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TO: David Sussman

FM: Daniel L. Carrier DLC by D.S.

RE: HYDROTHERMAL ALTERATION AND WELL LITHOLOGIES FOR GLASS MOUNTAIN WELLS: GMF68-8, GMF31-17 AND GMF 17A-6

SUMMARY

Petrologic, geochemical and temperature data from three exploratory wells indicate a well-developed geothermal system exists in the Glass Mountain area of the Medicine Lake volcano. Wells GMF68-8, GMF31-17 and GMF17A-6 penetrate a sequence of interlayered volcanic, contact metamorphic, and granodioritic intrusive rocks. The interlayered volcanics are the principal reservoir rocks for the Glass Mountain system. Alteration zoning is well-developed in all the wells and generally follows a sequence from zeolite-smectite to argillic and finally to propylitic with increasing depth. Strong argillic alteration and boiling temperatures observed in GMF68-8 and GMF31-17 suggest the upwelling of geothermal fluids, and correlate well with low-resistivity anomalies observed in time-domain electromagnetic and magnetotelluric data. The occurrence of only weak to moderate argillic alteration in GMF17A-6 is consistent with temperature data which indicate the well was not drilled in an area of upwelling and boiling. Strong propylitic alteration occurs in each well, and is primarily found along subvertical fractures and the brecciated tops and bottoms of lava flows. The association of fractures and lithologic boundaries with strong propylitic alteration suggests that these features are the preferred pathways for fluid flow.

Mineralogical data suggest that multiple hydrothermal systems have existed in the Glass Mountain area. Caution is therefore needed in using the first occurrence of epidote to identify the top of the reservoir. In addition to epidote, other significant hydrothermal minerals present include actinolite, wairakite, and clinopyroxene. Smectite and chlorite are the most common hydrothermal clays observed. Smectite occurs in trace amounts at 556°F in GMF68-8, roughly 150°F in excess of its equilibrium temperature stability range, suggesting that low matrix permeability exists in portions of the reservoir.

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INTRODUCTION

The Glass Mountain Federal Unit is formed from Unocal and Freeport-McMoran geothermal leases located at the summit of Medicine Lake volcano. Three deep exploratory wells have been completed in the Glass Mountain Federal Unit since 1984: GMF68-8, GMF31-17 and GMF17A-6 (Figure 1). This report discusses the general lithology and hydrothermal mineralogy of these wells. The objective is to describe the relationships existing at depth among rock-type, alteration, subsurface temperature, and permeability.

Mineralogy of the deep wells will be presented in two reports. This report discusses hydrothermal alteration and lithologic data. A subsequent report will discuss fluid inclusion data obtained on hydrothermal minerals. The ultimate goal of these studies is to develop a three-dimensional model of the Glass Mountain geothermal system. These reports follow an earlier study by Carrier (1987) which dealt with hydrothermal alteration and fluid inclusion data from Glass Mountain temperature boreholes.

GEOLOGIC SETTING

Medicine Lake is a Quaternary shield volcano situated in the southern part of the Cascade Range about 35 miles (56 km) east-northeast of Mount Shasta. Lavas attributed to the volcano are found over a 780 mi^2 (2000 km^2) area, and have an estimated volume of 145 mi^3 (600 km^3) (Donnelly-Nolan, 1988). Although Holocene volcanic rocks are principally bimodal basalt and rhyolite, the upper slopes of the volcano are dominated by andesite lavas of Pleistocene age. Silicic lavas account for 5 to 10% of the surface lavas on the volcano (Figure 1). The silicic lavas occur in four age groups based

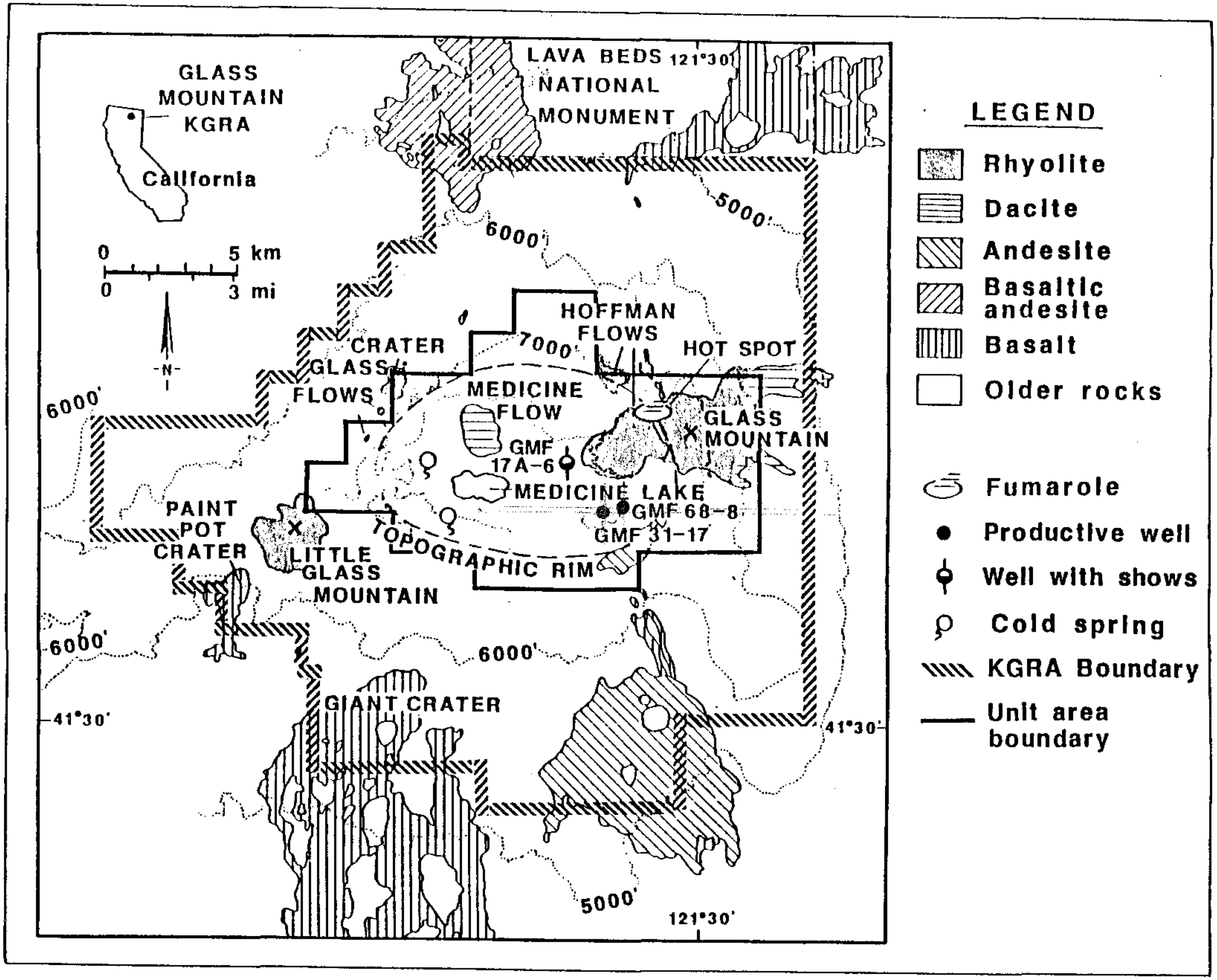

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Figure 1: Geologic map of Medicine Lake volcano showing lavas that are less than 11,000 years old (Donnelly - Nolan, 1988) and the Glass Mountain KGRA.

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on K-Ar age dates: 1.25 to 0.95 m.y., 0.61 to 0.43 m.y., 0.33 to 0.24 m.y., and 0.1 m.y. to about 1,000 years (Mertzman, 1982; Mertzman, 1983).

Several small volcanic centers of basalt, andesite, dacite and rhyolite coalesce to form a constructional rim on the summit of Medicine Lake volcano, enclosing a 4 x 6 mile oval depression. The topographic depression has been called a caldera by several authors (Anderson, 1941; Heiken, 1978; Donnelly-Nolan, 1988). However, there is no evidence on the surface for ring faults or massive tuffs, and no evidence for massive tuffs in the subsurface (Carrier, 1987).

Five silicic eruptive centers, all less than 2,000 years in age (Donnelly-Nolan, personal communication), are located in a 4.5 x 12 mile band across the upper flanks, topographic rim and the summit depression of Medicine Lake volcano (Figure 1). Glass Mountain is the youngest of these silicic centers. The three deep wells were drilled in the topographic depression, and each is located less than 3 miles from the Glass Mountain dome.

No basement rocks are exposed in the Glass Mountain area. Granodioritic xenoliths have been found in the young silicic lavas shown in Figure 1. Hausback (1984) suggested the xenoliths were fragments of a Sierran plutonic basement; however textures in the granodiorites indicate they are subvolcanic equivalents of Glass Mountain lavas. The oldest rocks exposed in the vicinity of the volcano are Tertiary basalt and andesitic pyroclastic rocks belonging to the Cedarville Series (Anderson, 1941). These are exposed in several small fault-block mountains north and east of the volcano. Overlying the Cedarville Series are high-alumina olivine basalts of Miocene to Pleistocene age that have been collectively lumped together into a group called the Warner Basalts. Xenoliths of high-alumina basalts have also been observed in the young silicic lavas on the Medicine Lake volcano.

METHODS AND DATA

Data presented in this report have been collected through several methods of study. Drill cutting samples were collected at 10 or 20-foot intervals, and spot cores were taken from depths of 6580 to 6603 feet and 8399 to 8417 feet in GMF68-8 and 8416 to 8436 feet in GMF31-17. The samples were logged using a binocular microscope. Representative samples were then selected for further analysis by thin section, x-ray diffraction (XRD) and whole-rock chemistry. The XRD analyses were done at the University of Utah Research Institute by Jeff Hulen and Susan Lutz. The basic data are reported in Appendix 1. Whole-rock chemical analyses data were done by Chemex Labs, in Sparks, Nevada. The data are presented in Appendix 2. In addition to the sample analyses, each well has been at least partially logged with a gamma ray tool. Dresser Atlas, Schlumberger and Welex logging companies have run logs over different intervals of the wells.

All well depths mentioned in this report are measured depths unless stated otherwise. Elevations, as determined by using true vertical depths, are displayed in the cross-sections. The surface elevation of GMF68-8 is 6991 feet, GMF31-17 is 7000 feet, and GMF17A-6 is 6733 feet. GMF68-8 is drilled as a vertical hole to 6603 feet, and as a directional hole to the measured total depth of 8417 feet and true vertical depth of 8394 feet. GMF31-17 is drilled as a vertical hole to about 2010 feet, and as a directional hole deviated to the measured total depth of 8787 feet and true vertical depth of 8518 feet. GMF17A-6 is drilled as a vertical hole to a measured total depth of 9620 feet and a true vertical depth of 9605 feet.

LITHOLOGY

Rock types and thicknesses have been determined for each well by integrating data obtained from drill cuttings, spot core samples, interpretation of gamma ray logs, and whole-rock chemical analyses. Generalized lithologic logs are presented for the wells in Figure 2. Rocks penetrated by the wells are assigned to one of three groups: interlayered volcanics, contact metamorphics, and granodioritic intrusives. The metamorphic rocks and the granodioritic intrusive rocks are found only in GMF31-17 and GMF17A-6.

The majority of the rocks drilled are interlayered volcanics. The volcanic group generally consists of calc-alkalic to slightly alkalic mafic, intermediate, and silicic lavas. Thinly bedded lithic tuffs, scorias, volcaniclastics, and sandstones occur in minor amounts. Mafic lavas are present in the greatest abundance and are dominated by clinopyroxene-bearing amygdaloidal basalts and basaltic andesites. Although the mafic rocks in general vary from aphyric to porphyritic, they become coarser grained at about 4600 feet measured depth (2500 feet in elevation), and contain microdiabase textures in trace to major amounts. These coarser grained mafic rocks possibly mark the base of the lavas related to the Medicine Lake volcano. That places the base of the volcano in the Glass Mountain area at an elevation which is 1500 feet lower than is evident by the flank exposures of Medicine Lake lavas. Rhyolite to dacite silicic lavas are second to the mafic lavas in abundance. Silicic lavas are more abundant in the wells than on the surface, accounting for 27% of the rocks drilled in the upper 4600 feet of the wells, and 20% of the volcanic rocks drilled below that depth. These rocks are typically microcrystalline to fine-crystalline, and are almost entirely composed of quartz, plagioclase, and potassium feldspar. Granophyric and spherulitic textures are common and well-developed. Micropegmatitic and axiolitic textures are also found in many of the silicic rocks. Dacitic rocks at 1750 to

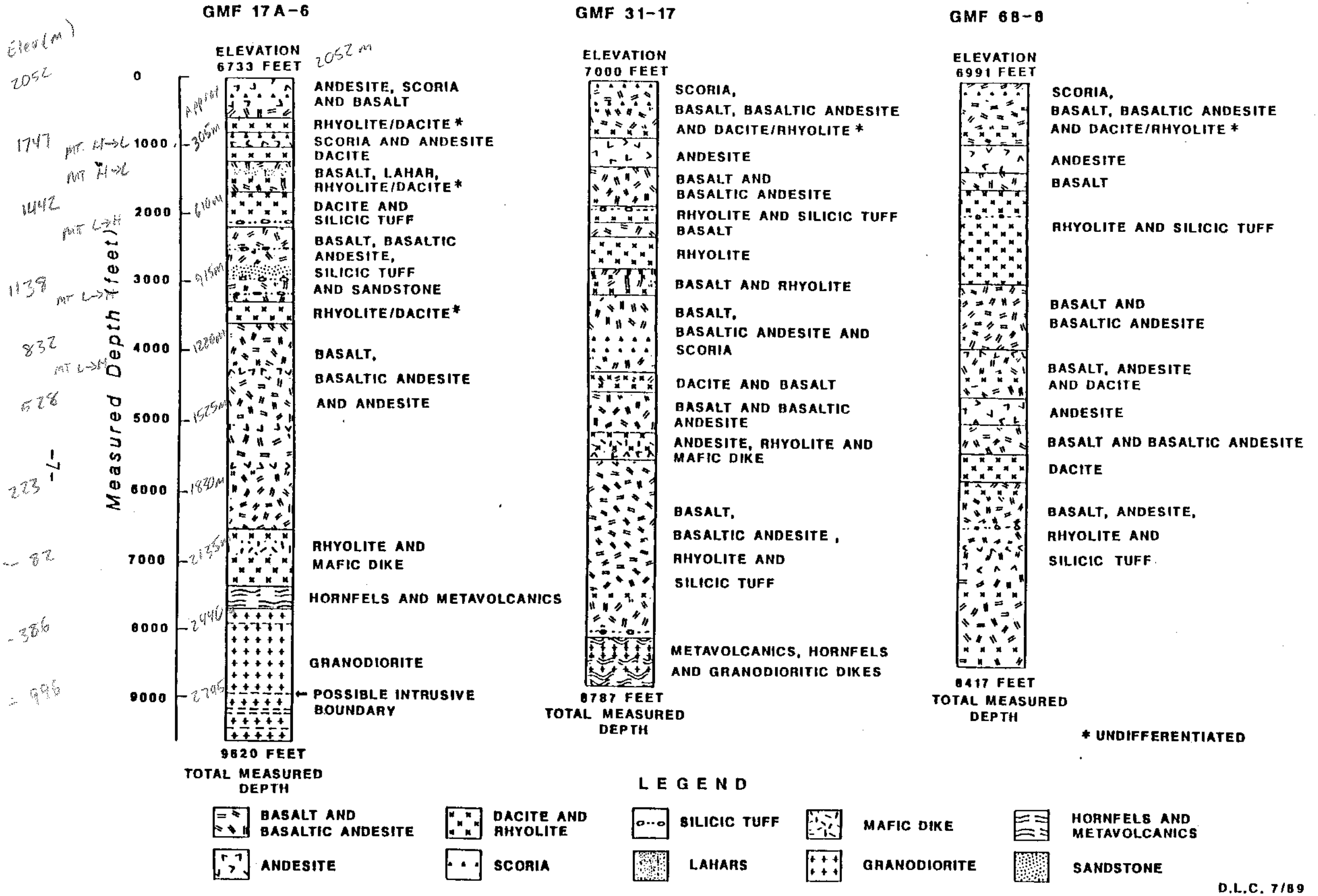

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Figure 2: Generalized lithologic profiles of GMF17A-6, GMF31-17, and GMF68-8.

2160 feet in GMF17A-6 contain fine-crystalline granodioritic xenoliths. Although andesite and trachyandesite lavas are the most common lavas exposed on the volcano (Hausback, 1984), they are the rarest of the lavas observed in the deep wells. The andesites drilled are orthopyroxene or clinopyroxene bearing, are commonly flow banded, and contain aphyric to porphyritic textures.

Contact metamorphic rocks are found at 7345 to 7690 feet in GMF17A-6, and at 8060 to 8787 feet in GMF31-17. The metamorphic rocks are in general meta-volcanics and hornfels. The hornfels, as sampled in GMF17A-6, is essentially fine-crystalline quartz-plagioclase-biotite rock containing minor hornblende and clinopyroxene. Near the base of the GMF17A-6 sequence at 7680 feet, the metamorphic rocks are moderate-to well-foliated, and appear to be intermediate between a hornfels and a phyllite or a fine-crystalline schist. Contact metamorphic rocks in GMF31-17 consist of meta-andesites, meta-dacites, and hornfels, all of which are intercalated with granodioritic dikes or sills. The meta-andesite and meta-dacite rocks have poorly defined textures, and the hornfels rocks contain well-developed granoblastic textures.

Granodiorites occur as shallow plutonic rocks at 7690 to 9620 feet in GMF17A-6 and as multiple thin dikes or sills at 8110 to 8787 feet in GMF31-17. The granodioritic rocks are fine-crystalline and contain biotite and hornblende. Exsolution textures are common in the potassium-rich portions of the granodiorites. The granodiorites are similar in composition and texture to the xenoliths of plutonic rocks contained in surface exposures of the young silicic rocks. Abrupt variations are observed in the percentages of potassium feldspar and mafic minerals in the granodiorite in GMF17A-6, and are possibly due to the drilling of multiple intrusive bodies. The more mafic zones have compositions that approach quartz diorite. The rapid change from volcanics to meta-volcanics to fine-crystalline granodiorite without intervening erosional events indicates that the granitic rocks have been intruded into the older Tertiary volcanics. Thus the granodiorite rocks probably represent intrusive phases related to late Tertiary or Quaternary silicic lavas and not Sierran plutonic rocks. The thickest granodioritic dike in GMF31-17 has an apparent measured thickness of 280 feet.

