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Silicic Magma Evolution at Mid-Ocean Ridges: Insights from the Southern Juan de Fuca Ridge

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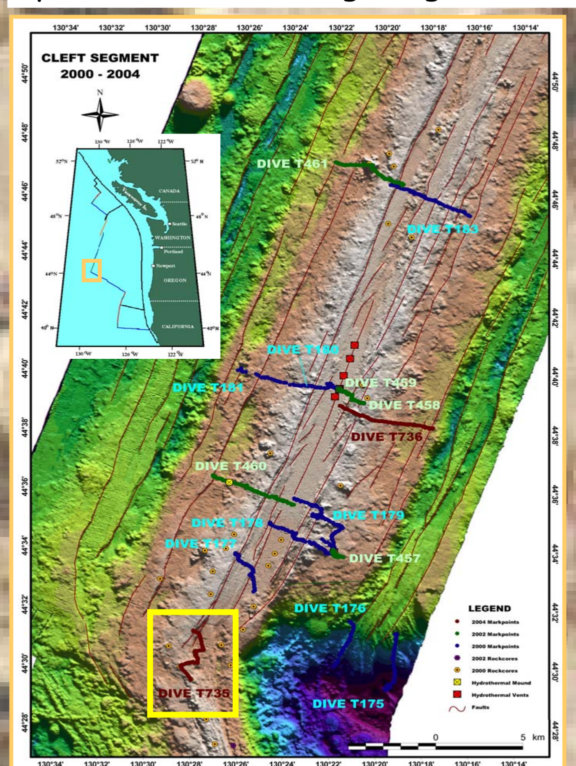
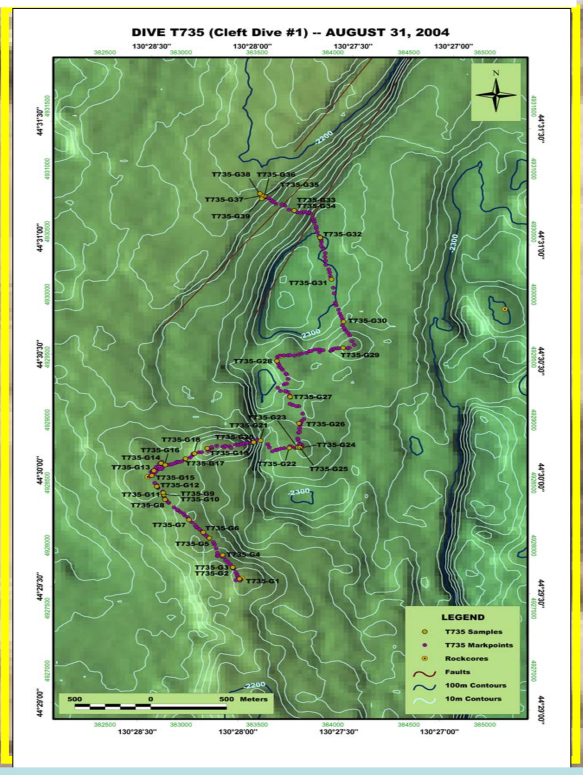
ABSTRACT

Dacites and hi-silica andesites recovered from hummocky, curved ridges that overshoot the ridge-transform intersection (RTI) of the southern Juan de Fuca Ridge (JdF) form two young-looking constructional domes (~ 34 m high) and provide a rare glimpse into silicic magmatism at mid-ocean ridges (MOR). The silicic lavas are unusually vesicular and crystalline compared to similar samples previously recovered from MOR such as the Galapagos Spreading Center (GSC). Mineral assemblages are dominated by microphenocrysts of ferroaugite and ferropigeonite, with lesser amounts of sodic plagioclase and FeTi oxides. Rare zircon, apatite, fayalite and fragments of myrmekite are present together with magnesian xenocrysts and quenched basaltic material.

