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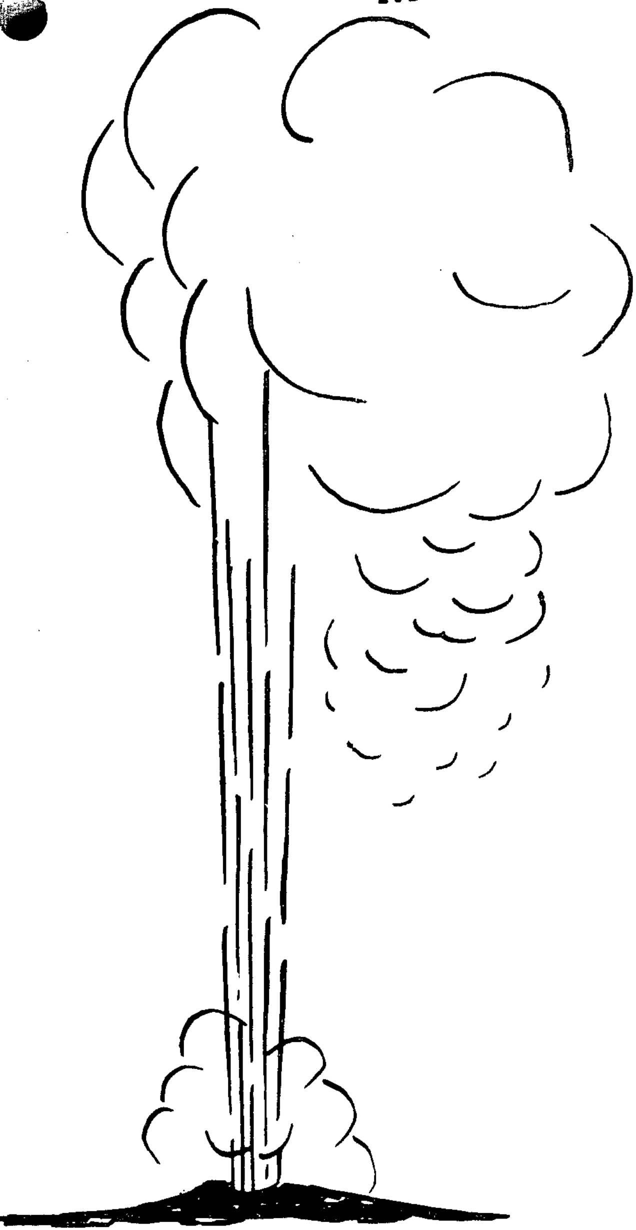

MULTIELEMENT GEOCHEMISTRY OF SOLID MATERIALS IN GEOTHERMAL SYSTEMS AND ITS APPLICATIONS

Part 1: The Hot-Water System at the Roosevelt Hot Springs KGRA, Utah

By
Robert W. Bamford
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Earth Science Laboratory
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ABSTRACT

Geochemical studies of the geothermal system at Roosevelt Hot Springs, Utah, have led to development of chemical criteria for recognition of major features of the system and to a three-dimensional model for chemical zoning in the system. Based on this improved level of understanding, several new or modified geochemical exploration and assessment techniques have been defined and are probably broadly applicable to evaluation of hot-water geothermal systems.

The main purpose of this work was the development or adaptation of solids geochemical exploration techniques for use in the geothermal environment. The approach used was multielement geochemical analysis of solid samples including soils, whole rock materials, and +3.3 specific gravity fractions derived by heavy liquid separation from the whole rock material. Whole rock materials were predominantly suites of contiguous 10-foot cuttings samples from geothermal wells, but also included suites of cuttings samples from temperature gradient drill holes, diamond drill core, and surface rock samples. A broad spectrum of major, minor, and trace elements was determined for these samples and used to establish spatial associations of hydrothermal element enrichments and depletions relative to critical geothermal features.

Principal zones distinguished in the geothermal system are a reservoir zone which encompasses all rock with high-temperature (>400°F) reservoir potential, a self-sealed zone developed at and beyond the reservoir zone margin and which is gradually encroaching on the reservoir, and a peripheral zone developed within and beyond outer parts of the self-sealed zone.

Hydrothermal element enrichments which characterize these zones are As, Li, Be, and Zn (and probably Fe, Mg, Cr, P, Co, Ni, Cu, Zr, La, and Ce) in the reservoir zone, especially at hot-water entries; Hg plus the reservoir zone assemblage (less Zn?) in inner parts of the self-sealed zone; Hg, Mn, and Zn plus the reservoir zone assemblage in outer parts of the self-sealed zone; and Mn and Zn (and possibly W and Mo) in the peripheral zone. Na, Sr, and possibly Ba are variably depleted from rock in the immediate vicinity of hot-water entries within the reservoir zone and inner self-sealed zone. Minor Hg enrichments are developed locally in the reservoir but are generally several orders of magnitude smaller than those which characterize the self-sealed zone.

The Roosevelt zoning model appears to be broadly applicable to other hot-water geothermal systems based on partially documented similarities in hydrothermal element distributions for a few of these systems, general similarities in thermal water chemistry for many systems, and tentatively inferred causes of key element deposition. The model thus provides a basis for establishing solids geochemical techniques applicable to the exploration and assessment of hot-water geothermal systems in general. Three multielement techniques, detailed soil surveys (or surface rock sampling), large-scale "surface" surveys utilizing shallow drill hole cuttings samples (commonly temperature gradient hole cuttings), and geochemical logging of deep drill holes, are indicated to be useful. These techniques, especially the geochemical logging, are shown to offer potentially high cost-effectiveness and, consequently, can be recommended for initial routine use.

The zoning model can possibly be utilized to provide insights into the nature and geometry of vapor-dominated systems evolved from hot-water systems, but otherwise is expected to have only limited applicability to these systems.

INTRODUCTION

Work to adapt or develop multielement geochemical techniques based on analysis of solid materials for application to the exploration and exploitation of geothermal resources was initiated at the Earth Science Laboratory (ESL) in July 1977. At that time in the geothermal industry familiarity with solids geochemical exploration techniques was limited. This, combined with a lack of specific evidence of their usefulness, had resulted in minimal interest and application. Only mercury soil geochemistry in geothermal systems was receiving significant attention, with activity underway both in technique development (e.g., Matlick and Buseck, 1976; and Klusman et al., 1977) and in exploration applications by industry. Primary emphasis in this work was on reconnaissance scale applications.

In contrast, multielement solids geochemical techniques were being widely used by the mining industry for successful location of ore zones in sulfide systems, some of which (especially epithermal class sulfide systems) could be considered paleoanalogues of geothermal systems in many important respects. Important similarities both with respect to general processes of formation and to the spectrum of transported elements in these systems were inferred from a variety of data (e.g., Skinner, et al., 1967, White et al., 1971, and Browne and Ellis, 1970). These similarities suggested that characteristic hydrothermal element distribution patterns (zoning) might develop in geothermal systems as they do in ore-bearing systems and could comprise useful systematics on which to base exploration and development techniques. Studies by Weissberg (1969) and Ewers and Keays (1977) at the Broadlands Geothermal

Field, New Zealand, appeared to provide initial tangible evidence of geothermal trace metal zoning. In view of the relatively low cost of geochemical techniques, it seemed multielement solids geochemistry had the potential to become a cost-effective new technology for the geothermal industry. What was needed was proof that this potential was real.

Initial work on solids geochemistry at ESL was directed to providing this evidence (Bamford, 1978, and Capuano and Bamford, 1978). Because of time constraints and the need for a real-earth model, the approach taken was empirical. Emphasis was placed on acquiring information on spatial relationships between reasonably well-defined geothermal resources and genetically related element patterns in two end-member systems: the hot-water system at Roosevelt Hot Springs, Utah and the vapor-dominated system at The Geysers, California. The rationale for starting investigation of both systems simultaneously was that most other systems were likely either to be similar or to have related hybrid characteristics. The work provided for investigation of a broad spectrum of trace elements, known or likely to be present in geothermal fluids, and several different types of samples (soils, rocks, and specific gravity and magnetic fractions derived from rocks). Data were acquired at a variety of scales in order to support, if possible, several different types of applications.

Results reported to date have suggested that multielement geochemical zoning is developed at both a relatively small scale of over hundreds of feet around individual steam entries and hot-water entries (HWEs) in geothermal wells, and at a larger scale of over thousands of feet both vertically and laterally in geothermal systems (Bamford, 1978). Based on the limited data available, zoning appeared to be quite similar for both hot-water and vapor-dominated systems. New data for The Geysers, however, suggests that this conclusion is probably in error and does not adequately consider the evolutionary complexity of vapor-dominated systems (Moore, et al., in prep.). Trace elements which displayed most consistent and useful zoning characteristics were As, Sb, Zn, Mn, B, and W. A +3.3 specific gravity concentrate sample appeared to be especially effective in delineating the hydrothermal trace element distributions since it maximized detection of these elements and reduced or eliminated those parts of chemical signatures which derive directly from original rock-forming materials. Other results indicated that detailed mercury-in-soil surveys could be useful for identifying and mapping structures controlling fluid flow in geothermal systems and for delineating areas overlying near-surface thermal activity (Capuano and Bamford, 1978).

Subsequent work on multielement solids geochemistry at ESL, both for The Geysers (Moore, et al., in prep.) and that currently reported for Roosevelt, has had as its principal goals the verification, modification and/or the refinement of these initial results. Additional multielement data have been acquired for new wells in a manner similar to that previously reported. For a few new and previously studied wells, more detailed chemical characterization has been achieved by analyzing individual ten-foot samples. Acquisition of a broader spectrum of trace, minor, and major element data has been facilitated by supplementing and supplanting conventional geochemical analyses with analyses by an Inductively Coupled Plasma Spectrometer (ICPQ) and has led to recognition of several additional potentially useful elements. Mercury distribution data have been acquired for subsurface samples and provide new insights into the general behavior of mercury in geothermal systems and into applications for such data. Applications of the overall geochemical results are defined and described with sufficient detail to permit initial use by others. Also, an estimate of potential cost-effectiveness is provided. At Roosevelt only (this report), extensive detailed documentation of surface arsenic and mercury distributions by grid sampling of soils over central parts of the system facilitates development of a system-scale geochemical zoning model. Aided by addition of the unifying surface survey data, the overall geochemical data package for Roosevelt provides new insight into the nature and geometry of the geothermal system and advances understanding of how geochemistry can be effectively used to aid selection of exploration well sites in other hot-water geothermal systems.

METHODS

For this study, geochemical data have been acquired for a variety of geologic materials including -80 mesh soil fractions, surface whole rock samples, fluids from geothermal wells, whole rock drill chip samples, and +3.3 specific gravity concentrate samples prepared from the drill chip samples. This spectrum of data was needed in order to corroborate the existence of specific kinds of geothermal geochemical distributions and to evaluate the relative utility of the various materials for geochemical exploration applications.

Enhancement of near-surface trace element geochemical signatures of some elements has been accomplished through the separation and analysis of a nonmagnetic +3.3 specific gravity heavy liquid concentrate fraction from original whole rock drill chip composite samples. In this manner, most rock-forming and alteration silicates, largely barren of some specific hydrothermally derived trace elements, are removed to leave samples which contain a large proportion of local hydrothermal oxides and sulfides that are relatively and systematically enriched in some of the trace elements of interest. The +3.3 sample fraction tends to selectively sample local hydrothermal vein material and thus can also provide documentation of hydrothermal redistribution of major and trace elements (e.g., Fe, Mn, and Zn) which often appears to be isochemical at the scale of the geochemical sampling and thus can remain undetected in whole rock sample data. Largest enhancements of hydrothermal geochemistry, whether the result of simple enrichment or local redistribution, are obtained where vein frequency is low and/or vein size is small. The +3.3 sample fraction has additional qualities of being readily reproduced, less sensitive to rock type effects than whole rock samples, and reasonably inexpensive to obtain. Occurrence of abundant high specific gravity nonhydrothermal material in the rocks sampled by this technique can confuse interpretation of +3.3 fraction data and must be continuously monitored.

Sample Collection and Preparation

Drill cuttings from both geothermal exploration wells and shallow temperature gradient holes are the predominant type of sample utilized in this work. In routine preparation procedures, individual ten-foot and five-foot cuttings samples were washed to remove drilling mud and exotic fines, crushed to -4 mesh, cleaned of iron drill bit and drill rod shavings with a hand magnet, pulverized to -80 mesh, and the resultant pulp stored for analysis. In most instances, composite samples were also prepared, each commonly containing 10 to 20 original samples and representing a 100-foot drilling interval. The practice of utilizing composited samples helps smooth potential random sampling biases of individual grab samples and decreases the number of samples which must be analyzed in the course of preliminary geochemical studies to a practical total.

Twenty to eighty grams of each -80 mesh composite sample were used to prepare the +3.3 specific gravity heavy liquid (methylene iodide) fraction. The -3.3 specific gravity fraction was discarded. A magnetic fraction, consisting mostly of magnetite with minor residual iron shavings, was separated from the +3.3 specific gravity fraction using a hand magnet. All sample fractions were weighed and then examined under a binocular microscope to determine their approximate mineral composition.

In order to assess the possible loss of mercury in whole rock samples resulting from heating during mechanical grinding, nine drill chip samples were prepared in duplicate, one portion being pulverized mechanically using a ceramic plate pulverizer, the other being hand-ground in an agate mortar to approximately the same particle size. Comparison of the results (Table 1) indicates that the method of grinding these samples does not systematically change the mercury content and should not be a significant factor in the preparation of samples for mercury analysis. Somewhat similar results have been obtained by other workers (Koksoy et al., 1967).

Table 1. Comparison of Mercury Concentrations in Duplicate Rock Samples Prepared by Two Grinding Methods.

	Mercury Content	
Sample	Hand Ground	Pulverized
1	5.63 ppm	4.71 ppm
2	11.9 ppm	12.1 ppm
3	47.8 ppm	49.4 ppm
4	245. ppm	251. ppm
5	559. ppm	603. ppm
6	58.7 ppm	73.0 ppm
7	51.0 ppm	55.6 ppm
8	131. ppb	109. ppb
9	64. ppb	52. ppb

Soil samples were collected at approximately 500 foot (152 m) intervals on a grid from a depth of 6 to 7 inches (15-18 cm). Selection of the sampling interval and depth was based on the lateral extent of soil mercury anomalies along traverses and variations of mercury content with depth determined in a previous study (Capuano and Bamford, 1978). Samples were collected in polyethylene bags and dried overnight at room temperature. Minus 80 mesh material was separated with a stainless steel sieve and sealed in airtight glass vials. Where planned sample locations fell on or near a roadway, dry wash, or drill pad, the sampling site was moved to a nearby location with undisturbed soils to minimize contamination.

Fluid samples from geothermal well 14-2 were obtained from A. H. Truesdell of the United States Geological Survey and from John Bowman of the Department of Geology and Geophysics of the University of Utah. A few drops of nitric acid were added at the time of collection to stabilize the solution. Although both samples had been collected more than eight months prior to analysis, their compositions, except for silicon, are similar, indicating that most major and minor element contents are relatively stable (Appendix G, Tables G-1, analyses 1-4). It is doubtful that trace element contents are similarly stable since some adsorption on containers and coprecipitation with silica is likely. No specific data are available, however, to document changes in the trace element contents of water samples with time.

Chemical Analysis

All whole rock drill cuttings samples, surface whole rock samples, fluid samples, and most +3.3 specific gravity samples have been routinely analyzed for 34 to 37 major, minor and trace elements. Na, K, Ca, Mg, Fe, Al, Si, Ti, P, Sr, Ba, V, Cr, Mn, Co, Ni, Cu, Mo, Pb, Zn, Cd, Ag, Au, As, Sb, Bi, U, Te, Sn, W, Li, Be, B, Zr, La, Ce, and Th were determined by means of the ESL inductively coupled argon plasma spectrometer (ICPQ). The ICPQ is an Applied Research Laboratories Model 137 with a 1080 lines/mm grating and dedicated computer operating system. Meaningful analyses could not be obtained for Si, B, and U in solids samples, due to loss of Si and B during sample digestion and to variable Fe spectral interference with U.

Limits of quantitative detection (LQD), representing lowest meaningful analytical values for elements determined by ICPQ are presented in Appendix H. Analytical precision (95% confidence level) at the LQD is approximately ± 100%, and at ten times the LQD is approximately ± 10%.

Conventional analytical methods were used to check ICPQ analytical values and to analyze for As and Sb, critical elements which are more effectively determined by conventional methods than by ICPQ analysis. Cu, Mo, Pb, Zn, Ag, Mn, Co, Ni, and Fe check analyses and the Sb analyses were performed using atomic absorption spectrophotometry (AAS). As was determined by a colorimetric method. These analyses and all preparation of drill cuttings samples were carried out by Rocky Mountain Geochemical Corporation, Salt Lake City, Utah. A limited number of additional analyses for Bi, In, Sn, and W were performed by Coors Spectrochemical Laboratory, Golden, Colorado using a volatile optical emission spectrographic (OES) method. Colorimetric As determinations on drill cuttings samples were made in the ESL Geochemical Laboratory and those on soil at Georesearch Laboratories, Salt Lake City, Utah. Mercury was determined on whole rock and soil samples at ESL using a Model 301 Gold Film Mercury Detector (Jerome Instruments Corp.).

Mineralogical Studies

Limited mineralogical studies were undertaken in order to identify the mineral constitution of whole rock and +3.3 specific gravity samples and to identify the mineralogical location of those trace elements with distributions apparently related to the geothermal system. Methods used included petrographic examination by transmitted and reflected light, X-ray diffraction, and analysis of selected mineral grains by electron microprobe. X-ray diffraction traces were prepared using the facilities of the Utah Biomedical Test Laboratory, a division of the University of Utah Research Institute, Salt Lake City. Smear mounts on glass slides of material hand-ground in an agate mortar were run at $2^\circ\ 2\theta$ per minute using Ni-filtered Cu $K\alpha$ radiation. Compositions of selected minerals from drill chip samples and +3.3 concentrates were determined using the microprobe facilities of the Earth and Mineral Sciences Experiment Station of The Pennsylvania State University. Mineral grains were qualitatively examined by the electron microprobe energy dispersive analytical system and quantitatively analyzed using the three crystal spectrometers. Data reduction procedures used were those of Bence and Albee (1968) with a modified version of the *a* matrix of Albee and Ray (1970). Optimum detection levels of the system are on the order of 300 ppm, although actual limits are more on the order of 1000 ppm.

Data Presentation and Interpretation

Data for the Roosevelt area are presented on two types of computer-generated plots: bar graph plots for display of data from individual drill holes, and plan and traverse plots for display of near-surface and soil data. Drill hole bar graph plots facilitate initial evaluation of relationships among geochemical data, geologic data, and geothermal phenomena. General geologic information and location of known or inferred hot water entries are presented at the scale of the bar graph plots. Locations of hot water entries have been determined independently based upon geophysical logs and drilling information; the reliability of these determinations is good for the few entries shown.

Plan plots of near-surface geochemical data derived from shallow temperature gradient holes similarly facilitate evaluation of large-scale areal distribution of elements relative to the geologic setting and to the proven geothermal resource. Because the drill chip data are limited to a maximum of 32 values distributed irregularly over a relatively large area, plots have only been roughly hand-contoured to show approximate data trends. Minimum contour values are lowest meaningful values determined by inspection and relationship to threshold values, if calculated. Each higher contour value is double that of the preceding lower value, thus helping to assure that data variations delineated are real rather than a consequence of random biases from sampling and analytical procedures.

Interpretations presented in this report are based primarily on the data graphics. Only large consistent changes in geochemistry are interpreted as significant. Approximate background values for principal lithologies represented in the well samples are established based on mean values from selected sets of minimally altered samples (Appendix E). These data facilitate distinguishing chemical variations due to changes in rock type from element enrichments and depletions due to hydrothermal effects. In some instances, however, some or many of the samples used in calculating the means were partly altered, especially when it was necessary to select samples entirely from the producing wells 14-2 or 72-16. In these instances, mean values for some of the more mobile elements establish local backgrounds only. High standard deviations associated with a few of the means (e.g., that for Mn in the quartz monzonite - Appendix E) indicate large variations in concentrations of an element within a sample set and suggest that the mean thus identified might not represent a useful background value. A specific tabulation of changes in microdiorite chemistry at the 2870 to 2890 HWE in well 14-2 is provided (Appendix E, Table E-2) because this HWE zone corresponds spatially to a rock type change, making it difficult to distinguish hydrothermal effects from the data graphics alone. Threshold values have been estimated for As and Hg in soil samples following the statistical methods of Sinclair (1974), and Lepeltier (1969) and, along with the background data for specific rock types (Appendix E, Tables E-1 and E-2), help to qualify the term "anomalous" as used in the text.

Although concentrations of from 34 to 37 elements have been determined for most samples, data presented in this report are limited to a few of these. Elements and multielement parameters selected for presentation are those with distributions most clearly related to the present geothermal system, and hence those with the most potential as exploration guides. The complete multi-element data package is available for open-file inspection at the Earth Science Laboratory of the University of Utah Research Institute in Salt Lake City, Utah.

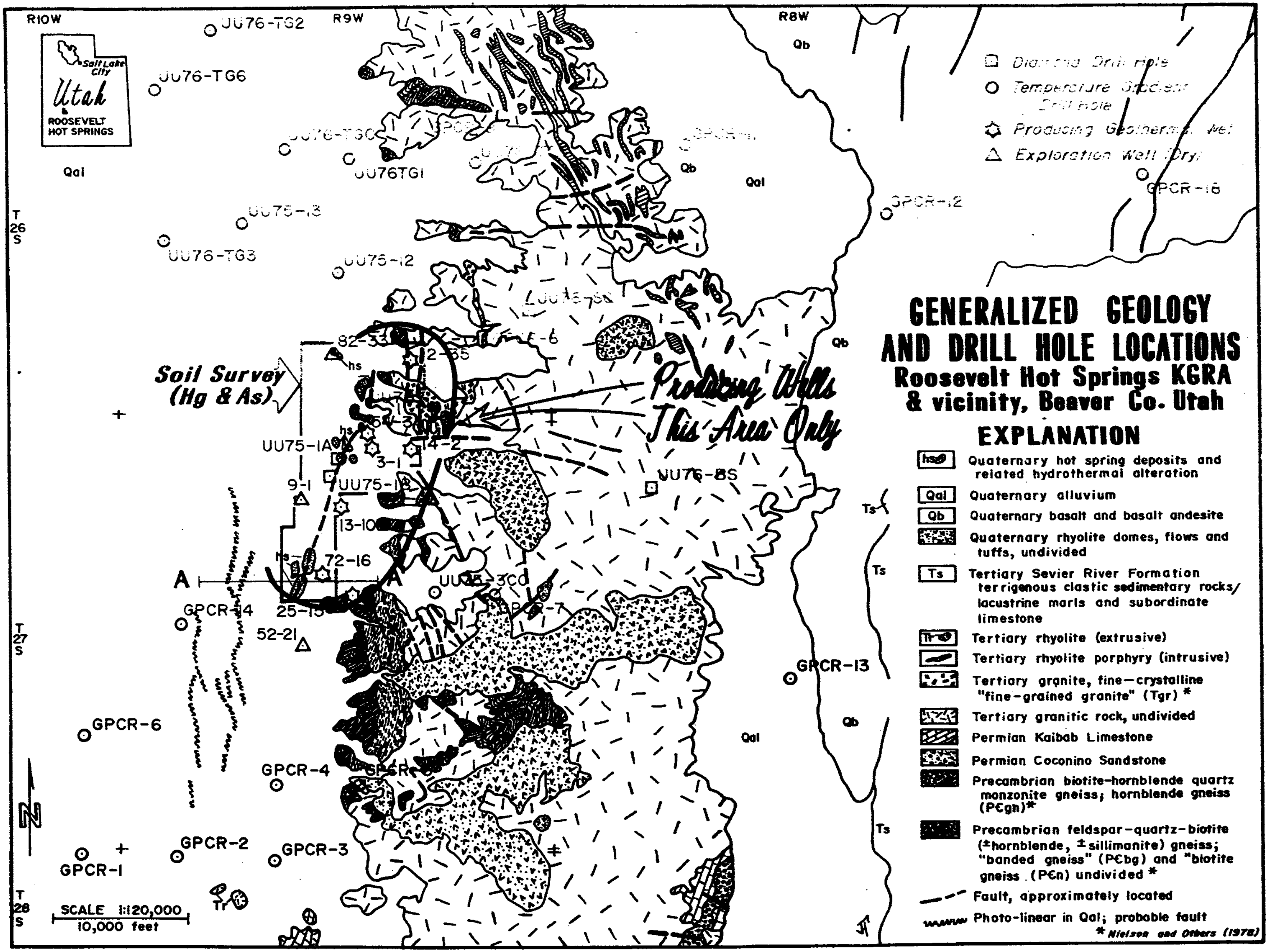
GEOLOGIC CHARACTERISTICS OF THE GEOTHERMAL SYSTEM

General Geology

The geology of the Roosevelt Hot Springs area has been mapped and discussed by Nielson et al. (1978). The bedrock geology of the area is dominated by felsic plutonic phases of the Tertiary Mineral Mountains Pluton as well as metamorphic and plutonic rocks of Precambrian age. Rhyolite flows, domes, and pyroclastics reflect igneous activity between 0.8 and 0.5 million years ago (Evans and Nash, 1978). Hot spring deposits, fumaroles, and hydrothermal alteration (related to the present geothermal system) occur within alluvium on the western margin of the Mineral Mountains.

The Roosevelt Hot Springs KGRA contains a structurally controlled hot-water geothermal system (Nielson et al., 1978). There are no lithologic units, except the Recent alluvium, which possess sufficient primary permeability to serve as productive aquifers. Four major fault trends are described by Nielson et al. (1978). These include large-scale north-south-trending, low-angle normal faults which have produced low-angle westward-dipping mylonite zones; numerous steeply dipping northwest-trending faults present only in the hanging wall of the major low-angle fault and also commonly marked by silicified mylonite zones; and steeply dipping east-west-trending and north-northeast-trending normal faults that cut both the hanging and foot walls of the low-angle normal faults and extend to an unknown depth. The low-angle and related high-angle northwest-trending fault zones are commonly the site of microdiorite dikes. Often both brecciated and nonbrecciated dikes occupy the same zone, suggesting several periods of dike intrusion and implying several periods of movement on the same faults. Nielson et al. (1978) propose that structural permeability present in strongly fractured rocks adjacent to mylonite zones or developed by fracturing of brittle silicified mylonite zones during recurrent fault movement exerts an important control on the location and configuration of the geothermal reservoir.

Two major structures are exposed in the study area (Figures 1 and 8A): the Opal Mound Fault, in the northern half of T27N, R9W, is a well defined north-northeast-trending, east-dipping normal fault; and the Negro Mag Wash Fault, in the northeast corner of T27N, R9W, is an east-west-trending fault with an inferred extension to the west. Hot spring deposits and fumarolic activity occur along or near the trend of the Opal Mound Fault near its proposed intersection with the poorly defined westward extension of the Negro Mag Wash Fault, indicating that the Opal Mound Fault or both faults have been zones of fluid discharge from the hot-water hydrothermal system. Lenzer et al. (1976) have suggested that the Opal Mound Fault is a major controlling structure for the subsurface hydrologic regime in the area. Reports on the subsurface relationships (Koenig and Gardner, 1977) show that the Opal Mound Fault is an eastward-dipping normal fault bounding a graben on the east and a narrow horst on the west. As presently known, the geothermal field at Roosevelt Hot Springs is bounded by the range front on the east and the Opal Mound Fault on the west (Nielson et al., 1978). Present drilling data indicate that the geothermal field may be terminated to the south between geothermal wells Utah State 52-21 and 72-16. The northern limits of the field are currently not defined.



□ Diamond Drill Hole
○ Temperature Gradient Drill Hole
✡ Producing Geothermal Well
△ Exploration Well (Dry)

GENERALIZED GEOLOGY AND DRILL HOLE LOCATIONS
Roosevelt Hot Springs KGRA & vicinity, Beaver Co. Utah

EXPLANATION

hs	Quaternary hot spring deposits and related hydrothermal alteration
Qal	Quaternary alluvium
Qb	Quaternary basalt and basalt andesite
▨	Quaternary rhyolite domes, flows and tuffs, undivided
Ts	Tertiary Sevier River Formation terrigenous clastic sedimentary rocks/ lacustrine marls and subordinate limestone
Tr	Tertiary rhyolite (extrusive)
▬	Tertiary rhyolite porphyry (intrusive)
▨	Tertiary granite, fine-crystalline "fine-grained granite" (Tgr) *
▨	Tertiary granitic rock, undivided
▨	Permian Kaibab Limestone
▨	Permian Coconino Sandstone
▨	Precambrian biotite-hornblende quartz monzonite gneiss; hornblende gneiss (P€gn)*
■	Precambrian feldspar-quartz-biotite (±hornblende, ±sillimanite) gneiss; "banded gneiss" (P€bg) and "biotite gneiss (P€n) undivided *
— —	Fault, approximately located
~~	Photo-linear in Qal; probable fault

* Nielson and Others (1978)

FIGURE 1

Surface hydrothermal alteration is minimal or not readily detected and confined to areas of recent hot spring activity, fault zones, joint surfaces, and zones of base metal mineralization. Alteration in many of the holes drilled in the district and surface alteration associated with hot spring activity have been discussed by Bryant and Parry (1977), Ballantyne and Parry (1978), Parry (1978), Parry et al. (1978), Rohrs and Parry (1978), Nielson et al. (1978), Ballantyne (1978), and Hulen (1978). Hulen has documented the coexistence in alluvium of unaltered Pleistocene pumice and obsidian clasts with altered clasts of Tertiary intrusive rock and Precambrian gneiss, indicating that hydrothermal processes have been active within the general area prior to deposition of the alluvium.

Hot spring deposits in the Roosevelt thermal area consist of opaline and chalcedonic sinter and hematite, silica, calcite, or manganese-oxide cemented alluvium. Gypsum, opal, kaolinite and native sulfur occur in fumarole vent areas. Alluvium, felsic plutonic rocks, and amphibolite facies gneiss have been altered by acidic sulfate water to alunite and opal at and near the surface, and commonly to kaolinite, alunite, and montmorillonite between the surface and the top of the water table (depth about 100 feet). Marcasite and pyrite occur below the water table. Deeper alteration sampled to a maximum depth of about 7400 feet consists of muscovite, chlorite, calcite, K-feldspar, albite, and epidote with pyrite and sparse chalcopyrite (Parry et al., 1978).

Paleohydrothermal Events

One or more periods of hydrothermal alteration and mineralization have affected parts of the Mineral Mountain area prior to and probably unrelated to the development of the present geothermal system. Most known economic mineralization and concomitant mining activity in the range are confined to the southern portion of the Mineral Mountains in the Bradshaw District (T29S, R9&10W), where gold, silver, copper, lead, zinc, and tungsten have been produced from contact metamorphic deposits and associated veins (Earll, 1957 and Nielson et al., 1978). A limited number of malachite-stained prospect pits are present within and to the north of the KGRA. Nielson (personal communication, 1979) believes that hydrothermal events responsible for most of the mineralization were associated with Tertiary igneous activity and with the development of low-angle denudation faults and northwest-trending high-angle upper plate faults about 10 million years ago. The spatial distribution of prospects suggests that these two fault systems may have served as conduits for the mineralizing and rock-altering solutions. Throughout the Mineral Mountains area, Tertiary mineralization is characterized by copper, lead, zinc, gold, silver, tungsten and manganese (Crawford and Buranek, 1957; Earll, 1957; Bullock, 1976). Analysis of mineralized rock chip samples from a prospect pit in the KGRA (Table 2, sample 612) confirms the hydrothermal concentration of copper, lead, zinc, and manganese.

The geochemical signatures of this mineralization appear to be distinct from those associated with the geothermal system. The absence of these chemical associations from the materials analyzed, and the very limited evidence of mineralization within the study area suggest that geochemical distributions related to this older event do not seriously interfere with or confuse interpretation of the geothermal-related trace element geochemistry.

Epigenetic hydrothermal alteration of several generations is present in drill cuttings samples from all of the geothermal wells studied. Veinlet minerals which occur below the zone of acid alteration, in decreasing order of abundance, are: calcite, chlorite, quartz, sericite, epidote, pyrite, magnetite-ilmenite ± hematite, and K-feldspar (Jeff Hulen, personal communication). Anhydrite veins also occur, but are primarily confined to deeper portions of the wells. The veins and veinlets transect all lithologies and cross-cut one another. Similar vein assemblages have been observed in alluvial clasts adjacent to unaltered obsidian clasts (Hulen, personal communication), reasonably establishing the age of some of the veining as older than the alluvium and probably older than the present geothermal system.

Ballantyne and Parry (1978), Rohrs and Parry (1978), Ballantyne (1978), and Nielson et al. (1978) have described hydrothermal alteration characteristics from cuttings from the three geothermal test wells Utah State 14-2, Utah State 72-16, and Utah State 52-21. All lithologies in the three wells are, at least locally, altered to various assemblages of the minerals chlorite, sericite, clay, epidote, K-feldspar, hematite, and calcite in varying intensity throughout the entire depths of the wells. The presence of epidote, a mineral which normally forms only at temperatures greater than about 220°C (Zen and Thompson, 1974), throughout all well depths and lithologies, including the near-surface alluvium (in clasts), suggests a pregeothermal age for some occurrences of this mineral, possibly related to one or more of the five Tertiary intrusive events recognized by Nielson et al. (1978). Other epidote may simply have formed earlier in the history of the geothermal system when the reservoir was much larger than at present (see later discussion of large-scale zoning).

Major Hydrothermal Features of the System

Several major hydrothermal features or zones defined by hydrothermal features constitute important frames of reference for interpretation of the geochemical data. These include hot-water entries (HWEs), the reservoir zone, and the self-sealed zone. For the most part, the general nature of these features is indicated by their names, but additional definition is needed in order to eliminate ambiguity in the use of the terms "reservoir zone" and "self-sealed zone." Since this is the first time that the occurrence of self-sealing in the Roosevelt geothermal system has been described *per se* in published literature, it is also necessary that available physical evidence of its existence be summarized. The following information defines, describes, and/or locates these important features for later reference and completes the geologic description of the geothermal system.

Hot Water Entries

A minimum of 4 separate hot-water entry zones (HWEs) have been independently interpreted as occurring within sample intervals investigated in the three geothermal wells Utah State 14-2, Utah State 72-16, and Utah State 52-21 (hereafter 14-2, 72-16, and 52-21). Definition of the HWEs locations is based on interpretations of geophysical logs, mud logs, geologic data, and well summary report data (Glenn and Hulen, 1979).

Hot water entry zones occur in 14-2 between 1600 and 1800 feet and between 2850 and 2890 feet (Glenn and Hulen, 1979). Discrete entries are indicated to occur near the boundaries of the lower zone at 2860 and 2890 feet, but cannot be unambiguously distinguished within the upper zone.

Two discrete entries occur in 72-16 at 312 and 628 feet, with the deeper of these possibly contributing to well production through flow down the outside of the casing; cement bond logs have been reinterpreted to suggest only fair to good bonding was obtained below 435 feet in the well (Glenn and Hulen, 1979). Sample was obtained close to but above a major lost circulation zone at 1245 feet in 72-16, which could be the main producing zone in the well. Sample lag was estimated at one foot when loss of circulation occurred (Earth Science Lab., 1978a, 72-16 mud log), placing the origin of the last cuttings sample at or near 1244 feet.

Well 52-21 lacks detectable HWEs.

Reservoir Zone

The reservoir zone, as defined in this report, includes all rock with high-temperature reservoir potential, whether or not all of this rock actually constitutes a thermal aquifer. The term "zone" is used here as elsewhere in the report to describe a large volume of rock characterized by specific but not necessarily pervasively developed hydrothermal features, which in this case include high-temperature water entries. In the well intervals studied, only one of the four known HWEs, that between 2860 and 2890 feet in well 14-2, is considered to be located within the reservoir zone. The three other known HWEs are located near or within the reservoir margin in rock displaying evidence of self-sealing and have been included in the self-sealed zone (below).

In terms of thermal regime, the reservoir zone at Roosevelt is generally characterized by temperatures greater than 400°F (204°C) and indications from temperature gradient data (Glenn and Hulen, 1979) of predominant convective heat transfer.

Self-Sealed Zone

Combined surface alteration mapping and subsurface alteration and geophysical data suggest that an irregularly shaped shell of self-sealed rock has developed around the reservoir zone margin and locally forms a self-sealed capping along parts of the Opal Mound Fault. Physical evidence for the self-sealing consists primarily of the occurrence of hydrothermal features (alteration, limonite, and sulfide accumulations, and/or siliceous and carbonate cements) similar to those associated with active HWEs and hot springs in rock shown to be mostly impermeable by geophysical logging (Glenn and Hulen, 1979) and the absence of significant surface leakage. In well 14-2, the interval extending from 800 feet, possibly higher, down to about 1800 feet is broadly characterized by relatively strong alteration, prominent limonite and minor sulfide accumulations, and only local permeability, and is included within the self-sealed zone (Figure 2A). Detectable hot-water influx occurs only between 1600 and 1800 feet where the zone is transitional into the reservoir zone. In well 72-16 the self-sealed zone, defined by siliceous and carbonate cementation, broadly developed argillization, limonite accumulations, and limited permeability, is considered to extend from near the surface down to and possibly below 650 feet (Figure 3A). Except for the two discrete and probably minor HWEs at or near depths of 312 feet and 628 feet, the altered and sealed rock in 72-16 is relatively impermeable and is demonstrably capable at present of preventing significant leakage of the high-temperature fluids encountered between 1245 and 1254 feet to the surface. Alteration and limonite and sulfide accumulations, similar to but in part much less prominent than those developed in wells 14-2 and 72-16, are recognized in rock penetrated by the dry well 52-21 (Ballantyne, 1978; Glenn and Hulen, 1979; and, for sulfide distribution only, Appendix C, Figure C-1). Since the well is dry, fairly hot (bottom hole temperature is 206°C), and located within about one mile of the producing wells 72-16 and 25-15, the occurrence and nature of the hydrothermal alteration suggest that rock penetrated by 52-21 originally displayed low to moderate reservoir zone permeability and is now probably entirely self-sealed.

At and near the surface, a variety of geothermal features including hot springs deposits, calcite- and silica-cemented rocks, and prominent alteration zones (Hulen, 1978; Nielson et al., 1978; Parry et al., 1978) attest to relatively widespread leakage of thermal waters to the surface in the past. Since present leakage is minimal, this suggests a self-sealed capping has developed locally. Concentrations of the surficial geothermal features near the north and south ends of the Opal Mound Fault (Figures 1 and 8A), suggest that the self-sealed capping is most prominently developed in these two areas.

As will be shown below, the inferences of self-sealed zone development from alteration and geophysical data are also supported by the geochemical results, since multielement signatures unambiguously associated with active HWEs are also commonly associated with the older self-sealed fluid pathways which collectively define the zone.

DETAILED ELEMENT DISTRIBUTIONS IN GEOTHERMAL WELLS

Distributions of major, minor, and trace elements in suites of contiguous 10-foot whole rock cuttings samples have been determined for two wells, 14-2 and 72-16, in order to provide more detailed characterization of spatial relationships between hydrothermal chemical patterns and previously described physical features of the geothermal system including known hot water entries (HWEs), the reservoir zone (as an entity), and the self-sealed zone. Similar data, based on analysis of both whole rock and +3.3 sp. gr. concentrates from 100-foot composite samples, has been reported previously for both of these wells (Bamford, 1978) and are partly included with this report along with new composite data for the dry well Utah State 52-21. For 72-16 (total depth 1254 feet), 111 individual grab samples from the interval 85 to 1244 feet were analyzed. For 14-2 (total depth 6108 feet), 330 individual grab samples from the interval 77 to 3200 feet were analyzed. For 52-21 (total depth 7,600 feet), a total of 74 100-foot cuttings composites from the interval 60 to 7,500 feet were made and analyzed. Geochemical data were derived for both whole rock and +3.3 sp. gr. samples from these composites.

Evaluation of the geochemical data and results which follow can be most readily accomplished if the concepts of the reservoir zone and self-sealed zone developed above are specifically kept in mind. This will help avoid confusion of the zones *per se* with individual self-sealed aquifers which collectively make up the self-sealed zones and with individual HWEs which occur both within the reservoir zone and the self-sealed zone near the reservoir boundary. It may also be useful to keep in mind that self-sealed zones probably commonly develop over time and that hydrothermal features which characterize the zone will commonly be geologically younger if located in or near active parts of the system and older if located well away from active parts of the system. Such features can be expected to vary in frequency of occurrence and magnitude of development as a function of total permeability over the life of the system. In most instances it will be the occurrence of the feature rather than its intensity of development that will be important in assigning rock to one zone or another.

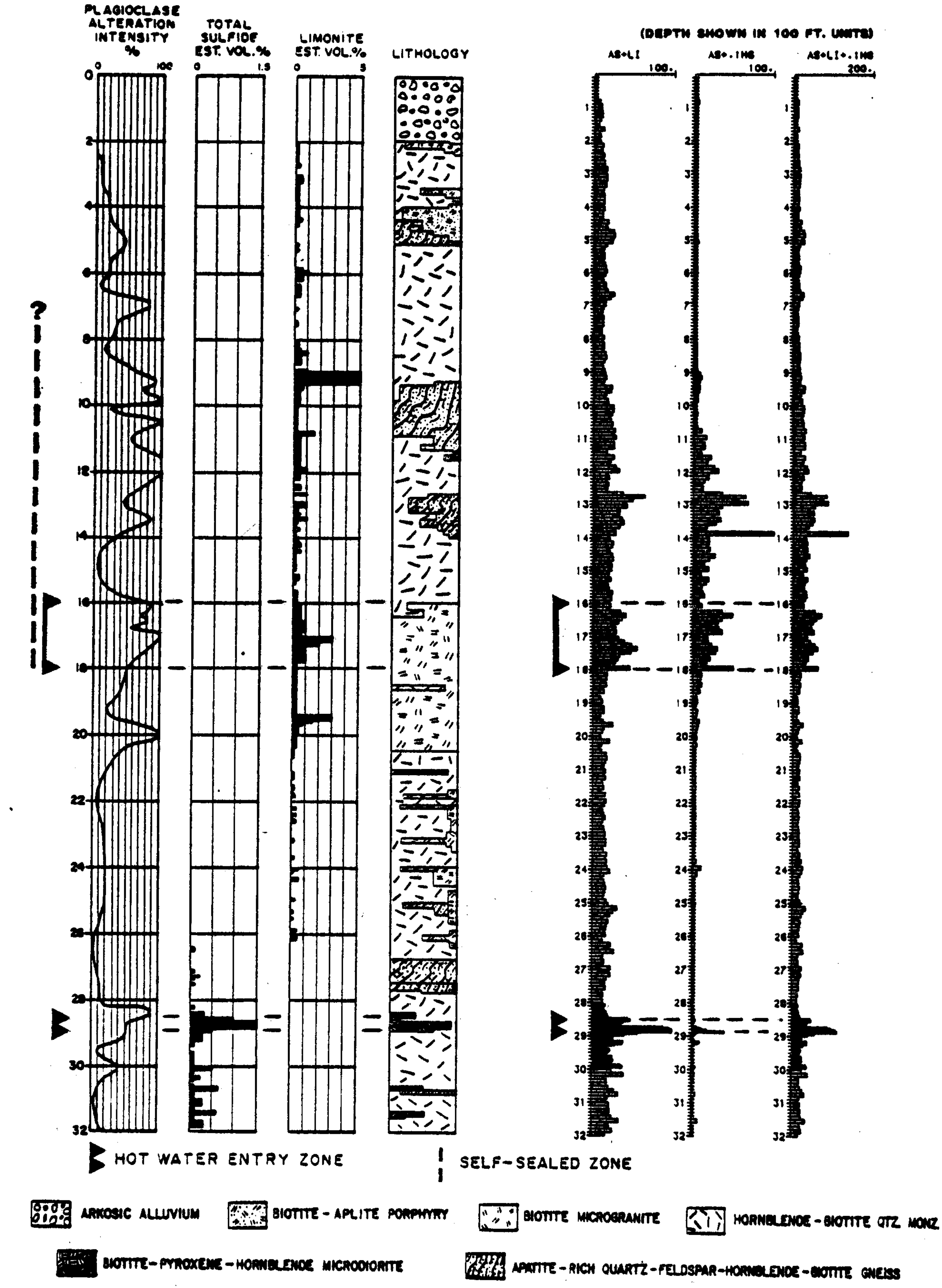
Minor and Trace Elements Anomalies of Geothermal Origin

Six minor or trace elements; As, Li, Hg, Sr, Zn and Mn, display evidence of pronounced, systematic, hydrothermal redistribution under subsurface geothermal conditions. Hydrothermal enrichments or depletions of these elements are large relative to element variations related to rock type. In addition or alternately they display consistent spatial relationships to known active HWEs and to self-sealed entries which collectively define the self-sealed zone.

Arsenic (As) and Lithium (Li)

As and Li display the most definitive and consistent hydrothermal behavior within the geothermal system. Anomalous concentrations of both elements are developed at or near all of the known active HWEs and are often confined to within ten feet of the entry (Figures 2B, 2C, and 3B, and Appendix E, Table E-2). Enrichments at the major(?) entries near 2890 feet in 14-2 and 312 feet in 72-16 are among the largest observed to date while those at the two remaining entries are similar in magnitude to anomalies elsewhere in these wells. These additional anomalies in both elements are most prominently

FIGURE 2A. GENERALIZED GEOLOGY, HOT WATER ENTRY LOCATIONS AND MULTIELEMENT PARAMETER PLOTS, UTAH STATE WELL 14-2



Geology and Alteration Data after Ballantyne and Parry, 1978, and Glenn and Hulen, 1979.

