TRACE-ELEMENT GEOCHEMISTRY OF GRADIENT HOLE CUTTINGS:

BEOWAWE GEOTHERMAL AREA, NEVADA

by

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ABSTRACT

Multielement geochemical analysis of drill cuttings from 26 shallow temperature-gradient drill holes and of surface rock samples reveals trace element distributions developed within these rocks as a consequence of chemical interaction with thermal fluid within the Beowawe geothermal area. The presently discharging thermal fluids are dilute in all components except silica, suggesting that the residence time of these fluids within the thermal reservoir has been short and that chemical interaction with the reservoir rock minimal. Interaction between these dilute fluids and rocks within the system has resulted in the development of weak chemical signatures. The absence of stronger signatures in rocks associated with the present system suggests that fluids have had a similar dilute chemistry for some time. The spatial distribution of elements commonly associated with geothermal systems, such as As, Hg and Li, are neither laterally nor vertically continuous. This suggests that there is not now, nor has there been in the past, pervasive movement of thermal fluid throughout the sampled rock but, instead, that isolated chemical anomalies represent distinct fluid-flow channels. Coherent near-surface enrichments of As and Mn are consistent with a system in which fluids discharge from along the Malpais Fault and flow downslope within shallow permeable horizons, depositing As near the discharge point and Mn more distally. Discontinuous As, Li and Hg concentrations near White Canyon to the east of the presently active surface features record the effects of chemical interaction of rocks with fluids chemically unlike the presently discharging fluids. The observed trace element distributions suggest that historically the Beowawe area has been the center of more than one hydrothermal event and that the near-surface portion of the present hot-water geothermal system is controlled by a single source fracture, the Malpais Fault, or an intersection of faults at the sinter terrace.

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INTRODUCTION

The Beowawe geothermal area lies in northern Nevada along the Lander and Eureka county line, approximately 30 km southeast of Battle Mountain (Figure 1). The geothermal potential of the area is currently being evaluated by Chevron Resources Company and Getty Oil Company. This study is part of a comprehensive ongoing case study of the area being prepared by the Earth Science Laboratory Division of the University of Utah Research Institute (ESL/UURI) in cooperation with these companies through the Industry Coupled Program of the Division of Geothermal Energy of the U. S. Department of Energy (DOE/DGE).

Multielement geochemical analysis of drill cuttings from 26 shallow temperature-gradient holes drilled by Chevron has been performed in an attempt to more closely define the near-surface geometry of the geothermal resource. Recent studies demonstrate that the trace element geochemistry of well cuttings from geothermal systems can be a useful exploration guide (Bamford and others, 1980; Christensen and others, 1980b; Christensen, 1980 a,b). Trace element distributions, developed as a consequence of temperature gradients and fluid flow within a geothermal system, place constraints on the possible geometry of the present system and may provide insight into its thermal and convective history.

ANALYTICAL TECHNIQUES

Drill cuttings were prepared for analysis by compositing individual washed 10-foot interval samples over 100-foot intervals (Bamford, 1978) and pulverizing to less than 270 mesh in a tungsten carbide shatterbox. Pulverized samples were dissolved by a four-acid digestion procedure (Christensen and others, 1980a).

Samples were analyzed for 37 elements by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) using an Applied Research Laboratories inductively coupled plasma quantometer (ICPQ) in the ESL geochemical laboratory. Elements determined by ICP-AES were 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. Specifics of the analytical instrumentation and procedures, as well as an evaluation of the quality of analyses are summarized in Christensen and others (1980a). In addition, As was determined on each sample solution by a colorimetric procedure and Hg was determined on solid samples by gold film mercury detector.

In order to distinguish chemical variations resulting from geothermal processes from the numerical dispersion of analytical values expected in natural normal or lognormal geochemical populations, elemental analytical values were evaluated graphically through the use of cumulative probability plots following the procedures described by Sinclair (1974, 1976) and Lepeltier (1969). The method permits estimation of population parameters and selection of discrimination thresholds for mixed distributions of two or more

numerical populations. An example of the application of this technique is presented in Christensen (1980b).

Of the elements investigated, the distributions of Hg, As, Li and Mn are most pertinent to the following discussion of the geochemistry of the Beowawe geothermal area. Data for these elements are presented graphically in this report as Figures 4 through 7. A data summary for all elements is included in the appendix; complete data is available on open file at ESL/UURI.