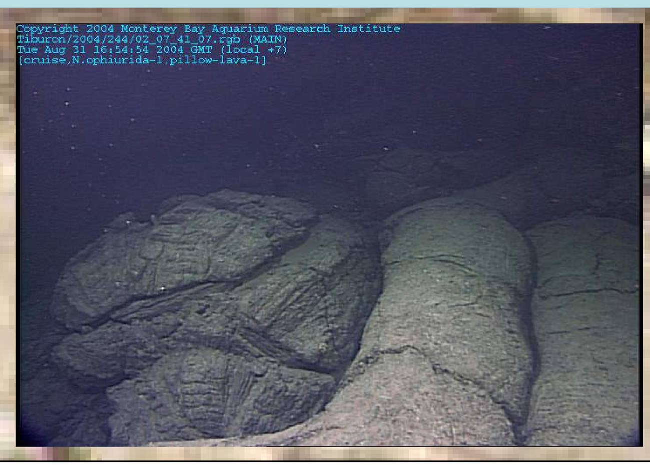
Zircons in five samples were analyzed in situ for U-Th and Oxygen isotopes by ion microprobe. The very limited Th/U range in JdF MORB and the silicic lavas, plus only a slightly greater range in Th isotopic composition (230Th/232Th) allow age estimates of 21 ka and 35 ka in two of the dacite glasses (by TIMS) – in agreement with zircon ages of 28 ± 4 ka. Ti concentrations in zircon average 14 ppm, and imply zircon crystallization at temperatures between ~770 and 840°C, consistent with zircon saturation temperatures from bulk lava compositions (830 - 880°C), major element models (approx. 900°C) and pyroxene thermometry. Overall, the isotopic, trace element and textural evidence from the zircons indicate they crystallized in-situ from a highly evolved melt, shortly before eruption. The crystal zoning patterns and the presence of basaltic inclusions together with linear trace element variation trends suggest the lavas are the result of magma mixing between relatively evolved MORB and rhyodacitic melts or plagiogranite that may be remobilized by propagation of basaltic melts in the static, RTI environment where crystallization is enhanced. The occurance and abundance of the silicic rocks corresponds to location where an axial magma chamber (AMC) refector is no longer imaged in the upper crust - suggesting magma chambers are likely small and/or ephemeral at the ridge segment terminus.



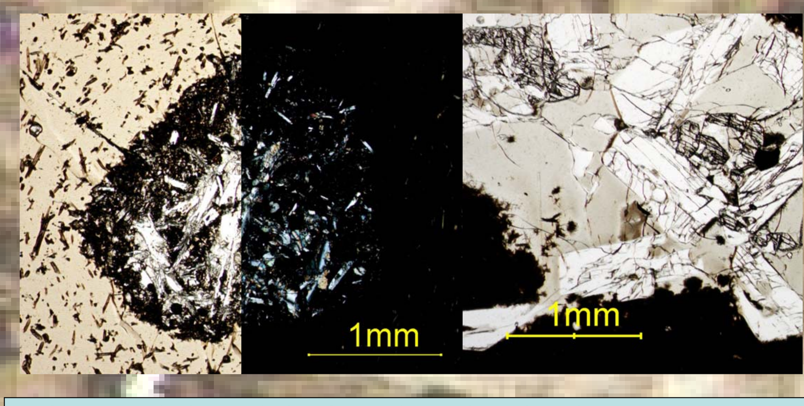
Overview of the 2000-2004 dive series to the Juan de Fuca Ridge.



Dive T735 collected lava samples from the Ridge-Transform Intersection (RTI). Evolved lavas (below) were collected from two constructional domes

