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April 9, 1990

Randolph C. Thompson
Unocal Geothermal Division
3576 Unocal Place
P.O. Box 6854
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Dear Randy:

The lithologies in well 13 are similar to those previously studied in the "6", "8", and "17" series groups. However, unlike the other wells, no granodiorite or microgranodiorite is present in these samples from well 13.

Three major rock types are present. 1) Porphyritic to aphyric basalts and porphyritic basaltic andesites are commonly amygdular. 2) Coarser-grained rocks with abundant clino- and ortho- pyroxene are termed microdiabase, implying an intrusive origin for this rock type. Some of the microdiabases also contain minor amounts of biotite or hornblende. Phenocrysts in the coarser-grained diabases are ophitically-textured. 3) Quartz latites or rhyodacites exhibit a variety of devitrification textures and probably were originally glassy.

In general, predominantly aphyric and amygdular basaltic andesite flows are present to 1200'. However, at 300' and 800', porphyritic dacite is also present. The dacites probably represent flows; they are flow-banded and contain altered phenocrysts of biotite and perthitically intergrown feldspars in glomeroporphyritic aggregates. Angular fragments of oxidized andesitic basalt in sample 1200' may represent cinders that are part of a volcanic cone at the base of the predominately basaltic flow section.

Samples from 1300' and 1400' are mostly porphyritic andesite and represent a flow or possibly, a shallow intrusive body. Sample 1460' is a mixture of many rock types and represents the contact between the andesite and an underlying thick (1500′-1800′) rhyodacite. The cuttings in 1460′ include basalt and andesite flow rocks and rhyodacite flows or tuffs. Because such a variety of lithologies are present in 1460′ and not in the overlying section, it is likely that this depth represents an erosional disconformity in the volcanic section.

The rhyodacite displays several different textures. Relict perlitic texture is evident at the top (1500′) and near the bottom (at 1800′), coarser-grained rhyodacite is present. This crystallization pattern suggests that the rhyodacite was deposited as a flow or a flow-dome complex; it may have cooled quickly to a glass near the surface (now 1500′) and more slowly near its center (now 1800′). Spherulitic devitrification is also common in the center of the rhyodacite body. At the base of the rhyodacite, sample 1890′ contains many cuttings with an argillic matrix and rounded andesite clasts along with resorbed quartz phenocrysts. This rock is probably an intraformational mudflow with an ashy matrix. One chip in sample 1890′ is of coarse-grained graphic intergrowths of feldspar and quartz which could have been derived from a granitic highland.

Below 2000′, the rocks consist predominately of diabase that is gouged or mylonitic and highly altered.

Samples from 2000′ to 2200′ are mostly microdiabase which probably represents a brecciated intrusive body. Within the microdiabase are altered phenocrysts of a ferromagnesian mineral, probably hornblende but possibly biotite, which are completely altered (deuterically?) to smectite. Clinopyroxene phenocrysts subophitically enclose plagioclase laths in the coarse-grained diabase at 2100′.

Samples from 2300′ to 2400′ are mostly hornblende microdiabase. The presence of potassium feldspar at 2300′ is somewhat problematical. There is certainly secondary adularia in this sample but it is also possible that some of the potassium feldspar is primary. In the latter case and considering the presence of hornblende, some of the lithologies at 2300′ and 2400′ may be termed porphyritic rhyodacite or quartz latite. Either way, samples 2300′ and 2400′ represent a different rock unit than from 2000′ to 2200′.

Some of the microbreccia in microdiabase at 2300′ and in andesite at 2370′ may have been caused by hydrothermal brecciation; both samples contain rounded, hematitic fragments within a silicified matrix.

Sample 2450′ is nearly identical to sample 2370′, and sample 2400′ is similar to sample 2300′. Samples 2370′ and 2450′ are vesicular basaltic andesites and both are intensely mineralized. This phenomenon may indicate that vescicular lithologies provide good permeability pathways for hydrothermal fluids.