FIGURE 2B. As, Li, Hg, Sr, Na, Mn, Pb, AND Zn, WHOLE ROCK SAMPLES, UTAH STATE WELL 14-2

(DEPTH SHOWN IN 100 FT UNITS)

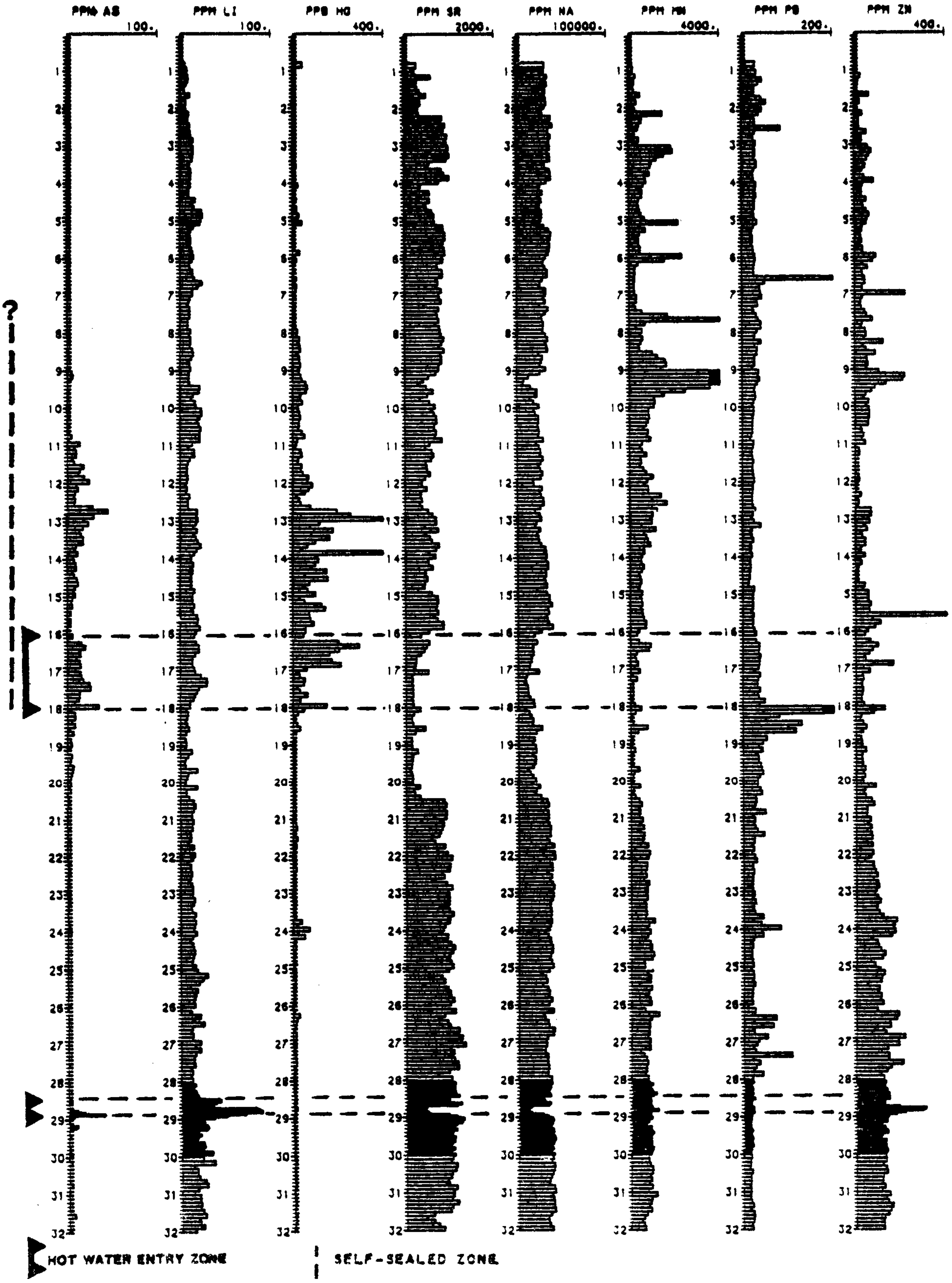


FIGURE 2C. Hg, As, Li Be, Na, and Zn CONCENTRATIONS LESS BACKGROUND VALUES, UTAH STATE WELL 14-2

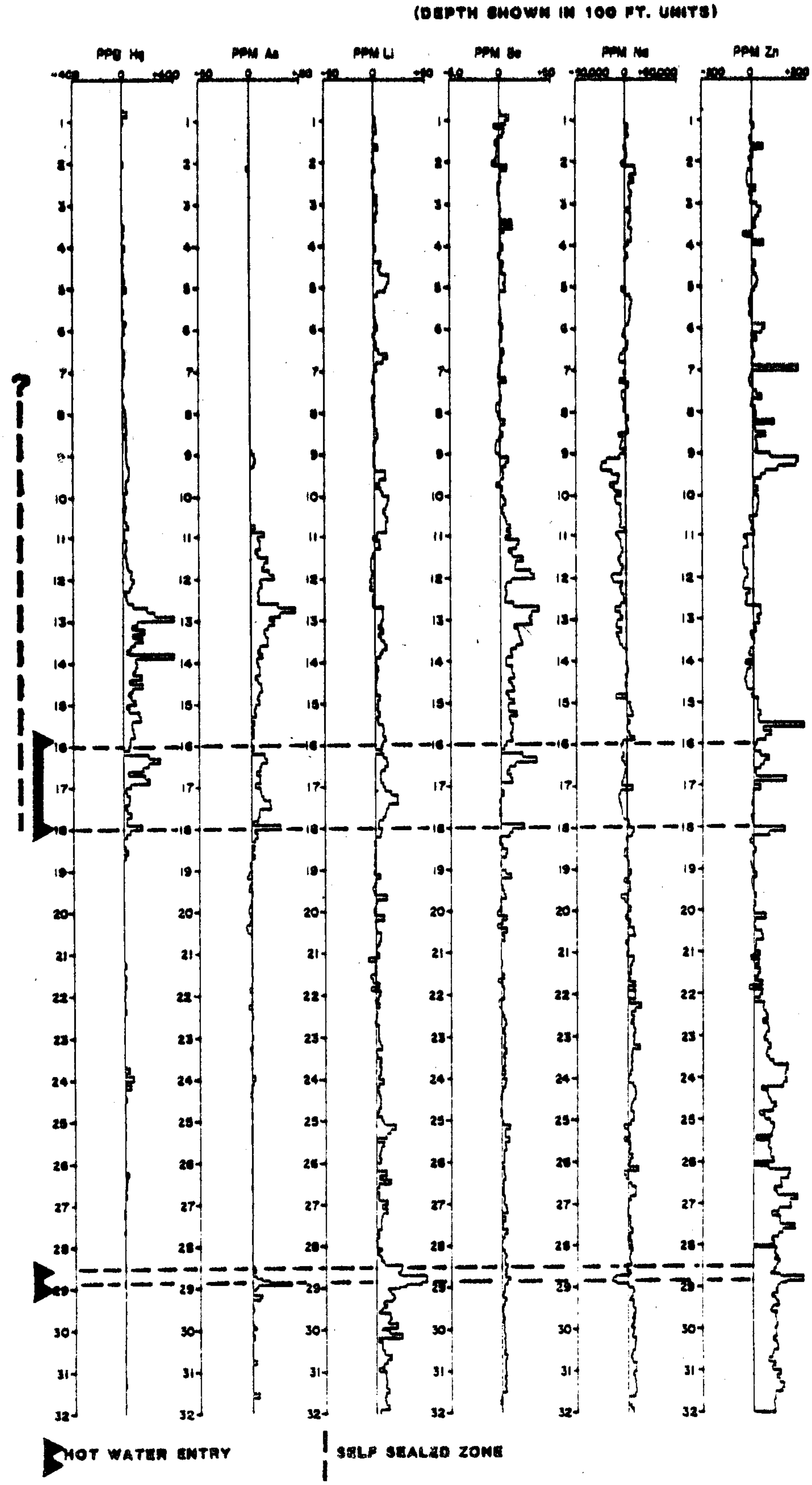


FIGURE 3A. GENERALIZED GEOLOGY, HOT WATER LOCATIONS, AND MULTIELEMENT PARAMETER PLOTS, UTAH STATE WELL 72-16

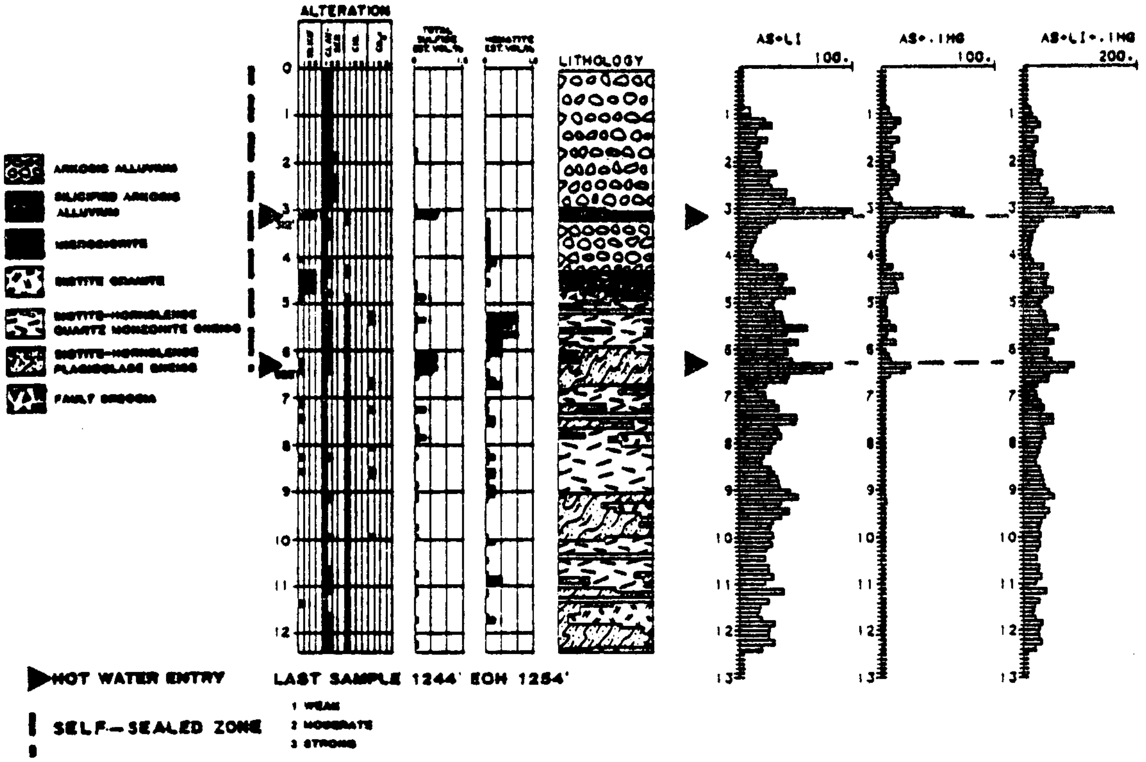
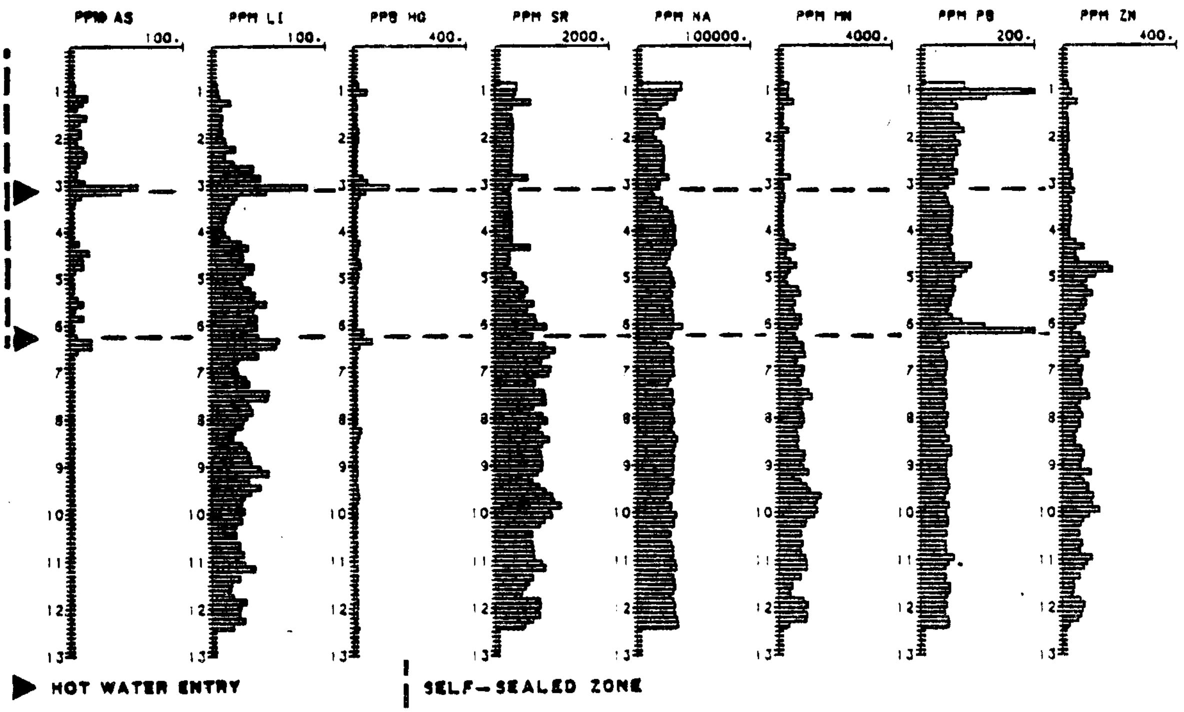

(DEPTH SHOWN IN 100 FT. UNITS)

FIGURE 3B. As, Li, Hg, Sr, Na, Mn, Pb, AND Zn WHOLE ROCK SAMPLES, UTAH STATE WELL 72-16


(DEPTH SHOWN IN 100 FT. UNITS)

Geology and Alteration data after Moore and Hulen (in Nielsen et al., 1978) developed within the self-sealed zone (e.g., Figures 2B, 2C, and 3B). Once having formed at an active HWE, the anomalies apparently commonly persist even when an entry becomes entirely self-sealed. The degree of enrichment of these elements near active and self-sealed HWEs is high compared to reasonable background values, ranging from 10- to 25-fold for As and about 2 to 9 fold for Li (cf. Figures 2A and 3A with Appendix E).

Additional widespread minor to moderate enrichment of Li without As is inferred for rocks in parts of 14-2 and throughout 72-16 based on comparison of Li in gneiss in these wells with Li in gneiss within the predominantly impermeable and weakly altered zone between 2800 and 5200 feet in well 52-21 (Appendix C, Figure C-2). Because of this broadly developed enrichment in and near the reservoir, calculated Li background values often constitute local backgrounds and make quantitative determination of the enrichment difficult for many of the rock types. Qualitative determinations can often be made, however; note for example the apparent enrichment of Li in the microgranite at the 1600 to 1800 foot HWE in 14-2 compared with the same rock immediately below the HWE between 1800 and about 2030 feet.

Mechanisms of As and Li deposition around HWEs have not yet been adequately investigated; however, limited information has been collected on possible or actual modes of occurrence of the elements (see discussion of "Mineralogical Occurrence" for details). Electron microprobe studies have shown that the principal mineral hosts for As are pyrite and hematite. Trace occurrences of realgar have been noted by Hulen (Appendix B, Figure B-4) and reported by other workers (Parry et al., 1978). Literature studies indicate that principal mineral hosts for Li are likely to be femic silicate minerals, in which Mg^{2+} may be replaced, and micas and clays which provide favorable structural sites (Wedepohl, 1978). Limited sampling and analysis of hydrothermally altered materials from the surface show that As is concentrated in opal deposits of the Opal Mound, in rocks and soils of hydrothermally altered areas, in manganese- cemented alluvium, and in vein-limonites. It is apparently not significantly concentrated in highly altered Hg-rich rocks immediately adjacent to fumaroles (Table 2). Li appears to be concentrated primarily in the rocks and soils of hydrothermally altered areas and in samples of limonitic vein materials.

Mercury (Hg)

Like As and Li, Hg is clearly concentrated within the self-sealed zone in well 14-2 (Figures 2B and 2C), near HWEs within the self-sealed zone in well 72-16 (Figure 3B), and throughout self-sealed rock in well 52-21 (Appendix C, Figure C-2). Hg differs from these elements, however, in that it appears to be significantly concentrated only at those active HWEs which are located very close to or within the inner margins of the self-sealed zone (for example, at the 1600 to 1800 foot entry zone in well 14-2 and the two HWEs in well 72-16), probably because these entries have in part been self-sealed themselves. Below about 2000 feet in well 14-2, Hg concentration remains low (generally <15 ppb) even at the prominent 2860 to 2890 foot entry zone (Figures 2B and Appendix B, Figures B-1A), suggesting that Hg deposition is probably inhibited under conditions existing throughout much of the reservoir. If this is correct and if the changes in conditions which cause initiation of Hg deposition are confined to the reservoir margins, it is likely that Hg

Table 2. Geochemistry of Selected Surface Samples, Roosevelt Hot Springs, Utah

Element	LQD	600	601-	601+	602-	602+	603-	603+	604	605	606	607
Na(%)	20(ppm)	.15	1.70	2.99	1.20	.25	2.43	3.03	2.06	1.55	2.90	1.79
K (%)	35	.14	2.27	2.95	1.95	.75	3.10	4.07	4.24	3.62	4.09	3.12
Ca(%)	12	.14	1.15	.94	.88	.21	1.07	.87	.33	.35	.48	.39
Mg(%)	12	.01	.64	.31	.59	.24	.58	.29	.10	.10	.13	.10
Fe(%)	25	.02	2.74	2.03	2.29	.86	2.38	1.52	.65	1.61	1.01	.74
Al(%)	14	.09	5.89	7.89	5.80	2.16	7.32	7.60	7.74	6.64	7.80	5.18
Ti(ppm)	2	19	2420	3540	3870	1250	3470	2450	1990	2370	1420	560
P	35	---	793	401	407	122	850	427	300	428	216	651
Sr	0.1	33	235	332	212	59	156	216	276	264	251	386
Ba	10	---	541	792	539	163	363	441	775	485	605	4.9%
Cr	5	---	33	21	34	14	16	6	6	7	---	9
Mn	10	388	682	497	504	168	1030	580	63	71	136	18.8%
Co	1	---	7	4	7	3	6	3	3	3	---	28
Ni	5	---	15	7	12	5	10	---	---	5	---	---
Cu	1	---	25	10	19	8	16	7	5	8	3	231
Mo	10	---	---	---	---	---	---	---	---	---	---	5
Pb	10	---	18	18	18	21	36	27	20	19	16	68
Zn	1	1	68	52	52	21	96	45	26	18	23	23
Cd	1	---	---	2	---	---	1	2	2	1	2	4
Ag*	2	---	---	---	---	---	---	---	---	---	---	<1
Au*	2	4	---	---	---	---	---	---	---	---	---	<.1
As*	1	145	4	8	17	51	1	2	2	6	1	858
Sb*	1	243	<1	<1	11	80	<1	<1	<1	11	<1	291
W	6	---	---	---	19	25	---	---	---	---	---	2940
Li	1	11	28	15	28	12	66	41	4	5	6	17
Be	0.2	99.8	2.3	2.6	2.5	2.6	5.6	4.9	3.0	2.8	4.3	18.6
Zr	2	---	89	50	107	36	81	46	32	32	23	17
La	2	---	63	69	39	14	52	42	36	44	20	37
Ce	10	---	103	120	59	19	83	66	54	70	28	42
Th	35	---	---	---	---	---	---	---	---	---	---	---
Hg*(ppb)	1(ppb)	352	239	167	650	1050	193	30	5690	5500	220	2210

* As determined colorimetrically; Sb, Au and Ag by AAS; Hg by gold film detector; all others by ICPQ.

--- Indicates analytical value less than ICPQ limit of quantitative detection (Appendix H). Other elements looked for but not detected include V, Te, and Sn.

Table 2 (cont.). Geochemistry of Selected Surface Samples, Roosevelt Hot Springs, Utah

Element	LQD	608	609	610	611	612	613	614	615	616	617
Na(%)	20(ppm)	.07	2.97	.65	.53	2.99	.22	2.11	.05	2.12	.31
K (%)	35	.26	5.21	3.83	.11	4.87	2.47	4.67	2.76	3.41	.28
Ca(%)	12	.06	.45	.33	.29	.20	.55	.36	.19	2.03	.13
Mg(%)	12	.03	.18	.19	.07	.05	.29	.09	.04	.15	.04
Fe(%)	25	.16	7.80	6.83	5.35	7.83	18.00	2.73	1.49	.22	.14
Al(%)	14	4.01	7.69	4.02	.94	7.45	2.77	6.62	10.90	7.16	.34
Ti(ppm)	2	2040	1650	965	536	801	465	484	3680	1500	122
P	35	336	279	444	234	338	1770	225	1570	406	47
Sr	0.1	266	131	167	47	273	241	233	542	362	58
Ba	10	326	2070	2770	866	1020	2250	854	411	567	---
Cr	5	24	---	---	---	---	---	---	32	---	---
Mn	10	173	2.6%	3.2%	9500	4300	8.6%	1.0%	---	---	---
Co	1	---	13	16	6	24	26	6	---	---	---
Ni	5	---	14	13	8	5	38	8	---	---	---
Cu	1	3	31	94	38	4.0%	86	20	6	4	3
Mo	10	---	29	17	32	28	54	---	---	---	11
Pb	10	15	82	54	24	671	292	41	---	17	---
Zn	1	7	610	678	123	918	1650	197	---	4	4
Cd	1	1	2	---	---	3	2	2	2	2	---
Ag*	2	---	---	---	<1	---	---	---	---	---	---
Au*	2	---	---	---	<.1	---	---	---	---	---	---
As*	1	5	13	7	10	17	46	10	9	3	3
Sb*	1	21	<1	<1	<1	5	<1	<1	<1	<1	10
W	6	29	---	---	---	---	---	---	---	---	---
Li	1	8	11	37	10	2	26	6	5	9	14
Be	0.2	3.4	3.1	7.1	1.8	3.5	9.4	3.8	0.8	3.1	1.1
Zr	2	42	14	8	---	5	5	4	17	18	4
La	2	34	306	119	16	55	163	34	74	50	6
Ce	10	56	406	261	48	101	181	50	122	71	15
Th	35	---	40	---	66	---	---	---	---	---	---
Hg*(ppb)	1(ppb)	49300	267	342	25	113	415	90	160	5440	48

* As determined colorimetrically; Sb, Au and Ag by AAS; Hb by gold film detector; all others by ICPQ.

--- Indicates analytical values less than ICPQ limit of quantitative detection (Appendix H). Other elements looked for but not detected include V, Te, and Sn.

Table 2 (cont.). Geochemistry of Selected Surface Samples
Roosevelt Hot Springs, Utah

Sample Number	Sample Description[1]
UTMM-600	Chalcedonic sinter from Opal Mound.
UTMM-601-	Soil: -80 mesh, 15 cm depth, on alluvium east of DH 72-16.
UTMM-601+	Soil: -10 to +80 mesh, 15 cm depth, on alluvium east of DH 72-16.
UTMM-602-	Soil: -80 mesh, 15 cm depth, poorly developed on Opal Mound.
UTMM-602+	Soil: -10 to +80 mesh, 15 cm depth, poorly developed on Opal Mound.
UTMM-603-	Soil: -80 mesh, 15 cm depth, on alluvium near DH 52-21. Location: 11600S 1900W.
UTMM-603+	Soil: -10 to +80 mesh, 15 cm depth, on alluvium near DH 52-21. Location: 11600S 1900W.
UTMM-604	Altered alluvium: channel sample from trench near fumarole.
UTMM-605	Altered alluvium near fumarole.
UTMM-606	Hematite-stained soil, 15 cm depth.
UTMM-607	Manganese-cemented alluvium.
UTMM-608	Altered alluvium from small pit on fumarole at Roosevelt Hot Springs.
UTMM-609	Limonite from veinlets in unaltered quartz monzonite.
UTMM-610	Quartz and limonite from veinlets in quartz monzonite. Location: 16450N 7500E.
UTMM-611	Hematite-cemented breccia from mylonite zone. Location: 19100N 10800E.
UTMM-612	Rock chips from malachite stained prospect pit area. Location: 12075N 3050E.
UTMM-613	Limonite from veinlets in unaltered quartz monzonite.

UTMM-614	Limonite from veinlets in unaltered quartz monzonite.
UTMM-615	Silica-cemented alluvium.
UTMM-616	Altered silica-cemented alluvium; some carbonate cement.
UTMM-617	Porous siliceous material: channel sample from trench near presently inactive fumarole.

1. Locations specified are relative to soil survey grid of Figure 8A. Locations of UTMM-601, 602, 604-609, 613-617 shown on Figure 8A.

distribution data of the type presented here can be useful in distinguishing reservoir zone HWEs from HWEs which have been or are being self-sealed and perhaps in providing an indication of the relative reservoir potential of rocks being penetrated by a well (e.g., at Roosevelt Hg continuously less than 15 ppb in well cuttings can provide a useful but, by itself, non-diagnostic indication of a relatively high reservoir potential; cf. data for 14-2 and 52-21, Figure 2B and Appendix C, Figure C-2).

Possible explanations for the observed Hg distributions include deposition in response to temperature decrease, to dilution of the thermal fluid by groundwater, and to increase in Eh or decrease in pH, to boiling, or to combinations thereof. Significant changes in thermal regime (essentially from convective isothermal to a conductive gradient with associated temperature decrease; Glenn and Hulen, 1979), possibly in hydrologic regime (increased groundwater mixing), and in Eh (an increase suggested by a transition from sulfides to limonites) take place at or near the reservoir boundary as distance from central parts of the reservoir increases, and could cause initiation of Hg deposition. Deposition of Hg (as HgS) in response to any or all of these changes would probably take place if the transporting agent for the Hg were either sulfide-bisulfide complexes (Weissberg, 1969; Dickson and Tunell, 1968; and Tunell, 1964), or chloride complexes (Kolonin and Ptitsyn, 1972), which are two of the more likely transporting agents for Hg in geothermal brines.

Unusually large concentrations of Hg occur immediately below the surface in rocks penetrated by DDHs UU75-1A and UU76-1 (Appendix B, Figures B-3A and

B-3C). These are developed above the present water table within self-sealed cap rock and may reflect enhanced primary Hg deposition from aqueous solutions during periods of refracturing and leakage to the surface. It may also result in part from adsorption of elemental Hg on fine-grained alteration minerals after remobilization or direct vapor transport (see below).

Evidence that Hg transport and deposition can be largely separate from that of other elements is provided by samples taken in proximity to fumaroles. These samples display high Hg concentrations but contain low or no anomalous concentrations of other elements which accumulate at HWEs such as As and Li (Table 2, Samples 604 and 605). Apparently, Hg enrichments at these locations primarily reflect vapor transport coupled with the unique tendency of Hg to be strongly partitioned into a vapor phase (e.g., see Robertson et al., 1978).

Strontium (Sr)

Sr is strongly depleted at the 2890 foot HWE in well 14-2, and is possibly also slightly depleted at the two entries in well 72-16 (Figures 2B and 3B, and Appendix E, Table E-2). The amount of depletion is small relative to variations in total Sr due to changes in rock type and therefore must be interpreted with care. Similar Sr depletions have been documented in hydrothermally altered oceanic basalts (Humphris and Thompson, 1978). Sr depletion indicated by raw concentration data can be used directly to corroborate identification of a HWE defined by As and Li (± Hg) anomalies.

Zinc (Zn) and Manganese (Mn)

Mn and Zn exhibit locally strong, spatially associated enrichments which are largely confined to rock above and within upper parts of the self-sealed zone in wells 14-2 and 52-21. Spatially associated enrichments of these elements are either poorly developed or absent from lower parts of the self-sealed zone and, in 14-2, from immediately adjacent parts of the reservoir zone (Figures 2B and 2C and Appendices B and C, Figures B-1A, B-1C, C-2, and C-4). This relationship is further illustrated by the lack of large concentrations of Mn and Zn in samples from the well 72-16 and from diamond drill holes UU75-1A and UU76-1, which penetrate self-sealed rocks and, in 72-16, the adjacent reservoir zone (Figure 3B and Appendix B, Figures B-2A, B-2C, B-3A, and B-3C).

Deeper within the reservoir zone, Mn appears to generally remain unchanged (approximately at background concentrations), while Zn is enriched, both broadly and at HWEs. The relatively high concentration of Zn at and around the 2890 foot HWE in well 14-2 (Figures 2B and 2C, and Appendix E, Table E2) provides clear evidence of this enrichment. Similar but much more pronounced enrichments of Zn within high temperature hot-water reservoirs have been noted at the Broadlands, New Zealand (Browne and Ellis, 1970; Browne, 1971; and Ewers and Keays, 1977) and in the Imperial Valley, California (Skinner et al., 1967). It is interesting to note the general similarity of the hydrothermal assemblages in all of these examples (i.e., Zn ± As [illegible] Pb, relatively abundant pyrite, and epidote) to those of outer halo assemblages in porphyry copper systems. The pronounced differences between Zn distributions indicated by whole rock data and +3.3 concentrate sample data (Figure 2B and

Appendix B, Figures B-1A and B-1C) are unusual and not fully understood. Two possible explanations are that, where Zn is low in +3.3 concentrates and high in whole rock samples, the Zn bearing phase is extremely fine-grained and thus remains with the less than +3.3 specific gravity fraction or that the Zn simply occurs in a low specific gravity phase. Whatever the explanation, the whole rock data probably more accurately reflect actual Zn distribution where these discrepancies exist.

These data indicate that Zn and Mn probably developed associated anomalies in rocks peripheral to the reservoir and that Zn without accompanying Mn is also enriched within the reservoir, producing a bimodal distribution. These findings for Zn correct and supplant earlier tentative conclusions regarding Zn distribution in the Roosevelt geothermal system (Bamford, 1978).

Lead (Pb)

The detailed well geochemistry reported here and the discovery of Pb impurities introduced during drilling require that previous conclusions regarding the nature and utility of small-scale Pb zoning peripheral to HWE [illegible] (Bamford, 1978) be modified and at least temporarily de-emphasized.

Lead impurities introduced during drilling significantly [illegible] interpretation of lead distributions in geothermal wells, [illegible] identified and their effect at least partly eliminated if [illegible] information is available. The principal source of these [illegible] metallic lead cores of plastic ball components of float [illegible] collars and possibly of plastic plugs in multiple stage [illegible]

Bristol, Halliburton Mfg., personal communication). Thus lead impurities will primarily occur in samples taken shortly after a section of casing or liner has been set and cemented in a well. Five casing runs were made in wells 14-2 and 72-16 before completion of sampling and prominent lead concentrations were detected in samples from immediately below four of these (i.e. below 650 feet and 1805 feet in 14-2 and 85 feet and 580 feet in 72-16; compare with Figures 2B and 3B). Much of the lead contaminant appears to be flushed out of the drill hole in the course of an additional 30 to 40 feet of drilling below the casing shoe, thus imposing useful limits on where the contamination is most likely to occur in mud drilling systems (air drilling may give rise to a different dispersion of the lead). The most obvious lead contamination in wells 14-2 and 72-16 is manifest as a single element anomaly while probable hydrothermal lead appears commonly to be sympathetically distributed with Zn (Figures 2B and 3B), thus tentatively suggesting associated geochemistry as an additional criterion for distinguishing between the two. For purposes of the following discussion all lead anomalies in samples from the intervals zero to 40 feet below the casing shoes in wells 14-2 and 72-16 are considered to result from introduced impurities. The prominent lead anomaly between 1805 and 1900 feet in 14-2 is suspect because a reamer had been added to the drill string starting with this interval and possibly increased the depth to which lead contaminants appeared in the cuttings.

Distribution data for probable hydrothermal Pb (Pb corrected for impurities) suggest that weak anomalies are developed somewhat randomly on a scale of tens of feet within the reservoir zone in association with sympathetic Zn concentrations of similar magnitude. These associated weak anomalies occur away from HWEs and are not obviously related in origin to the HWE. At or near HWEs, Pb remains constant or may be slightly enriched (Figure 2B and Bamford, 1978, Figures 3/14-2 and 6/14-2). Differences between these results and the peripheral zoning around HWEs previously reported for Pb and Zn (Bamford, 1978), derive not only from the subsequent recognition of the lead contamination problem but also from a significantly improved whole rock sample frequency (previously only 100-foot composite samples were used). It now appears that Pb geochemistry is of little if any practical importance in the Roosevelt geothermal system, but could be of value in other hot-water systems.

Antimony (Sb)

The relatively limited data obtained thus far to define Sb distribution suggest that this element is commonly deposited in close spatial association with As. Subsurface data, available for wells 72-16 and 52-21 only, show that Sb is closely associated with As and Hg enriched intervals in well 72-16 (cf. Figure 3B and Appendix A, Figure A-2C and see Appendix B, Figure B-2A) and is essentially absent (<1 ppm; distribution not shown) from the relatively As-poor rocks in well 52-21 (Appendix C, Figure C-2). Sb was not detected in intervals enriched in Hg but lacking As in either well. Limited surface data show anomalous Sb concentrations occur near and in part with As, Hg, and W trace element anomalies developed in soils over the Opal Mound Fault (Figure 9 and Table 2, sample 602) and in a variety of hot-spring (and fumarole?) deposits (Table 2, samples 600, 605, 607, 608, and 617).

It is probable that general associations of Sb with geothermal features will be similar to those of As, except that Sb concentrations are not as specifically developed at HWEs (Appendix A, Figure A-2C). More work is required to determine if routine determination of Sb in addition to As would be useful in exploration applications of solids geochemistry.

Beryllium (Be)

Be appears to be weakly concentrated at HWEs, moderately to strongly concentrated in self-sealed zones and is possibly also concentrated in the very near-surface environment (Figure 2C and Appendices A and C, Figures A-1C, A-2C, and C-17). Enrichments appear to be usefully documented only in the whole rock geochemical data, reflecting the predominantly lithophile character of the element. They are similarly distributed but less pronounced than those for As and Li, and thus may be of subordinate utility. Be is also shown to be highly enriched in the opal-rich material deposited above the Opal Mound Fault and moderately enriched in Mn-cemented alluvium (Table 2, samples 600 and 607).

Boron (B), Tungsten (W), and Molybdenum (Mo)

It is apparent that hydrothermal concentrations of B, W, and Mo in rock develop in geothermal systems but at Roosevelt are either not defined or are inadequately documented and understood. Therefore, development of useful generalizations regarding their nature is not possible at this time.

B has been tentatively shown to occur in anomalous concentrations in rock from within or near producing zones at The Geysers, California, (Bamford, 1978, Figures 10/G-1 and 10/G-1R) and is known to occur in relatively high concentrations in thermal fluids at Roosevelt (Appendix, Table G-1) and many other geothermal systems, including steam condensate at The Geysers (e.g., Cosner and Apps, 1978; Howard et al., 1978; Robertson et al., 1978, Table 1).

Anomalous W concentrations are developed at Roosevelt in several types of hot spring deposits (Table 2, samples 607 and 608) and in association with As and Hg anomalies in soils over the Opal Mound Fault (Figure 9 and Table 2, sample 602). Widespread W anomalies are possibly developed peripheral to the reservoir (see discussion of "Near-Surface Large-Scale Element Distributions"). Consistent with this interpretation, anomalous concentrations of W are observed in well 52-21 (Appendix C, Figures C-11 and C-17) but could be in part or entirely of nongeothermal origin. Relatively high W concentrations are a common characteristic of geothermal waters in general (e.g. Bowman et al., 1977).

Weakly anomalous concentrations of Mo, detected in +3.3 sp. gr. samples only, occur in general association with Zn and Mn in the interval between the surface and the self-sealed zone in well 14-2 (Appendix B, Figure B-10). A pronounced enrichment of Mo also occurs at the 2860 to 2890 HWE in well 14-2. Like W, Mo anomalies appear to be mainly developed peripheral to the reservoir and are broadly developed in well 52-21 (Appendix C, Figures C-9 and C-16) but might similarly be of non-geothermal origin.

Major Elements Anomalies of Geothermal Origin

A fringe benefit in using an ICPQ as the principal analytical tool in this work has been the necessary acquisition of a broad spectrum of good quality major element data which might otherwise have not been justified. As with most emission spectrometers, the ICPQ must be capable of determining many potential matrix elements, whether or not of immediate interest, in order to provide the spectral interference corrections necessary for production of good quality minor and trace element data. To date the principal use made of the major element data has been in qualitative verification of geologic logging of lithology and alteration (cf. Figures 2A and 3A and Appendix A, Figures A-1A, -1B, -1C, and A-2A, -2B, and -2C). A significant potential for development of a more quantitative computer-facilitated approach to utilization of such data is recognized but has yet to be developed.

Regarding more immediate goals of this work, most individual major element concentration variations due to hydrothermal processes appear to be inconsistent, to lack definition, or to be overwhelmed by compositional variations related to differences in rock type, and thus are not readily utilized in geochemical zoning schemes. One possible exception to this, however, is the element sodium.

Sodium (Na)

Distribution data for Na suggest that, like Sr, this element is depleted at HWEs and within the self-sealed zone (Figures 2B, 2C, and 3B, and Table 4). The amount of depletion is again small relative to total element concentration variations due to changes in rock type and therefore must be interpreted with care. As for Sr, the depletions indicated by raw concentration data can be used directly to corroborate a HWE location indicated by As and Li (± Hg) anomalies.

Other Element Anomalies of Geothermal Origin

Several other elements are indicated to be transported and deposited in the geothermal environment but yield results which are insufficiently consistent or interpretable (due mainly to complicated element behavior or, in a few instances, to poor quality data) to permit incorporation into predictive geochemical schemes at this time. Elements in this category include Mg, Fe, P, Ba, V (data not shown), Cr, Co, Ni, Cu, Zr, La, and Ce. Except for Ba, most of these elements appear to be variably concentrated at HWEs, especially the 2860 to 2890 reservoir zone entry in well 14-2 (Table 4 and Appendices A, B, and C), and within the self-sealed zones. Many may also be more broadly enriched within the reservoir zone. Ba is possibly depleted in the vicinity of HWEs, but this is not directly supported by data for the 2860 to 2890 entry zone in well 14-2 (Table 4). More and, for some elements (particularly P and V), better quality data are needed to facilitate a more complete evaluation of hydrothermal distributions of these elements.

Mineralogical Occurrence

Studies were undertaken in order to establish the mineral composition in drill chip samples, +3.3 specific gravity concentrates and magnetic separates, and to identify the mineralogical location of those trace elements with distributions apparently related to the geothermal system. The semi-quantitative mineral composition of +3.3 specific gravity concentrates (19 samples) and magnetic separates (3 samples) were determined by petrographic examination. Paragenetic and intergrain relationships were established by examination of polished thin sections of drill chips (10 samples). Efforts to identify the mineralogical location of trace elements by electron microprobe were only partially successful due to the low concentrations present relative to the detection limits of the method.

Minerals frequently present and abundant in the +3.3 specific gravity concentrates include pyrite, hematite, ilmenite, zircon, leucoxene, sphene, epidote and allanite. Hulen (in Nielson et al., 1978) has reported the local presence of traces of scheelite as a primary constituent of Tertiary biotite granite. Although not identified here, scheelite should also separate into the +3.3 specific gravity fraction. Magnetite, various rock-forming silicate minerals, calcite, drill steel and, less frequently, lead and copper shavings have been found as contaminants. The magnetic fraction consists of magnetite and hematite, both present in some abundance and frequently intergrown. Contaminants in the magnetic fraction include pyrite, drill steel and various silicate minerals.

Pyrite occurs as euhedral to subhedral grains disseminated throughout the rock as fracture fillings. Most pyrite occurs as euhedral grains in veinlets containing one or more of the minerals quartz, epidote, sericite, pyrite, calcite, or chlorite. These veinlets clearly cross-cut and post-date all igneous and most metamorphic textural elements. Occasionally pyrite is surrounded by, or replaced by, pseudomorphous hematite. A few grains of chalcopyrite and sphalerite were found as discrete blebs within or about the rims of the larger pyrite grains.

Zircon, sphene and allanite occur as euhedral primary igneous and metamorphic grains. The sphene is frequently altered to a fine-grained aggregate of quartz, calcite, iron oxide and leucoxene, especially in the near-surface samples. Epidote occurs within the quartz-epidote-sericite veinlets or within altered plagioclase grains. Allanite, zircon, and epidote all appear to have been unaffected by later hydrothermal or supergene alteration.

Magnetite occurs as euhedral to subhedral primary igneous and metamorphic grains in drill chip thin sections. Grains are frequently rimmed or replaced by hematite in complex bladed intergrowths. Examination of drill chips by binocular microscope suggests a greater abundance of finely disseminated hematite near fluid entries (Hulen, personal communication) although this is not evident from limited examination of thin sections.

Arsenic is present as a minor constituent of both pyrite and hematite. The distribution of As within a grouping of pyrite grains in gneiss from well 72-16 is shown in Figure 4. The maximum As content determined was 3.7 weight percent. Although Clarke (1960) has suggested approximately 0.5 weight percent as the limit of As solid solution in pyrite, Fleisher (1955) cites several occurrences with greater concentrations and suggests 5% as an approximate maximum. Optically, the pyrite grains appear to be uniform; no discrete arsenopyrite grains were detected during petrographic examination or with electron microprobe scanning. The As content is highly variable within and between pyrite grains, and shows no apparent regular variation between core and rim. Occasional rims of hematite about arsenical pyrite, or hematite pseudormorphs after pyrite, contain as much as 0.6 weight percent As and in one case also a trace of V (0.5%). Parry et al. (1978), and Hulen (in Nielson et al., 1978) report the presence of traces of realgar associated with opal and native sulfur in altered alluvium.

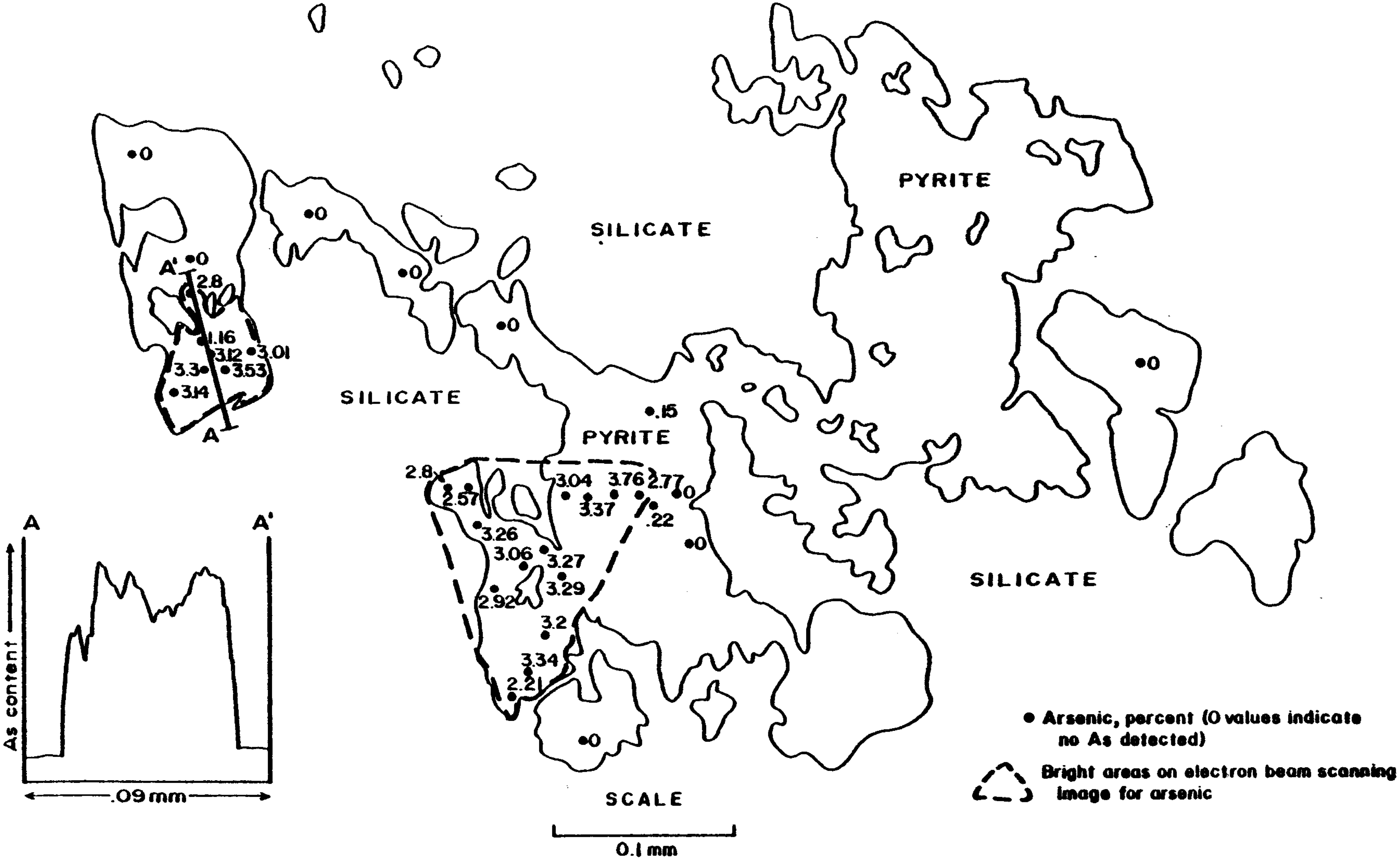


FIGURE 4 ARSENIC DISTRIBUTION IN PYRITE. DRILL CUTTING ROCK CHIP SAMPLE FROM 310'-320', WELL 72-16, ROOSEVELT HOT SPRINGS KGRA, UTAH.

The distributions of other elements associated with sulfide minerals are similarly variable. Pyrite grains occasionally have associated small grains of chalcopyrite and sphalerite, either within the grain or immediately adjacent to it. One pyrite from 1210'-1220' in well 72-16 is surrounded by small chalcopyrite grains and contains 1-3% Ni, apparently uniformly distributed throughout. Adjacent pyrite grains in the same drill cutting chip however are not associated with chalcopyrite and are devoid of any detectable trace constituents. Hulen (in Nielson et al., 1978) reports the presence of traces of chalcopyrite distributed irregularly throughout Roosevelt well cuttings and has documented the occurrence of occasional grains of bornite. Parry et al. (1978) have identified minor amounts of cinnabar associated with realgar, opal, and native sulfur in altered alluvium.

Allanite is a common component, apparently of primary igneous or metamorphic origin, in the basement rocks of the Roosevelt area. Electron microprobe energy dispersive analysis confirms the presence of 3-5% Ce, 2-3% La, and 1-3% Ag in allanite grains.

Contaminants in the samples contribute some trace element components to the sample chemistry. Samples from wells 72-16 and 14-2 both contain grains up to 0.2 mm diameter of nearly pure metallic Pb with about 0.5% Sr. A single grain observed in one +3.3 concentrate sample from geothermal well 72-16 was analyzed to be about 85% Zn with 1-2% each of Fe, Mn, Ti, Ca, S, Si and Sr. Analyses of drill steel shavings average about 94% Fe, 4% Cr, 1% Mn, 0.4% Si, 0.2% Mo, and 0.1% Ni. Cu shavings were observed but not analyzed. Introduction of these contaminant grains occurs during drilling and their presence is unavoidable. Fortunately, their abundance is limited and the magnitude of the contamination does not appear to be sufficient to obscure natural geochemical distribution patterns. Pb is the exception in this regard (see discussion above).

Mineralogical hosts for other trace and minor elements have not been determined but can be inferred from other evidence or reported occurrences. The fact that the concentrations of some elements are significantly enhanced in the pyrite-rich and oxide-rich +3.3 specific gravity concentrates suggests that they are present in the sulfide, oxides, and other +3.3 specific gravity phases. Ewers and Keays (1977), in their study of volatile and precious metal zoning in the Broadlands geothermal field, New Zealand, found that none of the trace elements they studied (Au, Ag, As, Sb, Tl, Se, Te, Co and Bi) formed recognizable discrete phases but rather were contained in solid solution in pyrite and base metal sulfides. They concluded that the more abundant sulfide phases precipitated from the Broadlands waters may have coprecipitated trace amounts of the minor elements, especially those of chalcophile character, through adsorption and incorporation into the sulfide structure. The detected presence of As and Ni in pyrite grains in this study suggests that this model may in part apply to some of the same elements at Roosevelt. Many of these and other important geothermal trace elements, however, also occur in oxide minerals (e.g., As in hematite), as discrete sulfide phases (e.g., As as realgar and Hg as cinnabar), and probably in silicate phases (e.g., Li and Be).

Identifying Locations of Hot-Water Entries

Distribution data for six elements are shown to provide useful indications of HWE locations in hot-water geothermal systems (above). The six elements are As, Li, Hg, Be, Sr, and Na. Of these, As and Li (and Be?) are by far the most reliable HWE indicators. These elements, along with Hg in peripheral parts of the reservoir, form concentrations at HWEs which are usually unambiguously anomalous compared to reasonable background values for individual rock types. Typically, Sr and Na appear to be depleted at HWEs but, because background values are higher and more variable, these depletions are not as readily established as anomalous. These element distributions can be utilized collectively to provide reliable information on HWE locations in wells drilled in hot-water geothermal systems.

In order to simplify and increase reliability of HWE location predictions, data for the elements As, Li, and Hg can be usefully combined and plotted as multielement parameters (e.g., Figures 2A and 3A). Because anomalous concentrations of these elements correlate positively with HWE location, the data sets are added and plotted directly. Hg values (in ppb) are multiplied by 0.1 before combination with unmodified As and Li values (in ppm) to give each data set an approximately equal weighting. The weighting procedure is based on inspection of available data and probably can be further refined as additional information on the relative reliability of individual elements is obtained. Use of raw data, as in these examples, should usually provide useful results since background variations for the elements, especially for As and Hg, are relatively small. Of the three parameters presented, that incorporating data for As, Li, and Hg is probably the most reliable; the utility of the As-Hg parameter is limited by the lack of Hg deposition within central parts of the reservoir and the As-Li parameter is affected somewhat by variation in Li related to rock type. Adjustment of the Li data by subtracting out mean background values for individual rock types (e.g., see Figure 2C) would probably significantly improve parameters incorporating this element. Optimum parameters for HWE location would possibly be As+Li+Be or (As+Li+Be)/(.1Na+Sr), if the data used were completely adjusted for background variations.

At Roosevelt, locations of three of the four known HWEs in Utah State Wells 14-2 and 72-16 are unambiguously predicted within about 10 feet by the multielement parameters and are verified by depletions in Na and Sr. The location of the fourth HWE, the entry zone between 1600 and 1800 feet in well 14-2, is also reasonably predicted but cannot be clearly distinguished from the geochemistry of the encompassing and overlying self-sealed rocks.

The problem of distinguishing between many self-sealed and active HWEs is probably not as significant as it first appears since it is likely that chemical differences between the two can often be recognized. At Roosevelt, for example, compared to active entry zones the impermeable outer part of the self-sealed zone is seen to be characterized by local high manganese and zinc enrichments. In addition the entire self-sealed zone, including the active HWEs within its innermost parts near the reservoir zone, is characterized by very high Hg enrichment. Additional data must be obtained, however, in order to test the validity of and to broaden distinguishing criteria. For the present, users of this technique should be aware that hydrothermal anomalies in some key elements, especially As and Li, will probably persist around paleoentry zones. Despite this complication, the technique is still highly predictive and should be of value in many phases of drilling and completing geothermal wells.

Predicting Approach to the Reservoir Zone

The self-sealed zone indicated to be broadly developed around the margin of the geothermal reservoir at Roosevelt has readily recognizable geochemical characteristics which can provide a reliable and inexpensive method of predicting approach to the reservoir zone during the drilling of an exploration well. All that is required is real time chemical analysis of cuttings samples for a limited suite of elements including As, Li, and Hg, and possibly Zn and Mn. The approximately 800-foot thick section of the self-sealed zone in well 14-2 provides an example of how this might work.

A first meaningful indication of approach to the reservoir zone and the HWEs near its outer margin in drill hole 14-2 is provided by the gradual and continuous increase in Hg which begins at about 780 feet (Figure 2B). Hints of a potential subjacent reservoir zone are indicated by erratic low-level Hg and As anomalies higher in the hole associated with locally anomalous concentrations of Mn and Zn, a chemistry which probably characterizes a useful outer halo assemblage in a large-scale zoning scheme applicable to hot-water geothermal systems (Bamford, 1978 and following section, this report). Hg increases somewhat irregularly but continuously from 780 feet to and beyond 1070 feet, where the upper limit of a continuous arsenic anomaly is encountered. Below this point, anomalous concentrations of Zn and Mn are essentially absent, while variable but generally high concentrations of Hg and As persist down to 1600 feet where they merge imperceptively into the anomalous chemistry of the upper, 1600 to 1800 foot, entry zone. This HWE lies within the inner margin of the self-sealed zone as defined earlier but, in the context of the observed chemical zoning, provides good evidence of proximity to the reservoir zone. Below about 1900 feet, Hg concentrations decrease markedly; As and Li display erratic low anomalous concentration; and Zn (possibly plus P, B, Zr, La, and Ce) concentration increases and becomes broadly anomalous in most rock types, providing general geochemical evidence of a high-temperature reservoir environment. Several hundred feet of fairly diagnostic continuously anomalous geochemistry thus provide a good indication of approach to the reservoir zone several additional hundreds of feet before the reservoir zone is reached.