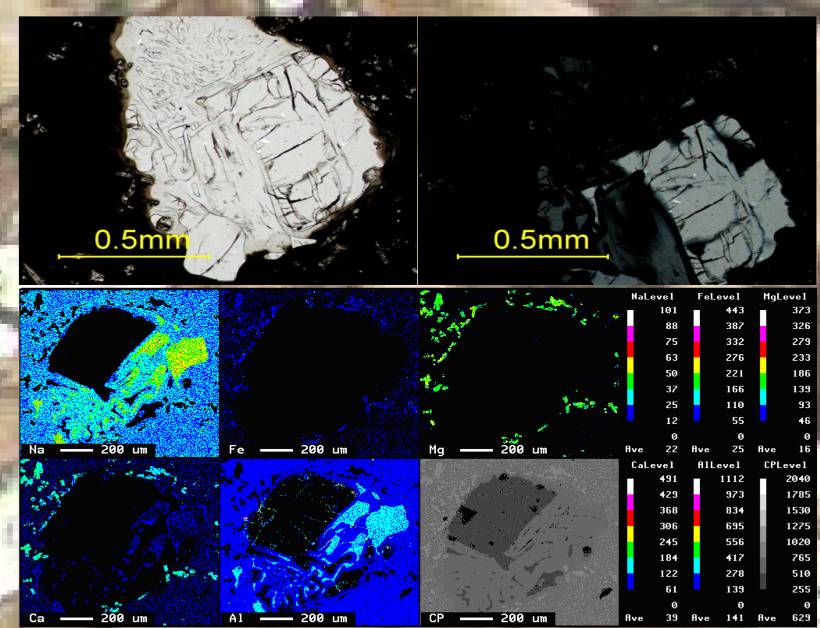


Mineralogy



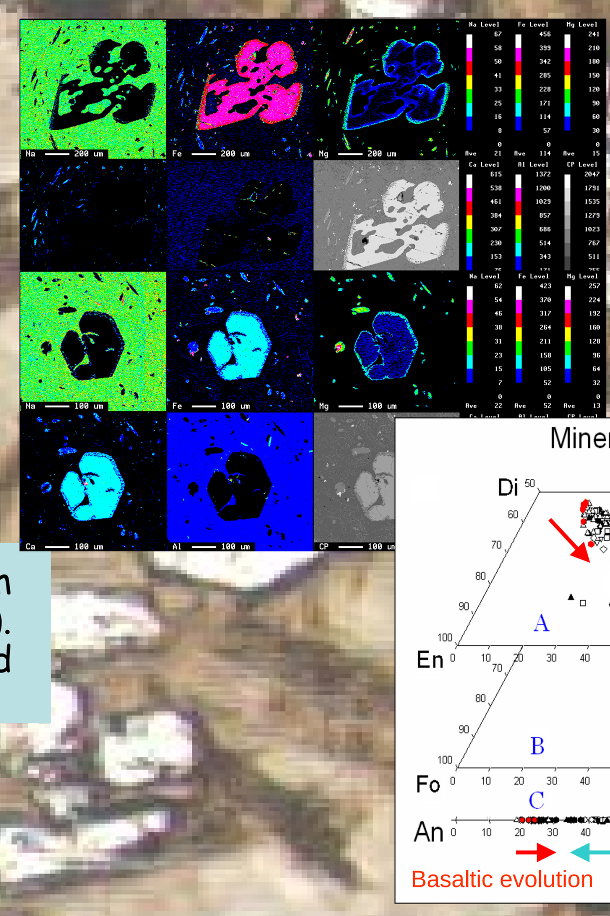
Left: Rounded xenolith of basalt enclosed in dacite.

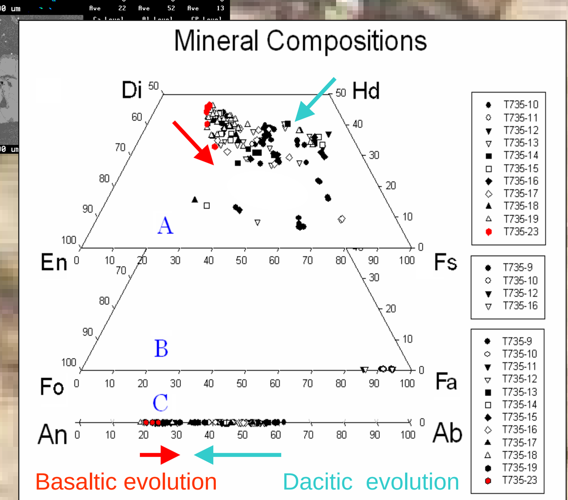
Right: Xenolith of (An34) Plag and fayalite (Fo15) in dacitic glass



Top: Optical images of Myrmekitic xenoliths in dacites.

Bottom: X-ray element map showing the plag+ quartz intergrowth.