Samples 2500′ and 2560′ contain two rock types; fine-grained, glassy andesite and coarser-grained diabase, both of which are probably just textural variations of the same rock. In sample 2500′, both rock types are vesicular and the vesicles are filled with fluid inclusion-rich (hydrothermal) quartz and/or epidote. The glassy, aphyric andesite probably represents the cooled borders of the intrusive body. In chips of diabase at 2500′, the clinopyroxene is coarse-grained and subophitically-encloses plagioclase.

Samples 2560′ and 2600′ are both intensely altered and mineralized, making the original rock type difficult to determine. However, these samples appear to be mostly microdiabase (flooded with secondary K-feldspar?). Sample 2560′ also contains some porphyritic rhyodacite; large quartz and zoned plagioclase phenocrysts are present in a devitrified matrix of quartz and potassium feldspar. Some fragments of the rhyodacite appear seriticized. Relict shard and pumice texture is evident in some chips indicating that the rhyodacite is at least partially tuffaceous.

The rocks from well 13 are mineralogically zoned with depth. Argillic alteration predominates down to about 1000′. Smectite and zeolite-filled amygdules are common in the argillic zone, although some calcite-filled amygdules are present at 600′ and 800′. X-ray diffraction analysis of the zeolite indicates that it is stilbite, a low-temperature, fibrous zeolite.

The first occurrence of hydrothermal veining (chlorite-smectite and quartz+pyrite) is at 1000′. The top of the propylitic zone is at 1100′, where epidote first appears as a trace mineral in veins. Veins of intergrown quartz and calcite (+/- epidote and wairakite) in samples from 1100′ to 1460′ suggest that this may be a zone of extensive boiling. Dark green, highly birefringent smectite is common in this zone and is especially abundant in sample 1400′. All of the lithologies in sample 1460′ are highly altered and it is likely that this interval is a lithologic contact that was permeable and promoted hydothermal alteration.

In general, the rhyodacite flow from 1500′ to 1890′ is not as altered as the overlying and underlying rocks. Chips of andesitic or diabasic rocks within the rhyodacite interval commonly contain veins and much epidote but the rhyodacite itself is commonly just silicified. Some chips of the (originally glassier?) rhyodacite are also sericitized. X-ray diffraction analyses of the clay fractions from samples 1600′, 1710′ and 1890′ indicate the presence of mixed-layer illite-smectite with about 10% smectite interlayers. Such illitic illite-smectites usually indicate temperatures up to 260°C (e.g. McDowell and Elders, 1980).

The microdiabases from 2000′ to 2300′ are brecciated and veined. In thin-section, sheared and microbrecciated or strained crystals in a dark chloritic matrix characterize mylonitic chips of diabase. Traces of talc in this interval may be associated with the fault gouge. Actinolite is present in this interval both in veins with hydrothermal quartz and as a (deuteric?) alteration product of primary clinopyroxene and/or amphibole in the diabase.

Dark green smectite is also a common alteration mineral in the interval from 2000′ to 2300′. At 2200′, this smectite occurs in veins with actinolite and quartz. Therefore, it must be a high-temperature variety of smectite (e.g. Eberl, Whitney and Khoury, 1978). From the X-ray diffraction pattern, it is not possible to distinguish this clay as saponite (magnesium-rich smectite) or a smectite-rich chlorite-smectite. Nevertheless, it appears to be identical in XRD and in thin-section to the clay in the lower portions of well 8 (termed smectite) and well 17 (termed chlorite-smectite). In well 13, the smectite is mostly absent in the hottest part of the well (below 2300′) and a very chloritic mixed-layer chlorite-smectite is the only clay mineral that persists to the bottom of the well.

From 2300′ down to 2600′, well-defined hydrothermal veins of prehnite+epidote and adularia+quartz (+/- epidote and actinolite) are common. Evidence for hydrothermal brecciation at 2370′ and 2450′ suggests that some boiling may have occurred locally. The presence of veins of anhydrite at 2370′ and 2470′ may indicate increased permeability due to hydrothermal brecciation and boiling.

Potassium feldspar flooding of the diabase below 2300′ is extensive. Because potassic alteration is typical of ascending and cooling solutions, the formation of K-feldspar in this zone may indicate the positioning of these rocks in or close to a major upflow zone (e.g. Giggenbach, 1984).

