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TOPICAL REPORT

HYDROTHERMAL ALTERATION AT THE ROO HOT SPRINGS THERMAL AREA, UTAH: CHARACTERIZATION OF ROCK TYPES AND ALTERATION IN GETTY OIL COMPANY WELL UTAH STATE 52-21

by
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AREA, UTAH: CHARACTERIZATION OF ROCK TYPES AND ALTERATION
IN GETTY OIL COMPANY WELL UTAH STATE 52-21

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Geoffrey H. Ballantyne

ABSTRACT

Getty Oil Company well 52-21 in the Roosevelt Hot Springs thermal area was drilled to 7500 feet in predominantly upper amphibolite facies metamorphic rocks. All lithologies in the drill hole are pervasively but weakly altered: the alteration assemblage is chlorite + sericite + clays with occasional traces of calcite, above 2300 feet, and chlorite + sericite + clays + calcite ± epidote below 2500 feet. A zone of increased alteration intensity from approximately 1800 feet to 2300 feet occurs within and adjacent to a dacite dike which cuts the metamorphic rocks. A second zone of stronger alteration extends from 6000 feet to the bottom of the drill hole.

The drill hole which is located approximately 5000 feet south of the centre of the silica apron known as the Opal Mound was apparently drilled beyond the influence of acid, high-sulfate brines such as have affected the upper portions of drill holes 72-16, 76-1 and University of Utah 1A and 1B.

INTRODUCTION

A research program consisting of petrographic work, x-ray diffraction, whole rock analysis and microprobe analysis of specific minerals has been carried out on drill cuttings from Getty Oil Company well 52-21 in the Roosevelt Hot Springs thermal area.

Drill hole 52-21 is located 2310 feet west and 990 feet south of the northeast corner of S.21, T27S, R9W. This location is approximately 5000 feet south of the centre of the Opal Mound. The hole was rotary drilled to a final depth of 7500 feet. (This, and all depth footages quoted in this report, are measured from the kelly bushing, 22 feet above ground level.) No diamond drill core was studied.

Drill cuttings were collected over 10 foot intervals during drilling and 74 samples, generally one from each 100 foot interval of the hole, were selected for use in this study. The sample selected from each 100 foot interval was that for which the most material was available. This should have involved no subjective geologic bias but may have biased the selection towards rocks with certain drilling characteristics. All 74 samples were prepared as thin sections and studied petrographically, 15 were prepared as polished thin sections and studied under reflected light, and for two of these microprobe analyses were made of the major minerals present; 17 samples were selected for whole rock chemical analyses and x-ray diffraction determination of clay mineralogy.

LABORATORY METHODS

Thin sections and polished thin sections were prepared from 0.5 to 1 gram splits of the drill cuttings cemented in epoxy and usually contained between 40 and 100 rock fragments. Mineral abundances were estimated visually. Where more than one rock type was present, proportions of each were determined by counting the rock fragments of each type.

Microprobe analyses were made using a 3-channel ARL electron microprobe operating at an accelerating voltage of 15kv and a sample current of 0.03 micro-amperes. X-rays were counted at 10 spots on each grain for approximately 13 seconds. Clinopyroxene and feldspar standards were used for most major and minor elements. A biotite standard was used for BaO and F, and a scapolite standard for Cl. The data were matrix corrected using the correction factors of Bence and Albee (1968) and Albee and Ray (1970). The computer program used for the correction calculates the structural water present based on a user-entered estimate of the ferric to total iron ratio, and utilizes this in the correction. For feldspars the program calculates the SiO₂ and Al₂O₃ contents on the basis of the CaO, K₂O, Na₂O and BaO present and corrects for this matrix.

Fused glass disks were prepared for x-ray fluorescence analyses using the method of Norrish and Hutton (1969). Carbon dioxide was determined by the method of Shapiro (1975), and sulfur was determined using a LECO furnace and titration. The clay fraction was extracted by peptizing the pulverized sample with calgon and centrifuging. X-ray diffraction patterns were obtained for oriented smears on glass slides following air-drying, heating to 250°C, heating to 550°C, and vapor glycolation at 60°C as appropriate.

ROCK TYPES

Drill hole 52-21 penetrated a relatively simple geologic section consisting of upper amphibolite facies metamorphic rocks overlain by approximately 600 feet of alluvium. One or more dikes of latite or dacite cut the metamorphic rocks in the interval 2050 to 2400.

The rock types are described in detail and compared to those occurring in other drill holes and in outcrop in the following sections. The information is presented diagrammatically in Figure 1.

Alluvium

The alluvium is a lithic arkose derived from volcanic, plutonic, and possibly metamorphic rocks, exposed in the Mineral Mountain Range to the east. It is apparently poorly cemented since only a few grains have limonite or carbonate coatings. Certainly there is no pervasive opal or chalcedony cement such as occurs in Thermal Power Company Well 72-16. Only one opal fragment was noted in the six thin sections of alluvial rock.

The source rocks for the alluvium include three identifiable groups of volcanic rocks known to outcrop in the Mineral Mountains (Evans and Nash, 1977). The volcanic rocks identified in the alluvium are: 1) Banded obsidian similar to that occurring as flows on Bailey Ridge and in Wild Horse Canyon. These flows which have been dated at 0.77 ± 0.08 m.y. (Lipman et al., 1978), show prominent flow banding and contain abundant microlites. 2) Devitrified rhyolite similar to that occurring in Big Cedar Cove and in Corral Canyon. Fragments of this rock type are dark and iron stained and do not exhibit banding or spherulites. The Big Corral Canyon rhyolite was dated by Lipman et al. at 7.90 ± 0.3 m.y. 3) Pumice lapilli such as occurs

Figure 1. Alteration and Rock Types in Getty Oil Company well 52-21.

in Ranch canyon. Material from this unit has been dated by Lipman et al. at 0.64 ± 0.04 m.y.

Lithic fragments of medium to coarse grained rock in the alluvium include microcline-bearing leucogranite, hornblende-plagioclase rock, and biotite-plagioclase-quartz fragments. The microcline bearing rock is definitely transported material since microcline does not occur in the underlying bedrock. The other rock types may be metamorphic and locally derived.

Since drill cuttings of the alluvium are not significantly more rounded than those derived from the underlying bedrock the criterion for a sample being alluvial is the occurrence of either volcanic rock or microcline-bearing lithic fragments. The deepest sample in which microcline-bearing rock was observed in thin section is from 550-560 feet.

Metamorphic Rocks

Below 560 feet the predominant lithologies are medium to coarse grained quartzo-feldspathic rocks. Quartz, alkali feldspar, oligoclase and biotite are always present, hornblende is almost always present and muscovite and sillimanite are present in some samples. Sphene, apatite and zircon are ubiquitous and probably present in all samples in at least trace amounts. Additional mineral phases considered to be due to hydrothermal alteration of those described above are discussed later in this report.