ALTERATION MINERALOGY

Alteration minerals present in the well samples are generally the same as those observed in other well-documented geothermal areas. The types and distribution of the minerals are shown as a function of depth in Figures 3, 4, and 5. Temperature, rock type, and permeability are the three main factors controlling the style and intensity of alteration in the Glass Mountain wells. A diagram summarizing the distribution of selected

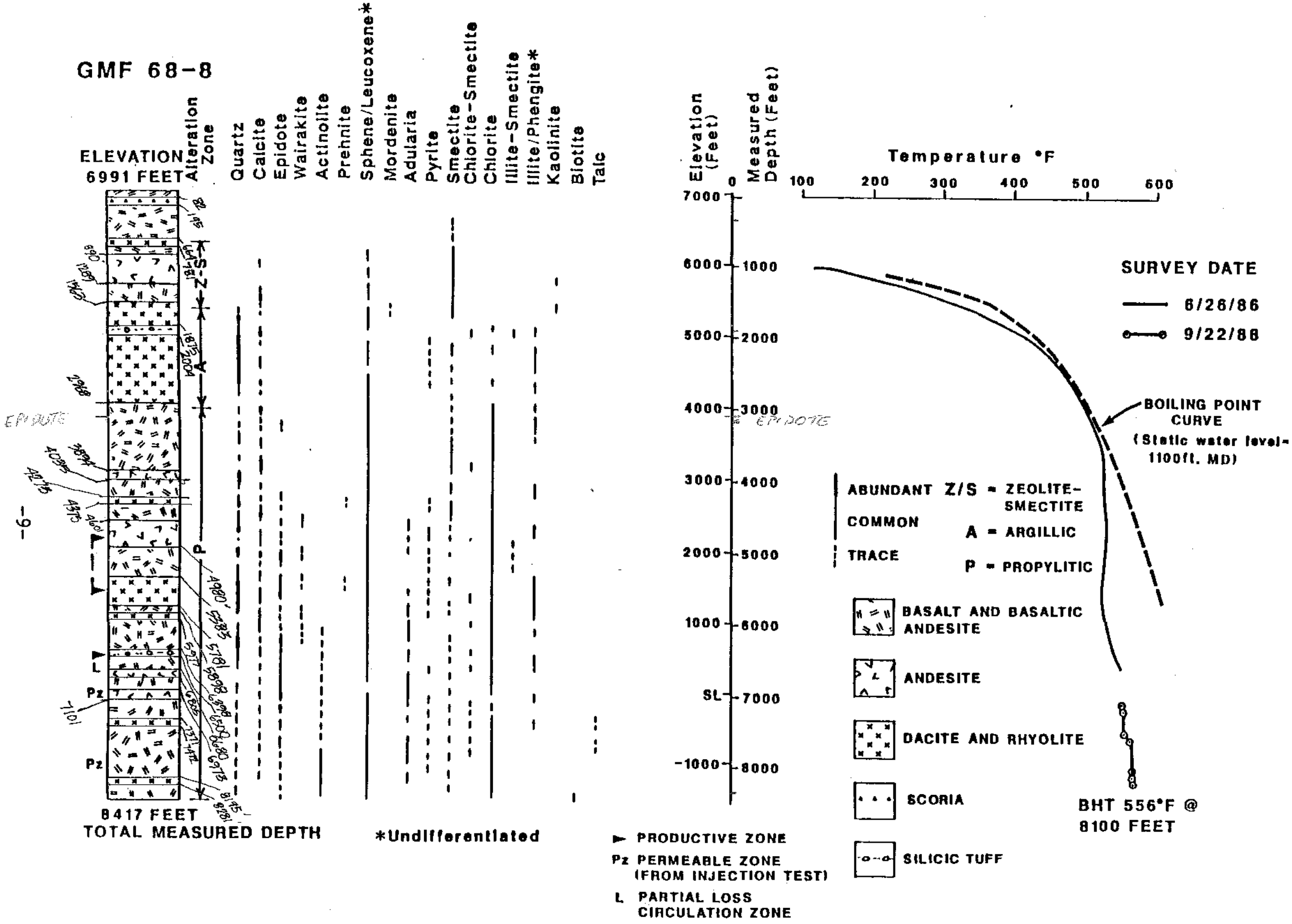

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Figure 3: Lithology, alteration zones, mineralogy, and downhole temperatures for GMF68-8. The 6/26/86 temperature survey was taken after the well was static for 311 days. The 9/22/88 temperature survey was taken a[illegible]r the well was deepened and four days after a 32-hour flow[illegible]st.

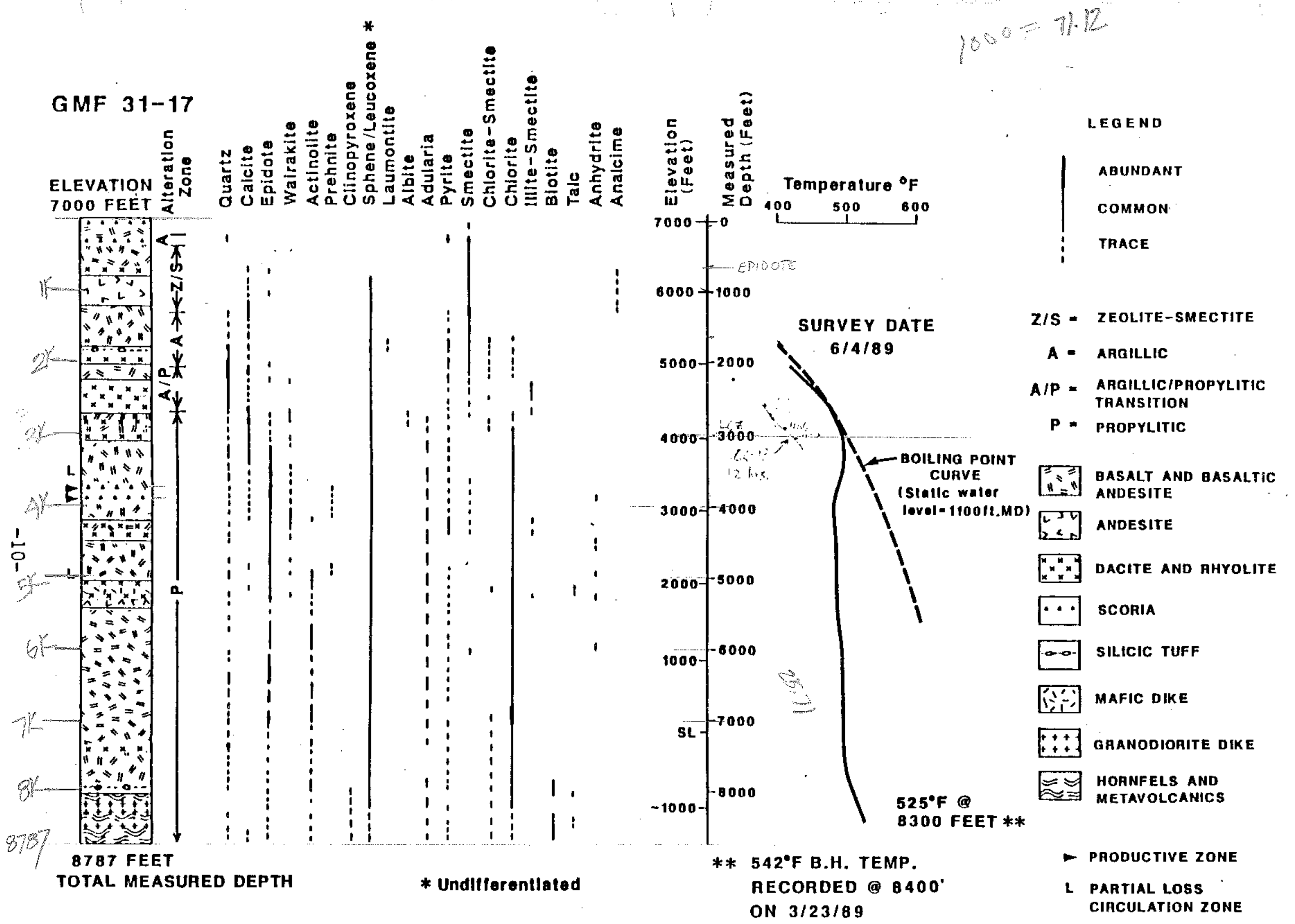

Figure 4: Lithology, alteration zones and mineralogy, and downhole temperatures for GMF31-17. The 6/4/89 survey of GMF31-17 was taken after the well had been static for 247 days.

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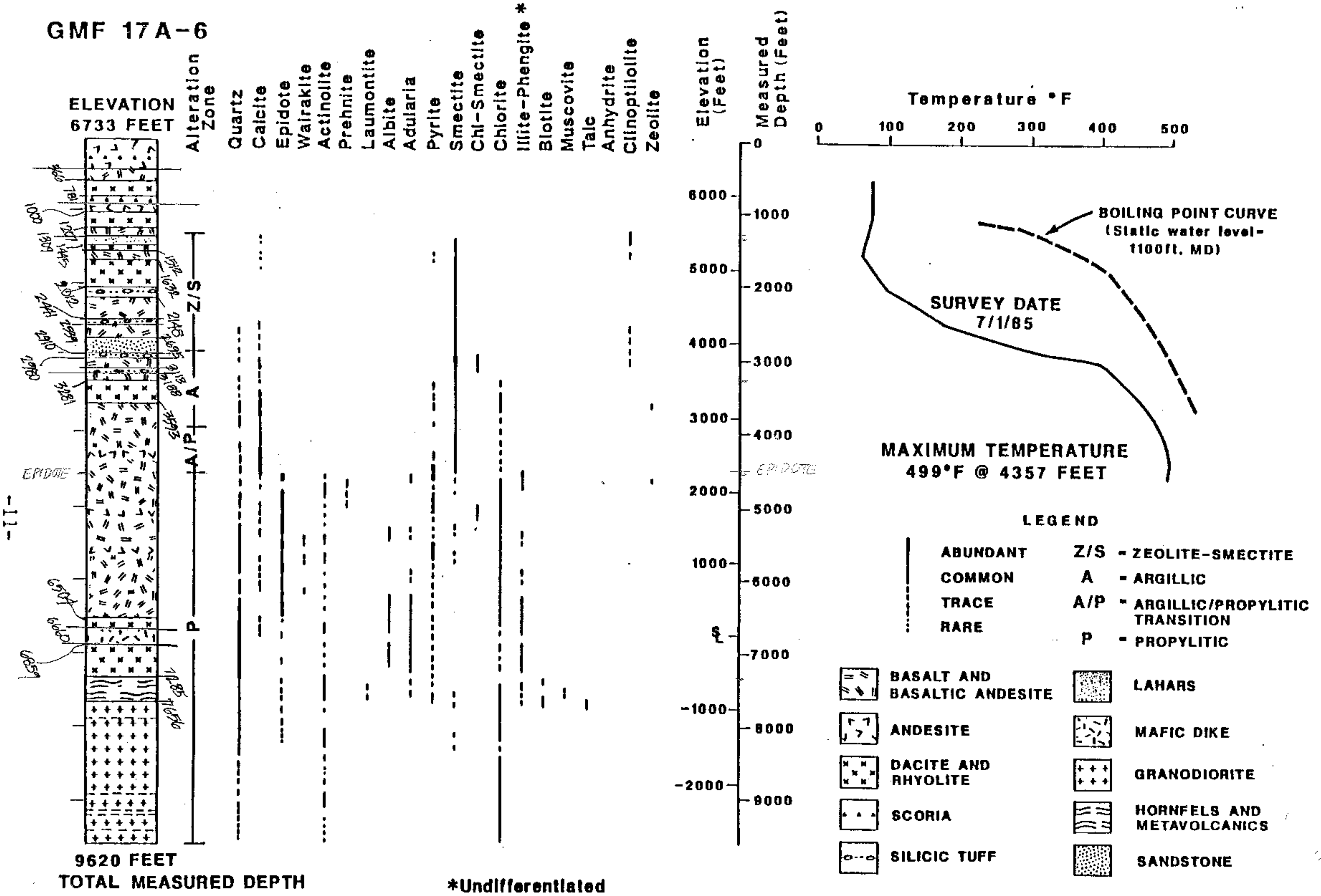

Figure 5: Lithology, alteration zones and mineralogy, and downhole temperatures for GMF17A-6. No stabilized temperature data are available for depths greater than 4550 feet.

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hydrothermal minerals with temperature is shown in Figure 6. Although the influence of rock type on an alteration assemblage is greatest at lower temperatures, it becomes an almost insignificant factor when formation temperatures exceed 500°F as in GMF68-8 (Figures 3 and 6). Permeability controls the intensity of the alteration, and determines the degree to which equilibrium between rocks and reservoir fluids is approached.

Most secondary minerals in the Glass Mountain samples are readily assigned to one of seven hydrothermal mineral groups: silica, carbonate, calcium silicate, phyllosilicate, non-calcium silicate zeolite, feldspar, and oxide-sulfate-sulfide. Members of each group and their mode of occurrence are shown in Table 1. Two of the most diagnostic hydrothermal mineral groups are calcium silicates and phyllosilicates, and they are discussed in further detail below.

Calcium Silicates

The calcium silicate minerals observed include epidote, actinolite, prehnite, clinopyroxene, sphene, and the zeolites wairakite, laumontite, and mordenite. Epidote and actinolite are the most common calcium silicate minerals, and wairakite is the most common zeolite. A cross-section depicting the distribution of epidote, actinolite and wairakite in the three wells is shown in Figure 7. Prehnite and hydrothermal clinopyroxene are found in the wells, but are rare. Sphene is problematic since the mineral can occur as both a primary and an alteration mineral. In addition, the XRD patterns of sphene and leucoxene, which is an iron-titanium-oxide alteration product of ilmenite, are difficult to distinguish.

Epidote is the most important calcium silicate for two reasons: its occurrence in active geothermal fields is frequently associated with the top of the reservoir, and it is easily distinguishable with a binocular microscope. Epidote is first observed in GMF68-8 and GMF17A-6 at temperatures exceeding 495°F, which is higher than the 460°F onset for epidote in several other fields (Brown, 1978). However, hydrothermal epidote is also observed to exist in an equilibrium assemblage with other alteration minerals at temperatures as low as 430°F in GMF31-17. Epidote occurs as open space fillings in fractures and vugs and as a replacement of primary plagioclase. Epidote becomes the dominant hydrothermal calcium silicate at 2740 feet in GMF31-17, 4120 feet in GMF68-8, and 4520 feet in GMF17A-6. The mineral is most abundant in GMF31-17, where XRD data show concentrations as great as 26 weight percent of the rock at 3760 to 3900 feet and 5230 to 5240 feet, and 23 weight percent of the rock at 5780 to 5840 feet. Anomalous traces of hydrothermal epidote were identified in lavas of GMF31-17 at 800 and 1100 feet in a lower-temperature assemblage consisting of zeolites and smectite clay. The epidote is not in equilibrium with the zeolite-smectite assemblage.

TABLE 1 Hydrothermal mineral groups and their mode of occurrence as observed in Glass Mountain Wells GMF68-8, GMF31-17 and GMF17A-6

Mineral Group	Mode of Occurrence veins & vugs	 replacement	Associated Veinlet Minerals	Primary Minerals Replaced	Comments
1. SILICA					
Quartz (QTZ)	X		CAL, EP, ACT, WAIR, PREH, SPH, CHL, ILL, PHG, BTE, KF, OLIG, PY, MAG, HEM, ANH		most common hydrothermal mineral
Cristobalite (CRIS)		X		(glass)	devitrification product
Chalcedony (CHAL)	X		CHL, PHG		rare in occurrence
2. CARBONATE					
Calcite (CAL)	X	X	QTZ, EP, WAIR, CHL PHG, PLAG, HEM		replace vein EP & WAIR at 2840/60 ft. in GMF31-17
Aragonite (ARAG)	X	X			replaces secondary cristobalite, usually in vugs
3. CALCIUM SILICATE					
Epidote (EP)	X	X	QTZ, CAL, ACT, WAIR, PREH, CHL, PGH, BTE, AB, KF, ANH, HEM	plagioclase	includes clinozoisite
Actinolite (ACT)	X	X	QTZ, EP, PREH, SPH, CHL, BTE, TLC, KF, MAG	pyroxene, hornblende	Fe content increases with depth
Wairakite (WAIR)	X	X	QTZ, EP, CAL, CHL, AB, KF	plagioclase	zeolite
Prehnite (PREH)	X		QTZ, EP, ACT, CHL, PGH, KF, ANH, HEM		relatively rare in G.M. rocks
Clinopyroxene (CPX)	X		QTZ, OLIG		also occurs as a contact metamorphic mineral
Sphene (SPH)	X		QTZ, EP, ACT, KF, MAG		also occurs as a primary mineral
Laumontite (LAU)	X				zeolite
Mordenite (MOR)	X				zeolite

TABLE 1 Continued

Mineral Group	Mode of Occurrence		Associated Veinlet Minerals	Primary Minerals Replaced	Comments
	veins & vugs	replacement			
4. PHYLLOSILICATE					
Smectite (SM)	X	X	ANAL, PY		most common low-temperature clay
Kaolinite (KAO)	X				
Chlorite (CHL)	X	X	QTZ, CHAL, CAL, EP, WAIR, PREH, ILL, PHG, HEM, LEU	pyroxene, amphibole, biotite	most common high-temperature clay
Illite/Phengite (ILL/PHG)	X	X	QTZ, CHAL, CAL, EP, WAIR, CHL, PY, HEM		differentiated in thin section but not in XRD
Chlorite-Smectite (mixed-layer) (C-S)	X	X			chlorite content increases with temperature
Illite-Smectite (I-S)	X	X			illite content increases with temperature
Biotite (BTE)	X	X	QTZ, ACT, TLC	amphibole	
Muscovite (MUS)	X	X		feldspars	
Talc (TLC)	X		ACT, BTE		
5. NON-CALCIUM SILICATE ZEOLITE					
Analcime (ANAL)	X		SM		low-temperature zeolite
Clinoptilolite (CLIN)	X				low-temperature zeolite
6. FELDSPAR					
Albite (AB)	X	X	QTZ, WAIR, KF	plagioclase	
Oligioclase (OLIG)	X		QTZ, CPX		gives way to anorthoclase
Adularia (KF)	X	X	QTZ, EP, ACT, WAIR, PREH, SPH, CHL, AB, MAG, LEU	plagioclase	

TABLE 1 Continued

Mineral Group	Mode of Occurrence		Associated Veinlet Minerals	Primary Minerals Replaced	Comments
	veins & vugs	replacement			
7. OXIDE-SULFATE-SULFIDE					
Pyrite (PY)	X		QTZ, EP, CHL, SM, ILL, KF, LEU		
Anhydrite (ANH)	X		QTZ, EP, PREH		
Magnetite (MAG)	X		QTZ, EP, ACT, SPH, KF		also a common primary mineral
Hematite (HEM)	X		QTZ, CAL, CHL		also a weathering product
Geothite (GEO)	X	X	HEM	primary magnetite	
Leucoxene (LEU)	X		QTZ, EP, WAIR, CHL, KF, PY		indistinguishable from sphene in XRD

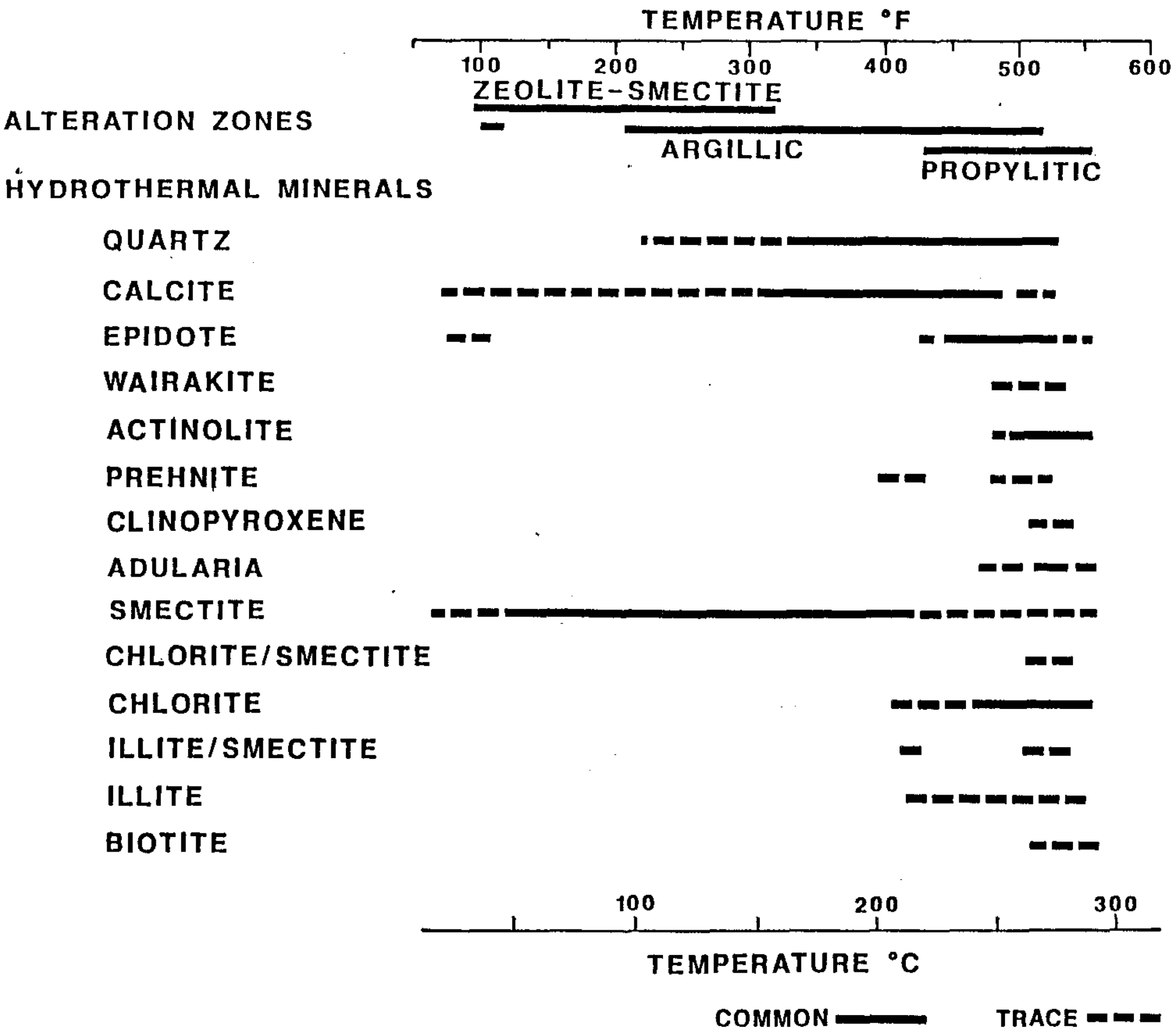

Figure 6: Temperature ranges for the occurrence of hydrothermal minerals and alteration zones in Glass Mountain deep wells. No temperature data are available for depths greater than 4550 feet in GMF17A-6.

