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CONFIDENTIAL

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1847

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Dear Dave,

Enclosed are the promised U decay-series diagrams for rocks from the Medicine Lake Highlands. Figure 1 plots Th isotopic composition [(^{230}Th)/(^{232}Th)] versus U/Th ratio [(^{238}U)/(^{232}Th)] for all of the Medicine Lake Rocks (note that parentheses indicate activities not concentrations). Figures 2 and 3 plot magmatic and crystalline xenocryst rocks separately. The indicated uncertainty is 1σ counting statistical error. Total analytical error on Th isotopic ratios is about equal to the counting statistical error. U/Th ratios are about twice as imprecise.

Members of radioactive decay series have equal activities in phases that have remained a closed system for at least five half-lives of the longest-lived nuclide in the series. Because ^{230}Th is a descendant of ^{238}U, (^{230}Th) will equal (^{238}U) and (^{230}Th)/(^{232}Th) will equal (^{238}U)/(^{232}Th) for all phases that have remained closed systems for more than about 350,000 years ($T_{1/2}$ for ^{230}Th = 75,200 y). Such phases are said to be "in equilibrium" and will all plot on the 45° "equiline" on the enclosed figures. A process that enriches U or Th with respect to the other will change the (^{238}U)/(^{232}Th) ratio, but will not affect the (^{230}Th)/(^{232}Th) ratio. Phases that are affected by this process will plot on horizontal line immediately after the process occurs. Materials plotting to the left of the equiline have excess ^{230}Th, and these materials will migrate vertically downward towards the equiline with time; materials to the right of the equiline have a deficiency in ^{230}Th with respect to ^{238}U and will migrate upward towards the equiline over time. The result is that cogenetic samples will fall on a line with a slope that will give the age of the fractionation event.

The Glass Mountain rhyolites and dacites as well as the Hoffman Dacite all fall on a horizontal line on Figure 2 with a (^{230}Th)/(^{232}Th) of 1.21±.01, suggesting that the rhyolites represent a single cogenetic magma body which experienced U - Th fractionation since about 10,000 BP. The degree of disequilibrium does not correlate to SiO_2 content or any other measure of fractionation, but it does seem to correlate to eruption sequence; the sample with the greatest ^{230}Th enrichment is an early erupted pumice block. This suggests that explosive degassing somehow removed U from the magma. An alternative explanation is that a process operating at the upper border of the magma chamber may have caused this disequilibrium. At present, it is uncertain whether or not the horizontal line provides information about the residence time of rhyolite in the Medicine Lake system.

The quench and cumulate textured andesite inclusions of Grove and Donnelly-Nolan (1986) have $(^{230}Th)/(^{232}Th) = 1.12 \pm .02$ and $(^{238}U)/(^{232}Th)$ ratios that cause them to cluster just to the left, but within 2σ counting error of the equiline (Figure 2). These values are distinct from those of the Glass Mountain rhyolite, indicating that the andesite and rhyolite are not related to a single liquid line of descent. Giant Crater basalts (not shown - data is not completely reduced) have ^{238}U-^{230}Th-^{232}Th systematics that are similar to those of the andesite inclusions suggesting that they could be genetically related to the andesite. A quench-textured basalt inclusion from the Hoffman Dacite has a composition that falls on the Th-enriched end of the rhyolite trend described above. The high Th isotopic ratio in this basalt may reflect contamination by the enclosing host, or it may indicate that this basalt is a predecessor for the rhyolites.

The inclusions with granitic textures are from young basalt, andesite, and rhyolite flows from throughout the Medicine Lake Highlands. These inclusions exhibit varying degrees of melting and widely diverse ^{238}U-^{230}Th-^{232}Th systematics (Figure 3). Most of these xenoliths fall within 2σ error of the equiline, and have $(^{230}Th)/(^{232}Th)$ ratios that span nearly the entire range measured for volcanic rocks for the world! Xenoliths with granitic compositions generally have $(^{230}Th)/(^{232}Th)$ ratios that are equal to those of the andesite inclusions or lower. The xenolith with the lowest $(^{230}Th)/(^{232}Th)$ ratio (0.35) is from the Paint Pot flow. It has equilibrium (^{238}U)-(^{230}Th) values and is melted to such a degree that all primary texture was obliterated. It now consists of anhedral feldspars, quartz, and magnetite floating in about 50 % colorless to red-brown glass. U/Th ratios this low are rare in unmetamorphosed igneous rocks, but are relatively common in high-grade (amphibolite to granulite facies) metamorphic rocks. Low ratios in granulites have been attributed to U loss during metamorphic dehydration, and it is likely that this sample was a granite which underwent devolatilization and perhaps melting more than about 300,000 years ago. Indeed, it may be a melted granulite from middle to deep crustal levels.