A note of caution is warranted regarding this example, however, since part of the self-sealed zone in 14-2 is probably unusually well developed. Had permeability been lower or less pervasively developed in the vicinity of the reservoir margin, self-sealed zone geochemistry would probably have been less pronounced and correspondingly more difficult to interpret. Intermediate depth rock in 52-21, which is probably entirely self-sealed, provides what might be considered a worst case example of the problem of interpreting self-sealed zone geochemistry developed in low permeability rock (for details see section entitled "A Generalized Zoning Model for the Roosevelt Geothermal System").

NEAR-SURFACE LARGE-SCALE ELEMENT DISTRIBUTIONS

Previous documentation of large-scale element zoning at Roosevelt by analysis of composited cuttings samples from shallow temperature gradient holes (Bamford, 1978) has been improved through expansion of both sample coverage and the spectrum of elements determined (for whole rock samples only) including the addition of Hg geochemical data. Acquisition of samples from eleven additional gradient holes, located primarily in the northwestern part of the KGRA, and one additional well increases total sample coverage to 32 sites within an approximately 170 square mile area (see Figure 1 for sample locations). Representative data are presented in map form for both whole rock samples and plus 3.3 sp. gr. fractions (less magnetics) derived from cuttings composites samples representing the depth interval 100 to 200 feet (Figures 5 to 7, and Appendix D). Data have also been derived for samples representing two other depth intervals, 0 to 100 feet and 200 to 300 feet, and are available for open-file inspection at ESL/UURI in Salt Lake City.

To facilitate description of spatial relationships between temperature gradient hole cuttings geochemistry and the geothermal resource at Roosevelt, the area within which all known producing wells are located (Figure 1) is delimited on the chemical distribution maps. This area is considered to reasonably outline nearer-surface parts of the reservoir, but probably is not relatable to the overall subsurface extent of the resource.

Anomalies of Definite to Probable Geothermal Origin

Arsenic (As), Mercury (Hg), Zinc (Zn), and Manganese (Mn)

The development of systematic large-scale hydrothermal trace element zoning above and around the geothermal reservoir at Roosevelt is best demonstrated by distribution data for the elements As, Hg, Zn, and Mn (Figures 5A, B, and C and 6A, B, C, and D). As and Hg anomalies are closely associated with geothermal phenomena such as active hot-water entries, zones of self-sealing, fumaroles, and more broadly with the area immediately overlying the known resource itself (see foregoing section and Figures 5A and 6A, B, and Table 2), and thereby are reasonably established as geothermal in origin and as potential indicators of proximity to the reservoir. In general, Zn and Mn anomalies are peripheral to the known resource area (Figures 5B, C and 6C, D), are equally well-developed in older lithologies and the Quaternary alluvium (cf. Figure 1), and have no obvious potential source other than the geothermal system (e.g., there is no evidence of appropriately located older mineralization nearby which might have been eroded to produce these anomalies in their present configuration). They, therefore, are also probably of geothermal origin and are potentially diagnostic of weak hydrothermal activity at the outer fringes of the system. The peripheral Zn anomalies differ from those developed within the reservoir (see previous discussion) both with respect to the environment in which they are found and their hydrothermal element associations, and thus are unlikely to be misidentified. Definition of the peripheral Zn and Mn anomalies, and thus perhaps of overall zoning relationships, is most effectively accomplished using +3.3 sp. gr. samples rather than whole rock samples (cf. Figures 5A, B, and C and 6A, C, and D), possibly in

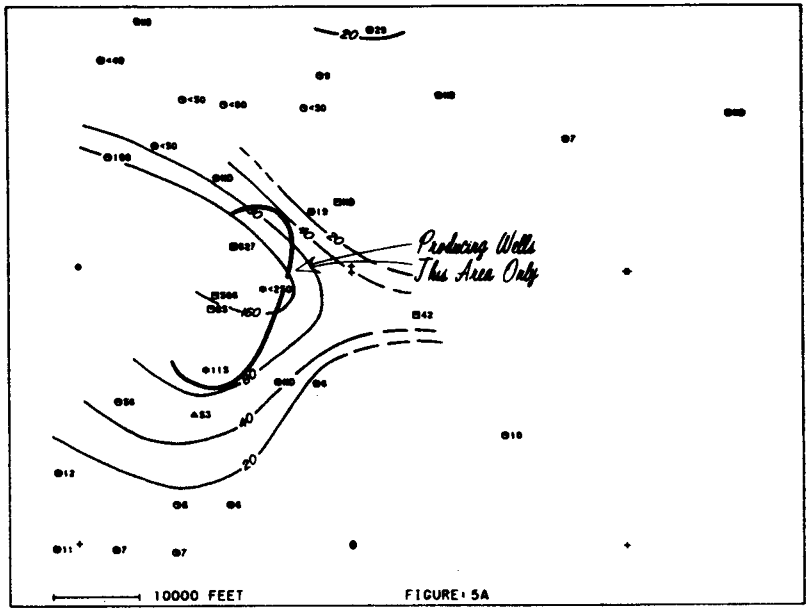


FIGURE: 5A

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

ARSENIC (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: COLOR

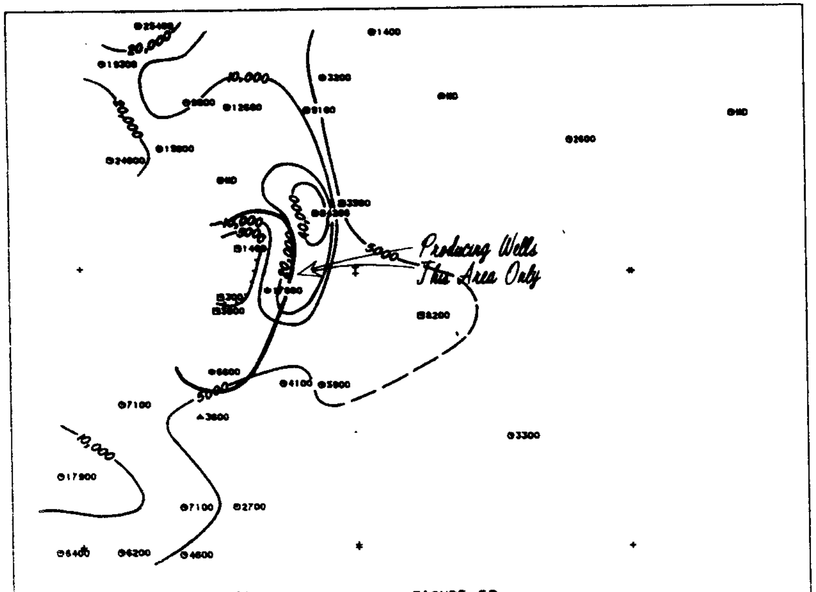


FIGURE: 5B

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

MANGANESE (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: AAS & ICPQ

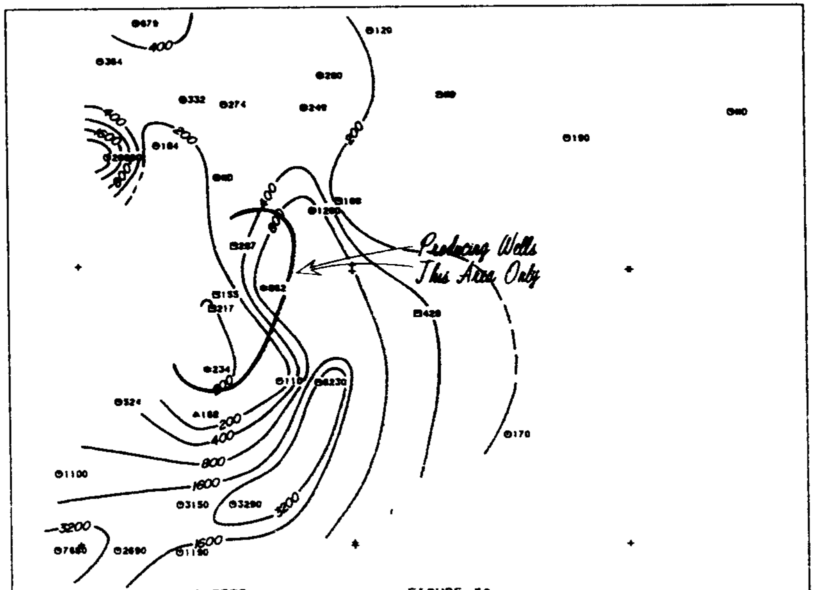


FIGURE: 5C

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

ZINC (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: AAS & ICPQ

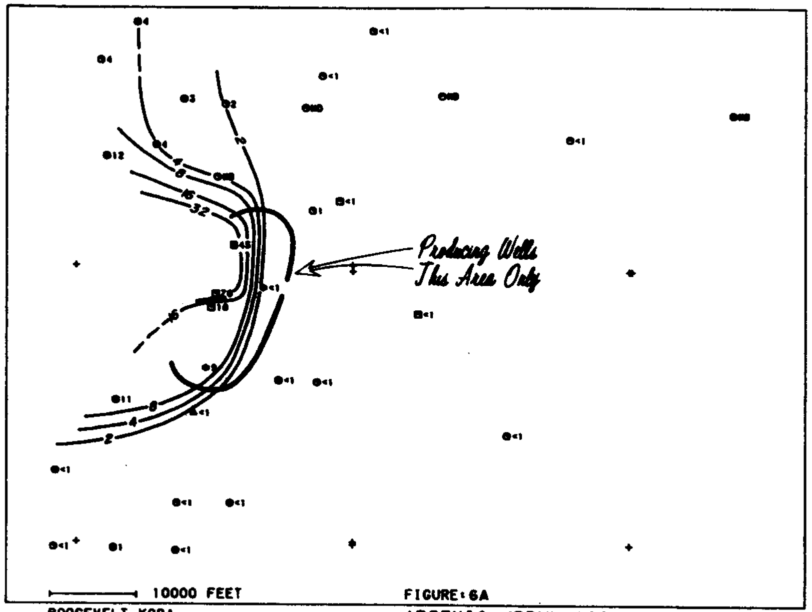


FIGURE: 6A

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

ARSENIC (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: COLOR

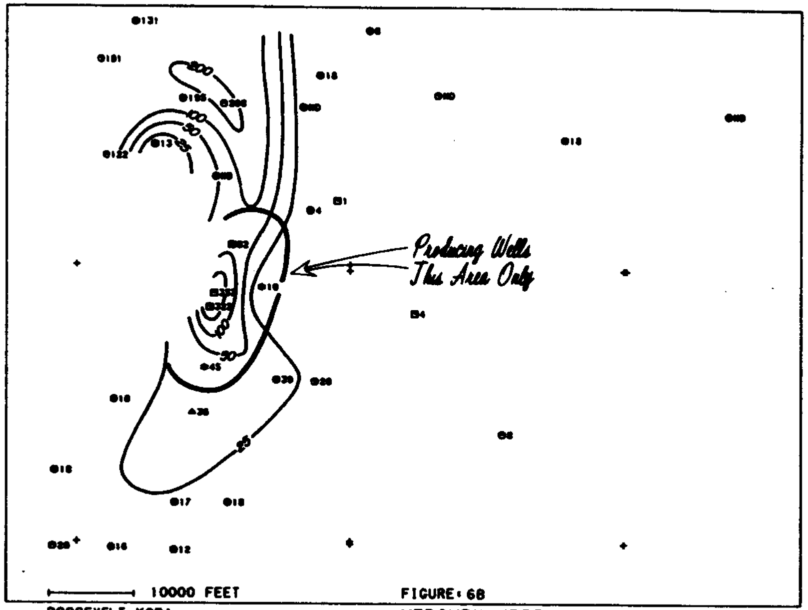


FIGURE: 6B

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

MERCURY (PPB) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: GOLD FILM

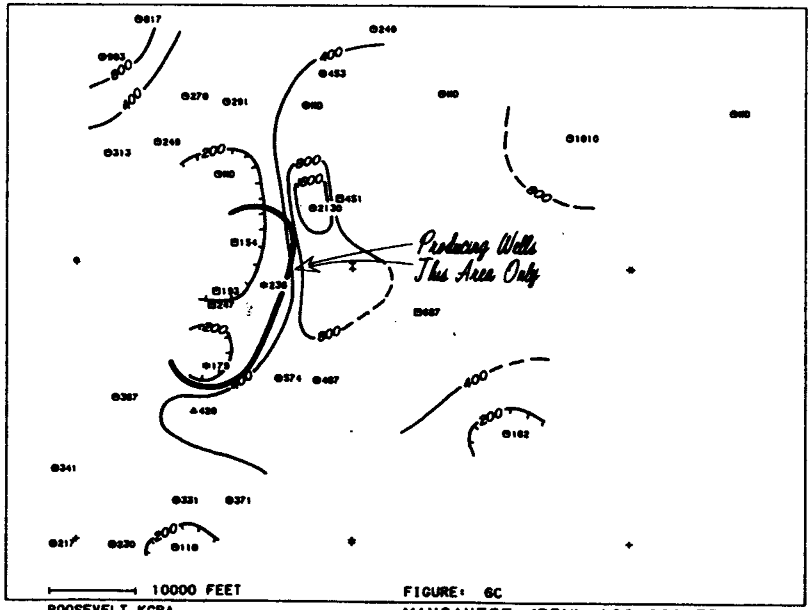


FIGURE: 6C

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

MANGANESE (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: ICPQ

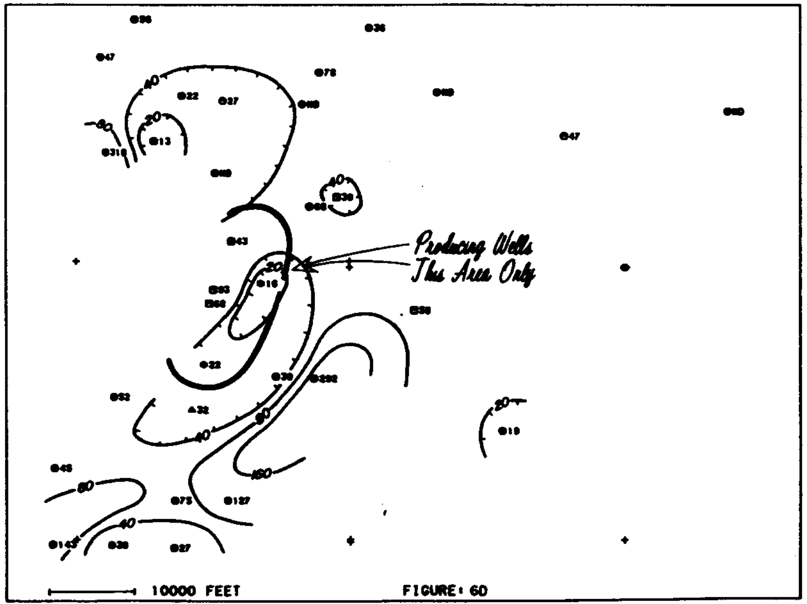


FIGURE: 6D

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

ZINC (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: AAS & ICPQ

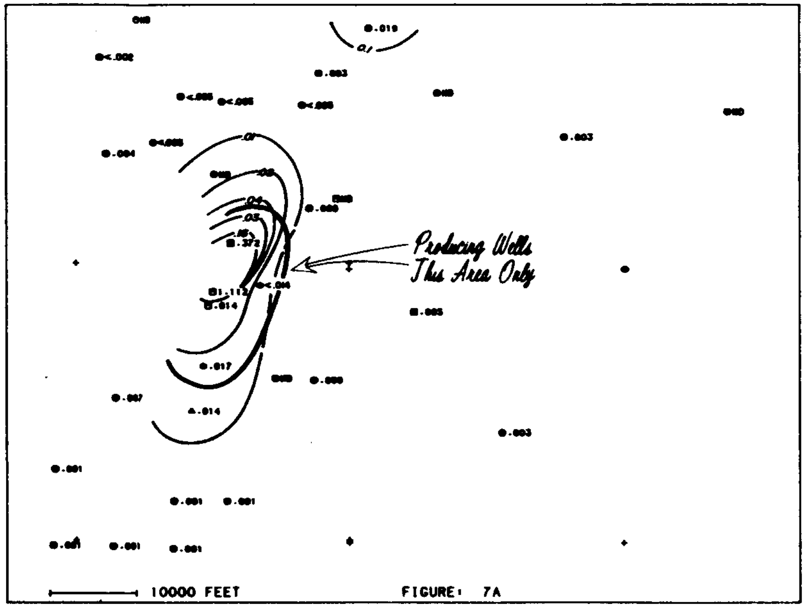


FIGURE: 7A

ROOSEVELT KGRA
BEAVER COUNTY.UTAH

AS/(ZN+MN). 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD:

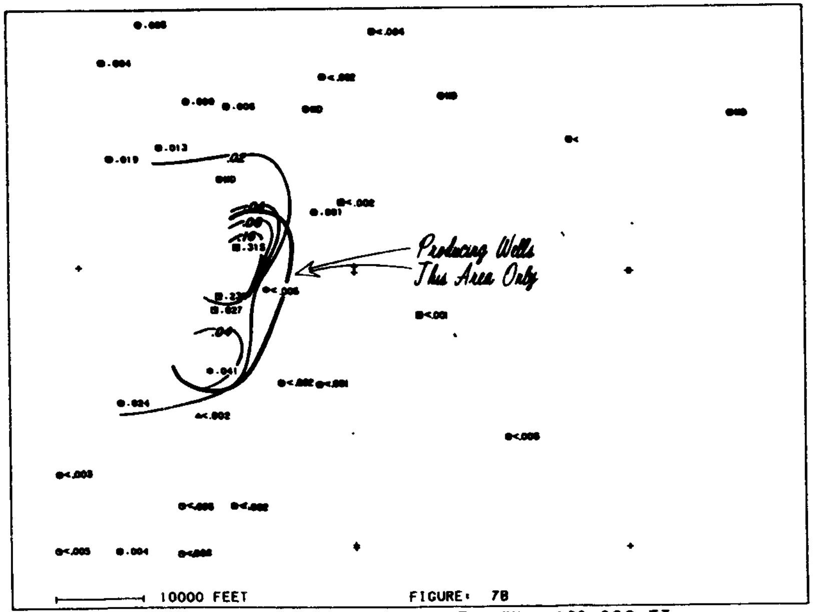


FIGURE: 7B

ROOSEVELT KGRA
BEAVER COUNTY.UTAH

AS/(ZN+MN). 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD:

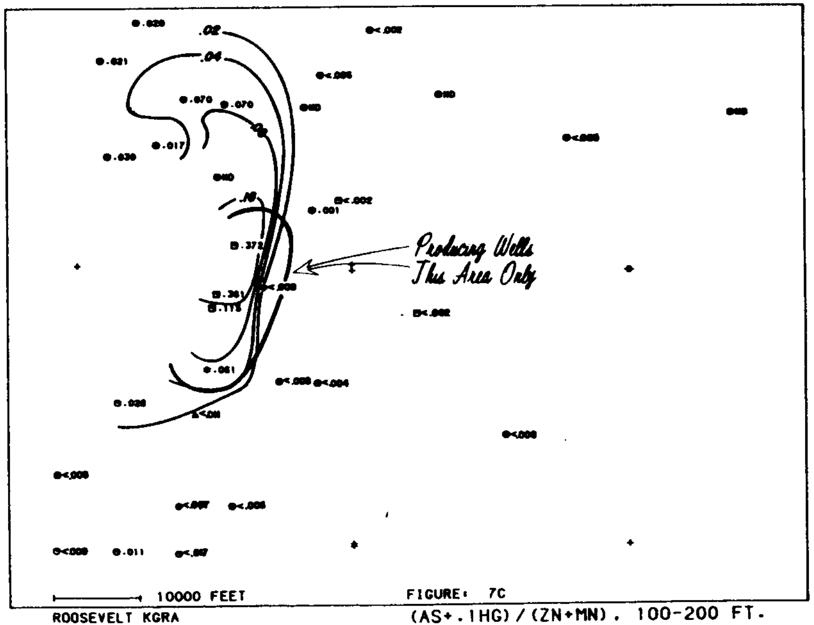


FIGURE: 7C

ROOSEVELT KGRA
BEAVER COUNTY.UTAH

(AS+.1HG)/(ZN+MN). 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD:

part due to local derivation and small scale redistribution of these elements (see discussion of Fe distributions below).

Multielement parameters As/(Zn+Mn), for +3.3 and whole rock data, and (As+0.1 Hg)/(Zn+Mn) for whole rock data only, combine the effects of the As-Hg-Zn-Mn zoning and define a more confined area above the resource than either As or Hg alone (Figures 7A, B, and C). Parameters incorporating As rather than (As+0.1 Hg) in the numerator define the most confined area over the resource, since the As anomaly is less diffuse than that for Hg. This more confined area may often constitute the best drilling target. These and other potentially useful geochemical approaches to target selection will be more fully discussed later in the report.

Lithium (Li) and Iron (Fe)

Large-scale zoning of Li and Fe in and around the resource area is also indicated, but anomalies are somewhat more discontinuous, less specifically zoned, or otherwise more difficult to define by means of large-scale near-surface sampling than those for As, Hg, Zn, and Mn.

Weak Li anomalies in whole rock samples appear to be developed over and to the south of the resource area (Appendix D, Figure D-2A). Li data for +3.3 concentrate samples do not display useful systematics, probably because of the lithophile character of the element, and are not presented. An association of Li with the As and Hg anomalies was anticipated from relationships established by the previously discussed well data, but is at best only partly demonstrated by the data. It is possible that Li is readily redistributed in the near-surface environment, decreasing its potential value as a specific target indicator in surface surveys.

Fe has apparently been strongly redistributed by geothermal processes, particularly in the vicinity and to the north of the known resource, but apparently has not been transported large distances and may be mostly locally derived. This is evidenced by the pronounced differences in Fe distributions recorded by corresponding +3.3 concentrate and whole rock data for both temperature gradient hole sample suites (Appendix D, Figures D-1A and D-2B) and geothermal well suites (Bamford, 1978, Figures 4/14-2, 7/14-2, 4/72-16, and 7/72-16 and Appendix C, Figures C-6 and C-13). Fe concentration in +3.3 samples is highest where geothermal activity is indicated to have been strongest (i.e., at or near active hot-water entries, zones of self-sealing, fumaroles, and over the known resource area), reflecting the capability of the +3.3 sampling procedure to selectively provide samples enriched in sulfide and oxide minerals which commonly constitute hydrothermal vein materials. In contrast, Fe in corresponding whole rock samples mostly displays correlation with lithology as would be expected if the Fe redistribution approximates an isochemical process at the scale of the sampling. A previously inferred antithetic relationship between hydrothermal pyrite and accessory magnetite (Bamford, 1978), also supports the concept of local derivation of the Fe.

Mn and Zn appear to be somewhat similar to Fe in displaying pronounced distribution differences in corresponding +3.3 concentrate and whole rock data sets (Figures 5B, 5C, 6c, and 6d, and Appendix B, Figures B-1A, B-1C, B-2A, B-2C) and may also have undergone a redistribution which appears to be isochemical at the scale of the sampling. As described previously, however, other explanations are also feasible (see discussion of well sample chemistry).

Cerium (Ce) and Lanthanum (La)

Broad anomalous concentrations of Ce and La appear to be developed over and somewhat beyond the known resource area (Appendix D, Figures D-3A and D-3B). Similar broad concentrations of these elements within and near the reservoir are indicated by the well data (see earlier discussion) and thus provide support for a geothermal origin for the anomalies. Whole rock data only are available to define near-surface distribution of these elements. However, comparison of corresponding whole rock and +3.3 distribution data from well 52-21 (Appendix C, Figures C-12 and C-18) shows that Ce and La anomalies are similarly and clearly defined by both types of data. This suggests that these anomalies could be defined by +3.3 concentrate sample geochemistry for the near-surface sample suite as well.

Anomalies of Possible Geothermal Origin

Molybdenum (Mo), Tungsten (W), and Tin (Sn)

Distribution data for Mo, W, and Sn suggest that these elements could also have been transported and concentrated by geothermal processes, but are less definitive in this regard than data for elements previously discussed in this section. Anomalous concentrations of all three elements appear to be distributed roughly peripheral to the resource area (Appendix D, Figures D-1B, D-1C, D-1D, and D-2C). Well data, primarily that for the +3.3 concentrate sample sets, provide limited additional support for this zoning relationship for Mo and possibly W, but not for Sn (Appendicies B and C, Figures B-1C, B-2C, C-9, and C-11). Mo anomalies are weakly developed above and within the self-sealed zone in wells 14-2 and 72-16 and are strongly developed throughout rock types intersected in the peripherally located well 52-21, but do not appear to be significantly developed within reservoir rock penetrated by Well 14-2 (Appendix B, Figure B-2C). W and Sn concentrations appear to be more pronounced thoughout 52-21 compared to 14-2 and 72-16, but this could in part be due to differences in analytical methods (Sn and W were determined by ICPQ for well 52-21 +3.3 concentrate samples and by a matrix compensated optical emission spectrographic technique for 14-2 and 72-16 +3.3 concentrate samples). The higher concentrations of all three elements in 52-21 (especially of Mo which occurs partly as MoS_2) compared to the other wells could also be at least in part due to rock type differences, since 52-21 intersects a significantly greater proportion of migmatitic gneiss. Documented enrichment of W and possibly Mo in hot spring waters relative to warm and cold spring waters (Wollenberg et al., 1977) supports a general inference of transport and deposition of these elements in or around hot-water geothermal systems. Also, transport and deposition of Mo under geothermal conditions at Roosevelt is specificially indicated by the Mo enrichment at the 2860 to 2890 foot HWE in well 14-2. More work is needed, however, to usefully establish the overall large-scale zoning behavior of Mo, W, and Sn in geothermal systems.

DETAILED MERCURY AND ARSENIC DISTRIBUTIONS IN SOILS

Previous geochemical studies at Roosevelt demonstrated that prominent As and Hg anomalies are developed at or near the surface within the area overlying the known resource (Capuano and Bamford, 1978; Bamford, 1978; and Parry et al., 1976), but did not adequately define the surface extent of these anomalies. In order to help remedy this deficiency and to provide information which might further improve interpretation of geochemical data from exploration wells and temperature gradient drill holes, a detailed surface soil survey was carried out. The survey was initially designed to provide reasonably comprehensive sampling of soils on a 500-foot grid over a relatively limited (1.5 square mile) area around the north end of the Opal Mound Fault. This area encompassed many of the best producing wells and a high concentration of surficial geothermal features. As geochemical results became available during the course of the work, the survey area was expanded in several directions to close off many of the stronger anomalies. In its final form the soil survey covered about 3 square miles over the central parts of the known geothermal system with sampling maintained on 500-foot centers (Figures 1 and 8A).

Relationship to Geologic Structure and Geothermal Features

Highest anomalous concentrations of Hg and, less obviously, As are developed along and near the trend of the prominent Opal Mound Fault (cf. Figures 8A, B, and C), which has been suggested to have had a significant influence on reservoir hydrology (Lenzer et al., 1976). Two large, distinctly separate anomalies occur over northern and southern portions of the fault. Hg

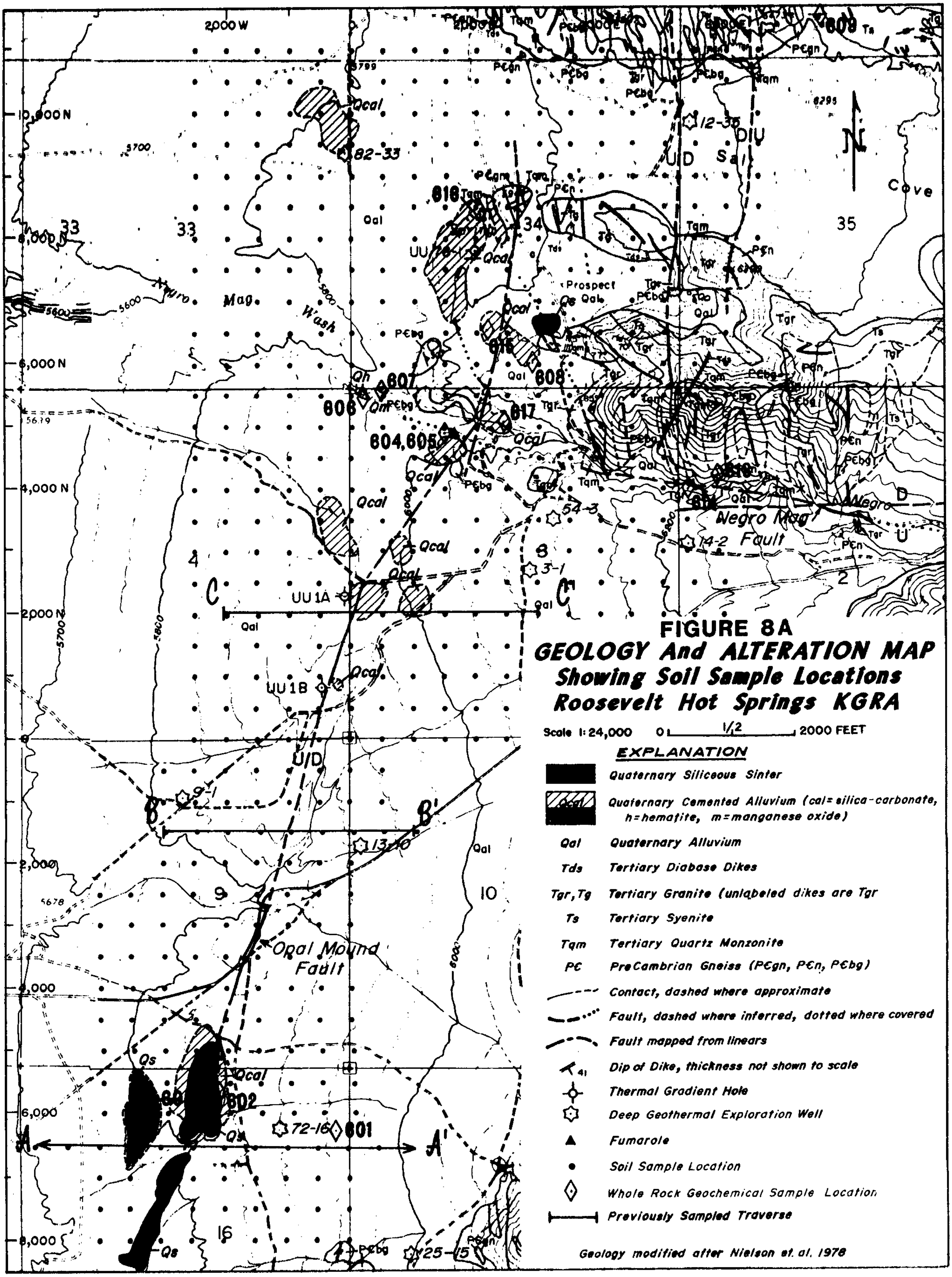
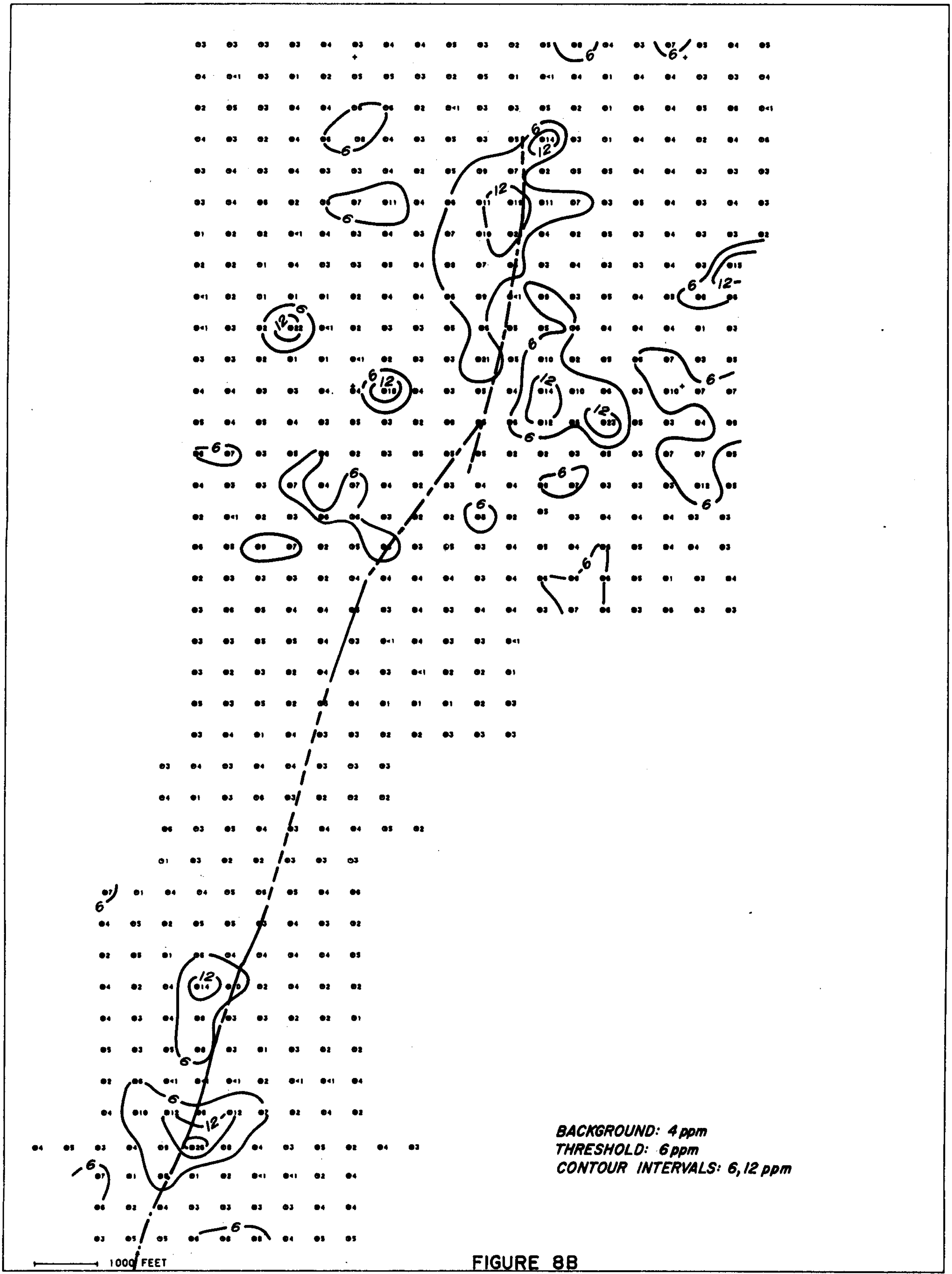


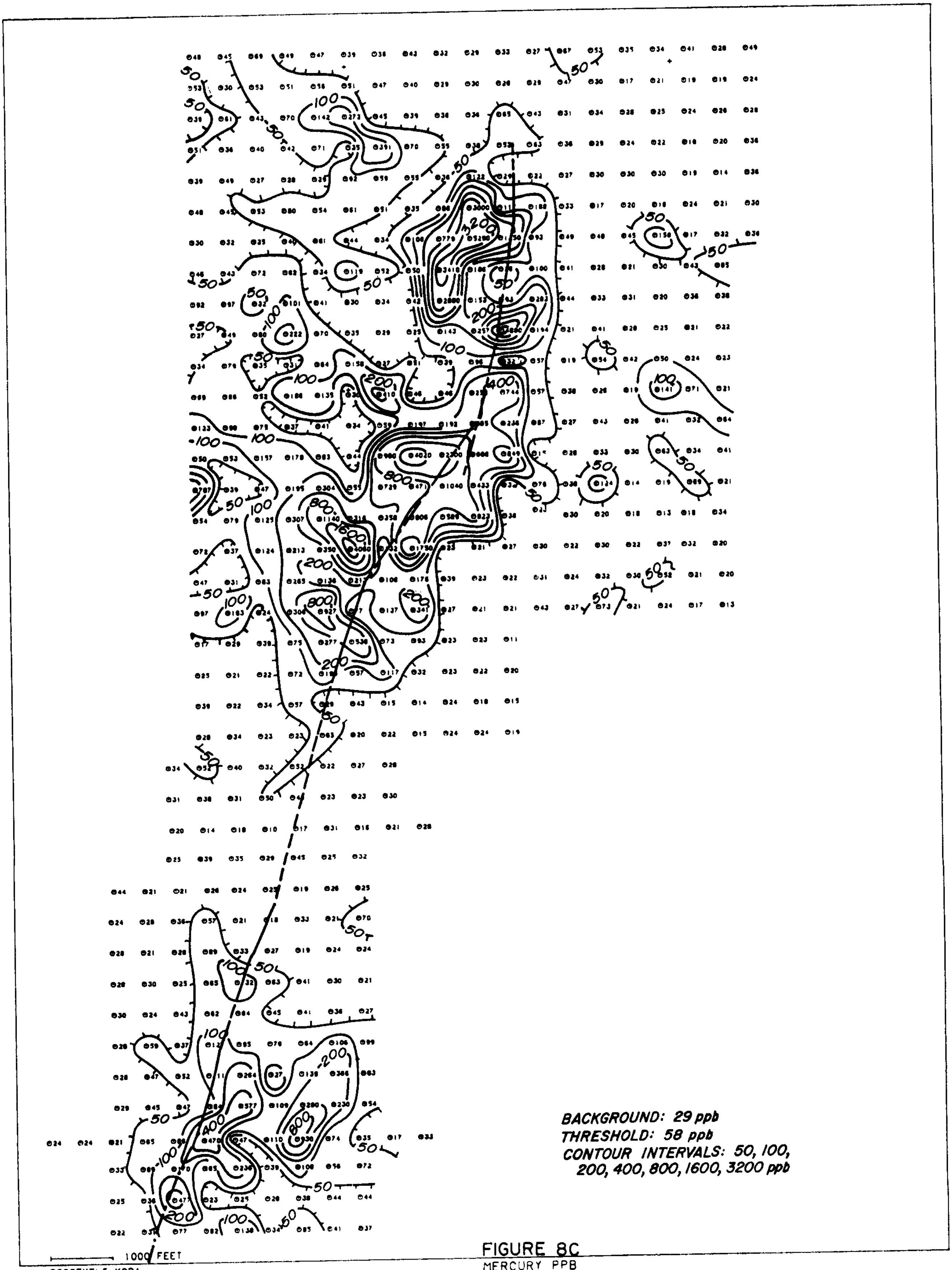
FIGURE 8A
GEOLOGY And ALTERATION MAP
Showing Soil Sample Locations
Roosevelt Hot Springs KGRA



BACKGROUND: 4 ppm
THRESHOLD: 6 ppm
CONTOUR INTERVALS: 6, 12 ppm

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE 8B
ARSENIC PPM
SAMPLE TYPE: SOIL (-80 MESH)
ANALYTICAL METHOD: COLORIMETRIC



BACKGROUND: 29 ppb
THRESHOLD: 58 ppb
CONTOUR INTERVALS: 50, 100, 200, 400, 800, 1600, 3200 ppb

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE 8C
MERCURY PPB
SAMPLE TYPE: SOIL (-80 MESH)
ANALYTICAL METHOD: GOLD FILM

and As geochemistry over the intervening part of the fault is essentially at background levels.

Another set of structures, predominantly northwest-trending, is also tentatively indicated by the geochemistry to have developed reservoir-to-surface permeability. An example would be the structure mapped in the southeast of section 34 and possibly extending to the northwest towards and through the vicinity of well 82-33 (Figures 1 and 8A). Weak but definite Hg and As anomalies occur along this and possibly similar parallel trends. The relatively low magnitude of these anomalies suggests that reservoir-to-surface permeability was much less well developed than along the Opal Mound Fault.

Little if any evidence of leakage along the inferred east-west trending extension of the Negro Mag fault is indicated by the geochemical data. This suggests that no significant reservoir-to-surface permeability has developed along this extension, and raises doubts regarding the importance of this extension in controlling reservoir hydrology.

Several lines of evidence suggest that the strong, broadly developed, coincident Hg and As soil anomalies documented here map, and are probably diagnostic of, an important part of the self-sealed zone which constitutes self-sealed capping over a very shallow part of the reservoir. Direct geologic evidence for the capping has been described earlier. The most compelling evidence that the geochemically anomalous capping overlies shallow reservoir is found in drilling results: the one exploration well drilled into this anomalous zone, Utah State, 72-16, encountered thermal fluids as shallow as 312 feet and, with a total depth of 1254 feet, is the shallowest and perhaps one of the best potential producers in the field. The superposition of the capping over the shallow reservoir is also supported by excellent spatial correspondence between the geochemical anomalies and dipole-dipole resistivity lows of <20 ohm-meters (Ward and Sill, 1976), high heat flux (Ward et al., 1978), and active geothermal features such as fumarolic activity and surface seepage. Apparently relatively direct reservoir-to-surface permeability has developed periodically in these areas, possibly due to reactivation of movement along the Opal Mound and related faults, causing the release of thermal waters and eventually the formation of the self-sealed cap.

Other Geochemical Distributions of Geothermal Origin in Soils

Multielement analysis of -80 mesh soil samples from previously sampled traverses at Roosevelt indicates that several additional elements develop surface anomalies as a result of geothermal processes and suggest that some of these elements might be usefully incorporated into future soil surveys. Data for one of the traverses, A-A' which crosses the Opal Mound Fault in the vicinity of prominent siliceous hot spring deposits (Figure 1), show that W and Sb are concentrated in the vicinity of the fault in close association with previously documented Hg and As anomalies (Figure 9). Spatially associated accumulations of both Sn and Th and broadly anomalous concentrations of Li were also tentatively identified. W, Sb, and possibly Sn accumulations have also been identified in either well or temperature gradient hole cuttings samples (see discussion above) and both W and Sb are known to accumulate in thermal waters (e.g., Howard et al., 1978; Cosner and Apps, 1978; and Wollenberg et al, 1977), further supporting a potential utility for some of these elements in geochemical exploration schemes. More work is needed,

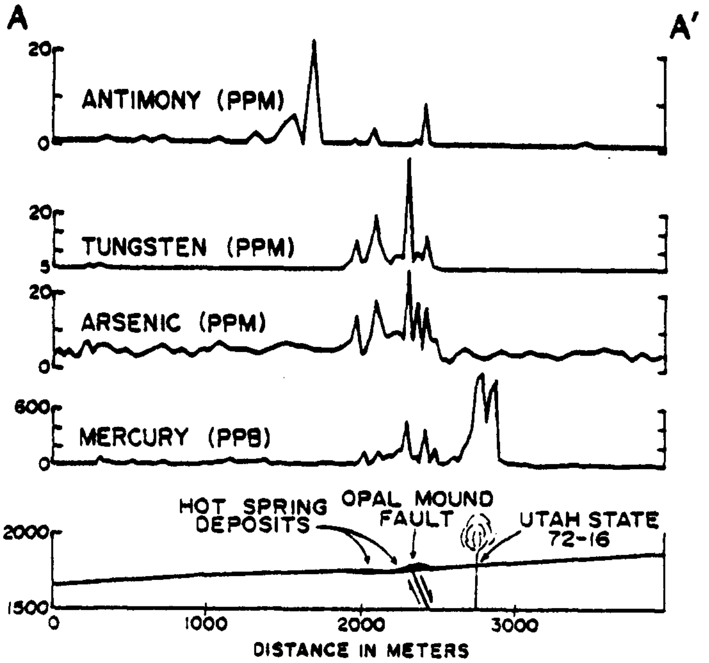


FIGURE 9. MULTI ELEMENT GEOCHEMISTRY OF-80 MESH SOIL, TRAVERSE A-A'

however, to evaluate this potential. ICPQ analysis of the grid soil samples for which As and Hg data are reported above can constitute a useful first step in this work.

THREE-DIMENSIONAL LARGE-SCALE ZONING MODEL

Geochemical zoning characteristics of the Roosevelt geothermal system can be usefully generalized in terms of three major system components: (1) the reservoir zone, (2) the self-sealed zone, and (3) a peripheral zone. These zones and their principal subzones appear to have distinct readily-defined geochemical characteristics and probably useful but at present less well-defined geological (and geophysical?) characteristics. Descriptions of these zones which follow constitute the basis for a working model of large-scale geochemical zoning in the Roosevelt geothermal system.

Reservoir Zone

Diagnostic geochemical characteristics of the reservoir zone include pronounced local anomalous enrichments of As, Li, and probably Be and Zn at HWEs; local depletions of Na and Sr at the HWEs; and probably broader enrichments of Zn and possibly Ce around HWEs (Figures 2B and 3B and Appendix A and B, Figures A-1C, A-2C, B-1A, B-1C, B-2A, B-2C). Prominent Hg anomalies appear to develop only at HWEs located within or near the reservoir marginal self-sealed zones and thus are not considered diagnostic of the reservoir environment. Except for the broad Zn (and Ce?) enrichments, distribution of these associated multielement anomalies is confined to the immediate vicinity of a reservoir zone HWE (± 10 feet) and therefore, in mimicking the occurrence of throughgoing permeability, will probably be irregular and restricted. The greatest proportion of reservoir zone rock penetrated by well 14-2 appears to have been only weakly permeable throughout the history of the geothermal system and correspondingly displays either weakly anomalous geochemistry or is not anomalous in the above named elements. It appears, however, that broad anomalies in Zn, Ce, and possibly La have developed in some of these less permeable rocks and might help to further characterize the zone.

Self-Sealed Zone

In this report the term self-sealed is used to describe a loss of effective permeability in a thermal aquifer due to mineral deposition and rock alteration. The general nature of the self-sealing is considered to be consistent with that described for other geothermal systems (Facca and Tonani, 1967 and Elders and Bird, 1976), although this is only partly demonstrated. Geochemical criteria for the recognition of self-sealed zones are spatially coincident Hg, As, Li, Be, ± Mn, ± Zn anomalies. These are similar to multielement anomalies which characterize the reservoir zone but can be distinguished by the additional Hg ± Mn association and, throughout much of the zone, by a lack of associated thermal fluid flux or permeability. Self-sealed zone characteristics are illustrated by data for Utah State Wells 14-2, 72-16, and 52-21 in the approximate intervals 800 to 1800 feet, 0 to 650 feet, and 0 to 7600 feet, respectively (Figures 2B and 3B and Appendices A and C, Figures A-1C, A-2C, C-1 and C-17).

Two major types of self-sealed zone are recognized at Roosevelt: a near-surface self-sealed or partly self-sealed capping where reservoir-to-surface permeability existed along parts of the Opal Mound Fault and a wide subsurface zone situated at or near the reservoir margin, similar to that previously described for Utah State Well 14-2. The subsurface zone is probably not a capping but rather reflects mineral deposition which started in the vicinity of the original reservoir boundary, probably in response to changes in thermal and hydrologic regime, and gradually encroached on the reservoir. It is probable that the encroachment continues at present. Development of self-sealed zones other than at the reservoir margin has not been observed but, because data are limited, cannot be entirely precluded at this time.

Based on the foregoing observations and earlier discussion, it is suggested that self-sealed zones, a few hundred to more than one thousand feet thick may commonly be developed at the upper and lateral margins of hot-water reservoirs. Their characteristic geochemistry and close spatial relationship to the reservoir are sufficient justification to assign self-sealed rocks to a specific geochemical zone as part of a large-scale chemical zoning model for hot-water geothermal systems. Apparent lateral continuity (i.e., continuity in the magnitude of anomalies) and the overall configuration of a self-sealed zone will depend mainly on the nature and geometry of original or imposed reservoir permeability. Degree of development of anomalies may be quite variable and the zone may pinch and swell or rise and fall abruptly in response to structural inhomogeneities, especially in fracture-controlled reservoirs. However, based in part on models developed for zoned ore deposits, it is proposed that these irregularities will commonly be sufficiently small compared to the overall size and geometry of the system such that adequate interpretations can be made. An example of anomaly variability within the self-sealed zone is provided by data for rock penetrated in well 52-21; this rock was probably originally weakly to moderately permeable down to about 2800 feet, only locally permeable below that (Glenn and Hulen, 1979), and now appears to be mostly self-sealed. Intensity of development of characteristic geochemistry varies roughly but directly with the indicated variations in original permeability (Appendix C, Figure C-2). Self-sealed zone geochemistry can probably be distinguished from that of the reservoir zone by characteristically strong Hg anomalies and the local occurrence of Mn anomalies. Characteristic geochemical signatures plus the absence of permeability confirm identification of major portions of a self-sealed zone. Since the zone may be commonly distinguished from the reservoir zone by high Hg concentrations, however, it may and probably often will include partly self-sealed HWEs at its inner margin. Consistent with this definition, the upper fluid entry in 14-2 and both of the sampled fluid entries in 72-16 are considered to be partly self-sealed and located within the self-sealed zone.

An excellent macroscopic description of a surface-exposed part of the self-sealed zone which constitutes a self-sealed capping is provided by the detailed logging of diamond drill core from University of Utah dual purpose alteration study/temperature gradient drill holes UU75-1A, UU75-1B, and UU76-1 (Appendix B, Figure B-4). These holes penetrate the zone to depths of 217, 230, and 201 feet, respectively. The two holes 75-1A and 76-1, located in central parts of the capping several hundred feet west of the main trace of the Opal Mound Fault (Figures 1 and 8A), provide the best geologic characterization. The logging documents numerous fractures and faults which are variously filled, partly filled, or invaded and surrounded by clays, quartz, opal, chlorite, pyrite, zones of silicification, or combinations thereof below the water table (depth about 100 feet) and by more oxidized but related primary hydrothermal and secondary mineral assemblages above the water table.

These characteristics correspond reasonably with descriptions of self-sealed zones in other geothermal systems (Facca and Tonani, 1967; Facca, 1973; Elders and Bird, 1976; and Bird and Elders, 1975). More detailed characterization of alteration in this zone is provided by several University of Utah Department of Geology and Geophysics reports (Parry et al., 1978: Rohrs and Parry, 1978; and Bryant and Parry, 1977). Minor and trace element data and opaque mineral data for core composite samples from the three diamond drill holes (Appendix B, Figures B-3A, -3B, and -3C) are similar in many important respects to corresponding data for the self-sealed zone penetrated in Wells 14-2, 72-16, and 52-21 (Figures 2B, 3B, and Appendix B and C, Figures B-1A, B-1C, B-2A, B-2C, C-2 and C-4). The most pronounced and diagnostic of these similarities are the associated moderate to strong Hg and As anomalies developed in low permeability rock.