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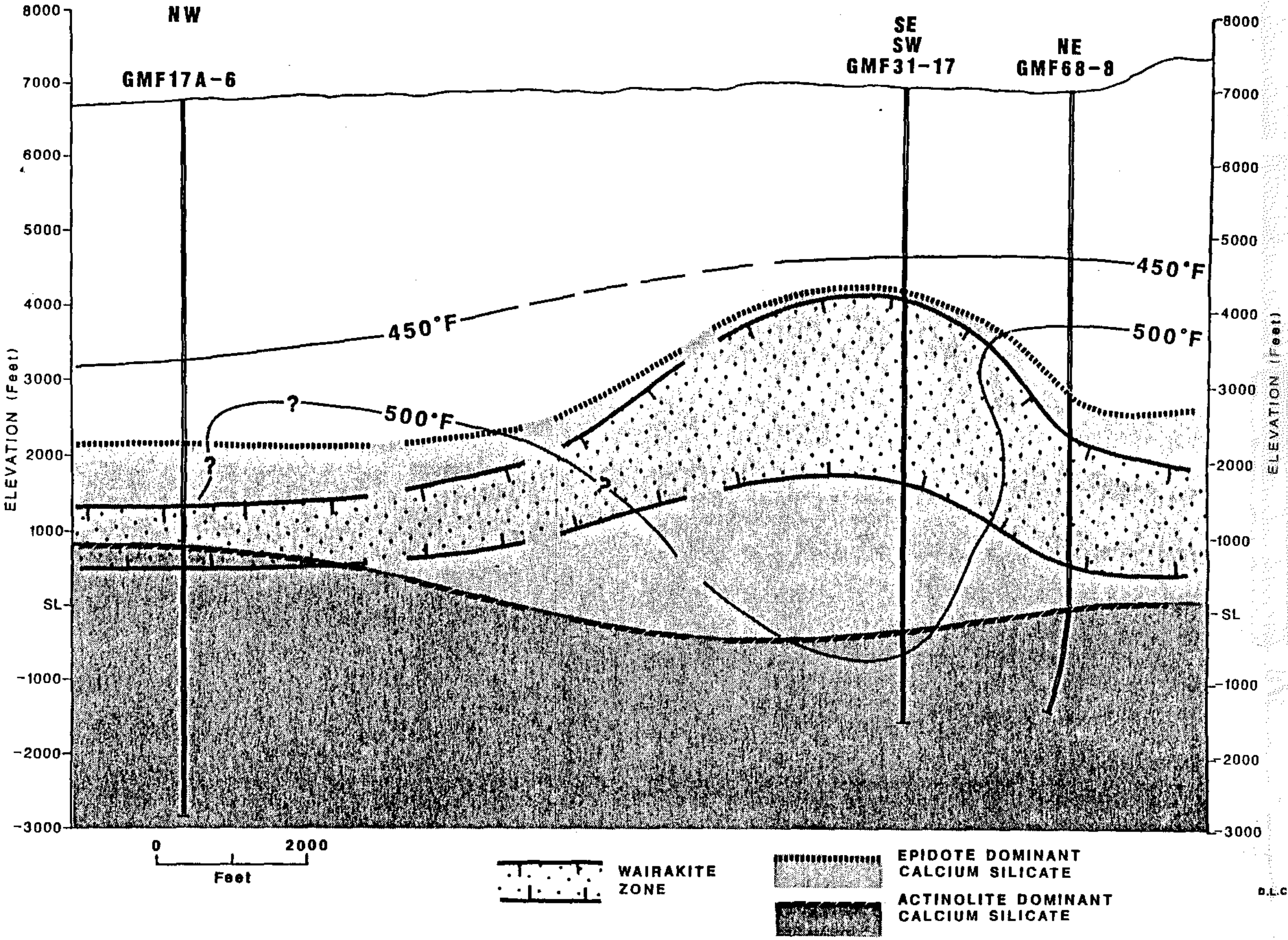

Figure 7: Cross-section showing the distribution of calcium silicate minerals epidote, actinolite and wairakite and subsurface temperatures as observe in Glass Mountain deep wells.

Actinolite is the second most common hydrothermal calcium silicate mineral observed in the wells, and is observed at temperatures greater than 480°F. The mineral first occurs at depths of 4220 feet in GMF31-17, 6400 feet in GMF68-8, and 4620 feet in GMF17A-6. It occurs as an alteration product of pyroxene and hornblende, and in veins commonly containing quartz, adularia and epidote. Actinolite replaces epidote as the dominant calcium silicate at depths below 7460 in GMF31-17, 6940 feet in GMF68-8, and 5950 feet in GMF17A-6. Below 8030 feet in GMF31-17, actinolite is also observed in veins containing talc and biotite (Table 1).

The calcium silicate zeolite, wairakite, is observed only at depths between 2800 and 6400 feet and at temperatures between 479 and 535°F. The mineral occurs in veins with quartz, epidote, adularia, and chlorite, and as an alteration product of plagioclase. As much as seven weight-percent of wairakite is observed at 2840 to 2860 feet in GMF31-17; however calcite is replacing both wairakite and epidote at this depth. The zeolite is least common in GMF17A-6, where it has only a spotty occurrence at 5400 to 6200 feet.

Most of the secondary clinopyroxene observed in GMF31-17 and GMF17A-6 formed as contact metamorphic minerals. Hydrothermal clinopyroxene does occur as a vein mineral in association with quartz and oligoclase at 8090 feet and 8421 feet in GMF31-17. It is uncertain whether the veins formed as part of a hydrothermal event closely following the metamorphic event, or as part of the present hydrothermal system. The veins of clinopyroxene in GMF31-17 are found at present-day temperatures as low as 515°F. Reported occurrences of clinopyroxene in other active geothermal systems are at temperatures in excess of 572°F (Bird, and others, 1984).

Phyllosilicates

The phyllosilicate group of alteration minerals consists of micas, clays, and talc. Hydrothermal micas observed in the wells include both biotite and rare muscovite. The clay minerals include smectite, chlorite, illite, phengite, kaolinite and mixed-layer chlorite-smectite and illite-smectite. Illite and phengite are both potassium-bearing clays that have similar x-ray diffraction patterns and have not been differentiated in this study. Illite and biotite also have similar x-ray diffraction patterns, and have been distinguished by using thin section analysis.

The hydrothermal clays are hydrous minerals and their formation is temperature-dependent. Temperature stability ranges for clays and other phyllosilicates are shown in Table 2. Clay minerals in the wells (Figure 6) occur at temperatures generally consistent with their stability ranges. The exception is smectite, which is observed at temperatures as

TABLE 2 Temperatures of occurrence, reported formation temperatures, and temperature stability ranges for selected hydrothermal phyllosilicate minerals

HYDROTHERMAL PHYLLOSILICATE MINERALS	TEMPERATURES OF OCCURRENCE AT GLASS MTN. (°F)	REPORTED FORMATION TEMPERATURES AND TEMPERATURE STABILITY RANGES (°F)	REFERENCE
Smectite	70 to 556*	86 to 284**	Browne (1984)
Kaolinite	190 to 300	122 to 302	Browne (1978)
Chlorite	483 to 556	>446	Browne (1978)
Illite/Phengite	450 to 535	>428	Browne (1984)
Chlorite-Smectite	375 to 542	392 to 518	Browne (1978)
Illite-Smectite	375 to 494	284 to 428	Browne (1984)
Biotite	511 to 556	>428***	Hulen and Nielson (1986)
Talc	485 to 546	no data	

* maximum temperature recorded in any of the wells
** does not include saponite (see Eberl, and others, 1978)
*** more commonly above 572°F (Elders, and others, 1981; Hulen and Nielson, 1986).

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high as 556°F in GMF68-8. Only the magnesium rich smectite saponite is stable at these temperatures. If the smectite identified in GMF68-8 is not saponite, then the existence of the smectite at such high temperatures suggests the rocks have low matrix permeability, and there is insufficient water for the smectite to react and form higher-ordered clays.

Smectite and chlorite are the most common clays observed in the wells (Figures 3, 4, and 5). Hydrothermal smectite forms primarily as a low-temperature alteration product of rocks high in magnesium and calcium and low in potassium (Deer, and others, 1975). Mafic lavas containing minerals high in magnesium and calcium alter readily to smectite at low temperatures and under saturated conditions. The alteration of high-potassium silicic rocks, however, tends to yield kaolinite and illite clays rather than smectite. The occurrence of smectite in the wells therefore generally follows the distribution of mafic rocks. Smectite is the most common clay observed at lower temperatures and in the upper 3000 feet of GMF68-8 and GMF31-17 and in the upper 4000 feet of GMF17A-6. At greater depths and temperatures, hydrothermal chlorite becomes the dominant clay. Chlorite formed at Glass Mountain as an alteration product of primary ferromagnesian minerals such as pyroxene, amphibole and biotite. Mixed-layer chlorite-smectite formed as an intermediate mineral between chlorite and smectite. The percentage of chlorite in the mixed-layered clays is observed to increase with temperature.

Hydrothermal biotite first occurs at 8409 feet in GMF68-8, 7900 feet in GMF31-17, and 7400 feet in GMF17A-6. The biotite occurs in GMF31-17 as a vein mineral together with actinolite and talc. In GMF17A-6 the biotite occurs as a ragged replacement of metamorphic mafic minerals in the hornfels, and in well-defined cross-cutting veinlets.

ALTERATION ZONES

Alteration zoning is well-developed in the Glass Mountain wells. Diagnostic assemblages of hydrothermal minerals are classified into three distinctive types or zones: zeolite-smectite, argillic, and propylitic. The classification is a modification of those presented by Rose and Burt (1979), Kristmannsdottir (1982), Guilbert and Park (1985), and Carrier (1987), and is based on observed mineralogy. Zeolite-smectite alteration is defined here by the presence of either low-temperature zeolites or hydrothermal smectite clay in concentrations greater than three percent of the whole-rock. Argillic alteration is defined by the presence of hydrothermal quartz and either hydrothermal smectite or kaolinite. Propylitic alteration begins when any two of the following four secondary minerals are present: albite, epidote, calcite (replacing plagioclase), and chlorite (greater than smectite). A cross-section showing the distribution of alteration zones in the wells is presented in Figure 8. The boundaries between the alteration zones are not always sharp. A transition zone is observed in GMF31-17 and GMF17A-6 between the argillic and propylitic alteration zones. Rocks in the transition zone have diagnostic minerals of both alteration assemblages.

The zeolite-smectite zone is found at 380 feet in GMF31-17, 700 feet in GMF68-8, and 1280 feet in GMF17A-6. The top of the zone is probably determined by lithology and the pre-existing water table in the area. At 1280 feet in GMF17A-6, the zeolite-smectite zone is anomalously deep relative to the present static water level in the well of about 1100 feet.

The argillic alteration zone occurs beneath the zeolite-smectite zone at 1320 feet in GMF31-17, 1640 feet in GMF68-8, and 2680 feet in GMF17A-6. Well-developed argillic alteration zones are found in GMF68-8 and GMF31-17, and coincide with observed boiling-point formation temperatures (Figures 3 and 4). Only weak to moderately developed argillic alteration is found in GMF17A-6, a well in which formation temperatures are considerably less than boiling (Figure 5). Argillic alteration in GMF68-8 becomes moderate to strong in intensity at 2080 to 2780 feet, and persists to 3000 feet. Argillic alteration in GMF31-17 occurs at 1320 feet, becomes moderate to strong in intensity at 1780 feet, and persists to at least 2100 feet. A zone of weak argillic alteration occurs in GMF31-17 at the anomalously shallow depth of 260 to 380 feet, and is possibly related to ancient hot spring activity. Argillic alteration in GMF17A-6 begins at 2680 feet, does not progress beyond weak to moderate in intensity, and persists to 3900 feet.

The propylitic alteration zone is first observed at 2740 feet in GMF31-17, 3000 feet in GMF68-8, and 4500 feet in GMF17A-6, and extends to the total depth of each well. Propylitic alteration is well-developed from its first occurrence in GMF31-17 and GMF17A-6, and becomes well-developed at 4120 feet in GMF68-8. Strong propylitic alteration is often observed in cutting samples to be associated with the brecciated zones at the tops and bottoms of lava flows, and in intervals of known production. In the spot cores, strong propylitic alteration is observed to line subvertical fractures and open spaces.

Transition zones are observed in GMF31-17 and GMF17A-6 between argillic and propylitic alteration. The transition zone in GMF31-17 occurs at 2100 to 2740 feet in silicic rocks, and is characterized by mixed-layered clays and the spotty occurrence of poorly crystallized epidote and chlorite. The occurrence of the transition zone is probably due to lithology. Silicic rocks as a whole are not as conducive as mafic rocks to the formation of epidote or chlorite. The transition zone in GMF17A-6 occurs at 3900 to 4500 feet. Although temperatures in the zone exceed 450°F (Figure 5) and chlorite is present, the chlorite remains subordinate to smectite. The transition zone in GMF17A-6 probably results from low matrix permeability which allows the smectite to exist at higher temperatures.

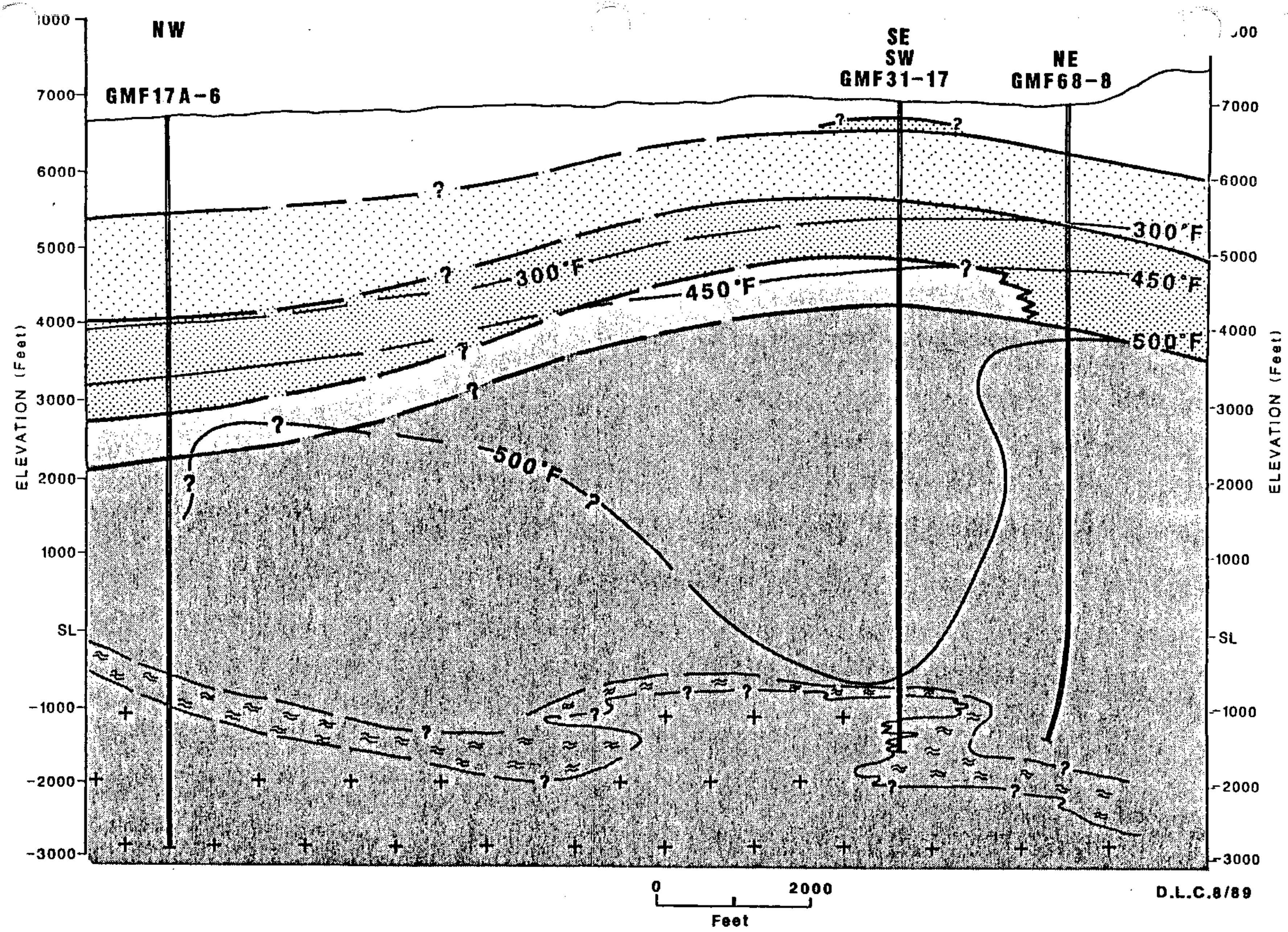

Figure 8: Cross-section showing generalized geology, alteration zones, and subsurface temperatures as observed in the Glass Mountain deep wells.

A good correlation is observed to exist between alteration zones and modelled low-resistivity anomalies (Figure 9). The resistivity data are compiled from one-dimensional inversions of time-domain electromagnetic (TDEM) and magnetotelluric (MT) data. Modelled low-resistivities in general coincide with the zones of argillic alteration and are believed to be associated with smectite clay (Nordquist, 1986). The lowest resistivities are modelled for the GMF31-17 and GMF68-8 areas, at which moderate to strong argillic alteration and boiling-point formation temperatures exist. Modelled resistivities in the GMF17A-6 area are not as low as at GMF31-17 and GMF68-8. In GMF17A-6, only weak to moderate argillic alteration and less than boiling-point formation temperatures are observed.

CONCLUSIONS

The deep well data show that reservoir rocks at Glass Mountain are dominantly layered volcanics. Primary permeability therefore probably has a much higher horizontal component than a vertical component. The thick sequence of volcanic rocks indicates that the area has had a long volcanic history. Further work is needed to substantiate the preliminary conclusion that the coarser grained volcanics observed at depths of 4600 feet mark the base of Medicine Lake volcano. The apparent depression of the pre-Medicine Lake lavas can be attributed to some combination of three factors: paleotopography, volcanic subsidence, or isostatic compensation. The absence of massive tuffs underlying the caldera floor indicates no catastrophic eruption of pumice and ash has occurred. Any subsidence is therefore probably the result of isostatic compensation.

The mineralogical data suggest that either multiple hydrothermal systems have existed in the Glass Mountain area, or that temperatures in the present geothermal system have declined. This is evident by the occurrence of epidote at an anomalously low temperature of 430°F at 2840 to 2860 feet in GMF31-17. Caution is therefore needed in using the first occurrence of epidote to identify the top of the reservoir. In addition, the replacement of epidote and wairakite by calcite at 2840 to 2860 feet in GMF31-17 is indicative of boiling and CO_2 exsolution. These processes are consistent with the boiling-point temperatures currently observed at those depths (Figure 4). In addition to epidote, hydrothermal clinopyroxene also appears at lower-than-expected temperatures in GMF31-17. The clinopyroxene-quartz-oligoclase and biotite-actinolite-talc veins in the contact metamorphic rocks in GMF31-17 and GMF17A-6 possibly record high-temperature hydrothermal alteration that closely followed the metamorphism. Fluid inclusion data will be useful in resolving these relationships further.