DISCUSSION

Geology

A comprehensive geologic study of the Beowawe area has recently been completed by Struhsacker (1980). The following discussion of the geology of Beowawe is largely abstracted from this work.
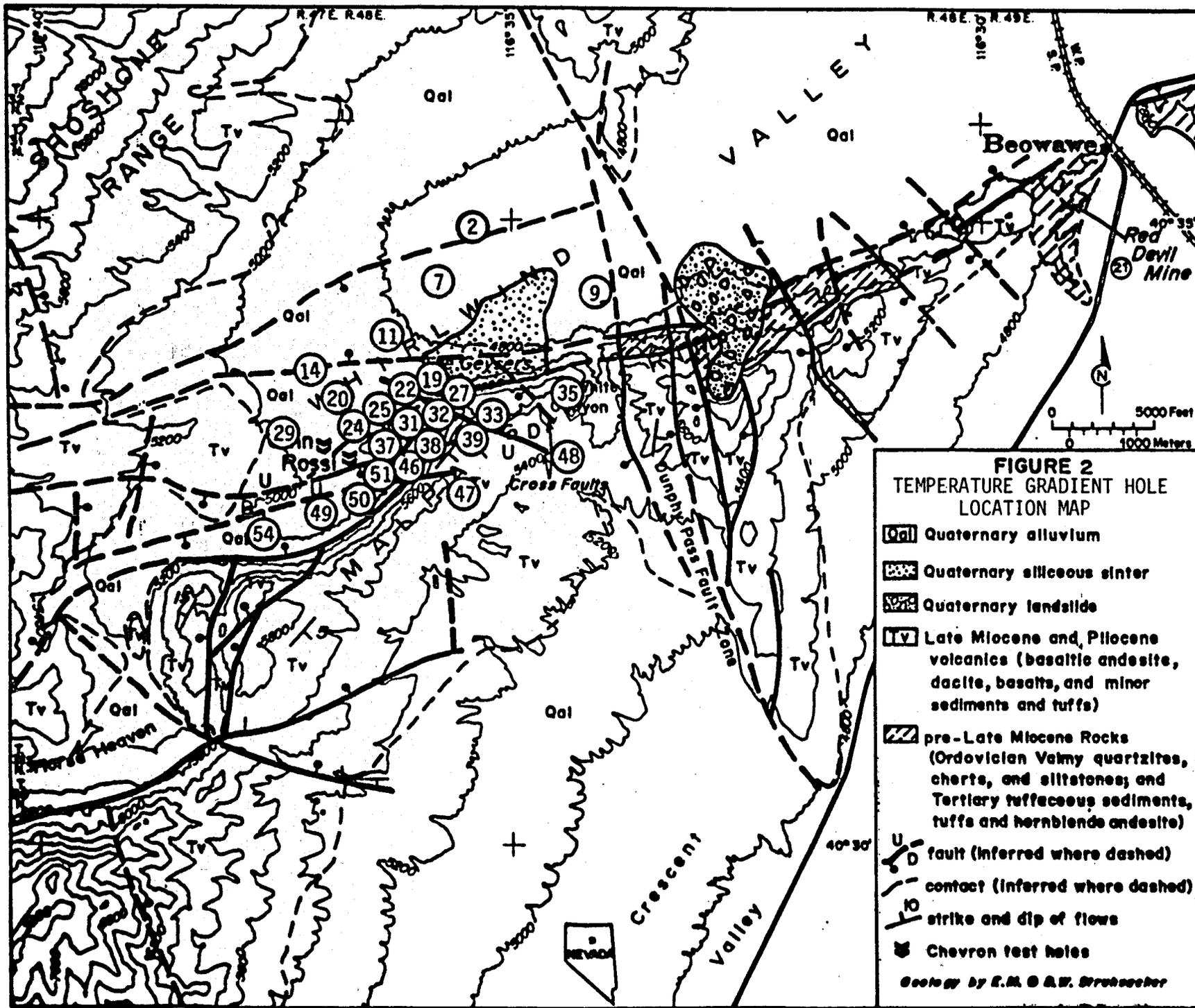
The Beowawe geothermal system lies near the axis of the Basin and Range physiographic province within the Battle Mountain heat flow high (Figure 1). The geothermal system is marked by the presence of hot springs and fumaroles associated with a large opaline sinter terrace. The terrace has developed along the fault-controlled Malpais Rim which bounds the southeast margin of Whirlwind Valley (Figure 1).
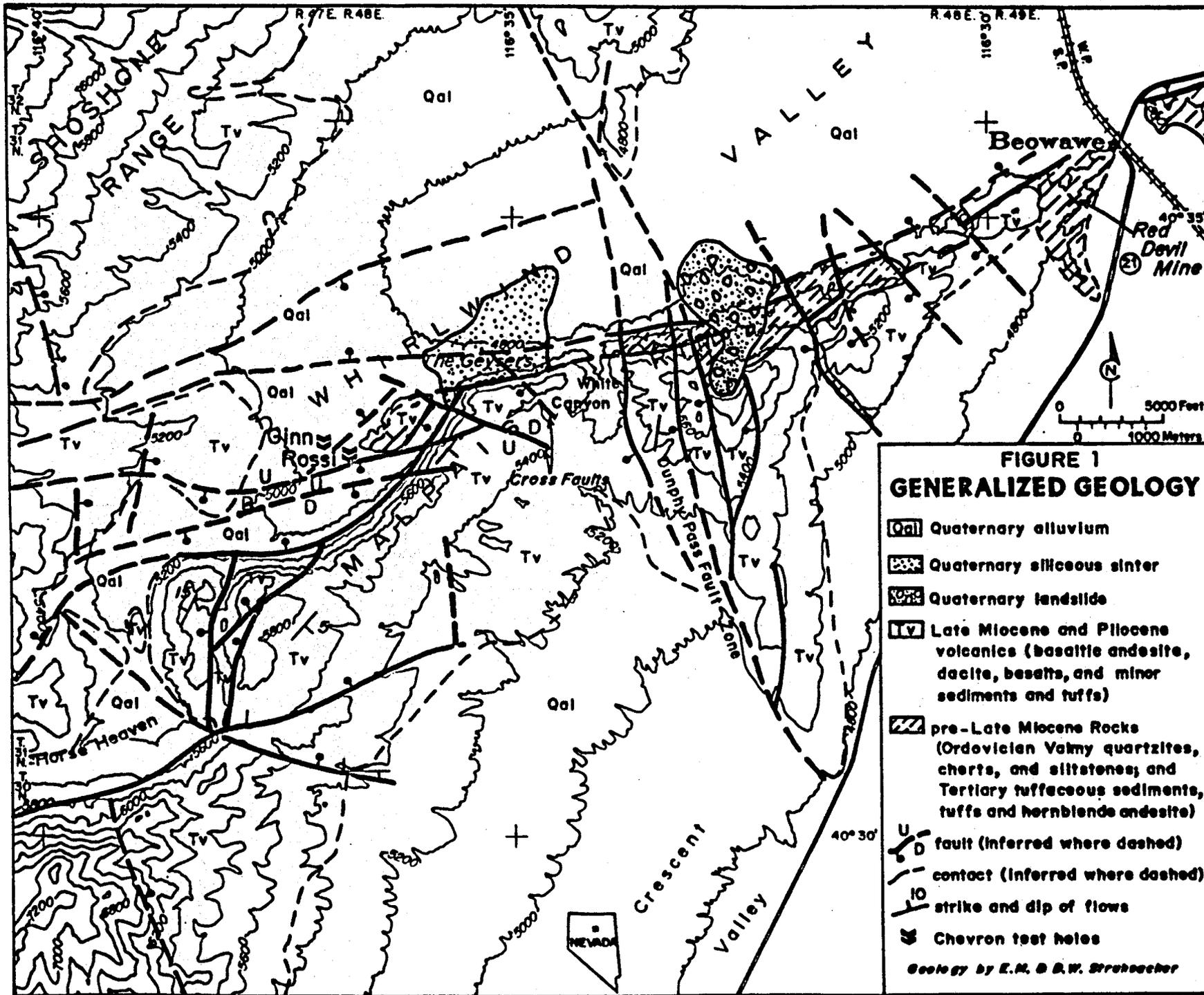
FIGURE 1
GENERALIZED GEOLOGY

Qal Quaternary alluvium

Quaternary siliceous sinter

Quaternary landslide

Tv Late Miocene and Pliocene
volcanics (basaltic andesite,
dacite, basalts, and minor
sediments and tuffs)

pre-Late Miocene Rocks
(Ordovician Valmy quartzites,
cherts, and siltstones; and
Tertiary tuffaceous sediments,
tuffs and hornblende andesite)

fault (inferred where dashed)

contact (inferred where dashed)

strike and dip of flows

Chevron test holes

Geology by E.H. & D.W. Struhsacker

FIGURE 2
TEMPERATURE GRADIENT HOLE
LOCATION MAP

Qal Quaternary alluvium

Quaternary siliceous sinter

Quaternary landslide

Tv Late Miocene and Pliocene
volcanics (basaltic andesite,
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Chevron test holes

Geology by E.M. & R.W. Struhsacker

The Beowawe geothermal system appears to be a high-temperature, hot-water system, localized within an area of structural complexity. Major fault systems active from pre-Tertiary to the present have controlled the deposition of volcanic rocks, the topography, and, apparently, the present geothermal fluid flow. Rocks exposed within the geothermal area include siliceous Ordovician eugeosynclinal rocks, Tertiary volcanic rocks ranging in composition from basalt to dacite, and Tertiary and Quaternary gravels.

Three major episodes of structural development are evident from the structures mapped within the geothermal area (Figure 1): a Paleozoic thrust faulting event, a NW-trending graben developed during mid-Miocene time, and NE-trending Basin and Range faulting.

In the vicinity of the geothermal area, the allochthonous siliceous rocks of the Ordovician Valmy Formation lie in exposed fault contact upon the subjacent autochthonous carbonates along the Roberts Mountain Thrust of the upper Devonian to lower Mississippian Antler Orogeny. The main thrust and the many subsidiary faults have severely fractured and folded the upper plate rocks, contributing to their effective permeability. Although the carbonates have not yet been penetrated by drill holes, it is presumed that they occur at greater depths throughout the area. Horizons of sandstone intersected within two deep drill holes in the area have been interpreted as tectonic slices of allochthonous Silurian Elder sandstone.

Major north-northwest-trending fractures occurring within the study area laterally confine a thick sequence of middle-Miocene calc-alkaline to alkaline flows. These flows accumulated in a graben produced by rifting along the

Oregon-Nevada lineament. The numerous north-trending splays of the Dunphy Pass Fault Zone (Figure 1) formed the eastern boundary of this graben. Continued activity on this fault zone after cessation of volcanism has resulted in measurable vertical displacement of volcanic units in the vicinity of White Canyon.

The east-northeast and east-trending faults of the Malpais fault zone (Figure 1) represent the final period of Basin and Range faulting. These post-date all volcanic units, suggesting a maximum age of 15.5 m.y. In general, north-northeast-trending Basin and Range normal faults dominate the regional structural terrain of north-central Nevada and give rise to the major ranges and valleys. The regional fault trend within the mapped area, however, is abruptly deflected eastward, producing the zone of structural complexity at the Beowawe area.