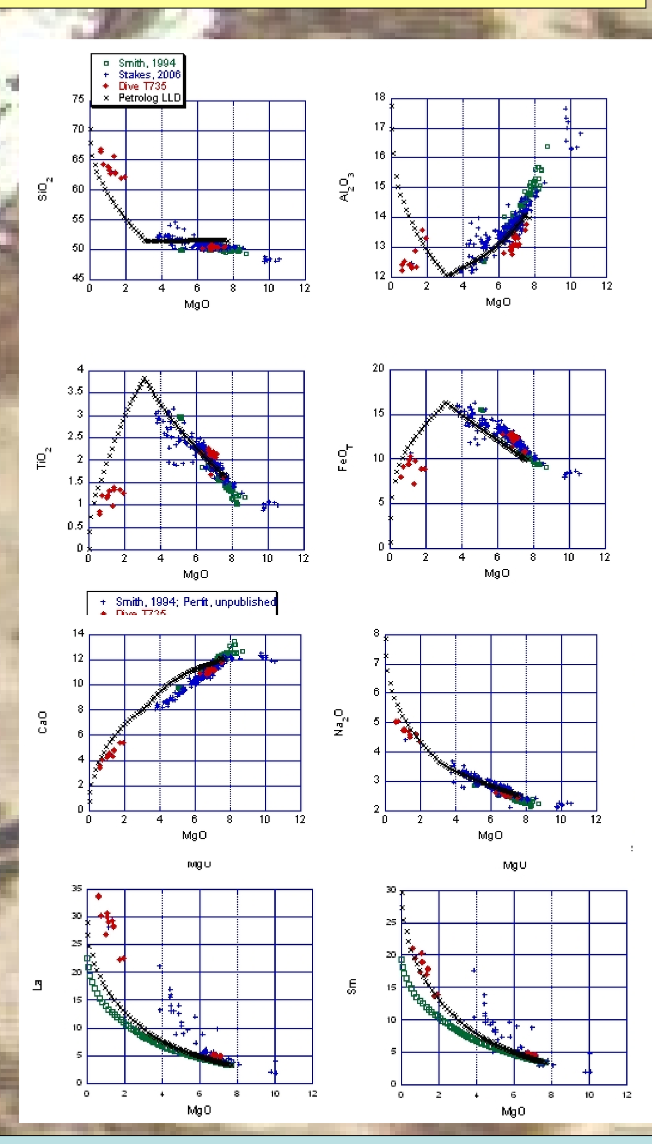




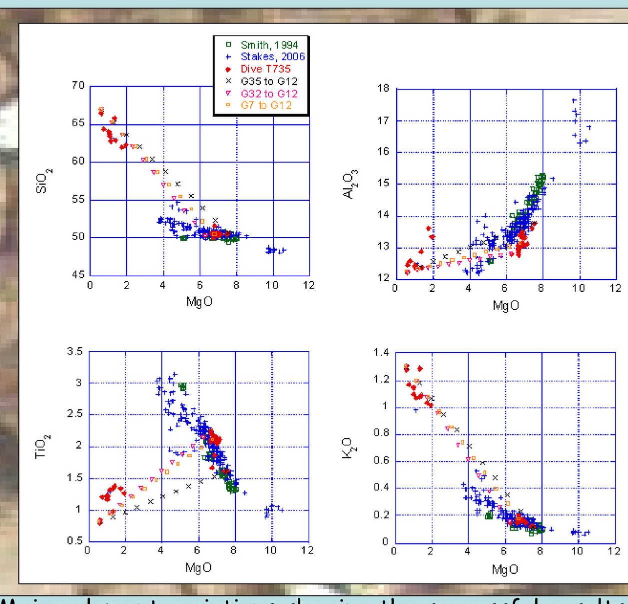
Above left: X-ray element maps of inversely zoned skeletal fayalite and ferroaugite in dacites.

Below right: Plots showing compositions of pyroxenes, olivine, and plagioclase in basalts, andesites and dacites. Arrows indicate direction of core to rim zoning in crystals. Inverse zoning in crystals in dacites is consitent with mixing of basaltic and highly evolved rhyodacitic melts.

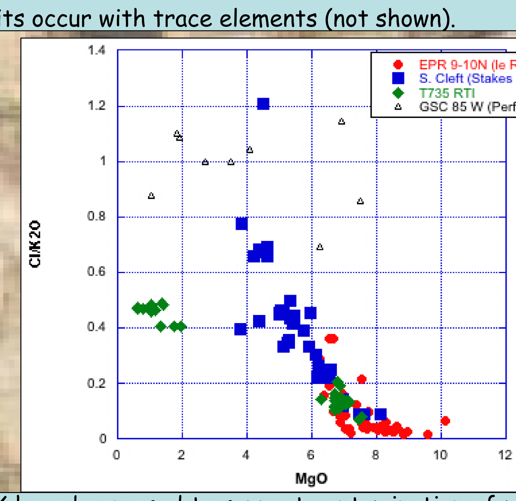
Lava Geochemistry



Major and trace element variations in S. Cleft lavas (andesites and dacites in red), showing partially successful results of fractional crystallization modelling.