The secondary mineral assemblage from 2300′ to 2600′ is certainly indicative of deposition from high-temperature hydrothermal fluids. Epidote commonly forms above 240°C; prehnite above 250oC; and actinolite at temperatures greater than 250°C (e.g. Browne, 1978, 1984; Hulen and Nielson, 1986; Bird et al., 1984). Traces of grossular garnet in a vein with prehnite and epidote at 2560′ may indicate temperatures above 300°C in this zone.

To conclude, the rocks in the lower portion of well 13 contain an abundance of unambiguous high-temperature hydrothermal minerals (particularly prehnite) in well-defined veins. The secondary (and perhaps metamorphic) mineral assemblage of biotite, actinolite and clinopyroxene which complicated interpretation of the hydrothermal alteration in the granodiorite of well 17 is not present.

At this point in your investigation, you should have the basis of a stratigraphic and structural framework for this area. If you don't and are willing to provide me with the thin-sections from, the depths of samples from, and the relative position of, wells 6, 8, 13 and 17, I would be very interested in working on this aspect of your investigation. Please contact me if you are interested in this proposal or if you have any questions concerning the X-ray diffraction or petrographic analyses of the rocks from well 13. Thanks for the opportunity to continue working on these interesting rocks.

Sincerely,

Susan Juch Lutz

Susan Juch Lutz
Manager,
X-ray Diffraction Lab

References:

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UNOCAL GEOTHERMAL DIVISION - RANDOLPH THOMPSON

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

WELL 13
MEDICINE LAKE

BULK + CLAY XRD

SAMPLE NO.	CRISTOBALITE	QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE	ANHYDRITE	MAGNETITE	HEMATITE	PYRITE	SPHENE, RUTILE, LEUCOXENE UNDIV	CLINOPYROXENE	AMPHIBOLE / ACTINOLITE	EPIDOTE	PREHNITE	WAIRAKITE	STILBITE	TALC	SMECTITE	MIXED-LAYER CHLORITE-SMECTITE	MIXED-LAYER ILLITE-SMECTITE		AMORPHOUS / BELOW DETECTION	
160 BULK		TR	44				14	3			2							10				`27	` GLASS
200 BULK	3	TR	61				20	TR			7							5				3	
CLAY																		100					
300 BULK	61		5	27			1	x2			TR					TR		4				—	x WITH GOETHITE
400 BULK	4		29				10	x2								4		43				8	x WITH GOETHITE
CLAY																*TR		100					*COARSE-GRAINED ZEOLITE
600 BULK	3		42		6		13	16								2		8				10	
CLAY																TR		100					
800 BULK		TR	52		3		18	1			′4					TR		•18					′ WITH ORTHOPYROXENE • WAS BIOTITE
CLAY																		100					
1000 BULK		4	34		5		15	3	1		2							31	2			3	
1100 BULK		6	37		8		16	6	1	2	1		TR					9	5			9	
CLAY																		55	45				
1200 BULK		14	15	2?	10		13	12	1	6	TR				3			4	11			9	
CLAY																		18	82				
1300 BULK		5	27	4	12		10	1	2	7	8		1		TR			2	14			7	
1400 BULK		2	35		3		22	1	2	2	13				TR			1	11			8	
CLAY																		82	18				
1460 BULK		7	32	5	4		11	1	3	10	3		TR					8	9			7	
1500 BULK	5	30	12	32	2		2	TR	1		1		1		5			1	1	TR		7	
1600 BULK	4	26	19	33	2		3	1	2	1	1		2					2	2			2	
CLAY																		19	57	+24			+ ~10% SM IN M.L. I/SM
1710 BULK	5	25	17	37	TR		2		2	2			2					1	2			5	CEMENT
CLAY																		3	36	+61			+ ~10% SM IN M.L. I/SM