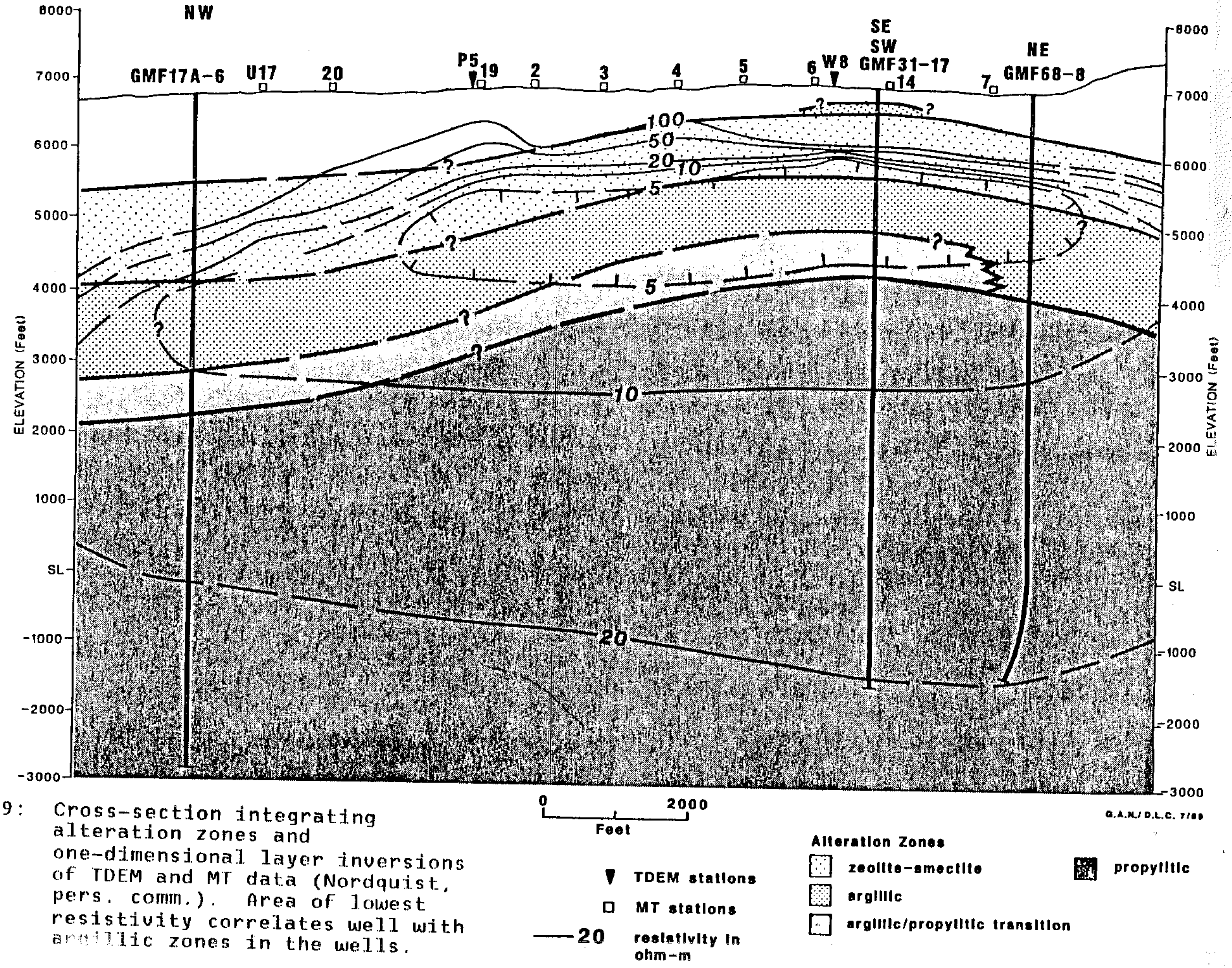

Figure 9: Cross-section integrating alteration zones and one-dimensional layer inversions of TDEM and MT data (Nordquist, pers. comm.). Area of lowest resistivity correlates well with argillic zones in the wells.

The systematic pattern of alteration zoning in the wells indicates a well-developed geothermal system has existed in the Glass Mountain area. Strong argillic alteration in GMF31-17 and GMF68-8 is due to the upwelling of thermal fluids in the area to levels where boiling occurs (Figures 3, and 4,). Similar upwelling or boiling of thermal fluids do not appear to have occurred in the GMF17A-6 area (Figure 5). TDEM and MT have been shown to be useful in the Glass Mountain area for predicting the occurrence of strong argillic alteration. The anomalously shallow weak argillic alteration at 260 feet in GMF31-17, together with the occurrence of epidote and wairakite at 2840 to 2860 feet, suggests that past hydrostatic water levels in the area have been shallower than the current 1100 feet. The occurrence of strong propylitic alteration along fractures and the brecciated tops and bottoms of lava flows suggests that these areas are a preferred pathway for geothermal fluids.

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Ctlg. No.: UCA07.2701

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Ctlg. No.: UCA07.2701

APPENDIX 1

XRD ANALYSES

KEY FOR XRD ANALYSES
PRESENT IN APPENDIX I

WELL	SAMPLE NO.	DEPTH (FEET)
GMF17A-6	6-1	7690-7700
	6-2	7160-70
	6-3	6820-30
	6-4	5710-20
	6-5	5260-70
	6-6	4620-30
	6-7	4910-20
	6-8	8230-40
GMF68-8	8-1	6460-80
	8-2	6140-60
	8-3	5840-60
	8-4	5400-20
	8-5	4660-80
	8-6	4120-40
	8-7	3200-20
	8-8	2660-2680
	8-9	6940-50
	8-10	7070-80
	8-11	7300-10
	8-12	7700-10
	8-13	7890-7900
	8-14	8060-70
	8-15	8160-70
	8-16	6593
	8-17A	8409
	8-17B	8413
	8-18	FLOW LINE SAMPLE
GMF31-17	17-1	800-10
	17-2	1100-10
	17-3	1300-10
	17-4	1790-1800
	17-5	2100-20
	17-6	2300-20
	17-7	2840-60
	17-8	3240-60
	17-9	3870-80
	17-10	4220-30
	17-11	4480-90
	17-12	4940-50
	17-13	5230-40
	17-14	5320-30
	17-15	5780-90
	17-16	6080-90
	17-17	6560-70
	17-18	7020-30
	17-19	7450-60
	17-20	8030-40
	17-21	8090-8100
	17-22	8250-60
	17-23	8787
	17-24	8420
	17-25	8422

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

January 23, 1985

Richard Gunderson, Geologist
Union Oil Company of California
Union Geothermal Division
2099 Range Avenue
Santa Rosa, CA 95406

Dear Richard:

[illegible]

The 31 Geysers area cuttings samples you recently submitted to our lab have been mineralogically analyzed by qualitative X-ray diffraction (XRD). Results of the analyses, a summary of methods by which the analyses were obtained, and all corresponding diffractograms accompany this letter.

[illegible]

Well 17A-6, from which 30 of the samples were obtained, is shown by XRD to be distinctly zoned mineralogically. Smectite is confined to the interval between 1400 and 4330 feet (depth). Four samples in this interval contain trace to minor clinoptilolite. The lower part of the smectite zone overlaps a chlorite zone which extends from 3940' to the deepest sample at 9590'. Epidote accompanies chlorite between 4750' and 7720'. Amphibole appears at 4750' and persists to the deepest sample. Mica (probably mostly biotite) is prominent below 7550'.

The upper part of well 17A-6 apparently penetrates interlayered basic and felsic volcanic rocks; the former mostly plagioclase, the latter composed principally of sanidine and cristobalite. These volcanics overlie probable metasedimentary rocks, in turn intruded by mica-amphibole quartz diorite(?). Much of the mineralogic zoning revealed by XRD, therefore, reflects rock type rather than alteration. Smectite, chlorite and epidote, however, are clearly secondary, as is the minor pyrite between 4750' and 6920'. Petrographic examination and clay-fraction XRD might reveal additional alteration phases.

Thank you for submitting these cuttings, and please call if I can clarify any aspect of their XRD mineralogy.

Sincerely,

Jeff Hulen

Jeffrey B. Hulen
Geologist

JBH/jp

BULK XRD

MINERALOGY, APPROX. WT.% ☐ (or) RELATIVE ABUNDANCE ☑

SAMPLE NO.	QUARTZ ✓	CRISTOBAL. ✓	TRIDYMITE	PLAGIOCL. ✓	K-FELDSP. ✓	CALCITE ✓	HEMATITE ✓	ILMENITE ✓	PYRITE ✓	ILLITE ✓	MICA ✓	CHLORITE ✓	SMECTITE ✓	MIXED-LAYER ILLITE-SMEC. ✓	MIXED-LAYER CHL.-SMEC. ✓	AMPHIBOLE	EPIDOTE	CLINOPTILOL.	LAUMONTITE				
KCF 82-15:																							
FILL BENEATH SHOE	M			m		m			TR?	m		m			m								
17A-6:																							
200-230′				M			TR?	m															
620-650′	m	M	m?	TR?	M		TR																
950-980′				M			TR	m															
1400-1430′	m			M			TR	m?					m					m					GLASS (M)
1600-1630′				M			TR	m?					m					TR					GLASS (M)
1800-1830′	TR	M	m?	m	M			TR?					m										
2100-2130′	TR	M		m	M		TR						m										
2400-2430′				M									TR										GLASS (M)
2750-2780′				M			TR						m					TR					
3040-3070′	m			M			TR	TR?					M		m			TR					
3400-3430′	M			M				m					m										
3940-3970′	m			M			TR	m				TR*	m										
4300-4330′	m			M			TR?	m?				TR*	m										
4750-4780′	m			M					TR			m*					TR						
5070-5100′	m			M					TR			m			m	m	m						
5400-5430′	m			M	TR	m	TR					m				m	m						
5950-5980′	m			M	TR		TR		TR			m				m	TR						
6300-6330′	m			M	m		TR		TR			m				m							
6600-6630′	M			M	m		TR		TR	m†		m				m	TR						[illegible]
6900-6930′	M			M	m				TR	m†		m				m	TR						

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

† POSSIBLY MICA
* MAY INCLUDE KAOLIN

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

BULK XRD

MINERALOGY, APPROX. WT.% ☐ (or) RELATIVE ABUNDANCE ☑

SAMPLE NO.	QUARTZ	CRISTOBAL.	TRIDYMITE	PLAGIOCL.	K-FELDSP.	CALCITE	HEMATITE	ILMENITE	PYRITE	ILLITE	MICA *	CHLORITE	SMECTITE	MIXED-LAYER ILLITE-SMEC.	MIXED-LAYER CHL.-SMEC.	AMPHIBOLE	CLINOPTIL.	LAUMONTITE	EPIDOTE			
7200-7230'	M			M	m		TR?					m				m						
7550-7580'	m			M	TR		TR?				m	m				m		m?				
7710-7720'	M			M	m		TR?				m	m				m			TR			
7800-7830'	M			M	m		TR?				m	m				m						
8100-8130'	M			M	m						m	m				m						
8400-8430'	M			M	m						m	m				m						
8700-8730'	M			M	m						m	m				m						
9000-9030'	M			M	m						m	m				m						
9300-9320'	M			M	m						m	m				m						
9590-9620'	M			M	m						m	m				m						

* MAY INCLUDE MINOR ILLITE

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

SEMI-QUANTITATIVE
MINERALOGIC ANALYSIS
BY X-RAY DIFFRACTION

-Methods and Procedures-

Bulk Analysis: Representative one-gram splits of bulk samples are ground in acetone in an agate mortar to <325 mesh ($< 45\ \mu$) then scanned at $2^\circ 2\theta$ per minute from $2\text{-}65^\circ 2\theta$. Diagnostic peaks of minerals identified on resulting diffractograms are rescanned on duplicate samples. Approximate weight percentages of the minerals are determined by comparing diagnostic peak intensities with those generated by standard pure phases mixed in various known proportions.

Clay Analysis: Bulk samples, at least 35 grams if possible, are sonically disaggregated in deionized water, allowed to settle sufficiently to yield the desired particle size fraction (generally $< 2\ \mu$ or $< 5\ \mu$), decanted and centrifuged. The resulting slurries are smeared on glass slides and X-rayed at $1^\circ 2\theta$ per minute following air-drying (2-37°), vapor glycolation for 24 hours at 60°C (2-22°), heating to 250°C for one hour (2-15°) and heating to 550°C for one hour (2-15°). Approximate weight percentages of the layer silicates identified on diffractograms corresponding to these treatments are determined by comparison of diagnostic peak intensities with those generated by pure reference clays in appropriate mixtures.

GMF 68-8 (FROM [illegible] 1985)

diffractometer using CuKα radiation at the following instrument settings: accelerating voltage - 40 kv; tube current - 40 ma; full-scale deflection - 2500 counts per second; time constant-one second. All samples were irradiated at 1°2θ per minute after the following treatments: air-drying (2-37°2θ), vapor glycolation at 60°C for 24 hours (2-22°2θ), heating to 250°C for one hour (2-15°2θ) and heating to 550°C for one hour (2-15°2θ). Approximate amounts of layer silicates identified on corresponding diffractograms were determined by comparing diagnostic peak intensities with those generated by reference standards.

Results and Discussion

The 16 samples analyzed comprise principally basalt and andesite, with two samples listed as "tuff or volcaniclastic", one dacite, and one altered silicic flow rock. As expected, plagioclase is the main component of the intermediate- to basic-composition rocks. The plagioclase is accompanied by minor magnetite, ilmenite and hematite, and probably pyroxene. The few and poorly-developed peaks of both clino- and orthopyroxene are masked by the strong and numerous reflections of the abundant plagioclase, and so are difficult to identify reliably; petrographic confirmation is necessary. Above 5000', the intermediate-composition rocks contain minor smectite; below 1200', minor quartz and chlorite and sporadic K-feldspar and calcite are present. Possible traces of analcime or wairakite occur below 4400', and 3% epidote is present in all samples below 4800'.

The rock field-named dacite at 1600' contains appreciable alkali feldspar and may actually be quartz latite or rhyolite. This sample also contains 2% mordenite and 10% smectite, and is probably hydrothermally altered. The altered silicic flow rock at 2200' is very rich in quartz and contains, in addition to minor smectite, 5% illite and 2% chlorite. The "tuff or volcaniclastic" at 5000' is shown by XRD to be an intermediate-composition rock which has been moderately propylitized.

The clay fractions extracted from the bulk cuttings samples show well-defined layer silicate zoning, probably in response to increasing temperature with depth, either presently or at some time in the past. Smectite and kaolin are strongly concentrated above 1900', below which depth chlorite and minor illite predominate. The rock at 1900' contains smectite-rich interstratified smectite-chlorite; three samples below 1900' contain mixed-layer chlorite-smectite which is much richer in chlorite. If the clay mineral zoning revealed in well 68 reflects the present thermal regime, it may be possible to establish vectors toward heat centers using layer silicate assemblages in combination with other available surface and downhole data.

KEY FOR XRD ANALYSES
FROM MARCH 16, 1988

WELL	SAMPLE NO.	DEPTH (FEET)
GMF17A-6	6-1	7690-7700
	6-2	7160-70
	6-3	6820-30
	6-4	5710-20
	6-5	5260-70
	6-6	4620-30
	6-7	4910-20
	6-8	8230-40

KEY FOR XRD ANALYSES

WELL	SAMPLE NO.	DEPTH (FEET)
GMF68-8	8-1	6460-80
	8-2	6140-60
	8-3	5840-60
	8-4	5400-20
	8-5	4660-80
	8-6	4120-40
	8-7	3200-20
	8-8	2660-2680

DAN CARRIER

MAR 23 1988

March 16, 1988

Earth Science Laboratory
University of Utah Research Institute
391-C Chipeta Way
Salt Lake City, Utah 84108

Dr. Daniel Carrier
Unocal Geothermal Division
Unocal Corporation
3576 Unocal Place
Santa Rosa, California 95406

Dear Dan:

Attached are tabulated results of XRD analysis and reconnaissance petrographic examination for 16 drill cuttings samples which you submitted in mid-November 1987. These results, initially mailed to you late in December, and which we discussed for several hours by telephone early in 1988, are reiterated and further interpreted in the text which follows.

Eight samples of the "6"-series group are dominated by three principal rock types: hornfels and allied intermediate-composition metavolcanic rock; quartz latite or rhyodacite; and altered basic to intermediate-composition volcanic rocks. The hornfels, restricted to sample 6-1, is essentially a fine-crystalline quartz-plagioclase-biotite rock with minor hornblende and clinopyroxene. Well-developed granoblastic texture is locally present, and a few of the clinopyroxenes are sieve-textured. Many chips, however, although mineralogically similar, lack these well-defined textures, and perhaps could be termed intermediate-composition metavolcanic rocks. Yet other chips are moderately- to well-foliated, and appear to be intermediate between hornfels and phyllite or fine-crystalline schist. Regardless of texture, however, all these rocks appear to have been metamorphosed to amphibolite grade. Hydrothermal biotite and amphibole are also locally present in sample 6-1, but these tend to occur as ragged replacements of metamorphic mafics or in well-defined cross-cutting veinlets. It's possible that sample 6-1 records contact metamorphism closely followed by high-temperature hydrothermal alteration.

Samples 6-2 and 6-3 contain principally chips of quartz latite or rhyodacite, consisting almost entirely of quartz, plagioclase and potassium feldspar (in decreasing order of abundance). This rock type is typically microcrystalline to fine-crystalline and displays well-developed granophyric, micropegmatitic, axiolitic and spherulitic textures. I've observed similar textures in the granophyrically crystallized interiors of the major intracaldera ash-flow sheets of the

Valles caldera. Even where intensely recrystallized, however, these ignimbrites retain at least vestiges of eutaxitic texture -- apparently absent in the 6-2 and 6-3 samples. The spherulitic and axiolitic textures of these samples, however, indicate that the original rock was at least partially glassy and subsequently devitrified. From the thin-sections alone, I can't say for certain if the rock represents a hypabyssal or subvolcanic intrusive, an extrusive dome, or a thick flow.

Samples 6-3 through 6-7 are mostly various textural varieties of altered, intermediate to basic composition volcanic and perhaps subvolcanic intrusive rocks (dikes?). Aphyric clinopyroxene basalt or basaltic andesite is the most common rock type; porphyritic variants are also present, and microdiorite and microdiabase account for trace to major amounts. Original mafics are largely converted to secondary phases (discussed in more detail below).

Sample 6-8 is unique in this group, consisting almost entirely of fine crystalline biotite granodiorite with minor biotite microgranodiorite (possibly a chilled border phase or a dike rock). Basalt and andesite chips accompanying the granodiorite in this sample could represent contamination from higher in the borehole.

Altered, basic- to intermediate-composition volcanic rocks (basalts and basaltic andesites) are also the principal lithologies represented in samples 8-1 through 8-7. These rocks are virtually identical to their counterparts in the "6"-series rocks. Samples 8-3 and 8-4, in addition, also contain porphyritic quartz latite or rhyodacite. Sample 8-8 is the same rock type as 6-2 and 6-3.

The rocks of all these cuttings samples are more or less hydrothermally altered and cut by hydrothermal veinlets; discrete hydrothermal veinlet fragments are also common. Intensity of alteration appears to reflect principally original chemical composition -- the more basaltic rocks tend to be the most thoroughly altered. Principal alteration products in these basic rocks are chlorite (and chloritic mixed-layer clay), epidote and leucoxene (probably mostly microcrystalline sphene); illite (with or without phengite), potassium feldpspar, actinolite, and leucoxene are also present. Illite and phengite predominate as secondary phases in the more felsic rocks in these samples. For example, the quartz latite of 6-3 contains about 11% illite plus phengite. Most of the coarser-crystalline quartz and orthoclase observed in these felsic rocks is believed to be primary rather than hydrothermal; these phases probably crystallized as micropegmatitic intergrowths late in the cooling history of the host rock. Hydrothermal biotite is confined principally to the hornfels of sample 6-1, and may have formed with actinolite shortly after contact metamorphism.