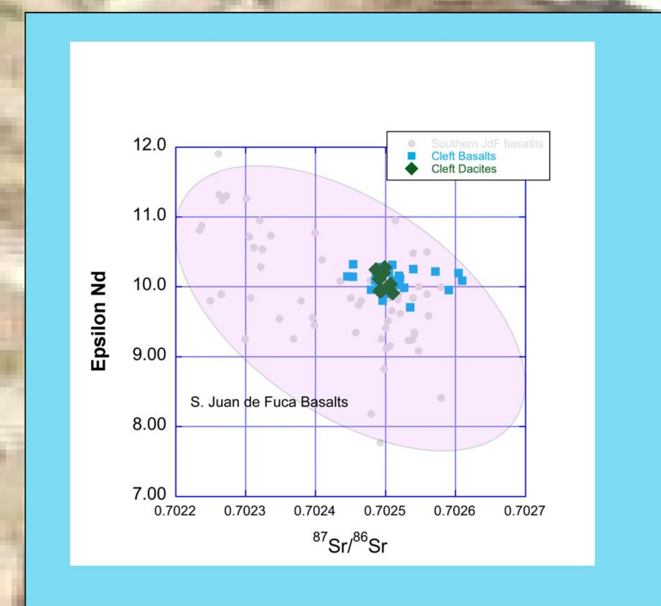


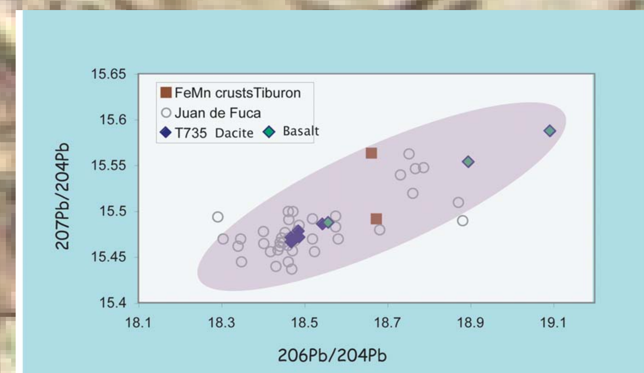
Major element variations showing the successful results of mixing between ferrobasalts and the most evolved dacite to generate the trends in the most evolved lavas. Similar good fits occur with trace elements (not shown).



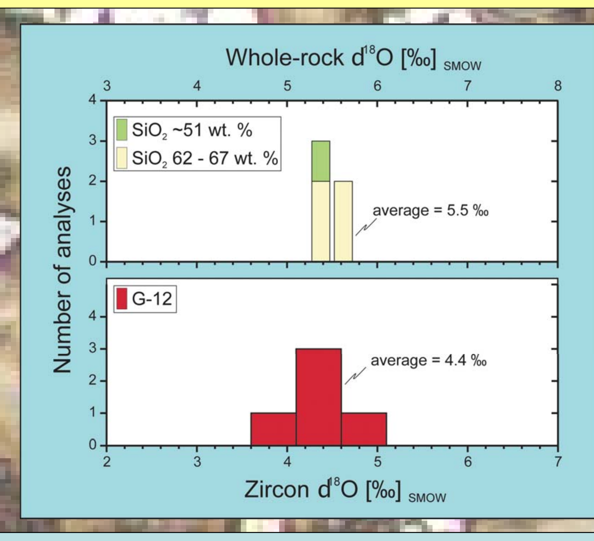
Cl/K have been used to support contamination of magmas by seawater and/or hydrothermal brines. High values in S. Cleft lavas similar to Galapagos SC lavas are consistent with some contamination.