The following listing puts some numeric constraints on the abundances of various primary rock constituents as estimated from 68 thin sections.

quartz	5 to 20%	sillimanite	0 to 10%
alkali feldspar	10 to 30%	garnet	trace
plagioclase	10 to 30%	sphene	trace to 30%
Biotite	1 to 20%	apatite	trace to 2%
hornblende	0 to 50%	zircon	trace
muscovite	0 to 5%	allanite	0 to trace

A feature which is not apparent from the estimates above, but is very obvious in the rocks, is the bimodal distribution of minerals in two different kinds of fragments. Both within samples and to a lesser extent between samples there is a tendency for hornblende, biotite, plagioclase, sphene, and apatite to occur together, and for quartz, alkali feldspar, plagioclase and minor biotite to occur together. The first of these two rock variants is finer grained and more equigranular with an average grainsize of 0.1 to 0.3 mm, while the quartz-alkali feldspar rock consists of unevenly sized grains with maximum dimensions of up to 2 mm. The existence of these two rock variants suggests either a layering within a single rock type or an intimate mixture of two distinct rock types, (a contact relationship). Since it is improbable that any drill hole would intersect such a contact over long distances it appears that the drill hole has penetrated a banded or gneissic rock type over most of its length. Occasional samples in which strong foliation is evident strongly support this argument, however such samples are uncommon. The periodic appearance of sillimanite over the length of the drill hole (see Figure 1) severely restricts the size of any possible post-metamorphic igneous rock intervals. In addition, with one minor exception noted below, plagioclase compositions

are very consistent, both between mafic-rich and quartzo-feldspathic rock variants and over the length of the drill hole.

Foliated gneisses, locally containing sillimanite, outcrop at several places along the western flank of the Mineral Mountain Range, the closest outcrops lying approximately 2000 feet northeast of drill hole 52-21.

Mineral Compositions

Microprobe analyses of plagioclase, alkali feldspar, biotite and hornblende were made for samples from 3570-3580 feet and 6680-6690 feet. Chlorite was also analysed in the deeper sample. The analyses are presented in Tables 1 and 2 along with corresponding structural formulae. Ferric to total iron weight ratios were not determined but estimates were made in order to achieve good matrix corrections. The biotites were assigned a ratio of 0.05, that of a biotite reported by Deer et al. (1966), from a garnet-sillimanite-mica schist. The amphiboles were arbitrarily assigned a middle-of-the-range value of 0.50.

The biotites have compositions typical of those reported from zones of high grade regional metamorphism (Deer et al., 1966) with the exception that they have higher fluorine contents (0.23 to 0.72%) than are common in such rocks.

The amphiboles are properly classified as common hornblendes since they have high calcium contents, low alkali contents and silica occupying 6.6 to 6.8 of the 8 tetrahedral sites.

The alkali feldspars are orthoclases with mole fraction Or in the range 0.87 to 0.90. They contain significant barium: up to 3.05 percent BaO in one sample. The microprobe work confirms the petrographic

TABLE 1 ANALYSES OF BIOTITES HORNBLENDES AND CHLORITES FROM DRILL HOLE 52-21

	3570-3580'		6680-6690'		3570-3580'		6670-6680'		6670-6680'	
	Biotite 1	Biotite 2	Biotite 1	Biotite 2	Hornblende 1	Hornblende 2	Hornblende 1	Hornblende 2	Chlorite 1	Chlorite 2
SiO2	34.5	36.6	36.8	35.7	45.6	45.7	44.5	45.8	25.3	25.4
TiO2	2.81	2.71	3.56	3.73	.52	.87	1.40	1.04	.09	.04
Al2O3	18.2	17.7	14.0	13.9	7.77	7.14	8.39	7.92	18.1	20.3
FeO	19.9	13.9	18.3	20.2	8.70	8.43	8.56	8.63	20.6	20.6
Fe2O3	1.16	.81	1.07	1.18	9.67	9.37	9.52	9.60	3.30	3.29
MnO	.21	.06	.33	.44	.43	.38	.49	.38	.59	.52
MgO	8.37	13.7	12.3	10.2	11.5	11.9	11.8	12.0	18.5	17.1
CaO	.01	.05	.07	.05	12.0	11.9	9.42	9.47	.25	.01
K2O	9.04	9.44	9.42	9.20	.76	.82	1.06	.96	.04	.02
Na2O	.21	.20	.08	.09	1.10	1.35	1.36	1.36	.03	.01
BAO	.53	.20	.52	.25	.01	.01	.07	.01	.01	.00
CL	.03	.04	.05	.07	.05	.05	.04	.01	.00	.00
F	.29	.72	.48	.46	.13	.29	.26	.13	.13	.18
H2O	3.77	3.70	3.69	3.66	1.95	1.88	1.90	1.97	11.5	11.5
O=CLF	.13	.31	.22	.21	.07	.13	.12	.06	.06	.08
TOTAL	99.2	100.1	100.9	99.34	100.3	100.2	98.9	99.3	98.9	99.3

NUMBER OF OXYGENS ON THE BASIS OF 24 OXYGENS FOR BIOTITE AND HORNBLENDE AND 18 OXYGENS FOR CHLORITE

Si	5.34	5.45	5.58	5.55	6.73	6.75	6.65	6.77	2.68	2.66
Ti	.33	.30	.41	.44	.06	.10	.16	.12	.01	.00
Al	3.32	3.10	2.50	2.55	1.35	1.24	1.48	1.38	2.26	2.51
FeII	2.57	1.73	2.32	2.63	1.07	1.04	1.07	1.07	1.83	1.80
FeIII	.14	.09	.12	.14	1.07	1.04	1.07	1.07	.26	.26
Mn	.03	.01	.04	.06	.05	.05	.06	.05	.05	.05
Mg	1.93	3.03	2.77	2.37	2.53	2.62	2.62	2.64	2.93	2.67
Ca	.00	.01	.01	.01	1.90	1.88	1.51	1.50	.03	.00
K	1.78	1.79	1.82	1.82	.14	.16	.20	.18	.01	.00
Na	.06	.06	.02	.03	.32	.39	.39	.39	.01	.00
BA	.03	.01	.03	.02	.00	.00	.00	.00	.00	.00
CL	.01	.01	.01	.02	.01	.01	.01	.00	.00	.00
F	.14	.34	.23	.23	.06	.14	.12	.06	.04	.06
OH	3.85	3.65	3.76	3.76	1.92	1.85	1.87	1.94	7.96	7.94

TABLE 2: ANALYSES OF FELDSPARS FROM DRILL HOLE 52-21

	3570-3580'		6680-6690'		3570-3580'		6680-6690'	
	Plagioclase 1	Plagioclase 2	Plagioclase 1	Plagioclase 2	Orthoclase 1	Orthoclase 2	Orthoclase 1	Orthoclase 2
SiO ₂ *	58.8	60.5	59.2	61.5	67.0	65.5	65.5	65.9
Al ₂ O ₃ *	23.8	24.7	22.6	22.1	19.3	18.8	20.1	18.8
CaO	5.89	6.29	4.80	3.85	0.10	0.07	0.18	0.03
K ₂ O	0.31	0.34	0.23	0.42	15.3	14.8	14.7	15.3
Na ₂ O	7.74	7.86	8.24	8.87	1.33	1.41	1.09	1.20
BaO	0.03	0.01	0.05	0.04	0.65	0.53	3.05	0.36
TOTAL	96.6	99.7	95.1	96.8	103.7	101.1	104.6	101.6
Number of ions on the basis of 8 oxygens.								
Si	2.71	2.70	2.76	2.81	2.98	2.99	2.94	2.99
Al	1.29	1.30	1.24	1.19	1.02	1.01	1.06	1.01
Ca	.29	.30	.24	.19	.00	.00	.01	.00
K	.02	.02	.01	.02	.87	.86	.84	.89
Na	.69	.68	.75	.79	.11	.12	.09	.11
Ba	.00	.00	.00	.00	.01	.01	.05	.01
Mole fractions (recalculated to total 1.0).								
An	.30	.31	.25	.20	.00	.00	.01	.00
Or	.02	.02	.02	.03	.89	.88	.90	.90
Ab	.68	.67	.73	.78	.11	.12	.09	.10

* Silica and alumina were calculated on the basis of the CaO, K₂O, Na₂O and BaO present.

observations that the alkali feldspars are homogenous and unmixed. Standard deviations for sodium for the 10 points analysed in each grain are less than one third of the sodium determined, much lower than they would be if perthites or cryptoperthites were present.

