^{3}He Cosmogenic Dating in Zircon, Apatite and Titanite

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What is cosmogenic dating?

Cosmogenic isotopes are produced in rock by the interaction of energetic particles with "target" nuclei in the rock. By measuring the abundance of ^{3}He (or ^{10}Be, ^{21}Ne, ^{26}Al, ^{36}Cl), the exposure age of surfaces in the landscape can be calculated.

How does it apply to active tectonics?

Knowing the *age* of surfaces in the landscape allows the calculation of the *rate* at which the surface is deformed by tectonic or erosional processes. This includes; faulted and folded terraces, alluvial fans, offset moraines, bedrock and basin-scale erosion, the age and rate of soil development, and more!

Why develop ^{3}He dating in these phases?

Conventional cosmogenic dating using ^{10}Be, ^{26}Al or ^{36}Cl requires time consuming and expensive preparation, and measurements on an accelerator mass spectrometer. In contrast, ^{3}He is measured cheaply and easily on a noble gas mass spectrometer. Previous use of ^{3}He has been primarily in olivine and pyroxene in volcanic rocks. ^{3}He dating in zircon, apatite and titanite will allow fast, cheap cosmogenic dating of more common rock types.

Our approach...

Our goal is to determine the production rate of ^{3}He in zircon and apatite by direct cross calibration to the known production rate of ^{10}Be in quartz. We separated minerals and measured He in glacial moraine boulders from the Nepal Himalaya, which were previously dated by ^{10}Be.

Methods

1) 5-25 mg of mineral is degassed under vacuum by heating of a platinum packet with a Nd-YAG laser.

2) Gas is purified in a vaccum line before ^{4}He and ^{3}He intensities are measured by peak switching between a faraday cup and an electron multiplier using an MAP-250 noble gas mass spectrometer.

3) ^{3}He Concentrations are calculated by comparison with a He standard.

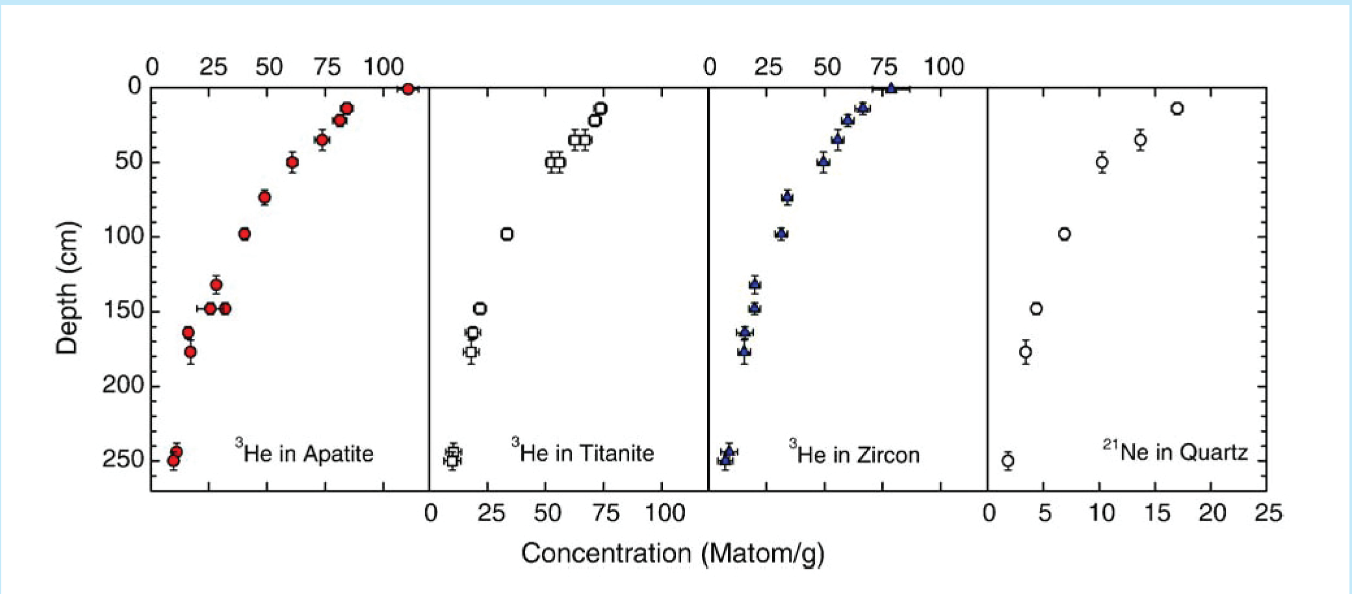
Analytical concerns

1) **Pressure broadening of the 4He peak**: to address this concern, samples of thorianite (ThO_2) were used to generate high pressures of pure ^{4}He. It was found that the ^{4}He peak was not "tailing" onto the ^{3}He peak at high pressures.

