V32C MCC: Level 2 Wednesday 1330h

Centennial Celebration of Radioisotopic Geochronology: Dates, Rates, and New Debates III Posters

Presiding: **P J Reimer,** Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory**; P W Layer,** Geophysical Institute, University of Alaska Fairbanks

V32C-1023 1330h POSTER

IntCal04: A New Consensus Radiocarbon Calibration Dataset from 0-26 ka BP

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Because atmosphere 14C levels have not been constant through time, it is necessary to calibrate radiocarbon dates with known age radiocarbon datasets in order to compare paleorecords based on 14C ages and those based on other timescales. The need for a consensus calibration dataset was acknowledged by the radiocarbon community as a way of preventing confusion and the subjective use of selected datasets (1). Since then, radiocarbon calibration datasets have been developed by international collaborations and presented for ratification at the International Radiocarbon Conference (2-4). The IntCal04 Radiocarbon Calibration/Comparison Working Group has put together a dataset which incorporates existing and new measurements of tree-ring records, foraminifera from varved sediments, and corals that meet a strict set of acceptance criteria (5). Uncertainties for both the calendar time scale and the radiocarbon ages have been quantified and included in the dataset combination using a statistical technique based on the ideas of Christen and Nicholls (6) and Gomez Portugal Aguilar (7). The IntCal04 dataset, which covers the range of 0 to 26 ka BP, was presented for ratification at the 19th International Radiocarbon Conference in Wellington, New Zealand, in September, 2003. This paper will highlight the differences between IntCal98 and the new IntCal04 dataset and give an example showing the effect on the calibrated age for a Younger Dryas age sample. 1. J. Klein, J. C. Lerman, P. E. Damon, E. K. Ralph, Radiocarbon 24, 103-150 (1982). 2. M. Stuiver, Radiocarbon 28, R2-R2 (1986). 3. M. Stuiver et al., Radiocarbon 40, 1041-1083 (1998). 4. M. Stuiver, P. J. Reimer, Radiocarbon 35, 215-230 (1993). 5. P. J. Reimer et al., Radiocarbon 44, 653-661. (2002). 6. J. A. Christen, G. Nicholls, "Random-walk radiocarbon calibration." (Mathematics Department, University of Auckland, 2000). 7.D. G. P. Aguilar, C. D. Litton, A. O'Hagan, Radiocarbon 44, 195-212 (2002).

V32C-1024 1330h POSTER

Laser Ablation MC-ICPMS *in situ* Uranium-Series Dating of U-Rich Speleothems.

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The timing and nature of rapid climate change events in the paleoclimate record are becoming increasingly under focus. These studies require high-resolution information on a temporal and spatial scale. U-rich speleothems ($\sim$100 ppm) from the Austrian Alps (Spötl *et al.*, Geology, 30, 815-818, 2002) record rapid climate transitions, such as glacier advance and retreat during the last several glacial cycles, a time scale that is appropriate for the application of U-series dating. Here we compare conventional U-series solution MC-ICPMS with LA-ICPMS techniques for these samples to demonstrate that *in situ* U-series analysis can achieve these goals. In this study, a 193 nm ArF excimer laser has been used for sampling a number of U-rich speleothem samples as well as natural and artificial standards. The ablated material is transported from the ablation cell with a helium gas flow before mixing with argon and subsequent introduction into a Nu Plamsa MC-ICPMS. This instrument is equipped with multiple ion counters at two mass unit separation, a configuration that allows for the simultaneous measurement in a single measurement cycle of the high intensity signals (^{238}U and ^{235}U) with Faraday collectors and the lower intensity signals (^{234}U, ^{232}Th, ^{230}Th) with ion counters. Ablation analyses, at 120μm spatial resolution, of samples containing $\sim$100 ppm levels of uranium, consume as little as $\sim$5 ng of ^{238}U, $\sim$200 fg of ^{234}U and $\sim$80 fg of ^{230}Th per analysis and result in within-run precision of up to $1.5^{o}/_{oo}$ for ^{234}U/^{238}U and up to $3^{o}/_{oo}$ for ^{230}Th/^{238}U at the $2\sigma_M$ level. This is more than a factor of two improvement in precision compared to first generation LA-MC-ICPMS *in situ* U-series studies (Stirling *et al.*, Geochim. Cosmochim. Acta, 64, 3737-3750, 2000). ^{234}U/^{238}U measurements are highly accurate and reproducible, however the accuracy of ^{230}Th/^{238}U measurements is affected by elemental fractionation between U and Th. In a previous study of the application of LA-MC-ICPMS to in situ U-series analysis Stirling *et al.* (2000) noted the effects of elemental fractionation between U and Th and highlighted the need for a matrix matched standard to accurately monitor this fractionation. In this study, we have evaluated several standard candidates. These include both natural secular equilibrium speleothem samples and artificial standards in the form of pressed powder pellets made from crushed speleothem material, and speleothem material that has been dissolved and reprecipitated.

