Closure profiles in thermochronology

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Most geophysical processes impart a characteristic thermal signature to the crust that is preserved in the form of isotopic variations in radiogenic minerals. Reading the record of these events permits unprecedented insights into the timing and rates of key dynamic processes. However, heat flow disturbances are often too subtle to be seen by conventional thermochronometric methods; i.e., interpolation of *T-t* data from bulk analyses. Rather, the highest resolution thermal histories require harnessing knowledge of the concentration distribution of the daughter product in the solid of interest. When tied to direct knowledge of the kinetic behaviour of the daughter product, this approach provides an absolute calibration from which empirically constrained thermochronometers can be evaluated.

By far the best opportunity to obtain detailed thermal histories from the K-Ar system is by application of $^{40}Ar/^{39}Ar$ step-heating to K-feldspars. K-feldspar is ideal in this role as it is widespread, is ^{40}K rich, is stable during lab heating, and yields two distinct sources of kinetic information (the age and Arrhenius spectra). Extensive experimental studies involving natural K-feldspars document the presence of discrete Ar retentivities that are well-modelled as multiple diffusion domain (MDD) sizes. Whether dictated by varying size, energetics, or nested behavior, meaningful thermal history data can be obtained using the MDD model provided that high correlation coefficients (>0.9) are observed between the age and Arrhenius spectra. The high correlation exhibited by many K-feldspars validates extrapolation of experimentally determined diffusion properties to conditions attending natural Ar loss within the crust. Thus the only requirement for recovering thermal histories from K-feldspar $^{40}Ar/^{39}Ar$ step-heating results is that Ar loss proceeds by volume diffusion and that laboratory Ar release adequately mimics the natural diffusion boundaries and mechanisms – a requirement implicitly met by those samples with highly correlated age and Arrhenius spectra.

With the advent of SIMS depth profiling, measurable gradients of Pb/Th and Pb/U have been observed over sub-µm length scales in monazites and zircons. Where these gradients can be shown to be due to diffusive Pb loss, they contain potentially valuable thermochronological data provided the diffusion behaviour of Pb is known. Routine application of this approach using monazite is at present limited by conflicting experimental results which predict Pb diffusivities at 700°C that differ by 8 orders of magnitude. In this circumstance, samples from geologically well-constrained environments can be used to 'anchor' the empirical results in geological time through utilization of both thermochronological and thermobarometric data.

The mission to really early Earth: A progress report

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Isotopic evidence suggests that life was present on Earth prior to 3.83 Ga, placing its emergence prior to the end of an intense bombardment of the inner solar system. This raises the possibility that life originated during the Hadean Eon (4.5-4.0 Ga), a period for which there is no known rock record. If so, how can we determine when the necessary ingredients for life, notably liquid water, first appeared? Detrital zircons older that 4 Ga from the Jack Hills, Western Australia, offer the prospect of unprecedented insights into surface environmental conditions during the earliest phase of Earth history. For example, zircons as old as 4.3 Ga were discovered to contain $\delta^{18}O_{SMOW}$ up to +8‰. These and other data indicate that Jack Hills zircons formed from multiple processes that require a hydrosphere (subduction-related melting and anatexis of clay-rich protoliths) within 200 m.y. of planetary accretion and challenge the view that continental and hydrosphere formation were frustrated by meteorite bombardment and basaltic igneous activity until ~4 Ga. These ancient zircons offer other opportunities to constrain the earliest evolution of the atmosphere, hydrosphere, and continents provided sufficient quantities can be obtained for analysis. **Age distribution**: As >4.2 Ga zircons make up only ~0.2% of the detrital population, we have refined a method to rapidly survey large numbers of $^{207}Pb/^{206}Pb$ ages. Using an ion microprobe in multi-collector mode, we can detemrine within ~5 sec whether a target zircon is >4 Ga. We have thus far surveyed over 15,000 grains (typically ~2 µg each) from which two age peaks are evident at ~3.3 Ga and ~4.0 Ga, tailing off at older ages. Zircons identified as being >4 Ga are then U-Pb dated using SHRIMP RG. We have thus far identified 135 zircons in the age range 4.1 to 4.2 Ga and 42 >4.2 Ga, including three that are ≥4.35 Ga. The oldest zircon (~8 µg) thus far dated is 4.37 Ga. **Inclusion mineralogy:** Numerous ~10-100-µm-sized inclusions have been found in >4 Ga zircons, including peraluminous mineral assemblages, sulfides (targeted for $\Delta^{33}S$ analysis), K-feldspar and phosphates. **Geodynamo origin**: Ultra-sensitive analysis methods demonstrate that a Jack Hills zircon carries an intrinsic remenant magnetism raising the possibility of constraining the time of geodynamo activation. **Extinct radioactivities**: RELAX Xe isotope analyses using 4.15 Ga zircons yield plutogenic ^{136}Xe as high as 35% and indicate a terrestrial Pu/U ratio indistinguishable from chondritic. This result has implications for interpreting mantle-derived Xe isotopes in terms of mantle evolution and the age of the atmosphere. We continue to expand our survey of zircon oxygen isotope compositions correlated with trace elements (Nd, Hf, Sr, etc.) in an effort to fully exploit this unique window on the Hadean Earth.