2) **Space-charge effects**: because machine sensitivity is calibrated with standards at low He pressures, it may not reflect the true sensitivity for higher pressures induced by the sample gas. This problem is solved by introducing a "spike" of ^{3}He rich standard during the analysis to evaluate the sensitivity during each analysis.

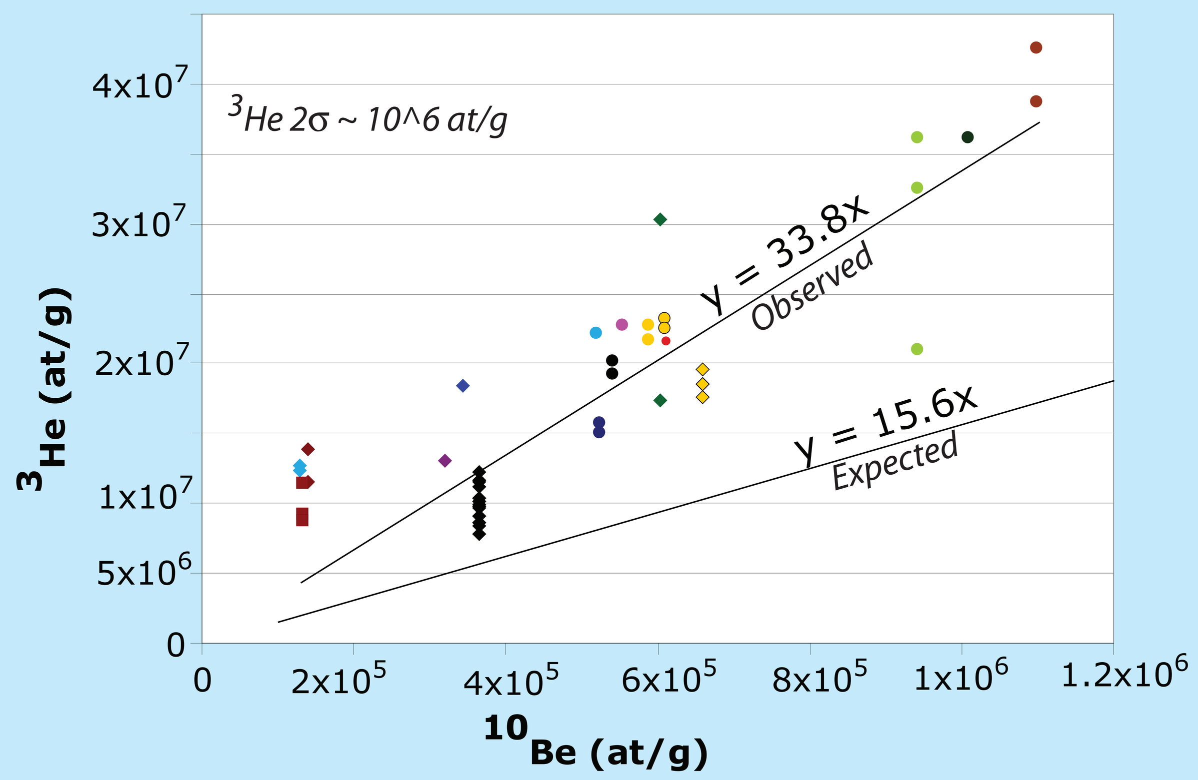
Previous Work:

Farley et al., 2006 calibrated the production rate of ^{3}He against ^{21}Ne in a Bolviian tuff. A production rate of 80 at/g/yr was found for zircon, 105 at/gyr in apatite and 90 at/g/yr in titanite. These depth profiles show exponential decay of ^{3}He with depth in the rock, confirming a cosmogenic source for the ^{3}He.