Peripheral Zone

Prominent but discontinuous Mn and Zn anomalies are developed within and beyond the outer margins of the self-sealed zone at Roosevelt and, where self-sealed zone geochemistry is minor or absent, are considered to define an outermost or peripheral geochemical zone in the system. Peripheral zone Mn-Zn anomalies thus might be broadly associated with sparsely and irregularly distributed low-level concentrations of Hg and As, constituting minor zones of self-sealing, and will grade into self-sealed zone anomalies as the reservoir is approached. Mo, W, and Sn may also be concentrated or redistributed in these peripheral zones. As discussed previously, however, a genetic relationship to the geothermal system is not adequately documented for peripherally situated anomalies in these elements.

The distance from the reservoir to the outer limits of readily detected peripheral zone geochemical anomalies varies as does the overall symmetry of these anomalies. This variability is probably a function of system hydrology, including the nature of leakage from the reservoir and the locus and degree of brine-groundwater mixing within the leakage zone. Zn appears to form one of the broadest and most coherent halos, being readily detectable to more than two miles beyond known production (Figures 5C and 6D). Mn also appears to form a fairly broad halo but, along with Fe, exhibits an asymmetry in its distribution toward the west or northwest (Figures 5B and 6C and Appendix D, Figures D-1A and D-2B). The asymmetry possibly reflects deposition associated with proposed thermal brine leakage or pluming in that direction from near the Opal Mound Fault (Dave Cole, personal communication) and accompanying groundwater-brine mixing.

A Generalized Zoning Model for the Roosevelt Geothermal System

Interpretations of geochemical zoning configurations for three important cross sections (Figures 10A, B, and C) provide an overview of interrelationships between the principal zones described above and, in combination with geochemical data, illustrate a generalized zoning model for the Roosevelt geothermal system. The interpretation is based on the documented geochemistry at the surface and in wells 14-2, 72-16, and 52-21; the known depth to (or absence of) the reservoir zone in wells 14-2, 72-16, and 52-21; and inferrence of depth to the reservoir zone from total well depths and surface geochemistry for producing wells 3-1, 54-3, 13-10, and 25-15.

Basic zoning relationships are most readily illustrated for a cross section through the producing wells 14-2 and 3-1, and diamond drill hole 75-1A

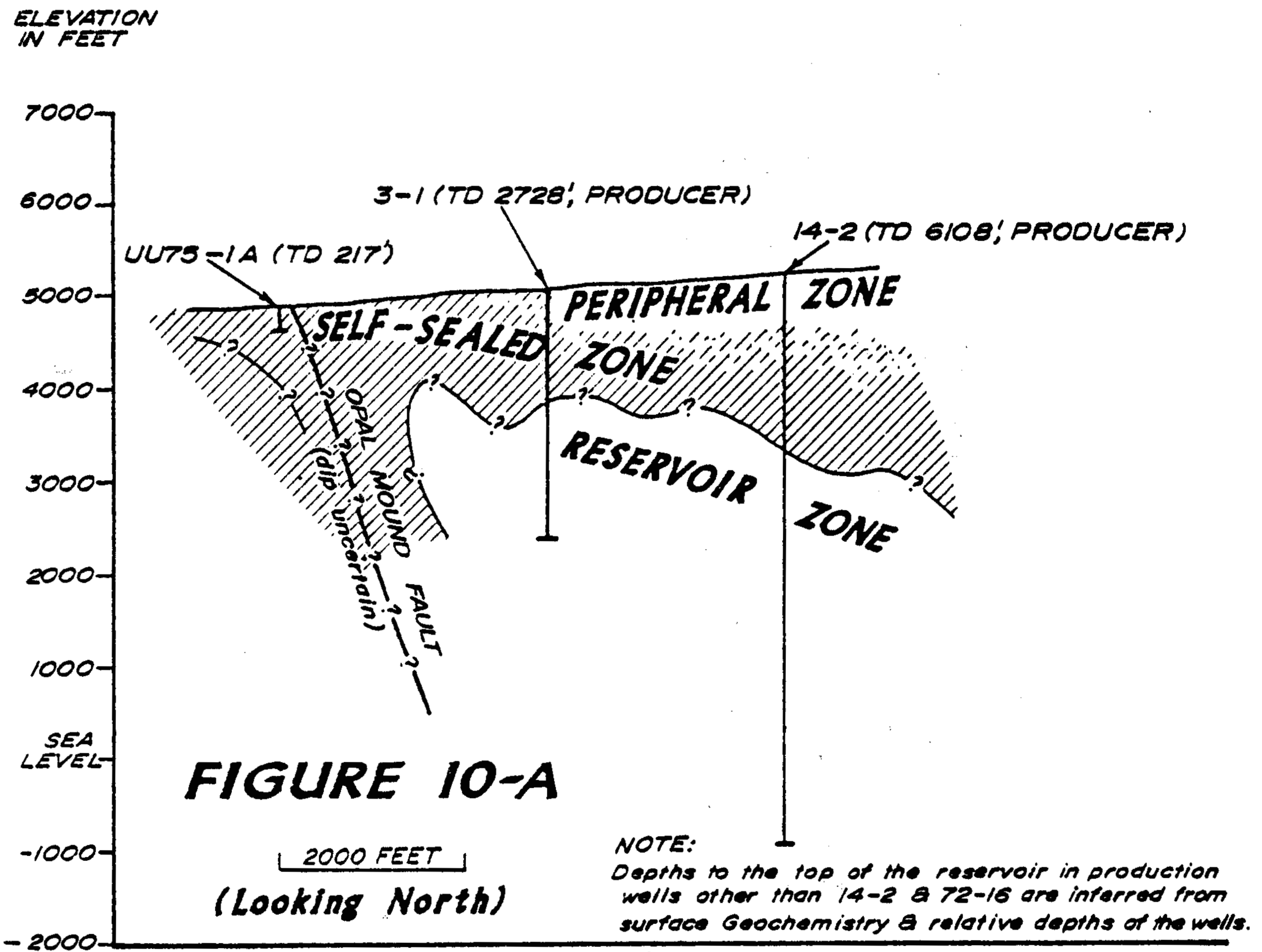


FIGURE 10-A

(Looking North)

NOTE:
Depths to the top of the reservoir in production wells other than 14-2 & 72-16 are inferred from surface Geochemistry & relative depths of the wells.

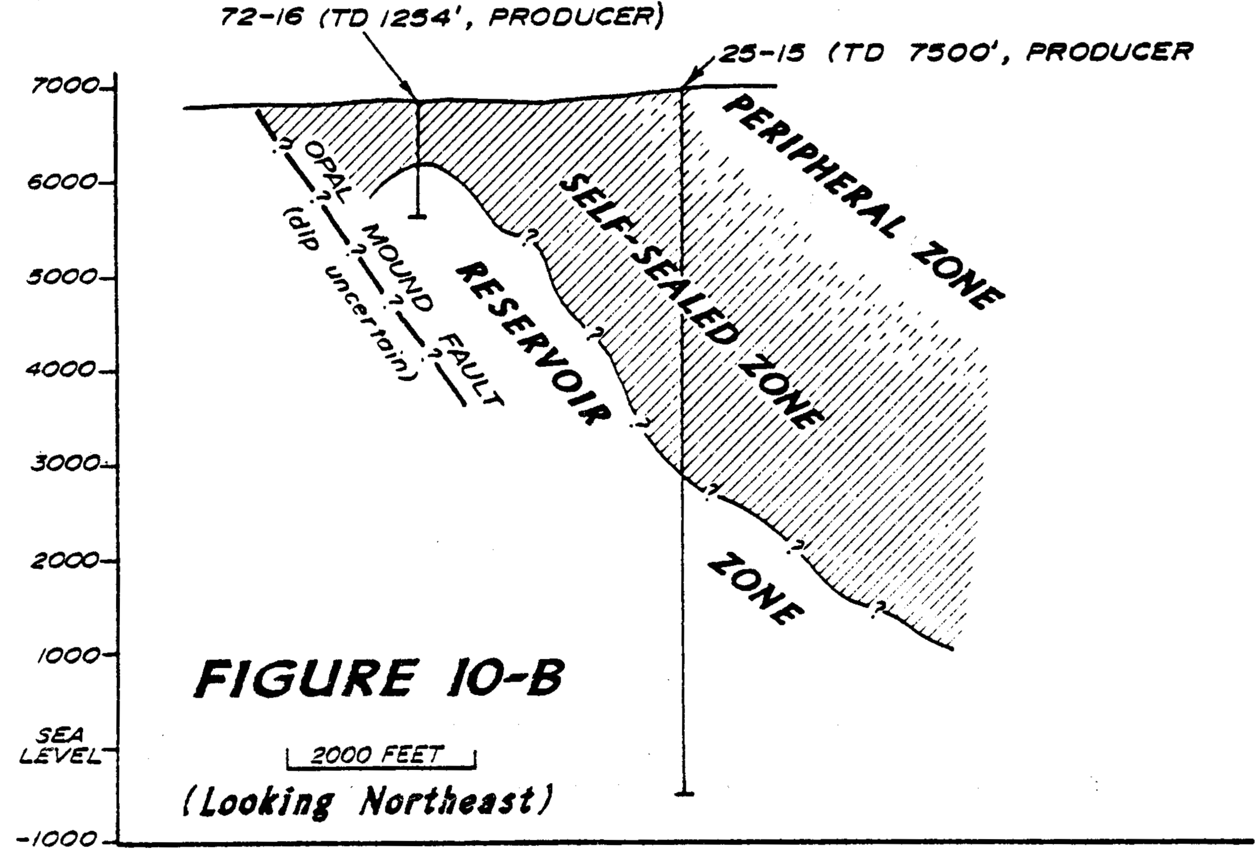
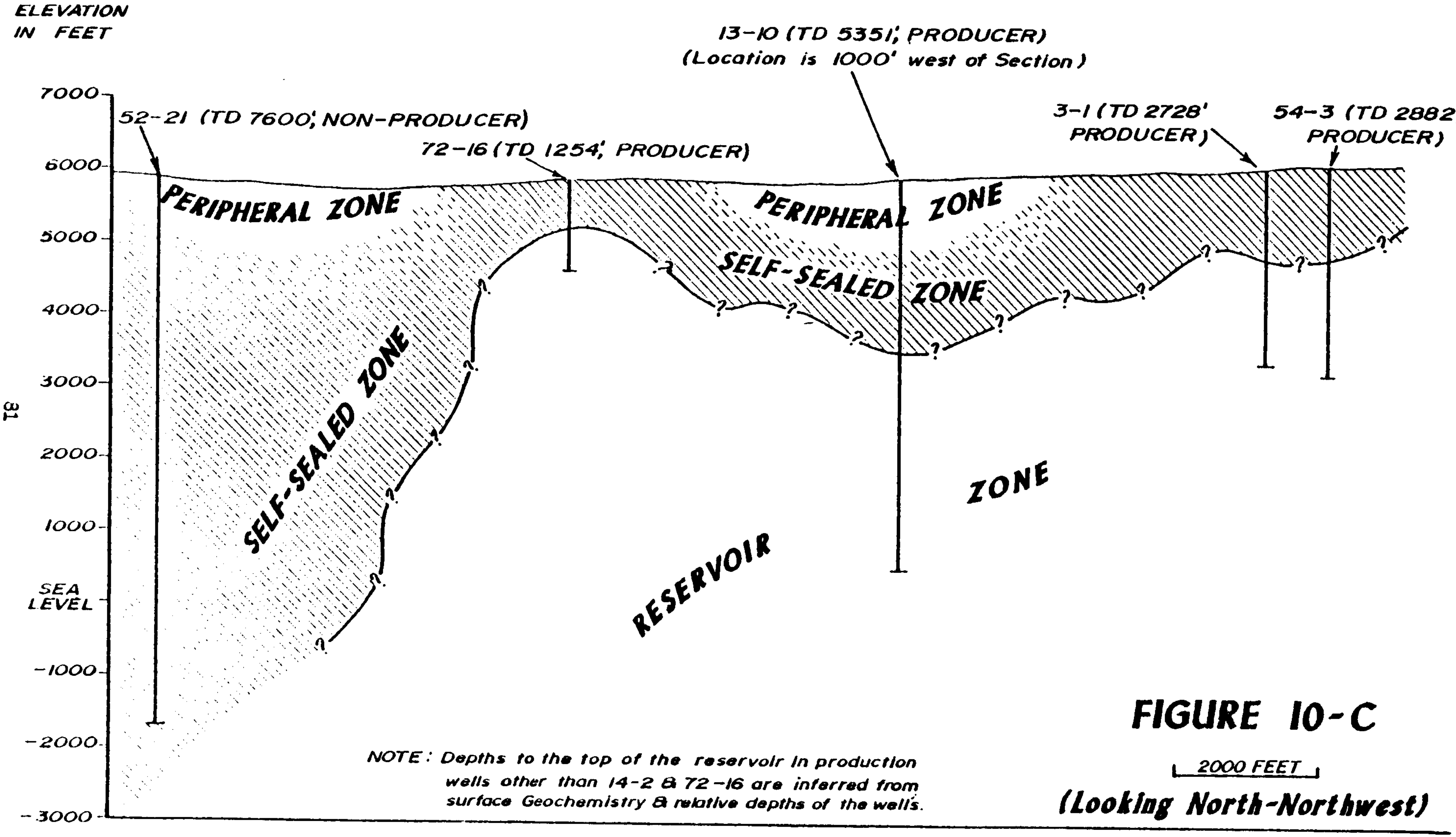


FIGURE 10-B

(Looking Northeast)



NOTE: Depths to the top of the reservoir in production wells other than 14-2 & 72-16 are inferred from surface Geochemistry & relative depths of the wells.

FIGURE 10-C

(Looking North-Northwest)

(Figure 10A), since data density for this cross section is relatively high. Depth to the top of the reservoir zone is fixed at about 1800 feet in 14-2, is inferred to be somewhat shallower in 3-1 (and nearby 54-3) based on the relatively shallow total depth required to obtain production in these wells, and is inferred to be very shallow (ca. 800 feet deep) beneath 75-1A based on gross similarities in geochemical, geological, geophysical characteristics of the drill site area and the setting in which the shallow production well 72-16 is located (for more information see the section on "Detailed Mercury and Arsenic Distributions in Soils"). The self-sealed zone is indicated to be variably developed along much of the reservoir margin and therefore is shown immediately above the reservoir dipping at a low angle toward the east. The fairly simple geometry assigned to the zone in this cross section is not essential to the model but is simply a best-fit interpretation of available data. This geometry of the self-sealed zone permits subsurface extensions of the zone to be joined directly with geochemically equivalent surface exposures in the vicinity of the Opal Mound Fault and DDH UU75-1A, where spatial relationship to the fault and abundant evidence of past hot-spring activity and permeability loss due to vein filling, matrix cementation, and alteration suggest that a self-sealed capping has developed. The position of peripheral zone geochemical assemblages is indicated based on geochemical data for 14-2 and on large-scale zoning relationships deduced from temperature gradient hole geochemistry.

Zoning relationships are similarly deduced and depicted for a cross section through producing wells 72-16 and 25-15 (Figure 10-B). This section simply suggests that the interface between the reservoir and self-sealed zones probably dips steeply to the east in this vicinity with an attitude which might roughly parallel the apparent attitude of the Opal Mound Fault. Interpretation is based primarily on the geochemistry from well 72-16, the geochemistry from well 72-16, the relative total depths of the two wells, and to a lesser extent on surface geochemistry. The steep downward plunge of the reservoir-self-sealed zone interface away from 72-16 is similar to and supported by the more directly inferred configuration of the reservoir between 72-16 and 52-21 (Figure 10-C).

The remaining cross section, which parallels the Opal Mound Fault on the east and passes through or near producing wells 54-3, 3-1, 13-10, 72-16 and dry well 52-21, provides a different perspective of possible zoning relationships and also usefully reveals interpretative complexities which can be anticipated for other geothermal systems. Positions of the principal geochemical zones in wells 3-1 and 54-3 are consistent with geometries presented in Figure 10A, are inferred for 13-10 based on surface geochemistry (no sealed zone is exposed at the surface in or near the area - Figures 8A, B, and C) and on the relatively deep drilling required to obtain adequate production, and are known for wells 72-16 and 52-21 based on drilling information, geophysical logs, and the geochemical data. The overall geometry thus inferred probably reflects the nature of original permeability development and a variable rate of self-sealing along the geothermal reservoir margin which itself relates to original permeability. The permeable zone forming the south end of the geothermal reservoir around wells 72-16, 25-15, and 52-21, for example, has possibly always been relatively narrow or restricted, causing self-sealing to be most extensive in this area.

The interpretative complexities referred to above are illustrated by data for the dry well 52-21 which show self-sealed zone geochemistry extending from surface to about 2,800 feet, probable but very weak self-sealed zone geochemistry from depths of 2,800 feet to about 7,000 feet, and increasing self-sealed zone geochemistry from 7,000 feet to the end of the hole at 7,600 feet (Appendix C, Figures C-2, C-3, C-4, and C-5). Potential difficulties in interpretation of these data derive from the weak and erratic development of self-sealed zone geochemistry in rock penetrated by the well between 2800 and about 7000 feet. In this part of the well, Hg concentrations are consistently higher than those of the reservoir zone, below 1900 feet, in 14-2 (cf. Appendix C, Figure C-2 and Appendix B, Figure B-1A) and thus suggest the possibility that these rocks may have also self-sealed but have developed weak geochemical signatures because of a relatively low original permeability. With other characteristic self-sealed zone geochemistry even more poorly developed in this interval, however, the Hg enrichments are not enough higher than reservoir zone values to unambiguously indicate a downward continuation of the self-sealed zone. Rock in this section of the well is only weakly altered (Ballantyne, 1978 and Jeff Hulen, personal communication), providing further support for the concept that the poor development of geochemical signatures and other evidence for past water-rock interaction primarily reflects limited development of throughgoing permeability at the time this rock was located within the reservoir zone. Original permeability at this time was apparently somewhat higher in rock penetrated by the last 600 feet of the well. These rocks now display fairly diagnostic self-sealed zone geochemistry, leading to the tentative but consistent interpretation that rock penetrated by well 52-21 has entirely self-sealed and that the interface between the reservoir and self-sealed zones has migrated to somewhere below and/or to the north of the well. The interpretation is indeterminant with respect to providing encouragement for deepening the well to define a resource. Had the well been drilled to a total depth of less than 7000 feet, the interpretation of extent of self-sealing would have been relatively indeterminant as well.

Applicability of the Model to Other Geothermal Systems

Published geologic descriptions and water geochemical data for several hot-water geothermal systems provide indications that the Roosevelt geochemical zoning model may be broadly applicable, especially with regard to the more critical aspects of the model which concern the chemical nature and geometry of the self-sealed and reservoir zones. Self-sealed zones are described for most other hot-water systems which have been subjected to reasonable geologic scrutiny and thus appear to be consistent features of this type of system (e.g., Bird and Elders, 1975; Hoagland and Elders, 1977; Elders et al., 1979; and Facca and Tonani, 1967). Where geologic documentation is sufficiently comprehensive to establish spatial relationships to overall system geometry, self-sealed zones appear to develop at or near the reservoir margin (within or near the "discharge volume" of Elders et al., 1979). Spatial association between the reservoir margin and potential causes of self-sealing (e.g., the change from isothermal convection to a conductive gradient producing rapid temperature decrease, increased thermal fluid-groundwater mixing, boiling, and/or increasingly oxidizing conditions), explain or provide further support for the characteristic development of self-sealing at that location in the system.

Although trace element assemblage distributions in rocks hosting and surrounding other hot-water geothermal reservoirs are poorly known, potential parallels with Roosevelt distributions can be inferred from several types of data. Relatively direct evidence of similarities in Zn and Cu distributions is provided by sulfide data for hot-water systems with well developed ore-mineral assemblages. In geothermal systems at the Broadlands, New Zealand, and in Imperial Valley, California, Zn (without accompanying Mn) and lesser amounts of Cu are principally concentrated as sulfides within the high temperature reservoir (Browne, 1971; Browne and Ellis, 1970; Ewers and Keays, 1977; Skinner et al., 1967; and McKibben, 1979), and thus at least partly reproduce the zoning at Roosevelt (sampling and chemical analysis have been carried out for other key zoning model elements at the Broadlands, but are not sufficiently continuous or extensive enough to permit further valid comparison). The presence of cinnabar in other quartz-rich self-sealed zones (Bird and Elders, 1975) and well documented associations of cinnabar and metacinnabar with silica in a broad spectrum of hot-springs deposits and subsurface Hg deposits associated with geothermal systems provide reasonable evidence that Hg, SiO_2, and S are often transported together in thermal fluids and can be expected in part to precipitate together from these fluids (Tunell, 1964 and Dickson and Tunnel, 1968), perhaps commonly producing zones of self-sealing. Similarities between the water geochemistry of the Roosevelt and many other hot-water systems (cf. Appendix G; Cosner and Apps, 1976; Howard et al., 1978; and Bowman et al., 1976) provide additional although less direct indications of potential parallels in trace metal deposition and zoning. Most thermal waters are shown to commonly contain significant concentrations of As, Sb, Li, Hg, Zn, Mn, and W, which constitute a majority of the key elements in the

Roosevelt zoning model. Coupled with reasonable inferences of similarities in conditions and chemical processes in most high-temperature hot-water reservoirs, the similarities in water geochemistry suggest that additional key element distributions of the Roosevelt zoning model also may be commonly reproduced in other hot-water systems.

APPLICATION OF SOLIDS GEOCHEMISTRY TO GEOTHERMAL EXPLORATION AND ASSESSMENT

Several types of geochemical techniques based on collection and analysis of solid materials are shown by this work to be useful and probably broadly applicable to the exploration and assessment of hot-water geothermal systems. These include: soil surveys, surface rock sampling, large-scale surface surveys utilizing shallow drill hole cuttings samples, and the geochemical logging of deep drill holes and exploration wells. To this point, however, questions pertaining to how and at what stage of geothermal exploration the different techniques might best be used have not been addressed. The following discussions should provide some broad initial guidelines for this use.

Soil Surveys

Soil sampling is the most readily accomplished type of surface survey, but also can be one of the most difficult to interpret due to the high susceptibility of original soil geochemical patterns to modification by contamination (e.g., from culture) and by secondary dispersion through mass-wasting and hydrogeochemical processes. The method is most likely to be successfully employed in relatively isolated, low relief, semi-arid to arid environments similar to that at Roosevelt Hot Springs and least likely to be successful in high-relief, high-rainfall areas or where the surface is strongly disturbed.

Detailed surveys of the type carried out at Roosevelt (500-foot grid spacing over a total area of several square miles) are useful primarily for defining the surface extent and configuration of reservoir-to-surface permeability developed throughout the history of a system. They thus can provide information about possible controls on reservoir permeability, especially in shallow fracture-controlled systems. For this reason and because logistics are simple, detailed soil surveys are most usefully carried out early in a project, possibly along with or even before temperature gradient drilling. Survey design should have as a principal objective the complete mapping of characteristic geochemical signatures developed in and around obvious geothermal features, such as hot spring deposits or active hot springs and fumaroles, and thus should seek to blanket such features with a grid of samples. The surveys should be carried out in stages, with the design of each follow-up stage being based on previous results in order that anomalies be defined as completely as possible with a minimum of expense and effort. Depending in part on initial results, later stages of the survey might include one or more of the following: simple expansion of the 500-foot grid; higher-density fill-in sampling to aid, for example, accurate delineation of narrow structurally controlled anomalies; and lower frequency sampling of peripheral areas to check for additional less obvious thermal system chemical anomalies.

The most useful elements to determine in soils are Hg and As. Other elements of possible importance are Sb, W, Li, Be, Zn, Mn, Th, and Sn. More data on distribution of these additional elements in soils over well studied geothermal reservoirs is needed, however, before their routine determination and interpretation in unknown systems is attempted.

Interpretation of detailed Hg and As data should initially be made in the context of concepts and data presented earlier in this report while interpretation of reconnaissance scale data (Hg only) should be made through reference to appropriate additional studies as well (e.g., Matlick and Buseck, 1976). Based on both types of data, it is tentatively suggested that at least three distinct types of Hg anomalies and combinations of these might be anticipated in association with geothermal systems: 1) relatively small-scale high-amplitude Hg anomalies (Hg commonly >400 ppb) associated with significant (>6 ppm?) As anomalies and locally with hot spring deposits, all reflecting predominantly direct deposition from thermal waters; 2) relatively small-scale high-amplitude Hg anomalies (Hg commonly >400 ppb) associated locally with acidic alteration and only trace amounts (<<6 ppm) of As, reflecting deposition from a thermal vapor; and 3) relatively large-scale low-amplitude Hg anomalies only (Hg commonly <<400 ppb), mostly without other directly associated evidence of thermal activity, which may constitute broad primary and secondary dispersion of Hg above and peripheral to a reservoir.

Surface Rock Sampling

Surface rock sampling is also readily accomplished, has relatively simple logistics, can provide the same type of information as soil surveys, and thus can also be usefully carried out early in a project if needed. Relative to soil surveys, rock sampling often offers the advantage of greater ease of interpretation, since it is subject to significantly fewer problems of secondary dispersion and is unlikely to be affected by contamination. Disadvantages of rock sampling are that outcrops may be limited or poorly distributed, limiting the area which can be effectively surveyed; representative samples are more difficult to obtain; a more highly skilled sampler, preferably a geologist, should generally be employed to carry out the survey; and sample collection is often slower and thus more expensive. Rock sampling will often be of greatest advantage in high relief terrane where outcrop is likely to be abundant and soil survey results are likely to be confused by mass-wasting. Rock survey procedures should probably emphasize chip composite sampling from veins coupled with the analysis of a +3.3 specific gravity concentrate sample made from the vein composite sample for As, Mn, Zn, Fe, and possibly Sb and Mo. This approach should generally provide a systematic enhancement of some hydrothermal chemical signatures similar to that obtained through analysis of concentrate samples from well cuttings, while helping to minimize non productive sampling of essentially barren bedrock which is likely to predominate in a geothermal prospect area. Analysis of the original whole rock vein composite samples and of rock chip composite samples of suspected hot spring deposits can also be undertaken to permit additional characterization through determination of Hg and lithophile elements such as Li, Be, and Ce. However, due to the subjective nature of the whole rock vein sample, results for this particular type of sample are likely to be somewhat more difficult to interpret than those for whole rock well cuttings and +3.3 concentrates from both surface rocks and well cuttings.

Large-scale Surface Surveys Utilizing Cuttings Samples from Shallow Drill Holes

Determination of large-scale geochemical distributions in geothermal systems can often be quickly and inexpensively accomplished through analysis of newly acquired and/or pre-existing temperature gradient hole cuttings samples (e.g., see Bamford and Christensen, 1979, and example this report). Like other surface surveys, this work is most usefully carried out in early stages of a project before exploration drilling is initiated. If samples are available from the start, it will probably be of advantage to obtain gradient hole chemical data before soil surveys are initiated, since the results can be used to plan these more detailed surveys and might often permit reductions in their size. Advantages of the gradient hole geochemistry compared to soil surveys include: the area surveyed is usually larger, the cuttings samples are more representative of a large rock volume and can provide more sensitive detection of weak geothermal anomalies, contamination and secondary dispersion problems are minimized, fewer samples are analyzed but more elements can be usefully determined, and samples may frequently be available at the start of a project. Disadvantages of the approach stem primarily from the inherent low sample density; only large-scale distributions can be mapped and in some instances important local anomalies may be missed.

A fundamental requirement for useful acquisition of gradient hole geochemical data is that the gradient holes themselves be reasonably distributed. An optimum distribution, which might sometimes be approximated but seldom fully achieved, would be to have holes on about one mile centers in areas of greater interest and on two mile centers in peripheral areas. A rough minimum requirement would be to have about ten holes fairly uniformly distributed over a ten to twenty square mile area. Hole distribution greatly inferior to this probably would not provide useful results. In some cases, it may be of advantage to drill a few additional holes to improve sample distribution.

Samples analyzed in this type of survey can usefully include both +3.3 concentrate fractions and whole rock material from composited grab samples but can also be confined to whole rock material without significant loss of effectiveness. Elements determined should include As, Zn, Mn, and Fe (and possibly Sb and Mo) for the +3.3 fractions, and Hg and Li (and possibly Be and W) in addition to the +3.3 sample elements for whole rock material. Useful drill hole composite intervals are 100, 150, or 200 feet. If only one composite is to be made and analysed for each hole and the holes are deep enough, the composites should be made up from samples taken below the water table in order to minimize effects of element redistribution in the near-surface environment. Generally, in order to provide a check on distribution patterns, it will be useful to prepare and analyze two composite samples from adjacent equivalent depth intervals in each hole, and to initially plot the results separately by depth interval. If deep, >1000 foot, gradient holes have been drilled, it may be useful to chemically log these over their entire length (see below).

Careful collection of the original grab samples at no greater than 10-foot intervals is important. Negligence in this phase of the work or during sample handling and preparation can degrade or invalidate the entire procedure.

Geochemical Logging of Deep Drill Holes

Geochemical logging of cuttings from exploration wells and a variety of other types of deep drill holes used in geothermal exploration (stratigraphic tests, slim holes, deep temperature gradient holes, etc.) can provide general information on the nature and evolution of a hot-water geothermal system and more specific information on the three-dimensional geometry of the system, approach to the reservoir, and locations of hot-water entry zones (HWEs) as described earlier. Because results are commonly definitive and readily interpreted, it is suggested that geochemical logging can be usefully added to routine data acquisition procedures employed during deep drilling.

Samples used for geochemical logging are the cuttings grab samples routinely acquired in the course of drilling. Depending on purpose, these can be analyzed individually (only analysis of whole rock material is practical), composited and whole rock materials or +3.3 concentrate samples analyzed, or combinations of individual and composite sample analysis can be used. Each approach has specific advantages and disadvantages, as discussed earlier. About one pound (500 grams) of sample should be collected at ten-foot or smaller intervals (trial analysis of samples collected every five feet within the interval 2800 to 3000 feet in well 14-2 around the 2860 to 2890 entry zone indicated that data acquisition at this greater frequency is probably unnecessary). Samples acquired by mud drilling should be thoroughly washed in an 80 mesh stainless steel sieve (to prevent loss of fines) as soon as collected to remove the drilling mud, hand-picked or otherwise made free of any lost circulation material, and then dried (in air or a low-temperature, <100°F, oven) in a relatively contamination-free environment. Air-drilling samples do not require special handling but may present more of a collection problem if material is erratically hanging up in the muffler. Evaluation of alternative sampling procedures for air drilling systems may be warranted to obtain consistent and representative sampling. In both types of systems, care must be taken to ensure careful and accurate sample collection and handling. Routine employment of a mud logging crew or equivalent for these purposes is strongly recommended.

Several different analytical schemes may be employed, depending again on the primary purpose of the work. Chemical logging of critical element distributions (e.g., Hg, As, & Li) in whole rock material can be accomplished on a real time basis by employing a mobile laboratory at perhaps double normal costs, but it would probably be justified in some circumstances. In many cases it could be more advantageous, however, to contract to have all preparation and analytical work done at a permanent laboratory facility with a specified turn-around time which could be as low as several days depending on the nature and consistency of the work load. Under these conditions additional alternatives are possible. For example, one potentially effective scheme would be to composite all samples in 100-foot intervals, separate a +3.3 concentrate, and then analyze both the +3.3 concentrate (for As, Zn, Mn, Fe, and possibly, Sb, and Mo) and the whole rock composite material (for Hg and Li, and possibly Be and W, in addition to the +3.3 fraction elements). This would provide comprehensive chemical data, useful for all types of interpretation except precise location of specific HWEs, at minimal cost. If greater accuracy in HWE location were also desired, detailed analysis of individual 10-foot samples from 100-foot intervals indicated to be anomalous by the composite data could be carried out.

COST-EFFECTIVENESS OF SOLIDS GEOCHEMICAL TECHNIQUES

The potential cost-effectiveness of solids geochemical techniques in geothermal applications is indicated to be high. Multielement geochemical data of the type and quality necessary can be obtained from many commercial and private laboratories at reasonable cost and can be interpreted with relatively little ambiguity to provide information pertinent to the efficient evaluation of a geothermal system.

Sample Collection and Analytical Costs

For detailed soil surveys, sample collection costs are estimated at $830/square mile assuming a 500-foot grid-spacing, personnel (2 people) and field expenses of $350 per day, and an average collection rate of 40 samples per day. Analytical charges from a commercial laboratory for determination of As and Hg are about $6 per sample, equivalent to a cost of about $570 per square mile. Total basic cost of an As-Hg soil survey thus would be about $1400 per square mile plus orientation survey costs, which might run several hundred dollars.

Costs of surface rock sampling at about the same scale could be several times greater than for the As-Hg soil survey, because sample collection would probably be slower, but a greater variety of useful chemical data could be generated from these samples.

For large-scale surface surveys utilizing pre-existing temperature gradient drill hole cuttings, no sample collection costs will be directly incurred unless fill-in holes or an entire array of holes are to be drilled specifically for the geochemical survey. Analytical costs per unit area could vary greatly depending on hole spacing and survey purpose but might commonly average about $68 per square mile assuming, for example, that hole spacing over a 36 square mile area is on two mile centers (total of 16 holes), that two 100-foot composites and corresponding +3.3 concentrate samples are prepared and analyzed for each hole, and that the +3.3 concentrate sample is analyzed for As, Zn, Mg and Fe, and the corresponding whole rock material for As, Li, Be, Hg, Zn, Mn, Fe, and S.

Cost for routine geochemical logging of deep drill holes would be about $310 per thousand feet of hole assuming no sample acquisition cost, that analytical work is done in a permanent laboratory facility, that 100-foot composite samples are used, and that whole rock material only is analyzed by high-precision procedures for As, Li, Be, Hg, Zn, Mn, Fe, and S. Real time acquisition of As, Li, and Hg data (only) using a mobile laboratory can be roughly estimated to add about $140 per thousand feet to this cost for 100-foot composite data plus $180 per thousand feet if high-precision (± 10 feet) location of water entries is required on a real time basis. Additional assumptions used in obtaining the real-time figures are that sample preparation and analytical costs for a mobile laboratory will be twice normal, that approximately 10% of the individual cuttings grab samples from a well will have to be analyzed to provide precise entry locations, and that other analytical work will be done, as originally indicated, at the permanent laboratory facility. The total cost of geochemical logging which includes real-time high-precision data acquistion thus would be about $630 per 1000 feet. Data processing and plotting using computer methods might add from $20 to $50 per 1000 feet to these costs depending on approach. In view of the diversity of information that can be extracted from the geochemical logs and the much greater cost of obtaining partly similar information using geophysical logging (estimated to be $1500 per thousand feet of hole for a suite of 4 logs plus $1300 to $1800 per thousand feet in rig standby at The Geysers - Gene Suemnicht, personal communication), the potential relative cost-effectiveness of geochemical logging is considered to be good.

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APPENDIX A

Additional multielement geochemistry for
Utah State Wells 14-2 and 72-16

FIGURE A-1A. K, Ca, Mg, Fe, Al, Ti, AND P, WHOLE ROCK SAMPLES, UTAH STATE WELL 14-2

(DEPTH SHOWN IN 100 FT. UNITS)

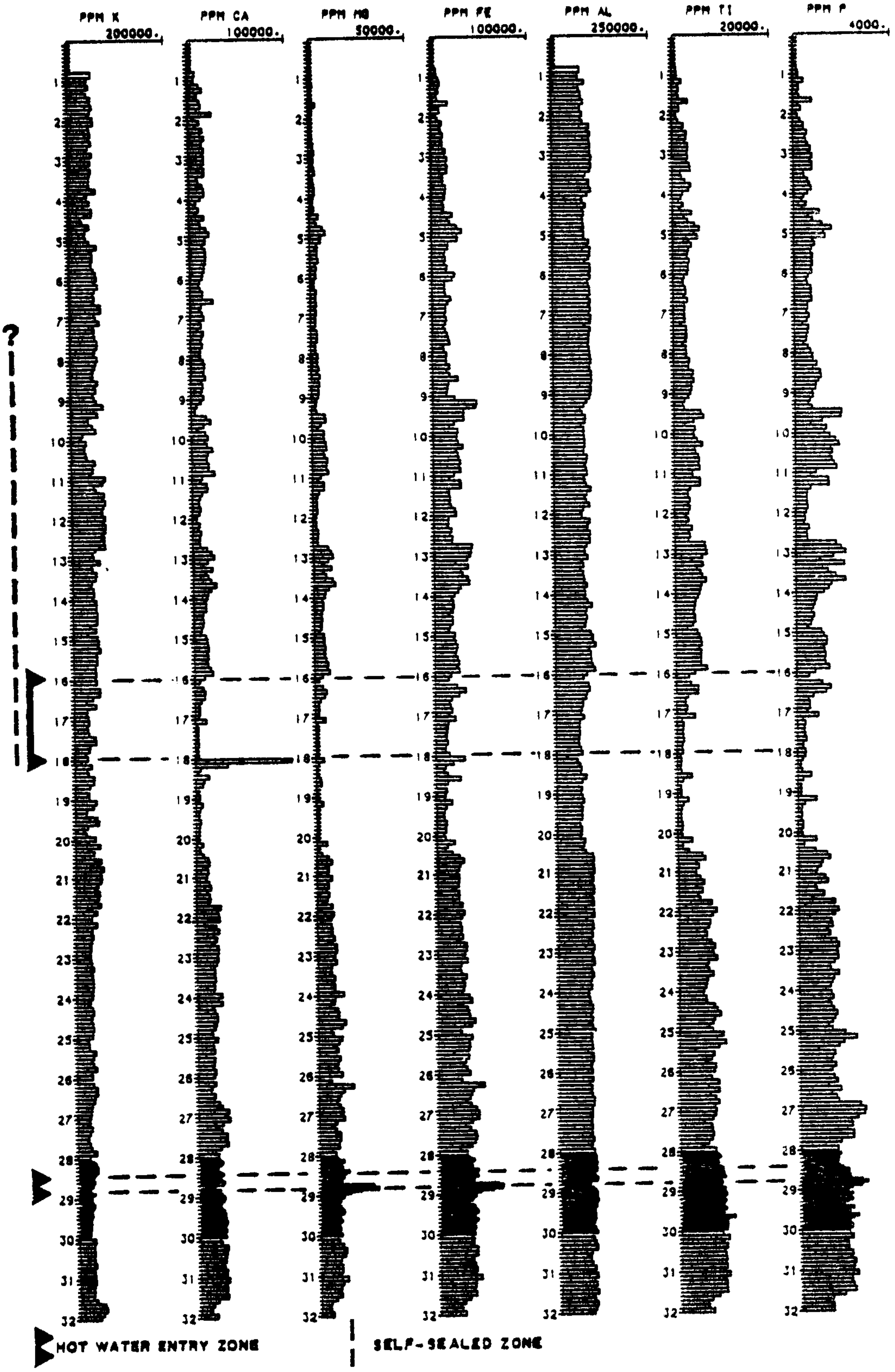


FIGURE A-1B. Ba, Cr, Co, Ni, Cu, Mo, AND Cd, WHOLE ROCK SAMPLES, UTAH STATE WELL 14-2

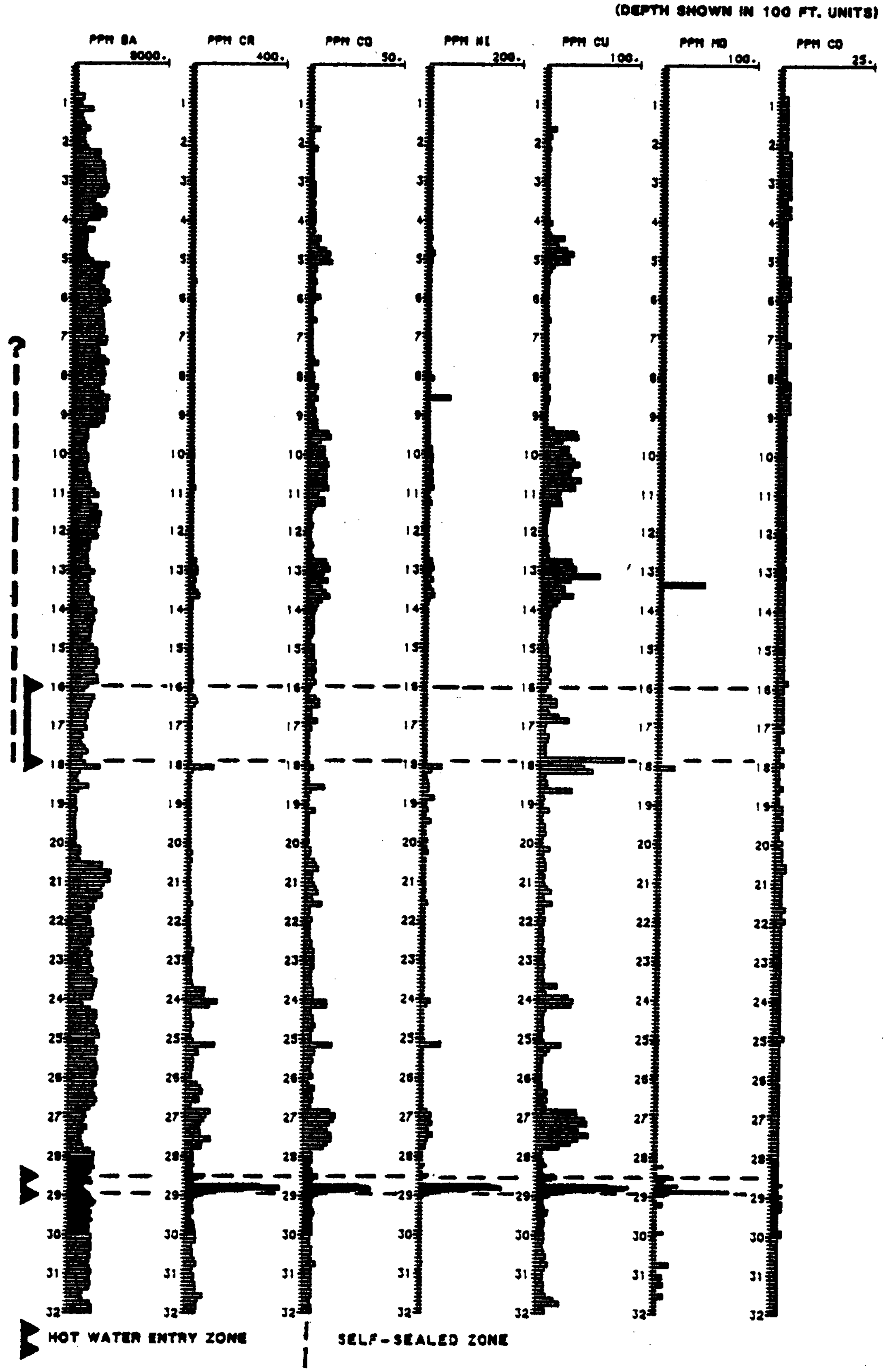


FIGURE A-1C. Sn, W, Be, Zr, La, AND Ce, WHOLE ROCK SAMPLES, UTAH STATE WELL 14-2

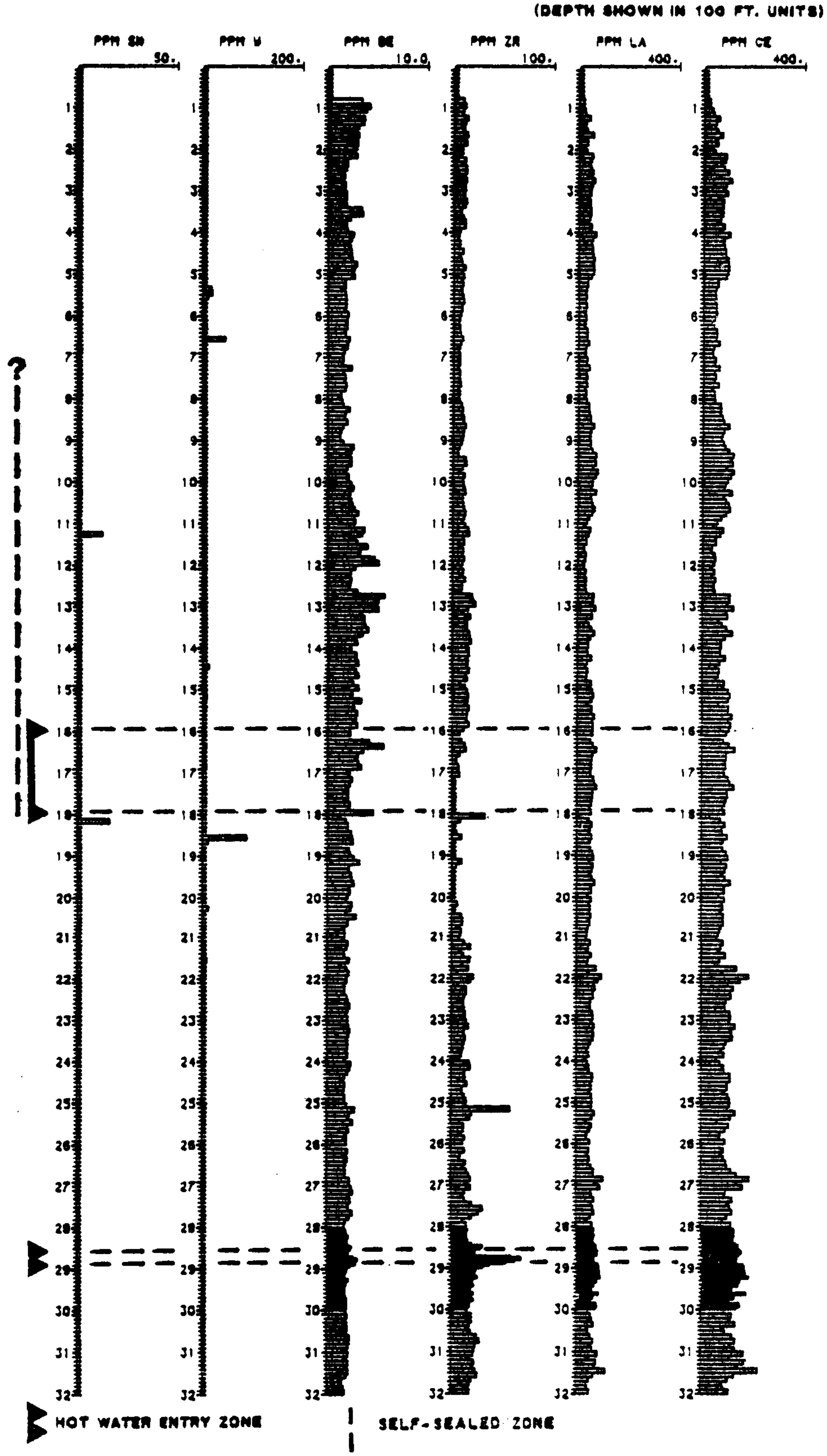


FIGURE A-2A. K, Ca, Mg, Fe, Al, Ti, AND P, WHOLE ROCK SAMPLES, UTAH STATE WELL 72-16

(DEPTH SHOWN IN 100 FT. UNITS)

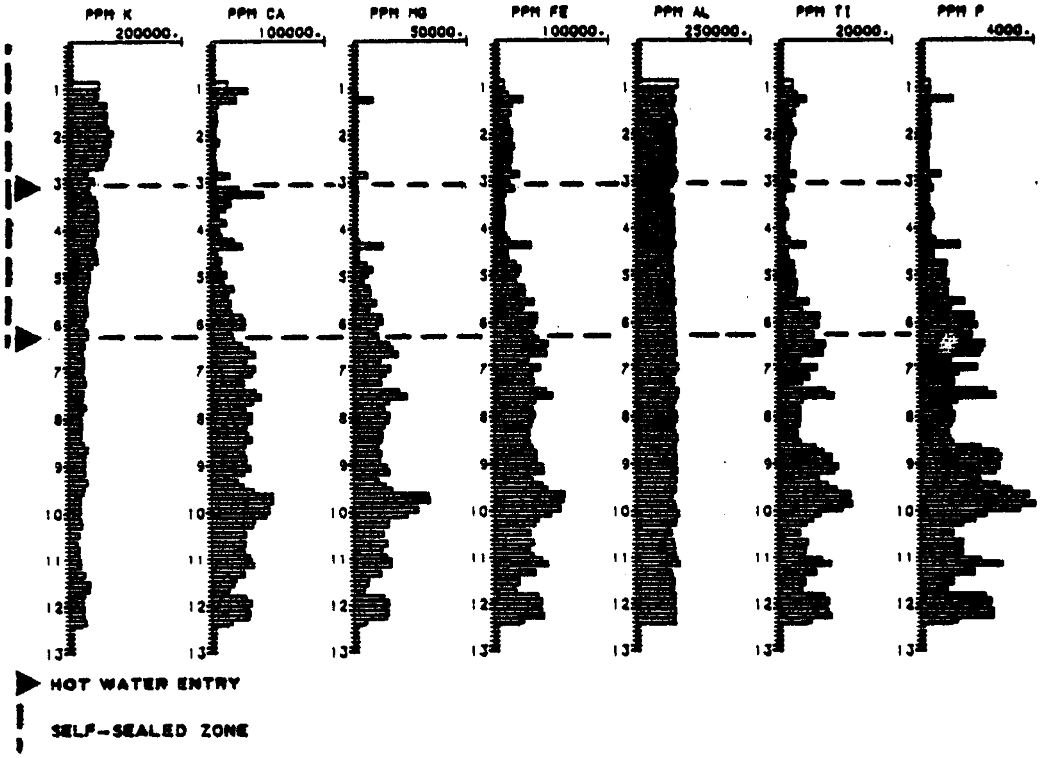


FIGURE A-2B. Ba, Cr, Co, Ni, Cu, Mo, AND Cd, WHOLE ROCK SAMPLES, UTAH STATE WELL 72-16

(DEPTH SHOWN IN 100 FT. UNITS)

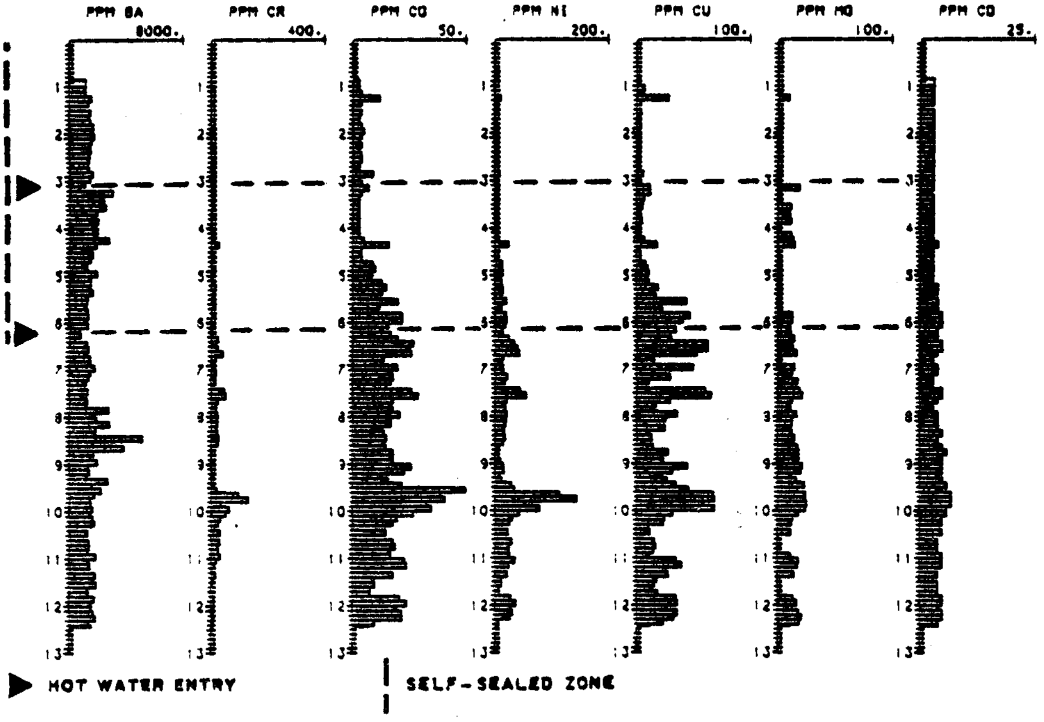
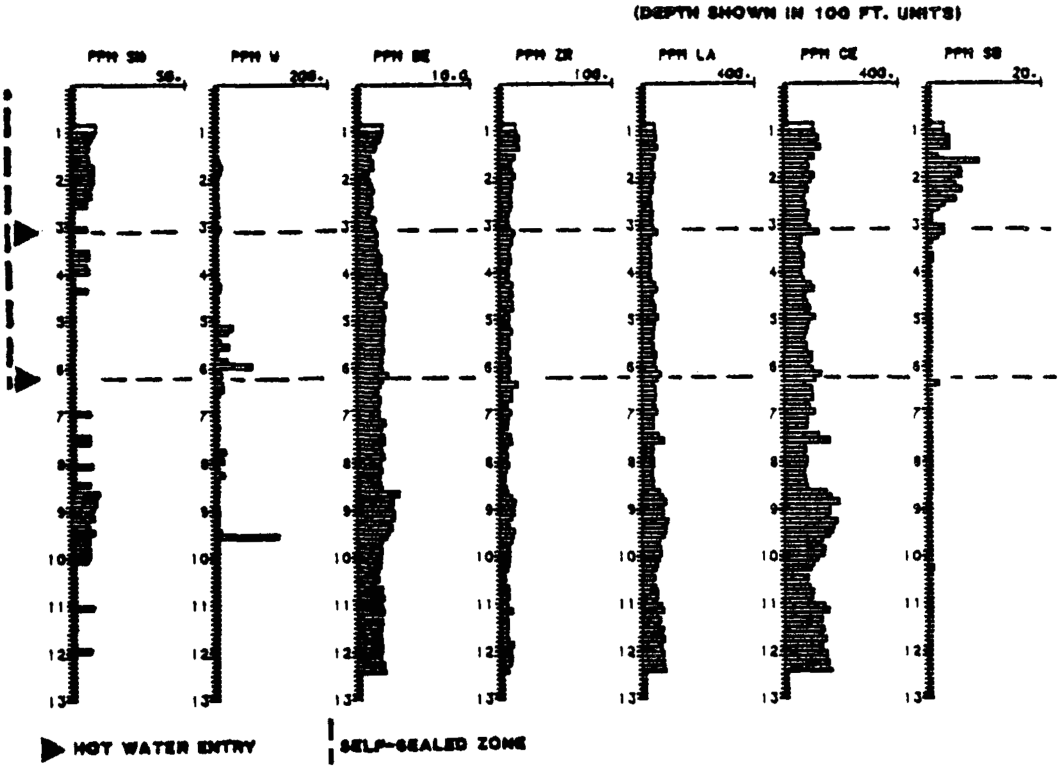


FIGURE A-2C. Sn, W, Be, Zr, La, Ce, AND Sb, WHOLE ROCK SAMPLES, UTAH STATE WELL 72-16



APPENDIX B

Selected geochemical, mineralogical, and geological data for 100-foot cuttings composite samples from Utah State Wells 14-2 and 72-16 and for core samples from diamond drill holes UU76-1, UU75-1A, and UU75-1B.

