CA-GMT-913-2

Memorandum

CONFIDENTIAL

UNOCAL 76

DAVID SUSSMAN
DEC 21 1989

December 20, 1989

TO: David Sussman

FM: Daniel L. Carrier

RE: FLUID INCLUSION STUDIES ON SAMPLES FROM GLASS MOUNTAIN DEEP-EXPLORATION WELLS

SUMMARY

Fluid inclusion data from cuttings and spot core samples show that several hydrothermal systems have existed at Glass Mountain, and that the temperatures of the present system, as defined by GMF68-8 and GMF31-17, have declined by 30 to 100°F. The temperature decline is most apparent in rocks from 5000 to 6600 feet in GMF68-8. Fluid inclusions from those depths record hydrothermal activity which reached temperatures of about 612°F and subsequently declined to 504 to 540°F. A 7°F temperature reversal is currently measured in GMF68-8 between 4800 to 6000 feet, suggesting that this former zone of high-temperature activity is now a conduit for cooler recharge into the reservoir.

Most of the fluid inclusions have low-salinity and low-gas contents. Salinities >0.8 weight percent NaCl equivalent, or >8000 ppm, are observed in only four rock samples. Inclusions in three of these samples contain hypersaline fluids ($\geq$40 weight percent) and in the fourth contain fluids that have salinities of 2 to 6 weight percent. The hypersaline inclusions are all secondary, were formed at temperatures >752°F, and are probably derived from the exsolution of a magmatic aqueous phase during local intrusive activity.

Temperatures of formation for the fluid inclusions range from 410 to >752°F. Fluid Inclusion temperatures of secondary minerals such as clinopyroxene are higher than current rock temperatures at the same depths. These secondary minerals were probably formed during an earlier hydrothermal event or a higher-temperature phase of the current system. However, additional inclusion data are needed to better quantify the relationship between the alteration minerals and wellbore temperatures.

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Ctlg. No.: UCA07.2702

RECOMMENDATIONS

The following recommendations are made:

1. Analyze fluid inclusions in samples from GMF87-13 and future wells to provide data on deep temperatures, and to determine which portions of the system are heating or cooling.

2. Thoroughly monitor the chemistry and enthalpy of GMF68-8 during future flowtests to determine if the permeable zone at 5000 to 6600 feet is indeed a conduit for recharge to the main reservoir.

3. Collect additional inclusion data on the diagnostic hydrothermal minerals epidote and actinolite to better define the relationship between mineralogy temperatures and wellbore temperatures for use in designing casing points and unraveling the history of the geothermal system.

4. Better characterize any past changes in reservoir fluid chemistry through time by more precisely determining the salinities of fluid inclusions in selected hydrothermal minerals.

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INTRODUCTION

Geological and geochemical studies completed during 1989 on three deep exploration wells (Figure 1) have shown that the Glass Mountain geothermal system contains benign, low-TDS reservoir fluids (Carrier, 1989a), reservoir temperatures of 479 to 556°F (Carrier, 1989b), and well-developed hydrothermal alteration (Carrier, 1989c). However, there are notable differences in both the alteration mineralogy and wellbore temperatures at comparable depths between the wells (Figure 2). A recent study which focussed on the secondary mineralogical aspects of the wells concluded that either multiple hydrothermal systems have existed in the area, or that temperatures of the present system have declined since the alteration minerals formed (Carrier, 1989c). For example, reservoir temperatures at comparable depths in the three deep wells differ by as much as 60°F, and in GMF31-17, hydrothermal minerals such as epidote and clinopyroxene presently occur at temperatures of 430°F and 515°F or, 30 to 60°F less than those observed in several other geothermal fields.

Fluid inclusion data have been obtained on hydrothermal minerals collected from the three deep wells drilled at Glass Mountain: GMF68-8, GMF31-17 and GMF17A-6. The purpose of collecting fluid inclusion data is to obtain information on the temperatures and geochemistry of fluids responsible for mineral deposition, and on the variations of these properties in time and space. Such information will aid the exploration and development of the Glass Mountain field by providing data on deep temperatures, and by identifying which portions of the system are heating or cooling. This report is a companion to an earlier study (Carrier 1989c) which dealt with hydrothermal alteration and lithologic data in the same deep wells.