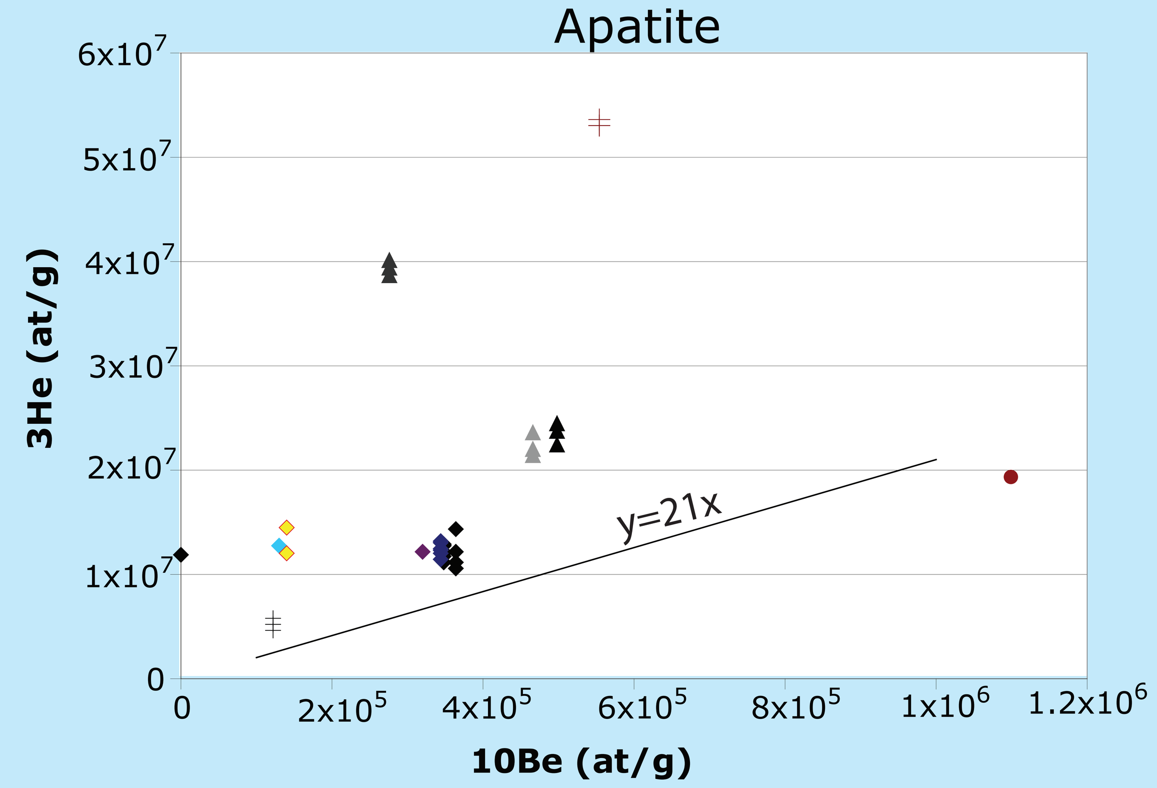


Direct comparison of ^{3}He and ^{10}Be

Zircon

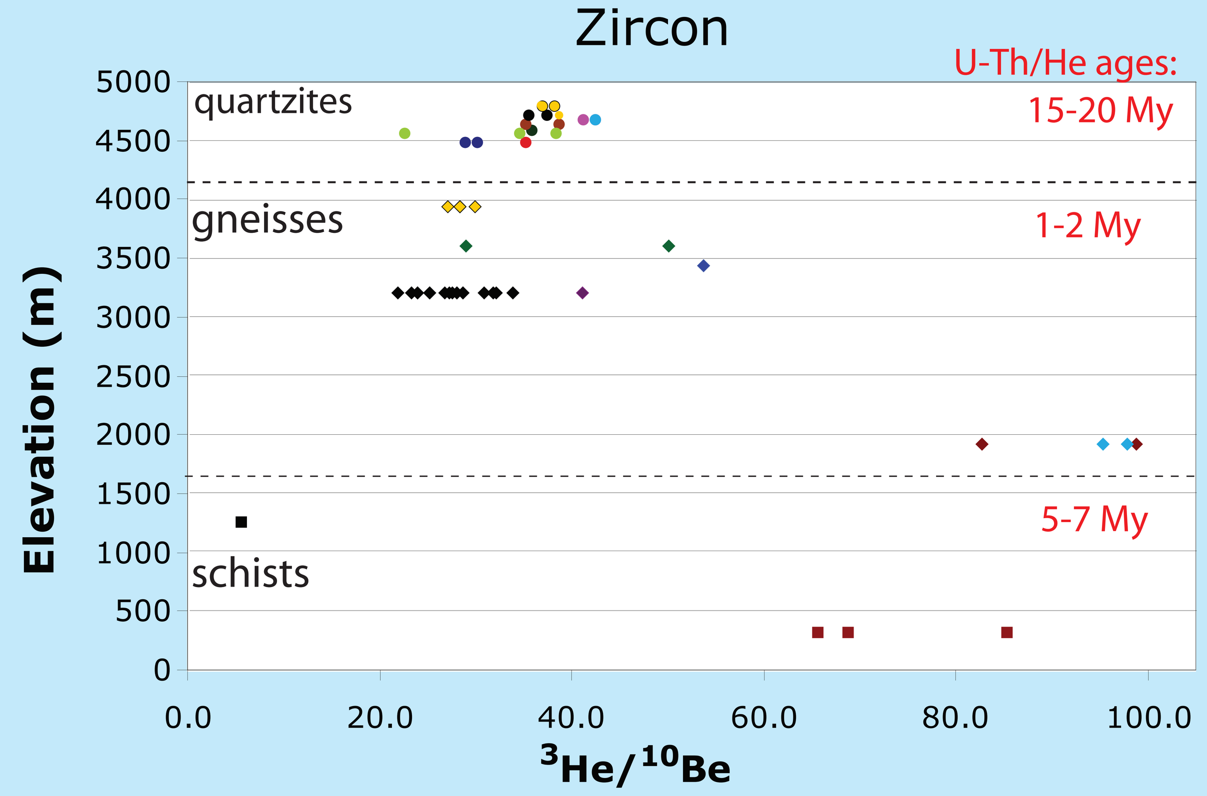


Apatite



Plotting ^{3}He/^{10}Be against elevation

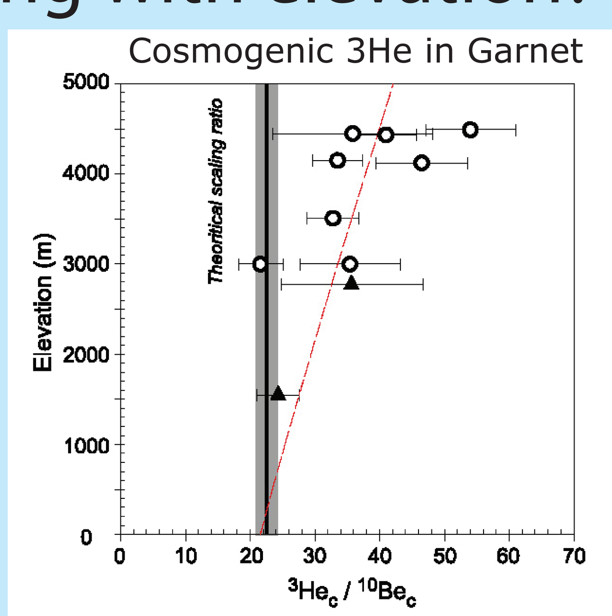
Zircon



Is overproduction increasing with elevation?

Because ^{3}He and ^{10}Be are both produced by neutron spallation, it has often been assumed that both production rates scale with elevation according to the attenuation length of the fast neutron flux. However, because ^{3}He has a lower energy threshold for spallation reactions, its production rate may scale differently with elevation than ^{10}Be. One possibility is that, because the neutron energy spectrum is more energetic at high elevations and low latitudes, neutrons could engage in a primary spallation event, creating additional lower energy neautrons with enough energy to spall a ^{3}He nucei, but not enough to spall a ^{10}Be nuclei. This production pattern would appear as a lower attenuation length for ^{3}He, similar to that observed by Gayer et al., 2004 who measured cosmogenic ^{3}He in Himalayan garnets and found a pattern similar to what we observe in zircon.