The plagioclase is oligoclase in the range An₁₉ to An₃₁. The calcium-rich end of this compositional range corresponds closely with the 14° maximum extinction angle measured on albite twins in these samples. Since maximum extinction angles in the range 12 to 16° were measured in almost all samples, the analysed plagioclases are representative. The microprobe work indicates that the plagioclase is unzoned which confirms petrographic observation. Barium oxide contents do not exceed 0.05%.

Petrogenesis of the Gneiss

The mineralogy of the gneisses places them in the sillimanite-stable zone of the amphibolite facies. Several samples show coexisting quartz, orthoclase, sillimanite and muscovite suggesting proximity in pressure-temperature space to the univariant equilibrium curve for the reaction:

Experimental data on this reaction has been published by Evans (1965). It should be noted however that there is no textural evidence for this specific reaction occurring in the rocks from this drill hole. In fact petrographic study seems to indicate that biotite may be the principal reactant mineral involved in sillimanite formation since sillimanite needles are commonly seen growing within biotite grains.

Meta-Gabbro

A meta-gabbro composed chiefly of plagioclase (80%) and blue-green hornblende (20%) comprises approximately 3 percent of the rock fragments in the samples from 2540-2550 feet and 2660-2670 feet. This rock is distinguished from other amphibole and plagioclase-rich horizons in the metamorphic rocks by a pronounced equigranular texture dominated by polygonal-shaped plagioclase grains and also by the calcic nature of the plagioclase. The plagioclase is labradorite near An_{60} and is twice as calcium-rich as any other plagioclase noted in the drill hole. The rock has an average grain size of 0.2 to 0.4 mm. Traces of biotite and alkali feldspar occur and apatite and sphene are common accessories.

Dacite Dikes

Fragments of fine grained holocrystalline dacite comprise 80 percent of the sample from 2050-2060 feet, 25 percent of the sample from 2160-2170 feet, 20 percent of the sample from 2240-2250 feet and 10 percent of the sample from 2330-2340 feet. Trace amounts of dacite in deeper samples are probably due to contamination. The drill hole is inferred to have intersected one or more dacite dikes in the interval 1970 feet (the end of the preceeding sample studied) to 2340 feet.

The dacite consists predominantly of slender lathes of plagioclase, 0.1 to 0.3 mm long, and similarly sized plates of biotite and needles of hornblende. Quartz and alkali feldspar are equant, finer grained, and occur interstitially.

The plagioclase grains are zoned and the cores are largely replaced by sericite in most fragments. Since they are small, altered and poorly

twinned, optical compositional determinations are uncertain. Maximum extinction angles on albite twins are in the range 11° to 14° indicating compositions of either An_{8-11} or An_{29-32} . The mafic minerals are almost completely altered in some samples and in others, (where they are mostly biotite), are only weakly altered. Grain size, degree of orientation (a minority of fragments are pilotaxitic) and the mafic mineralogy, vary somewhat between and within samples.

The dacite is similar to the type III dacite, the most abundant hypabyssal rock reported from drill hole 14-2 (Ballantyne, J.M., 1978, p. 7). It is apparently not closely similar to any of the hypabyssal rock variants noted in drill hole 72-16 (Rohrs and Parry, 1978, p. 7-9). The following is an estimated average composition for the dacite in drill hole 52-21:

quartz	5-10%
plagioclase	50%
biotite	25%
hornblende	10%
leucoxene	5%
opaques	

ALTERATION

All of the samples studied from drill hole 52-21 show obvious signs of hydrothermal alteration. The alteration assemblage is chlorite + sericite + clays + traces of calcite in the upper portion of the drill hole giving way to chlorite + sericite + clay + calcite ± epidote below 2300 feet.

Methods of Investigation

Determination of the alteration assemblage, textural relationships between reactant and product minerals, and overall alteration intensity were made chiefly by a petrographic study of the seventy four thin sections and fifteen polished thin sections. Relative mineral abundances were estimated visually for the 74 thin sections and an estimate was made of the average percent replacement of plagioclase in each sample.

A limited characterization of the composition of reactant and product mineral phases was made by analysing biotite, hornblende, plagioclase and alkali feldspar in samples from 3570-3580 feet and 6680-6690 feet and chlorite from the 6680-6690 foot sample.

Alteration Intensity and Mineral Abundances

Estimated percent replacement of plagioclase and relative abundance of the various product and reactant phases is shown on Figure 1.

The principle features apparent on this figure are:

- 1) Calcite is present only rarely, and in trace amounts, above 2300 feet and increases in abundance down-hole from that point.
(Calcite first appears in hornblende pseudomorphs and in veins or mylonite zones.)

- 2) Calcite appears as a replacement of plagioclase only below 2500 feet.
- 3) Epidote occurs only below 2300 feet.
- 4) There is a complimentary relationship between hornblende abundance, and the intensity of plagioclase alteration and chlorite and calcite abundances. This suggests that hornblende is highly susceptible to alteration and that it is replaced by chlorite and calcite, both suggestions being supported by textural observations.
- 5) Both the plagioclase alteration intensity graph and the relative mineral abundance graphs indicate two zones of more intense alteration: (i) the zone from 1800 to 2300 feet which contains the dacite dikes, and (ii) the lowermost 1500 feet of the drill hole.

Product - Reactant Relationships

Biotite is commonly partially or completely altered to chlorite plus a titanium oxide. The titanium oxide, which occurs as fine needles within the chlorite, serves to distinguish chlorite replacing biotite from chlorite replacing hornblende. (The direct evidence for this is seen in partially replaced biotite and hornblende grains.) As shown in Tables 1 and 2, the reactant biotites have considerably higher titanium contents (2.71 to 3.73 percent) than the hornblendes (0.52 to 1.40 percent).

Hornblende is often partially or wholly replaced either by chlorite or by fine mixtures of chlorite, calcite and clay. Inclusions of apatite are

very common in fresh hornblende grains and the apatite crystals survive the alteration and assist in identifying pseudomorphs after hornblende.

Plagioclase is always partially replaced by clays and by sericite, and at depth by calcite, and rarely by chlorite. Except in the upper 800 feet of the hole, which has probably been subjected to supergene conditions, sericite is more abundant than clay. In none of the samples is more than 50 percent of the plagioclase replaced and plagioclase birefringence is obvious in even the most strongly altered grains. This is consistent with the absence of minerals of the advanced argillic group.