Exposed reservoir rocks within the Beowawe area include the Paleozoic siliceous eugeosynclinal rocks of the Valmy Formation and overlying Tertiary volcanic units. The Valmy Formation consists of siliceous siltstone with significant amounts of quartzite, sandstone, bedded chert, siliceous conglomerate, and locally bedded nodular barite. Tectonism has severely fractured the Valmy rocks to produce cataclastic textures. Tertiary volcanic rocks include dikes, flows, and tuffs locally interbedded with interflow tuffaceous and alluvial horizons. The generalized stratigraphy of the drill holes is summarized in Figure 3.
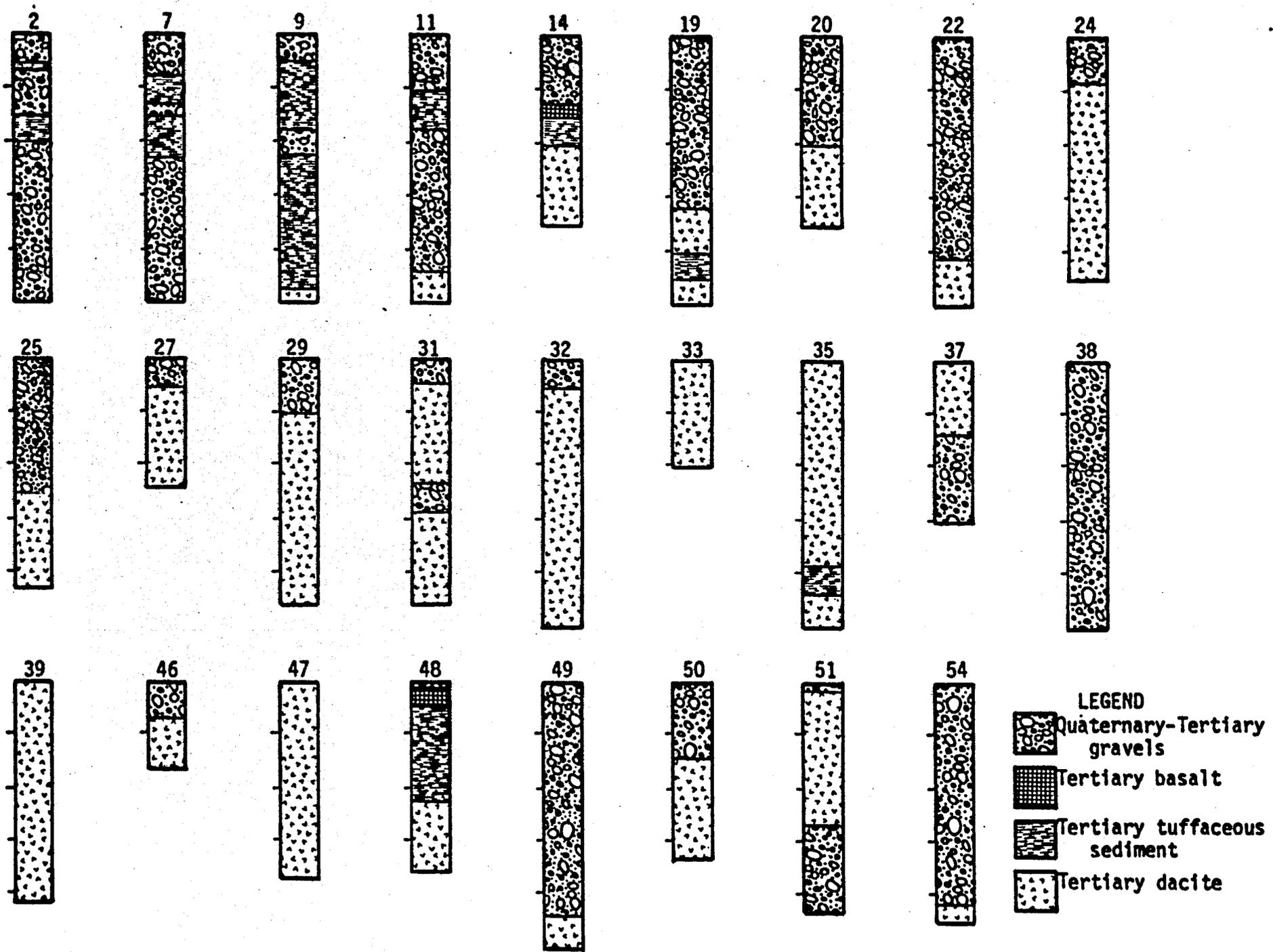
Figure 3. Generalized stratigraphy of temperature gradient holes.

LEGEND

Quaternary-Tertiary gravels

Tertiary basalt

Tertiary tuffaceous sediment

Tertiary dacite

Surface hydrothermal alteration is closely associated with the Malpais Fault, extending from the sinter terrace to the town of Beowawe. The modern hydrothermal activity is centered on the sinter terrace at the western end of this zone along the Terrace Fault. Erosion along the Malpais Scarp has exposed areas of silica veining, argillization, pyritization, and limonitization. The intensity of alteration varies greatly due, apparently, to the influence of cross fractures and lithologic control within the Malpais Fault Zone during hydrothermal activity.

The intersection of the Malpais Fault with the Dunphy Pass Fault zone at the mouth of White Canyon has been the center of intense hydrothermal activity in the past. A dense swarm of east-trending chalcedony veins cuts Tertiary dacite and highly fractured rocks of the Valmy Formation. Argillic alteration of the volcanic rock in the vein swarm increases toward the individual veins. Primary disseminated magnetite and secondary pyrite are replaced by abundant limonite. Displacement of the alteration zone across White Canyon indicates motion on the Dunphy Pass Fault zone subsequent to the deposition of the chalcedony veins.

At the Red Devil Mine near the northeast end of the alteration zone, a northeast-trending vertical fracture zone controls a 30 m-wide fault breccia in Valmy Formation quartzite, siltstone, and conglomerate. The breccia is characterized by quartz-pyrite veins and cinnabar films along fracture surfaces. The relative age of this mineralization is uncertain.

The Ginn and Rossi wells drilled by Chevron (Figure 1) penetrate a poorly defined zonal sequence of hydrothermal alteration products (Struhsacker,

1980). In general, the pervasive alteration through the Miocene volcanic section changes with depth from a clay-calcite-quartz-pyrite assemblage to a chlorite-calcite-clay-pyrite assemblage. A quartz-calcite-pyrite-chlorite-sericite-epidote assemblage is characteristic below the Tertiary-Ordovician contact.

Chemistry of Thermal Fluids

The thermal fluids discharging at the surface and obtained from wells in the Beowawe area are anomalous compared to many other previously studied hydrothermal systems (Bamford, 1978; Bamford and others, 1980; Christensen, 1980a, b) because of their low concentrations of dissolved material. These dilute fluids, however, are very similar to those obtained from many other Basin and Range geothermal systems of similar temperature (Mariner and others, 1974; Sanders and Miles, 1974). Selected fluid compositions from the Beowawe area are summarized in Table 1. In general, the fluids are alkaline (pH = 8-9) and have total dissolved solids less than 1400 mg/l. Sodium is the principal cation; chloride, sulfate, and carbonate species are all significant anions. Trace elements which are frequently enriched in thermal fluids (Ellis, 1979), such as As, Sb, W, B, Li, Rb, Cs, F and Br, are all present at relatively low concentrations.