Three granitic xenoliths have high $(^{230}Th)/(^{232}Th)$ ratios. One sample is extensively melted and is from the Burnt Lava Flow. It has $(^{230}Th)/(^{232}Th) = 1.56$, which is the highest Th isotopic value measured for the Medicine Lake Highlands. It is conceivable that this sample represents Mesozoic or early Cenozoic basement rock that is unrelated to the Medicine Lake system. The other two samples with high Th isotopic ratios are from the Hoffman Dacite. The compositions of these samples are nearly identical with $(^{230}Th)/(^{232}Th)$ ratios that slightly exceed those of the rhyolites and dacites, and strong Th-enrichments. The Th enrichment in these samples may have resulted from devolatilization immediately before incorporation into the host lava. The time interval between devolatilization and eruption must have been relatively short (< 10,000 y?).

We also analyzed an unmelted gabbroic xenolith (50 wt. % SiO_2) from the Glass Mountain Rhyolite. The sample has a $(^{230}Th)/(^{232}Th)$ ratio that exceeds those of all of the magmatic samples and is in radioactive equilibrium. This sample has an unusual mineralogy in that it has and olivine, clinopyroxene, orthopyroxene, hornblende, and biotite. All reaction relationships from Bowen's reaction series are found in this one sample. This sample probably represents a gabbroic rock not related to the Medicine Lake System which was metasomatized at high temperature more than 300,000 years ago.

Our interpretations of these data are still preliminary; they should be finalized by next summer. As soon as Joe Hill completes his thesis, we will send you a copy. In addition, we hope to present our results to your geothermal group next summer.