Sillimanite products were not identified. However sillimanite is commonly associated with muscovite which may represent an alteration product.

Alkali feldspar and quartz are apparently unaltered. Likewise apatite grains are as abundant in the most strongly altered zones as elsewhere and appear to have preserved their original texture in these zones. (It is probable however that they have undergone chemical exchange (Parry et al., 1978).)

The precursor to epidote grains appearing in a few samples is not known. The epidote-bearing grains contain only sericitized plagioclase and quartz in addition to epidote.

Chlorite compositions

Complete microprobe analyses were obtained for two chlorites in the sample from 6680-6690 feet (see Table 2). In order to obtain a good matrix correction, the chlorites were assigned a ferric to total iron weight ratio of 0.126, that value being the average value for nine chlorites reported

from propylitized rocks by Downey (1976).

The chlorite has silica/aluminum ratios placing it in the ripidolite series with Fe/Fe+Mg atomic ratios of 0.42 to 0.44.

These compositions are more siliceous than those of chlorites from drill hole 14-2 (Ballantyne, J.M., 1978) and from the samples from within the propylitized haloes of porphyry copper deposits (Ballantyne G.H., in preparation). The compositions of chlorites from drill holes 52-21 and 14-2 are compared on Figure 2.

Sulfide and Oxide Minerals. Conversion of primary oxide constituents of the metamorphic rock to sulfides has apparently occurred only locally and on a very minor scale.

Figure 1 records the relative abundance of opaque minerals in the 74 thin sections and it can be seen that this shows little variation down-hole.

Table 3 records the opaque minerals identified in 15 polished thin sections. Identification of opaques in samples from 3570-3580 feet and 6680-6690 feet was confirmed by x-ray spectral analysis using an energy dispersive system on an ARL microprobe.

Vein Fillings

Monomineralic fragments of calcite are common below 2300 feet and many of these are probably fragments of calcite veins. Other calcite rich drill cuttings contain fragments of quartz and alkali-feldspar and are probably from calcite-cemented mylonite zones.

Bulk Rock Chemistry

Chemical analyses of selected samples from Getty Oil Co. 52-21 are

Figure 2. Composition of Chlorites in Getty Oil Company well 52-21.

TABLE 3: OPAQUE MINERALS IDENTIFIED UNDER REFLECTED LIGHT

Sample Interval	Magnetite	Ilmenite	Hematite	Pyrite	Chalcopyrite
550-560		X	X		
820-830	X	X	X	X	X
1510-1520	X	X?		X	X
1760-1770	X	X?		X	X
2050-2060	X	X	X		X
2440-2450	no opaques				
2980-2990	X	X		X	
3570-3580	X	X			
4100-4110	X	X?		X	X
4530-4540	X			X	X
5150-5160	X	X?		X	X
5550-5560	no opaques				
6060-6070	X	X		X	X
6680-6690	X			X	X
7490-7500				X	

Note: Ilmenite occurrences marked with a question mark do not exhibit diagnostic hematite exsolution and may be titaniferous magnetite.

shown in Table 4. All of the samples analysed are amphibolite facies gneiss which has been weakly altered. The heterogeneity of the gneiss is indicated by the variability of chemical composition among the samples analyzed. The presence of calcite and sulfide minerals is reflected in the CO₂ and sulfur analyses.

Clay Mineralogy

Potassium mica is the only clay identified by x-ray diffraction. The clay size fraction generally does not include coarsely crystalline chlorite which replaces other ferromagnesian minerals. Clay observed in thin-section is widely distributed in the rock but occurs in such small amounts as to preclude detection by x-ray methods.

TABLE 4: CHEMICAL ANALYSES OF ROCKS FROM GETTY OIL CO. WELL UTAH STATE 52-21, ROOSEVELT
HOT SPRINGS THERMAL AREA, UTAH

	1130	1510	1760	2440	2870	3140	3570	4010	4430	4930	5270	5650	6060	6490	6880	7180	7490
SiO ₂	60.3	64.5	64.5	65.2	68.9	71.4	66.1	68.7	54.7	67.0	65.8	56.9	68.8	64.7	66.5	63.4	65.3
Al ₂ O ₃	14.6	13.5	14.6	15.3	14.4	14.8	13.8	14.6	16.8	14.9	14.1	16.1	15.0	13.0	14.1	15.5	12.5
TiO ₂	0.84	0.61	0.64	0.66	0.24	0.18	0.53	0.28	1.3	0.49	0.37	0.88	0.31	0.20	0.27	0.75	0.41
Fe ₂ O ₃ ^b	5.7	6.6	6.1	6.8	1.8	1.7	6.4	2.4	6.8	3.4	5.1	7.9	3.0	8.6	3.7	5.1	8.5
MnO	0.03	0.08	0.07	0.06	0.01	0.02	0.05	0.00	0.07	0.01	0.04	0.08	0.02	0.04	0.00	0.02	0.05
MgO	2.4	2.4	1.8	1.8	0.43	0.46	1.7	0.65	2.8	0.92	1.9	3.1	0.79	0.44	0.61	1.1	1.6
CaO	3.7	3.7	1.3	0.49	1.7	2.2	2.5	3.0	5.7	3.9	3.3	6.2	2.3	1.6	1.5	3.2	1.6
Na ₂ O	3.5	2.9	2.7	2.2	3.8	4.0	3.4	4.2	4.2	4.0	4.0	3.8	3.7	3.4	3.2	3.7	3.0
K ₂ O	3.7	2.4	3.7	2.8	4.8	3.7	2.8	2.1	3.3	1.8	2.5	1.7	4.4	3.9	4.5	3.9	2.5
P ₂ O ₅	0.33	0.16	0.05	0.02	0.08	0.08	0.14	0.12	0.63	0.20	0.17	0.43	0.12	0.07	0.06	0.26	0.05
CO ₂ ^c	0.26	0.10	0.09	0.17	0.23	0.14	0.29	0.08	0.56	0.11	0.15	0.15	0.34	0.36	0.30	0.58	0.36
S ^d	0.03	0.10	0.02	0.01	0.03	0.02	0.04	0.03	0.11	0.03	0.03	0.12	0.04	0.02	0.03	0.06	0.02
LOI	1.7	1.8	1.9	3.1	1.6	1.1	1.4	0.91	1.7	0.74	0.68	0.72	1.6	.00	1.70	1.6	1.2
TOTAL	96.8	98.7	97.4	98.4	97.8	99.6	98.8	97.0	98.0	97.4	98.0	97.8	100	96.0	96.0	98.5	96.7

a X-ray emission analysis using the method of Norrish and Hutton (1969)

b total Fe as Fe₂O₃

c CO₂ using the method of Shapiro (1975)

d LECO induction furnace and titration

RECOMMENDATIONS

1). The alluvial portion of all drill holes in the Roosevelt area should be searched for opal and chalcedony fragments which may indicate proximity to major hot water conduits and opal aprons now covered by more recent alluvium. Furthermore, since it is established (especially for drill hole 72-16) that at least some alteration post-dates the alluvium, studying the alluvium is an effective way of locating high level geothermal activity.