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

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz
3-9-90

UNOCAL GEOTHERMAL DIVISION - RANDOLPH THOMPSON

WELL 13
MEDICINE LAKE

BULK + CLAY XRD

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

SAMPLE NO.	CRISTOBALITE	QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE	ANHYDRITE	MAGNETITE	HEMATITE	PYRITE	SPHENE, RUTILE LEUCOXENE UNDIV.	CLINO-PYROXENE	AMPHIBOLE / ACTINOLITE	EPIDOTE	PREHNITE	WAIRAKITE		TALC	SMECTITE	MIXED-LAYER CHLORITE-SMECTITE	MIXED-LAYER ILLITE-SMECTITE		AMORPHOUS / BELOW DETECTION	
1800 BULK	2	14	19	32	3		3		2	3	1		TR					9	4			8	CEMENT W/PERLITE
1890 BULK	2	20	14	30	4		3		4	7			TR		4				9	3		—	
CLAY																		TR	46	+54			+ ~10% SM IN M.L. 14SM
2000 BULK		2	30	9	4		9		2	2	15	1/1	1				1	16	1			6	
2100 BULK		5	35	6	3		10	1	2	4	9		TR		1			10	4			10	
CLAY																		44	56				
2200 BULK		2	45		3		15		2	3	10	TR?/TR	TR	TR				16	1			3	
CLAY												TR					2	44	54				
2300 BULK		9	31	10	2		9		1	12	8	2/	1	TR			1	9	5			—	
2370 BULK		10	26	11		2	5	1	1	13			14	5					11			1	
CLAY																			•99	1			• ESSENTIALLY PURE CHLORITE
2400 BULK		6	45	11	2		10		1	4	7	1/	1					8	1			3	CEMENT W/PERLITE
2450 BULK		10	23	6		3	3	1	TR	15			16	6					11			6	
CLAY																			•100				• ESSENTIALLY PURE CHLORITE
2500 BULK		5	40	11	1		4		3	10	6	/2	8						10			—	
2560 BULK		7	31	7	1		7		3	13	3	1/1	12	1					11	2		—	
CLAY												5							•91	+4			+ ~10% SM IN M.L. 14/SM • VERY CHLORITIC
* 2600(?) BULK		10	26	5	1		4	1		17			15	4					9			8	

* dupl. of 2450'

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

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

S. Lutz
3-9-90

ROCK TYPES

SAMPLE FOOTAGE	BASALT	ANDESITE	PORPHYRITIC ANDESITE	MICRODIORITE + MICRODIABASE	RHYODACITE OR QTZ LATITE	PORPHYRITIC RHYODACITE	MICRO GRANODIORITE	HORNBLENDE MICROGRANODIORITE	DACITE	RHYOLITE ASH FLOW TUFF	VOLCANIC CONGLOMERATE	GOUGE	MICROBRECCIA	VEIN FRAGS.		
160		aMM	m													
200		m	'MM												' FLOW-BANDED	
300									'MM						' DEVITRIFIED, SOME PERLITIC TEX, ALTER. BIOTITE	GRAPHIC F
400		aMM		TR												
600		aMM														
800									'MM						' MUCH ALTERED BIOTITE, SOME CPX + OPX.	MORE XL THAN 30
1000		aM	m	+m									m		+ FLOW-BANDED	
1100		aMM										TR	m			
1200		aMM											m		ANGULAR FRAGS. + HEM. = CINDERS ?	
1300			aMM		'm								m		' SPHERULITIC	
1400		·m	MM									m	m		· ALTERED	
1460		am	M		'M					'm?		m	m		' DEVITRIFIED, ALSO RELICT SHARD TEX.	MIXTURE OF ROCKS
1500				TR	'MM								TR		' RELICT PERLITIC TEX, SPHERULITIC DEVITR.	
1600		am		·m	M							TR	TR		· EPIDOTE	
1710				m	'MM										' SPHERULITIC DEVITR. CEMENT	
1800		m		'm	M								TR		' COARSE GR. W/ CPX + OPX CEMENT	
1890		aM			M		'TR?				·M				' ONE CLAST GRAPHIC FSPAR a - FILLED W/ QTZ	· ROUND ANDESITE CLASTS IN CLAYEY MATRIX
2000				MM								M	m		CPX > BIO BIOTITE → SMECTITE	
2100		aTR		'MM	'TR							M	m		CPX + OPX >> BIO; COARSE \ RELICT PERLITIC TEX.	
2200				'MM								m	m		CPX + OPX >> BIO · COARSE GR. = DIABASE	
2300				xMM								\M	\m		x CPX + HB. \ HYDROTHERMAL BRECCIA? \ CROSS-CUTTING VEINS	
2370		aMM										\m	M		a - FILLED WITH QTZ, EP \ HYDROTHERMAL BRECCIA	
2400				·MM								\M	m		· SIM TO 2300' \ MYLONITE	
2450		aMM											M		a - MINERALIZED SIM TO 2370'	
2500		a·M		a·M								M	m		a - FILLED WITH QTZ, EP · SAME ROCK - DIFF. TEX.	
2560		m		M		\m				m?		m	m		\ LARGE PLAG IN DEVITRIFIED MATRIX	
* 2600		m		M								m	m			