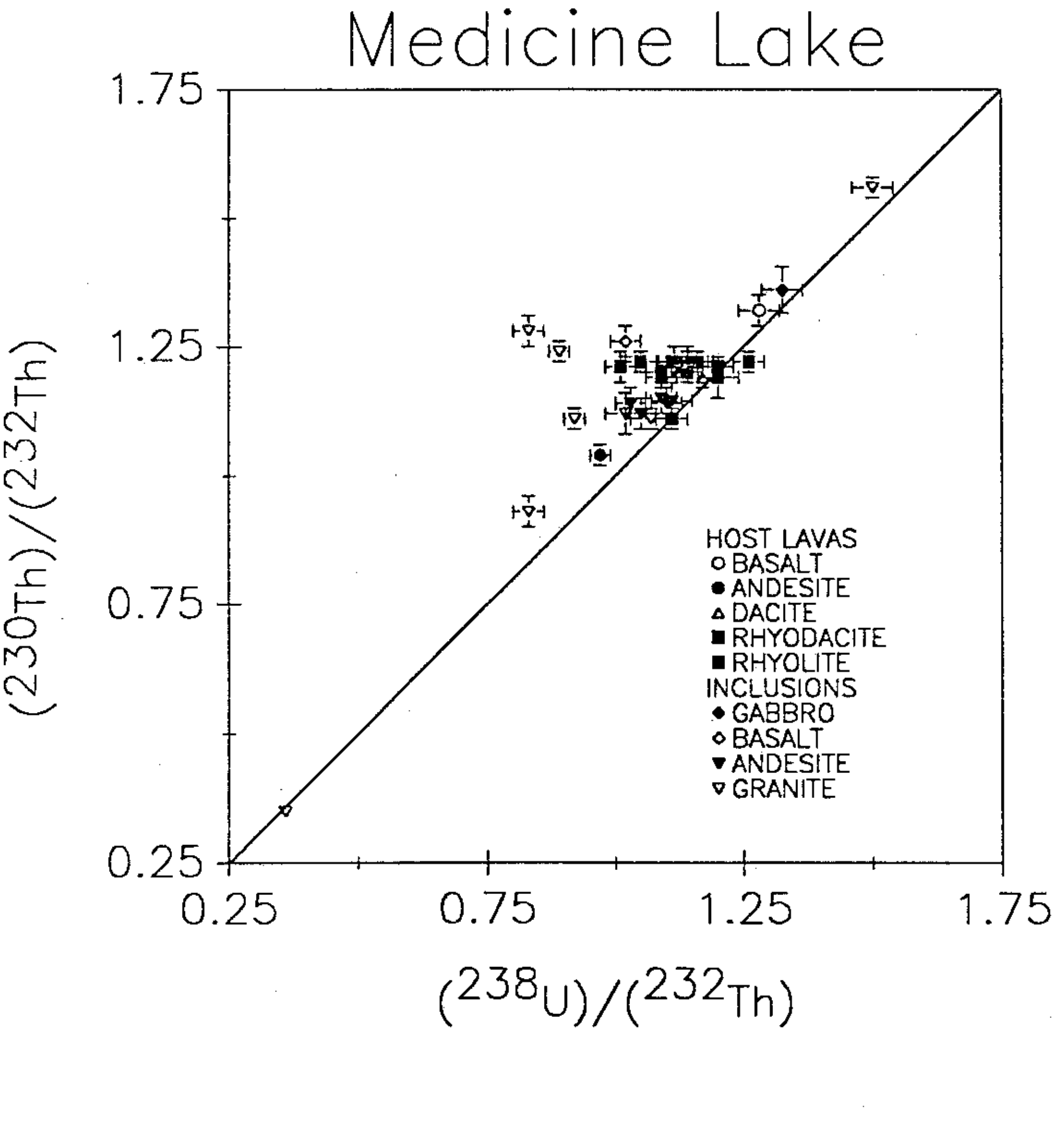
It was a pleasure meeting you at AGU. Thanks for the excellent dinner.

Happy New Year!

Mark Reagan

Mark Reagan

Figure 1



Medicine Lake
1.75
1.25
0.75
0.25
0.25
0.75
1.25
1.75
$(^{230}Th)/(^{232}Th)$
$(^{238}U)/(^{232}Th)$
HOST LAVAS
BASALT
ANDESITE
DACITE
RHYODACITE
RHYOLITE
INCLUSIONS
GABBRO
BASALT
ANDESITE
GRANITE

