	2 x 94	92-94	T	Drilled by USGS for shallow temperature and water-level measurement. Water level altitude 5/1/73.

Table 5. Description of wells in the Long Valley area, Mono County, California.

Well ID	Township Range location	Site description	Date completed (mo/day/yr)	Altitudes M.P./W.L. (feet)	Well depth (feet)	Casing	Zone of perforations (feet)	Logs	Comments
CH-5	-5G	Southeastern most well	10/20/74	6931/6888	856	1.25 x 856	210-215	D,T	Drilled by USGS for heat-flow measurement. Perforated 8/4/82.
PD	-6K	Probation Dept.		7014/6994	150			none	
MCL	-21L	McGee Creek Lodge		(7000)/(6959)	51	6			Domestic well. Water-level altitude 5/18/72.

Table 6. Water level measurements from 1982-1984 in selected wells in Long Valley caldera, Mono County, California.

Well ID: Name or number abbreviation used in figures and tables throughout report.
Measuring point altitude: Altitude rounded to nearest foot from levelling done in July-August 1984, except for values in parentheses which were estimated from topographic maps.
Location: Township, range, section, and quarter section, all referenced to Mount Diablo baseline and meridian.

Depth to water: Values with superscript P were measured when well was being pumped; values with superscript R were measured after well had recently been pumped; values with superscript * were used to construct the water-table contour map. SW indicates standing water at site.

Well ID	Measuring point altitude (ft)	Location (T/R-S)	Depth to water, feet below measuring point													
			1982				1983				1984			
			Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water
DC	7515	2S/27E-34A	-	-	-	-	-	-	-	-	7/20	171.9	8/30	173.1*		
27R1	7041	2S/28E-27R1	-	-	11/18	39.0	6/3	37.86	11/4	39.0	4/2	36.0	7/25	38^{P}	11/12	35.65
28P1	7110	-28P1	-	-	-	-	6/3	117.7	11/4	77.42	-	-	7/25	76.43*	11/12	80.79
30N2	6914	2S/29E-30N2	8/5	8.62	11/18	9.50	6/3	5.15	11/4	9.02	4/2	6.3	7/25	8.65*	11/12	9.51
31P1	6916	-31P1	8/5	4.70	11/18	4.29	6/3	2.10	11/4	3.00	4/2	2.0	7/25	3.73*	11/12	3.89
35N1	(6914)	-35N1	-	-	-	-	-	-	-	-	-	-	7/25	1.71*	11/12	3.28
36P1	(6980)	-36P1	-	-	-	-	-	-	-	-	-	-	7/25	72.8*	11/12	74.0
PLV-2	7734	3S/27E-3K	-	-	-	-	-	-	-	-	-	-	8/30	398*	11/12	404.0
PLV-1	8509	-22J	-	-	-	-	-	-	-	-	-	-	8/30	986*	11/12	986.0
LM	7330	3S/28E-6L	-	-	-	-	-	-	-	-	-	-	9/00	65*	11/12	60.41
FP-1	(7320)	-15A	-	-	-	-	-	-	11/4	277.2*	-	-	-	-	-	-
LAV-1	7205	-15P	-	-	-	-	6/2	2.3	11/4	2.3	4/2	2.3	7/27	2.31	-	-
LC	7683	-20H	-	-	-	-	9/29	301.7	11/4	318.55	7/27	412.2	9/3	422.5	-	-
CH-6	7249	-22C	8/24	206.6	11/16	206.8	6/2	205.00	11/3	204.07	5/11	204.5	7/27	204.03*	11/12	204.68
LV-15	(7340)	-30R	8/4	3.95	11/18	3.68	6/2	SW	11/3	SW	4/2	SW	7/27	SW*	11/12	SW
END-2	(7350)	-32E	-	-	-	-	8/15	41.5	-	-	-	-	-	-	-	-
M-1	(7308)	-32F	-	-	12/3	63.	7/7	55	8/17	58	-	-	-	-	-	-
SS-1	7179	-33P	8/5	16.12	11/18	20.41	-	-	11/3	19.48	-	-	7/19	17.95*	11/12	22.64

Table 6. Water level measurements from 1982-1984 in selected wells in Long Valley caldera, Mono County, California (continued)

Well ID	Measuring point altitude (ft)	Location (T/R-S)	Depth to water, feet below measuring point											
			1982				1983				1984			
			Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water	Date	Depth to water
SS-2	7180	-33P	-	-	-	-	-	-	-	-	-	-	7/19	7.65	-	-
CR	7162	-33Q	-	-	-	-	-	-	-	-	-	-	7/19	11.33*	-	-
CW	7089	-35E	8/5	12.95	11/16	12.70	6/2	12.68	11/3	12.20	4/3	13.33	7/26	11.00*	11/10	12.80
2A	6922	3S/29E-2A	5/26	3.50	-	-	-	-	-	-	-	-	7/25	4.60P*	11/12	4.06
LV-25	6875	-7A	8/5	6.58	11/18	8.65	6/3	2.07	11/4	7.24	4/2	5.35	7/25	8.10*	11/12	10.20
LV-30	6896	-18G	8/5	2.8	11/18	4.58	6/3	1.40	11/4	5.40	4/2	4.85	7/25	3.25*	11/12	3.74
CH-1	6972	-19C	8/5	41.77	11/16	41.89	6/2	41.85	11/3	40.95	4/4	41.03	7/27	40.68*	11/12	40.79
CH-7	6957	-19R	8/24	6.0	11/17	6.64	6/2	4.17	11/4	5.36	4/2	5.25	7/25	5.56*	11/12	
CH-3	6882	-27L	8/24	8.55	11/17	8.05	6/2	8.68	11/4	7.93	4/2	7.8	7/25	7.53*	11/12	7.04
LV-18	6966	-29M	8/27	21.18	11/17	20.35	6/2	14.74	11/4	18.45	4/2	19.2	7/25	17.99*	11/12	18.30
LV-45	6985	-29R	8/5	30.34	11/17	30.0	6/2	29.48	11/4	29.4	4/2	28.9	7/25	28.29*	11/12	28.09
CH-10	7076	-30E	8/4	69.1	11/18	69.4	6/2	69.0	11/3	68.60	4/2	71.2	7/27	69.24*	11/9	70.09
CH-10A	7080	-30E	-	-	-	-	9/28	72.6	11/3	72.88	4/2	74.4	7/27	73.50	11/9	74.41
CH-10B	7080	-30E	-	-	-	-	9/28	72.42	11/3	72.62	4/2	74.4	7/27	73.25	11/9	74.14
AP	7090	4S/28E-1M	-	-	-	-	-	-	-	-	-	-	10/9	22.59*	-	-
SQ	7102	-3J	-	-	-	-	-	-	-	-	7/17	21.25R	9/2	12.90*	-	-
LV-2	7168	-4P	8/26	28.86	12/5	31.53	6/1	26.85	11/4	30.07	-	-	7/26	29.01*	11/12	32.65
SC-1	7471	-6L	8/5	94.15	11/18	102.6	9/3	93.3	11/3	96.27	4/3	95.8	7/27	93.36*	-	-
SC-2	7472	-6L	-	-	-	-	9/3	108.57	11/3	108.15	4/3	102.85	7/27	101.06	11/12	101.97
LP	7126	-10D	-	-	-	-	-	-	-	-	-	-	7/19	11.4*	-	-
CH-5	6931	4S/29E-5G	8/24	44.6	11/17	44.55	7/08	44.24	11/4	43.37	4/3	43.8	7/27	43.25*	11/12	42.95
PD	7014	-6K	-	-	-	-	-	-	-	-	-	-	7/19	20.2*	-	-