2). Zoning studies, targeted on specific minerals whose compositions vary in response to thermal and chemical conditions; are recommended since, as in drill hole 52-21, mineralogic assemblages are often constant over thousands of feet, limiting their usefulness as pointers towards high temperature areas of the geothermal system.

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The work was planned and co-ordinated by Dr. W.T. Parry.

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ABSTRACT

Getty Oil Company well 52-21 in the Roosevelt Hot Springs thermal area was drilled to 7500 feet in predominantly upper amphibolite facies metamorphic rocks. All lithologies in the drill hole are pervasively but weakly altered: the alteration assemblage is chlorite + sericite + clays with occasional traces of calcite, above 2300 feet, and chlorite + sericite + clays + calcite $\pm$ epidote below 2500 feet. A zone of increased alteration intensity from approximately 1800 feet to 2300 feet occurs within and adjacent to a dacite dike which cuts the metamorphic rocks. A second zone of stronger alteration extends from 6000 feet to the bottom of the drill hole.

The drill hole which is located approximately 5000 feet south of the centre of the silica apron known as the Opal Mound was apparently drilled beyond the influence of acid, high-sulfate brines such as have affected the upper portions of drill holes 72-16, 76-1 and University of Utah 1A and 1B.

INTRODUCTION

A research program consisting of petrographic work, x-ray diffraction, whole rock analysis and microprobe analysis of specific minerals has been carried out on drill cuttings from Getty Oil Company well 52-21 in the Roosevelt Hot Springs thermal area.

Drill hole 52-21 is located 2310 feet west and 990 feet south of the northeast corner of S.21, T27S, R9W. This location is approximately 5000 feet south of the centre of the Opal Mound. The hole was rotary drilled to a final depth of 7500 feet. (This, and all depth footages quoted in this report, are measured from the kelly bushing, 22 feet above ground level.) No diamond drill core was studied.

Drill cuttings were collected over 10 foot intervals during drilling and 74 samples, generally one from each 100 foot interval of the hole, were selected for use in this study. The sample selected from each 100 foot interval was that for which the most material was available. This should have involved no subjective geologic bias but may have biased the selection towards rocks with certain drilling characteristics. All 74 samples were prepared as thin sections and studied petrographically, 15 were prepared as polished thin sections and studied under reflected light, and for two of these microprobe analyses were made of the major minerals present; 17 samples were selected for whole rock chemical analyses and x-ray diffraction determination of clay mineralogy.

LABORATORY METHODS

Thin sections and polished thin sections were prepared from 0.5 to 1 gram splits of the drill cuttings cemented in epoxy and usually contained between 40 and 100 rock fragments. Mineral abundances were estimated visually. Where more than one rock type was present, proportions of each were determined by counting the rock fragments of each type.

Microprobe analyses were made using a 3-channel ARL electron microprobe operating at an accelerating voltage of 15kv and a sample current of 0.03 micro-amperes. X-rays were counted at 10 spots on each grain for approximately 13 seconds. Clinopyroxene and feldspar standards were used for most major and minor elements. A biotite standard was used for BaO and F, and a scapolite standard for Cl. The data were matrix corrected using the correction factors of Bence and Albee (1968) and Albee and Ray (1970). The computer program used for the correction calculates the structural water present based on a user-entered estimate of the ferric to total iron ratio, and utilizes this in the correction. For feldspars the program calculates the SiO₂ and Al₂O₃ contents on the basis of the CaO, K₂O, Na₂O and BaO present and corrects for this matrix.

Fused glass disks were prepared for x-ray fluorescence analyses using the method of Norrish and Hutton (1969). Carbon dioxide was determined by the method of Shapiro (1975), and sulfur was determined using a LECO furnace and titration. The clay fraction was extracted by peptizing the pulverized sample with calgon and centrifuging. X-ray diffraction patterns were obtained for oriented smears on glass slides following air-drying, heating to 250°C, heating to 550°C, and vapor glycolation at 60°C as appropriate.

ROCK TYPES

Drill hole 52-21 penetrated a relatively simple geologic section consisting of upper amphibolite facies metamorphic rocks overlain by approximately 600 feet of alluvium. One or more dikes of latite or dacite cut the metamorphic rocks in the interval 2050 to 2400.

The rock types are described in detail and compared to those occurring in other drill holes and in outcrop in the following sections. The information is presented diagrammatically in Figure 1.

Alluvium

The alluvium is a lithic arkose derived from volcanic, plutonic, and possibly metamorphic rocks, exposed in the Mineral Mountain Range to the east. It is apparently poorly cemented since only a few grains have limonite or carbonate coatings. Certainly there is no pervasive opal or chalcedony cement such as occurs in Thermal Power Company Well 72-16. Only one opal fragment was noted in the six thin sections of alluvial rock.

The source rocks for the alluvium include three identifiable groups of volcanic rocks known to outcrop in the Mineral Mountains (Evans and Nash, 1977). The volcanic rocks identified in the alluvium are: 1) Banded obsidian similar to that occurring as flows on Bailey Ridge and in Wild Horse Canyon. These flows which have been dated at 0.77 ± 0.08 m.y. (Lipman et al., 1978), show prominent flow banding and contain abundant microlites. 2) Devitrified rhyolite similar to that occurring in Big Cedar Cove and in Corral Canyon. Fragments of this rock type are dark and iron stained and do not exhibit banding or spherulites. The Big Corral Canyon rhyolite was dated by Lipman et al. at 7.90 ± 0.3 m.y. 3) Pumice lapilli such as occurs

Figure 1. Alteration and Rock Types in Getty Oil Company well 52-21.

in Ranch canyon. Material from this unit has been dated by Lipman et al. at 0.64 ± 0.04 m.y.

Lithic fragments of medium to coarse grained rock in the alluvium include microcline-bearing leucogranite, hornblende-plagioclase rock, and biotite-plagioclase-quartz fragments. The microcline bearing rock is definitely transported material since microcline does not occur in the underlying bedrock. The other rock types may be metamorphic and locally derived.

Since drill cuttings of the alluvium are not significantly more rounded than those derived from the underlying bedrock the criterion for a sample being alluvial is the occurrence of either volcanic rock or microcline-bearing lithic fragments. The deepest sample in which microcline-bearing rock was observed in thin section is from 550-560 feet.

Metamorphic Rocks

Below 560 feet the predominant lithologies are medium to coarse grained quartzo-feldspathic rocks. Quartz, alkali feldspar, oligoclase and biotite are always present, hornblende is almost always present and muscovite and sillimanite are present in some samples. Sphene, apatite and zircon are ubiquitous and probably present in all samples in at least trace amounts. Additional mineral phases considered to be due to hydrothermal alteration of those described above are discussed later in this report.