Isotope Geochemistry

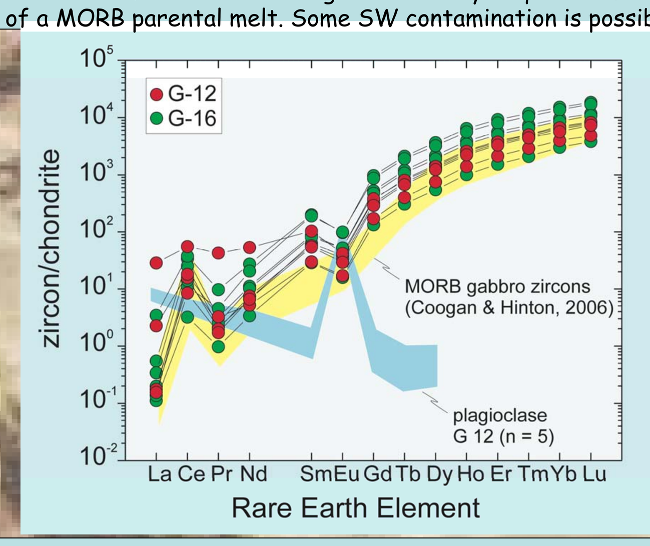




Zircon studies



Whole-rock and zircon d18O values for T735 dacites; top and bottom axes are scaled for a zircon- melt fractionation of -1 ‰. Oxygen isotopic compositions for zircon are in equilibrium with melt compositions. Note that dacite and basalt whole-rock d18O are subequal, in contrast to the expectation of ~1‰ elevated d18O in the dacites if these were generated by equilibrium fractional crystallization of a MORB parental melt. Some SW contamination is possible.



Chondrite-normalized REE abundances for T735 dacite zircons and plagioclase. Zircons overlap with the range of MORB gabbro zircons but tend to have higher overall REE abundances. Eu/Eu* in zircon and plagioclase are mutually consistent with Eu^{2+}/Eu^{3+} = 0.66 and melt REE compositions, suggesting that zircon crystallized in equilibrium with the host dacite.

U-Series Geochemistry

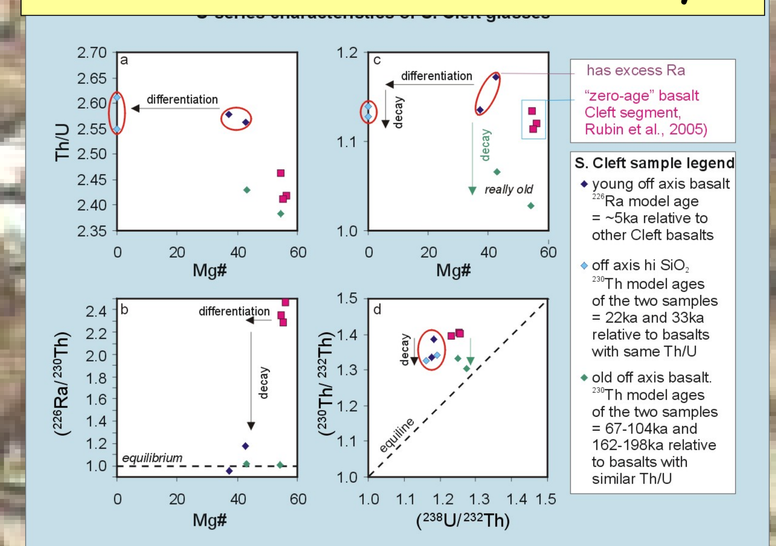
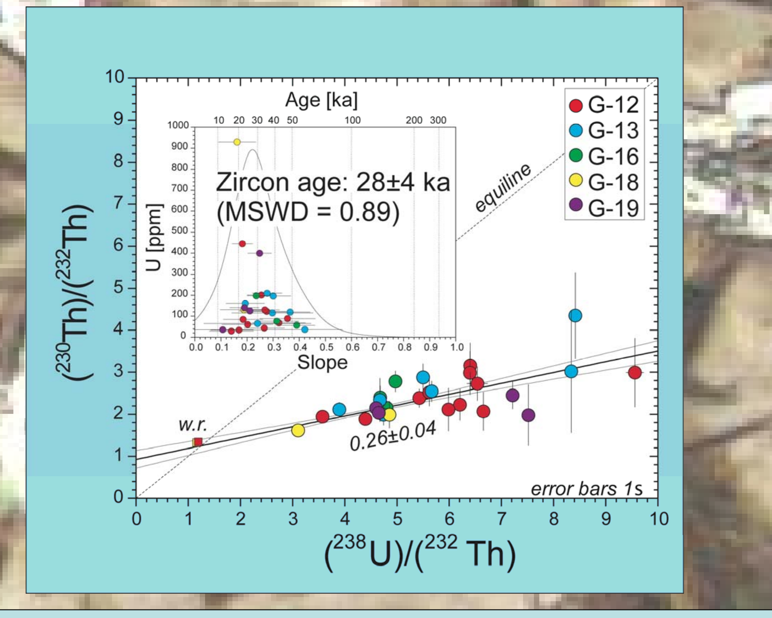