Hydrothermal vein-forming minerals in these samples occur in numerous combinations. The principal vein-forming minerals are quartz, calcite, epidote, chlorite (with mixed-layer chlorite/smectite?) and illite or phengite. Important subordinate phases comprise potassium feldspar, actinolite, prehnite and wairakite. Vein biotite occurs only in sample 6-1. For other vein minerals occuring only locally or in trace amounts, please refer to the attached tables.

The alteration and vein assemblages detected during this study provide general information about the temperatures of the hydrothermal fluids from which these secondary phases were deposited. For example, epidote tends to form above 240°C; prehnite above 215°C; wairakite above 210°C; actinolite above 280°C; and biotite above 220oC (more commonly above 300°C) (e.g Browne, 1978, 1984; Hulen and Nielson, 1986). The mixed-layer chlorite-smectite detected in clay-fractions (especially from the "8"-series samples), if similar to that occurring in analogous rocks in Icelandic geothermal fields, could indicate formation temperatures ranging between 200°C and 270°C (Browne, 1984). Although geothermometry based only on alteration mineralogy is at best an imprecise technique, it seems certain that the rocks represented by the "6" and "8" sample series were once extensively invaded by hydrothermal fluids exceeding 200°C and locally hotter than 300°C.

Thanks very much for the opportunity to work with these particularly interesting drill cuttings. If you have further questions concerning the X-ray or petrographic signatures of these rocks, or if I can further assist you in your geothermal exploration and development work, please write or telephone me at (801)-524-3446.

Sincerely,

Jeff Hulen

Jeffrey B. Hulen

REFERENCES

Browne, P.R.L., 1978, Hydrothermal alteration in active geothermal fields: Ann. Rev. Earth Planet. Sci., 6, 229-250.

Browne, P.R.L., 1978, Lectures on geothermal geology and petrology: United Nations Univ., Geoth. Training Prog., Rept. 1984-2, 92 p.

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CLAY FRACTION

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

SAMPLE NO.	SMECTITE	MIXED-LAYER SMECT.-CHLOR. Ⓐ	MIXED-LAYER CHLOR.-SMEC.	CHLORITE	ILLITE	MIXED-LAYER ILLITE-SMEC. ©	KAOLIN
68-400	100						
68-800	100						
68-1200	97						3
68-1600	95						5
68-1900		40		50	5	5	
68-2200	55			10	35		
68-3000				90	10		
68-3400	37			60	3		
68-3800	65		15 Ⓔ	20			
68-4400	5			95			
68-4800	3			93	4		
68-5000	Tr			98	2		
68-5200				98	2		
68-5600		5		80	15		
68-6000			10 Ⓑ	75	15		
68-6400			5 Ⓔ	80	15		

Ⓐ >75% SMECTITE
Ⓑ 90% CHLORITE
© >80% ILLITE
Ⓓ MAY INCLUDE PRIMARY MICA
Ⓔ ~50% CHLORITE

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INST ITE , EARTH SCIENCE LABORATORY

ALEX SCHRIENER

NOV 19 1985

BULK

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

SAMPLE NO.	QUARTZ	CRISTOBALITE	K-FELDSP.	PLAGIOCLASE	CALCITE	MORDENITE	MAGNETITE	ILMENITE	HEMATITE	PYRITE	CLINOPYROXENE (&) ORTHOPYROX.	AMPHIBOLE	EPIDOTE	APATITE	SMECTITE	ILLITE + MICA	CHLORITE	KAOLIN	ANALCIME OR WAIRAKITE		OTHER *	
68-400				62			2?	1	1						1						33	
68-800				55				1	2		>10?			1?	6						<25	
68-1200				58				1	1		>10?			1?	9						<20	
68-1600	8	15	40	12		2			1						10		TR?	TR?			12	
68-1900	17		5	48	1			2	3		>5?				5		2				<12	
68-2200	40		32	17					1						3	5	2					
68-3000	14		2	45	7				4		>10?				2	2	6				<8	
68-3400	10		1?	46	3				4		>10?				5		3				<18	
68-3800	8			48				2	2		>10?			1?	14		7				<8	
68-4400	8			48	8			1	4		>10?				3		8				<10	
68-4800	14		2	53				2	2		?	2			TR		5		TR?		20	
68-5000	13		2	48	1				2				3				11				20	
68-5200	9			53	1				2				3				9				23	
68-5600	11		2	47	3				3				3				4		1?		26	
68-6000	11		1	52	3				3				3				5		1?		21	
68-6400	12		2	55	4				3			2	3				5		TR?		14	

* INCLUDES AMORPHOUS PHASES, THOSE BELOW DETECTION LIMIT, AND THOSE WHOSE REFLECTIONS ARE MASKED BY PLAGIOCLASE PEAKS. MAY INCLUDE SOME LOST CIRCULATION MATERIAL.

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

ALEX SCHRIENER

UNIVERSITY OF UTAH RESEARCH INSTITUTE, EARTH SCIENCE LABORATORY

NOV 19 1985

UNOCAL GEOTHERMAL - DANIEL CARRIER

10 CUTTINGS SAMPLES
8-9 TO 8-18

REVISED BULK XRD

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

SAMPLE NO.	QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE	CLINOPYROXENE	ACTINOLITE	EPIDOTE	PREHNITE	ANHYDRITE	ILMENITE AND/OR MAGNETITE	HEMATITE	PYRITE	SPHENE/LEUCOXENE	SMECTITE	MIXED-LAYER CHLOR-SMECT.	ILLITE AND PHENGITE	BIOTITE	CHLORITE	TALC	OTHER			
8-9 6940-50′	7	45	5	TR	3	9‡	4			9	2		9	1	TR			5					TR. SERPENTINE
8-10 7070-80	41	34	17		TR	TR	2			1	TR		3	1				1					
8-11 7300-10	8	38	5	1	15	5	5			7	2		6	1	1	TR		5	1				TR. SERPENTINE
8-12 7700-10	4	46	7	TR	3	8‡	6	TR		9	TR	TR	7	1		TR		8	1				
8-13 7890-7900	1	49	6		2	10	5		TR	10		TR	7	1		1		7					
8-14 8060-8070′	3	51	3		2	9‡	3			13		TR	7	1		TR		8					
8-15 8160-8170′	2	54	3	TR	2	10‡	3			10		TR	6	1		TR		9					
8-16 6593	11	46				7	9			7	TR		11					9					
8-17B 8413	1	41	3	TR		19	5			10		1	7	TR			11	6					
8-18 FLOWLINE SAMPLE	18	45	18				7					TR	5					7					

‡ POSSIBLY INCLUDING VERY MINOR PRIMARY HORNBLENDE

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz
11-21-88

ROCK TYPES - REVISED

SAMPLE NO.	BASALT OR BASALTIC ANDESITE	DIABASE Ⓐ	MICRODIABASE Ⓑ	QTZ. LATITE OR QTZ. MICROMONZONITE Ⓒ	RHYODACITE TO MICROGRANODIORITE		HYDROTHERMAL BRECCIA (E)	GOUGE MICROBRECCIA	VEIN FRAGMENTS						
8-9	MM		m					m	m						
8-10	TR			MM				TR	m						
8-11	MM		m					m	TR						
8-12	MM		m	TR				m	m						
8-13	MM		m	m				m	m						
8-14		m	MM	M				m	m						
8-15			MM	M				TR	TR						
8-16			MM												
8-17A							MM								
8-17B			MM												
8-18					MM										Ⓐ Ⓑ & Ⓒ PROBABLY
															INTRUSIVE WITH
															Ⓐ, Ⓑ & Ⓒ PROBABLY
															JUST DIFFERENT
															TEXTURAL VARIETIES
															OF SAME ROCK TYPE.
															QTZ LATITE -
															INITIALLY GLASSY:
															WELL-DEVELOPED
															SPHERULITIC,
															GRANOPHYRIC &
															MICROPEGMATITIC
															TEXTURES.

10 CUTTINGS SAMPLES: ROCK TYPES OBSERVED DURING RECONNAISSANCE PETROGRAPHY

for: Unocal Geothermal Division, Unocal Corporation -- Daniel Carrier

16 Cuttings Samples
Clay-Fraction XRD

MINERALOGY, APPROX. WT.% ☒ (or)RELATIVE ABUNDANCE ☐

SAMPLE NO.	SMECTITE	ILLITE & PHENG. UNDIVIDED	CHLORITE	MIXED-LAYER CHLOR/SMEC.	BIOTITE	TALC
6-1	5		8		*83	2
6-2	TR?	70	30			
6-3	2	93	5			
6-4	3	5	92			
6-5			100			
6-6	13		87			
6-7	1	2	97			
6-8	15		10	5	*70	
8-1	8	42	44	6		
8-2	5	15	75	5		
8-3	3	16	72	9		
8-4	1	11	82	6		
8-5	1	49	50	TR?		
8-6	4	11	72	13		
8-7	3	*23	58	16		
8-8	26	41	33			

* INCLUDES MINOR PHENGITE

* PROBABLY INCLUDES SOME CELADONITE

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

for: Unocal Geothermal Division, Unocal Corporation -- Daniel Carrier

16 Cuttings Samples
Bulk XRD

MINERALOGY, APPROX. WT.% ☒ (or) RELATIVE ABUNDANCE ☐

	SAMPLE NO.	QUARTZ	PLAGIOCL.	K-FELDSP.	CALCITE	CLINOPYROX.	ACTINOLITE *	HORNBLENDE	EPIDOTE	PREHNITE	ANHYDRITE	ILMENITE &/OR MAGNETITE	HEMATITE	PYRITE	SPHENE/LEUCOXENE	WAIRAKITE	SMECTITE	MIXED-LAYER CHLOR.-SMEC.	ILLITE AND PHENGITE ⊛	BIOTITE	CHLORITE	TALC	OTHER Ⓐ	
	6-1 ⑦ 7690-7700′	14	51		TR	3	2	3	1		TR	2	TR	2	TR		1		2	16	3	TR		
	6-2 ⑥ 7160-70′	42	30	22					TR			TR			TR				4	TR?	2			
	6-3 ⑤ 6820-30′	45	21	16		TR	2		1		TR	TR	TR	TR	1		TR		11	TR?	3			
GMF 17A-6	6-4 ④ 5710-20′	4	50	3	2	7	3		6			5	TR	TR	8		TR		1		11			
	6-5 ③ 5260-70′	11	45	11		3	2		7			1	TR	TR	8						12			
	6-6 ① 4620-30	11	42	9		1?	3		7	1		1		1	9		2				13			
	6-7 ② 4910-20	19	38	10	TR	1?	2		5	2		1		1	8				TR		13			TR. UNKNOWN HIGH N HIGH RELIEF, LOW BIREFRINGENCE MINERAL
	6-8 ⑧ 8230-40	32	40	17	TR		1		1			1	TR	TR	TR		1	TR	1	3	1			
	8-1 6460-80	16	33	9	2	10	1		3			2	5		8		TR	TR	5		6			TR UNKNOWN, HIGH N, MOD-HIGH BIREFRINGENT SIM. TO ANHYDRITE *
	8-2 6140-60	11	34	7	TR	13	2		4			2	5	TR	9	1	TR	TR	2		10			
	8-3 5840-60	17	35	11	1	10			2			1	4	TR	6	TR?	TR	TR	3		10			
	8-4 5400-20	13	35	8	1	5			3	TR		1	3	1	8	TR?	TR	TR	3		9		8	
GMF 68-8	8-5 4660-80	20	30	5	1	5			4			TR	4	2	8	5	TR	TR	6		10			
	8-6 4120-40	16	33	5	3	5?	1 (or)	1	TR			2	4	TR	9		TR	‡SEE CHL.	3		7‡		10	
	8-7 3200-20	7	43		2	15						3	3		8		TR	TR	4		3		12	
	8-8 2660-80	45	29	19								TR	TR		2		1		2		2			

* REPLACES ORIGINAL MAFICS.

⊛ PHENGITE = BROWN TO GREEN IRON-RICH ILLITE ANALOGUE

‡ INCLUDES MINOR MIXED-LAYER CHLOR/SMEC.

* BUT W/INCLINED EXTINCTION

Ⓐ AMORPHOUS, BELOW DETECTION LIMIT; MAY INCLUDE METASTABLE GLASS.

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

Sample No.	BASALT OR ANDESITE	Ⓐ PORPHYRITIC BASALT OR ANDESITE	Ⓑ MICRODIABASE & MICRODIORITE	Ⓒ QTZ. LATITE OR RHYODACITE	Ⓓ PORPHYRITIC QTZ. LATITE OR RHYODACITE	QUARTZ MICRO-DIORITE OR MICRO-GRANODIORITE	BIOTITE GRANODIORITE	BIOTITE MICRO-GRANODIORITE	HBL-BTE-QTZ PLAG. (± CPX) HORNFELS(?) *	INTERMEDIATE COMP. METAVOLCANIC ROCK. (?) ✦	VEIN FRAGMENTS	GOUGE/MICROBRECCIA			NOTES OTHER
6-1									MM	m	m				
6-2				MM*							TR				
6-3		m	m	MM*							m				m-QTZ-SER. ROCK
6-4	M	m	M								m	m			TR-QTZ-CHL-ROCK
6-5	M	m	TR	m	m						m	TR			RHYODACITE (?) POST-DATES ANDESITE
6-6	MM	m	TR	TR?							m				CHIP OF PERLITE CEMENT
6-7	MM	m	TR								m	TR			
6-8	TR						MM	m			TR	TR			‡
8-1	M	M	TR	TR		m					m	TR			ALSO TR LOST CIRCULATION MATERIAL
8-2	MM	m	m	m							m				
8-3	M	m		m	M						TR	m			CHALCEDONY CHIP
8-4	M	m	TR	TR	m						m				"
8-5	M	M	TR		TR?						m				TR - QTZ-SER. ROCK
8-6	MM	m									TR				
8-7	m	MM									TR	m			MICROXLN SER.-QTZ-CHLORITE ROCK
8-8	TR			MM*							TR	TR			

*QUARTZ LATITE.

ALL PROBABLY SLIGHT VARIATIONS OF THE SAME ROCK TYPE. PROBABLY INTRUSIVE, PROBABLY INITIALLY GLASSY IN PART. WELL-DEVELOPED SPHERULITIC, GRANOPHYRIC, & MICROPEGMATITIC TEXTURES (NOTE: COULD ALSO BE A DOME OR THICK FLOW).

‡ ORIGINAL MAFICS IN GRANODIORITE REPLACED BY FINE-CRYSTALLINE, GREEN-BROWN BIOTITE & GREEN ACTINOLITE. BOTH POSSIBLY DEUTERIC.

✱ A FEW FRAGMENTS ARE MODERATELY- TO WELL-FOLIATED, INTERMEDIATE BETWEEN HORNFELS & SCHIST. MAY INCLUDE MINOR INTERMEDIATE-COMPOSITION METAVOLCANIC ROCK.

✦ MASSIVELY REXLZD. BUT RECOGNIZABLE APPARENT VOLCANIC TEXTURE. ?

Ⓐ & Ⓑ PROBABLY JUST DIFFERENT TEXTURAL VARIETIES OF SAME ROCK TYPE.

Ⓒ & Ⓓ AS ABOVE.

16 Cuttings Samples: Rock Types Observed During Reconnaissance Petrography

Sample No.	QTZ	CAL	KF ± QTZ	EP ± Q,KF	ACT ± Q,KF,EP	CHL ± QTZ	*PHENGITE ± ILLITE CHL, QTZ	PREHNITE ± EP, QTZ, KF	WAIRAKITE ± EP, QTZ, KF	LEUCOXENE	BIOTITE				
6-1	✓			✓	✓						✓				CPXN
6-2	✓		*✓			✓									
6-3	✓		*✓	✓	✓ BTE?	✓	✓								ILLITE-PYRITE
6-4	✓	✓		✓		✓									CHLORITE-CALCITE
6-5	✓	✓ TR		✓		✓				✓					CHL-EP-LEUCOXN
6-6	✓	✓ TR	✓	✓	✓	✓		✓							" " " WITH PY & KFSP ACT-Q-CH-EP-PREHN.
6-7	✓	✓	✓?	✓		✓		✓							ONE VNLT. FRAG.: EP + ⊛ UNKNOWN HIGH RELIEF, HIGH N, LOW BIREF. MINERL
6-8															
8-1	✓	✓	✓	✓		✓	✓								CAL-CH-PHENGITE; Q-CAL-ILLITE-CHL
8-2	✓	✓		✓		✓	✓								WAIRAKITE-CHLORITE-LEUCOXENE
8-3	✓	✓		✓		✓	✓								PHENG-CHL-CALCITE
8-4	✓	✓		✓		✓	✓ TR	✓ TR							& CH-EP-LEUC. ✓
8-5	✓	✓		✓		✓	✓		✓						PHENG.-CHL-CHALCEDONY PHENG.-WAIRAKITE
8-6	✓	✓	✓ CAL	✓		✓	✓								CHL-CAL-HEM CHL-CAL-QTZ CHL-EP-LEUCOX.
8-7	✓	✓													
8-8	✓		*✓												QTZ-HEMATITE

* PROBABLY MICROPEGMATITIC Q-KFSP INTERGROWTH

⊛ POSSIBLY PREHNITE VIEWED ⊥ TO C AXIS

TR = SCATTERED TRACES

* PHENGITE = GREEN TO BROWN (TRANSMITTED LIGHT); IRON-RICH ILLITE ANALOGUE.

16 Cuttings Samples: Veinlets Observed During Reconnaissance Petrography

SEMI-QUANTITATIVE
MINERALOGIC ANALYSIS
BY X-RAY DIFFRACTION

-Methods and Procedures-

Bulk Analysis: Representative one-gram splits of bulk samples are ground in acetone in an agate mortar to < 325 mesh (< 45 μ) then scanned at 2°2θ per minute from 2-65°2θ. Diagnostic peaks of minerals identified on resulting diffractograms are rescanned on duplicate samples. Approximate weight percentages of the minerals are determined by comparing diagnostic peak intensities with those generated by standard pure phases mixed in various known proportions.

Clay Analysis: Bulk samples, at least 35 grams if possible, are sonically disaggregated in deionized water, allowed to settle sufficiently to yield the desired particle size fraction (generally < 2 μ or < 5 μ), decanted and centrifuged. The resulting slurries are smeared on glass slides and X-rayed at 1°2θ per minute following air-drying (2-37°) vapor glycolation for 24 hours at 60°C (2-22°), heating to 250°C for one hour (2-15°) and heating to 550°C for one hour (2-15°). Approximate weight percentages of the layer silicates identified on diffractograms corresponding to these treatments are determined by comparison of diagnostic peak intensities with those generated by pure reference clays in appropriate mixtures.

KEY FOR XRD ANALYSES
FROM NOVEMBER 21, 1988

WELL	SAMPLE NO.	DEPTH (FEET)
GMF68-8	8-9	6940-50
	8-10	7070-80
	8-11	7300-10
	8-12	7700-10
	8-13	7890-7900
	8-14	8060-70
	8-15	8160-70
	8-16	6593
	8-17A	8409
	8-17B	8413
	8-18	FLOW LINE SAMPLE

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

November 21, 1988

Dr. Daniel Carrier
Unocal Geothermal Division
Unocal Corporation
3576 Unocal Place
Santa Rosa CA 95406

Dear Dr. Carrier,

Attached are the revised results of XRD analysis and reconnaissance petrographic analysis of cuttings from the "8"-series group. These results, initially mailed to you in mid-October, are further interpreted in the text that follows.

Most of these samples from the "8"-series group (except for 8-10 and 8-18) are dominated by porphyritic to aphyric basalt to basaltic andesite and similar but slightly more coarsely-crystalline microdiabase. All or most appear to have contained primary pyroxene and are altered to a variety of secondary phases. Actinolite has replaced some of the pyroxene and all the primary hornblende, although traces of the latter may still be present in a few chips.

Sample 8-10 is quartz latite to quartz monzonite, essentially identical to that documented for previously analyzed samples 6-2 and 6-3. Well-developed spherulitic, granophyric and micropegmatitic textures are locally present. The lithology and devitrification textures of sample 8-10 may represent either a thick flow, or an extrusive dome, or possibly a shallow (hypabyssal or subvolcanic) intrusive.