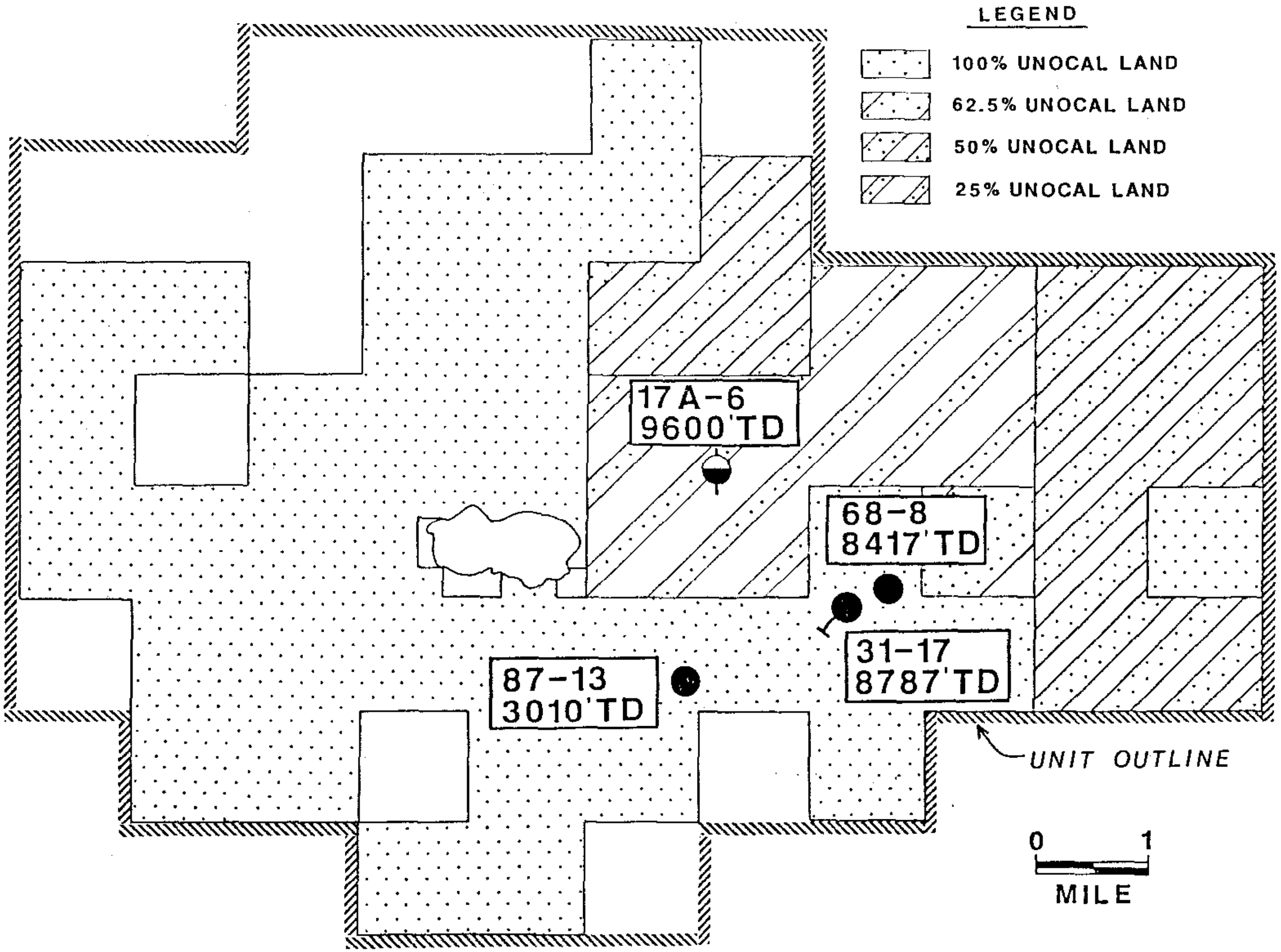

Figure 1 LOCATION MAP FOR THE GLASS MOUNTAIN UNIT

Generalized Geology
X-Section

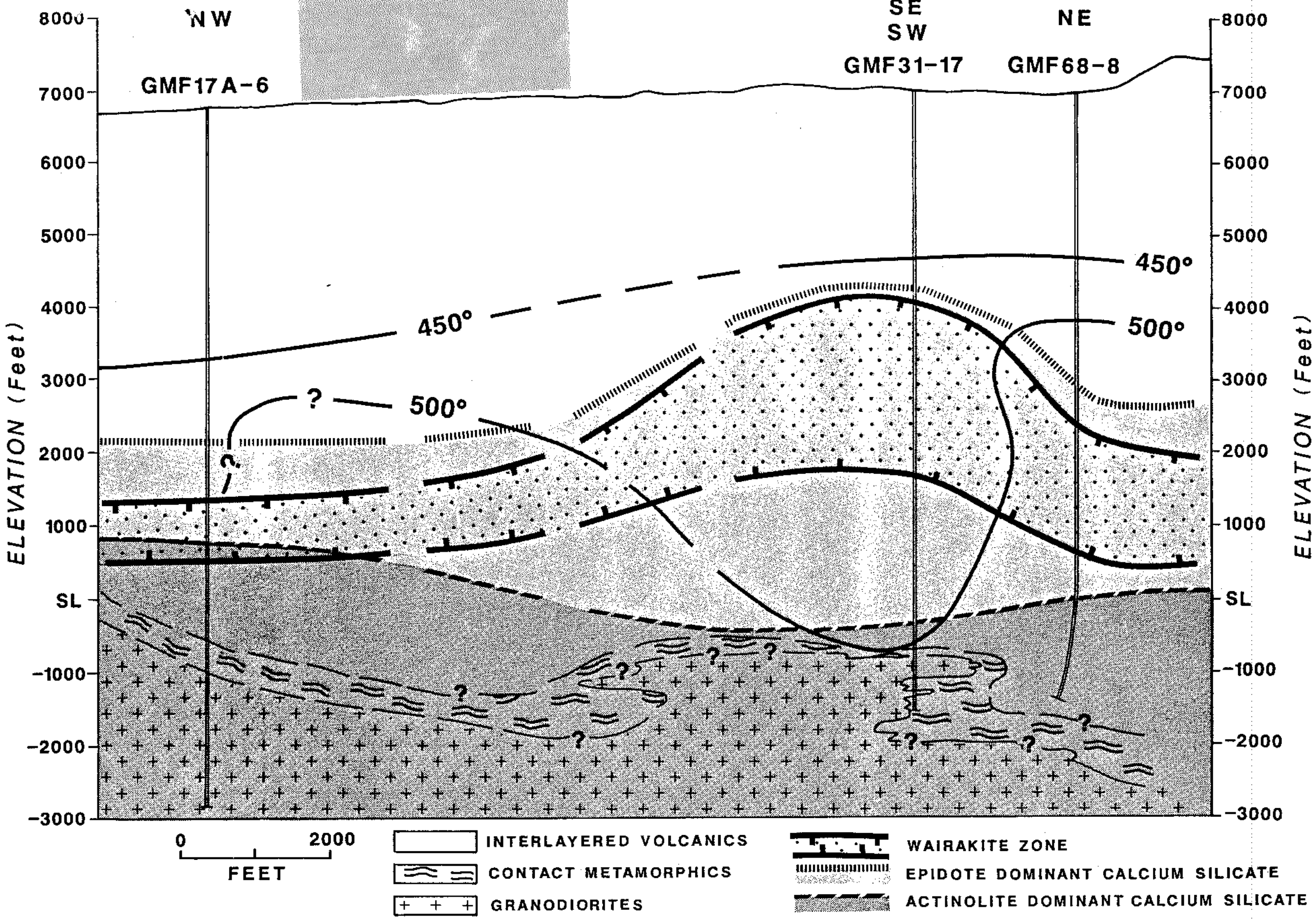

Figure 2: Cross-section showing generalized geology, subsurface temperatures, and the distribution of calcium silicate minerals epidote, actinolite, and wairakite as observed in Glass Mountain deep wells. Modified from Carrier (1989c).

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BACKGROUND LITHOLOGY

Rocks penetrated by the wells are assigned to one of three groups: interlayered volcanics, contact metamorphics, and granodioritic intrusives (Carrier, 1989c). The majority of the rocks drilled are Tertiary to Quaternary interlayered volcanics, and consist of calc-alkalic to slightly alkalic mafic, intermediate, and silicic lavas. Interlayered with the lavas are lesser amounts of thinly bedded lithic tuffs, scorias, volcaniclastics, and sandstones. The interlayered volcanics grade into contact metamorphic rocks at 8060 feet in GMF31-17 and at 7345 feet in GMF17A-6. Granodiorites occur as shallow plutonic rocks at 7690 feet in GMF17A-6 and multiple thin dikes or sills at 8110 feet in GMF31-17. The granodiorites have been intruded into the Tertiary volcanics and are possibly intrusive phases of late Tertiary to Quaternary silicic lavas found on the surface and at shallow depths in wells and boreholes (Carrier, 1989c). Intrusion of the granodiorites produced the contact metamorphic rocks and possibly some hydrothermal alteration. The active hydrothermal system and its associated alteration products are superimposed on the contact metamorphism and any hydrothermal alteration produced during the intrusion of the granodiorites.