FIGURE B-1A

DH 14-2

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

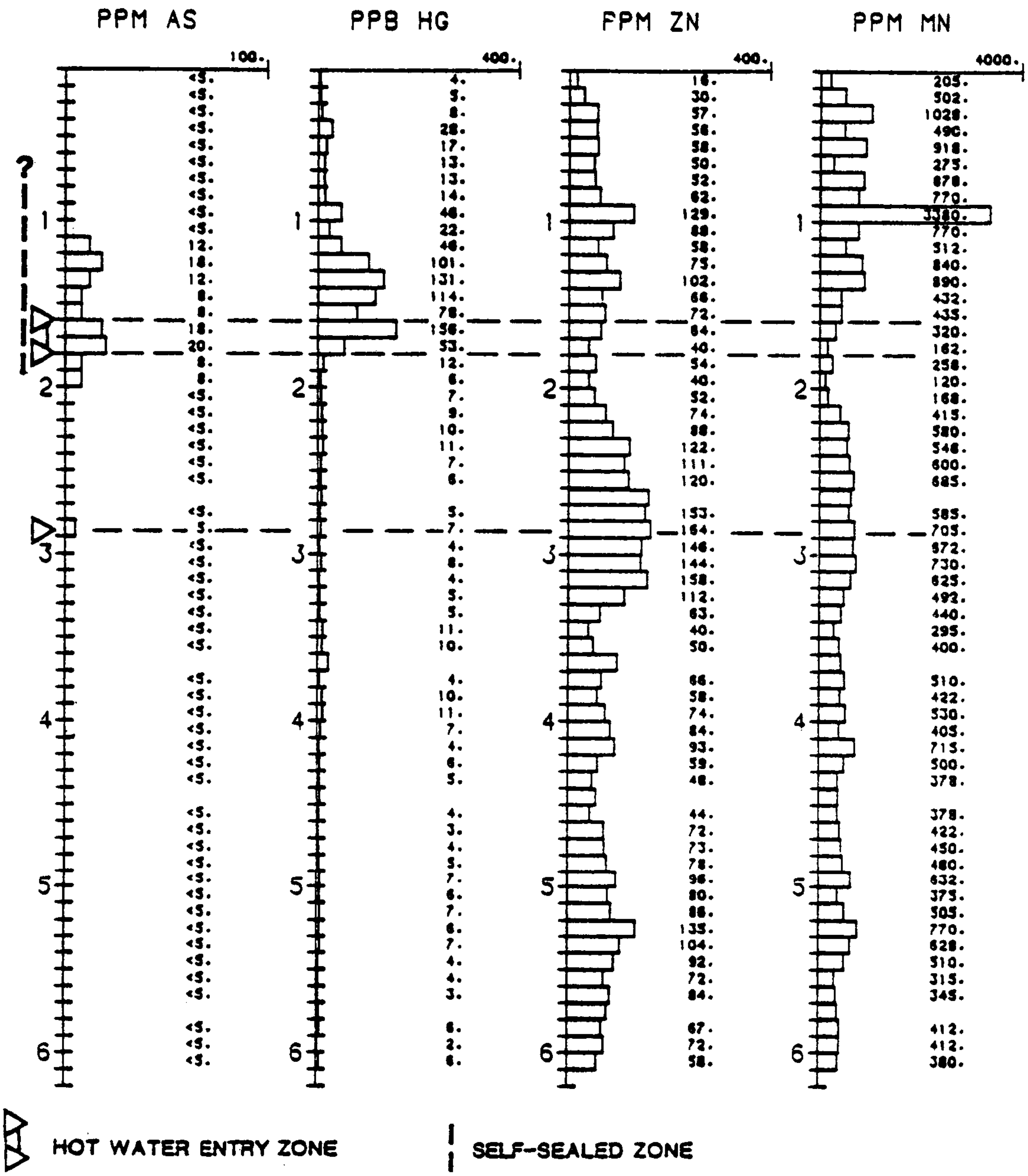
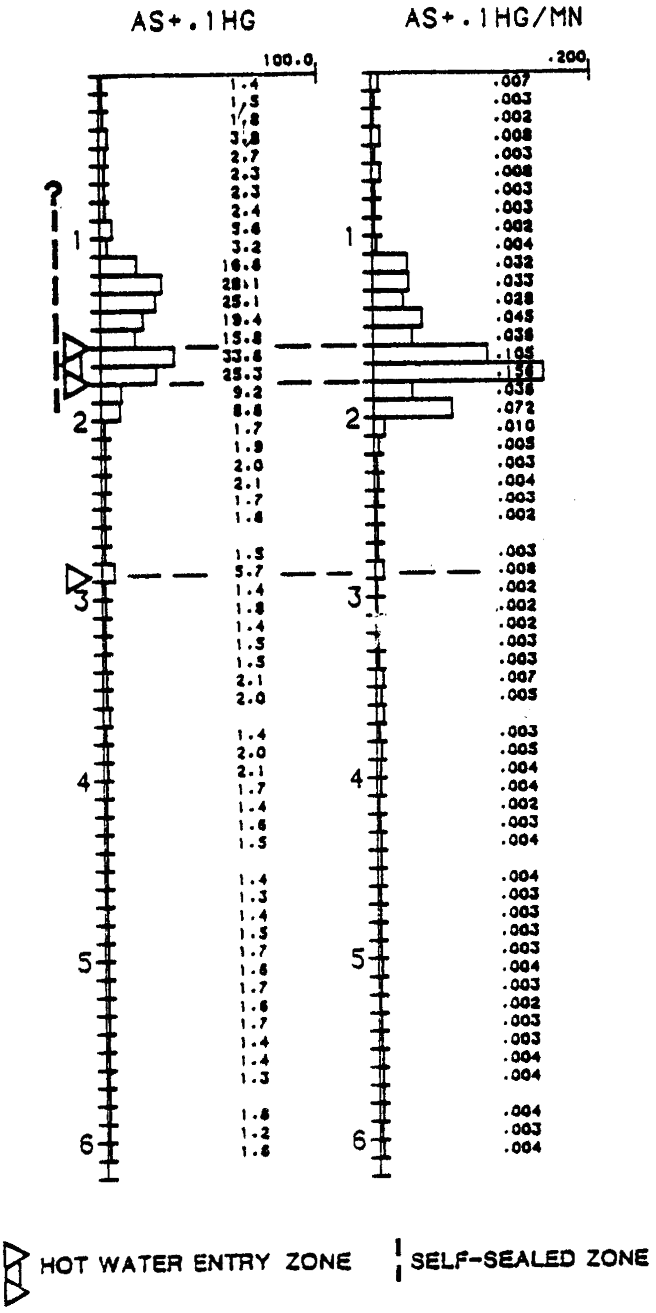


FIGURE B-1B

DH 14-2

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



DH 14-2

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE B-1C

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

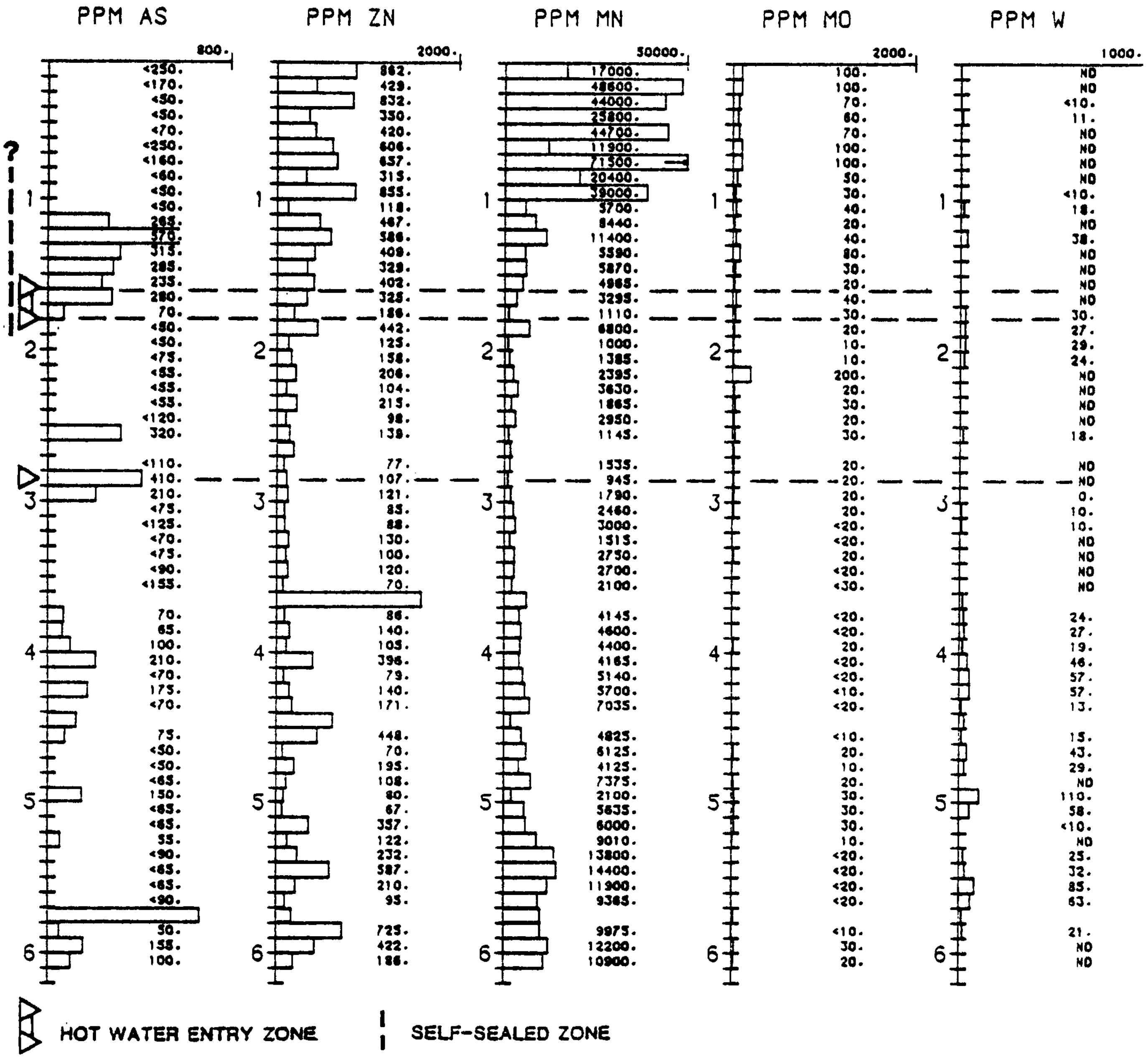


FIGURE B-1D

DH 14-2

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

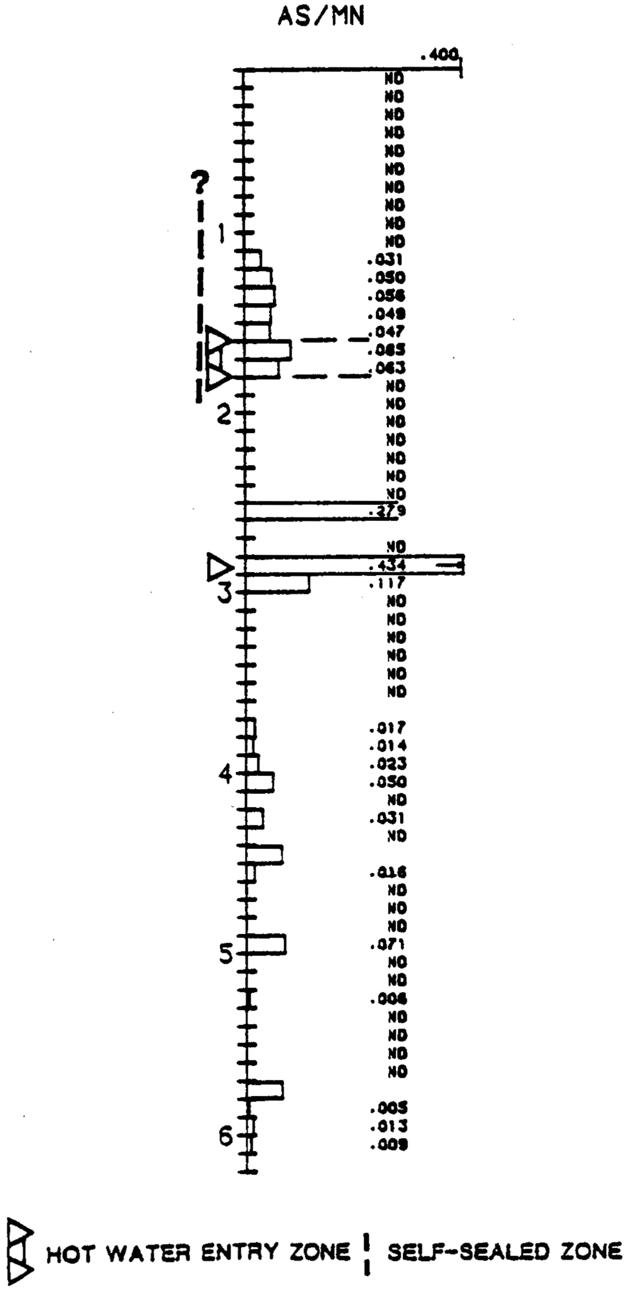


FIGURE B-2A

DH 72-16

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 200.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

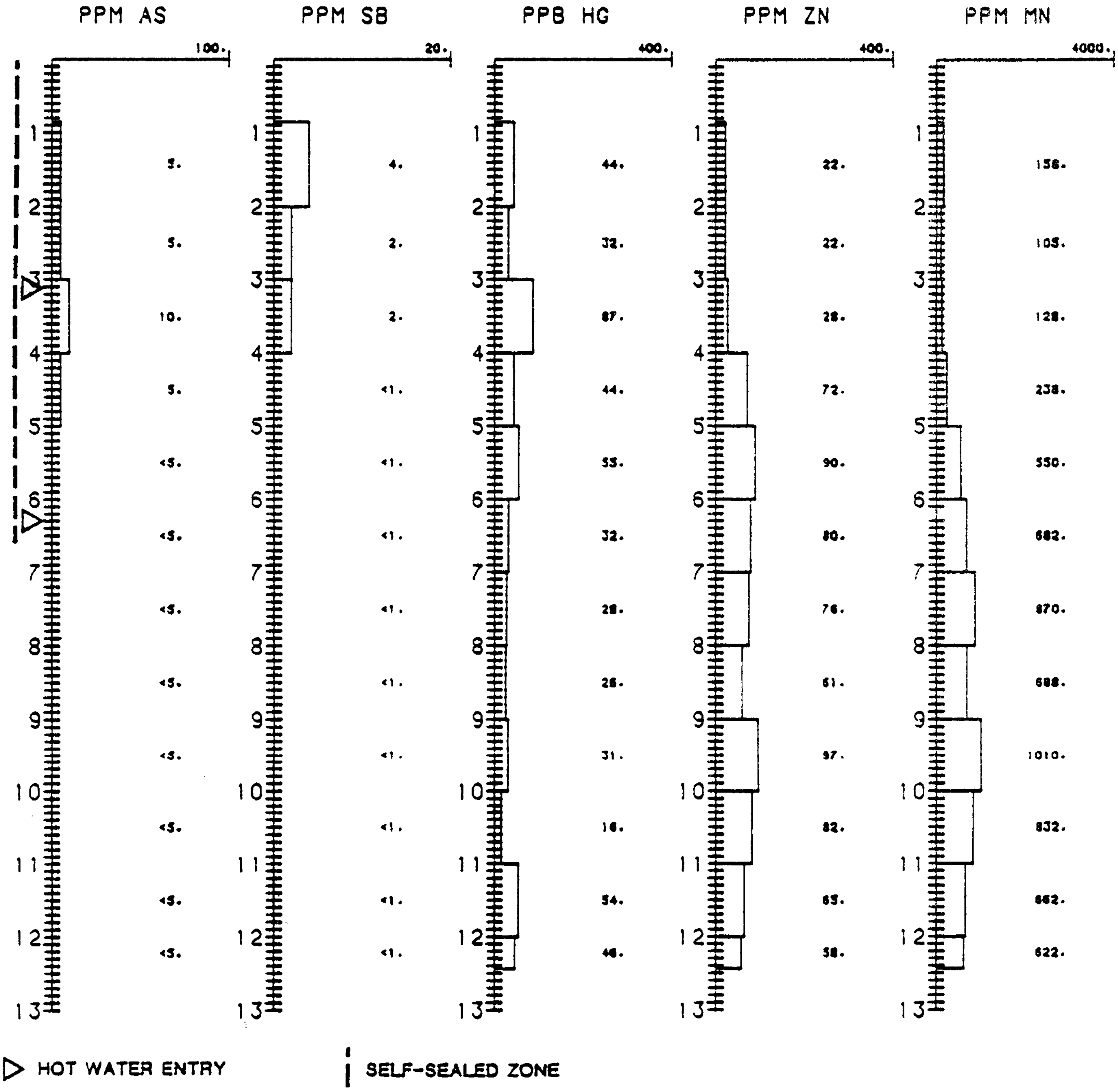


FIGURE B-2B

DH 72-16

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 200.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

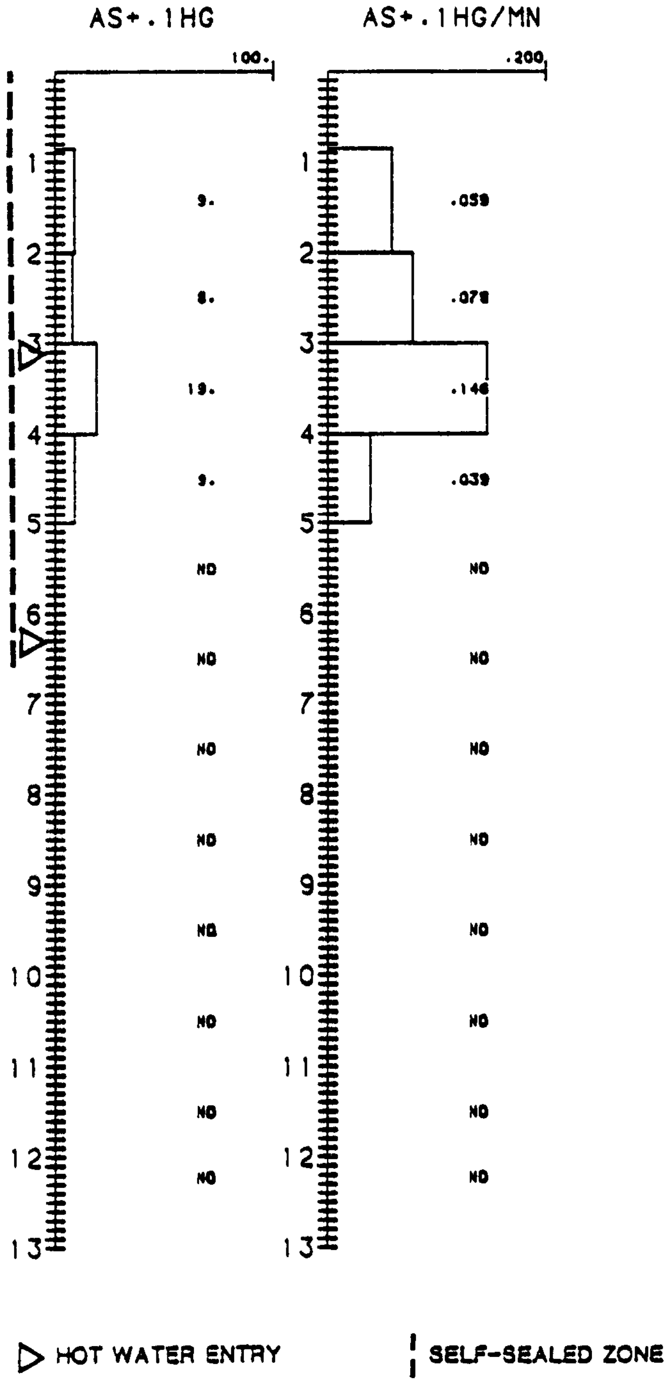
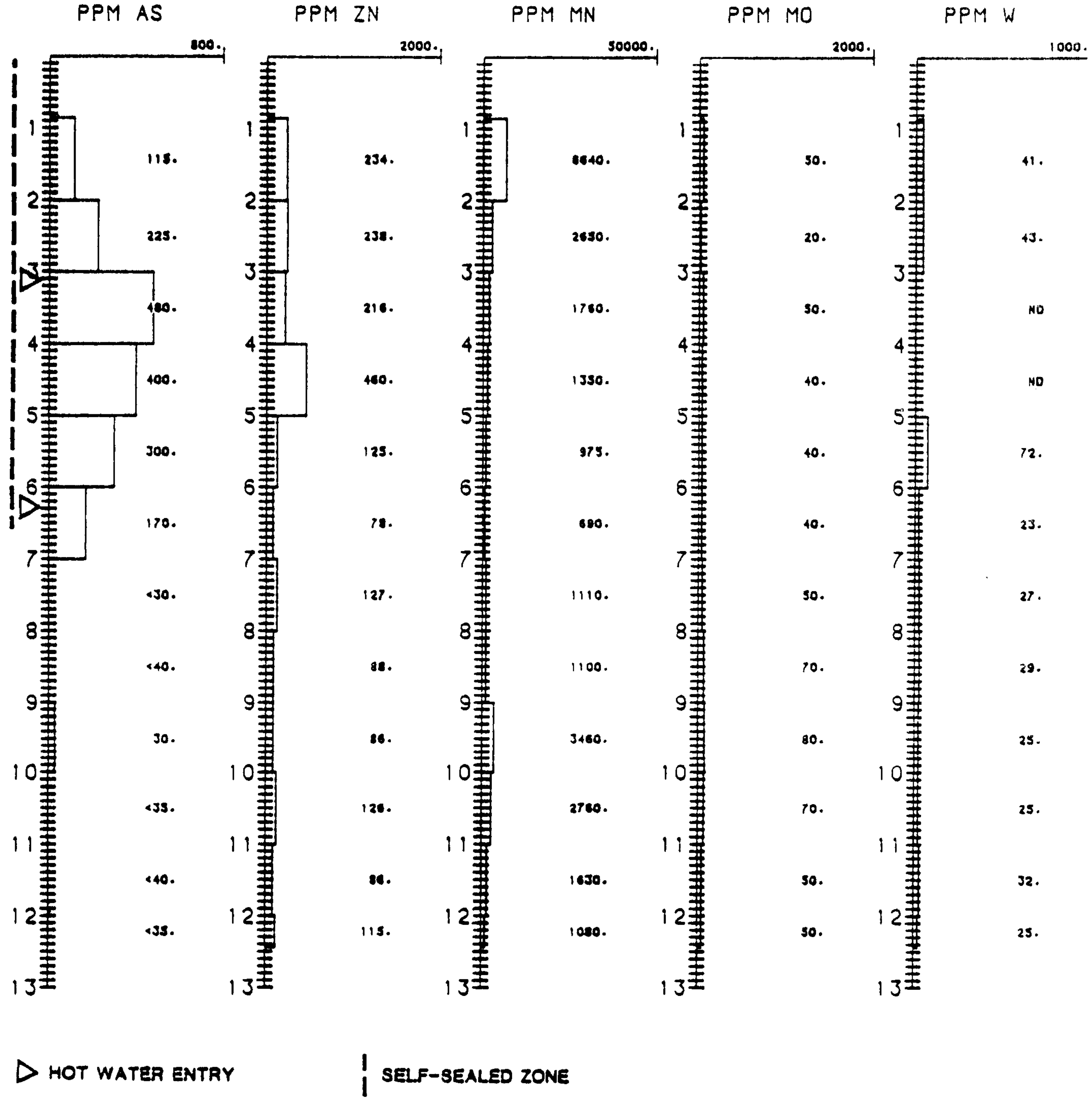


FIGURE B-2C

DH 72-16

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 200.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

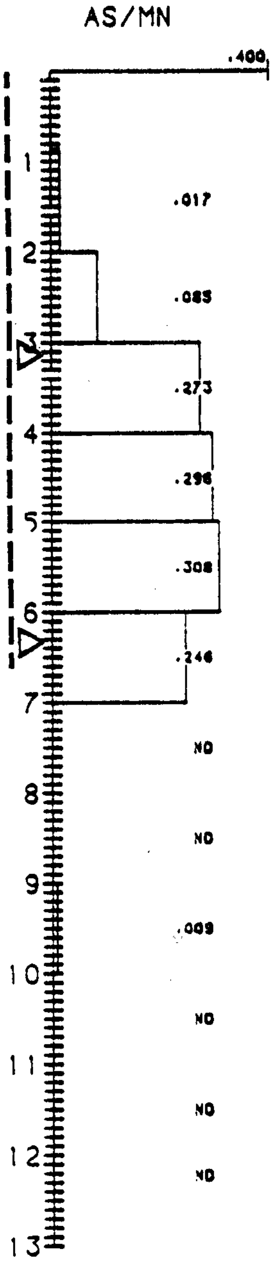


DH 72-16

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

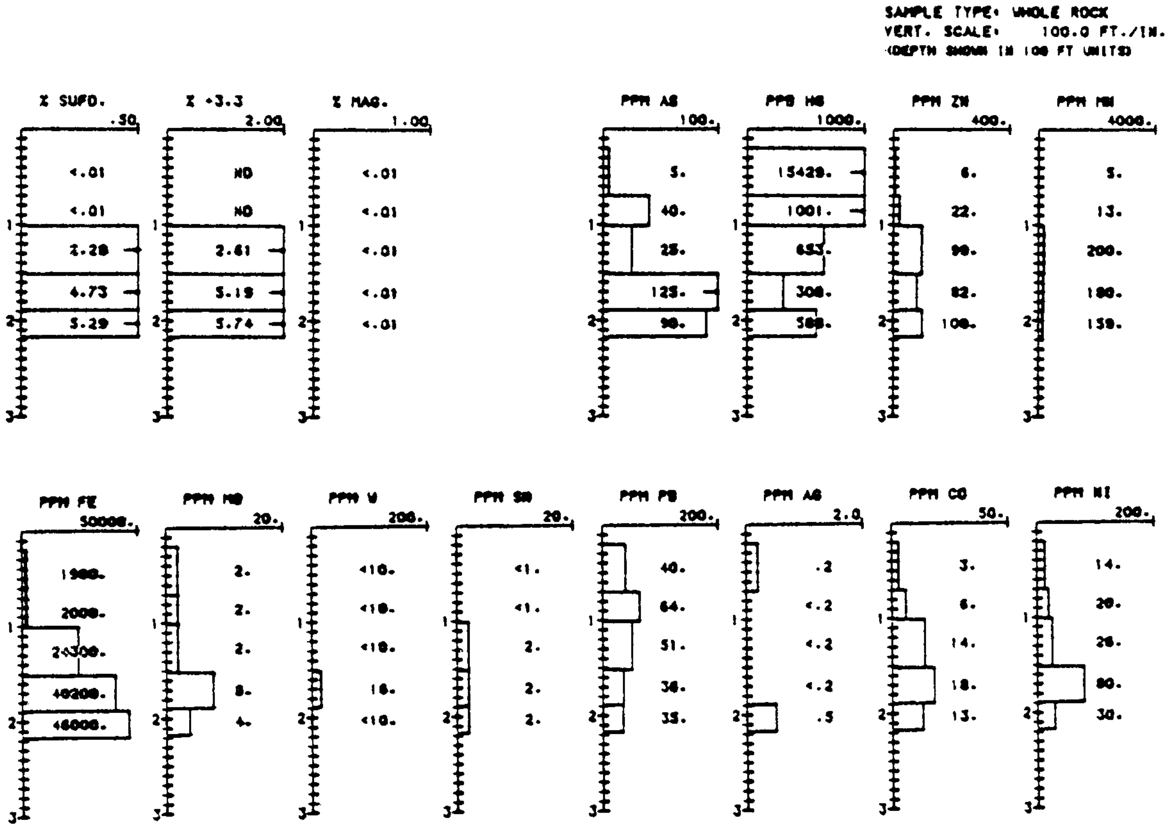
FIGURE B-2D

SAMPLE TYPE: +3.3 LESS MAG
VERT.. SCALE: 200.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)



▷ HOT WATER ENTRY ¦ SELF-SEALED ZONE

FIGURE B-3A GEOCHEMICAL AND MINERALOGICAL DATA FOR DDH UU75-1A



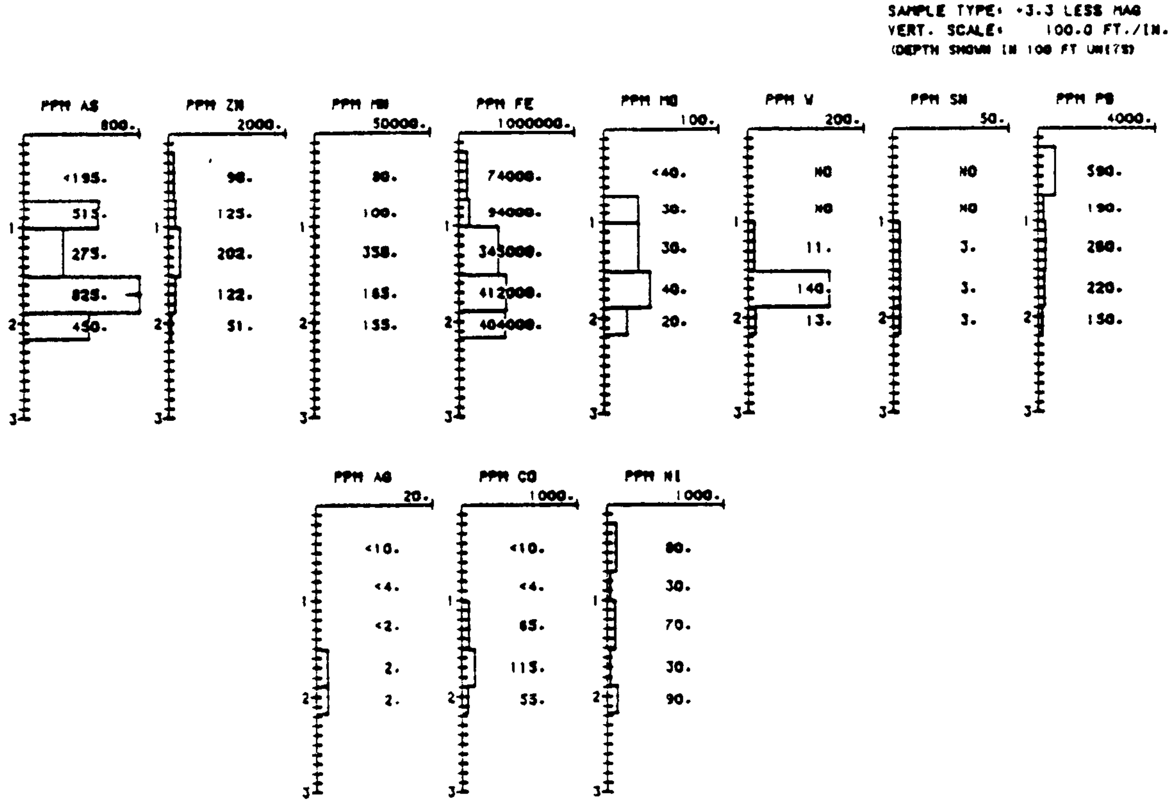
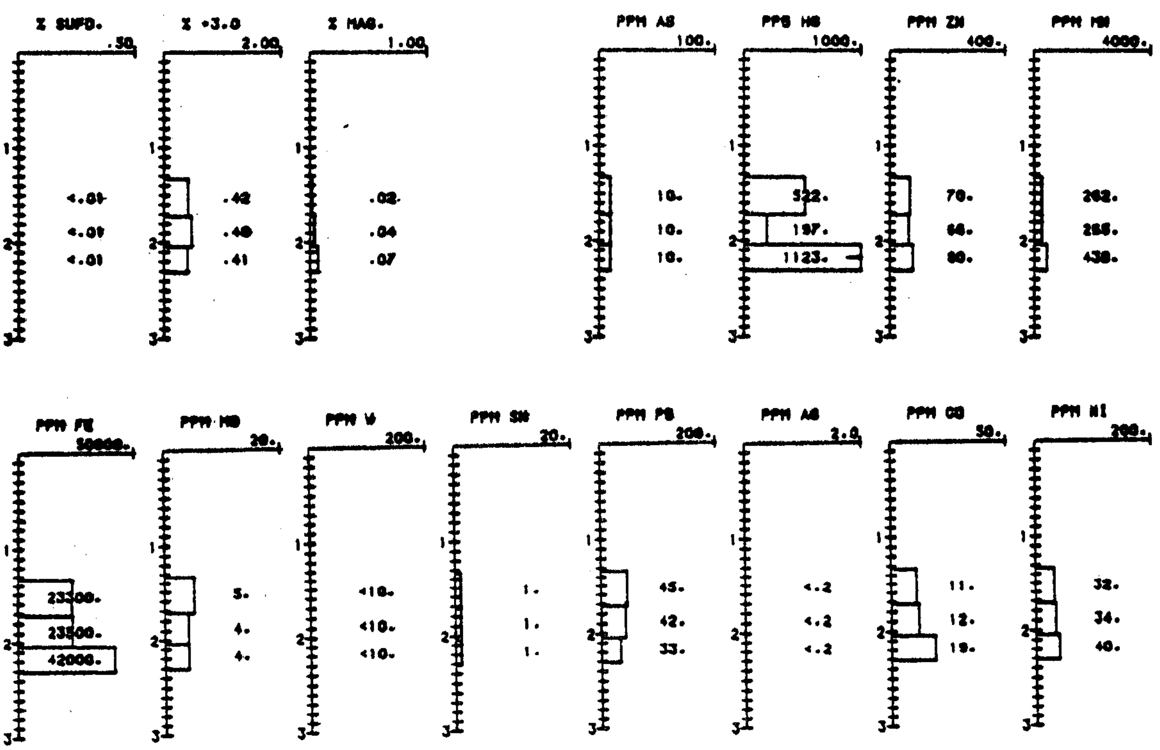


FIGURE B-3B GEOCHEMICAL AND MINERALOGICAL DATA FOR DDH UU75-1B


SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 100.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

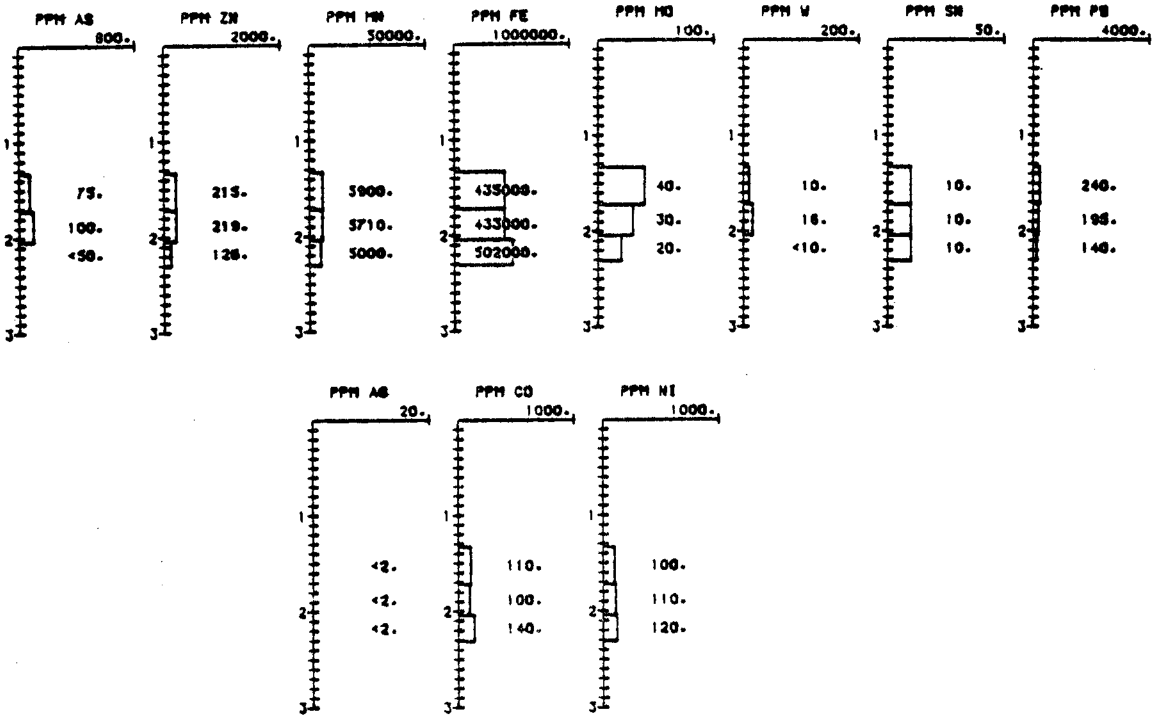
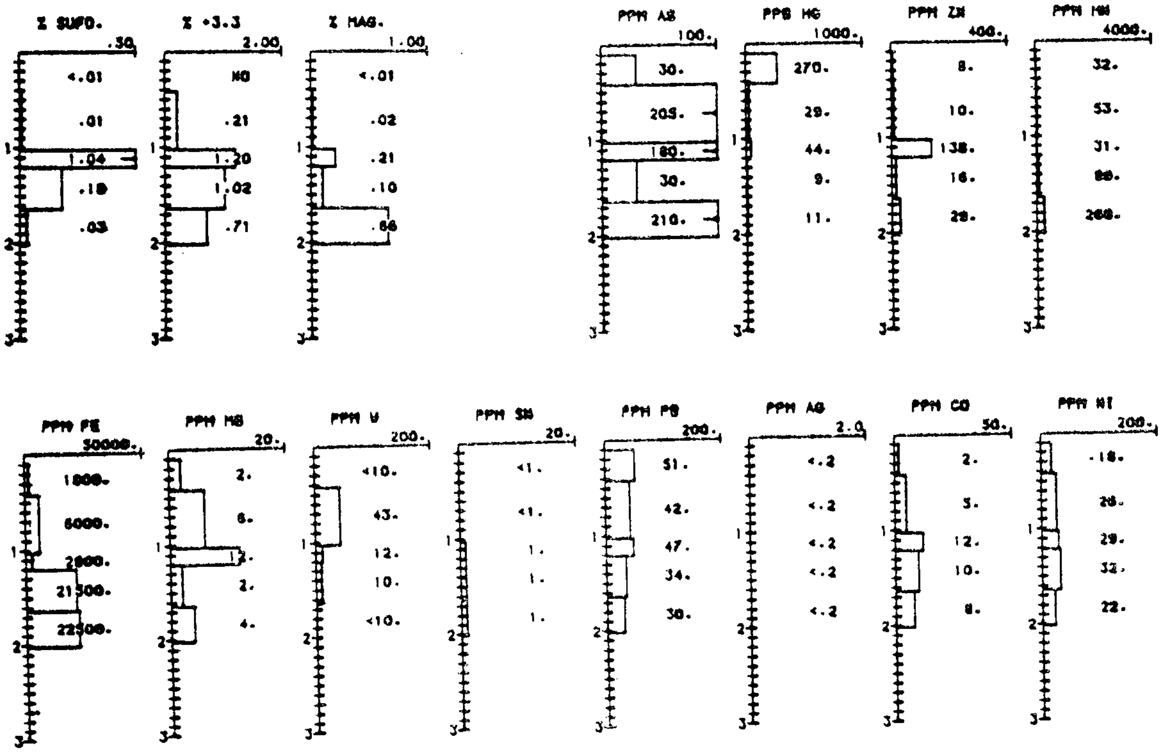

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 100.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

FIGURE B-3C GEOCHEMICAL AND MINERALOGICAL DATA FOR DDH UU76-1

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 100.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)



SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 100.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

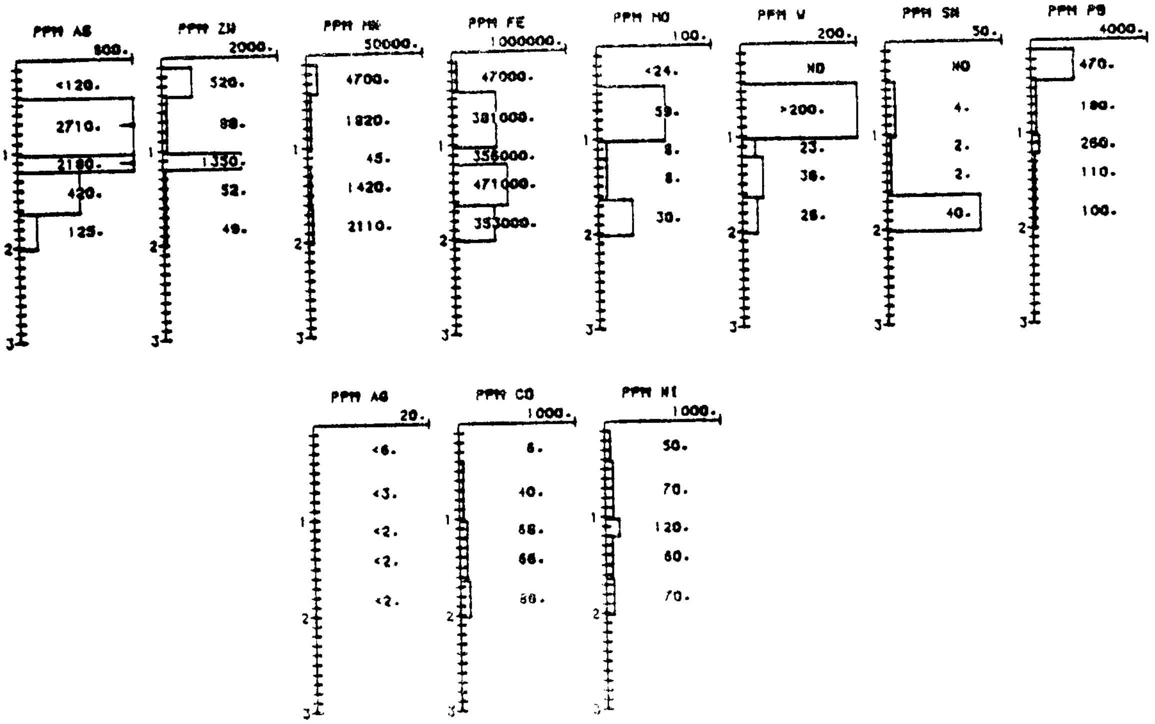


FIGURE B-4

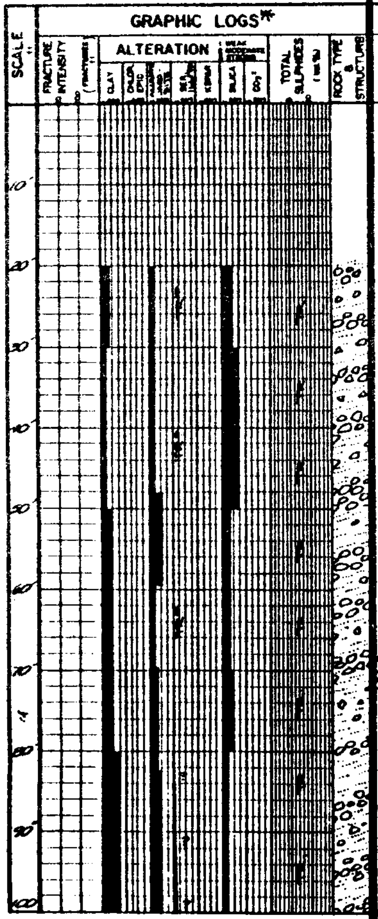
UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH DDH 1A
DEPOSIT TYPE GEOTH.
LOGGED BY J. B. HULEN JULY, AUG. 1977

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m/ft.)
COLLAR ELEV. (m/ft.)
CO-ORDINATES LAT. LON.
GRID 3866 m N 24 m E
T. 27S R. 9W SEC. 4

SHEET NO. 1 OF 5

CORE SIZE (mm in.)	FROM (m/ft.)	TO	GEOPHYSICAL LOGS LOG RUN	DEPTH (m/ft.)	DATE	COMPANY



GEOLOGIC NOTES* (Use also for general comments)

DOWN HOLE LOCATION: DISTANCE DOWN HOLE ft.	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinfill, Replacement); TYPE (Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: DOWN HOLE DIST. (m/ft)	FOLIATION ∢ WITH CORE	BEDDING ∢ WITH CORE	FRACTURE ∢ WITH CORE	DESCRIPTION OF STRUCTURES Post or Pre-Ore (Evidence)	FRACTURE INTENSITY (ft. per metre)	DOWN HOLE SURVEY DATA: ~~DEPTH~~	~~INCLINATION~~	~~BEARING~~	THIN & POLISHED SECTIONS: DEPTH ft.	SAMPLE NUMBER
0-20'		Qal?	NO CORE	20 - app. 75': MINOR ERRATICALLY DISTRIBUTED NATIVE SULFUR (W/TR. REALGAR). SULFUR OCCURS AS: ① DISS., IRREG. MASSES OF SUBHEDRAL XLS. AVG. 1 mm. DIA. (UP TO 3 mm. DIA.) - COMMONLY INTERCONNECTED BY TINY VNLTS. ② SUBH. XLINE CRUSTS ON AND INTERGROWN WITH OPAL & CLAY IN VNLTS. & PARTIALLY LINING VUGS - REALGAR APPEARS TO BE CRYPTOXLINE, OCCURS IN AMORPHOUS CLOTS & STAINS AVG ≤1 mm. DIA. (UP TO 2 mm DIA.) - RARE RELICT PYRITE GRAINS LOCALLY PRESENT					ALTERED ALLUVIUM TENDS TO CRUMBLE RATHER THAN FRACTURE ½ core intact 201-2015		W. P. SILL ⊛ SAMPLES (core intact) 25[illegible]-26[illegible]' 80[illegible]-07[illegible]' 9[illegible]-9[illegible]' 123-123[illegible]' 155[illegible]-156[illegible]' 167[illegible]-168[illegible]' 192[illegible]-192[illegible]' 208[illegible]-208[illegible]' 211-211.5' A. TRIPP SAMPLES (core missing) 69[illegible]-70' 118[illegible]-118[illegible]' 165-165[illegible]' 201-202[illegible]' 210[illegible]-211'				
20-59.2'		ALTERED ALLUVIUM	SILTY TO SANDY GRAVEL; ANGULAR-SUBANG. FRAGS OF ALT. FSP, QTZ, GRANITIC RX, & POSS. VOLC. RX (INTENSITY OF ALTN. PRECLUDES ACCURATE I.D.) FR. ≤≤1 mm TO AT LEAST 5 cm MAX DIMENSION; OVERALL BLEACHED, PUNKY, CRUMBLY ASPECT; LOCALLY DENSE AND PORCELLANEOUS IN IRREGULAR PATCHES; APPEARS TO BE A V. FINE-XLINE. AGGREGATE OF SILICA, CLAY (AND POSS. TR. ILLITE) W/ALUNITE; POROSITY VARIABLE FR. <1%-20% - VUGS ARE IRREG., TEND TO BE ELONGATE, UP TO 15 mm. MAX. DIMENSION, COMMONLY PARTIALLY LINED W/BOTRYOIDAL OPAL & CLAY (OCC. W/TR. S & As_2S_3); A FEW (10/meter?) VUGGY, IRREGULAR CLAY-OPAL VNLTS. up to 20 mm. WIDE (AVG. ~ ½ mm. WIDE)													
59.2-62.8' (80% CORE RECOVERY)		ALTERED ALLUVIUM	SAME AS ABOVE, EXC. 15-20% POROSITY, PRIMARILY DUE TO SOLN. OF FSP. FRAGS. & FSP. PORTIONS OF GRANITIC FRAGS, RATHER THAN IRREG. VUGS AS ABOVE.  frothy latticework in dissolved fsp. xl. (silica-clay boxwork)	1% LIMONITE, PREDOMINANTLY POWDERY REDDISH-BRN. HEMATITE W/MINOR GOE. & HEM., AS: ① DISS. ANH. GRAINS, AVG. ≤0.1 mm DIA. ② AS DENSE TO LOOSE AGGREGATES OF THESE GRAINS UP TO 30 mm. (AVG ~ 2 mm) MAX. DIMENSION. ③ AS RARE IRREG., DISCONTINUOUS VNLTS. SUB-∥ TO BEDDING, UP TO 10 mm. (AVG. < 1 mm) WIDE COMPOSED OF THE MASSES DESCRIBED ABOVE.											