Sample 8-18 is a rhyodacite to microgranodiorite with a sub-trachytic texture. It exhibits more flow texture than 8-10 but could also represent a dome or shallow intrusive.

Sample 8-17A may be a hydrothermal breccia; subrounded and altered clasts are present within a fine-grained matrix. The clasts are composed of fragments of porphyritic to aphyric basaltic andesite. Quartz-filled fractures crosscut the clasts within the breccia. Fragments of lineated rock lacking phenocrysts may represent minor amounts of gouge or microbreccia material in samples 8-9 to 8-15.

Like the 6-series rocks, samples 8-9 to 8-17 host a variety of secondary minerals indicative of formation at relatively high temperatures. For example, actinolite generally forms at temperatures above 280°C; biotite forms above 220 °C (more commonly above 300°C); and epidote forms above 240° C (e.g. Browne, 1978, 1984; Hulen and Nielson, 1986). Other secondary alteration phases in these samples (such as chlorite) are ambiguous as geothermometers. Some of the actinolite could be deuteric in origin, as could the chlorite and epidote, but the common occurrence of these minerals as well-developed veinlets strongly argues in favor of a fairly high-temperature hydrothermal origin. Minor amounts of discrete smectite in these samples are probably saponite; trioctahedral smectites that are more stable at higher temperatures than their dioctahedral counterparts (Eberl, Whitney and Khoury, 1978).

Traces of subordinate phases such as prehnite and serpentine identified petrographically in samples 8-11 and 8-12 also suggest a fairly high-temperature alteration of these rocks. Prehnite is believed to form between 250°C to 350° C (e.g. Bird et al., 1984).

Thank you for the opportunity to work with these interesting cuttings and for sending another core chip of sample 8-17. Diffraction of the "17"-series group is nearly completed, so those results should be forthcoming in the next few weeks. Please call me at (801) 524-3425 if you have any further questions concerning the x-ray or petrographic signatures of these rocks.

Sincerely,

Susan Lutz

Susan Lutz
Manager,
X-ray Diffraction Laboratory

References:

Browne, P.R.L., 1978, Hydrothermal alteration in active geothermal fields: Ann. Rev. Earth Planet. Sci., v. 6, p. 229-250.

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UNOCAL GEOTHERMAL - DANIEL CARRIER

8-9 TO 8-18

REVISED CLAY XRD

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

SAMPLE NO.	SMECTITE	ILLITE AND PHENGITE (UNDIV.)	CHLORITE	MIXED LAYER CHLOR/SMECT.	BIOTITE	TALC
8-9	16		79	5		
8-10	10	76	14			
8-11	7	15	56	14		8
8-12	4		86			10
8-13	8		92			
8-14	15		85			
8-15	18		82			
8-16			100			
8-17B	3		63		34	
8-18			100			

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz
11-21-88

SAMPLE NO.	VEINLETS														
	QUARTZ	CALCITE	KF ± QTZ	EP ± Q, KF	ACT ± Q, KF, EP	CHL ± QTZ	ILLITE ± PHENGITE QTZ	PREHNITE ± EP QTZ KF	WAIRAKITE ± EP QTZ KF	LEUCOXENE	BIOTITE ± QTZ	TALC - ACT.			
8-9	° TR	TR	✓	✓	✓	✓	TR								KF, EP-PHENGITE CAL-HEM
8-10	✓		* ✓	✓		✓									
8-11	✓	✓		✓	✓	✓		TR							PHENGITE - EP - HEM EP - PREHNITE
8-12	✓	TR	✓	✓	✓	✓	TR	TR		TR		✓			QTZ - ACT EP - LEUCOXENE
8-13	✓	TR	✓	• ✓	✓	✓	TR		? TR	✓					KF, EP - LEUCOXENE QTZ - ANH - EP
8-14	✓			✓	✓	✓	TR			TR					QTZ - ACT, PHENGITE - CHALCEDONY
8-15	✓	TR		✓	✓	✓				TR					EP - KF - ACT
8-16				✓	✓	✓									CHL - QTZ NODULES
8-17A	✓										✓				
8-17B	✓			✓	✓★	✓									ACT - Q - KF - MAG - SPH. ± EP
8-18			* ✓	✓											EP - QTZ NODULE + VEIN

* MICROPEGMATITIC Q-KF INTERGROWTH

° CHALCEDONY

★ WITH SPHENE

TR - SCATTERED TRACES

• WITH ANHYDRITE

10 CUTTINGS SAMPLES : VEINLETS OBSERVED DURING RECONNAISSANCE PETROGRAPHY

KEY FOR XRD ANALYSES
FROM DECEMBER 28, 1988

WELL	SAMPLE NO.	DEPTH (FEET)
GMF31-17	17-1	800-10
	17-2	1100-10
	17-3	1300-10
	17-4	1790-1800
	17-5	2100-20
	17-6	2300-20
	17-7	2840-60
	17-8	3240-60
	17-9	3870-80
	17-10	4220-30
	17-11	4480-90
	17-12	4940-50
	17-13	5230-40
	17-14	5320-30
	17-15	5780-90
	17-16	6080-90
	17-17	6560-70
	17-18	7020-30
	17-19	7450-60
	17-20	8030-40
	17-21	8090-8100
	17-22	8250-60
	17-23	8787
	17-24	8420
	17-25	8422

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

December 28, 1988

Dr. Daniel Carrier
Unocal Geothermal Division
Unocal Corporation
3576 Unocal Place
Santa Rosa, California 95406

Dear Dr. Carrier,

The x-ray diffraction analysis and reconnaissance petrographic analysis of cuttings from the "17"-series group are complete and appended to this letter. The results are further interpreted in the text that follows.

Rock type and mineralogy-

The "17"-series group is predominantly andesite and dacite. Compositional and textural variations of the andesite are orthopyroxene or clinopyroxene andesites, porphyritic or aphyric andesites, amygdaloidal basaltic andesites, microdiabase and meta-andesite and meta-diabase. Dacitic composition rocks include the varieties, dacite and rhyo-dacite, both porphyritic and aphyric. The lowest part of this group is granodiorite, which may or may not be genetically related to the overlying dacite.

Samples 17-1 through 17-3 exhibit relict perlitic and other devitrification textures preserved in cristobalite which has partially altered to aragonite. Most of the original mafic content of the groundmass has altered to hematite. Aragonite, smectite and traces of analcime are present as amygdule fillings. Hematite has also replaced the aragonite in some of the amygdules. Orthopyroxene phenocrysts are also common in the more phyric andesites. This interval of rocks seems to represent an originally glassy andesite flow.

Samples 17-4 through 17-6 are predominately dacite. Granophyric and spherulitic texture is well developed. Sieve-textured feldspar phenocrysts are also common in this interval. Sample 17-6 is partially silicified and partially granophyric. It could represent the originally glassy border of a shallow dacite intrusive.

Samples 17-7 through 17-16 are predominately flow-banded andesites and clinopyroxene andesites. Rare orthopyroxene phenocrysts subophitically enclose plagioclase phenocrysts in some chips. Microdiabase is common below sample 17-12 where it probably represents a slightly coarser-crystalline variant of the andesites. This interval is characterized by the alteration minerals: epidote, leucoxene and chlorite-rich chlorite-smectite. Subordinate anhydrite and wairakite are also present. The leucoxene outlines amygdules where it probably replaced primary magnetite. Quartz veins are common in samples 17-14 through 17-16.

Samples 17-17 through 17-20 are mostly porphyritic andesites and samples 17-22 and 17-25 are coarser-grained granodiorites. The granodiorites contain primary phenocrysts of hornblende and biotite. Sample 17-19 contains clasts of sandstone (now hornfels) with grains of rounded quartz that exhibit overgrowths. It may be possible that this granophyric-textured sample represents a basal flow which has picked up some grains of country rock during its deposition. Alternatively, if this dacite represents a shallow intrusive, the hornfels may be xenoliths.

Below sample 17-20 and above the granodiorite of sample 17-25, there is a zone of contact metamorphism. Granoblastic recrystallization of the original micro-diorite is locally evident in sample 17-24. The rocks is this zone are better termed meta-andesite and meta-diabase, metamorphic equivalents of the igneous rocks. Samples 17-22 and 17-25 probably represent the granodiorite intrusive responsible for the metamorphism.

Minor amounts of actinolite are present in samples 17-12 through 17-16 where it is associated with epidote and possibly crosscut by chorite-quartz veins. In other chips, the formation of epidote seems to post-date chlorite formation. The iron content of the tremolite-actinolite increases with depth, at the depth of sample 17-20 it appears pleochroic and green in plane light.

Some of the amphibole in samples 17-17 and 17-22 may be primary hornblende but most is altered to actinolite. In samples 17-18 and 17-19, the actinolite does not appear to have altered from primary hornblende and occurs in irregular veins. By the depth of sample 17-20, veins and nodules of actinolite and fine-grained veins of biotite-actinolite-talc become common. Sample 17-25 contains both primary hornblende, and primary and secondary biotite.

Most of clinopyroxene in the zone of contact metamorphism (samples 17-21, 17-23 and 17-24) is probably metamorphic in origin. It appears polygonal and equigranular, and is enclosed in potassium feldspar, triple-junction quartz, or more rarely, biotite in an incipient granoblastic texture. Although some of the clinopyroxene may be primary, it does not occur in the usual interstitial manner of igneous pyroxene.

The presence of secondary biotite in samples from the bottom of this well is also associated with thermal metamorphism of the granodiorite: the biotite occurs in fine-grained aggregates or poorly defined veinlets. However, the overlying volcanic flow rocks contain well-defined crosscutting veins of biotite-actinolite-talc that are more positively hydrothermal in origin.

Alteration zoning-

The rocks penetrated by this well clearly show well-defined mineralogic zoning which is related to increased temperatures with depth. The problem is distinguishing hydrothermal alteration from contact metamorphism.

The origin of high-level smectite, quartz and calcite, and mid-level epidote, wairakite and prehnite is almost certainly hydrothermal because these minerals occur in veinlets (and in some amygules). Some of the deeper biotite, actinolite (and rare clinopyroxene?) also occur in veins and are probably hydrothermal. However, much of the biotite and especially clinopyroxene in the zone of metamorphism is metamorphic, the rock is trying to become a hornfels.

The vein assemblages do provide information about the temperatures of the hydrothermal fluids from which some of the secondary phases were deposited. Epidote tends to form above 240° C; prehnite above 215° C; wairakite above 210° C; actinolite above 280° C; and biotite above 220° C (more commonly above 300° C) (e.g. Browne, 1978, 1984; Hulen and Nielson, 1986).

The layer silicate mineralogy of this well also reflects zoning related to temperature. Samples 17-1 through 17-4 contain 10% to 20% smectite. The air-dried basal spacing of the smectite at 14A suggests that calcium and/or magnesium are the principal interlayer cations. Because these smectites are high-level and occur in rocks that contain analcime rather than wairakite, they probably formed at low temperatures, below 160° C (Hulen and Nielson, 1986).

Samples 17-5 through 17-15 contain discrete chlorite and some mixed-layer chlorite-smectite. Some samples in this interval also contain mixed-layer illite-smectite. The amount of illite interlayers in the illite-smectite is about 70-90%. These low-expandability mixed-layer clays usually form between 175° C and 220° C (Browne, 1984) from precursor smectites, so they could have been generated during incipient to low-grade metamorphism as well as subsequent hydrothermal alteration.

Below sample 17-16, the chlorites are either discrete forms or they occur in mixed-layer chlorite-smectite. This variety of chlorite-smectite is ordered and contains about 60 to 90% smectite as indicated by a superlattice peak at about 29A (in air-dried samples). Mixed-layer chlorite-smectites are stable between 200° C and 270° C (Browne, 1984), a temperature also permitting a low-grade metamorphic origin.

Samples 17-19 through 17-25 contain two varieties of mixed-layer chlorite-smectite. one with about 50% chlorite and the other with about 80% chlorite interlayers. The occurrence of the unordered. 50% chlorite variety with clinopyroxene, epidote and biotite, may indicate a cooling trend at depth since the higher temperature phases were formed.

Discussion-

Traces of the high-temperature alteration phases, actinolite and epidote, are present in a few fragments from the highest levels in this well (samples 17-1 and 17-2). The unusual occurrence of these high-temperature alteration phases in lower-temperature argillically-altered rocks may possibly represent lithic fragments of altered rock in dacite dikes at this level.

Veins containing intergrown calcite and quartz are common in sample 17-4. Calcite is replacing both wairakite and epidote in sample 17-7. Both these occurrences of calcite suggest that boiling (and CO^2 exsolution) has occurred at these levels at some time.

Below the depth of samples 17-16 and 17-17, a change in alteration occurs. Samples 17-14 and 17-16 are partially silicified. Samples 17-17 to 17-24 contain less epidote, anhydrite and leucoxene, and more actinolite, biotite, talc and ordered chlorite-smectite as alteration minerals. Perhaps the change in mineralogy reflects the change from a vapor-dominated upper zone to a water-dominated reservoir zone.

To conclude, the alteration in this well is zoned as a result of both metamorphic and hydrothermal processes. A shallow argillic zone contains abundant smectite, illite-smectite and hematite, possibly as a result of hydrothermal alteration. Cristobalite occurs as a devitrification product and aragonite, a low temperature alteration of the glass. The andesitic flow rocks in this interval may be locally cut by dacite dikes. Underneath this zone is a hydrothermal, propyliticaIly-altered zone containing abundant epidote, chlorite and wairakite that probably formed at moderately high temperatures. Subordinate amounts of anhydrite, prehnite and illite-smectite are also present as vein-forming minerals. A silicified interval at the base of this zone may mark the transition into the lower, higher-temperature, more potassic, alteration zone. This interval is characterized by hydrothermal veins of actinolite-biotite-talc. The hydrothermal alteration in this zone seems to be superimposed on an older contact metamorphic zone characterized by biotite and clinopyroxene, which may represent a pyroxene-hornfels facies of metamorphism. The chlorite-poor chlorite-smectite in this zone may be the result of a much later, and cooler, hydrothermal system. Intrusive rocks are penetrated in the lowest part of the well. Some of the secondary biotite in the granodiorite appears to be of metamorphic rather than hydrothermal origin. This intrusive body may represent the source of thermal metamorphism.

Thanks for the opportunity to work with these interesting cuttings. I realize that this interpretation of the origin of the clinopyroxene at the bottom of the well differs from yours. However, Jeff Hulen and I both looked at the thin-sections and we are fairly confident that most of this pyroxene is neither igneous nor hydrothermal. If you care to discuss this further or if you have any more questions about the x-ray or petrographic signatures of these rocks, please call.

Sincerely,

Susan Lutz

Susan Lutz
Manager,
X-ray Diffraction Laboratory

References

Browne, P.R.L., 1978, Hydrothermal alteration in active geothermal fields: Ann. Rev. Earth Planet. Sci., v. 6, p 229-250.

Browne, P.R.L., 1984, Lectures on geothermal geology and petrology: United Nations Univ., Geoth. Training Prog., Rept. 1984-2, 92 p.

Hulen, J.B. and Nielson, D.L., 1986, Hydrothermal alteration in the Baca geothermal system, Redondo dome, Valles caldera, New Mexico: J. Geophs. Res., v. 91, p. 1897-1886.

17- SERIES		ROCK TYPES													
		PPYTIC BASALT/ANDESITE	BASALT ANDESITE	DACITE,	RHYODACITE	PPYTIC DACITE, RHYODACITE	MICRODIABASE	META-ANDESITE & META-BASALT	MICROGRANO-DIORITE	FINE-XLN HBL GRANODIORITE	BRECCIA (INTRUSION?) MICROBRECCIA	VEIN FRAGMENTS	GOUGE MICROBRECCIA	PPYTIC MICRO-METADIORITE	
17-1				M*				TR			m①				DACITE POST-DATES ANDESITE
17-2			MM								TR				
17-3		Ma	Ma	m							TR				
17-4		m	m	M②	M②						TR				
17-5		m	M	m	m										
17-6				MM	m					M③	M				ONE DACITE FRAG. CONTAINS GRAPHIC MICRO-GRA
17-7				MMa							M				
17-8		m	M	M	m			TR☒			TR				
17-9		m	Ma	M④				m⑤			M				
17-10		m	m	MM	M④			TR⑤		TR	m				
17-11		m	M	m		TR					M				TR HIGH-T GREASE
17-12		M	M	TR	TR						TR				OPHITIC CPXN IN ANDESITE
17-13				M②	m②	M					m				OPHITIC CPXN IN ANDESITE
17-14		m	M	m	m	m					M				
17-15		m	M	m		m					M				
17-16			M	m?		m		TR			M				
17-17		MM	m	TR							m				
17-18		m	≠M			m					M	m?			
17-19			TR	MM②		TR					m				GRANOPHYRE
17-20			MMa								TR				
17-21			TR?				MM				TR				TR. QTZ-BTE. HORNFELS TR. GRAPHIC GRANITE
17-22			TR				TR		MM		TR				
17-23							M								M- METADIABASE
17-24													M		M- METADIORITE
17-25									M						WITH BIOTITE
* PERLITIC, SOME W/ PINPOINT DEVITRIFICATION															☒ LOCALLY DEVELOPED GRANOBLASTIC REXLZN
ⓐ AMYGDALOIDAL															
① ALSO POSSIBLY AMYGDULE FRAGMENTS															
② PATCHY GRANOPHYRIC DEVITRIFICATION															
③ COULD BE IN PART HYDROTHERMAL															
☒ COULD BE GRANOPHYRIC PORTION OF DACITE.															
④, ⑤ COULD BE JUST DIFFERENT PARTS OF															
SAME ROCK															
≠ POSSIBLY VERY FINE CRYSTALLINE															
MICRODIORITE															

17-SERIES	VEINLETS & VEINLET FRAGS.														
SAMPLE NO:	QUARTZ	CALCITE	PY - QTZ	EP ± Q, KF, CHL	SERICITE	CHL ± QTZ	WAIR ± EP QTZ KF CAL	ANALCIME	SMECTITE	HEMATITE	PREHNITE ± Q, EP KF, CHL	KF ± QTZ	ACTINOLITE ± BTE KF EP		
17-1				✓				✓SM	✓						HEM ± GOE
17-2									✓	✓					
17-3		✓?							✓	✓					
17-4	✓		✓												Q - CALCITE Q - LEUCOXENE
17-5	✓	✓	✓												Q - LEUCOXENE
17-6	✓✓														QUARTZ
17-7	✓	✓		✓	✓	✓	✓								WAI - EP - CAL - CHL QTZ - KF - WAI - AB
17-8	✓	✓		✓		✓	✓								WAI - EP - CHL SIDERITE?
17-9	✓			✓		✓					✓	✓			QTZ - EP - ANH - PREHNITE
17-10	✓			✓			✓				✓		✓TR		
17-11				✓		✓	✓								Q - LEUCOXENE
17-12	✓			✓		✓					✓				EP - ANHYDRITE
17-13	✓			✓											Q - HEMATITE
17-14	✓			✓	✓?										ANHYDRITE
17-15	✓			✓		✓						✓	✓		LEUCOXENE
17-16	✓			✓		✓									
17-17	✓			✓		✓						✓			
17-18	✓			✓								✓	✓		
17-19	✓			✓								✓			
17-20	✓			✓		✓						✓	✓✓		QTZ - ACT - BTE PHENGITE?
17-21	✓											✓	✓✓		KF - QTZ BTE - QTZ
17-22				✓											
17-23	✓	✓		✓									✓		CLINOPYROXENE BTE ± QTZ
17-24															
17-25															