METHODS AND DATA

Fluid inclusion determinations were made by T. James Reynolds of FLUID INC. in Denver, Colorado on selected samples of drill cuttings and spot cores. The basic data are reported in Appendix 1. The general principles of fluid inclusion analysis are discussed in Roedder (1984), and are briefly summarized here. To analyze a fluid inclusion, it is heated to the temperature at which the liquid, vapor, and solid in the inclusion are homogenized, and then cooled to the temperature at which the liquid in the inclusion freezes. The homogenization temperature is used to determine the temperature at which an inclusion formed, and the freezing-point determination is used to calculate the salinity of the fluid trapped in the inclusion by the method of Potter and others (1978). One wt. % NaCl is approximately equal to a total dissolved solids (TDS) of 10,000 ppm. The accuracy of the homogenization temperatures reported here is better than one percent of the measured values, or for this study roughly 4 to 7°F. The accuracy of temperatures measured during freezing-point determinations is better than 0.9°F. By increasing the precision of the freezing-point temperatures, the precision of the inclusion salinity measurements is also increased. However, to do that requires about 10 times the labor (Reynolds, personal communication), and was therefore not practical for this study. Fluid inclusion temperatures of formation have been determined by pressure-correcting the homogenization temperatures using current wellbore pressures and the phase diagram shown in Appendix 1.

Although both primary and secondary fluid inclusions were measured in this study, most of the fluid inclusions observed and analyzed were primary inclusions. Primary fluid inclusions form when a mineral experiences irregularities during growth or recrystallization, and small amounts of the fluid medium are trapped in the new crystal. Secondary fluid inclusions form when fractures developed in existing crystals are healed at some later time. Secondary inclusions give no information on the nature of the fluids which formed a mineral but do provide some insight into postdepositional conditions. Primary inclusions were analyzed in hydrothermal quartz, epidote, actinolite, wairakite, anorthoclase, and albite or adularia recrystallized from plagioclase in the wall rock. Hydrothermal quartz provides the best primary fluid inclusion data, and was analyzed whenever possible. Secondary inclusion analysis was restricted to hydrothermal and primary quartz.

Each fluid inclusion must be carefully examined to determine not only if it is primary or secondary, but also if the inclusion has been affected by post-formation processes. Fluid inclusions tend to have reduced surface area over time and become more equant by mineral solution and redeposition. When this process results in an inclusion separating into smaller and more equant inclusions, the process is known as "necking down" (Craig and Vaughan, 1981). If "necking down" occurs after phase separation and a vapor bubble is isolated from the liquid in an inclusion, then a postdepositional vapor-rich inclusion is formed. These vapor-rich inclusions are an accident of postdepositional processes and are unrelated to the vapor-rich inclusions associated with boiling-point conditions.

GEOCHEMISTRY DATA

Freezing-point temperatures for most of the fluid inclusions range between 31.1 and 32°F, indicating that the salinities of the trapped fluids are in general <0.8 wt. % NaCl, or less than 8000 ppm. Since current reservoir fluids have an average TDS of 3000 ppm (Carrier, 1989a), attempts at utilizing fluid inclusion salinities to characterize changes in reservoir chemistry through time will require that freezing-point temperatures be more precisely determined. The freezing-point data also indicate that the inclusions contain <0.15 wt.% CO_2. The low gas content of the inclusions is similar to the low non-condensible gas content of fluid produced during 1988 flowtests of GMF31-17 and GMF68-8 (Carrier, 1989a).

Salinities >0.8 wt.% are observed in inclusions from a total of four samples in the wells. Hypersaline fluid inclusions containing $\geq$40 wt.% NaCl equivalent are observed at 7720 feet and 8350 feet in GMF17A-6 and at 3840 feet in GMF31-17. These inclusions are probably derived from the exsolution of an aqueous phase from a nearby magma (Reynolds and Beane, 1985). The hypersaline inclusions occur in GMF17A-6 as secondary inclusions in quartz phenocrysts in granodioritic rocks, possibly suggesting that there was more than one phase of granodioritic intrusion. The hypersaline fluid inclusions in GMF31-17 occur as secondary fluid inclusions in hydrothermal quartz in a scoria deposit. These secondary fluid inclusions are only sparsely present, occur in conjunction with vapor-rich inclusions, and are probably associated with local near-surface intrusive activity. Physical expression of this intrusive activity is evident by the numerous phreatomagmatic explosion craters visible at the surface near GMF31-17, including the 250-foot deep Alcohol Crater (Hausback, 1984). The fourth sample containing salinities >0.8 wt.% is from 7570 feet in GMF17A-6. Recrystallized plagioclase in meta-volcanic rocks at that depth contain fluid inclusions with salinities of 2 to 6 wt.%. The geological significance of these inclusions has not yet been determined. However, similar salinities are observed in inclusions collected from ancient alteration products that exist in temperature boreholes GMF45-36 and GMF56-3 (Carrier, 1987).

GEOTHERMOMETRY

Temperatures of formation for the fluid inclusions range from 410 to >752°F and are plotted along with measured temperatures and a boiling-point curve for each well in Figures 3, 4, and 5. The temperatures >752°F are measured only for the hypersaline fluid inclusions, and are further evidence of their derivation from a magmatic aqueous phase. Temperatures as great as 707°F are measured for low-salinity inclusions from GMF17A-6. Temperatures for the low-salinity inclusions are distributed in distinct groups and probably indicate the existence of multiple hydrothermal systems or multiple phases of the current geothermal system. The details of these and all the temperatures of formation are discussed on a well to well basis in this section.

Fluid inclusion temperatures in vein minerals are useful to infer where zones of permeability have existed, and possibly still do exist; however, the fluid inclusion technique does not provide quantitative information about the degree of permeability at the sample point. A long history of permeability is inferred for a vein or interval of wall rock when primary inclusions show that several alteration minerals were formed over a broad, continuous temperature range. If wellbore temperatures are significantly less than the mineral temperatures at a depth, then the rocks or veins there are considered to have become impermeable. No wellbore temperatures are observed which are significantly higher than the fluid inclusion temperatures measured on samples from the same depths.