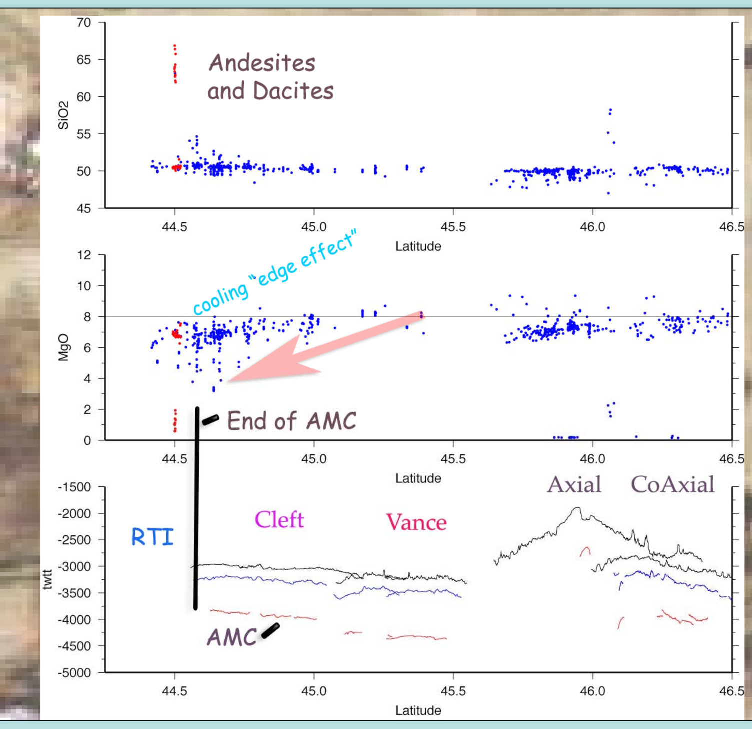
Fig ?. U-series signarues in S. Cleft glasses and age estimates. S. Cleft glasses are shown in 3 colors of diamonds (see legend panel) and are plotted with nearby young Cleft Sheet Flow samples (red squares; these were reported in Rubin et al., Nature, 2005) U-series nuclides were analyzed by TIMS at the Univ. of Hawaii. (analyitical methods are described in this same reference)

Three important aspects of the data are:

1. strong similarity of Th/U in high silica glasses with nearby MORB with slightly reduced ^{230}Th allows aus to estimate high silica magma ages of 22 to 33 ka. We have not yet analyzed ^{226}Ra in these two samples but anticipate secular equilibrium.
2. one near axis S. Cleft basalt displays a ^{226}Ra excess, which allows a rough age estimateof ~5ka by comparison to N. Cleft lavas at similar Th/U
3. Two older S. Cleft basalts have MgO and Th/U that are intermediate between this yopung S. Cleft basalt and the N. Cleft samples, allowing for rough 230Th decay age estimates of 67-104ka and 162-198ka, respectively.



(230Th)/(232Th) vs. (238U)/(232Th) isochron diagram showing T735 dacite zircon and whole rock compositions. Error-weighted regression line is indicated and overlaps within uncertainty with whole rock values. Inset shows two-point melt - zircon model isochron slopes and U abundances of zircons. Average slope from two-point isochrons overlaps with the zircon isochron, corresponding to an average zircon crystallization age of 28 ± 4 ka.



Profile of Southern Juan de Fuca Ridge showing glass geochemistry relative to depth, crustal thickness (blue) and location of Axial Magma Chamber (AMC) reflector(red) [from Carbotte et al. pers. Comm]