UNOCAL GEOTHERMAL- DANIEL CARRIER

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

17- SERIES BULK XRD SAMPLE NO.		CRISTOBALITE	QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE / ARAGONITE	CLINOPXN / ORTHOPXN	ACTINOLITE / HORNBLENDE	EPIDOTE	SPHENE & LEUCOXENE UNDIV.	MAGNETITE & ILMENITE UNDIV.	HEMATITE	PYRITE	ANHYDRITE	WAIRAKITE / ANALCIME	SMECTITE	CHLORITE & CHLORITE-SMECT UNDIV.	ILLITE & ILLITE-SMECT UNDIV.	BIOTITE	TALC		AMORPHOUS OR BELOW DETECT.	OTHER	
800'	17-1	24	1	33	7	/TR	1/T		TR	5	1	12			/TR	12							3	GOETHITE
1100'	17-2		TR	31	2?	/1	8/TR		TR	11	4	4			/TR	17						•22		• MOSTLY GLASS
1300'	17-3		TR	26		/3	1/TR			9	5	7			/TR	22						•27		• MOSTLY GLASS
1790'	17-4	25	6	15	26	1	TR			5	1	2	3			8	1					7	TR	LAUMONTITE ? IN QTZ VEIN
2100'	17-5	5?	16	30	10	2/1			TR	13	TR		4			4	3					12		
2300	17-6		22	26	15	2			1	6		1	3		TR	4	1	12				7		
2840	17-7		10	26	5	12			8	11		2	TR		7		11	2				6		
3240	17-8		13	25	13	3	7		6	7	5	3			2		4		TR			12		
3870	17-9		10	23	10	1			26	9		2	3	TR	2	1	12						1	PREHNITE
4220	17-10		15	31	15	1	1	TR	13	7	2		3		4		5	2					1	PREHNITE
4480	17-11		8	26	4		1		16	12	1	2	~~3~~	1	3		11	1				11		
4940	17-12		6	27	8	TR	11	3	8	11	4	2	X	TR	1		7					11		
5230'	17-13		12	28	9	TR	13	3.	8	9	5	1	TR				5			TR		6	1	DRILL STEEL
5320'	17-14		8	24	14		1?	2	26	9		TR	TR	TR			5					10	TR	DRILL STEEL
5780'	17-15		11	23	4			5	23	13	1		TR				7					13		
6080'	17-16		11	22	6			5	17	10	2	TR	1	TR			12					14		
6560	17-17		4	35	5			12	9	7	8		1				8					11		
7020	17-18		8	22	8			3	18	11	4		TR				16					10		
7540	17-19		24	26	17			1	3	*11	1		TR				7					10		*? VERY FINE-GRAINED
8030	17-20		2	35	4		TR	14	2	5	11		1				8		3	1		14		
8090	17-21		1	38	3		15	4	1	3	9		1				3	5	4	4		9		
8250	17-22		17	40	26		1	1/1	1		3						4					3		
8787	17-23		3	30	8		17	1	TR	10	6						2	5	8			10		
8420	17-24		1	46	2		19			2?.	9		TR					5	4	5		7		
8423	17-25		18	35	14		TR	1/3	2	2	7		TR				4		13				1	APATITE

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz

28-88

UNOCAL GEOTHERMAL - DANIEL CARRIER

17-SERIES

MINERALOGY, APPROX. WT.% ☑ (or) RELATIVE ABUNDANCE ☐

CLAY XRD SAMPLE NO.	SMECTITE	★CHLORITE & MIXED-LAYER CHL-SM UNDIV	CHLORITE	MIXED-LAYER CHLORITE-SMECT.	MIXED-LAYER ILLITE-SMECTITE	ILLITE	BIOTITE	TALC	ACTINOLITE	% CHL IN M.L. CHL/SM	% IL IN M.L. IL/SM	BASAL SPACING OF A.D. SMECTITE	CH-SM ORDERED SUPERLATTICE	★MOSTLY CHLORITE BUT MAY CONTAIN SOME CHLORITE-RICH (80-90% CHLORITE-SMECTITE
17-1	100											14.7		
17-2	100											15.0		
17-3	100											14.7		
17-4	98	2										13.8		
17-5	32	68												
17-6	23	2			75						~70	14.3		
17-7	TR	78			+22						~90			+MAY CONTAIN SOME ILLITE OR 10Å MICA
17-8		100												
17-9	10	90										128	TR	
17-10	1	53			46						~90			
17-11			100											
17-12	4	96												
17-13			64	34				2	TR				TR	
17-14		100			TR			TR	TR				TR	
17-15		100							✓					
17-16	1	99							✓					
17-17		100							✓					
17-18		98		2					TR					
17-19		86		14					TR					
17-20		80		6			+14	TR	✓					
17-21		22		24			19	35	✓					
17-22		66		34									✓	
17-23		29		35			+23	13	TR				✓	+MAY INCLUDE SOME MIXED LAYER IL-SM
17-24		11		21			19	49						
17-25		15		7			78		TR					

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz
12-28-88

APPENDIX 2

MAJOR OXIDE ANALYSES

Bondar-Clegg, Inc.
12980 West Cedar Dr.
Lakewood, Colorado
U.S.A. 80228
Phone: (303) 989-1404
ex: 45-693

BONDAR-CLEGG

Geochemical Lab Report

UNION GEOTHERMAL
MR. RICHARD GUNDERSON
UNION GEOTHERMAL
P.O. BOX 6854
SANTA ROSA, CA 95406

ALEX SCHRIENER
JAN 28 1986

Bondar-Clegg, Inc.
12980 West Cedar Dr.
Lakewood, Colorado
U.S.A. 80228
Phone: (303) 989-1404
ex: 45-693

BONDAR-CLEGG

Geochemical Lab Report

REPORT: 155-0321 (COMPLETE)

REFERENCE INFO:

CLIENT: UNION GEOTHERMAL
PROJECT: RG-01

SUBMITTED BY: GUNDERSON
DATE PRINTED: 3-OCT-85

ORDER	ELEMENT	NUMBER OF ANALYSES	LOWER DETECTION LIMIT	EXTRACTION	METHOD
1	SiO2 Silica (SiO2)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
2	Al2O3 Alumina (Al2O3)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
3	Fe2O3* Total Iron (Fe2O3*)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
4	MnO Manganese (MnO)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
5	MgO Magnesium (MgO)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
6	CaO Calcium (CaO)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
7	Na2O Sodium (Na2O)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
8	K2O Potassium (K2O)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
9	TiO2 Titanium (TiO2)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
10	P2O5 Phosphorous (P2O5)	49	0.05 PCT	MULTI ACID - MIBK	D.C. Plasma
11	LOI Loss on Ignition	49	0.05 PCT	MULTI ACID - MIBK	Gravimetric

SAMPLE TYPES	NUMBER
R ROCKS	49

SIZE FRACTIONS	NUMBER
6 -100	49

SAMPLE PREPARATIONS	NUMBER
PREP AS PER 1ST	49
REPORT IN SERIES	49

REMARKS: CE EUL HO LA LU ND SCL SM TB THL TM YB
TO FOLLOW

REPORT COPIES TO: MR. RICHARD GUNDERSON

INVOICE TO: MR. RICHARD GUNDERSON

ALEX SCHRIENER
JAN 28 1986

Bondar-Clegg, Inc.
12980 West Cedar Dr.
Lakewood, Colorado
U.S.A. 80228
Phone: (303) 989-1404
Telex: 45-693

BONDAR-CLEGG

Ge
La

ALEX SCHRIENER

JAN 28 1986

REPORT: 155-0321 PROJECT: RG-01 PAGE 1

SAMPLE NUMBER	ELEMENT UNITS	SiO2 PCT	Al2O3 PCT	Fe2O3* PCT	MnO PCT	MgO PCT	CaO PCT	Na2O PCT	K2O PCT	TiO2 PCT	P2O5 PCT	LOI PCT
R6 14-23-816		66.50	14.50	3.40	0.07	0.80	2.50	4.50	4.30	0.65	0.14	0.50
R6 14-23-1462		54.00	15.00	9.10	0.14	3.90	8.00	4.00	1.60	1.50	0.30	2.10
R6 14-23-1903		70.00	13.00	1.70	0.04	0.60	1.50	4.00	4.50	0.25	0.04	2.30
R6 17A-6-200		57.00	15.50	8.20	0.13	3.20	6.80	4.30	1.60	1.35	0.30	0.95
R6 17A-6-2100		56.00	15.00	9.20	0.16	2.80	6.80	4.40	1.80	1.70	0.50	1.50
R6 17A-6-4750		52.50	16.00	8.90	0.14	4.50	9.40	4.00	0.70	1.30	0.25	1.40
R6 17A-6-5820		74.50	13.00	1.00	0.01	0.50	1.00	4.00	4.60	0.10	0.06	0.60
R6 17A-6-6900		56.50	17.00	7.10	0.07	3.50	8.10	4.00	1.50	1.05	0.25	0.95
R6 17A-6-7710		66.00	15.00	3.60	0.06	1.80	4.20	4.20	3.80	0.70	0.17	0.50
R6 17A-6-7750		70.50	14.00	2.90	0.05	0.80	2.50	4.50	3.80	0.30	0.09	0.35
R6 17A-6-8400		64.00	15.50	5.00	0.09	1.60	4.30	4.80	2.90	0.90	0.35	0.65
R6 17A-6-9000		66.00	15.50	4.40	0.08	1.30	3.50	4.50	3.10	0.85	0.20	0.45
R6 18-34-1049		68.50	14.00	3.00	0.07	0.80	2.60	4.00	3.50	0.65	0.13	0.95
R6 18-34-1269		74.50	13.00	1.70	0.04	0.40	1.30	4.00	4.00	0.25	0.09	0.25
R6 18-34-2507		65.00	15.50	4.20	0.08	1.20	3.50	4.30	3.80	0.80	0.25	0.60
18-34-3498		53.50	17.00	7.50	0.14	5.00	9.50	3.50	0.90	1.10	0.20	0.65
R6 27-27-1266		56.00	17.00	6.90	0.12	4.50	8.30	3.50	1.40	1.05	0.25	0.30
R6 27-27-2145		53.50	17.00	7.00	0.12	5.40	9.20	3.50	1.10	0.95	0.25	0.25
6 27-27-2785		51.00	16.50	8.50	0.15	5.40	9.50	3.80	1.00	1.45	0.40	0.85
6 28-32-485		67.50	14.50	3.10	0.10	1.10	2.80	4.00	3.30	0.50	0.10	2.35
6 28-32-1061		69.00	14.50	3.20	0.06	0.90	2.50	4.50	3.80	0.55	0.12	0.40
6 28-32-1497		71.50	14.00	2.40	0.04	0.70	2.00	4.00	4.10	0.40	0.09	0.30
6 28-32-2258		72.00	12.50	2.50	0.05	0.50	1.50	4.00	3.30	0.50	0.11	1.70
6 28-32-2514		67.50	13.00	2.20	0.05	0.40	1.50	3.50	4.10	0.45	0.11	5.70
6 28-32-3187		72.00	13.00	1.00	0.04	0.20	1.20	3.50	3.90	0.05	0.01	2.45
6 28-32-3968		58.00	13.00	6.50	0.25	1.70	4.50	4.00	1.50	1.35	0.65	7.30
6 29-1-467		70.00	14.00	2.50	0.06	0.60	2.30	4.50	3.40	0.55	0.15	0.30
6 29-1-873		60.00	15.00	5.80	0.15	3.00	6.50	3.80	2.00	0.95	0.20	0.30
6 29-1-2375		70.00	12.00	1.40	0.03	0.20	1.20	3.80	4.50	0.25	0.04	4.25
29-1-3088		55.50	15.50	7.50	0.13	3.80	8.00	3.70	1.20	1.30	0.25	1.30
45-36-1419		58.50	15.00	7.50	0.16	2.50	5.00	4.50	1.40	1.50	0.30	1.85
45-36-2379		48.00	15.50	9.00	0.17	5.50	10.00	3.30	0.50	1.70	0.40	3.85
45-36-2842		46.50	18.00	9.20	0.18	4.00	7.00	4.50	1.20	1.50	0.35	4.85
57-13-781		71.00	13.50	2.50	0.05	0.60	1.80	4.30	4.20	0.45	0.04	0.25
56-13-1423		70.50	12.50	1.30	0.03	0.30	1.20	4.00	4.50	0.15	0.03	4.80
57-13-1637		71.50	12.50	1.30	0.03	0.30	1.20	4.00	4.30	0.20	0.04	3.80
7-13-2929		54.50	17.00	6.10	0.12	4.50	8.50	4.00	1.00	0.90	0.20	1.45
62-21-1700		49.50	16.50	7.00	0.14	6.70	10.00	3.00	0.40	0.90	0.10	4.45
65-26-625		68.50	14.00	2.90	0.06	1.00	2.80	4.50	4.10	0.55	0.11	0.25
65-26-988		62.50	14.50	5.20	0.11	1.80	4.50	5.00	2.70	1.20	0.25	0.35

ALEX SCHRIENER

JAN 28 1986

REPORT: 155-0321 PROJECT: RG-01

SAMPLE NUMBER	ELEMENT UNITS	SiO_2 PCT	Al_2O_3 PCT	Fe_2O_3* PCT	MnO PCT	MgO PCT	CaO PCT	Na_2O PCT	K_2O PCT	TiO_2 PCT	P_2O_5 PCT	LOI PCT
R6 65-26-1784		71.00	13.00	1.50	0.03	0.20	1.00	3.50	5.00	0.15	0.02	3.95
R6 68-16-504		71.50	13.50	2.20	0.04	0.50	1.80	4.00	4.90	0.35	0.10	0.20
R6 68-16-1338		72.00	12.50	1.80	0.04	0.35	1.50	4.50	4.50	0.30	0.01	1.50
R6 68-16-1857		73.50	12.50	1.40	0.03	0.20	1.10	4.00	4.50	0.15	0.05	1.45
R6 68-16-2227		57.00	16.00	5.80	0.10	3.90	7.80	3.80	1.70	0.80	0.20	1.15
R6 68-16-2936		72.50	13.50	1.50	0.04	0.20	1.10	4.50	4.80	0.08	<0.01	0.35
R6 86-23-1085		55.50	18.50	6.00	0.10	4.10	8.50	3.50	1.00	0.65	0.15	1.10
R6 86-23-2103		55.00	17.00	7.50	0.12	3.90	8.20	3.50	1.80	1.00	0.45	0.75
R6 86-23-3197		51.50	15.50	10.00	0.16	4.20	8.00	4.00	1.80	1.40	0.70	1.90

Chemex Labs Inc.
Analytical Chemists * Geochemists * Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

T NION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

UAN

OCT 20 1988

*** INVOICE NUMBER I8824092 ***

BILLING INFORMATION

Date : 29-SEP-88
Project :
P.O. # : 480926
Account : CDN

Billing : For analysis performed on Certificate A8824092

Terms : Net payment in 30 Days
1.5% per month (18% per annum) charged on overdue accounts.

Please remit payments to:

CHEMEX LABS, INC.
994 West Glendale Ave.,
Suite 7, Sparks, Nevada,
U.S.A. 89431

CHEMEX CODE		ANALYSIS DESCRIPTION	SAMPLES ANALYZED	UNIT PRICE	AMOUNT
G12	-	A-12 W.R.A.	16	16.00	256.00
Sample preparation and other charges :					
217	-	Geochem - RING ONLY	16	2.50	40.00
232	-	Total ICP digestion	16	0.00	0.00
				Total Cost $	296.00
				TOTAL PAYABLE (U.S.) $	296.00

Chemex Labs Inc.
Analytical Chemists * Geochemists * Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

UNION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

Comments: ATTN: DANIEL CARRIER

A8824092

CERTIFICATE A8824092

UNION OIL COMPANY OF CALIFORNIA
PROJECT :
\# : 488926

Samples submitted to our lab in Sparks, NV.
This report was printed on 29-SEP-88.

SAMPLE PREPARATION

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION
217	16	Geochem:Ring only,no crush/split
232	16	Total ICP digestion

* NOTE 1:

Code 1000 is used for repeat gold analyses. It shows typical sample variability due to coarse gold effects. Each value is correct for its particular subsample.

ANALYTICAL PROCEDURES

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION	METHOD	DETECTION LIMIT	UPPER LIMIT
592	16	SiO2 %: Whole rock	ICP-AES	0.01	99.00
594	16	Al2O3 %: Whole rock	ICP-AES	0.01	99.00
586	16	Fe2O3(total) %: Whole rock	ICP-AES	0.01	99.00
593	16	MgO %: Whole rock	ICP-AES	0.01	99.00
588	16	CaO %: Whole rock	ICP-AES	0.01	99.00
599	16	Na2O %: Whole rock	ICP-AES	0.01	99.00
821	16	K2O %: Whole rock	ICP-AES	0.01	99.0
595	16	TiO2 %: Whole rock	ICP-AES	0.01	99.00
597	16	P2O5 %: Whole rock	ICP-AES	0.01	99.00
596	16	MnO %: Whole rock	ICP-AES	0.01	99.00
542	16	BaO %: Whole rock	ICP-AES	0.01	99.00
475	16	L.O.I. %: Loss on ignition	FURNACE	0.01	99.00
540	16	Total %	CALCULATION	0.01	N/A

Chemex Labs Inc.
Analytical Chemists • Geochemists • Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

To ION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406
Project :
Comments: ATTN: DANIEL CARRIER

Page No 1
Tot. Pages: 1
Date : 29-SEP-88
Invoice # : I-8824092
P.O. # : 480926

CERTIFICATE OF ANALYSIS A8824092

SAMPLE DESCRIPTION	PREP CODE		SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %	BaO %	LOI %	TOTAL %
31-3180	217	232	55.77	17.60	7.81	4.02	7.89	3.95	1.10	0.93	0.22	0.12	0.04	1.84	101.30
31-3660	217	232	55.19	18.05	7.97	3.72	8.19	3.60	0.78	1.00	0.29	0.12	0.05	1.65	100.60
31-4300	217	232	64.16	15.76	4.16	1.49	3.79	4.65	2.26	0.60	0.22	0.09	0.09	1.66	98.94
31-4510	217	232	51.56	17.50	9.77	5.21	9.15	3.30	0.67	1.14	0.24	0.14	0.04	1.83	100.55
31-4600	217	232	50.37	17.91	9.10	4.94	9.31	3.66	0.38	1.18	0.28	0.14	0.04	2.31	99.63
31-4780	217	232	50.38	17.11	9.66	5.56	9.14	3.78	0.53	1.42	0.35	0.15	0.03	1.91	100.05
31-4960	217	232	49.32	17.98	10.15	3.27	10.13	3.48	0.12	1.13	0.24	0.15	0.03	3.02	99.03
31-5020	217	232	54.38	18.64	7.90	3.65	7.12	3.54	0.73	1.05	0.29	0.12	0.05	2.99	100.45
31-5160	217	232	72.22	14.54	2.31	0.45	1.24	4.76	4.44	0.37	0.11	0.02	0.09	0.80	101.35
31-5320	217	232	55.61	17.03	6.61	3.88	8.60	3.04	1.04	0.52	0.14	0.10	0.03	2.48	99.09
31-6280	217	232	51.07	18.59	8.45	5.64	9.09	3.62	0.56	0.90	0.25	0.13	0.03	1.72	100.05
31-6540	217	232	50.51	19.16	8.72	4.34	9.45	3.52	0.20	1.03	0.22	0.13	0.03	1.64	98.96
31-6940	217	232	49.31	18.00	9.38	6.10	9.04	3.40	0.46	1.14	0.29	0.16	0.03	1.50	98.82
31-7240	217	232	48.94	19.83	8.58	5.29	9.87	3.24	0.07	0.94	0.17	0.14	0.02	1.46	98.56
31-7600	217	232	49.49	17.87	9.17	6.17	8.82	3.42	< 0.01	1.08	0.24	0.15	0.06	1.43	97.92
31-8090	217	232	51.10	18.29	9.33	5.58	8.66	3.89	0.19	1.06	0.32	0.14	0.04	0.45	99.06

CERTIFICATION :

Chemex Labs Inc.
Analytical Chemists * Geochemists * Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

T ON OIL COMPANY OF CALIFORNIA
JNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

Project :
Comments: ATTN: DANIEL CARRIER

Page N
Tot. Pa :1
Date :29-SEP-88
Invoice # :I-8824092
P.O. # :480926

CERTIFICATE OF ANALYSIS A8824092

SAMPLE DESCRIPTION	PREP CODE		SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %	BaO %	LOI %	TOTAL %
31-3180	217	232	55.77	17.60	7.81	4.02	7.89	3.95	1.10	0.93	0.22	0.12	0.04	1.84	101.30
31-3660	217	232	55.19	18.05	7.97	3.72	8.19	3.60	0.78	1.00	0.29	0.12	0.05	1.65	100.60
31-4300	217	232	64.16	15.76	4.16	1.49	3.79	4.65	2.26	0.60	0.22	0.09	0.09	1.66	98.94
31-4510	217	232	51.56	17.50	9.77	5.21	9.15	3.30	0.67	1.14	0.24	0.14	0.04	1.83	100.55
31-4600	217	232	50.37	17.91	9.10	4.94	9.31	3.66	0.38	1.18	0.28	0.14	0.04	2.31	99.63
31-4780	217	232	50.38	17.11	9.66	5.56	9.14	3.78	0.53	1.42	0.35	0.15	0.03	1.91	100.05
31-4960	217	232	49.32	17.98	10.15	3.27	10.13	3.48	0.12	1.13	0.24	0.15	0.03	3.02	99.03
31-5020	217	232	54.38	18.64	7.90	3.65	7.12	3.54	0.73	1.05	0.29	0.12	0.05	2.99	100.45
31-5160	217	232	72.22	14.54	2.31	0.45	1.24	4.76	4.44	0.37	0.11	0.02	0.09	0.80	101.35
31-5320	217	232	55.61	17.03	6.61	3.88	8.60	3.04	1.04	0.52	0.14	0.10	0.03	2.48	99.09
31-6280	217	232	51.07	18.59	8.45	5.64	9.09	3.62	0.56	0.90	0.25	0.13	0.03	1.72	100.05
31-6540	217	232	50.51	19.16	8.72	4.34	9.45	3.52	0.20	1.03	0.22	0.13	0.03	1.64	98.96
31-6940	217	232	49.31	18.00	9.38	6.10	9.04	3.40	0.46	1.14	0.29	0.16	0.03	1.50	98.82
31-7240	217	232	48.94	19.83	8.58	5.29	9.87	3.24	0.07	0.94	0.17	0.14	0.02	1.46	98.56
31-7600	217	232	49.49	17.87	9.17	6.17	8.82	3.42	< 0.01	1.08	0.24	0.15	0.06	1.43	97.92
31-8090	217	232	51.10	18.29	9.33	5.58	8.66	3.89	0.19	1.06	0.32	0.14	0.04	0.45	99.06

CERTIFICATION :

Chemex Labs Inc.
Analytical Chemists • Geochemists • Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

To: UNION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

Comments: ATTN: DANIEL CARRIER

CERTIFICATE A8824092

UNION OIL COMPANY OF CALIFORNIA
PROJECT :
P.O. # : 480926

ples submitted to our lab in Sparks, NV.
This report was printed on 29-SEP-88.