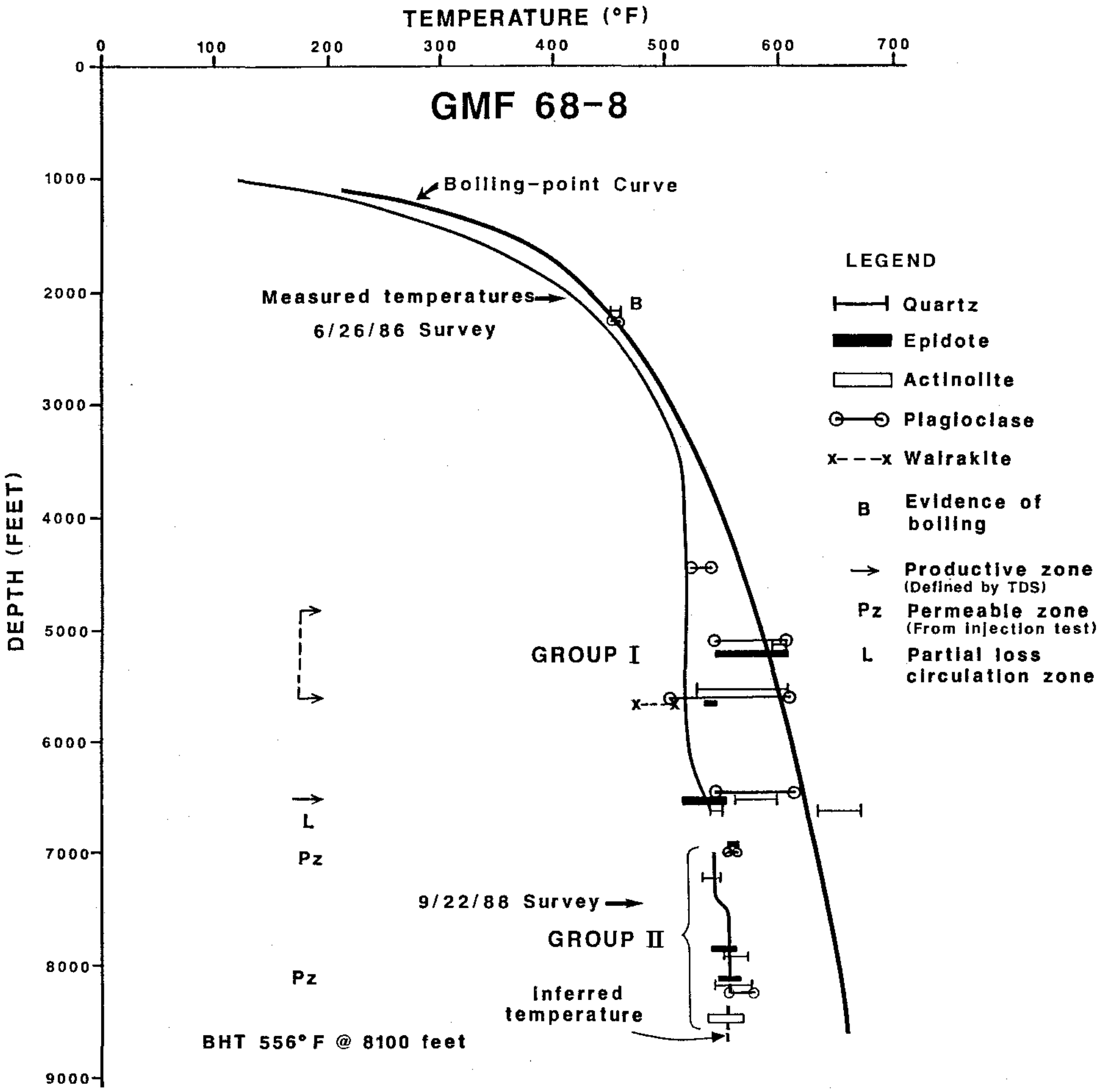
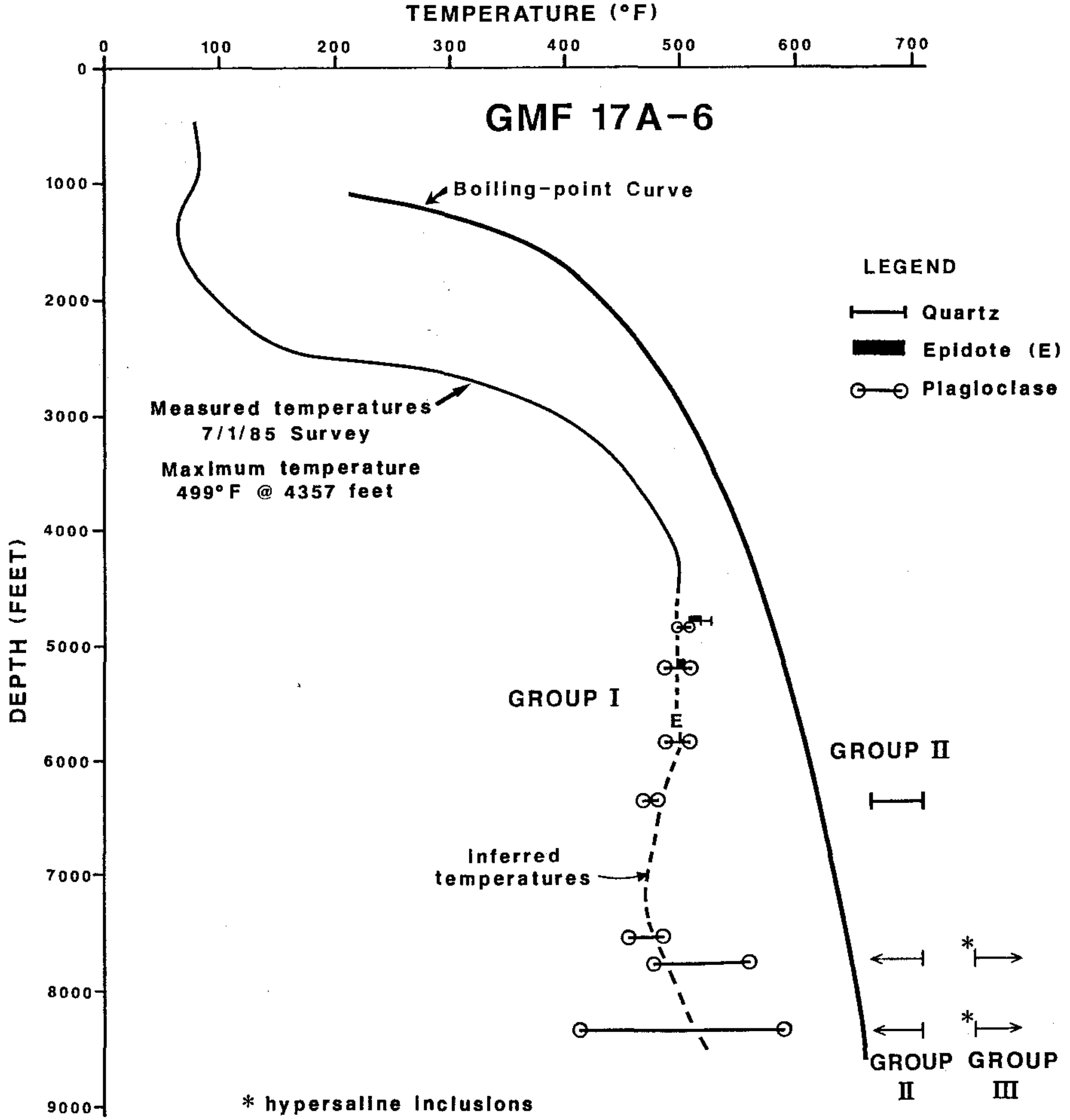