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

⊛ THERMAL CONDUCTIVITY

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

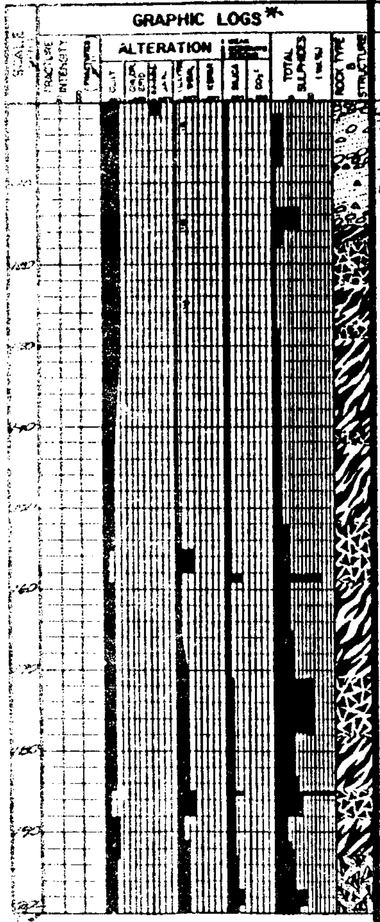
PROJECT ROOSEVELT
DRILL HOLE UNIV. OF UTAH DDH 1A
DEPOSIT TYPE GEOTH.
LOGGED BY J. B. HULEN

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (ft)
COLLAR ELEV. (ft)
CO-ORDINATES LAT.
LON.
GRID 3866 m. N 240 m. E
T 27S R 9W SEC. 4

SHEET № 2 OF 5

CORE SIZE (in.)	FROM (ft)	TO	GEOPHYSICAL LOGS LOG RUN	DEPTH (ft)	DATE	COMPANY

GRAPHIC LOGS* — ALTERATION



GEOLOGIC NOTES* (Use also for general comments)

DOWN HOLE LOCATION: DISTANCE DOWN HOLE (ft)	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinlet, Replacement); TYPE (Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: DOWN HOLE DIST (ft)	FOLIATION ∢ WITH CORE	BEDDING ∢ WITH CORE	FRACTURE ∢ WITH CORE	DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))	FRACTURE INTENSITY	DOWN HOLE SURVEY DATA: DEPTH (ft)	INCLINATION	BEARING	THIN & POLISHED SECTIONS: DEPTH (ft)	SAMPLE NUMBER
69.5-71.5'		ALTERED ALLUVIUM	SAME AS 59^5-69^5'	SAME AS 59^5-69^5, EXC. ~0.2% HEMATITIC LIMONITE											
71^5-82^1'		ALTERED ALLUVIUM	SAME AS 59^5-69^5', EXC. TO 80' ROCK IS HARDER, MORE DENSE, W/ MORE OBVIOUS PORCELLANEOUS ALUNITE – 15-20% POROSITY TO 78.1'; <5% TO 82.1'.	LIMONITE, SAME AS 59^5-69^5', EXC. GOETHITE AND JAROSITE MORE ABUNDANT — PATCHES OF HEM. AND OF GOE-JAR. TEND TO BE MUTUALLY EXCLUSIVE 79-82^1': 7% LIMO. 71^5-79': 3% LIMO. (LOCAL BANDS & PATCHES W/ UP TO 20% LIMO.)											
82^1-90^6'		ALTERED ALLUVIUM	SAME AS 20-59^5', EXC. 4-5% POROSITY, AVG 4-5% (UP TO 10%) LT. YELLOWISH-GRAY PULVERULENT TO PORCELLANEOUS JAROSITE-ALUNITE, ALMOST TOTALLY INTERSTITIAL TO LARGER FRAGMENTS	<0.1% HEM., TR. GOE TEXTURALLY SIMILAR TO 59^5-69^5'											
90^6-101^7'		ALTERED ALLUVIUM	SAME AS ABOVE, EXC. FSP FRAGS ARE EXTENSIVELY STAINED PINK TO MAROON BY FINELY DIVIDED HEMATITE; RARE RELICT FRESH FSP LOCALLY PRESENT – OVERALL AVG 7% JAROSITE-ALUNITE (VARIES FR. <1-10%)	←											
101^7-108' (16% CORE REC.)		ALTERED ALLUVIUM	SAME AS 20-59^5', EXC. NO ALUNITE, ~2% POROSITY, MOSTLY UNOXIDIZED	PYRITE 3%, TEXTURALLY SIMILAR TO HEMATITE FR. 59^5-69^5', EXC. GRAINS ARE PREDOMINANTLY SUBHEDRAL, AVG. ~0.1 MM.											
108-113' (10% CORE REC.)		ALTERED ALLUVIUM	SAME AS 20-59^5' EXC. NO ALUNITE, ~2% POROSITY, MOSTLY UNOXIDIZED	SAME AS ABOVE, EXC. <1% PY., ~1% JAROSITE TEXTURALLY SIMILAR TO PYRITE											

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH DDH 1A
DEPOSIT TYPE GEOTH
LOGGED BY J.B. HULEN

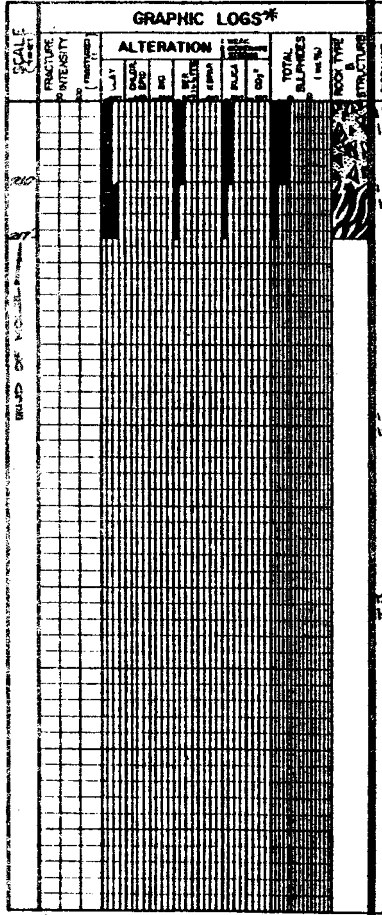
DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (ft.)
COLLAR ELEV. (ft.)
CO-ORDINATES LAT.
LON.
GRID 3066 m N 24 m E
T 27S R 9W SEC. 4

GEOPHYSICAL LOGS

SHEET No. 3 OF 5

CORE SIZE (in.)	FROM (ft.)	TO	LOG RUN	DEPTH (ft.)	DATE	COMPANY

GRAPHIC LOGS*



GEOLOGIC NOTES* (Use also for general comments)

DISTANCE DOWN HOLE ft.	ELEVATION	ROCK TYPE	DESCRIPTION (MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE)	MINERALIZATION (DISTRIBUTION: Massive, Disseminated, Veinfill, Replacement; TYPE: Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))	FRACTURE INTENSITY
113–115^{8}'		ALTERED ALLUVIUM	SAME AS 20–59^{5} EXC. NO ALUNITE, ~2% POROSITY, MOSTLY UNOXIDIZED	SAME AS 101^{7}–108', EXC. 7% PYRITE		
115^{8}–117^{6}'		ALTERED GNEISS (BTE–QTZ–FSP. PROMINENTLY BANDED)	… FINE–MED. XLINE; LENSOID MASSES OF PARTIALLY–TOTALLY ALTERED FLAKY BIOTITE, UP TO AT LEAST 60 MM. X 15 MM IN X-SECTION; PROMINENT STREAKY TEXTURE LOCALLY PRESERVED; UNOXIDIZED TO 117^{3}', PARTIALLY OXIDIZED & BLEACHED TO 117^{6}'; FSP. THROUGHOUT ALT. TO MONTM.–KAOLINITE	OVERALL 3% PY, TEXTURALLY SIMILAR TO 101^{7}–108'; SLIGHT OXDN. OF PY TO GOE – VAR. BELOW !		>50?
117^{6}–122'		ALTERED FLT GOUGE & BRECCIA	… CHAOTIC JUMBLE OF QTZ, ALT. FSP. & BTE. & GNEISSIC FRAGMENTS; THESE ALTERED TO CLAY (BTE ONLY PARTIALLY ALTERED); RARE OPAL VNLTS. ≤ 1MM WIDE; ≥75% OXIDIZED TO 121'; SOMEWHAT LESS OXDN. TO 122'	~1% PY, AS ABOVE, TO 121'; 1^{5}% PY TO 122'; PY IS PARTIALLY OXIDIZED TO GOETHITE		
122–145^{6}'		ALTERED GNEISS (BTE–QTZ–FSP. (PROMINENTLY BANDED)	SAME AS 115^{8}–117^{6}; ROCK IS OVERALL A FINE (<1mm) TO MED. (2-5 mm.) – XLINE AGGREGATE OF BTE (PARTIALLY TO TOTALLY ARGILLIZED), FSP (≥95% ARGILLIZED & QTZ, W/ LOCALLY PROMINENT PRESERVED GNEISSIC TEXTURE; CLAYS APPEAR TO BE MONTM. & KAOLIN ① MONTM(?) IS A WAXY, YELLOWISH TO GREENISH VARIETY (-IES?) PARTIALLY REPLACING BIOTITE & FSP IN IRREG. PATCHES ② KAOLIN IS PURE WHITE, INTERGROWN W/ MONTM.(?) REPLACING FSPS. (MUCH RARER THAN MONT)	OVERALL AVG. ~ 2% PYRITE, AS DISS., GENERALLY SUBH. GRAINS ≤ 0.1 MM DIA., AND AS DENSE TO LOOSE AGGREGATES OF THESE GRAINS UP TO 5 MM (AVG ≤ 1 MM) IN DIA. — ALSO AS SCATTERED GRAINS & GRAIN AGGREGATES W/ CLAY IN STKWK. VNLTS. PY IS COMMONLY TARNISHED TO DULL BRONZE, REDDISH-BROWN, & BLUE TO GRAY (CC IN PART?)	DIFFICULT TO ESTIMATE FRACTURE DENSITY; CORE IS COATED W/ THICK CLAY JACKET, BUT PROB. ≥ 50 FRACS/m. FLTS. 128–129' 141–142' 143–145^{6}'	>50?

③ ILLITE OR SER. (BLEACHED BIOTITE?) INTERGROWN W/ BOTH TYPES OF CLAY BUT IRREGULARY DISTRIBUTED & UNCOMMON

CLAYS & ILLITE ALSO OCCUR IN COMMON STOCKWORK VNLTS. & FILMY FRACTURE COATINGS, WITH AND WITHOUT SULFIDES (PARAGENESIS UNCERTAIN)

*NOTE : GRAPHIC LOGS AND GEOLOGIC NOTES NOT AT SAME SCALE.

FIGURE B-4 (cont.)

GEOPHYSICAL LOGS SHEET NO. 4 OF 5

CORE SIZE (mm. in.)	FROM (m ft.)	TO	LOG RUN	DEPTH (m ft.)	DATE	COMPANY

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH DDH 1A
DEPOSIT TYPE GEOTH.
LOGGED BY J.B. HULEN

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m ft)
COLLAR ELEV. (m ft)
CO-ORDINATES LAT. LON.
GRID 3866 m. N 24 m. E
T 27S R 9W SEC. 4

GRAPHIC LOGS* — GEOLOGIC NOTES* (Use also for general comments)

DISTANCE DOWN HOLE ft.	ROCK TYPE	DESCRIPTION (MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE)	MINERALIZATION (DISTRIBUTION: Massive, Disseminated, Veinlet, Replacement; TYPE: Hypogene, Supergene, Ore and Lineage Mineralogy)	STRUCTURE: DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))
143.5-152'	ALTERED GNEISS (BANDED)	SAME AS ABOVE, EXC. MINOR VUGGY, DISCONTINUOUS SILICA VNLTS, AVG. ≤1 MM (UP TO 10 MM.) WIDE — VUGS IN THESE COMMONLY LINED WITH COLLOFORM WHITE MINERAL, THEN (ON WHITE MINERAL) TINY (≤0.1 MM. LONG) EUHEDRAL, WATER-CLEAR QTZ. XLS	SAME AS 122-143.5'	149.8-149.9': FLT. GOUGE & BX. OTHERWISE SAME AS 122-143.5'
152-159'	FAULT GOUGE & BX. (ALTERED)	DEGREE OF COMMINUTION HIGHLY VARIABLE; STRONGLY SERICITIZED TO 158'; SILICA FLOODING W/ BLUISH-GRAY CHALCEDONY (?) 158-159'.	152-158': 1% PY, SAME AS 122-143.5' 158-159': 12% PY IN SILICIFIED ZONE (BANDED 2 mm. SILICA-SULFIDE VNLT. AT 40° TO CORE AXIS AT 158')	GOUGE & BX.
159-171'	ALTERED GNEISS (BANDED)	SAME AS 122-143.5'; BTE IS ALMOST TOTALLY ALTERED TO WAXY GREENISH CLAY, BUT RELICT BTE. IS LOCALLY PRESENT.	1% PY, SAME AS 122-143.5'	FRACS. SAME AS 122-143.5'
171-177.8'	ALTERED FLT. GOUGE & BX.	... BLEACHED APPEARANCE, STRONGLY SERICITIZED WITH MINOR SILICA & CLAY	~10% PY, SAME AS 122-143.5'; ALSO ≤0.1% RESINOUS BROWNISH-RED MINERAL (SP?) TEXTURALLY SIMILAR TO PY., BUT INDIVIDUAL GRAINS SLIGHTLY LARGER	CRUSHED, BRXTD.
177.8-185'	ALTERED GNEISS (BANDED)	... SAME AS 122-143.5' EXC. MORE STRONGLY SERICITIC. SER. INCREASING DOWNHOLE	5-7% PY, SAME AS 122-143.5'	FRACS.: SAME AS 122-143.5'
185-188'	ALTERED FLT. GOUGE & BX	... STRONGLY SERICITIZED	PY, SAME AS 122-143.5' 185-185.8': >25% 185.8-188': 8-10%	

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH DDH 1A
DEPOSIT TYPE GEOTH.
LOGGED BY J.B. HULEN

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m/ft.)
COLLAR ELEV. (m/ft.)
CO-ORDINATES LAT. / LON.
GRID 3066 m. N 24 m. E
T. 27S R. 9W SEC. 4

GEOPHYSICAL LOGS

SHEET No. 5 OF 5

CORE SIZE (mm/in.)	FROM (m/ft.)	TO	LOG RUN	DEPTH (m/ft.)	DATE	COMPANY

DISTANCE DOWN HOLE (m/ft.)	ELEVATION	ROCK TYPE	DESCRIPTION (MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE)	MINERALIZATION (DISTRIBUTION: Massive, Disseminated, Veinfill, Replacement; TYPE: Hypogene, Supergene, Ore and Limonite Mineralogy)	DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))
188- 192^{2}		ALTERED GNEISS (BANDED)	SAME AS 122-143^{5}	PY, 3%, TEXTURALLY SAME AS 122-143^{5}; ALSO POSS. TR. SP.	FRACTURING: SEE 122-143^{5}
192^{2}- 210^{2}		ALTERED FAULT GOUGE & PY	... DEGREE OF COMMINUTION HIGHLY VARIABLE, SUBANG-ANG. FRAGMENTS, UP TO AT LEAST 75 MM. MAX. DIMENSION, EMBEDDED IN SILICA-CLAY-SER-SULFIDE ROCK FLOUR, IN WHICH RELATIVE PROPORTIONS OF THESE 4 COMPONENTS VARY CONSIDERABLY ALONG THE LENGTH OF THE INTERVAL. FRAGMENTS ARE RICHER IN GREEN CLAY THAN MATRIX. MANY FRAGS. DISPLAY RELICT GNEISSIC TEXTURE	PY, OVERALL ~5%, SAME AS 122-143^{5} EXC. SOME SULFIDE AGGREGATES MAY REACH 15 mm. MAX. DIMENSION	GOUGE & PY; SOME POST-SULFIDE MOVEMENT (SMEARED SULFIDE ON VNLTS.)
210^{2}- 217		ALTERED GNEISS (BANDED)	SAME AS 122-143^{5}, EXC. MORE COARSELY XLINE, MORE DISTINCT RELICT FOLIATION; RELICT BIE. COMMON	PY, SHARP DECREASE FROM 192^{2}-210^{2}; ~2%, TEXTURALLY SIMILAR TO 122-143^{5}	FRACS. ≤5/m.? (DIFFICULT TO DETERMINE — SEE 122-143^{5})

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. OF UTAH DDH 1B
DEPOSIT TYPE GEOTH.
LOGGED BY J. B. HULEN JULY 1977

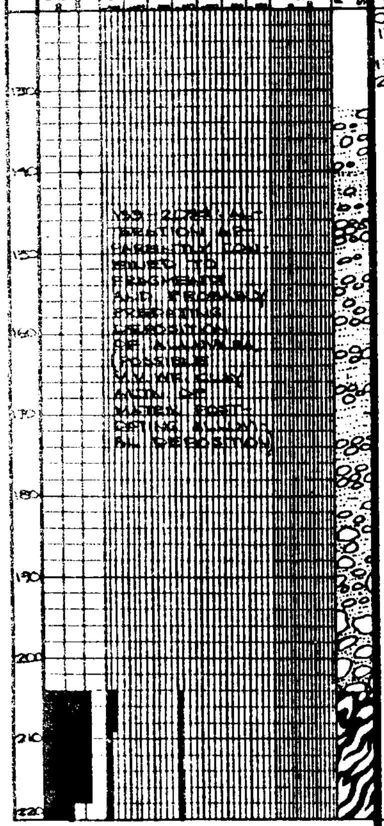
DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH ~~(m.)~~ (ft.)
COLLAR ELEV. ~~(m.)~~ (ft.)
CO-ORDINATES LAT. LON.
GRID 3500 m. N 150 m. W.
T. 27S R. 9W SEC. 4 (SE¼, SE¼)

GEOPHYSICAL LOGS

SHEET No. 1 OF 2

CORE SIZE (~~mm~~ in.)	FROM (~~m.~~ ft.)	TO	LOG RUN	DEPTH (~~m.~~ ft.)	DATE	COMPANY

GRAPHIC LOGS *



133-204': ALTERATION APPARENTLY CONFINED TO FRAGMENTS AND PROBABLY PREDATING DEPOSITION OF ALLUVIUM (POSSIBLE V. WK CLAY ALTN OF MATRIX POST-DATING ALLUVIAL DEPOSITION)

GEOLOGIC NOTES * (Use also for general comments)

DOWN HOLE LOCATION: DISTANCE DOWN HOLE (ft.)	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinlet, Replacement) / TYPE (Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))
0-133'		Qal?	NO CORE		
133-204'		ARKOSIC ALLUVIUM	... OVERALL A SILTY TO SANDY ARKOSIC GRAVEL, SEMI-CONSOLIDATED, WITH NO READILY APPARENT BEDDING. ANGULAR & SUBANGULAR FRAGMENTS FROM << 1mm TO AT LEAST 30 cm MAX. DIMENSION. THESE CONSIST OF VARIOUS TEXTURAL VARIETIES OF BTE. GRANITE, BTE-QTZ-FSP. GNEISS, FELSIC-INTERMEDIATE VOLCANIC RX. MANY OF THE FRAGMENTS ARE PARTIALLY ALTERED TO CLAY OR CLAY-SERICITE IN IRREG PATCHES & RARE VNLTS, BUT THE MATRIX APPEARS TO BE UNALTERED OR PERHAPS LOCALLY WEAKLY ARGILLIZED (VNLTS. END ABRUPTLY WITHIN AND AT BOUNDARY OF FRAGMENTS) (STRONGLY BLEACHED & ARGILLIZED OR CLAY-SERICITIZED FRAGMENTS MAY BE EMBEDDED WITHIN BROWNISH, CRUMBLY, APPARENTLY UNALTERED SILT-CLAY MATRIX — 140-143±: ALLUVIUM IS STAINED RED TO ORANGE-BRN; COMPOSED PRIMARILY OF CLAY, SILT & FINE SAND-SIZE PARTICLES (POSS. W/ SOME ASH) — 143-149': > 95% OBVIOUS GRANITIC ROCK FRAGMENTS (DOMINANTLY GRAVEL-SIZE) FSPS. CLAY SERICITIZED IN FRAGS. — GRAVEL BECOMES DOMINANT CLASTIC COMPONENT BELOW 182'	(± IN THIN FILMS AROUND FRAGS) MANY OF THE FRAGMENTS ARE STAINED W/ GOETHITIC LIMONITE IN IRREG PATCHES; A FEW FRAGMENTS CONTAIN DISS. GOE. PSEUDOMORPHS/SULFIDE — THESE ARE ALSO PRESENT W/ CLAY, SER. & QTZ. IN VNLTS. CUTTING SOME FRAGMENTS (BUT NOT MATRIX) 172±-175±: STRONG GOETHITIC STAINING OF MATRIX & FRAGMENTS MATRIX OVERALL IS LIGHTLY STAINED DULL REDDISH TO BROWNISH-GRAY W/ FINELY DISS. FEOX	ALLUVIUM CRUMBLES RATHER THAN FRACTURES

STRUCTURE: DOWN HOLE UNIT (m. ft.) | FOLIATION ∢ WITH CORE | BEDDING ∢ WITH CORE | FRACTURE ∢ WITH CORE
FRACTURE INTENSITY
DOWN HOLE SURVEY DATA: DEPTH (ft.) | INCLINATION | BEARING
THIN & POLISHED SECTIONS: DEPTH (ft.) | SAMPLE NUMBER

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES ARE NOT AT SAME SCALE

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

SHEET NO. 2 OF 2

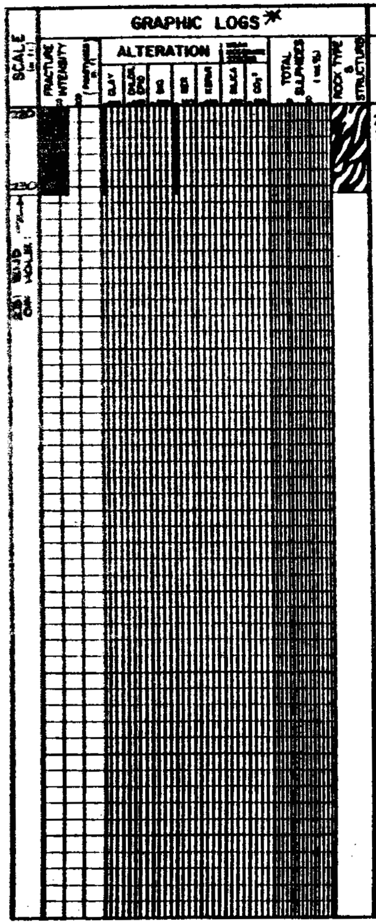
PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH DDH 1B
DEPOSIT TYPE GEOTH.
LOGGED BY J.B. HULEN

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m/ft.)
COLLAR ELEV. (m/ft.)
CO-ORDINATES LAT. LON.
GRID ~~3500~~ m. N 150 m E
T 27S R 9W SEC. 4 (SE¼, SE¼)

GEOPHYSICAL LOGS

CORE SIZE (cm/in.)	FROM (m/ft.)	TO	LOG RUN	DEPTH (m/ft.)	DATE	COMPANY

GRAPHIC LOGS*



GEOLOGIC NOTES* (Use also for general comments)

DOWN HOLE LOCATION: DISTANCE DOWN HOLE (m/ft.)	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinlet, Replacement) / TYPE (Hypogene, Supergene, Ore and Lincoln Mineralogy)	STRUCTURE: DOWN HOLE DIST. (m/ft.)	FOLIATION ∠ with CORE	BEDDING ∠ with CORE	FRACTURE ∠ with CORE	DESCRIPTION OF STRUCTURES Post or Pre-Ore (Evidence)	FRACTURE INTENSITY	DOWN HOLE SURVEY DATA: DEPTH (m/ft.)	INCLINATION	BEARING	THIN & POLISHED SECTIONS: DEPTH (m/ft.)	SAMPLE NUMBER
204–231'		ALTERED BTE-QTZ-FSP. GNEISS (PROMINENTLY BANDED)	GEN. FINE-XLINE. - LOCALLY MORE CRSLY-XLINE.: PROMINENT STREAKY APPEARANCE DEFINED BY SEGREGATION OF BTE. AND LIGHT-COLORED CONSTITUENTS; INCIPIENT SILLIMANITE (?) PORPHYROBLASTS RARE, LOCALLY PRESENT 203½-209': ERRATIC, WK.-MOD. CLAY-SERICITIZATION (illite?) OF FSPS, BLEACHING OF BIOTITE. 209-231': SAME AS ABOVE, BUT LESS INTENSE — MUCH FRESH BTE. OVERALL: THIN FILMS OF CLAY ON STONE. FRACTURES	2-3% LIMONITE, DOMINANTLY GOETHITE, PRIMARILY AS FILMS ON FRACTURE SURFACES, COMMONLY ADMIXED W/CLAY, BUT ALSO AS RARE (<0.1%) DISS. ANH. GOETHITE GRAINS AVG. ≤ 0.1 mm. DIA. & IRREG. TABULAR AGGREGATES		0-60°			204 - 218' → >100 218 - 231' → ~100 STOCKWORK BOTH PRE- & POST ALTN.-MINRLZ. (SMEARED GOETHITE AGGREGATES) ∆ TOMP SAMPLES (core missing) 134^{5} - 135' 153 - 153^{5}' 172 - 172^{5}' 180^{4} - 180^{8}' 183^{5} - 183^{8}' 187^{5} - 188' 192 - 192^{5}' 198^{8} - 199^{0}' 200^{7} - 201^{3}' 203^{5} - 204^{0}' 209^{7} - 210^{0}' 225^{5} - 226^{0}' 227^{5} - 227^{8}'	>100 ~100					

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

FIGURE B-4 (cont.)

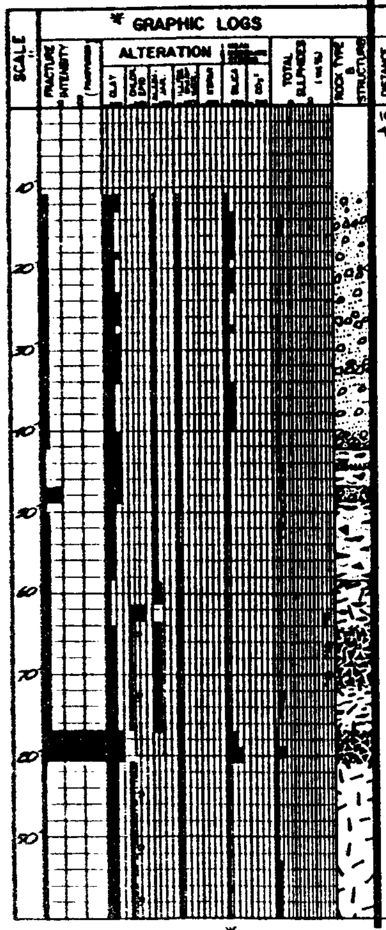
UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH 76-1
DEPOSIT TYPE GEOTH.
LOGGED BY J.B. HULEN JULY 1977

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH ~~m~~ (ft.)
COLLAR ELEV. ~~m~~ (ft)
CO-ORDINATES LAT. LON.
GRID 5620 m N 600 m E
T 26S R 9W SEC 34 (SW¼)

SHEET NO. 1 OF 4

CORE SIZE (~~mm~~ in.)	FROM (~~m~~ ft.)	TO	GEOPHYSICAL LOGS LOG RUN	DEPTH (~~m~~ ft.)	DATE	COMPANY
NX	10.8'	201.5'				



DOWN HOLE LOCATION: DISTANCE DOWN HOLE ft.	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinfill, Replacement); TYPE (Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: BEDDING ∢ with core	FRACTURE ∢ with core	DESCRIPTION OF STRUCTURES Post or Pre-Ore (Evidence)	FRACTURE INTENSITY
10.8'-122'		ALTERED ALLUVIUM (Largely granitic fragments as near as the logger can tell) (also misc. lithic frags [volc.] & obsidian)	SILTY TO SANDY GRAVEL; ANG-SUBANG FRAGS FR. <<1 mm. TO AT LEAST 30 cm. MAX DIMENSION; CRUDE BEDDING LOCALLY APPARENT; POROSITY 7-25% (MAX IN GRAVEL LAYERS) IRREG. ELONGATE VUGS (SECONDARY) (UP TO 15 mm. MAX DIMENSION) "ROCK" IS LIGHT-COLORED, W/ OVERALL PUNKY, CRUMBY, VUGGY CHARACTER, BUT IS LOCALLY PORCELLANEOUS (ALUNITE?); OVERALL, APPEARS TO BE A FINE-XLINE AGGREGATE OF QTZ (& OPAL), CLAY, AND FINE WHITE MICA (ILLITE? BLEACHED CHL.?) -RARE PARTIALLY UNALTERED FSP BELOW 31.5' - THROUGHOUT: HYALITE-CLAY VNLTS AT ALL ∢s TO CORE AXIS; IRREG, AVG < 1 mm. WIDE (UP TO 7 mm.); VUGGY (VUGS UP TO 25 x 7 mm IN X-SECT) — VUGS LINED W/ BOTRYOIDAL HYALITE; EST AVG. 7-10 VNLTS/m - 23½-25', 26-27, 36.5-38': UNKNOWN GRAYISH TO GREENISH-YELLOW MINRL, LOCALLY UP TO 1%, AS DISS, IRREG MASSES UP TO 5 mm DIA. W/ OPAL (HYALITE), ALUNITE, CLAY, RARELY LIMONITE; ALSO PARTIALLY LINING VUGS & W/ ABOVE MINERALS IN SCATTERED VNLTS; TRACES OF As_2S_3 W/ THE SULFUR - SPHENE IN GRANITIC FRAGS. ALT. TO PAPERY BUFF-COLORED BOX-WORKS OF UNKNOWN MINRL.	- OVERALL: 3-4% GOETHITIC TO HEMATITIC (largely the latter) LIMONITE AS: ① DISS IRREG GRAINS AVG ≤ 0.1 mm DIA IN BOTH MATRIX AND FRAGS. ② AS PARTIAL VUG LININGS W/ MINERALS DESCRIBED ← TO THE LEFT ③ W/ ABOVE MINERALS IN VNLTS. - OVERALL FORMER SULFIDE CONTENT 3-4%, BUT IN VUGGY, GRAVEL LAYERS UP TO 7-9% - RARE, SCATTERED 'ISLANDS', UP TO 10 MM. DIA., OF UNOXIDIZED PYRITE BELOW 121' (MAY BE NATIVE SULFUR IN PART)	60-90°	50-80°	"ROCK" TENDS TO CRUMBLE, RATHER THAN FRACTURE; FRACTURES →	5?

W.R. SILL SAMPLES (Core Intact)
21^{30} - 21^{85}'
24 - 24^{30}'
26^{30} - 27^{10}'
42^{30} - 43^{20}'
50^{20} - 50^{80}'
58^{30} - 58^{70}'
78 - 78^{50}'
88 - 88^{50}'
100^{30} - 101^{10}'
108^{30} - 109'
112^{70} - 113^{05}'
124^{50} - 125^{05}'
155 - 155^{65}'
199^{55} - 200^{20}'

DOWN HOLE SURVEY DATA: DEPTH ft. | INCLINATION | BEARING
THIN & POLISHED SECTIONS: DEPTH ft. | SAMPLE NUMBER

* NOTE: GEOLOGIC NOTES & GRAPHIC LOGS NOT AT SAME SCALE

FIGURE B-4 (cont.)

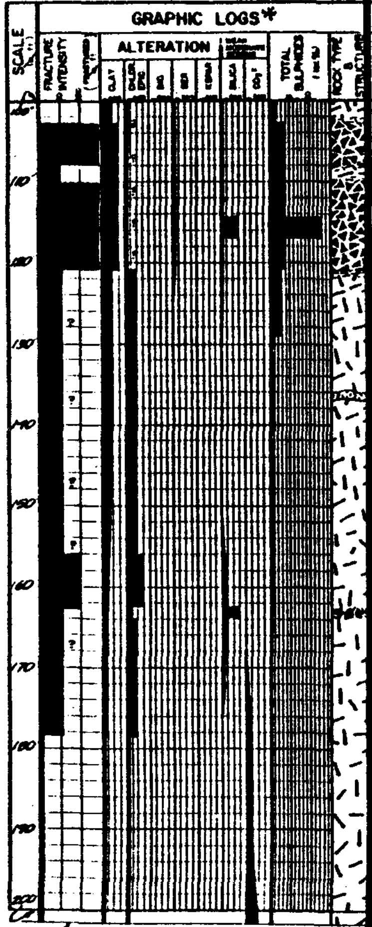
UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV of UTAH 76-1
DEPOSIT TYPE GEOTH.
LOGGED BY J.B. HULEN JULY 1977

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m/ft.)
COLLAR ELEV. (m/ft.)
CO-ORDINATES LAT. LON.
GRID 5620 m N 600 m E
T 26S R 9W SEC. 34 (SW¼)

SHEET NO. 2 OF 4

CORE SIZE (m/in.)	FROM (m/ft.)	TO	GEOPHYSICAL LOGS LOG RUN	DEPTH (m/ft.)	DATE	COMPANY



80.5' (END OF HOLE)

GEOLOGIC NOTES* (Use also for general comments)

DOWN HOLE LOCATION: DISTANCE DOWN HOLE (ft.)	ELEVATION	ROCK TYPE	DESCRIPTION: MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE	MINERALIZATION: DISTRIBUTION (Massive, Disseminated, Veinfill, Replacement) / TYPE (Hypogene, Supergene, Ore and Limonite Mineralogy)	STRUCTURE: DESCRIPTION OF STRUCTURES (Post or Pre-Ore (Evidence))
42^{3}–47'		ALTERED TUFF (?) (Air Fall?)	... PUNKY, V. LT. GRAY; 10% ANGULAR FRAGS. & PROB. BROKEN XLS., ERRATICALLY DISTRIBUTED, SET IN A V. FINE-XLINE MATRIX; FRAGS UP TO 15 mm DIA. (AVG. 5 mm.) ALTN. ESS. SAME AS 10^{2}–42^{3}', EXC. PROB. MUCH LESS OR NO ALUNITE	(~5% fragments at top of interval to 15% at base) (fragments commonly porous, vuggy — may be pumice in part)	44–45': GOUGE & BX.
47–49^{3}'		ALTERED ALLUVIUM (?) (May be fragment-rich altered tuff)	... ESSENTIALLY IDENTICAL TO 10^{2}–42^{3}'; HEMATITE–JAROSITE–CLAY–OPAL VNLT. UP TO 10 mm WIDE SUB-// TO CORE AXIS ENTIRE LENGTH OF INTERVAL (POSS. W/ SOME NATIVE S)	SAME AS 10^{2}–42^{2}' LIMONITE IS PREDOMINANTLY BRICK RED TO MAROON PULVERULENT HEMATITE W/ MINOR YELLOWISH-GRAY-BROWN JAROSITE	
49^{3}–50^{2}'		ALTERED TUFF (?)	... SAME AS 42^{3}–47', EXC. RICHER IN FRAGS, LESS ALTERED (SOME RELICT FSP (SANIDINE?))		
50^{2}–50^{7}'		ALTERED LITHIC TUFF (?)	... SAME AS 42^{3}–47' EXC. RICHER IN OBVIOUS GRANITIC FRAGMENTS, SCATTERED RELICT FSP	additional notes: overall 30–35% fragments up to at lst. 30 mm. dia.	
50^{7}–80'		ALTERED GRANITIC ROCK (PROBABLY BTE. QTZ. MONZ.)	CRS-XLINE; PRONOUNCED CATACLASTIC (?) FOLIATED ASPECT HIGHLIGHTED BY CRUDELY SUBPARALLEL ELONGATE VUGS (SUB// TO "CATACLASTIC" FOLIATION) UP TO 15X5 mm X-SECT. (AVG. ~ 3X1 mm.), ACCOUNTING FOR 7–10 VOL. % OF ROCK. VUGS ARE COMMONLY PARTIALLY TO COMPLETELY LINED W/ CLAY, MINOR OPAL, DRUSIES OF TINY WHITE XLS. (ZEOLITE?) – STR. CHL. ALTN. 61^{3}–64' (MASSES OF FINE-XLINE CHL. THIS INTERVAL UP TO 15 mm DIA.	OBVIOUS SULFIDES BEGIN TO APPEAR AT ~ 75'; THESE OCCUR MAINLY AS DISS. IRREG. GRAINS ≤ 0.1 mm. (may ∴ be present, but unrecognized higher in hole); ALSO OCCUR BELOW 77' AS RARE AGGREG. OF THESE GRAINS UP TO 5 mm DIA. MANY GRAINS & GRAIN AGGREGATES ARE DULL BROWNISH & SUBMETALLIC (MAY BE SPHALERITE IN PART) SULF. ALSO OCCUR IN PART AS IRREG. GRAINS & GRAIN AGGREGATES ALONG CLAY–SILICA VNLTS.	62–71(?)' (MUCH LOST CORE THIS INTERVAL): FLT. ZONE W/ GOUGE & BRECCIA 77–80': SILICIFIED FLT. ZONE

77–80': HEAVILY ARGILLIZED & SILICIFIED PORTION OF FLT. ZONE ~ 5–7% DK. BROWNISH-GRAY SUBMETALLIC MINRL. (W/ SOME OBVIOUS PYRITE) IN STREAKY SUB// BANDS @ ~40° TO CORE AXIS,

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH 76-1
DEPOSIT TYPE GEOTHERMAL
LOGGED BY J.B. HULEN JULY 1977

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (m. ft.)
COLLAR ELEV. (m. ft.)
CO-ORDINATES LAT. LON.
GRID 5620 m. N 600 m. E
T 26S R 9W SEC 34 (SW¼)

SHEET NO. 3 OF 4

CORE SIZE (mm in.)	FROM (m ft.)	TO	GEOPHYSICAL LOGS LOG RUN	DEPTH (m ft.)	DATE	COMPANY

GRAPHIC LOGS* — GEOLOGIC NOTES* (Use also for general comments)

DISTANCE DOWN HOLE (ft.)	ROCK TYPE	DESCRIPTION (MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE)	MINERALIZATION (DISTRIBUTION / TYPE)	FRACTURE ∢ WITH CORE	DESCRIPTION OF STRUCTURES	FRACTURE INTENSITY
80^{7}-92^{8}'	ALTERED GRANITIC ROCK	... SAME AS 58^{1}-80^{7}', EXC. TR OR NO ILLITE (BLCHD. CHL?) chl	DISS. PY. ~ 0.1%, TEXTURALLY SIMILAR TO 58^{1}-80^{7}'.			
92^{8}-102^{8}	ALTERED GRANITIC ROCK	... SAME AS 58^{1}-80^{7}' 5-7% IRREG. VUGS, AVG. ~ 2mm. MAX DIMENSION; THESE MAY BE LINED OR PARTIALLY LINED W/ VARIOUS ALTN. MINRLS. SAME AS 58^{1}-80^{7}'; FOLIATED ASPECT SOMEWHAT MORE VAGUE. CLAY VNLTS UP TO 2mm WIDE (AVG. ≤ 1mm), FROM ⊥ TO SUB∥ TO CORE AXIS ~ OTHERWISE CLAY ALTN AFFECTS MAINLY SMALLER FSP XLS. (LARGER XLS COMMONLY UNALTERED)	OVERALL ~ 1½%, BUT ERRATICALLY DISTRIBUTED FROM <0.5->5%; OCCURS AS DISS. IRREG. GRAINS, AVG. ~ 0.1mm DIA, AND RARE AGGREGATES OF THESE GRAINS UP TO 10mm DIA. SOME DISS BROWNISH-BRONZY MATERIAL, TEXTURALLY SIMILAR TO ABOVE, WHICH MAY BE PYRITE IN PART; ALL SULF PARTIALLY & ERRATICALLY ALTERED TO BRICK-RED PULVERULENT HEMATITE	10-25	FRACTURED RARE — BRECCIATED, FOLLOWING CLAY VNLTS.	1-2/ft
102^{8}-120^{7}	ALTERED GRANITIC GOUGE & BRECCIA (FLT ZONE)	... DEGREE OF COMMINUTION HIGHLY VARIABLE; FINELY GROUND TO 108', RELATIVELY UNBROKEN 108-110'; THOROUGHLY CRUSHED 110-120^{7}'; RELICT BTE APPEARS AT 112^{7}' ~ NONTRONITE (W/ SOME CHL?) AT 115' — LATTER OCCURS AS FILMY FRACTURE COATINGS & INTERGROWN W/ RELICT BTE.	SAME AS ABOVE EXCEPT AVG. 4% TOTAL SULFIDE OVERALL ~ PARTIALLY ALTERED TO BRICK-RED HEMATITE; GRAIN SIZE OF SULF. MAY REACH 1mm. 114^{5}-117': 12-15% DISS. PYRITE IN STRONGLY SILICIFIED PORTION OF FAULT ZONE (30° ∢ W/ CORE AXIS)		GOUGE & BX.	
120^{7}-128^{2}	ALTERED BIOTITE GRANITE	... CRS-XLLINE; K-SP. REL. FRESH; PLAG. ALTERED; BTE PARTIALLY TO TOTALLY REPLACED W/ VARIOUS MIXTURES OF CHLORITE, NONTRONITE(?) & PYRITE-HEMATITE; PAPERY BUFF-COLORED BOXWORKS REPLACING SPHENE (~2-3%) CHL-CLAY VNLTS COMMON	SAME AS 102^{8}-120^{7}', ALSO OCCURS W/ CHL & CLAY (& HEM) IN VNLTS ~2%. ALSO ~1% DISS. HEM., TEXTURALLY SIMILAR TO PYRITE, PROBABLY PARTIALLY AFTER ORIG. ROCK MAGNETITE (also minor hem vnlts)		? ? VARIABLE: AVG PERHAPS 15-20/ft STKWK — ALONG PRE-EXISTING VNLTS FIGURE MAY BE LOW BECAUSE MANY VNLTS. FAIL WHEN SUBJECTED TO MODERATE PRESSURE	←

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

FIGURE B-4 (cont.)

UURI EARTH SCIENCE LAB

PROJECT ROOSEVELT
DRILL HOLE UNIV. of UTAH 76-1
DEPOSIT TYPE GEOTH
LOGGED BY J.B. HULEN JULY 1977

DATE STARTED
DATE COMPLETED
DRILLING CO.
FINAL DEPTH (~~m~~ ft)
COLLAR ELEV. (~~m~~ ft)
CO-ORDINATES LAT / LON.
GRID 5620 m N 600 m E
T 26S R 9W SEC 34 (SW¼)

GEOPHYSICAL LOGS SHEET No 1 OF 1

CORE SIZE (~~mm~~ in)	FROM (~~m~~ ft)	TO	LOG RUN	DEPTH (~~m~~ ft)	DATE	COMPANY

SCALE	GRAPHIC LOGS* (FRACTURE INTENSITY; ALTERATION: CLAY, CHLOR./EPIC, BIO, SER, K-SPAR, SILICA, $CO_3^=$; TOTAL SULPHIDES; ROCK TYPE & STRUCTURE)	DISTANCE DOWN HOLE (ft)	ELEVATION	ROCK TYPE	DESCRIPTION (MINERALOGY, ALTERATION, TEXTURES, GRAIN SIZE, FRAGMENT SIZE)	MINERALIZATION (DISTRIBUTION / TYPE)	FRACTURE ∠ with CORE	DESCRIPTION OF STRUCTURES	FRACTURE INTENSITY
		120±-170±'		ALTERED BIOTITE QTZ. MONZ.	... SAME AS 120±-128±' TEXTURALLY; 5-7% DISS. IRREG. MASSES FINE-XLINE BTE., PARTIALLY-TOTALLY ALTERED TO CHL, MONTM(?), & HEMATITE; 2-3% PAPERY BOXWORKS PSEUDOMORPHING SPHENE; CLAY OCCURS AS IRREG PATCHES PARTIALL TO TALLY REPLACING FSP & BTE, and IN VNLTS W/CHL, HEM, RARER PYRITE, MINOR EUH. GYPSUM; CHL PARTIALLY REPLACES BTE. AND OCCURS IN THE VNLTS. DESCRIBED ABOVE (VNLTS avg <0.5 MM. DIA, OCCUR AT ALL ∠S TO CORE AXIS, BUT SL. PREDOMINANCE OF 20°-30° VNLTS) — OVERALL CLAY MOD TO ~145', BECOMING PROG. WKR. DOWNHOLE — A FEW IRREG. scattered DISC. QTZ VNLTS APPEAR BELOW 163±' — WK. $CO_3^=$, PRED/SPHENE, APPEARS BELOW 170' (some relict sphene below 170') 156-162±': ABUND. QTZ-CHL-CLAY-HEM-(GYP) VNLTS; SUB// TO CORE PREDOM. ORIENTATION 136-137': APLITE DIKE 162±-163±': STRONGLY BXTED & SILICIFIED ZONE CUT BY CHL-HEM VNLTS	PYRITE: 0.1-0.3% OVERALL, TEXTURALLY SIMILAR TO 120±-128±', EXC. GREATER TENDENCY TO OCCUR W/CHL, CLAY, HEM, GYP IN VNLTS. HEMATITE: ① ~1% 2% DISS. IRREG. GRAINS TEXTURALLY SIMILAR TO DISS. PY. PROB. REPLACING ORIG. ROCK MAGNETITE IN PART? (BOTH POWDERY & DK. GRAY METALLIC) ② W/CHL, CLAY, GYP. IN VNLTS. ③ AS DISCRETE HAIRLINE VNLTS, COMMONLY ALONG CLEAVAGE PLANES & CRYSTAL BOUNDARIES (ESP. Kspar) * Also much less hem. overall	STK. WK.	SAME AS 120±-128±' BUT ABUNDANT HAIRLINE STOCK. HEM VNLTS. COMMONLY WILL BREAK W/ ONLY MODERATE PRESSURE. ∴ 15-20/m. MAY BE A LOW FIGURE ALSO: FRAC. DENSITY VARIABLE ALONG THE LENGTH OF THIS INTERVAL FROM <15/m TO (LOCALLY) ≥100/m.	15-20±
		170±-201±'		BTE. QTZ MONZ, SLIGHTLY ALTERED	— Same as above except much fresher — all primary minerals only partially altered, commonly apparently unaltered; chl.-clay-gyp.-hem. vnlts. persist, but are less common. — Primary magnetite appears at 170±' — Vuggy, 2 mm.-wide qtz.-chl.-calcite vnlt. at 201.4'	Same as above except hem. is both pulverulent & specular variety, implying that much of the hematite seen above this interval is not derived from primary sulfide oxidation.	STK. WK.	BREAK ALONG PRE-EXISTING VNLTS	1-2/m.