The following listing puts some numeric constraints on the abundances of various primary rock constituents as estimated from 68 thin sections.

quartz	5 to 20%	sillimanite	0 to 10%
alkali feldspar	10 to 30%	garnet	trace
plagioclase	10 to 30%	sphene	trace to 30%
Biotite	1 to 20%	apatite	trace to 2%
hornblende	0 to 50%	zircon	trace
muscovite	0 to 5%	allanite	0 to trace

A feature which is not apparent from the estimates above, but is very obvious in the rocks, is the bimodal distribution of minerals in two different kinds of fragments. Both within samples and to a lesser extent between samples there is a tendency for hornblende, biotite, plagioclase, sphene, and apatite to occur together, and for quartz, alkali feldspar, plagioclase and minor biotite to occur together. The first of these two rock variants is finer grained and more equigranular with an average grain size of 0.1 to 0.3 mm, while the quartz-alkali feldspar rock consists of unevenly sized grains with maximum dimensions of up to 2 mm. The existence of these two rock variants suggests either a layering within a single rock type or an intimate mixture of two distinct rock types, (a contact relationship). Since it is improbable that any drill hole would intersect such a contact over long distances it appears that the drill hole has penetrated a banded or gneissic rock type over most of its length. Occasional samples in which strong foliation is evident strongly support this argument, however such samples are uncommon. The periodic appearance of sillimanite over the length of the drill hole (see Figure 1) severely restricts the size of any possible post-metamorphic igneous rock intervals. In addition, with one minor exception noted below, plagioclase compositions

are very consistent, both between mafic-rich and quartzo-feldspathic rock variants and over the length of the drill hole.

Foliated gneisses, locally containing sillimanite, outcrop at several places along the western flank of the Mineral Mountain Range, the closest outcrops lying approximately 2000 feet northeast of drill hole 52-21.

Mineral Compositions

Microprobe analyses of plagioclase, alkali feldspar, biotite and hornblende were made for samples from 3570-3580 feet and 6680-6690 feet. Chlorite was also analysed in the deeper sample. The analyses are presented in Tables 1 and 2 along with corresponding structural formulae. Ferric to total iron weight ratios were not determined but estimates were made in order to achieve good matrix corrections. The biotites were assigned a ratio of 0.05, that of a biotite reported by Deer et al. (1966), from a garnet-sillimanite-mica schist. The amphiboles were arbitrarily assigned a middle-of-the-range value of 0.50.

The biotites have compositions typical of those reported from zones of high grade regional metamorphism (Deer et al., 1966) with the exception that they have higher fluorine contents (0.23 to 0.72%) than are common in such rocks.

The amphiboles are properly classified as common hornblendes since they have high calcium contents, low alkali contents and silica occupying 6.6 to 6.8 of the 8 tetrahedral sites.

The alkali feldspars are orthoclases with mole fraction Or in the range 0.87 to 0.90. They contain significant barium: up to 3.05 percent BaO in one sample. The microprobe work confirms the petrographic

TABLE 1 ANALYSES OF BIOTITES HORNBLENDES AND CHLORITES FROM DRILL HOLE 52-21

	3570-3580'		6680-6690'		3570-3580'		6670-6680'		6670-6680'	
	Biotite 1	Biotite 2	Biotite 1	Biotite 2	Hornblende 1	Hornblende 2	Hornblende 1	Hornblende 2	Chlorite 1	Chlorite 2
SiO2	34.5	36.6	36.8	35.7	45.6	45.7	44.5	45.8	25.3	25.4
TiO2	2.81	2.71	3.56	3.73	.52	.87	1.40	1.04	.09	.04
Al2O3	18.2	17.7	14.0	13.9	7.77	7.14	8.39	7.92	18.1	20.3
FeO	19.9	13.9	18.3	20.2	8.70	8.43	8.56	8.63	20.6	20.6
Fe2O3	1.16	.81	1.07	1.18	9.67	9.37	9.52	9.60	3.30	3.29
MnO	.21	.06	.33	.44	.43	.38	.49	.38	.59	.52
MgO	8.37	13.7	12.3	10.2	11.5	11.9	11.8	12.0	18.5	17.1
CaO	.01	.05	.07	.05	12.0	11.9	9.42	9.47	.25	.01
K2O	9.04	9.44	9.42	9.20	.76	.82	1.06	.96	.04	.02
Na2O	.21	.20	.08	.09	1.10	1.35	1.36	1.36	.03	.01
BAO	.53	.20	.52	.25	.01	.01	.07	.01	.01	.00
CL	.03	.04	.05	.07	.05	.05	.04	.01	.00	.00
F	.29	.72	.48	.46	.13	.29	.26	.13	.13	.18
H2O	3.77	3.70	3.69	3.66	1.95	1.88	1.90	1.97	11.5	11.5
O=CLF	.13	.31	.22	.21	.07	.13	.12	.06	.06	.08
TOTAL	99.2	100.1	100.9	99.34	100.3	100.2	98.9	99.3	98.9	99.3

NUMBER OF OXYGENS ON THE BASIS OF 24 OXYGENS FOR BIOTITE AND HORNBLENDE AND 18 OXYGENS FOR CHLORITE

SI	5.34	5.45	5.58	5.55	6.73	6.75	6.65	6.77	2.68	2.66
TI	.33	.30	.41	.44	.06	.10	.16	.12	.01	.00
AL	3.32	3.10	2.50	2.55	1.35	1.24	1.48	1.38	2.26	2.51
FEII	2.57	1.73	2.32	2.63	1.07	1.04	1.07	1.07	1.83	1.80
FEIII	.14	.09	.12	.14	1.07	1.04	1.07	1.07	.26	.26
MN	.03	.01	.04	.06	.05	.05	.06	.05	.05	.05
MG	1.93	3.03	2.77	2.37	2.53	2.62	2.62	2.64	2.93	2.67
CA	.00	.01	.01	.01	1.90	1.88	1.51	1.50	.03	.00
K	1.78	1.79	1.82	1.82	.14	.16	.20	.18	.01	.00
NA	.06	.06	.02	.03	.32	.39	.39	.39	.01	.00
BA	.03	.01	.03	.02	.00	.00	.00	.00	.00	.00
CL	.01	.01	.01	.02	.01	.01	.01	.00	.00	.00
F	.14	.34	.23	.23	.06	.14	.12	.06	.04	.06
OH	3.85	3.65	3.76	3.76	1.92	1.85	1.87	1.94	7.96	7.94

TABLE 2: ANALYSES OF FELDSPARS FROM DRILL HOLE 52-21

	3570-3580'		6680-6690'		3570-3580'		6680-6690'	
	Plagioclase 1	Plagioclase 2	Plagioclase 1	Plagioclase 2	Orthoclase 1	Orthoclase 2	Orthoclase 1	Orthoclase 2
SiO ₂ *	58.8	60.5	59.2	61.5	67.0	65.5	65.5	65.9
Al ₂ O ₃ *	23.8	24.7	22.6	22.1	19.3	18.8	20.1	18.8
CaO	5.89	6.29	4.80	3.85	0.10	0.07	0.18	0.03
K ₂ O	0.31	0.34	0.23	0.42	15.3	14.8	14.7	15.3
Na ₂ O	7.74	7.86	8.24	8.87	1.33	1.41	1.09	1.20
BaO	0.03	0.01	0.05	0.04	0.65	0.53	3.05	0.36
TOTAL	96.6	99.7	95.1	96.8	103.7	101.1	104.6	101.6
Number of ions on the basis of 8 oxygens.								
Si	2.71	2.70	2.76	2.81	2.98	2.99	2.94	2.99
Al	1.29	1.30	1.24	1.19	1.02	1.01	1.06	1.01
Ca	.29	.30	.24	.19	.00	.00	.01	.00
K	.02	.02	.01	.02	.87	.86	.84	.89
Na	.69	.68	.75	.79	.11	.12	.09	.11
Ba	.00	.00	.00	.00	.01	.01	.05	.01
Mole fractions (recalculated to total 1.0).								
An	.30	.31	.25	.20	.00	.00	.01	.00
Or	.02	.02	.02	.03	.89	.88	.90	.90
Ab	.68	.67	.73	.78	.11	.12	.09	.10

* Silica and alumina were calculated on the basis of the CaO, K₂O, Na₂O and BaO present.

observations that the alkali feldspars are homogenous and unmixed. Standard deviations for sodium for the 10 points analysed in each grain are less than one third of the sodium determined, much lower than they would be if perthites or cryptoperthites were present.