a - AMYGDULAR

* dupl. of 2450'

WELL 13 MEDICINE LAKE

ROCK TYPES OBSERVED DURING RECONNAISSANCE PETROGRAPHY

SAMPLE FOOTAGE	VEINLETS & VEINLET FRAGMENTS: QTZ	QTZ + PY	QTZ + CC	ANH + CC	CALCITE	CHL + CC	SMECTITE	WAIR + CC EP QTZ	EP + CC	EPIDOTE	PREHNITE	KF + QTZ	ACT + QTZ	TALC	
160															MAGN → HEM, GLASSY
200															SOME SMECTITE BIO → SMECT
300															
400															SMECT, ZEOLITES IN AMYGDULES, MAGN → HEM
600															CC-FILLED AMYGDULES, HEM
800					√										ZEOLITE, CC, SMECT-FILLED AMYGDULES
1000		√			√	√									FIRST PY, CHL
1100	√	√ + LEUC	√		√	√			• √ + QTZ						• FIRST EP BOILING ASSEMBLAGE?
1200	√	√	√			√		√ + CC							MAGN → HEM QTZ + WAIR IN AMYGDULES
1300	√	√	√		√	√		√	√	√					EP + CHL + PY, LEUCOXENE
1400		√	√					√							MUCH DK. GREEN SMECTITE, TR CHALCEDONY
1460	√		√		√		√ + QTZ			√					PLAG → EP + CHL, LEUCOXENE,
1500	√				√			√ + QTZ							SILICIFIED, BIG WAIR VEINS
1600	√	√	√		√					√					EP IN MICRODIABASE SILICIFIED RHYODACITE
1710	√									√					"
1800	√	√								√ + CHL					" LEUCOXENE
1890	√	√			√			√ EP CC PY		√					SOME SERICITE
2000		√				√				√ + QTZ			√ + EP	√	FIRST ACTINOLITE, TALC MUCH SMECTITE
2100	√						√ + QTZ	√	√				√		
2200					√		√		√		√		√	√ + ACT	ACT + QTZ + SMECTITE FIRST PREHNITE
2300	√ + CHL	√	• √ + EP							√ + QTZ	√	' √		√	• BOILING ASSEMBLAGE? ' KF FLOODING?
2370				• √ + EP		√		√		√	√ + EP	√ + EP			INTENSELY MINERALIZED (ANH + GYPSUM, HEM)
2400	√									√ + QTZ		√ + ACT	√ + EP		KF + QTZ + ACT + EP VEINS KF FLOODING
2450				√ + EP		√				√ + QTZ	√ + EP	√			MINERALIZED, HEM LEUCOXENE
2500		√			√				√	√ + QTZ	√ + EP	√	√ + EP		KF FLOODING
2560						√				√ + QTZ	√ + EP		√		LOTS OF ACTINOLITE + CHL IN DIABASE, SOME SERICITE
* 2600	√					√				√ + QTZ	√ + EP	√ EP PREH			HEM + LEUCOXENE KF FLOODING, MINERALIZED

TR. GARN + PRE… + E…

* dupl. of 2450'

WELL 13
MEDICINE LAKE

VEINLETS OBSERVED DURING
RECONNAISSANCE PETROGRAPHY