TABLE 1
FLUID COMPOSITIONS FROM THE BEOWAWE AREA

	1	2	3	4	5	6
	Hot Spring	Hot Spring	Blowing Well	Blowing Well	Ginn 1-13 Well	Rossi 21-19 Well
Na	234	280	261	210	260	180
K	15	40	27	8	41	18
Ca	<.25	1.5	<.25	1.0	16	30
Mg	<.5	---	<.5	---	.3	8.9
Fe	<.025	<.09	<.025	<.07	---	2.0
Si	124	229	167	154	---	---
Sr	.02	---	.06	---	---	---
Ba	<.625	.05	<.625	.05	---	---
Mn	<.25	<.003	<.25	<.003	---	.09
Mo	<1.25	.011	<1.25	.019	---	---
As	<.625	.033	<.625	.04	---	<.05
Sb	<.75	.011	<.75	.013	---	---
W	<.125	.135	<.125	.150	---	---
Li	1.25	---	1.5	---	1.8	1.1
B	2.0	---	2.2	---	2.2	1.1
Rb	---	.320	---	.145	---	---
Cs	---	.220	---	.200	---	---
HCO_3	---	---	---	---	290	180
CO_3	---	---	---	---	22	<2
SO_4	100	---	103	---	60	35
Cl	4	67	10	56	76	32
F	1.2	---	1.2	---	10	3.5
Br	---	.145	---	.135	---	---
TDS	906	---	1120	---	1390	570
pH ($20^{\circ}C$)	$8.4 \pm .2$	---	$9.0 \pm .2$	---	8.6	8.1
T, $^{\circ}C$	95°	Steam	95°	88°	---	---

*all analytic values in mg/l.
**dash (---) indicates value not determined
***the following elements were analyzed for in samples 1 and 3 but are present in concentrations below the analytical limits of detection: Al, Ti, P, V, Cr, Co, Cu, Pb, Zn, Cd, Ag, Au, Bi, U, Te, Sn, Be, Zr, La, Ce, Th.

1. Hot spring below sinter terrace. Collected 6-24-80. Analyzed at ESL, 7-1980.
2. Hot spring below sinter terrace; from Wollenberg and others, 1977.
3. Blowing well brine. Collected 6-24-80. Analyzed by ESL, 7-1980.
4. Blowing well brine; from Wollenberg and others, 1977.
5. Ginn 1-13 drill stem test at total depth, 6-28-74; from Chevron, 1979.
6. Rossi 21-19 flow test, 12-76; from Chevron, 1979.

Although the salinities and trace element concentrations are low, silica contents are unusually high, suggesting that the fluids have had short residence times within the system and have undergone relatively little chemical interaction with the reservoir rocks. Several other processes could produce this particular chemistry, however, and can not be neglected. These include fluid transit through a low surface area environment, equilibration with siliceous reservoir rocks, or loss of elements to depositional phases.

Chemistry of Surface Samples

The chemistry of a number of surface rock samples from the Beowawe area is summarized in Table 2 and their locations indicated on Figure 2. These samples consist of materials which have clearly been affected by interaction with thermal fluids. Samples 1 through 4, collected near the mouth of White Canyon, document the trace element signature associated with the older chalcedonic veining present along the Malpais Fault in that area. The only consistent enrichment is that of As. The copper concentration in sample 1 is consistent with relatively high levels of Cu measured in other unaltered Valmy Formation samples and is attributed to a primary lithologic concentration in these eugeosynclinal sediments. Samples of opaline sinter (sample 5) and altered basaltic andesite (sample 6) from the active geothermal area are deficient in As and Li when compared to altered rocks in the Roosevelt system (Bamford and others, 1980; Christensen and others, 1980b), reflecting the dilute fluids at Beowawe. The only notably higher concentrations in these samples are those of Mn. As might be expected from the dilute thermal fluids, the trace element signature of solids affected by these fluids is also very weak.

TABLE 2

GEOCHEMISTRY OF SELECTED SURFACE SAMPLES

	1	2	3	4	5	6
	Valmy Chert: Breccia & silica-hematite veining	Silicified, argillized volcanic breccia	Argillized volcanic breccia	Chalcedonic vein material	Opaline sinter @ The Geyser terrace	Argillized, basaltic andesite
Na	279	957	6600	317	7560	6540
K	4120	53000	35600	1390	10500	11400
Ca	822	1690	3680	29000	3130	1760
Mg	644	523	638	4220	970	801
Fe	12200	16400	32600	4240	28100	48300
Al	26100	38500	55100	4610	37500	97600
Ti	1310	2530	3790	107	2640	4870
P	356	458	903	94	468	868
Sr	78	81	136	51	202	275
Ba	882	1090	1390	460	971	1530
Mn	43	42	60	80	123	139
Co	<1	<1	2	<1	2	1
Cu	17	6	9	7	7	5
Pb	<10	15	22	<10	17	33
Zn	<5	<5	39	<5	22	42
Ag	<2	<2	4	2	<2	<2
As	30	145	65	23	7	8
Li	16	36	15	52	42	50
Be	1.3	5.4	4.4	6.1	3.4	1.9
Zr	39	250	314	8	219	398
La	13	34	50	5	40	64
Ce	20	59	96	<10	64	127

* all values in mg/kg

** The following elements were analyzed for but are present at or below analytical limits of detections: V, Cr, Ni, Mo, Cd, Au, Sb, Bi, U, Te, Sn, and Th. Si, W, and B are lost or contaminated during sample preparation or analysis.