Figure 4 FLUID INCLUSIONS AND MEASURED TEMPERATURES FOR GMF 68-8


TEMPERATURE (°F)
0
100
200
300
400
500
600
700
GMF 17A-6
DEPTH (FEET)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Boiling-point Curve
Measured temperatures
7/1/85 Survey
Maximum temperature
499°F @ 4357 feet
LEGEND
Quartz
Epidote (E)
Plagioclase
E
GROUP I
GROUP II
Inferred
temperatures
*
*
GROUP
II
GROUP
III
* hypersaline inclusions
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GMF31-17

Temperatures of formation for inclusions from GMF31-17 (Figure 3) cluster in two groups: those which plot near the current temperature profile of the well, and those which in general plot above the boiling-point curve. Despite the differences in temperatures of formation, all but one set of inclusions have low salinities. The one exception is a set of hypersaline inclusions found as secondary inclusions in hydrothermal quartz at 3840 feet. Whether these low-salinity inclusions were formed during different phases of the same event, or two separate hydrothermal events, is unclear. However, the temperatures of the low-salinity Group I and Group II inclusions differ by 120° to 300°F. If the inclusions represent different phases of the same event, then the reservoir rocks at the sampled depths were probably impermeable through much of the thermal decline. The details of the data are discussed further below.

The fluid inclusions in the first group have temperatures of formation at or just greater than measured wellbore values (Figure 3), and are probably associated with the present hydrothermal system. Inclusion temperatures at 3840, 4860, 7020 and 7450 feet range from 5 to 35°F hotter than current wellbore temperatures, and indicate that temperatures at those depths have declined. Vapor-rich inclusions, which are generally indicative of boiling conditions, coexist with two-phase inclusions in samples of vein quartz at 8030 feet. However, temperatures of formation for the two-phase inclusions are 516 to 532°F, and are in good agreement with wellbore temperatures of 518°F. Therefore, it is likely the vapor-rich inclusions actually formed by the "necking down" of selected two-phase inclusions.

The second group of fluid inclusions were formed in two hydrothermal events: a low-salinity hydrothermal event, and the high-temperature, hypersaline event discussed above. The low-salinity fluid inclusions in Group II are all found in hydrothermal quartz, and have temperatures which generally plot above the current boiling-point curve. These inclusions were probably formed when the static-water level of the reservoir was higher than at present, which suggests the hydrothermal activity occurred during relatively recent times. The highest temperatures measured for the low-salinity inclusions are 662 to 680°F for inclusions found at 6560 feet. Temperatures of these inclusions exceed the boiling-point curve for a reservoir with a static-water level at the present ground surface, and suggests these inclusions were formed when the hydrothermal system contained excess heat and was overpressured.

GMF68-8

Fluid inclusion temperatures in GMF68-8 (Figure 4) are separable by depth into one group at 2200 to 6600 feet and a second group at 6600 to 8413 feet. Inclusions in the first group have temperatures which span a nearly continuous range from values near the boiling-point depth curve down to temperatures currently measured in the wellbore. No vapor-rich inclusions were observed in any of the higher-temperature inclusions of Group I. Temperatures of inclusions in the second group essentially match the current temperatures measured in the wellbore.

The inclusion temperatures suggest that higher relative permeabilities existed and possibly still exist at 2200 to 6600 feet than at 6600 to 8413 feet. The 5000 to 6600-foot interval of GMF68-8 is presently the most productive zone in the well (Rossknecht, 1988). However, the fluid inclusion data indicate that the temperatures of the hydrothermal activity there have declined 100°F from a high of about 612°F. Fluid inclusion temperatures in secondary minerals track the full decline, suggesting the interval remained permeable during the drop in temperatures. At 6600 to 8413 feet, inclusion temperatures for secondary minerals match the current well temperatures, and provide no evidence of previous higher temperature activity. The implications are that rocks at these depths were probably less permeable and possibly cooler during the 612°F activity than rocks at 5000 to 6600 feet. Therefore, fluid inclusion data suggest that the minor permeability observed at 6600 to 8413 feet in injection surveys (Rossknecht, 1988) is either recent in origin or not directly connected to the upper reservoir.

Although inclusion data indicate that ancient hydrothermal activity was hottest at 5000 to 6600 feet in GMF68-8, a 7°F temperature reversal is currently measured over this interval (Figure 4). The temperature reversal occurs between 4800 and 6000 feet and coincides with a zone of significant production (Rossknecht, 1988). The implication is that this zone of ancient high-temperature outflow or upflow is now a conduit by which cooler waters possibly enter the reservoir. If cooler waters are entering the reservoir at 4800 to 6000 feet, then continual production could increase the draw on the cooler water and possibly hasten the thermal decline of the reservoir in the GMF68-8 area. Additional long-term flowtest geochemical and enthalpy data are needed to test this hypothesis.

GMF17A-6

Temperatures of formation for fluid inclusions measured in GMF17A-6 (Figure 5) are separable into three groups. Group I inclusions have temperatures 80 to 200°F less than the boiling-point curve, and are found predominately in recrystallized plagioclase from the wall rock. Recrystallized plagioclase was extensively analyzed in this well because of a notable lack of vein filling minerals. The relative scarcity of veining in GMF17A-6 is consistent with the low apparent permeabilities observed during drilling and production tests. Group II inclusions have temperatures as high as 707°F (375°C), low salinities, and are found in hydrothermal quartz. Although inclusion temperatures in the hydrothermal quartz exist over a range of values, only the maximum temperatures are known. Group III inclusions have temperatures >752°F, are hypersaline, and are probably a derivative of an aqueous magmatic phase. These inclusions are found as secondary inclusions in primary quartz in granodioritic rocks.

Since the GMF17A-6 well was plugged at 4357 feet prior to obtaining a static temperature profile, a positive correlation between fluid inclusion temperatures and measured wellbore temperatures is not possible. However, the secondary minerals containing Group II and III fluid inclusions are probably relics of older or shorter-lived hydrothermal events than those containing the Group I inclusions. It is likely that the inclusions in the recrystallized plagioclase would be destroyed in a long-lived hydrothermal event at temperatures as high as those which formed the Group II and III inclusions (Reynolds, personal communication). Therefore, it is speculated that temperatures at depths greater than 4357 feet in GMF17A-6 are within 25 to 50°F of the Group I inclusion temperatures.