Figure 2

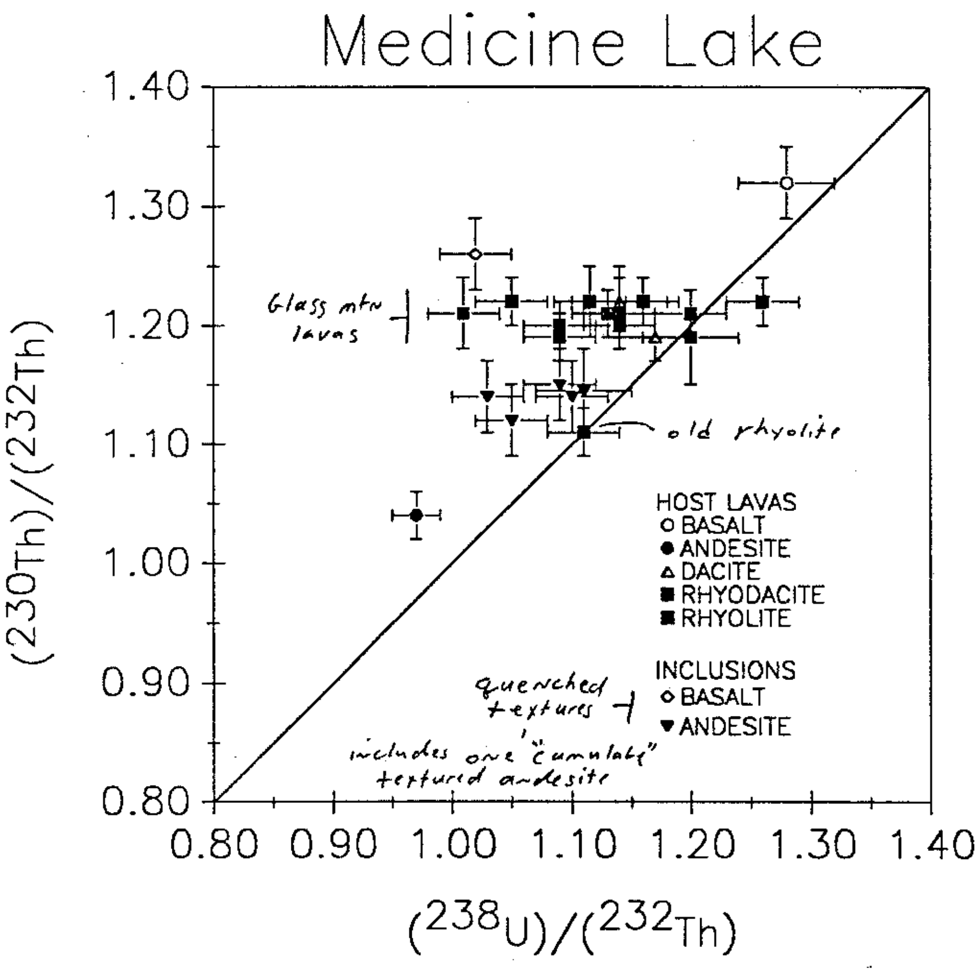
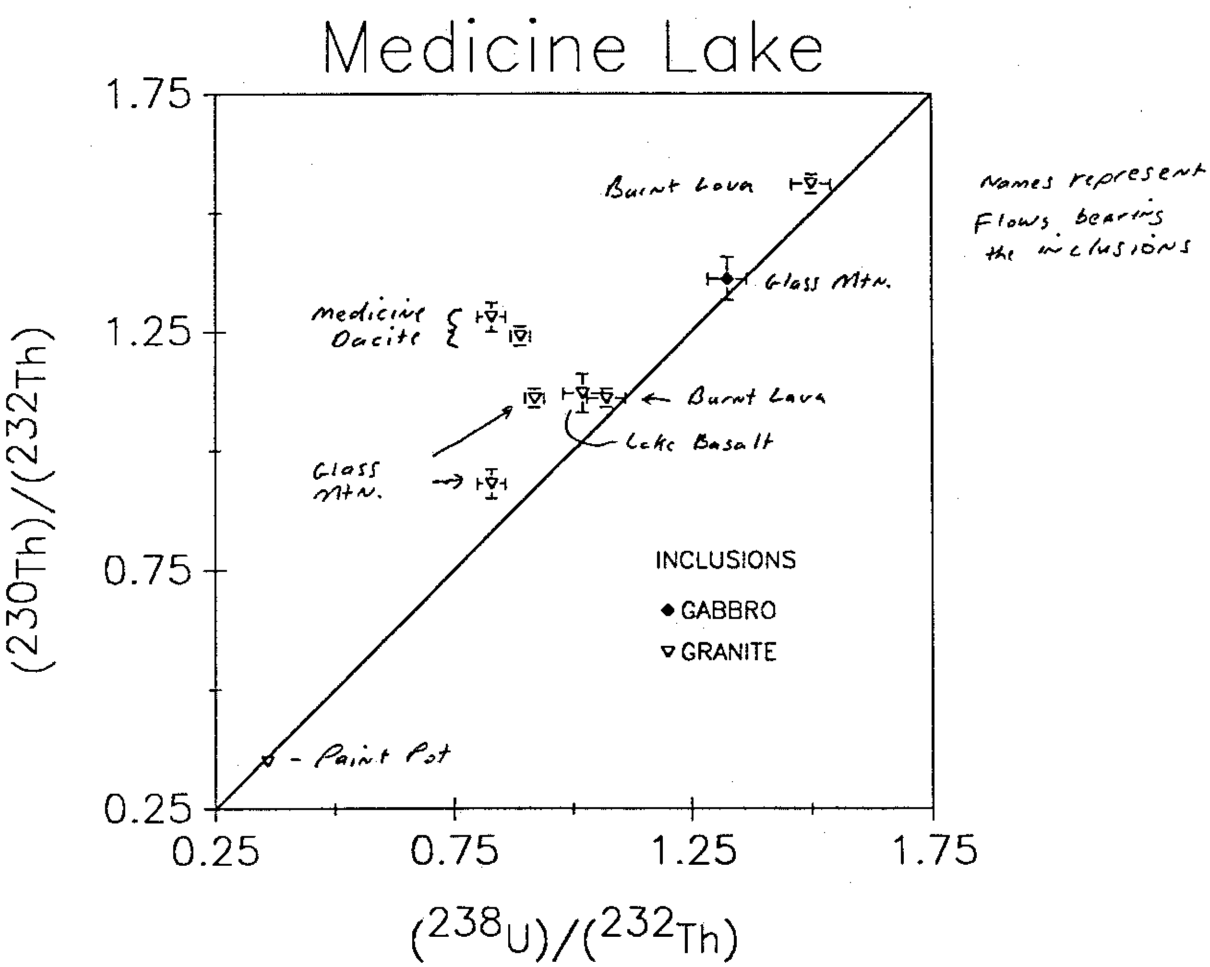