Cosmogenic 3He in Garnet



Gayer et al., 2004

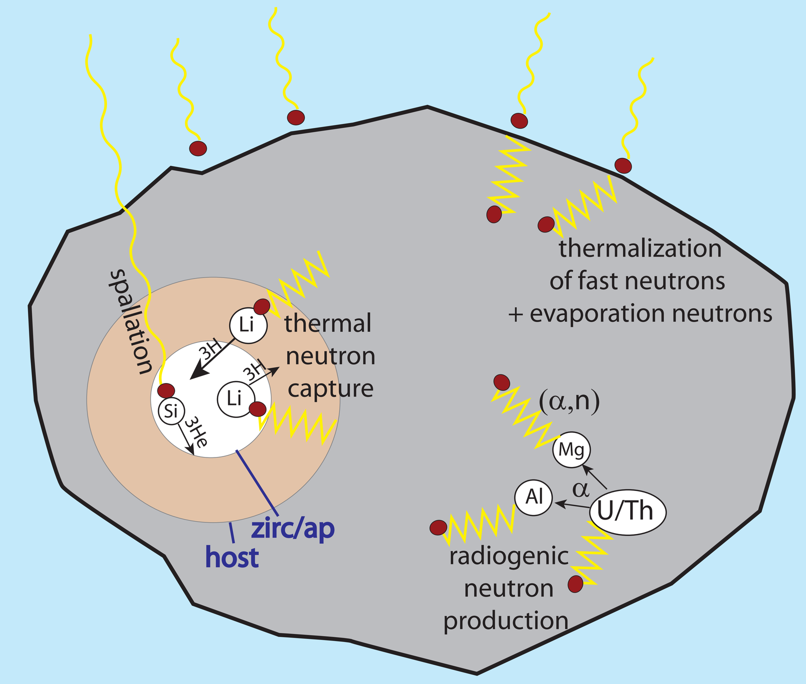
Other explanations for overproduction?

It is important to consider non-cosmogenic sources of ^{3}He, produced by a variety of "nucleogenic" reactions, including thermal neutron capture by ^{6}Li:

$^6Li(n,\alpha)\rightarrow{}^3H\rightarrow{}^3He$

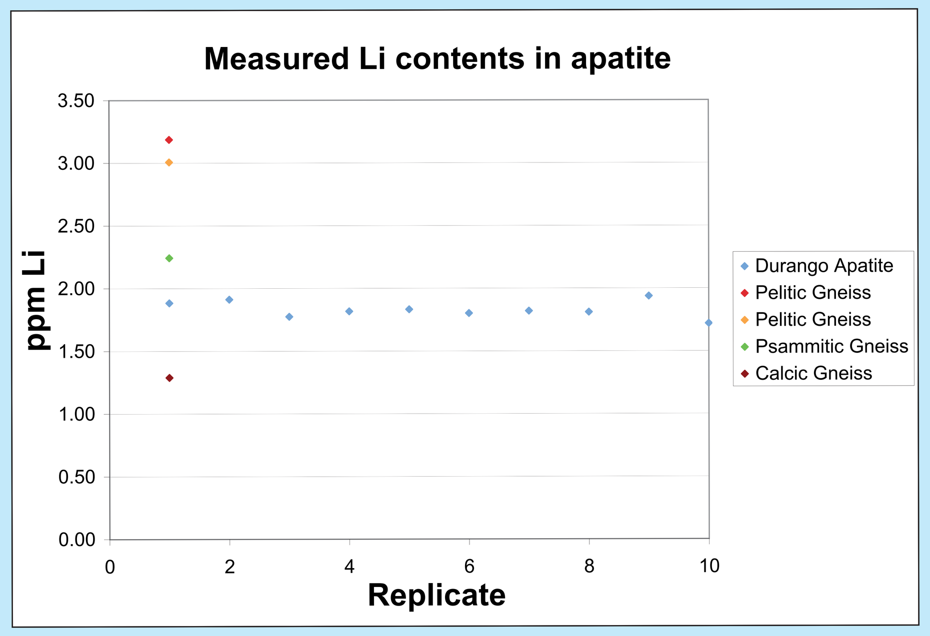
To evaluate the importance of this reaction, a model was constructed which considers; 1) thermal neutron flux from slowing of fast neutrons near the surface and from radiogenic sources below the surface, 2) the U-Th/He closure age and cosmogenic exposure age of the sample, and 3) Li content in the crystal of interest as well as in the "host" mineral surrounding it. Point 3 is particularly important because ^{3}H produced via ^{6}Li can be injected from a high Li host into the zircon or apatite.