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Element Distributions

The distributions of Hg, As, Li, and Mn are presented in map sections for five depth intervals in Figures 4 through 7. These elements have been found to be readily distributed by thermal fluids in other systems (Bamford and others, 1980; Christensen, 1980 a,b).
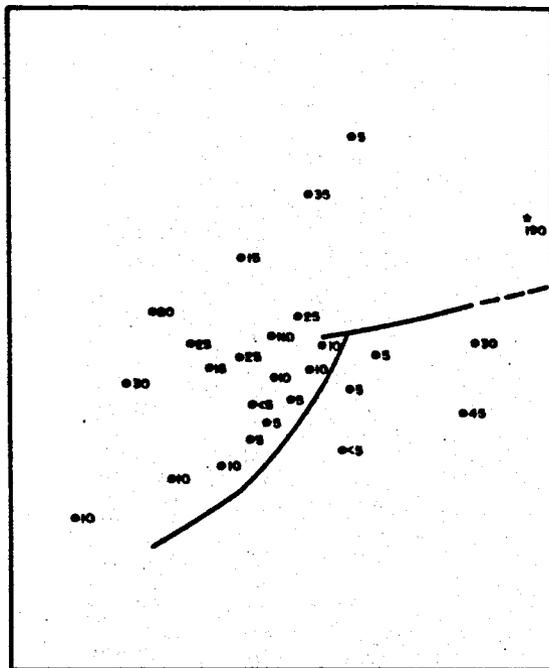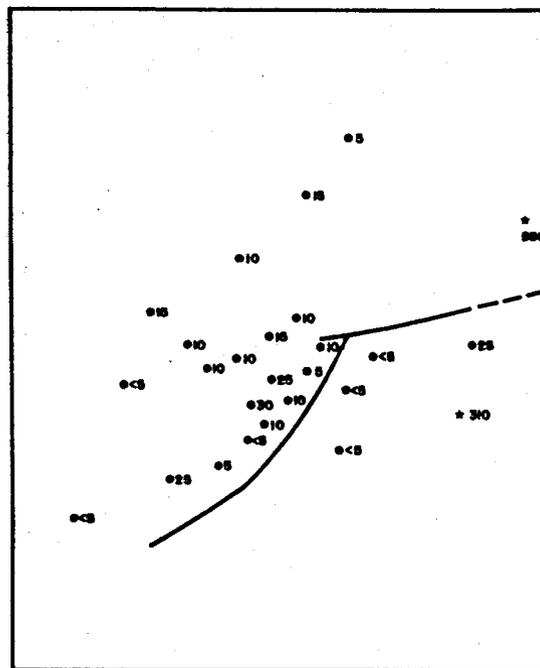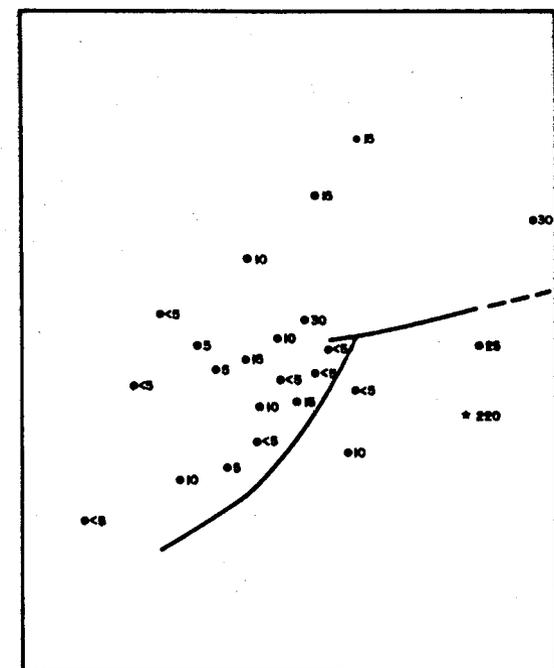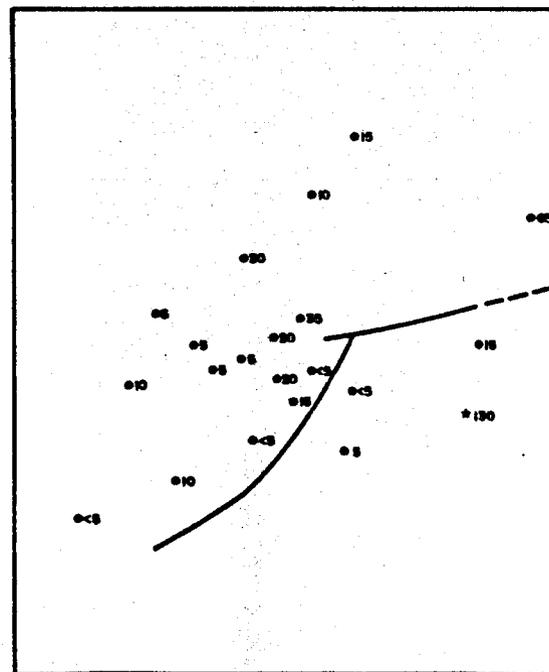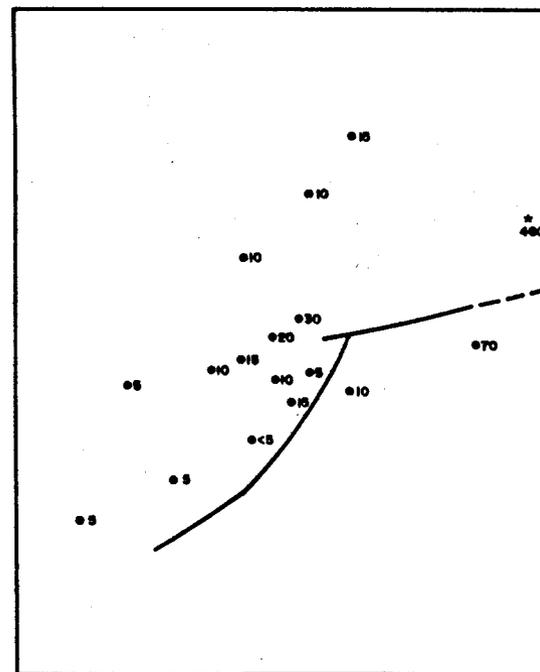