Medicine Lake
1.40
1.30
1.20
1.10
1.00
0.90
0.80
(230Th)/(232Th)
0.80 0.90 1.00 1.10 1.20 1.30 1.40
(238U)/(232Th)
Glass mtn lavas
old rhyolite
HOST LAVAS
BASALT
ANDESITE
DACITE
RHYODACITE
RHYOLITE
INCLUSIONS
BASALT
ANDESITE
quenched textures
includes one "cumulate" textured andesite

Figure 3



Medicine Lake
1.75
1.25
0.75
0.25
0.25
0.75
1.25
1.75
(230Th)/(232Th)
(238U)/(232Th)
Burnt Lava
Glass Mtn.
Medicine Dacite
Burnt Lava
Lake Basalt
Glass Mtn.
INCLUSIONS
GABBRO
GRANITE
Paint Pot
Names represent Flows bearing the inclusions

Univer-ity of Arizona	K-Ar data on basalt sample	$\lambda_\beta = 4.963 \times 10^{-10}\ yr^{-1}$
Isotope Geochemistry Lab	Cooperative research project with Dr. Brian Smith	$\lambda_e = 0.581 \times 10^{-10}\ yr^{-1}$
Date: July 13, 1984	Union Science and Technology	$\lambda = 5.544 \times 10^{-10}\ yr^{-1}$
		$^{40}K/K = 1.167 \times 10^{-4}$ atom/atom

SAMPLE NUMBER	SAMPLE DESCRIPTION & LOCATION	K-ANALYSES		RADIOGENIC $^{40}Ar \times 10^{-12}$ m/g		% ATMOSPHERIC ^{40}Ar		AGE IN MILLIOI YEARS
		INDIVIDUAL % K	MEAN	INDIVIDUAL ANALYSES	MEAN	INDIVIDUAL ANALYSES	MEAN	
UAKA 84-136	Groundmass consisting of plagioclase concentrate (#54-19/1059-1060)	0.993 0.988 0.984 1.002	0.992	0.640 0.527 0.685 0.658	0.628	81.2 83.3 79.4 80.1	81.0	0.365 ± 0.021
UAKA 84-137	Groundmass plagioclase concentrate, dacite (Union Oil #75-6/362-363)	2.168 2.156 2.083	2.136	0.722 0.616 0.651 0.549	0.635	87.2 88.8 88.1 89.0	88.3	0.171 ± 0.016
UAKA 84-135	Groundmass consisting of plagioclase concentrate (52-30/760-761)	1.621 1.622 1.644	1.629	0.546 0.496 0.582 0.532	0.539	92.8 93.5 95.4 91.4	93.9	0.191 ± 0.038
UAKA 84-138	Glass, vitrophyre (#52-30/1799-1808)	3.549 3.543 3.520 3.570 3.546	3.546	0.297 -1.409 -2.314 -1.016 -2.458 -2.592 -2.250 -2.506	-1.781			