DISCUSSION

The fluid inclusion data suggest that when secondary minerals in the wells occur at anomalously low temperatures relative to those observed in other active fields, it is because temperatures in the current Glass Mountain hydrothermal system have declined from levels which were in thermal equilibrium with the mineralogy. A diagram summarizing the distribution of selected hydrothermal minerals with temperature is shown in Figure 6. Development of a working model relating secondary mineralogy and current temperatures would be useful in calibrating future casing points, and unravelling the history of hydrothermal activity at Glass Mountain. However, before the goal of developing such a working model can be met, additional fluid inclusion temperature data are needed for the diagnostic secondary minerals of epidote, actinolite and biotite. Presented below is a discussion of the documentable relationships which are observed between several secondary mineralogy and current temperatures. In addition, specific suggestions are made for the additional fluid inclusion analyses which would increase the understanding of the Glass Mountain hydrothermal system.

Fluid inclusions have been successful in establishing the relationship between wellbore temperatures and hydrothermal clinopyroxene in GMF31-17. Although hydrothermal clinopyroxene occurs in other active geothermal systems at temperatures in excess of 572°F (Bird, and others, 1984), secondary clinopyroxene is found in GMF31-17 at current temperatures of 515 to 542°F. Fluid inclusions were surveyed in anorthoclase in a vein at 8421 feet which contained clinopyroxene, quartz, oligoclase, and anorthoclase. The anorthoclase was a late-stage mineral that has inclusion temperatures of 554 to

572°F, and appears to have formed after the clinopyroxene and orthoclase. Therefore, the clinopyroxene probably formed at temperatures of 572°F or higher, and is either a relic of the currently active system when temperatures were 30 to 60°F hotter, or was formed during an older hydrothermal event.

More fluid inclusion data are needed to establish at what temperatures epidote was formed in all three of the wells. Inclusions in epidote from GMF68-8 and GMF17A-6 (Figures 4 and 5) indicate the mineral formed at temperatures ranging from 496 to 608°F, and are consistent with the ≥495°F occurrence of epidote in those wells (Carrier, 1989c). However, epidote in GMF31-17 exists in equilibrium with an alteration assemblage at depths as shallow as 2100 feet and wellbore temperatures as low as 430°F. The first occurrence of epidote at 430°F is 30°F less than the mineral's 460°F onset in several other fields (Brown, 1978), and 65°F less than its 495°F onset in GMF68-8 and GMF17A-6. Epidote has been surveyed in GMF31-17, but only at 3840 feet (Figure 3). The temperature of formation for epidote at 3840 feet ranged from 486 to 495°F, and is comparable to current wellbore temperatures of 479°F (Figure 2).

Temperatures of formation for actinolite are measured only in GMF68-8 on samples from 8409 and 8413 feet, and range from 538 to 565°F. Although static temperatures are not available for GMF68-8 below 8100 feet, the mineral temperatures are approximately those expected in the well when temperatures of 556°F at 8100 feet are extrapolated to 8413 feet (Figure 4). However, the first occurrence of actinolite is at much shallower depths than 8409 feet and lower temperatures than 556°F in all the wells: 6400 feet and 535°F in GMF68-8, 4220 feet and 480°F in GMF31-17, and 4620 feet and about 500°F in GMF17A-6 (Carrier, 1989c). More fluid inclusion data are needed to establish the relationship between actinolite and wellbore temperatures at these shallower depths. Actinolite should also be further studied in GMF31-17, where it occurs at 7800 feet and 511°F in veins containing actinolite, biotite and talc.

Hydrothermal biotite is observed in other geothermal fields at temperatures as low as 428°F, however, it is more commonly found at temperatures above 572°F (Elders, and others, 1981; Hulen and Nielson, 1986). At Glass Mountain, it is suspected that the biotite was formed during a hydrothermal event associated with the intrusion of the granodiorites drilled in GMF17A-6 and GMF31-17. In GMF17A-6 the first biotite occurs 290 feet above the granodiorite in metavolcanics at 7400 feet, and in GMF31-17, the first biotite occurs 610 feet above the granodiorite in altered volcanics located at 7900 feet. Hydrothermal biotite is also observed in GMF68-8 at 8409 feet, or just eight feet from the well's total depth, suggesting that granodiorite exists 300 to 1000 feet from the bottom of the well. Therefore, fluid inclusion analysis of actinolite in the veins at 7800 feet will possibly establish the mineralogical and thermal significance not only of actinolite, but of biotite and talc as well.