SAMPLE PREPARATION

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION
217	16	Geochem:Ring only,no crush/split
232	16	Total ICP digestion

• NOTE 1:

Code 1000 is used for repeat gold analyses. It shows typical sample variability due to coarse gold effects. Each value is correct for its particular subsample.

ANALYTICAL PROCEDURES

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION	METHOD	DETECTION LIMIT	UPPER LIMIT
592	16	SiO_2 %: Whole rock	ICP-AES	0.01	99.00
594	16	Al_2O_3 %: Whole rock	ICP-AES	0.01	99.00
586	16	Fe_2O_3(total) %: Whole rock	ICP-AES	0.01	99.00
593	16	MgO %: Whole rock	ICP-AES	0.01	99.00
588	16	CaO %: Whole rock	ICP-AES	0.01	99.00
599	16	Na_2O %: Whole rock	ICP-AES	0.01	99.00
821	16	K_2O %: Whole rock	ICP-AES	0.01	99.0
595	16	TiO_2 %: Whole rock	ICP-AES	0.01	99.00
597	16	P_2O_5 %: Whole rock	ICP-AES	0.01	99.00
596	16	MnO %: Whole rock	ICP-AES	0.01	99.00
542	16	BaO %: Whole rock	ICP-AES	0.01	99.00
475	16	L.O.I. %: Loss on ignition	FURNACE	0.01	99.00
540	16	Total %	CALCULATION	0.01	N/A

Chemex Labs Inc.
Analytical Chemists • Geochemists • Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

ION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406
Project :
Comments: ATTN: DANIEL L. CARRIER

Page 1
Tot. Pages: 1
Date : 4-JAN-89
Invoice # : I-8829139
P.O. # : 480926

CERTIFICATE OF ANALYSIS A8829139

SAMPLE DESCRIPTION	PREP CODE		SiO2 %	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %	BaO %	LOI %	TOTAL %
6-1090-00	217	232	65.17	15.17	5.37	2.03	3.96	4.02	3.63	0.68	0.19	0.08	0.06	< 0.01	100.35
6-2020-30	217	232	65.91	15.31	5.09	1.28	3.20	4.88	3.31	0.77	0.28	0.08	0.07	0.86	101.05
6-4630-40	217	232	52.79	15.13	9.85	2.81	6.58	4.24	2.03	1.56	0.48	0.17	0.06	2.73	98.44
6-5010-20	218	232	58.70	16.59	6.51	2.36	6.73	4.35	1.74	0.99	0.31	0.13	0.05	1.84	100.30
6-5220-30	218	232	54.33	17.77	7.24	3.51	7.65	3.95	1.90	0.96	0.25	0.12	0.04	1.72	99.45
6-5560-70	218	232	61.59	16.73	5.40	1.74	4.69	5.54	2.17	0.82	0.22	0.12	0.06	1.26	100.35
6-6110-20	218	232	52.49	16.52	9.88	3.66	7.40	4.46	0.81	1.43	0.35	0.16	0.04	1.33	98.54
6-6360-70	218	232	50.51	16.48	10.12	5.60	9.18	3.45	0.89	1.47	0.43	0.17	0.03	1.28	99.62
6-6650-60	218	232	76.18	12.79	1.38	0.16	0.56	4.02	4.44	0.09	0.06	0.02	0.01	0.37	100.10
6-7010-20	218	232	76.07	13.21	1.27	0.20	0.65	4.20	4.29	0.10	0.05	0.01	0.01	0.38	100.45
6-7430-40	218	232	50.09	17.45	9.47	6.18	8.64	3.47	0.73	1.07	0.26	0.12	0.02	1.33	98.84
8-200-20	217	232	50.92	17.54	9.76	5.32	9.23	3.56	0.86	1.10	0.23	0.15	0.02	0.05	98.75
8-420-40	217	232	50.40	17.17	9.61	5.25	9.07	3.53	0.91	1.13	0.24	0.15	0.02	1.63	99.12
8-1000-20	217	232	55.65	17.30	7.48	3.70	6.66	3.80	1.57	0.94	0.33	0.12	0.05	1.53	99.14
8-1280-00	217	232	55.96	16.87	7.36	3.25	6.77	4.13	2.10	0.90	0.36	0.15	0.05	0.97	98.88
8-1380-00	217	232	51.13	16.89	9.64	4.14	7.54	4.10	1.07	1.21	0.35	0.13	0.03	2.60	98.84
8-1740-60	217	232	70.50	14.10	3.49	0.35	1.81	4.35	4.89	0.54	0.24	0.04	0.07	0.52	100.95
8-3140-60	217	232	51.70	16.95	9.16	3.39	7.92	3.43	1.63	1.07	0.40	0.16	0.04	3.25	99.11
8-3940-60	217	232	56.28	17.20	8.10	3.16	6.91	4.10	2.12	0.99	0.39	0.13	0.04	1.04	100.45
8-4860-80	217	232	60.32	16.43	6.48	1.88	5.02	4.76	2.49	0.95	0.48	0.13	0.06	1.10	100.10
8-5560-80	217	232	67.90	14.75	4.03	0.81	2.20	4.53	3.50	0.46	0.13	0.05	0.08	0.81	99.26
8-7410-20	217	232	61.24	15.74	6.00	1.95	4.47	4.61	2.48	0.88	0.26	0.08	0.07	1.07	98.86
8-7050-60	217	232	73.40	12.94	2.75	0.88	1.80	2.67	3.68	0.19	0.11	0.05	0.01	1.00	99.49
17-1010-20 ①	217	232	57.37	17.72	7.27	3.52	6.78	3.97	1.52	0.96	0.35	0.12	0.05	1.51	101.15
17-1200-10 ②	217	232	54.95	17.45	7.26	3.00	6.37	3.86	1.52	0.96	0.37	0.11	0.05	2.72	98.63
17-1310-20 ③	217	232	53.22	16.06	8.26	2.45	4.91	3.65	1.03	1.37	0.45	0.13	0.04	6.86	98.44
17-1600-10 ④	217	232	48.22	16.32	9.74	4.23	8.02	3.60	0.91	1.31	0.33	0.16	0.03	2.50	95.38
17-2100-20 ⑤	217	232	49.27	16.79	9.78	4.26	8.17	3.74	0.85	1.29	0.31	0.16	0.03	3.03	97.69
17-4300-10 ⑥	217	232	63.62	15.69	4.21	1.57	3.85	4.57	2.30	0.58	0.25	0.09	0.08	1.50	98.32
17-5160-70 ⑦	217	232	72.35	14.54	2.41	0.32	1.21	4.77	4.53	0.35	0.10	0.02	0.09	0.68	101.40
17-6940-50 ⑧	217	232	49.15	17.85	9.20	5.91	8.84	3.40	0.44	1.07	0.28	0.16	0.02	1.54	97.87
17-7420-30 ⑨	217	232	70.48	14.05	2.71	0.73	1.82	3.83	3.87	0.43	0.12	0.04	0.07	0.57	98.73
8-F.L.	205	232	65.95	15.25	4.67	1.61	2.99	4.55	2.60	0.72	0.21	0.06	0.09	1.12	99.83

CERTIFICATION

Chemex Labs Inc.
Analytical Chemists * Geochemists * Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

To: UNION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

A8829139

Comments: ATTN: DANIEL L. CARRIER

CERTIFICATE A8829139

UNION OIL COMPANY OF CALIFORNIA
PROJECT :
P.O.# : 480926

Samples submitted to our lab in Sparks, NV.
This report was printed on 4-JAN-89.

SAMPLE PREPARATION

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION
205	1	Rock Geochem: Crush,split,ring
217	24	Geochem:Ring only,no crush/split
218	8	Pulverize only - no crush/split
232	33	Total ICP digestion

* NOTE 1:

Code 1000 is used for repeat gold analyses It shows typical sample variability due to coarse gold effects. Each value is correct for its particular subsample.

ANALYTICAL PROCEDURES

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION	METHOD	DETECTION LIMIT	UPPER LIMIT
592	33	SiO2 %: Whole rock	ICP-AES	0.01	99.00
594	33	Al2O3 %: Whole rock	ICP-AES	0.01	99.00
586	33	Fe2O3(total) %: Whole rock	ICP-AES	0.01	99.00
593	33	MgO %: Whole rock	ICP-AES	0.01	99.00
588	33	CaO %: Whole rock	ICP-AES	0.01	99.00
599	33	Na2O %: Whole rock	ICP-AES	0.01	99.00
821	33	K2O %: Whole rock	ICP-AES	0.01	99.0
595	33	TiO2 %: Whole rock	ICP-AES	0.01	99.00
597	33	P2O5 %: Whole rock	ICP-AES	0.01	99.00
596	33	MnO %: Whole rock	ICP-AES	0.01	99.00
542	33	BaO %: Whole rock	ICP-AES	0.01	99.00
475	33	L.O.I. %: Loss on ignition	FURNACE	0.01	99.00
540	33	Total %	CALCULATION	0.01	N/A

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PHONE (702) 356-5395

To . UNION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406
Project :
Comments: ATTN: DANIEL L. CARRIER

Page No. : 1
Tot. Pages: 1
Date : 4-JAN-89
Invoice # : I-8829139
P.O. # : 480926

CERTIFICATE OF ANALYSIS A8829139

SAMPLE DESCRIPTION	PREP CODE		SiO2 %	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %	BaO %	LOI %	TOTAL %
6-1090-00	217	232	65.17	15.17	5.37	2.03	3.96	4.02	3.63	0.68	0.19	0.08	0.06	< 0.01	100.35
6-2020-30	217	232	65.91	15.31	5.09	1.28	3.20	4.88	3.31	0.77	0.28	0.08	0.07	0.86	101.05
6-4630-40	217	232	52.79	15.13	9.85	2.81	6.58	4.24	2.03	1.56	0.48	0.17	0.06	2.73	98.44
6-5010-20	218	232	58.70	16.59	6.51	2.36	6.73	4.35	1.74	0.99	0.31	0.13	0.05	1.84	100.30
6-5220-30	218	232	54.33	17.77	7.24	3.51	7.65	3.95	1.90	0.96	0.25	0.12	0.04	1.72	99.45
6-5560-70	218	232	61.59	16.73	5.40	1.74	4.69	5.54	2.17	0.82	0.22	0.12	0.06	1.26	100.35
6-6110-20	218	232	52.49	16.52	9.88	3.66	7.40	4.46	0.81	1.43	0.35	0.16	0.04	1.33	98.54
6-6360-70	218	232	50.51	16.48	10.12	5.60	9.18	3.45	0.89	1.47	0.43	0.17	0.03	1.28	99.62
6-6650-60	218	232	76.18	12.79	1.38	0.16	0.56	4.02	4.44	0.09	0.06	0.02	0.01	0.37	100.10
6-7010-20	218	232	76.07	13.21	1.27	0.20	0.65	4.20	4.29	0.10	0.05	0.01	0.01	0.38	100.45
6-7430-40	218	232	50.09	17.45	9.47	6.18	8.64	3.47	0.73	1.07	0.26	0.12	0.02	1.33	98.84
8-200-20	217	232	50.92	17.54	9.76	5.32	9.23	3.56	0.86	1.10	0.23	0.15	0.02	0.05	98.75
8-420-40	217	232	50.40	17.17	9.61	5.25	9.07	3.53	0.91	1.13	0.24	0.15	0.02	1.63	99.12
8-1000-20	217	232	55.65	17.30	7.48	3.70	6.66	3.80	1.57	0.94	0.33	0.12	0.05	1.53	99.14
8-1280-00	217	232	55.96	16.87	7.36	3.25	6.77	4.13	2.10	0.90	0.36	0.15	0.05	0.97	98.88
8-1380-00	217	232	51.13	16.89	9.64	4.14	7.54	4.10	1.07	1.21	0.35	0.13	0.03	2.60	98.84
8-1740-60	217	232	70.50	14.10	3.49	0.35	1.81	4.35	4.89	0.54	0.24	0.04	0.07	0.52	100.95
8-3140-60	217	232	51.70	16.95	9.16	3.39	7.92	3.43	1.63	1.07	0.40	0.16	0.04	3.25	99.11
8-3940-60	217	232	56.28	17.20	8.10	3.16	6.91	4.10	2.12	0.99	0.39	0.13	0.04	1.04	100.45
8-4860-80	217	232	60.32	16.43	6.48	1.88	5.02	4.76	2.49	0.95	0.48	0.13	0.06	1.10	100.10
8-5560-80	217	232	67.90	14.75	4.03	0.81	2.20	4.53	3.50	0.46	0.13	0.05	0.08	0.81	99.26
8-7410-20	217	232	61.24	15.74	6.00	1.95	4.47	4.61	2.48	0.88	0.26	0.08	0.07	1.07	98.86
8-7050-60	217	232	73.40	12.94	2.75	0.88	1.80	2.67	3.68	0.19	0.11	0.05	0.01	1.00	99.49
17-1010-20	217	232	57.37	17.72	7.27	3.52	6.78	3.97	1.52	0.96	0.35	0.12	0.05	1.51	101.15
17-1200-10	217	232	54.95	17.45	7.26	3.00	6.37	3.86	1.52	0.96	0.37	0.11	0.05	2.72	98.63
17-1310-20	217	232	53.22	16.06	8.26	2.45	4.91	3.65	1.03	1.37	0.45	0.13	0.04	6.86	98.44
17-1600-10	217	232	48.22	16.32	9.74	4.23	8.02	3.60	0.91	1.31	0.33	0.16	0.03	2.50	95.38
17-2100-20	217	232	49.27	16.79	9.78	4.26	8.17	3.74	0.85	1.29	0.31	0.16	0.03	3.03	97.69
17-4300-10	217	232	63.62	15.69	4.21	1.57	3.85	4.57	2.30	0.58	0.25	0.09	0.08	1.50	98.32
17-5160-70	217	232	72.35	14.54	2.41	0.32	1.21	4.77	4.53	0.35	0.10	0.02	0.09	0.68	101.40
17-6940-50	217	232	49.15	17.85	9.20	5.91	8.84	3.40	0.44	1.07	0.28	0.16	0.02	1.54	97.87
17-7420-30	217	232	70.48	14.05	2.71	0.73	1.82	3.83	3.87	0.43	0.12	0.04	0.07	0.57	98.73
8-F.L.	205	232	65.95	15.25	4.67	1.61	2.99	4.55	2.60	0.72	0.21	0.06	0.09	1.12	99.83

CERTIFICATION

Chemex Labs Inc.
Analytical Chemists * Geochemists * Registered Assayers
994 WEST GLENDALE AVE., SUITE 7, SPARKS,
NEVADA, U.S.A. 89431
PHONE (702) 356-5395

TO UNION OIL COMPANY OF CALIFORNIA
UNION GEOTHERMAL DIVISION
3576 UNOCAL PLACE, P.O. BOX 6854
SANTA ROSA, CALIFORNIA
95406

* INVOICE NUMBER I8829139 *

BILLING INFORMATION

Date : 4-JAN-89
Project :
P.O. # : 480926
Account : CDN

Comments: AFE #480926

Billing : For analysis performed on
Certificate A8829139

Terms : Net payment in 30 Days
1.5% per month (18% per annum)
charged on overdue accounts.

Please remit payments to:

CHEMEX LABS, INC.
994 West Glendale Ave.,
Suite 7, Sparks, Nevada,
U.S.A. 89431

CHEMEX CODE		ANALYSIS DESCRIPTION	SAMPLES ANALYZED	UNIT PRICE	AMOUNT
G12	-	A-12 W.R.A.	33	16.00	528.00
Sample preparation and other charges :					
205	-	Rock Geochem - RING	1	3.00	3.00
232	-	Total ICP digestion	1	0.00	0.00
217	-	Geochem - RING ONLY	24	2.50	60.00
232	-	Total ICP digestion	24	0.00	0.00
218	-	Pulverize only -no crush	8	3.25	26.00
232	-	Total ICP digestion	8	0.00	0.00
				Total Cost $	617.00
				TOTAL PAYABLE (U.S.) $	617.00

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To: UNION OIL COMPANY OF CALIFORNIA
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95406

A8829139

Comments: ATTN: DANIEL L. CARRIER

CERTIFICATE A8829139

UNION OIL COMPANY OF CALIFORNIA
PROJECT :
P.O.# : 480926

Samples submitted to our lab in Sparks, NV.
This report was printed on 4-JAN-89.

SAMPLE PREPARATION

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION
205	1	Rock Geochem: Crush,split,ring
217	24	Geochem:Ring only,no crush/split
218	8	Pulverize only - no crush/split
232	33	Total ICP digestion

* NOTE 1:

Code 1000 is used for repeat gold analyses It shows typical sample variability due to coarse gold effects. Each value is correct for its particular subsample.

ANALYTICAL PROCEDURES

CHEMEX CODE	NUMBER SAMPLES	DESCRIPTION	METHOD	DETECTION LIMIT	UPPER LIMIT
592	33	SiO_2 %: Whole rock	ICP-AES	0.01	99.00
594	33	Al_2O_3 %: Whole rock	ICP-AES	0.01	99.00
586	33	Fe_2O_3(total) %: Whole rock	ICP-AES	0.01	99.00
593	33	MgO %: Whole rock	ICP-AES	0.01	99.00
588	33	CaO %: Whole rock	ICP-AES	0.01	99.00
599	33	Na_2O %: Whole rock	ICP-AES	0.01	99.00
821	33	K_2O %: Whole rock	ICP-AES	0.01	99.0
595	33	TiO_2 %: Whole rock	ICP-AES	0.01	99.00
597	33	P_2O_5 %: Whole rock	ICP-AES	0.01	99.00
596	33	MnO %: Whole rock	ICP-AES	0.01	99.00
542	33	BaO %: Whole rock	ICP-AES	0.01	99.00
475	33	L.O.I. %: Loss on ignition	FURNACE	0.01	99.00
540	33	Total %	CALCULATION	0.01	N/A