Down hole survey data: DEPTH (~~m~~ ft) | INCLINATION | BEARING

Thin & polished sections: DEPTH (~~m~~ ft) | SAMPLE NUMBER

* NOTE: GRAPHIC LOGS & GEOLOGIC NOTES NOT AT SAME SCALE

APPENDIX C

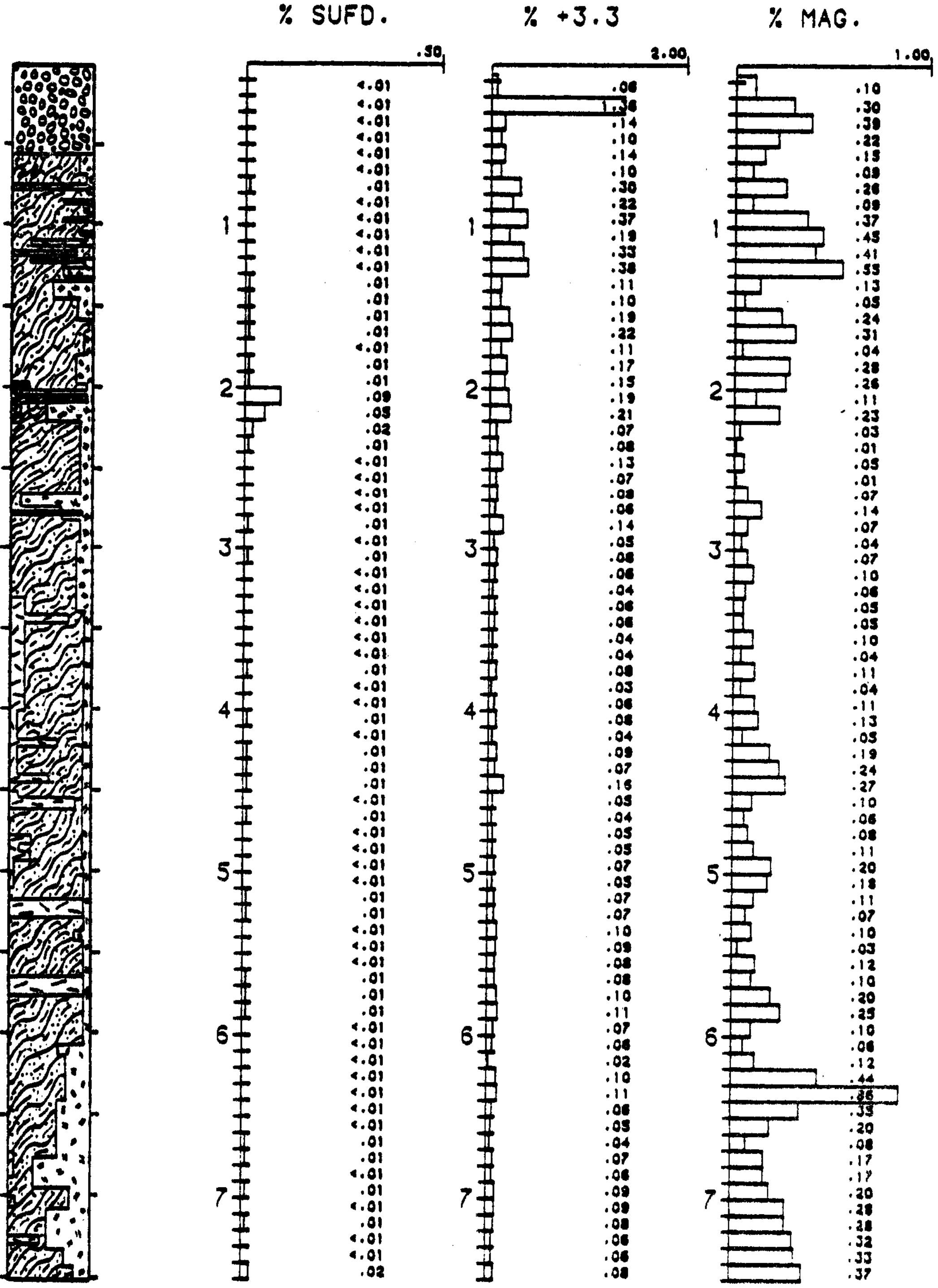
Multielement geochemical data for 100-foot cuttings composite samples from Utah State Well 52-21

FIGURE C-1

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



▨ ARKOSIC ALLUVIUM

■ BIOTITE-HORNBLENDE MICRODIORITE

▨ LEUCOCRATIC GRANITE AND GRANITIC SEGREGATIONS

▨ BIOTITE-HORNBLENDE QUARTZ MONZONITE GNEISS

▨ FELDSPAR-QUARTZ-BIOTITE GNEISS

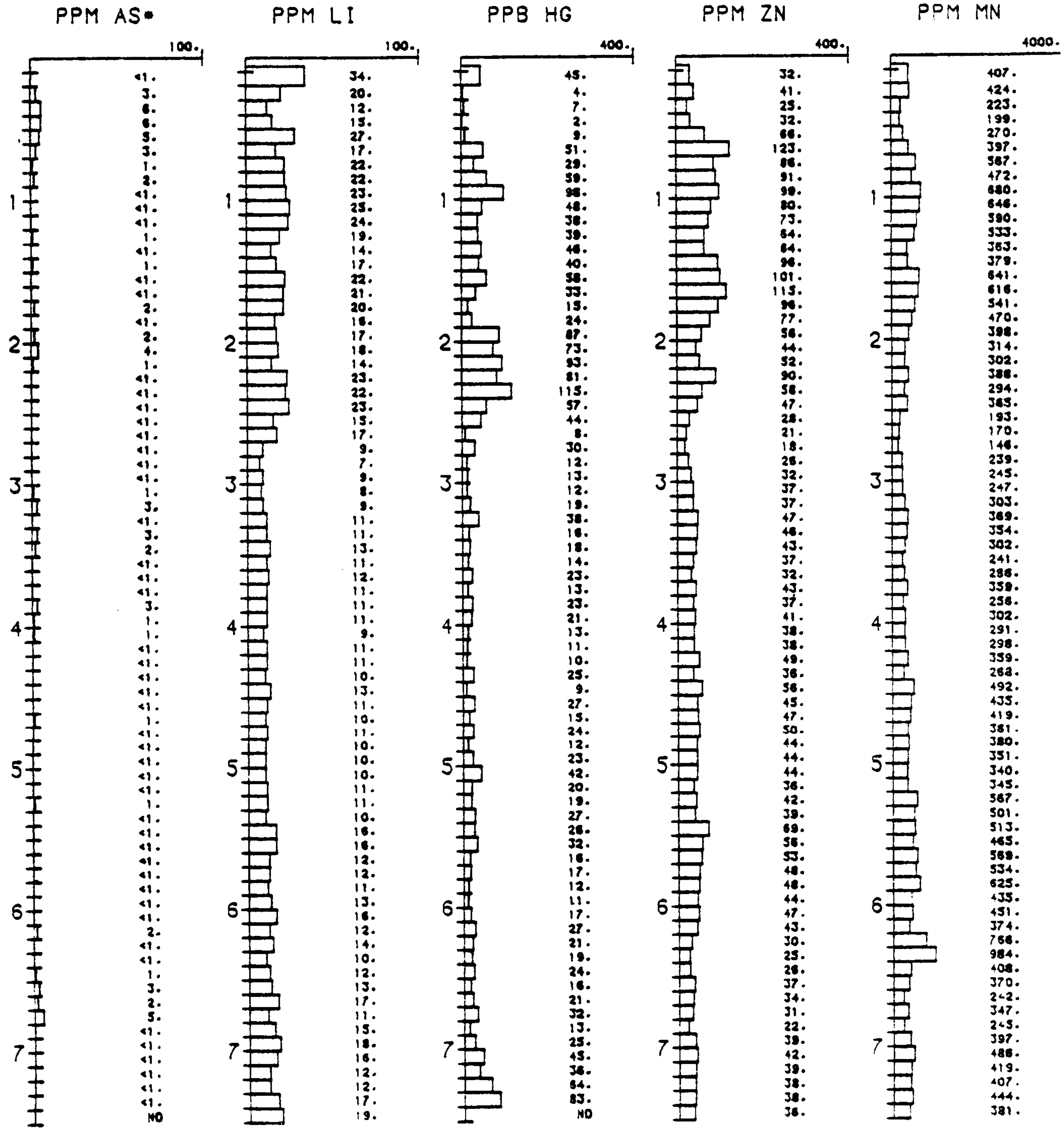
Geology after Glenn & Hulen, 1979

FIGURE C-2

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE C-3

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

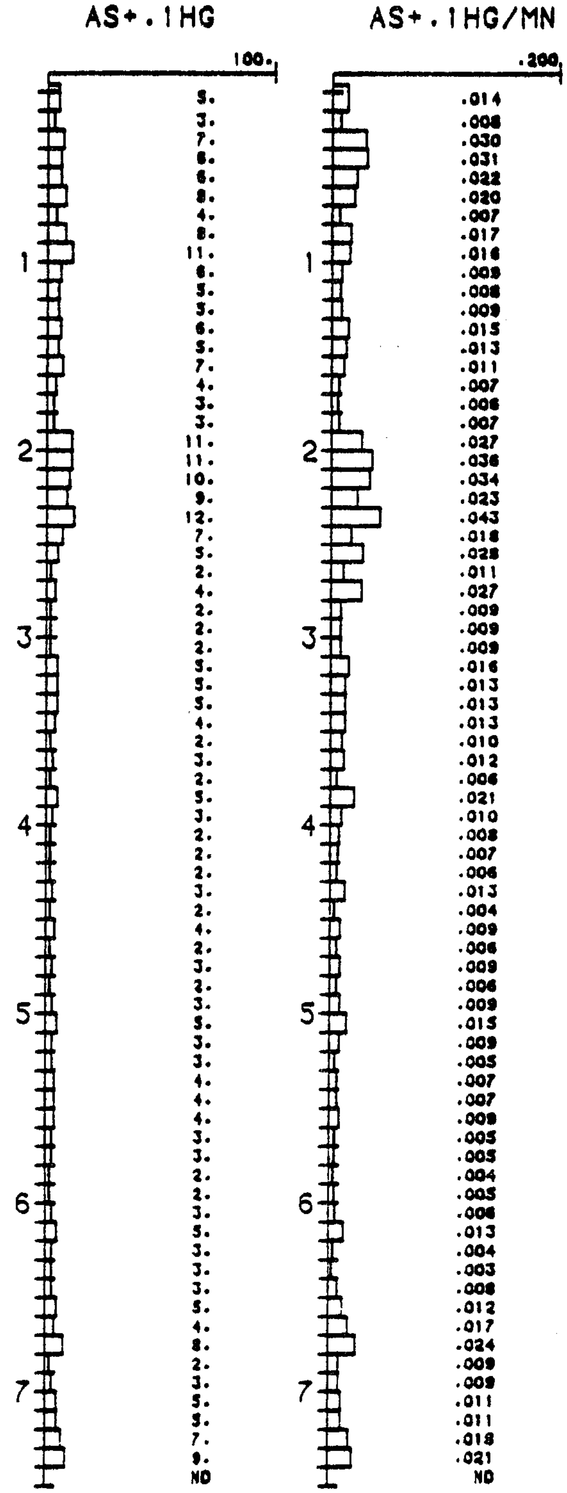
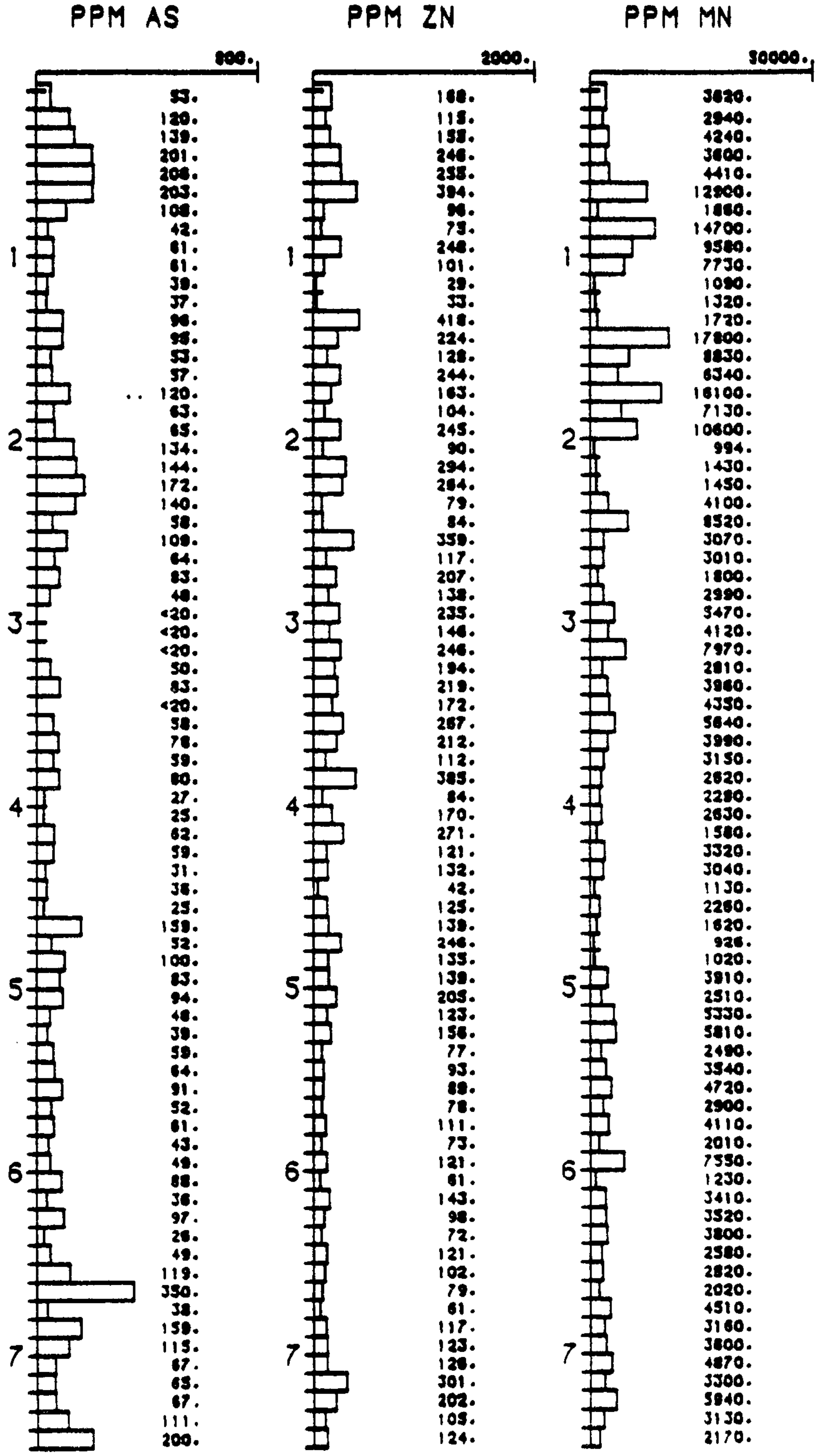


FIGURE C-4

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE C-5

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

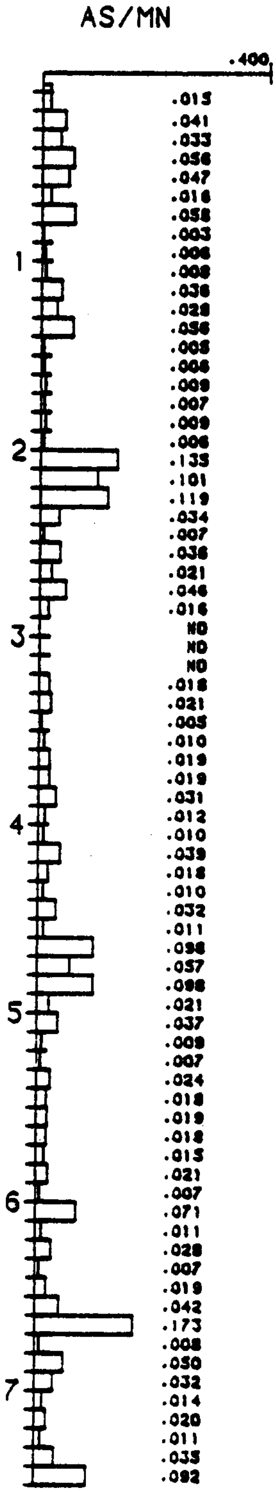


FIGURE C-6

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

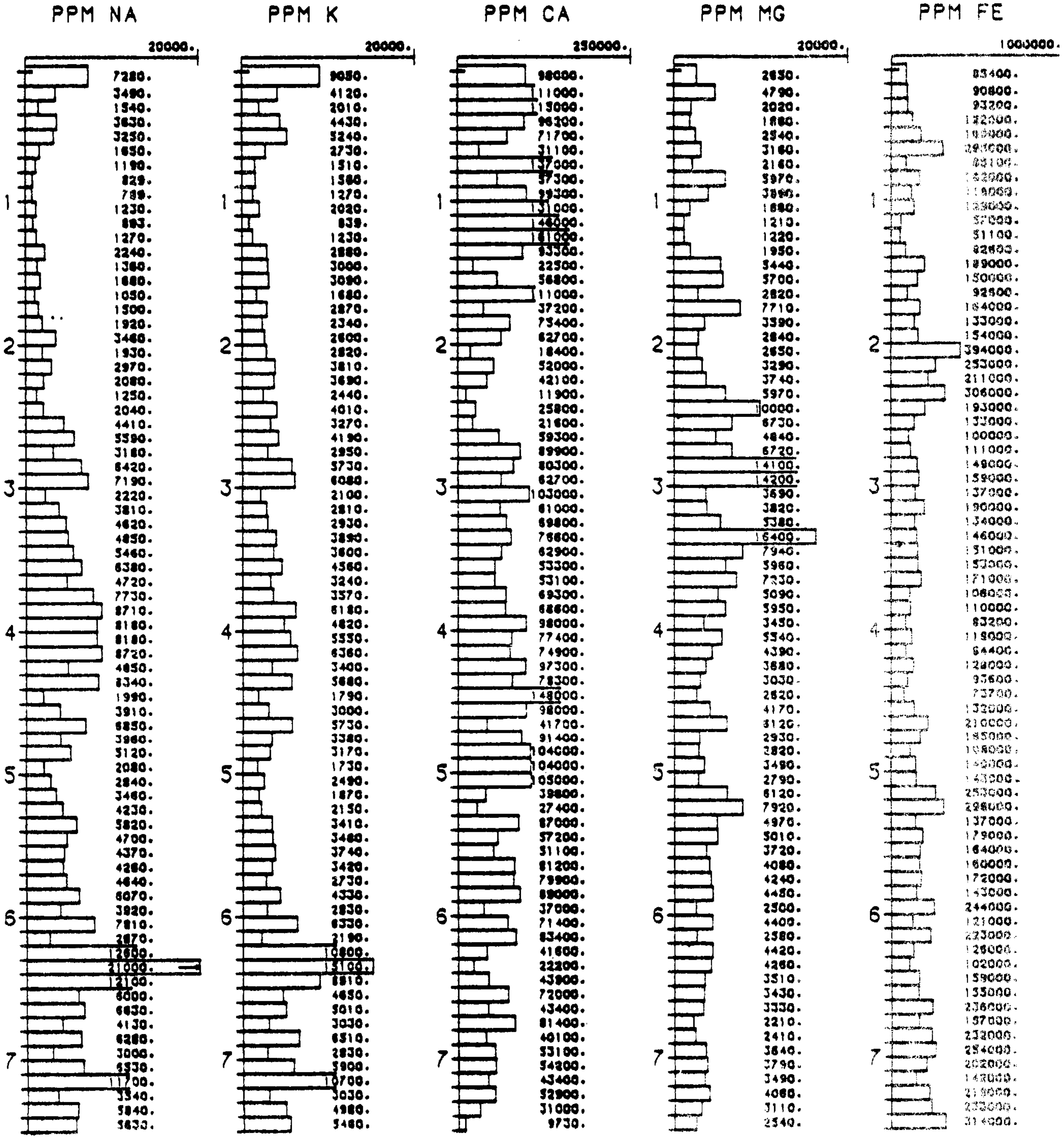


FIGURE C-7

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

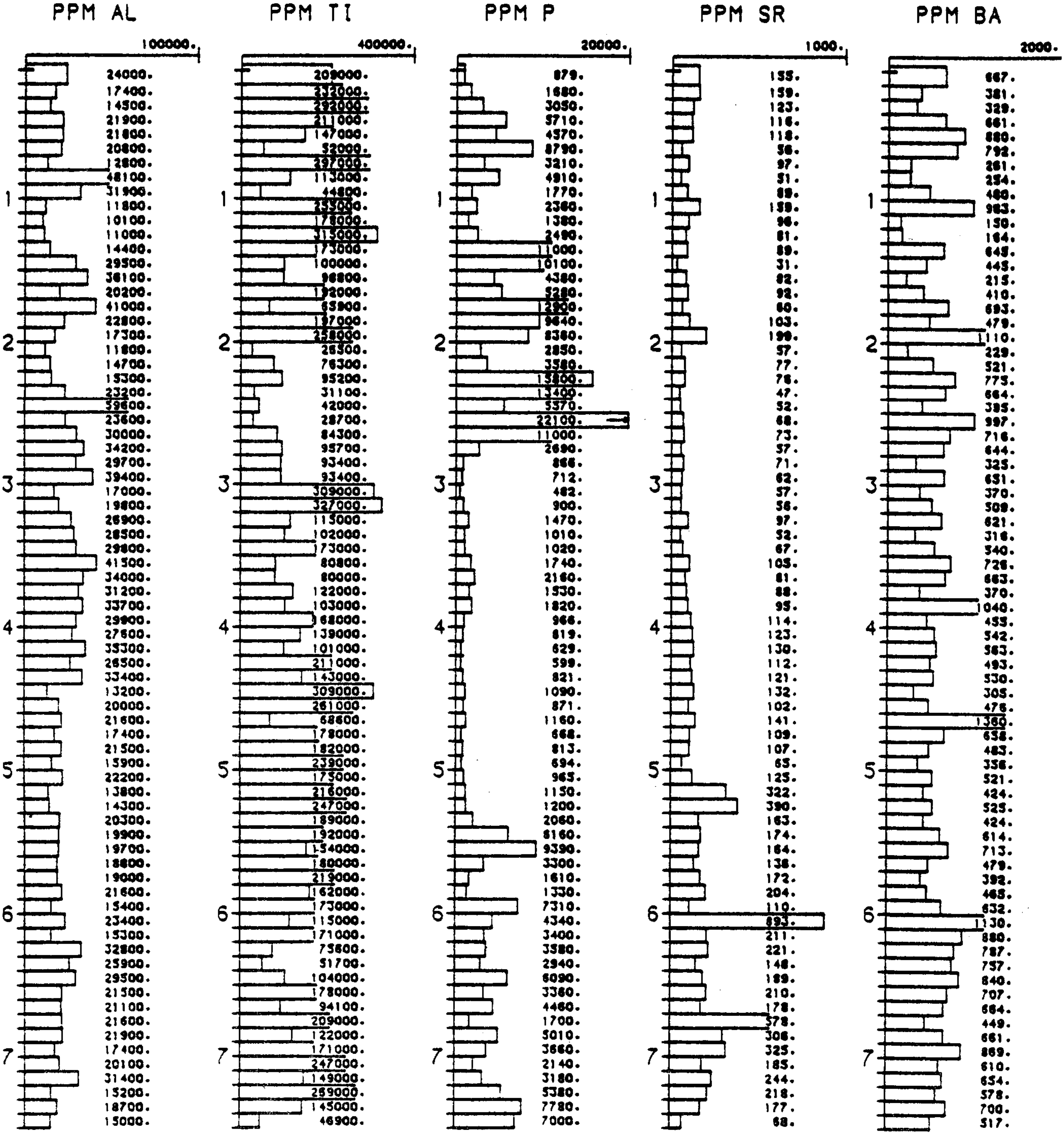


FIGURE C-8

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

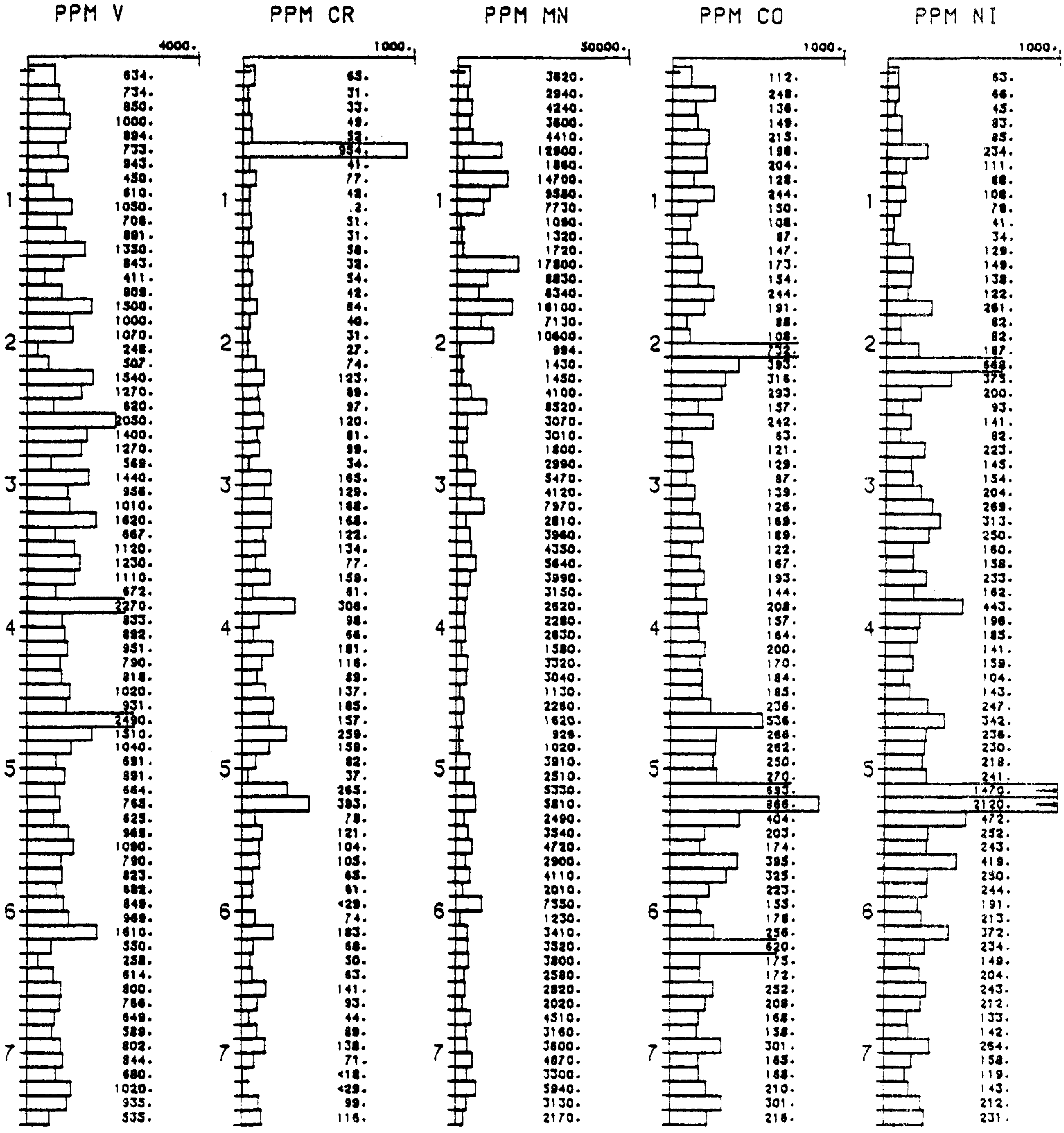


FIGURE C-9

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

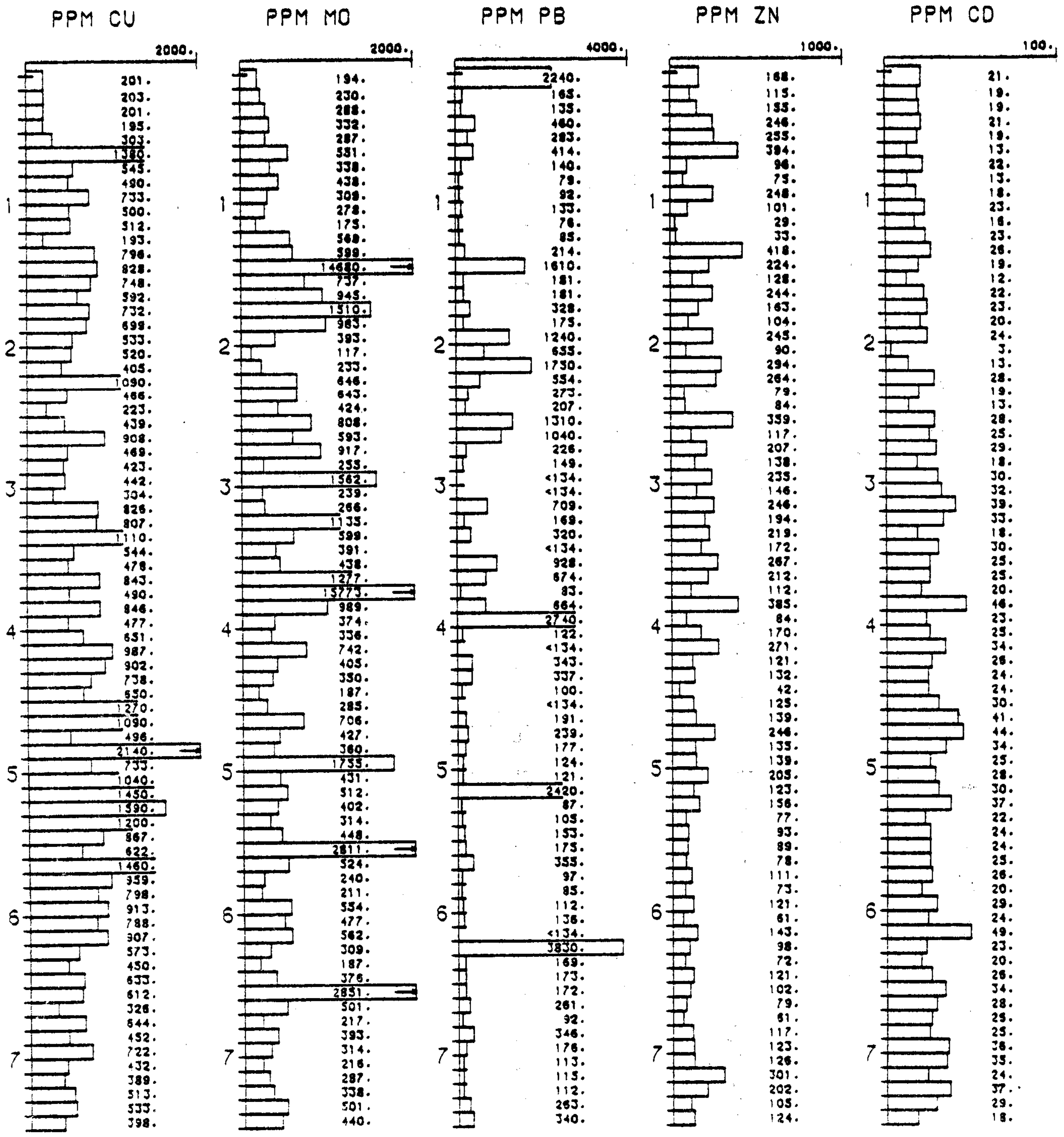


FIGURE C-10

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

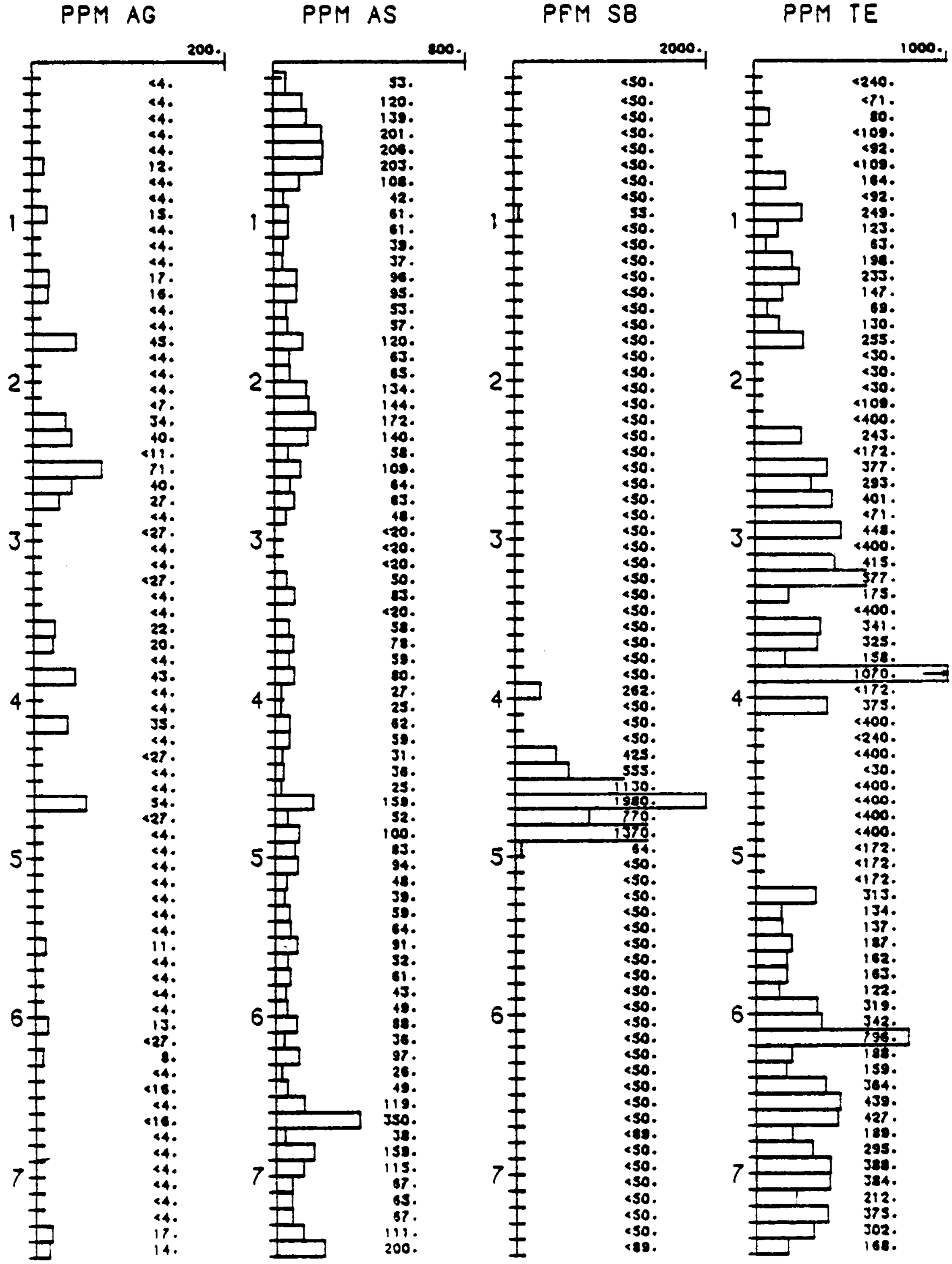
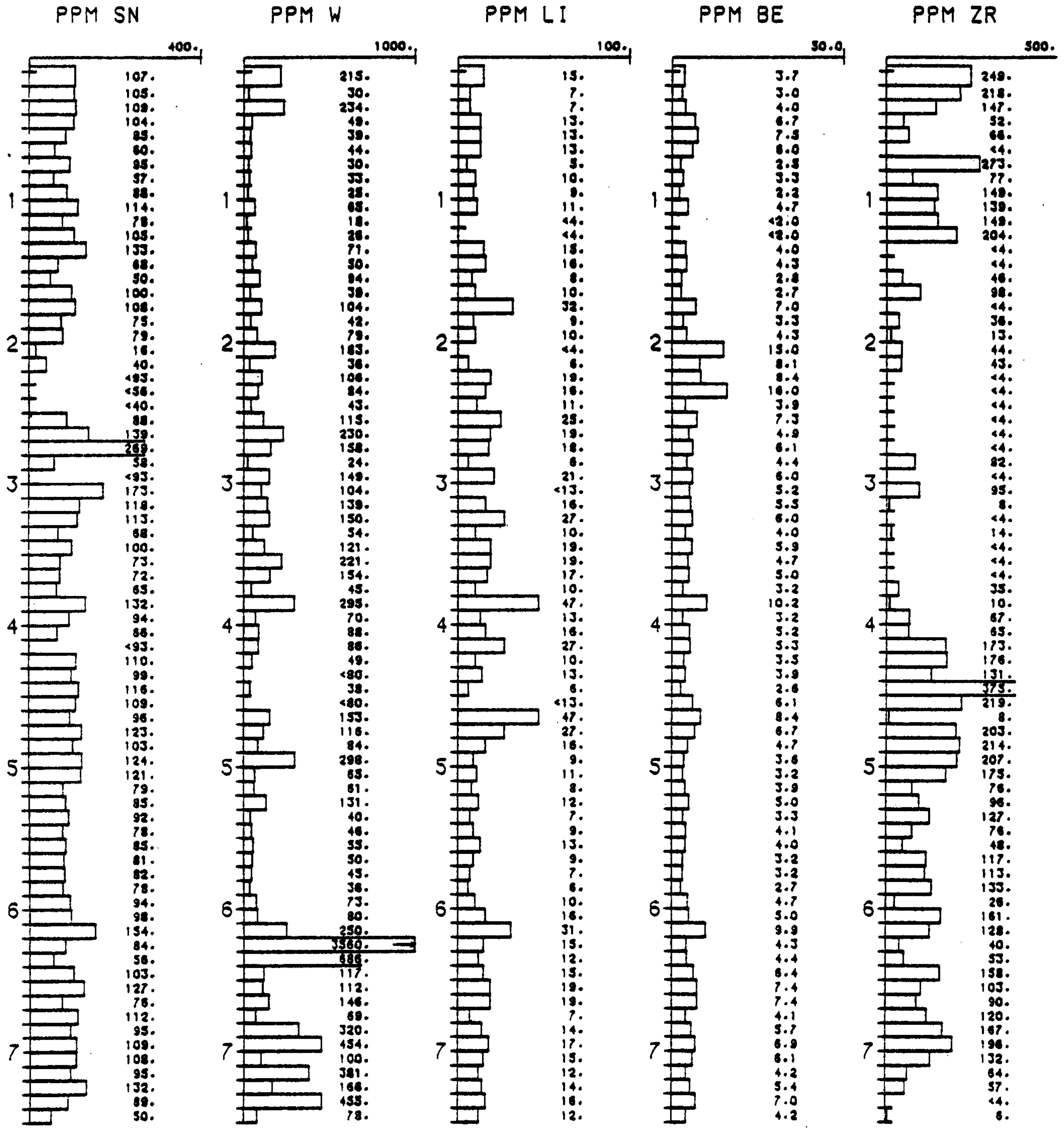


FIGURE C-11

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



]