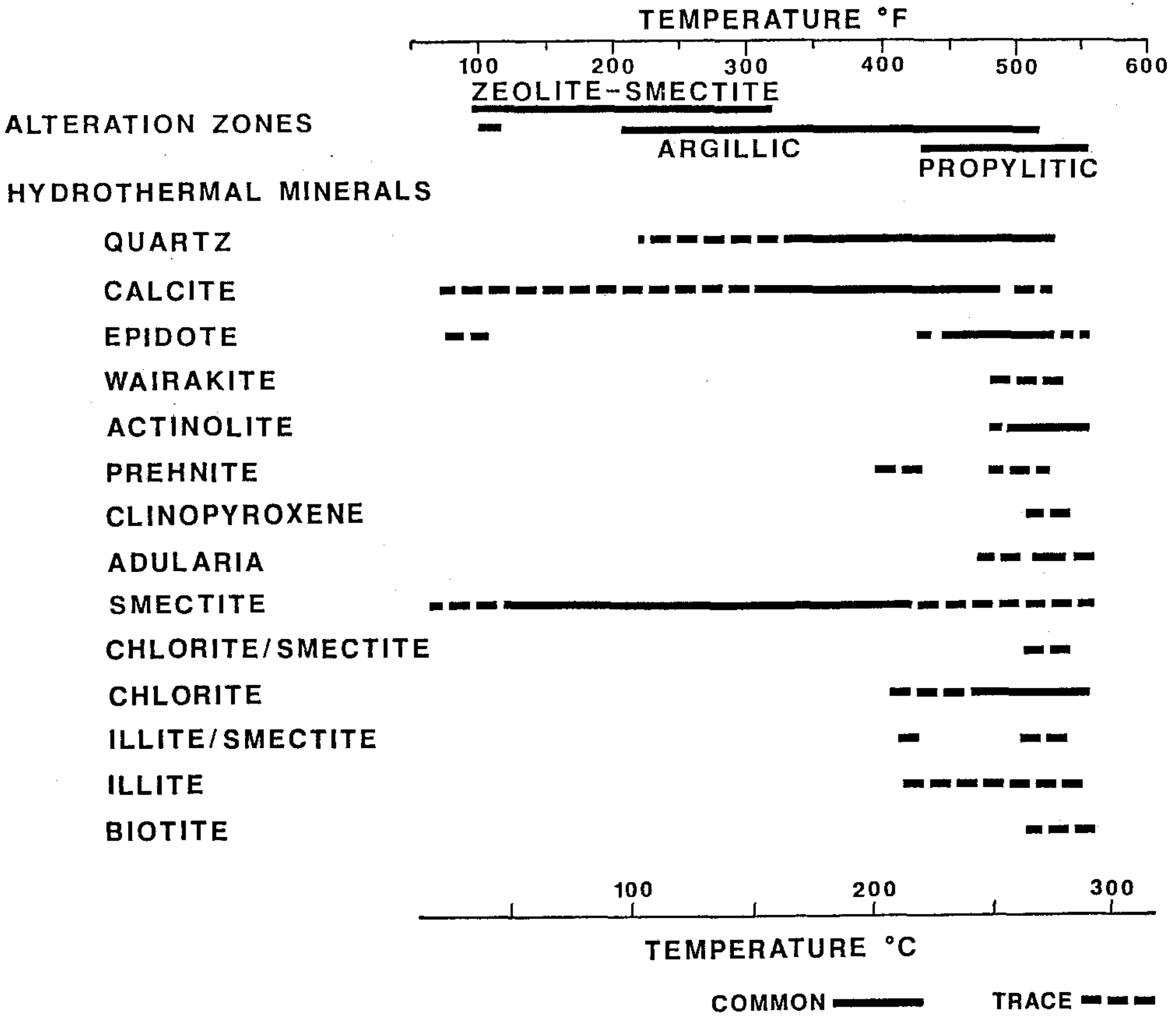


Figure 6: Temperature ranges for the occurrence of hydrothermal minerals and alteration zones in Glass Mountain deep wells (Carrier, 1989). No temperature data are available for depths greater than 4550 feet in GMF17A-6. Epidotes occurring at the anomalously low temperatures of 100°F are found in GMF31-17 as accidental fragments in a dacite lava.

REFERENCES

Bird, D.K., Schiffman, P., Elders, W.A., Williams, A.E., and McDowell, S.D., 1984, Calc-silicate mineralization in active geothermal systems. Econ. Geol., v. 79, p. 671-695.

Brown, P.R.L., 1978, Hydrothermal alteration in active geothermal fields. Ann. Rev. Earth Planet. Sci., v. 6, p. 229-50.

Carrier, D.L., 1987, Analysis of Mineralogy and fluid inclusion data from Glass Mountain area temperature boreholes. Unocal Memorandum, 22 p.

Carrier, D.L., 1989a, Analysis of chemical data from 1988 flowtests of GMF68-8 and GMF31-17. Unocal Memorandum, 34p.

Carrier, D.L., 1989b, Glass Mountain borehole and well data, 1981-1988. Unocal Memorandum, 39p.

Carrier, D.L., 1989c, Hydrothermal alteration and well lithologies for Glass Mountain. Unocal Memorandum, 28p.

Craig, J.R., and Vaughan, D.J., 1981, Ore Microscopy and Ore Petrography, John Wiley and Sons, New York, p. 168-180.

Elders, W.A., Hoagland, J.R., and Williams, A.E., 1981, The distribution of hydrothermal mineral zones in the Cerro Prieto geothermal field of Baja California, Mexico. Geothermics, v. 10, p. 245-253.

Hausback, B.P., 1984, Surficial geology of the Medicine Lake Highland. Unocal Memorandum, 20p.

Hulen, J.B., and Nielson, D.L., 1986, Hydrothermal alteration in the Baca geothermal system, Redondo Dome, Valles Caldera, New Mexico. Jour. Geophys. Res., v. 91, No. B2, p. 1867-1886.

Potter, R.W., Jr., Clynne, M.A., and Brown, D.L., 1978, Freezing point depression of aqueous sodium chloride solutions. Econ. Geol., v. 73, p. 284-285.

Reynolds, T.J., and Beane, R.E., 1985, Evolution of hydrothermal fluid characteristics at the Santa Rita, New Mexico porphyry copper deposit. Econ. Geol., v. 73, p. 1328-1347.

Roedder, E., 1984, Fluid Inclusions. Mineralogical Society of America: Reviews in Mineralogy, v. 12, 646p.

Rossknecht, T., 1988, Glass Mountain well evaluation: Report to the Bureau of Land Management. Unocal Memorandum.

Appendix I

Fluid Inclusion Basic Data from Fluid Inc.

November 18, 1987

INVOICE

TO: Dan Carrier
Unocal Geothermal Division
P.O. Box 6854
Santa Rosa, CA 95406

FROM: T. James Reynolds
Social Security #461-96-3072

FOR: AFE #460912

AMOUNT: 36 hours data collection and report compilation at $50/hr.

TOTAL AMOUNT DUE: $1,800.00

PAYMENT DUE UPON RECEIPT

Please remit check to:

T. J. Reynolds
P.O. Box 6873
Denver, CO 80206

November 18, 1987

MEMO

TO: Dan Carrier
Unocal Geothermal

FROM: Jim Reynolds
FLUID INC.

RE: Continuation of fluid inclusion studies of report dated April 16, 1987.

The fluid inclusion data collected from 3 holes are attached. Data from sample 56-3-1723.5 was collected from veinlets in a core specimen. All other data are from drill cuttings. Also attached are information required to pressure correct the fluid inclusion data.

56-3-1723.5

Veinlet paragenesis: epidote + quartz ⟶ wairakite ⟶ calcite

Incs in Qtz.

T_h	T_{mp}	sal
84°C		
113		
115		
117		
125	-0.7°C	1.25 wt% NaCl eq.
127		

Incs. in Wairakite

T_h	T_{mp}	sal
100°C		
104	-1.2°C	2.1 wt% NaCl eq.
116	-1.2	2.1
117		
141		
144		
149	-1.1	1.9

HOLE 68

SALINITIES: All inclusions studied exhibit final melting of ice between -0.5°C and 0.0°C indicating that the salinity of the geothermal fluid responsible for propylitic alteration (plag + mafics → epidote + quartz + chlorite + calcite) is less than 1 weight percent NaCl equivalent.

HOMOGENIZATION TEMPERATURES (°C):

SAMPLE DEPTH	EPIDOTE	QUARTZ	PLAG	NOTES
2200-20	--	230-240	230-240	Rock is not propylitically altered; mostly now quartz + clay. Two planes of vapor-rich inclusions indicate boiling at this depth or lower.
4420-40	--	--	270-280	--
5020-40	280-320	310-320	280-320	--
5540-60	275-280	270-320	260-320	Wairakite: 240-260
6560-70	260-285	290-315	280-320	--

HOLE 17A-6

SALINITIES: Unless otherwise noted, all inclusions studied exhibit final melting of ice between -0.5°C and 0.0°C indicating that the salinity of the geothermal fluid responsible for propylitic alteration (plag + mafics ⟶ epidote + quartz + chlorite + calcite) or for initial hydrothermal alteration of feldspars in the intrusive rock of this hole is less than 1 weight percent NaCl equivalent.