The plagioclase is oligoclase in the range An₁₉ to An₃₁. The calcium-rich end of this compositional range corresponds closely with the 14° maximum extinction angle measured on albite twins in these samples. Since maximum extinction angles in the range 12 to 16° were measured in almost all samples, the analysed plagioclases are representative. The microprobe work indicates that the plagioclase is unzoned which confirms petrographic observation. Barium oxide contents do not exceed 0.05%.

Petrogenesis of the Gneiss

The mineralogy of the gneisses places them in the sillimanite-stable zone of the amphibolite facies. Several samples show coexisting quartz, orthoclase, sillimanite and muscovite suggesting proximity in pressure-temperature space to the univariant equilibrium curve for the reaction:

Experimental data on this reaction has been published by Evans (1965). It should be noted however that there is no textural evidence for this specific reaction occurring in the rocks from this drill hole. In fact petrographic study seems to indicate that biotite may be the principal reactant mineral involved in sillimanite formation since sillimanite needles are commonly seen growing within biotite grains.

Meta-Gabbro

A meta-gabbro composed chiefly of plagioclase (80%) and blue-green hornblende (20%) comprises approximately 3 percent of the rock fragments in the samples from 2540-2550 feet and 2660-2670 feet. This rock is distinguished from other amphibole and plagioclase-rich horizons in the metamorphic rocks by a pronounced equigranular texture dominated by polygonal-shaped plagioclase grains and also by the calcic nature of the plagioclase. The plagioclase is labradorite near An₆₀ and is twice as calcium-rich as any other plagioclase noted in the drill hole. The rock has an average grain size of 0.2 to 0.4 mm. Traces of biotite and alkali feldspar occur and apatite and sphene are common accessories.

Dacite Dikes

Fragments of fine grained holocrystalline dacite comprise 80 percent of the sample from 2050-2060 feet, 25 percent of the sample from 2160-2170 feet, 20 percent of the sample from 2240-2250 feet and 10 percent of the sample from 2330-2340 feet. Trace amounts of dacite in deeper samples are probably due to contamination. The drill hole is inferred to have intersected one or more dacite dikes in the interval 1970 feet (the end of the preceeding sample studied) to 2340 feet.

The dacite consists predominantly of slender lathes of plagioclase, 0.1 to 0.3 mm long, and similarly sized plates of biotite and needles of hornblende. Quartz and alkali feldspar are equant, finer grained, and occur interstitially.

The plagioclase grains are zoned and the cores are largely replaced by sericite in most fragments. Since they are small, altered and poorly

twinned, optical compositional determinations are uncertain. Maximum extinction angles on albite twins are in the range 11° to 14° indicating compositions of either An_{8-11} or An_{29-32} . The mafic minerals are almost completely altered in some samples and in others, (where they are mostly biotite), are only weakly altered. Grain size, degree of orientation (a minority of fragments are pilotaxitic) and the mafic mineralogy, vary somewhat between and within samples.

The dacite is similar to the type III dacite, the most abundant hypabyssal rock reported from drill hole 14-2 (Ballantyne, J.M., 1978, p. 7). It is apparently not closely similar to any of the hypabyssal rock variants noted in drill hole 72-16 (Rohrs and Parry, 1978, p. 7-9). The following is an estimated average composition for the dacite in drill hole 52-21:

quartz	5-10%
plagioclase	50%
biotite	25%
hornblende	10%
leucoxene	5%
opaques	

ALTERATION

All of the samples studied from drill hole 52-21 show obvious signs of hydrothermal alteration. The alteration assemblage is chlorite + sericite + clays + traces of calcite in the upper portion of the drill hole giving way to chlorite + sericite + clay + calcite ± epidote below 2300 feet.

Methods of Investigation

Determination of the alteration assemblage, textural relationships between reactant and product minerals, and overall alteration intensity were made chiefly by a petrographic study of the seventy four thin sections and fifteen polished thin sections. Relative mineral abundances were estimated visually for the 74 thin sections and an estimate was made of the average percent replacement of plagioclase in each sample.

A limited characterization of the composition of reactant and product mineral phases was made by analysing biotite, hornblende, plagioclase and alkali feldspar in samples from 3570-3580 feet and 6680-6690 feet and chlorite from the 6680-6690 foot sample.

Alteration Intensity and Mineral Abundances

Estimated percent replacement of plagioclase and relative abundance of the various product and reactant phases is shown on Figure 1.

The principle features apparent on this figure are:

- 1) Calcite is present only rarely, and in trace amounts, above 2300 feet and increases in abundance down-hole from that point.

(Calcite first appears in hornblende pseudomorphs and in veins or mylonite zones.)

- 2) Calcite appears as a replacement of plagioclase only below 2500 feet.
- 3) Epidote occurs only below 2300 feet.
- 4) There is a complimentary relationship between hornblende abundance, and the intensity of plagioclase alteration and chlorite and calcite abundances. This suggests that hornblende is highly susceptible to alteration and that it is replaced by chlorite and calcite, both suggestions being supported by textural observations.
- 5) Both the plagioclase alteration intensity graph and the relative mineral abundance graphs indicate two zones of more intense alteration: (i) the zone from 1800 to 2300 feet which contains the dacite dikes, and (ii) the lowermost 1500 feet of the drill hole.

Product - Reactant Relationships

Biotite is commonly partially or completely altered to chlorite plus a titanium oxide. The titanium oxide, which occurs as fine needles within the chlorite, serves to distinguish chlorite replacing biotite from chlorite replacing hornblende. (The direct evidence for this is seen in partially replaced biotite and hornblende grains.) As shown in Tables 1 and 2, the reactant biotites have considerably higher titanium contents (2.71 to 3.73 percent) than the hornblendes (0.52 to 1.40 percent).

Hornblende is often partially or wholly replaced either by chlorite or by fine mixtures of chlorite, calcite and clay. Inclusions of apatite are

very common in fresh hornblende grains and the apatite crystals survive the alteration and assist in identifying pseudomorphs after hornblende.

Plagioclase is always partially replaced by clays and by sericite, and at depth by calcite, and rarely by chlorite. Except in the upper 800 feet of the hole, which has probably been subjected to supergene conditions, sericite is more abundant than clay. In none of the samples is more than 50 percent of the plagioclase replaced and plagioclase birefringence is obvious in even the most strongly altered grains. This is consistent with the absence of minerals of the advanced argillic group.

Sillimanite products were not identified. However sillimanite is commonly associated with muscovite which may represent an alteration product.