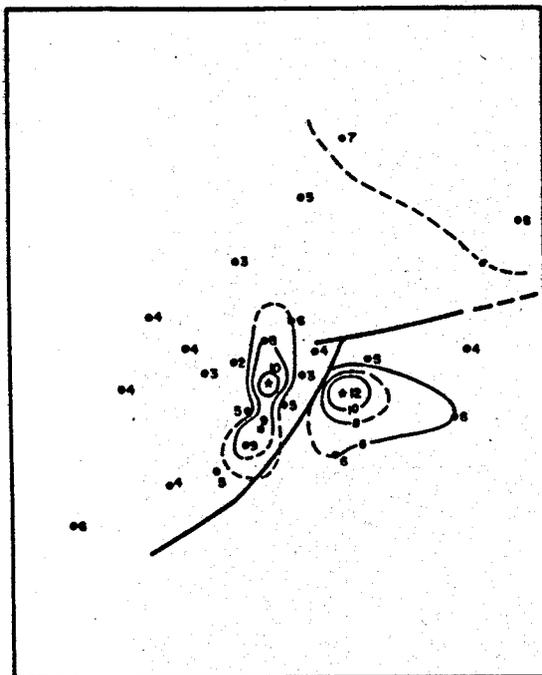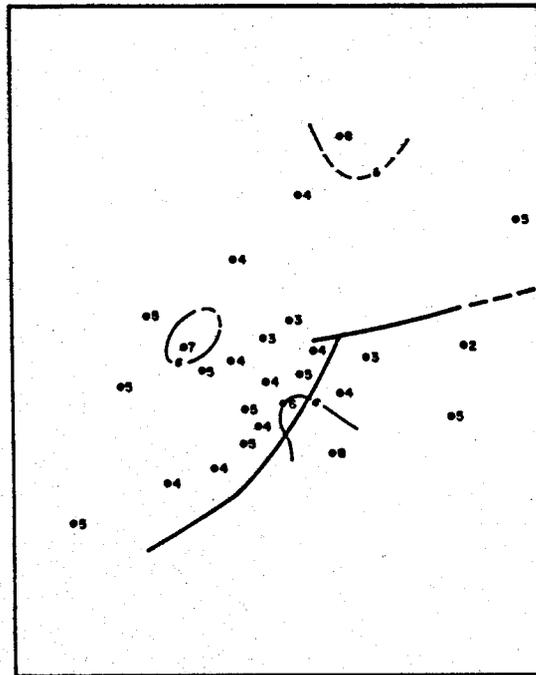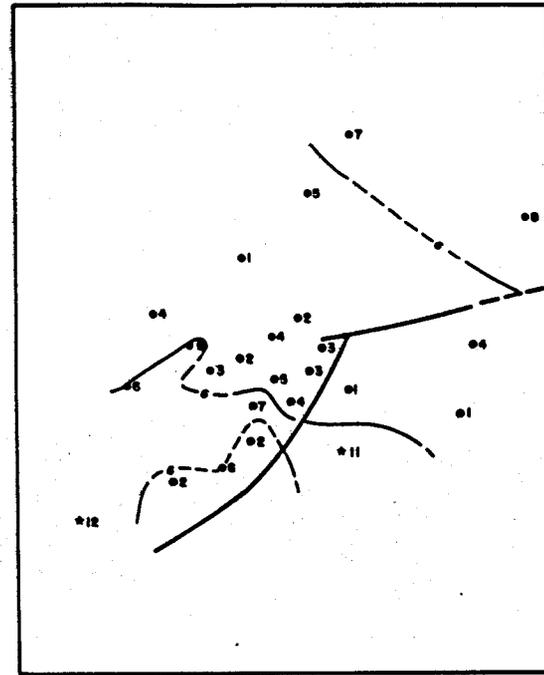
Figure 4. Mercury distribution in drill cuttings: (A) 0-100 feet
(B) 100-200 feet
(C) 200-300 feet
(D) 300-400 feet
(E) 400-500 feet
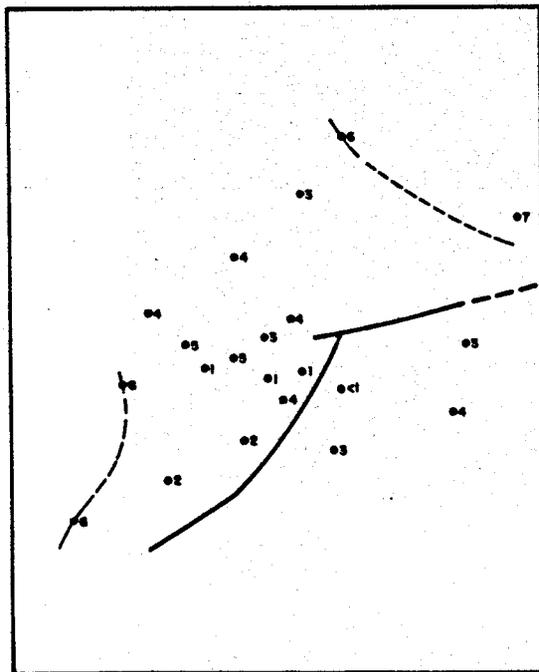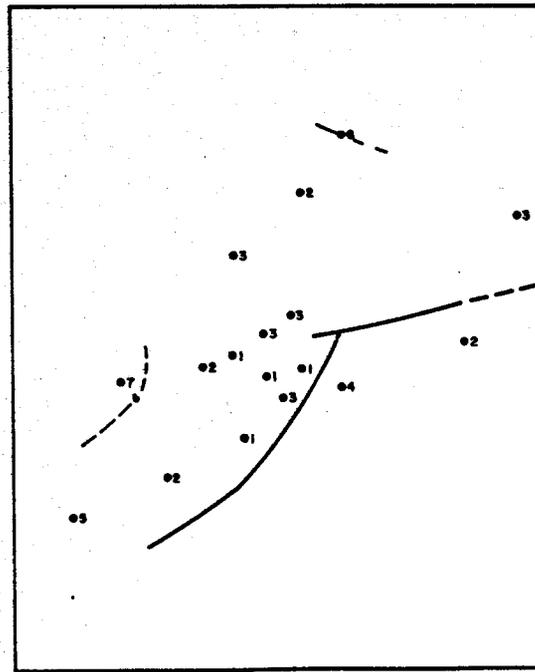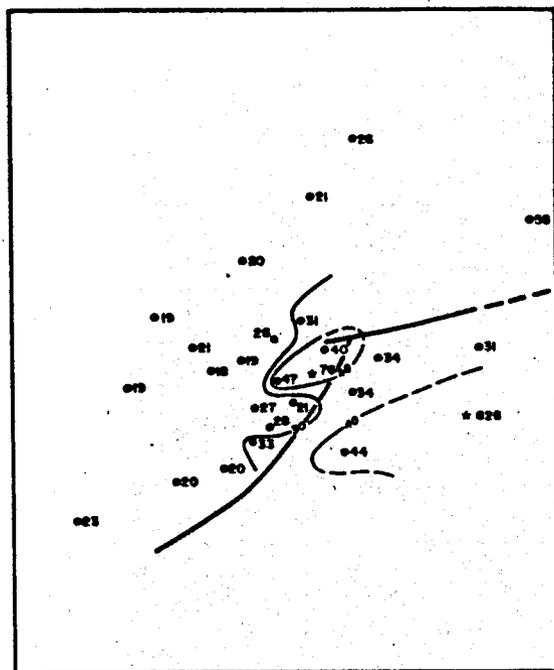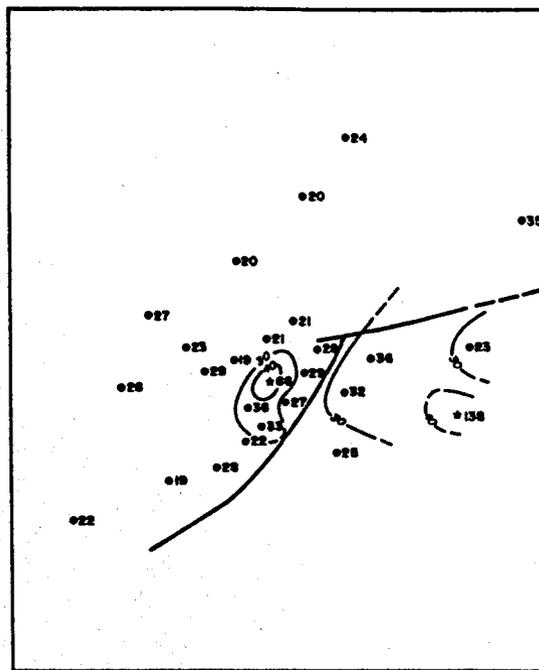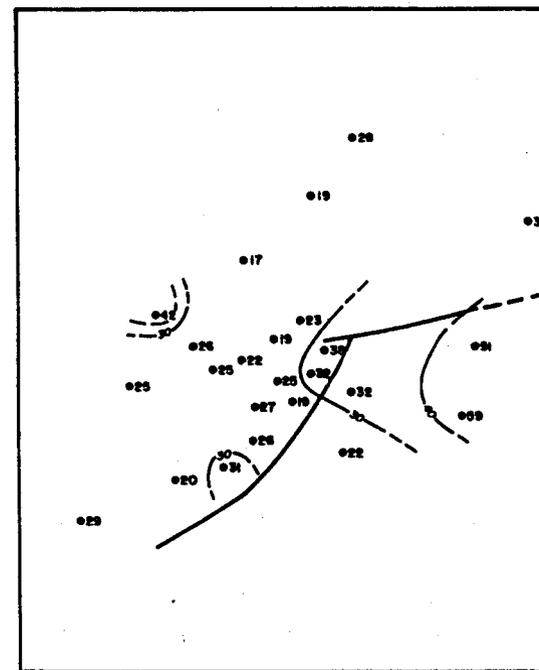Dark lines indicate the location of the Malpais Fault.