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

FIGURE C-12

SAMPLE TYPE: +3.3 LESS MAG
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

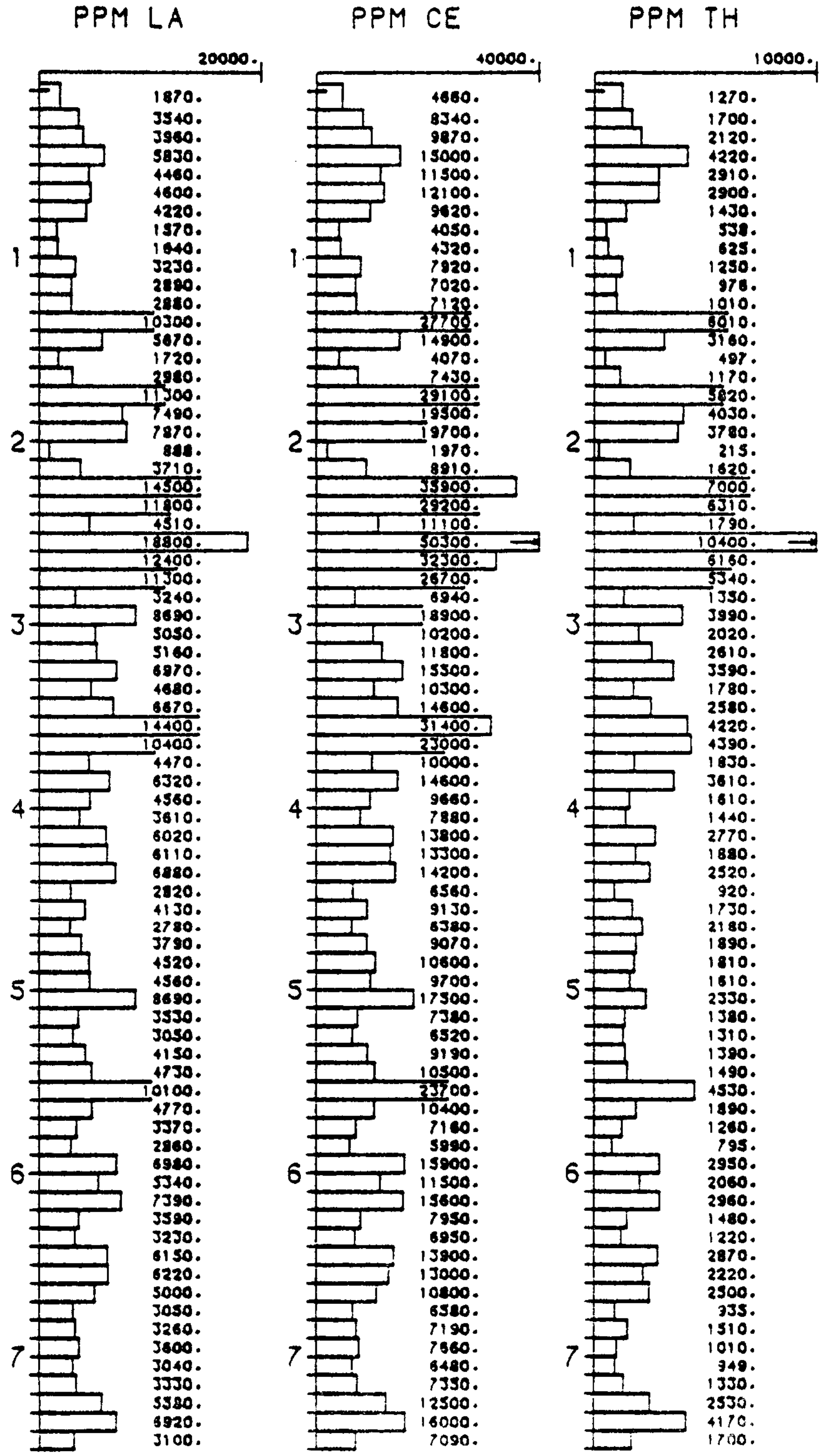


FIGURE C-13

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

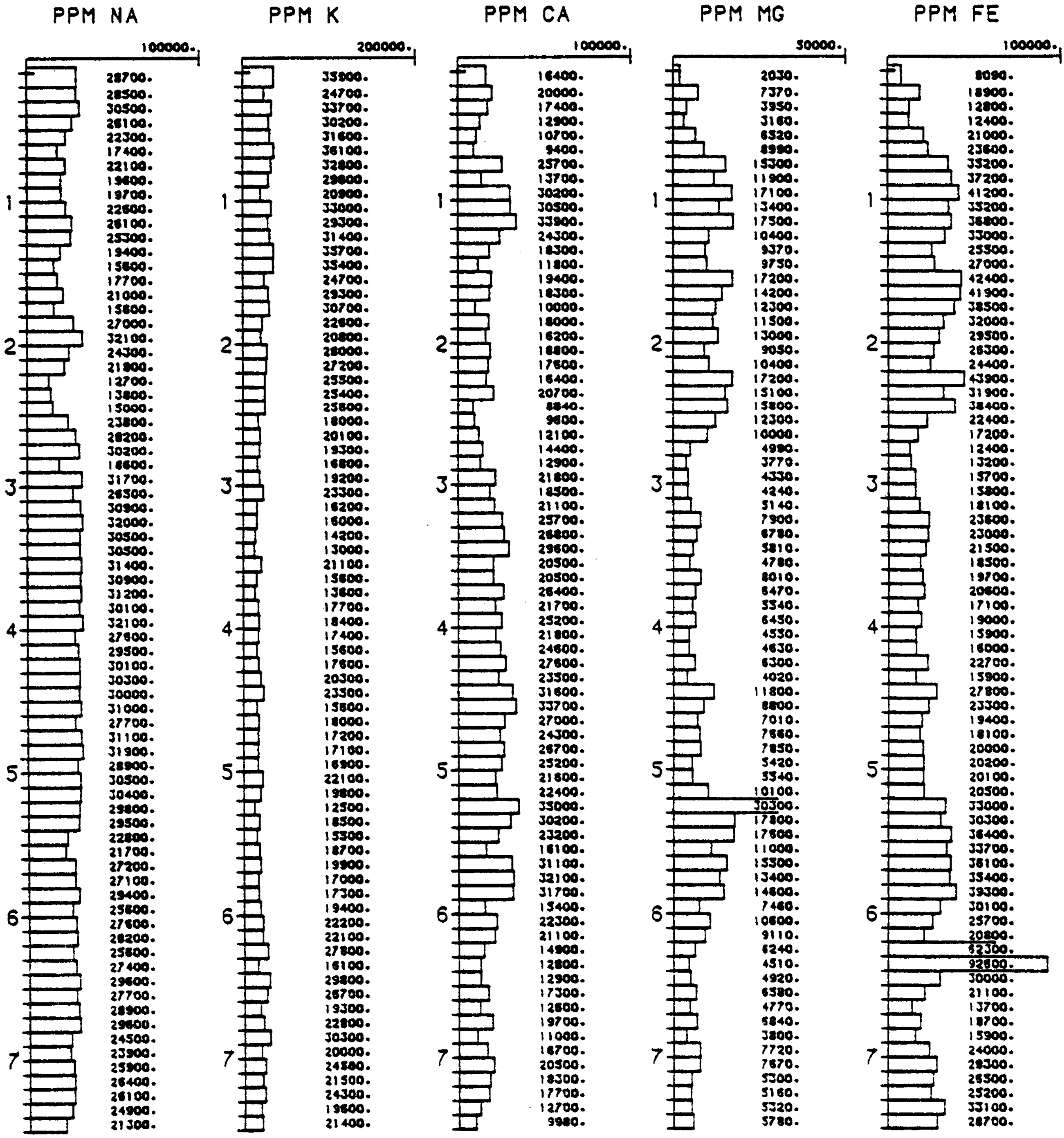


FIGURE C-14

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

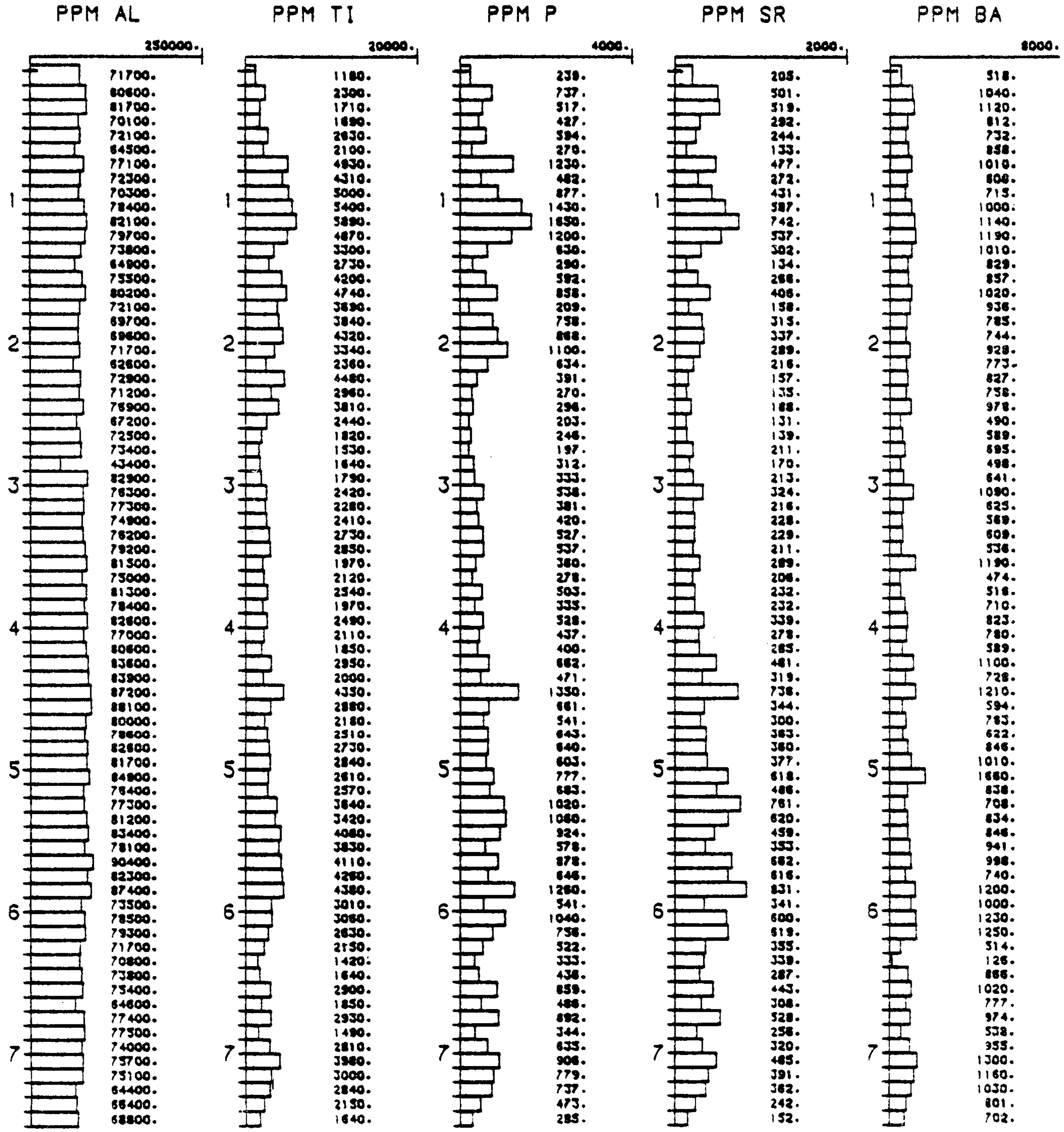


FIGURE C-15

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

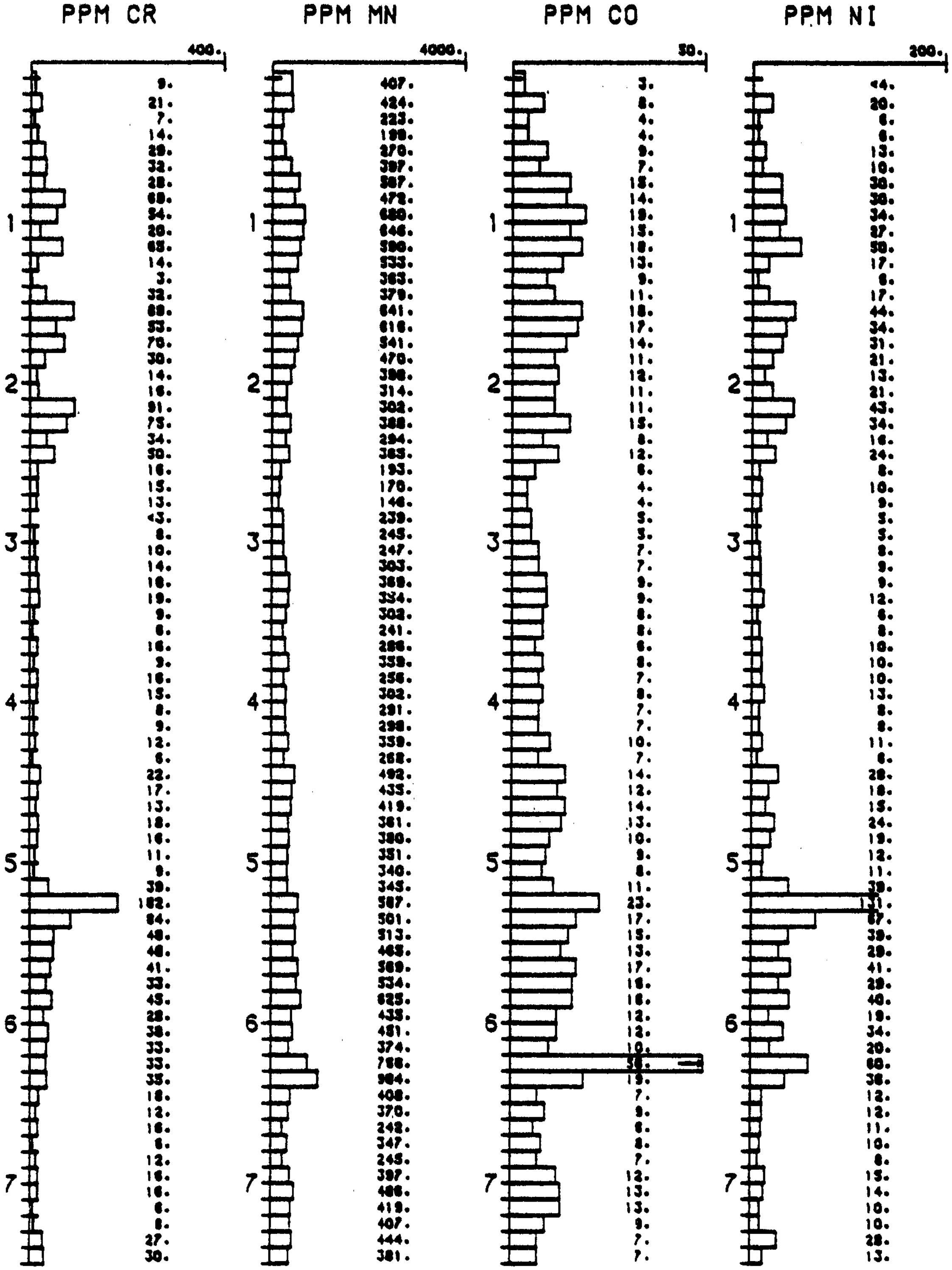


FIGURE C-16

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

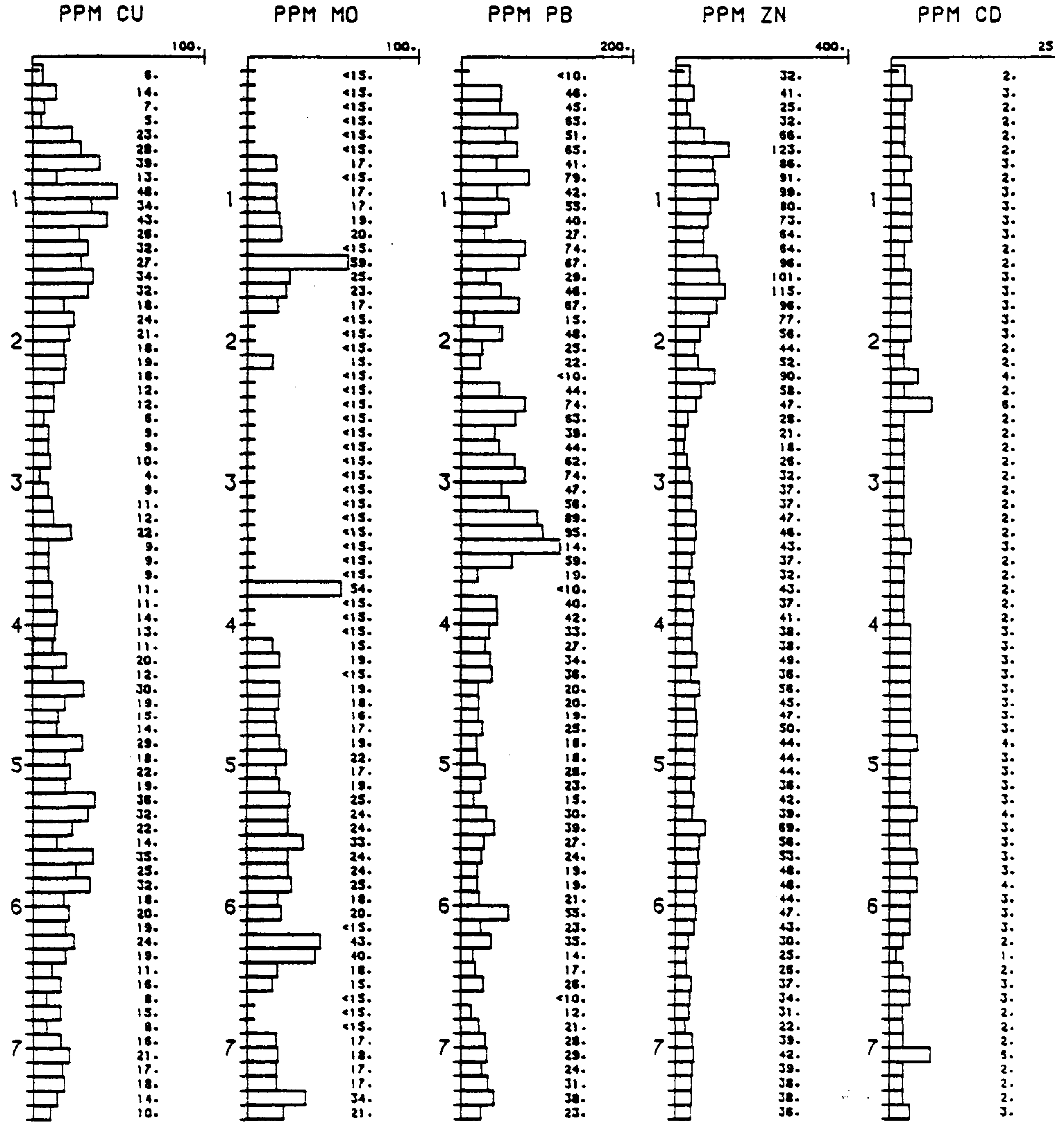


FIGURE C-17

DH 52-21

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

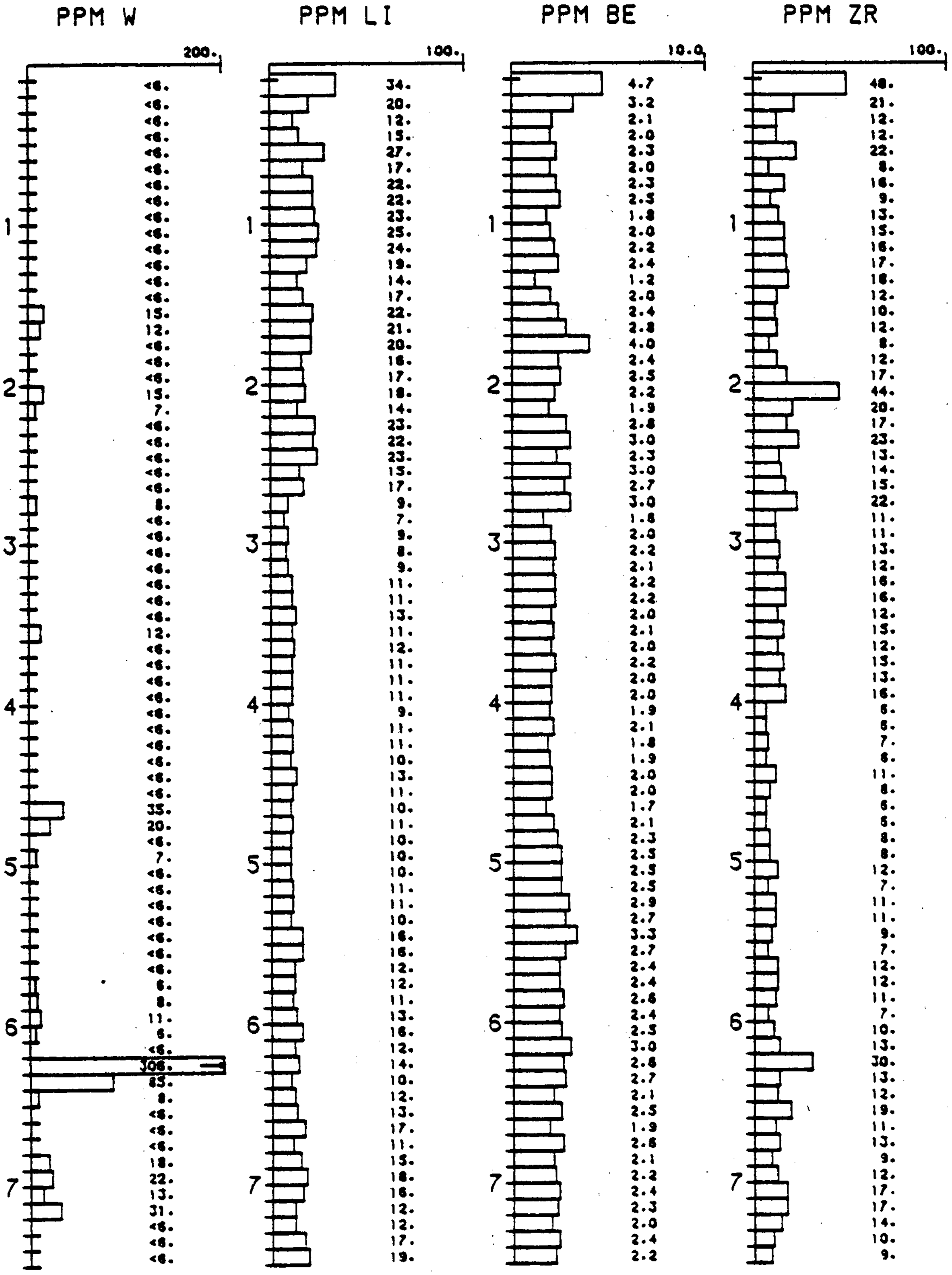
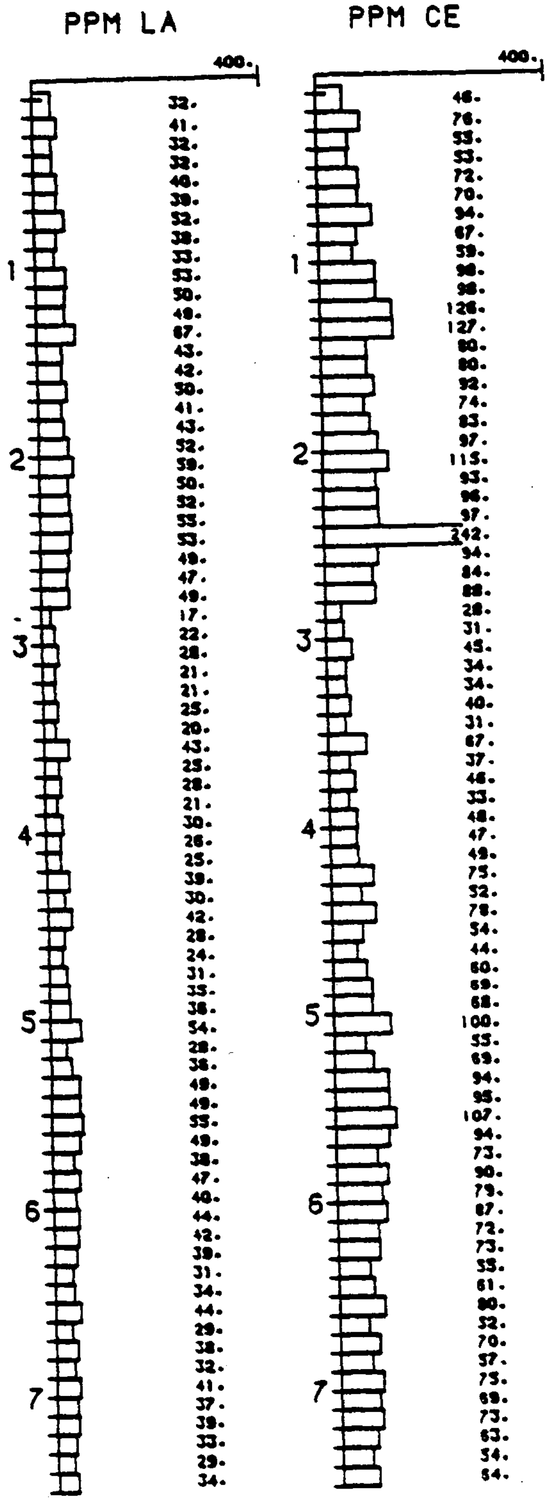


FIGURE C-18

DH 52-21

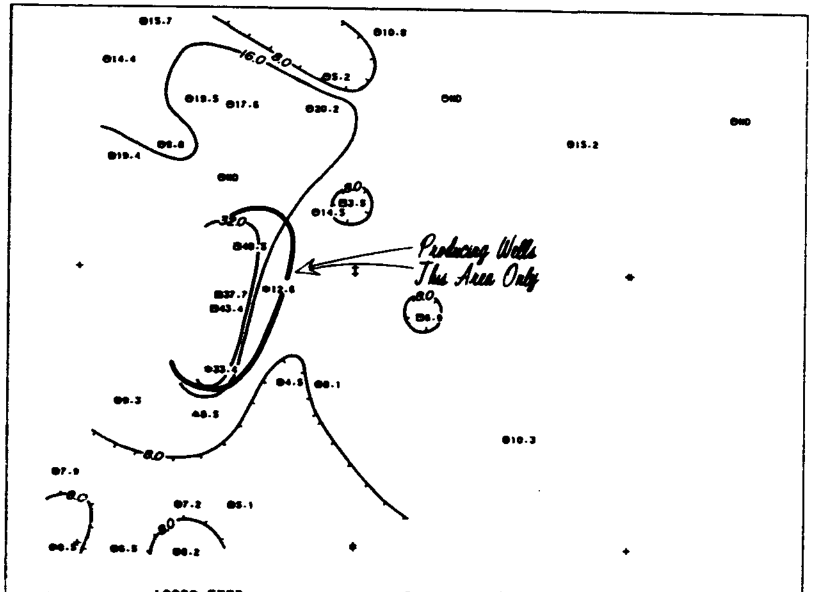
ROOSEVELT KGRA
BEAVER COUNTY, UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)



APPENDIX D

Additional multielement maps for +3.3 concentrate samples (less magnetics) and whole rock samples from drill cuttings.

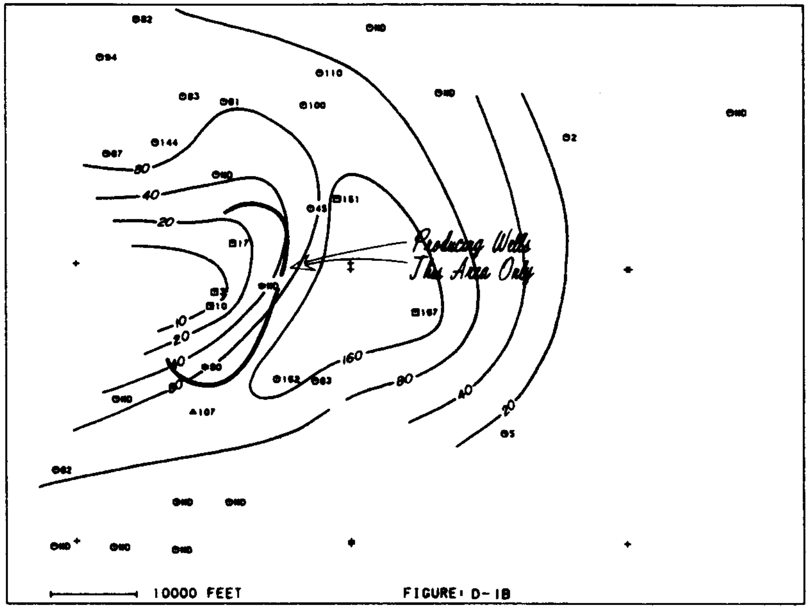


10000 FEET

FIGURE: D-1A

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

IRON (%) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: AAS & ICPQ

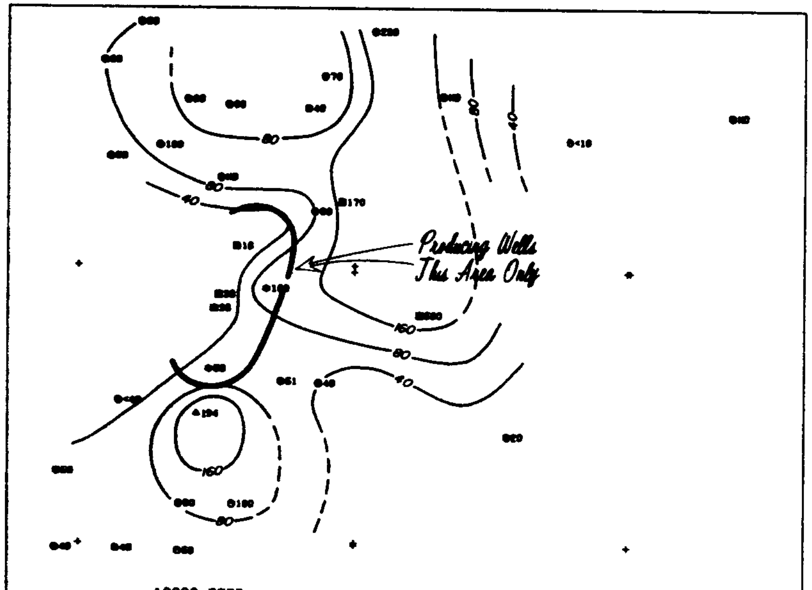


10000 FEET

FIGURE: D-1B

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

TIN (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: OES & ICPQ

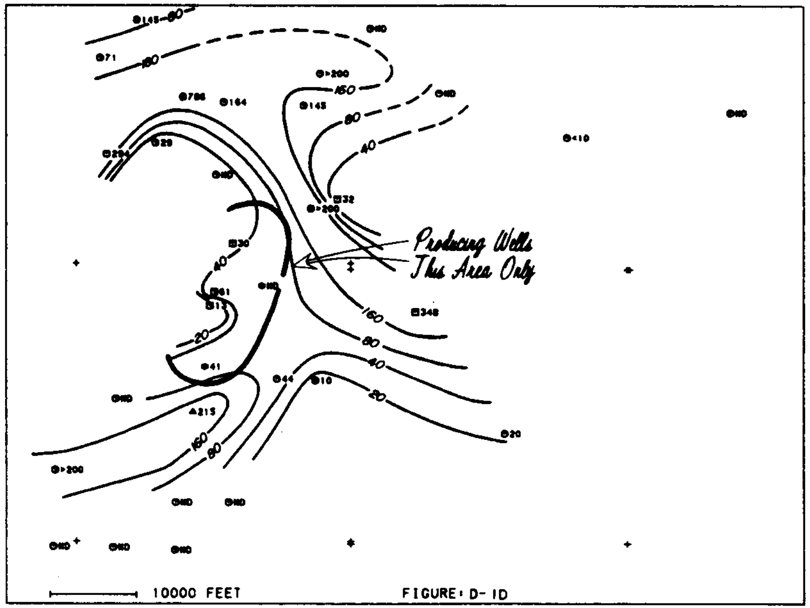


10000 FEET

FIGURE: D-1C

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

MOLYBDENUM (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: AAS



10000 FEET

FIGURE: D-1D

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

TUNGSTEN (PPM) 100-200 FT.
SAMPLE TYPE: +3.3 LESS MAG.
ANALYTICAL METHOD: OES & ICPQ

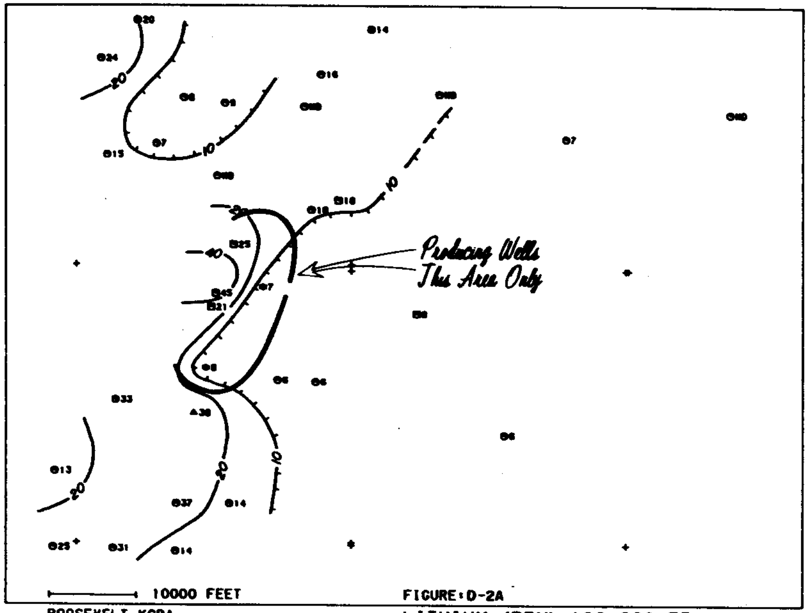


FIGURE: D-2A

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

LITHIUM (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: ICPQ

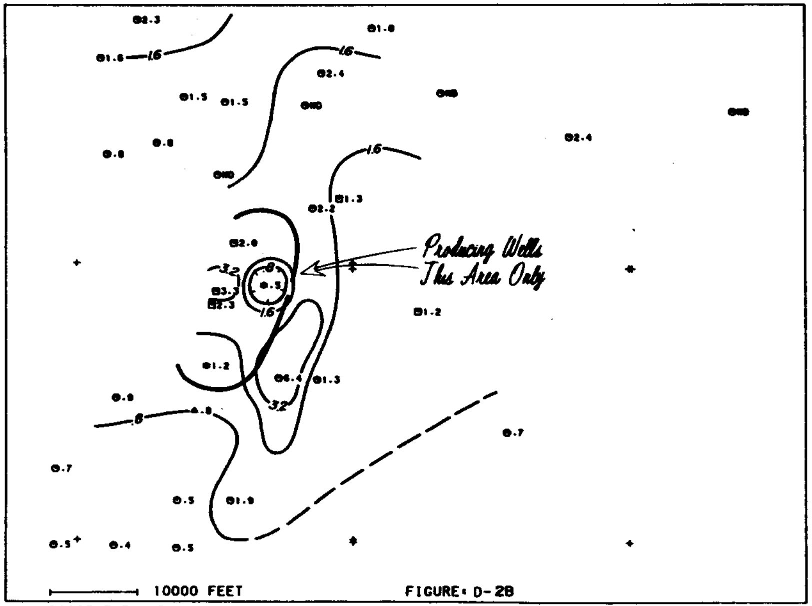


FIGURE: D-2B

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

IRON (%) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: AAS & ICPQ

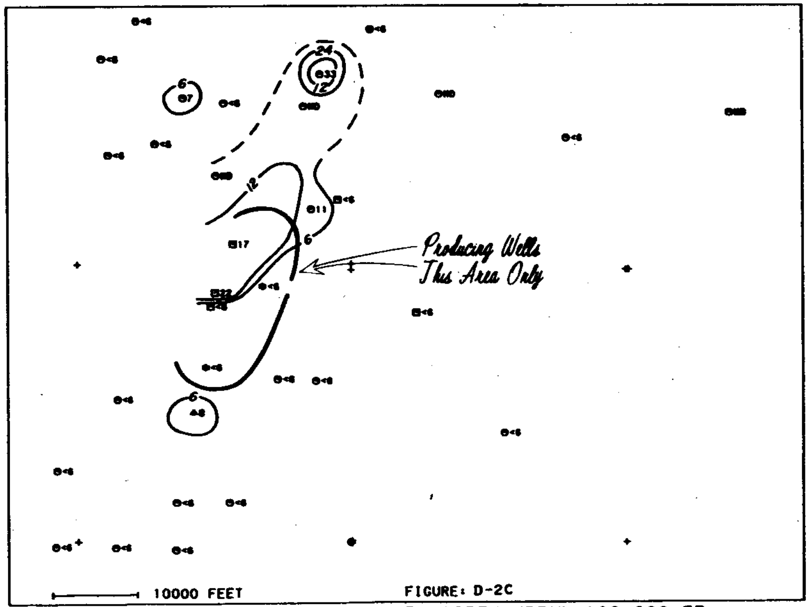


FIGURE: D-2C

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

TUNGSTEN (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: ICPQ

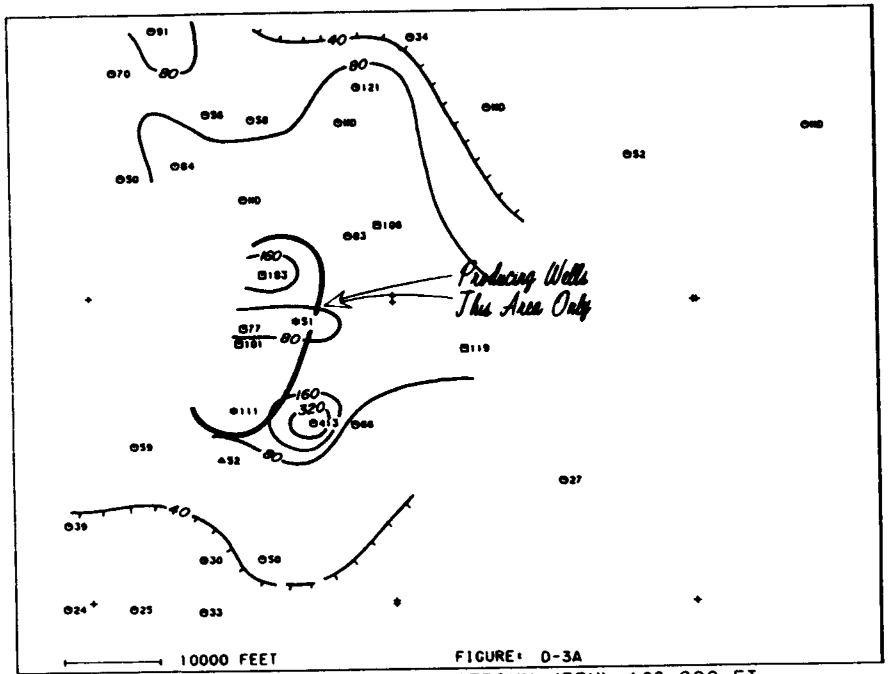


FIGURE: D-3A

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

CERIUM (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: ICPQ

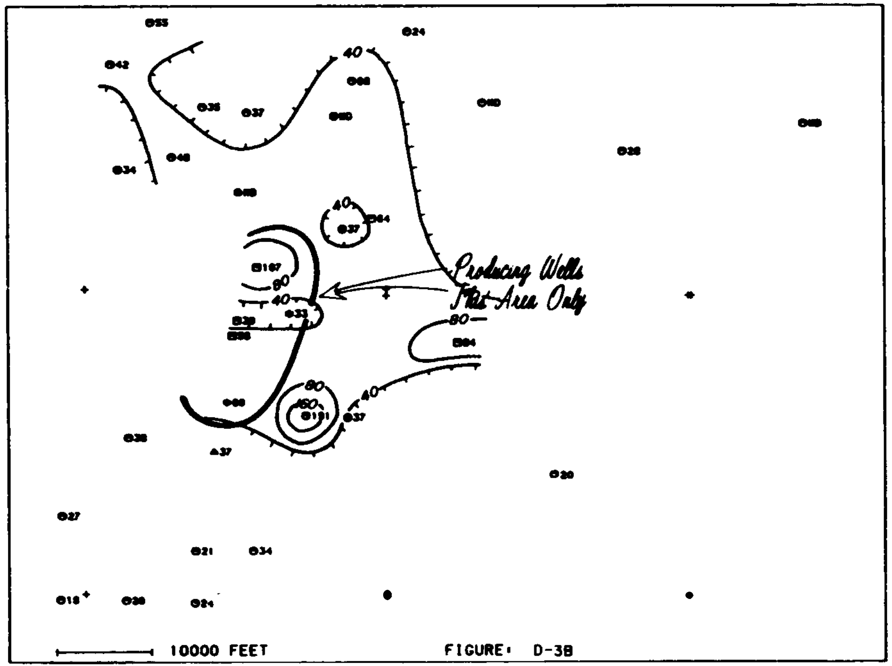


FIGURE: D-3B

ROOSEVELT KGRA
BEAVER COUNTY, UTAH

LANTHANUM (PPM) 100-200 FT.
SAMPLE TYPE: WHOLE ROCK
ANALYTICAL METHOD: ICPQ

APPENDIX E

Estimated background compositions of principal lithologies in geothermal wells, Roosevelt Hot Springs KGRA, Utah.

Table E-1. Means and Standard Deviations of Element Data for Relatively Unaltered Samples of Principal Lithologies in Utah State Wells 14-2, 72-16, and 52-21.

	Arkosic Alluvium		Biotite Aplite Porphyry		Biotite Microgranite		Hornblende-Biotite Quartz Monzonite		Biotite-Hornblende Quartz Monzonite Gneiss		Quartz-Feldspar-Hornblende-Biotite Gneiss	
	(Qal)		(Tgr)		(Tgr)		(Tqm)		(PЄgn)		(PЄbg)	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Na%	3.24	.16	2.67	.17	1.69	.28	3.29	.36	3.23	.21	3.06	.15
K%	4.34	.56	4.28	.89	3.20	.91	5.20	.43	2.25	.09	1.73	.31
Ca%	1.18	.52	.78	.16	.64	.76	1.29	.27	3.23	.31	2.47	,36
Mg%	.13	.09	.19	.04	.11	.06	.31	.06	1.31	.14	.67	.19
Fe%	.87	.38	1.29	.12	1.05	.25	1.54	.30	3.14	.20	2.00	.33
Al%	7.47	.56	8.05	.43	6.32	.33	9.42	.47	8.61	.47	7.96	.36
Ti ppm	1570	678	1700	414	973	158	2790	561	3550	299	2570	600
P ppm	316	179	410	93	190	48	629	138	1040	85	544	260
Sr ppm	342	113	408	105	147	23	797	108	841	98	305	104
Ba ppm	911	320	1250	330	548	119	2570	363	2700	1417	734	229
V ppm	<40		<40		<40		<40		115	6	<52	
Cr ppm	<5		<5		<7		<5		23	2	14	4
Mn ppm	273	100	560	121	133	99	828	1060	725	113	329	66
Co ppm	<2		3	1	2	.4	3	1	15	2	9	2
Ni ppm	<5		<5		<10		<5		18	2	13	7
Cu ppm	4	3	5	2	9	14	4	2	17	8	15	8
Mo ppm	<1		<1		<1		<10		13	1	<19	
Pb ppm	35	10	31	1	67	67	29	6	45	3	50	34
Zn ppm	22	16	33	2	34	13	41	19	52	9	42	7
As ppm	<1		<1		5	2	<1		<1		<2	
Sb ppm	<20		<20		<20		<20		<1		<25	
Sn ppm	<7		<7		<8		<7		<8		<3	
W ppm	<6		<6		<6		<7		<8		<7	
Li ppm	7	2	10	1	8	3	12	2	23	5	11	1
Be ppm	3.3	.5	2.4	.2	2.3	.2	1.8	.2	2.1	.1	2.1	.1
Zr ppm	11	2	6	1	3	2	8	1	6	1	12	3
La ppm	32	11	59	8	60	7	34	4	40	2	27	7
Ce ppm	49	14	89	11	92	11	51	8	75	4	47	16
Hg ppb	4	2	12	8	10	5	8	7	19	9	19	7
Samples From Drill Hole	14-2		14-2		14-2		14-2		72-16		52-21	
# of Samples	10		4		17		22		5		14	
Intervals	90'-190'		400'-440'		1810'-1850' 1860'-1910' 1920'-2010'		510'-650' 700'-780'		800'-850'		2900'-3500' 3600'-4000' 4400'-4500' 4700'-5000'	

Table E-2. Changes in microdiorite chemistry at the 2860 to 2890 feet hot water entry zone (HWE), Utah State Well 14-2

Element	Conc.(ppm) @ HWE[1]		Background Conc. (ppm)[2,3]		Change (ppm)	Relative Change
	$\bar{x}_2$	s_2	$\bar{x}_1$	s_1	$\bar{x}_2-\bar{x}_1$	$(\bar{x}_1-\bar{x}_2)/\bar{x}_1$
Na	1.27%	.18%	2.57%	.54%	-1.3%	-.51
K	2.77%	.48%	3.17%	.29%	-.4%	-.13
Ca	1.64%	.43%	2.15%	.32%	-.51%	-.28
Mg	2.66%	.36%	.93%	.20%	+1.73%	+1.86
Fe	6.16%	.44%	3.32%	.10%	+2.84%	+.86
Al	7.90%	.46%	6.91%	1.91%	+.99%	+.14
Ti	.84%	.03%	.66%	.17%	+.18%	+.27
P	2590	118	2010	3.4	+580	+.29
Sr	423	8	632	311	-209	-.33
Ba	1420	147	1360	440	+60	+.04
V	150	22	56	12	+94	+1.68
Cr	357	92	81	77	+276	+3.41
Mn	964	160	541	222	+423	+.78
Co	32	5	12	4	+20	+1.67
Ni	151	33	30	25	+121	+4.03
Cu	89	11	24	19	+65	+2.71
Mo	36	28	5	3	+31	+6.2
Pb	21	3	17	5	+4	+.24
Zn	255	58	88	54	+167	+1.90
As*	18	15	<1	<.55	+17	+17
Li	83	8	29	7	+54	+1.86
Be	2.9	.2	2.4	.2	+.5	+.21
Zr	62	7	46	17	+16	+.35
La	73	3	47	20	+26	+.55
Ce	141	7	83	36	+58	+.70
Hg	14ppb	4ppb	19ppb	8ppb	-5ppb	-.26

[1] Based on data for four contiguous samples distinctly anomalous in As and Li from the interval 2870 to 2890 feet, Utah State Well 14-2.

[2] Based on data for 6 weakly to strongly altered samples containing 75% to 95% microdiorite (Tmd) as follows: 14-2/2110 to 2115 (90% Tmd, 10% Tqm), 14-2/2865 to 2870(95% Tmd, 5% Tqm), 14-2/3795 to 3780 (75% Tmd, 25% Tqm, 14-2/3990 to 3995 (85% Tmd, 15% Tqm), 52-21/2050/2060 (90% Tmd, 10% Tgr), and 52-21/2060-2070 (90% Tmd, 10% Tgr). One or more of these samples were positively anomalous in Hg, Be, Ce, Zn and possibly other elements, thus making the calculated mean background values positively biased.

[3] Values less than the detection limit were set equal to the detection limit for all calculations.

APPENDIX F

Geothermal exploration wells,
Roosevelt Hot Springs KGRA, Utah

APPENDIX F

Geothermal Exploration Wells, Roosevelt Hot Springs KGRA, Utah[a]

Well	Total Depth		Bottom Hole Temperature	Production Capability	
Utah State	Feet	Meters	°C		
3-1	2728	831	Hot	Yes	Good flow but production unsafe[e].
9-1	6885	2098	225[c]	No[e]	Poor permeability.
12-35	7324	2232	≈227	Yes	Possible shallow cool water contamination.
13-10	5351	1631	Hot	Yes	
14-2	6108	1862	268[d]	Yes	
25-15	≈7500	≈2286		Yes	Shallow cool water contamination, less than wells to the north.
52-21	7600[b]	2316[b]	206[b]	No[b]	
54-3	2882	878	>260	Yes	Best well, >500 btu./lb.
72-16	1254	382	243[d]	Yes	
82-33	6208	1892	149to177	No[e]	Reinjection well

a. All data from Koenig and Gardiner (1977), except as otherwise noted.
b. Earth Science Laboratory, 1978b.
c. Geothermal Resource Council Bulletin, 1979; P.O. Box 98, Davis, CA., 95616, vol. 8, no. 8, p. 6.
d. Earth Science Laboratory, 1978a.
e. Lenzer, Crosby, and Berge, 1976.

APPENDIX G

Chemistry of thermal waters and steam condensates,
Roosevelt Hot Springs KGRA, Utah

Table G-1. CHEMISTRY OF THERMAL WATERS, ROOSEVELT HOT SPRINGS KGRA UTAH: A SUMMARY[a]

Sample No.		1	2	3	4	5	6	7	8	9
Well: Utah State[b]		14-2[f,g]	14-2[f,h]	14-2	14-2	54-3	54-3	72-16	72-16	72-16[i]
Source/Analyst		ESL	ESL	USGS	USGS	Woodward-Clyde Consultants	Phillips Petroleum Company	USGS	USGS	Univ. of Utah
Reference		This Report	This Report	ESL, 1978a	ESL, 1978a	White, 1978	Lenzer et al., 1976	ESL, 1978a	ESL, 1978a	Ward et al., 1978
Collected		5/78	7/78	11/77	11/77	11/75	8/75			1/77
Analyzed		8/79	8/79	3/77	3/77			10/77	10/77	
Na	ppm	2070	2340	2150	2200	2000	2000	1800	2000	2072
K	ppm	384	419	390	410	400	410	380	400	403
Ca	ppm	11	6.8	9.2	6.9	7.0	10.1	12.4	12.20	31
Mg	ppm	0.28	<0.24	0.6	0.08	0.1	0.24	0.29	0.29	0.26
Fe	ppm	0.13	<0.02			0.2				0.016
Al	ppm	0.31	<0.28			0.5				
Si	ppm	226	31	299	383	140	>262	238	244	299
Sr	ppm	1.44	1.28			<5		1.36	1.20	
Ba	ppm	0.24	<0.24			<0.4				
Mn	ppm	<0.20	<0.20			<0.02				
Cu	ppm	<0.20	<0.20							
Pb	ppm	<0.20	<0.20			0.18				
Zn	ppm	<0.20	<0.20							
As	ppm	3.2	3.6	3.0	2.2	3.8				
Li	ppm	25	28			20	19.0	15.0	16.0	
Be	ppm	0.004	<0.004							
B	ppm	23	25	29	28	28	29	26.4	27.2	
Ce	ppm	<0.20	<0.20			3.1				
Br	ppm					<5				
Rb	ppm					3.9				
F	ppm			5.2	4.8	6.0	5.0	5.2	5.3	
Cl	ppm			3650	3650	3600	3400	2110	3260	3532
HCO_3	ppm					200	200	181	181	25
SO_4	ppm			78	60	55	54	33	32	48
NO_3	ppm					<0.05	tr.			
NH_4	ppm					<1				
PO_4	ppm	<2	<2			<1				
T.D.S.[c]	ppm					6700	6442	6074	6444	6752
pH				5.9	6.2	6.7 to 7	6.5	7.83	7.53	5.0
T	°C			14	9		>260			92
$\delta^{18}O$	°/oo			-13.46	-13.27					
Geothermometer T(Na-K-Ca)[d]	°C	284	291	256	293	295	293	289	288	274
T (Na-K-Ca-Mg)[e]	°C	-	-	-	-	-	-	-	-	-

FOOTNOTES

a. A blank indicates data not determined or information not available.
b. For well locations see Figure 1, or footnotes k and l.
c. Total dissolved solids.
d. Calculated using the method of Fournier and Truesdell (1973, 1974). $\beta = 1/3$.
e. Calculated using the method of Fournier and Potter (1978).
f. Elements analyzed for but present at concentrations less than ICPQ limits of quantitative detection (Appendix C) include: Ti, V, Cr, Co, Ni, Mo, Cd, Ag, Au, Sb, Bi, U, Te, Sn, W, Zr, La, Th.
g. Sample supplied by J.R. Bowman, Univ. of Utah, Salt Lake City, Utah. Precipitate was noted in the original sample container.
h. Sample supplied by A.H. Truesdell, U.S.G.S., Menlo Park, CA. Precipitation in the original bottle is suspected.
i. Surface leakage.
j. Flow test at 7170 to 7500 feet.
k. Location: Sec. 34 dcb, T26S, R9W.
l. Location: Sec. 34 bdd, T26S, R9W (Salt Spring). Flowing at the time of collection (personal communication, W.T. Parry, Univ. of Utah, Salt Lake City, Utah, 1979).

Table G-1 (cont.). CHEMISTRY OF THERMAL WATERS, ROOSEVELT HOT SPRINGS KGRA UTAH: A SUMMARY[a]

Sample No.	10	11	12	13	14	15	16	17	18	19
Well: Utah State[b]	3-1	52-21[j]	52-21[j]	52-21[j]	9-1	Roos. Hot Spring[k]	Roos. Hot Spring[k]	Roos. Seep[l]	Roos. Seep[l]	Roos. Seep[l]
Source/Analyst	Phillips Petroleum Company	Getty Oil Company	Getty Oil Company	Getty Oil Company	Univ. of Utah	USGS	USGS	Univ. of Utah	Phillips Petroleum Company	Phillips Petroleum Company
Reference	Lenzer et al., 1976	ESL, 1978b	ESL, 1978b	ESL, 1978b	Parry et al., 1976	Mundorff, 1970	Mundorff, 1970	Ward et al., 1978	Lenzer et al., 1976	Lenzer et al., 1976
Collected	5/75	11/78	11/78	11/78		11/50	9/57	6/75	5/73	8/75
Analyzed		12/78	12/78	12/78						
Na	2437	1845	1900	1900	2210	2080	2500	1840	2400	1800
K	448	237	218	216	425	472	488	274	378	280
Ca	8.0	106	114	107	83	19	22	122	113	107
Mg	0.01	5.2	3.9	4.0		3.3	0	25	17	23.6
Fe		0.31	6.9	6.3						
Al		<0.1	<0.1	<0.1			0.04			
Si	262(?)	234	67	65	170	189	146	81	36	50
Sr										
Ba										
Mn										
Cu										
Pb										
Zn										
As										
Li	20.0						0.27			17
Be										
B	25	24.4	27.0	27.0			38		37	29
Ce										
Br										
Rb										
F	5.0	2.8	3.4	3.6		7.1	7.5		5.2	3.3
Cl	4090	2810.8	2885.1	2881.6	3800	3810	4240	3210	3800	3200
HCO_3	180	602.9	550.0	615.0		158	156	298	536	300
SO_4	59	78	86	85	122	65	73	120	142	70
NO_3	0.1	0.5	1.3	1.3		1.9	11		tr.	tr.
NH_4										
PO_4										
T.D.S.[c]	7067	5940	5727	5677		7040	7800	6063	7506	5948
pH	6.3	6.4	7.3	6.8			7.9	6.5	8.2	6.43
T	>205					85	55	25	17	28
$\delta^{18}O$										
Geothermometer										
T(Na-K-Ca)[d]	292	227	219	219	262	293	284	235	246	239
T (Na-K-Ca-Mg)[e]	-	209	210	209	-	283	-	139	181	141

FOOTNOTES

a. A blank indicates data not determined or information not available.
b. For well locations see Figure 1, or footnotes k and l.
c. Total dissolved solids.
d. Calculated using the method of Fournier and Truesdell (1973, 1974). $\beta = 1/3$.
e. Calculated using the method of Fournier and Potter (1978).
f. Elements analyzed for but present at concentrations less than ICPQ limits of quantitative detection (Appendix C) include: Ti, V, Cr, Co, Ni, Mo, Cd, Ag, Au, Sb, Bi, U, Te, Sn, W, Zr, La, Th.
g. Sample supplied by J.R. Bowman, Univ. of Utah, Salt Lake City, Utah. Precipitate was noted in the original sample container.
h. Sample supplied by A.H. Truesdell, U.S.G.S., Menlo Park, CA. Precipitation in the original bottle is suspected.
i. Surface leakage.
j. Flow test at 7170 to 7500 feet.
k. Location: Sec. 34 dcb, T26S, R9W.
l. Location: Sec. 34 bdd, T26S, R9W (Salt Spring). Flowing at the time of collection (personal communication, W.T. Parry, Univ. of Utah, Salt Lake City, Utah, 1979).

Table G-2. CHEMISTRY OF UTAH STATE WELL 14-2 STEAM CONDENSATES
ROOSEVELT HOT SPRINGS KGRA, UTAH[1]

Sample		1	2	3
Source/Analyst		ESL[2]	USGS	USGS
Reference		This Report	ESL,1978a	ESL,1978a
Collected		?/78	11/76	11/76
Analyzed		8/79	3/77	3/77
Na	ppm	<0.40	<0.5	<1
K	ppm	<0.70	<0.1	<0.1
Ca	ppm	<0.24	6.6	52
Mg	ppm	<0.24	<0.05	<0.05
Si	ppm	<0.10	<1	<1
As	ppm	<0.20	<0.01	0.02
B	ppm	0.39	0.55	0.6
F	ppm		<0.1	<0.1
Cl	ppm		2	1
SO_4	ppm		3	2
pH	ppm		4.5	4.9
$\delta^{18}O$	o/oo		-15.87	-15.82

1. Blank indicates data not determined or information not available.

2. Elements present at concentrations less than ICPQ limits of quantitative detection (Appendix H) include: Fe, Al, Ti, P, Sr, Ba, V, Cr, Mn, Co Ni, Cu, Mo, Pb, Zn, Cd, Ag, Au, Sb, Bi, U, Te, Sn, W, Li, Be, Zr, La, Ce, Th. Sample supplied by A. H. Truesdell, U. S. Geological Survey, Menlo Park, CA.

APPENDIX H

Approximate limits of quantitative detection (LQD) for the Inductively Coupled Plasma Spectrometer (ICPQ).

APPENDIX H

Approximate Limits of Quantitative Detection * (LQD) for the Inductively Coupled Argon Plasma Spectrometer (ICPQ).

Element	Solutions	Whole Rock**	+3.3 Concentrates**
Na	.40	20	40
K	.70	35	70
Ca	.24	12	24
Mg	.24	12	24
Fe	---	25	50
Fe	.02	---	---
Al	.28	14	28
Si	.10	---	---
Ti	.04	2	4
P	.70	35	70
Sr	.002	.1	.2
Ba	.20	10	20
V	.80	40	80
Cr	.10	5	10
Mn	.20	10	20
Co	.02	1	2
Ni	.10	5	10
Cu	.02	1	2
Mo	.20	10	20
Pb	.20	10	20
Zn	.02	1	2
Cd	.02	1	2
Ag	.04	2	4
Au	.04	2	4
As	.20	10	20
Sb	.40	20	40
Bi	1.20	60	120
U	1.20	---	---
Te	.60	30	60
Sn	.14	7	14
W	.12	6	12
Li	.02	1	2
Be	.004	.2	.4
B	.04	---	---
Zr	.04	2	4
La	.04	2	4
Ce	.20	10	20
Th	.70	35	70

* All values in parts per million (ppm).

** Whole rock samples are analyzed in a 2% solution, +3.3 concentrates in a 1% solution.

--- Si and B not determined in solids due to loss during sample digestion.
U not determined in solids due to variable Fe spectral interference.

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