HOMOGENIZATION TEMPERATURES (°C):

SAMPLE DEPTH	EPIDOTE	QUARTZ	PLAG	NOTES
4800-10	260-265	265-270	255-260	--
5210-20	254,256	--	250-260	--
5800-10	253	--	245-255	--
6350-60	--	350-375*	235-240	--
7260-70	--	--	--	silicified rock
7570-80	--	--	225-240	sill (?) salinities 2-6 wt%
7720-30	--	≤375*	235-285	--
8350-60	--	≤375*	200-300	--

*high salinity (>40 wt% NaCl eq.), high temperature (>400°C) magmatic inclusions also sparsely present in quartz phenocrysts along healed microfractures - origin of such inclusions is explained in Reynolds and Beane (1985).

PRESSURE CORRECTING THE FLUID INCLUSION DATA

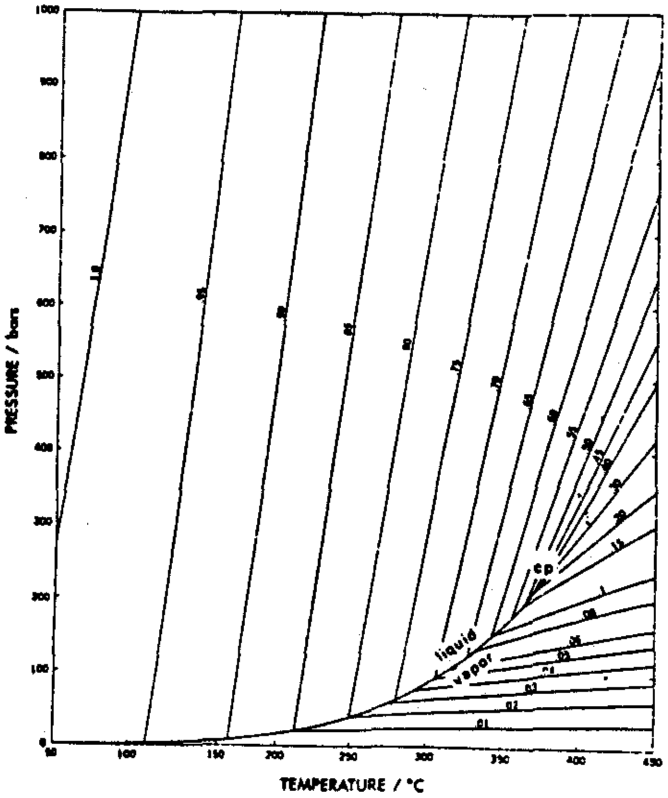
Fluid inclusions provide one with only a minimum temperature condition of entrapment in most cases. To obtain the true temperature of entrapment, the pressure must be known. Obviously, there is considerable interpretation involved in obtaining a pressure, so data from inclusions is typically presented without a pressure correction. Please see Roedder and Bodnar, 1980, Geologic Pressure Determinations from Fluid Inclusion Studies, Ann. Rev. Earth Planet. Sci. 8:263-301 for a thorough discussion of the limitations and procedures.

The relationship between pressure and depth is pressure equals density times depth times gravity, or with all necessary conversion factors included:

$$P \text{ (bars)} = \rho \text{ (g/cm}^3\text{)} \times d \text{ (ft)} \times .0299$$

A density of 1.0g/cm^3 is often assumed to be a good approximation for an overlying column of water if the sample is at hydrostatic load. A density of 2.7g/cm^3 is often assumed to be a good approximation for an overlying column of rock if the sample is at lithostatic load.

As all the inclusions of this study are almost pure water, once pressure is approximated and the homogenization temperature is determined, use the following pure water phase diagram to determine the true temperature of entrapment of the inclusions:



ORIGINAL

DAN CARRIER

JAN 4 1989

December 29, 1988

MEMO

TO: Dan Carrier
Unocal Geothermal

FROM: Jim Reynolds
FLUID INC.

RE: Continuation of fluid inclusion studies of report dated April 16, 1987 and MEMO of November 18, 1987

The fluid inclusion data collected from 2 holes are attached. Sample 31-17-8421 has an unknown mineral (K-spar?, plag?) in a vein containing pyroxene. Paragenesis of this mineral is not obvious: it may be contemporaneous with pyroxene or later(?) actinolite(?). More work is needed to tie down the identity and parageneses of the minerals in this pyroxene-bearing vein.

HOLE 31-17

SALINITIES: Except for sample 3840-50, all inclusions studied exhibit final melting of ice between -0.5°C and 0.0°C. Sample 3840-50 contains a few high salinity (>40 wt%NaCl eq.), high temperature (>400°C) magmatic inclusions, as well as vapor-rich inclusions, sparsely present in fragments of hydrothermal quartz. Origin of such inclusions is explained in Reynolds and Beane (1985).

HOMOGENIZATION TEMPERATURES (°C):

SAMPLE DEPTH	QTZ	EPID	UNKNOWN	NOTES
2540-60	250-260			rock not propylitically altered; mostly now quartz + clay
3840-50	290-305	250-255		
4860	255-265			
5780	V330-340			
6560	*350-360			
7020	255-265B?			
7450-60	250-260			
8030-40	V260-270B V330-340B V330-360	255-265		
C8421			280-290	needs more work

*Secondary inclusions only

C = core specimen; other specimens are from drill cuttings

V = vein material; other material is replacement from wall rock

B = boiling

PAID

29 December 1988

INVOICE

To: Dan Carrier
Unocal Geothermal Division
3576 Unocal Place, P.O. Box 6854
Santa Rosa, CA 95406

FROM: T. James Reynolds
Social Security #461-96-3072

FOR: Continuation of fluid inclusion studies on 17 additional samples

AMOUNT:	17 doubly-polished plates at $30/each	$ 510.00
	27 hrs. data collection and compilation at $50/hr.	1,350.00
	liquid and gaseous N_2 expenses	31.00
TOTAL DUE:		$ 1,891.00

PAYMENT DUE UPON RECEIPT

Please remit check to:

T. J. Reynolds
P.O. Box 6873
Denver, CO 80206

28 March 1989

MEMO

TO: Dan Carrier
Unocal Geothermal

FROM: Jim Reynolds
FLUID INC.

RE: Identification of unknown alteration mineral with primary inclusions in sample 31-17-C8421 (report of December 29, 1988).

The vein in this sample contains clinopyroxene, quartz, oligoclase, and oligoclase gives way to anorthoclase. Anorthoclase has abundant primary fluid inclusions which homogenize at 280-290°C and contain dilute fluids (<1 wt% NaCl eq.).