Some Neutron Processes in Rock

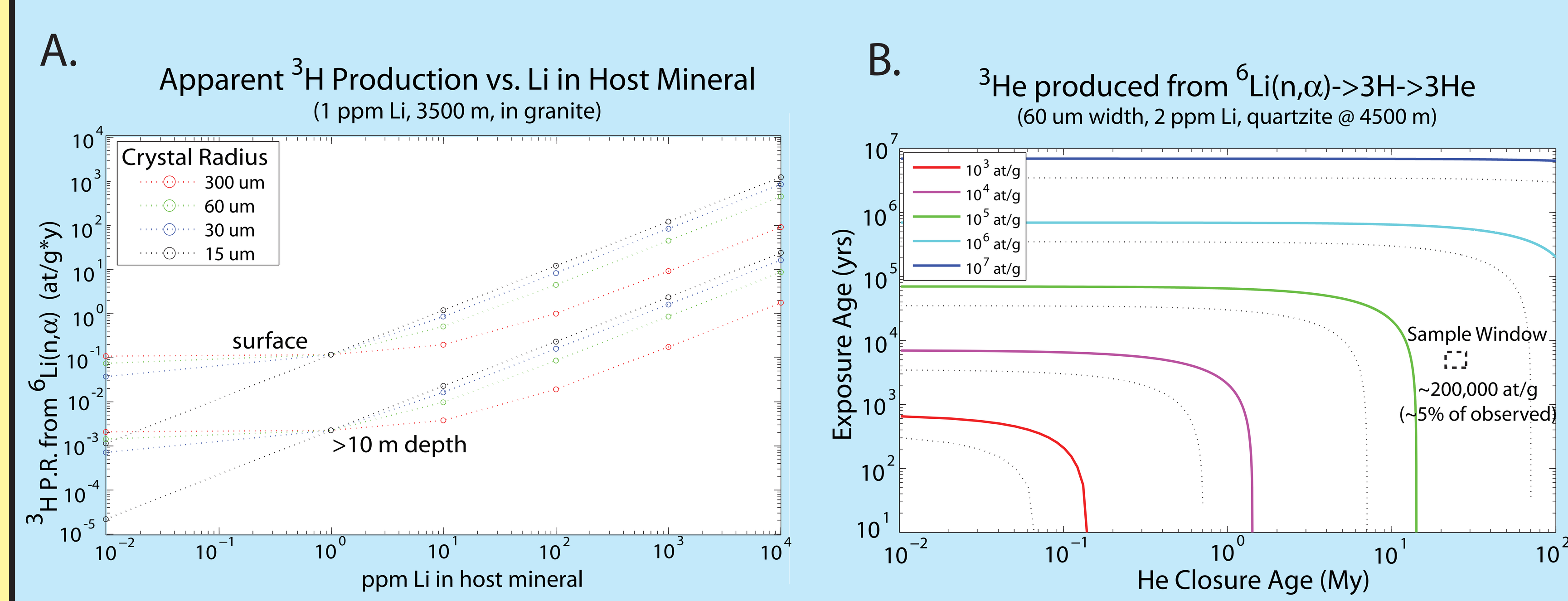


Measuring Li:

Li contents have been measured on apatites using the ICPMS at Caltech. Results show good reproducibility, suggesting Li can be accurately measured by this technique. Observed values range from ~1-3 ppm, with similar or lesser values expected for zircon.



Model Results:



Plot A shows the importance of grain size in determining the production of ^{3}He from ^{6}Li. Production in small grains is dominated by implanted ^{3}He, and is linearly related to Li content in the host. Larger grains have most of their 3He produced internally, and thus the apparent production rate from Li flattens when the host Li content becomes very low. Plot B shows the expected ^{3}He produced from ^{6}Li as a function of exposure age and U-Th/He closure age. This result is for a 1 ppm zircon/apatite embedded in a quartzite at 4500 m, and shows that production from 6Li is <5% of the total observed 3He.

Conclusions and future work:

1) Based on the work of Farley et al., 2006 it appears that this technique is ready to be applied to low-Li samples, in settings outside of Nepal.

2) It is likely that a problem exists with the currently accepted scaling models when applied in the Nepal Himalaya. To confirm this we plan to:
a) measure Li in more samples of zircon and apatite
b) explore hand sample petrgraphy to determine "host" minerals
c) measure 3He and closure age in Li-rich phases to estimate thermal neutron flux in the rock