DAN CARRIER

MAR 2 3 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 ~~[illegible]~~ 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.

Hulen, J.B., and Nielson, D.L., 1986, Hydrothermal alteration in the Baca geothermal system, Redondo dome, Valles caldera, New Mexico: J. Geophs. Res., 91, 1867-1886.

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

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

16 Cuttings Samples
Bulk XRD

MINERALOGY, APPROX. WT.% [x] (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	14	51		TR	3	2	3	1		TR	2	TR	2	TR		1		2	16	3	TR		
6-2	42	30	22					TR			TR			TR				4	TR?	2			
6-3	45	21	16		TR	2		1		TR	TR	TR	TR	1		TR		11	TR?	3			
6-4	4	50	3	2	7	3		6			5	TR	TR	8		TR		1		11			
6-5	11	45	11		3	2		7			1	TR	TR	8						12			
6-6	11	42	9		1?	3		7	1		1		1	9		2				13			
6-7	19	38	10	TR	1?	2		5	2		1		1	8				TR		13			TR. UNKNOWN, HIGH N, HIGH RELIEF, LOW BIREFRINGENCE MINERAL
6-8	32	40	17	TR		1		1			1	TR	TR	TR		1	TR	1	3	1			
8-1	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	11	34	7	TR	13	2		4			2	5	TR	9	1	TR	TR	2		10			
8-3	17	35	11	1	10			2			1	4	TR	6	TR?	TR	TR	3		10			
8-4	13	35	8	1	5			5	TR		1	3	1	8	TR?	TR	TR	3		9		8	
8-5	20	30	5	1	5			4			TR	4	2	8	5	TR	TR	6		10			
8-6	16	33	5	3	5?	1 (OR)	1	TR			2	4	TR	9		TR	‡SEE CHL.	3		7‡		10	
8-7	7	43		2	15						3	3		8		TR	TR	4		3		12	
8-8	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 for: Unocal Geothermal Division, Unocal Corporation -- Daniel Carrier

16 Cuttings Samples
Clay-Fraction XRD

MINERALOGY, APPROX. WT.% [X] (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

Sample No.	Basalt or Andesite	Ⓐ Porphyritic Basalt or Andesite	Ⓑ Microdiabase & Microdiorite	Ⓒ Qtz. Latite or Rhyodacite	Ⓓ Porphyritic Qtz. Latite or Rhyodacite	Quartz Microdiorite or Microgranodiorite	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.	Veinlets: 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 $2^\circ 2\theta$ 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 μ or < 5 μ), 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.