Figure 5. Arsenic distribution in drill cuttings: (A) 0-100 feet (B) 100-200 feet (C) 200-300 feet (D) 300-400 feet (E) 400-500 feet Dark lines indicate the location of the Malpais Fault.

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Figure 6. Lithium distribution in drill cuttings: (A) 0-100 feet (B) 100-200 feet (C) 200-300 feet (D) 300-400 feet (E) 400-500 feet Dark lines indicate the location of the Malpais Fault.
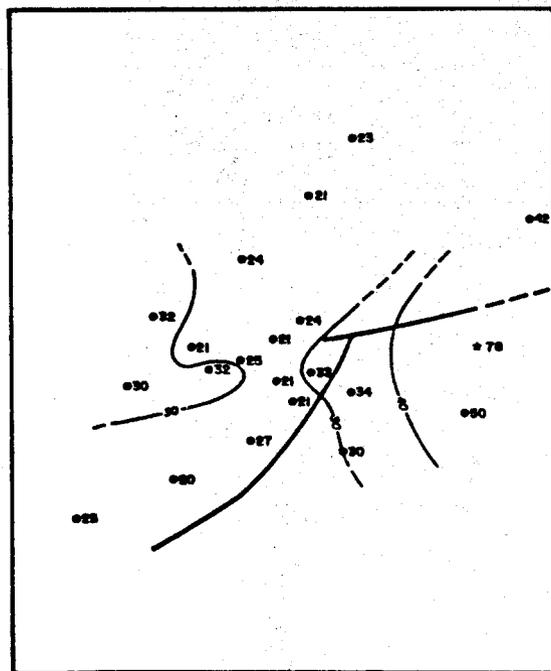
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Figure 7. Manganese distribution in
drill cuttings: (A) 0-100 feet
(B) 100-200 feet
(C) 200-300 feet
(D) 300-400 feet
(E) 400-500 feet
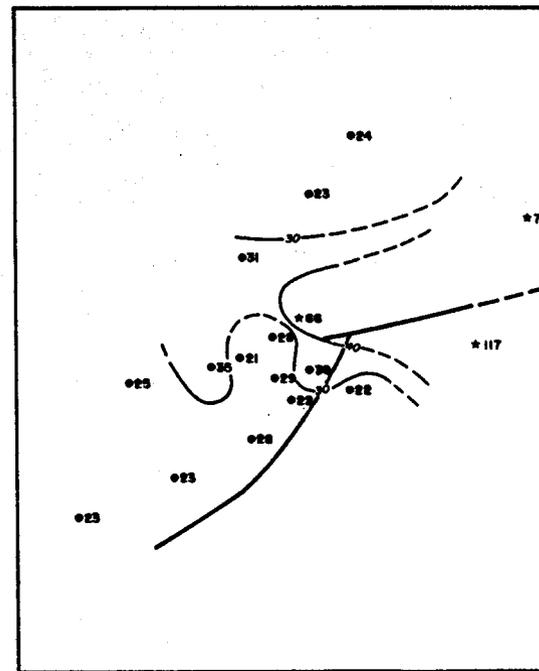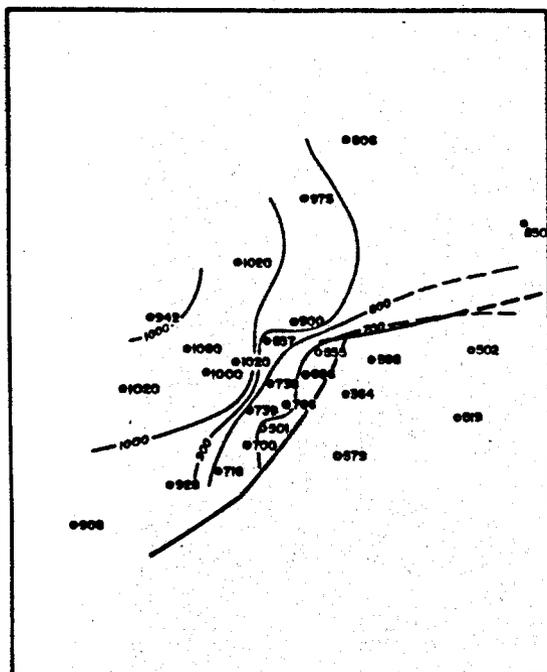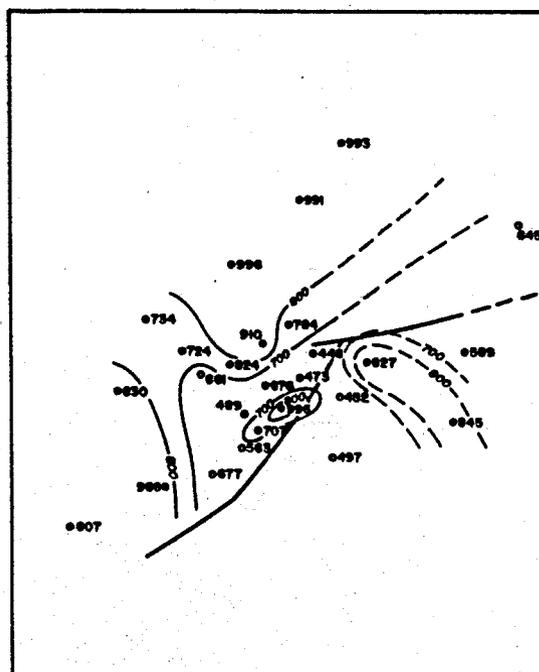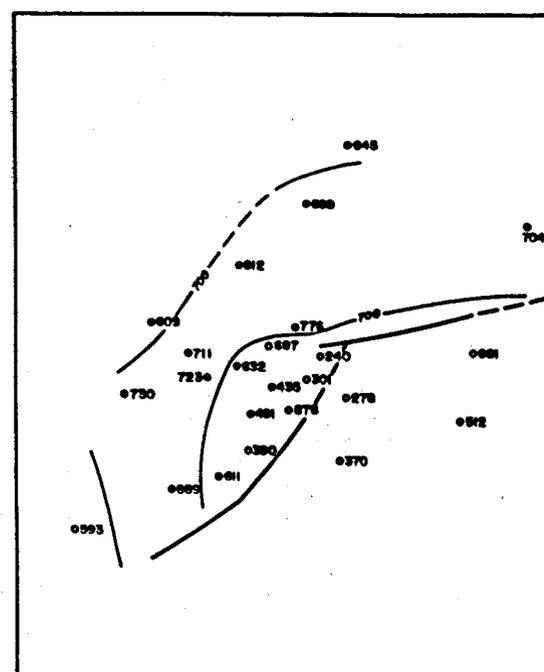Dark lines indicate the location
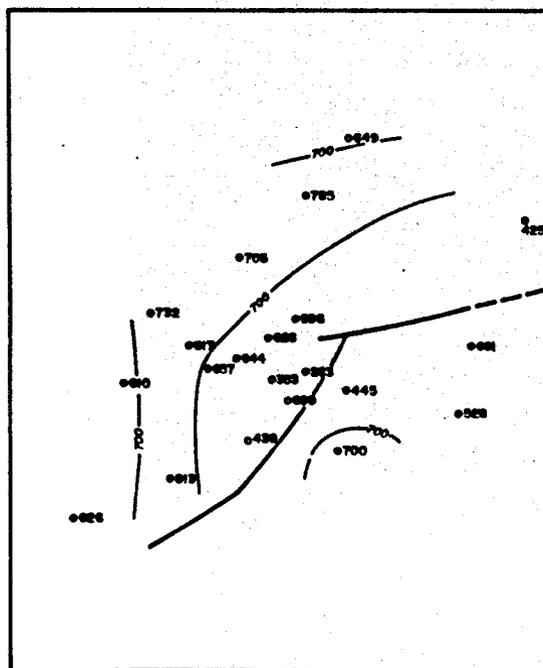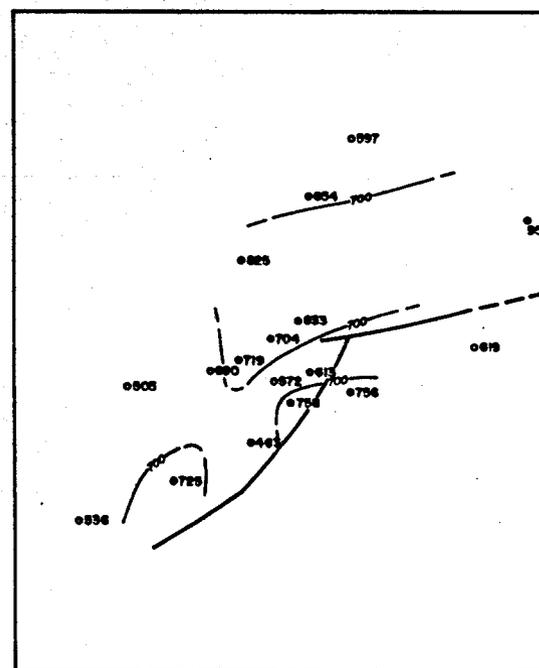of the Malpais Fault.

Statistically, Hg analytical values belong to two lognormal populations with a threshold value between them of 110 ppb. The anomalous values are restricted to drill holes 48 and 9 (Figure 4). Hole 35, located between these two, has concentrations consistently greater than the mean. The anomalous sample intervals have two common factors: they are located east of the presently active thermal area near the trace of the Dunphy Pass Fault zone and are composed primarily of tuffaceous sediments. The anomalous concentrations are apparently not associated spatially with the present geothermal system and are not laterally or vertically continous. Two interpretations are plausible. The Dunphy Pass Fault zone may represent a structure along which fluids have risen and migrated laterally through permeable tuffaceous sediments, a model consistent with the anomalous temperature gradient observed in hole 48 (E. Struhsacker, personal communication). Alternatively, the coincidence of anomalous Hg concentrations and tuffaceous horizons may be a consequence of primary enrichment of Hg in these rocks.