Alkali feldspar and quartz are apparently unaltered. Likewise apatite grains are as abundant in the most strongly altered zones as elsewhere and appear to have preserved their original texture in these zones. (It is probable however that they have undergone chemical exchange (Parry et al., 1978).)

The precursor to epidote grains appearing in a few samples is not known. The epidote-bearing grains contain only sericitized plagioclase and quartz in addition to epidote.

Chlorite compositions

Complete microprobe analyses were obtained for two chlorites in the sample from 6680-6690 feet (see Table 2). In order to obtain a good matrix correction, the chlorites were assigned a ferric to total iron weight ratio of 0.126, that value being the average value for nine chlorites reported

from propylitized rocks by Downey (1976).

The chlorite has silica/aluminum ratios placing it in the ripidolite series with Fe/Fe+Mg atomic ratios of 0.42 to 0.44.

These compositions are more siliceous than those of chlorites from drill hole 14-2 (Ballantyne, J.M., 1978) and from the samples from within the propylitized haloes of porphyry copper deposits (Ballantyne G.H., in preparation). The compositions of chlorites from drill holes 52-21 and 14-2 are compared on Figure 2.

Sulfide and Oxide Minerals. Conversion of primary oxide constituents of the metamorphic rock to sulfides has apparently occurred only locally and on a very minor scale.

Figure 1 records the relative abundance of opaque minerals in the 74 thin sections and it can be seen that this shows little variation down-hole.

Table 3 records the opaque minerals identified in 15 polished thin sections. Identification of opaques in samples from 3570-3580 feet and 6680-6690 feet was confirmed by x-ray spectral analysis using an energy dispersive system on an ARL microprobe.

Vein Fillings

Monomineralic fragments of calcite are common below 2300 feet and many of these are probably fragments of calcite veins. Other calcite rich drill cuttings contain fragments of quartz and alkali-feldspar and are probably from calcite-cemented mylonite zones.

Bulk Rock Chemistry

Chemical analyses of selected samples from Getty Oil Co. 52-21 are

Figure 2. Composition of Chlorites in Getty Oil Company well 52-21.

TABLE 3: OPAQUE MINERALS IDENTIFIED UNDER REFLECTED LIGHT

Sample Interval	Magnetite	Ilmenite	Hematite	Pyrite	Chalcopyrite
550-560		X	X		
820-830	X	X	X	X	X
1510-1520	X	X?		X	X
1760-1770	X	X?		X	X
2050-2060	X	X	X		X
2440-2450	no opaques				
2980-2990	X	X		X	
3570-3580	X	X			
4100-4110	X	X?		X	X
4530-4540	X			X	X
5150-5160	X	X?		X	X
5550-5560	no opaques				
6060-6070	X	X		X	X
6680-6690	X			X	X
7490-7500				X	

Note: Ilmenite occurrences marked with a question mark do not exhibit diagnostic hematite exsolution and may be titaniferous magnetite.

shown in Table 4. All of the samples analysed are amphibolite facies gneiss which has been weakly altered. The heterogeneity of the gneiss is indicated by the variability of chemical composition among the samples analyzed. The presence of calcite and sulfide minerals is reflected in the CO₂ and sulfur analyses.

Clay Mineralogy

Potassium mica is the only clay identified by x-ray diffraction. The clay size fraction generally does not include coarsely crystalline chlorite which replaces other ferromagnesian minerals. Clay observed in thin-section is widely distributed in the rock but occurs in such small amounts as to preclude detection by x-ray methods.

TABLE 4: CHEMICAL ANALYSES OF ROCKS FROM GETTY OIL CO. WELL UTAH STATE 52-21, ROOSEVELT
HOT SPRINGS THERMAL AREA, UTAH

	1130	1510	1760	2440	2870	3140	3570	4010	4430	4930	5270	5650	6060	6490	6880	7180	7490
SiO ₂	60.3	64.5	64.5	65.2	68.9	71.4	66.1	68.7	54.7	67.0	65.8	56.9	68.8	64.7	66.5	63.4	65.3
Al ₂ O ₃	14.6	13.5	14.6	15.3	14.4	14.8	13.8	14.6	16.8	14.9	14.1	16.1	15.0	13.0	14.1	15.5	12.5
TiO ₂ ^a	0.84	0.61	0.64	0.66	0.24	0.18	0.53	0.28	1.3	0.49	0.37	0.88	0.31	0.20	0.27	0.75	0.41
Fe ₂ O ₃ ^b	5.7	6.6	6.1	6.8	1.8	1.7	6.4	2.4	6.8	3.4	5.1	7.9	3.0	8.6	3.7	5.1	8.5
MnO	0.03	0.08	0.07	0.06	0.01	0.02	0.05	0.00	0.07	0.01	0.04	0.08	0.02	0.04	0.00	0.02	0.05
MgO	2.4	2.4	1.8	1.8	0.43	0.46	1.7	0.65	2.8	0.92	1.9	3.1	0.79	0.44	0.61	1.1	1.6
CaO	3.7	3.7	1.3	0.49	1.7	2.2	2.5	3.0	5.7	3.9	3.3	6.2	2.3	1.6	1.5	3.2	1.6
Na ₂ O	3.5	2.9	2.7	2.2	3.8	4.0	3.4	4.2	4.2	4.0	4.0	3.8	3.7	3.4	3.2	3.7	3.0
K ₂ O	3.7	2.4	3.7	2.8	4.8	3.7	2.8	2.1	3.3	1.8	2.5	1.7	4.4	3.9	4.5	3.9	2.5
P ₂ O ₅ ^c	0.33	0.16	0.05	0.02	0.08	0.08	0.14	0.12	0.63	0.20	0.17	0.43	0.12	0.07	0.06	0.26	0.05
CO ₂ ^d	0.26	0.10	0.09	0.17	0.23	0.14	0.29	0.08	0.56	0.11	0.15	0.15	0.34	0.36	0.30	0.58	0.36
S ^d	0.03	0.10	0.02	0.01	0.03	0.02	0.04	0.03	0.11	0.03	0.03	0.12	0.04	0.02	0.03	0.06	0.02
LOI	1.7	1.8	1.9	3.1	1.6	1.1	1.4	0.91	1.7	0.74	0.68	0.72	1.6	.00	1.70	1.6	1.2
TOTAL	96.8	98.7	97.4	98.4	97.8	99.6	98.8	97.0	98.0	97.4	98.0	97.8	100	96.0	96.0	98.5	96.7

a X-ray emission analysis using the method of Norrish and Hutton (1969)

b total Fe as Fe₂O₃

c CO₂ using the method of Shapiro (1975)

d LECO induction furnace and titration

RECOMMENDATIONS

1). The alluvial portion of all drill holes in the Roosevelt area should be searched for opal and chalcedony fragments which may indicate proximity to major hot water conduits and opal aprons now covered by more recent alluvium. Furthermore, since it is established (especially for drill hole 72-16) that at least some alteration post-dates the alluvium, studying the alluvium is an effective way of locating high level geothermal activity.

2). Zoning studies, targeted on specific minerals whose compositions vary in response to thermal and chemical conditions; are recommended since, as in drill hole 52-21, mineralogic assemblages are often constant over thousands of feet, limiting their usefulness as pointers towards high temperature areas of the geothermal system.

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The work was planned and co-ordinated by Dr. W.T. Parry.

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