Arsenic concentrations are generally greater and its distribution spatially coherent in the upper sample level (Figure 5). Statistically, the analytical values constitute a single numerical population. Comparison with analyses of surface samples (Table 2) shows that these concentrations are significantly lower than in materials affected by the earlier alteration event. The laterally and vertically discontinuous distribution of higher values and the consistently low concentrations within the lower two levels imply that there has never been a pervasive flux of As-enriched thermal fluid through the area, but rather that fluid flow has apparently been restricted to discrete structures or permeable zones. The clustering of slightly higher As

concentrations at the shallowest level to the west of the sinter terrace is believed to be a consequence of surface or near-surface discharge of thermal fluids from discrete fluid channels followed by downslope movement of the cooling fluids within shallow aquifers. The possible contribution of mechanical or hydrologic dispersion of As from the older alteration, particularly within alluvial intervals, cannot be evaluated from the available data.

Lithium is an element that is characteristically enriched in thermal fluids (Brondi and others, 1973) and may form dispersion patterns in rocks affected by fluid interactions (Bamford and others, 1980; Christensen and others, 1980b). At Beowawe, Li forms two lognormal numerical populations with a threshold concentration value of 65 ppm. The distribution of Li in samples (Figure 6), like that of As and Hg, is not laterally or vertically continuous. Anomalously high values are located near the trace of the Dunphy Pass Fault zone and near Whirlwind Butte just west of the sinter terrace. As with the As values, there appears to be a coherent pattern only at the shallowest level (0-100') of sampling. Anomalous Li concentrations, however, continue to depth. The extremely high concentration of Li (626 ppm) occurring in the shallowest level of drill hole 48, is associated with unaltered Tertiary basalt and an overlying calcite-bearing tuffaceous lake deposit, suggesting the likelihood of lithologic control.

Statistically, Mn concentrations appear to form a single normal population with a mean of about 700 ppm. Contours of Mn concentrations (Figure 7), however, outline an area of Mn enrichment within cuttings samples

to the north and west of the Malpais escarpment, peripheral and downslope from the point of presently discharging Mn-bearing fluids. Generally, concentrations are greater near the surface than at depth. The geometry suggests that Mn has been enriched by surface or near-surface discharge and flow of fluid downslope away from the system.

The distributions of other elements do not seem to be related to geothermal redistributions. Some elements, particularly Ba, Sr, Na, K, Ca, Mg, Fe, Al, and Ti are clearly lithologically controlled. Copper appears to possess a normal numerical and spatial distribution except for anomalous concentrations in hole 9, within alluvium at the mouth of White Canyon. This area is downslope from exposures of relatively Cu-rich metasediments of the Valmy Formation. Similarly, unusually high Ba concentrations within alluvial sediments are undoubtedly related to clasts of Valmy-derived barite.

Conclusions

The trace element geochemistry of the Beowawe geothermal system, although not as strongly developed and diagnostic as at other areas (Christensen, 1980a; Christensen and others, 1980b), does provide insight into the geometry and chemical history of the Beowawe system.

The present thermal fluids at Beowawe are dilute in all components except SiO_2, suggesting that their residence time within the geothermal system has been short and chemical interaction with the reservoir rock minimal. Interaction between these dilute fluids and rocks within the system has resulted in weak geochemical signatures which are not clearly distinguishable from the normal chemical variability within the rocks. The absence of

stronger geochemical signatures in rocks associated with the present system suggests that the fluids have had a similar dilute chemistry for some time. The more pronounced chemical signature of the older alteration and intense veining localized near the mouth of White Canyon indicates a different fluid chemistry or different physical conditions.

The spatial distributions of elements commonly associated with geothermal systems, such as As, Li and Hg, are neither laterally nor vertically coherent but rather are marked by restricted point anomalies. This overall pattern suggests that there is not now, nor has there been in the past, pervasive movement of fluid throughout the sampled rocks. Isolated chemical concentrations probably represent the intersection of the drill holes with fracture zones or permeable horizons through which fluids have coursed. The coherent near-surface enrichment of As immediately to the west of the active system and the peripheral Mn enrichment downslope are consistent with a system in which fluids slightly enriched in Mn and As discharge from along the Malpais Fault and flow downslope within alluvium or permeable bedrock. As the fluids cool, As is deposited near the discharge point and Mn more distally. Mn may also be redistributed by supergene processes, being locally leached from rocks by warm discharging fluids, mobilized downslope, and deposited in cooler zones away from the active discharge area. Similar zoning of As and Mn is observed in soils at the Roosevelt Hot Springs thermal area, Utah. These chemical distributions suggest that the near-surface portion of the Beowawe system is controlled by a single-source fracture, the Malpais Fault or an intersection of faults near The Geysers, and that this portion of the thermal area has been affected by dilute fluids throughout its history.

Concentrations of Hg, As, and Li and anomalous temperature gradients along the trend of White Canyon suggest that this may be a zone of fluid leakage overlying a zone of thermal fluid convection. The chemical differences between samples from the White Canyon area and the samples near the present fluid discharge area, however, may indicate that the element enrichments are the consequence of interaction with chemically different fluids. If thermal fluids occur at depth along the Dunphy Pass Fault zone and the observed chemical anomalies are related to the present fluids, it is likely that the fractures controlling fluid flow are not connected with those of the Malpais Fault, and that two separate convection systems exist. More likely, the chemical signatures in the White Canyon area record the effects of water-rock interaction during an older hydrothermal event characterized by fluids much different from the present dilute waters. If so, the Dunphy Pass Fault zone may well represent a deep conduit to the Beowawe system, as proposed by Struhsacker and Smith (1980).

This geochemical model is based upon the known geochemistry of 26 gradient holes covering some 13 square kilometers and penetrating to a maximum depth of 150 meters. The observed geochemistry at this level places some limits upon the possible near-surface geometry and activity of the geothermal system but cannot unambiguously outline its dimensions. Continuing work will evaluate the chemistry of cuttings from the three deep drill holes within the system (Struhsacker, 1980) and may more precisely define the system.

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APPENDIX

SUMMARY OF GEOCHEMICAL DATA

Element	Minimum	Maximum	Mean	Standard Deviation
Na, ppm	5340	28700	24100	3520
K, ppm	14600	41600	27200	7320
Ca, ppm	10700	130000	27600	16300
Mg, ppm	1640	32200	6710	4790
Fe, ppm	13700	68000	50300	10100
Al, ppm	47900	80300	71100	4960
Ti, ppm	1810	8010	5440	1410
P, ppm	218	2020	1100	422
Sr, ppm	165	507	245	44
Ba, ppm	840	2420	1440	284
V, ppm	<150	214	--	--
Cr, ppm	<2	37	--	--
Mn, ppm	240	1080	688	186
Co, ppm	11	145	25	17
Ni, ppm	<5	17	--	--
Ca, ppm	5	24	10	4
Mo, ppm	<50	<50	<50	--
Pb, ppm	10	38	24	5
Zn, ppm	32	137	108	13
Cd, ppm	<5	<5	<5	--
Ag, ppm	<2	2.5	<2	--
Au, ppm	<4	<4	<4	--
As, ppm	<1	12	<4	--
Sb, ppm	<30	<30	<30	--
Bi, ppm	<100	<100	<100	--
U, ppm	<2000	<2000	<2000	--
Te, ppm	<50	<50	<50	--
Su, ppm	<5	8	<5	--
Li, ppm	17	626	36	58
Be, ppm	1.5	5.1	3.8	0.7
Zr, ppm	161	521	392	89
La, ppm	15	71	53	10
Ce, ppm	28	149	105	24
Th, ppm	<150	<150	<150	--
Hg, ppb	<5	550	<289	--

As determined colorimetrically, Hg by gold film detector, all other elements by ICPQ.
Si lost during digestion; W and B contaminated during sample preparation and analysis.