V32C-1025 1330h POSTER

^{210}Pb-^{226}Ra and Other U-Series Disequilibria in Very Young MORB and Loihi Tholeiites

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Direct observations of submarine volcanic eruptions are very sparse. Radiometric age constraints on submarine lava flows are thus an essential component for understanding even the most recent histories of oceanic crust formation. Chronometers in the decadal to century time frame have heretofore been lacking. This study focuses on the development and application of ^{210}Pb-^{226}Ra disequilibria as a geochronometer to provide quantitative eruption age constraints over the past 100 years, using submersible-collected samples from the North Cleft segment of the Juan de Fuca Ridge (JDFR) and adjacent Axial seamount, 9°50'N East Pacific Rise (EPR) and Loihi (Hawaii), areas with known stratigraphic field relations between mapped lava flows. The data set provides a unique opportunity to calibrate the ^{210}Pb-^{226}Ra geochronometer because it represents a broad selection of "zero age" (^{210}Po-^{210}Pb dated) and near-zero-age submarine lavas (glasses). ^{238}U-^{230}Th-^{226}Ra-^{210}Pb radioactive disequilibria in these samples will be discussed to rationalize the range of conditions responsible for producing ^{210}Pb-^{226}Ra disequilibria (effective half life = 22 yrs) as an initial step towards using this signature to constrain eruption ages and petrogenetic time scales. We will also investigate the temporal aspects of petrogenetic conditions responsible for producing the other disequilibria in these rocks, without the uncertainty imposed by decay corrections for rocks of unknown age. These data augment those we previously reported from the Aldo-Kihi and neighboring lava flows at 17°26'S EPR (Rubin et al., EOS, 82, F1279, 2001). Systematic differences between and within study areas exist: most normal zero age MORB display modest ^{210}Pb deficits (3-10%); older MORB (the N-cleft sheet flow) have smaller deficits (0-3%); rocks erupted in 1998 from Axial seamount have 8-15% ^{210}Pb excesses; and, rocks erupted in 1996 at Loihi are in equilibrium within error. Disequilibria amongst other nuclides are all within the range of previously published values. Data broadly fall within the negatively correlated array of (^{226}Ra/^{230}Th) and (^{230}Th/^{238}U) (Sims et al., GCA, 66, 2002), yet within each geographic locale data are positively correlated. Although (^{210}Pb/^{226}Ra) covaries with some major/trace element signatures of low pressure crystal fractionation, it also covaries negatively with (^{226}Ra/^{230}Th) in all but the Loihi samples, raising the intriguing possibility that some or all of the ^{210}Pb-^{226}Ra disequilibria arises deeper within the mantle (i.e., during melting or transport. This would shorten dramatically the time scales over which those processes occur). The suite of petrogenetic variations will be examined in the context of existing models for basaltic melt genesis.

V32C-1026 1330h POSTER

Young monazite ages timing extension and contraction: Problems and interpretations

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Monazite, a rare-earth and radiogenic phosphate mineral, is frequently used to time metamorphic and igneous events. The potential exists to date monazite in rock thin section using an ion microprobe; a method that preserves key textural features and facilitates our interpretation of the age. However, the application of monazite geochronology is hindered by a lack of understanding of the pressure-temperature (P-T) conditions at which the mineral forms in metamorphic rocks. In the Himalayas, monazites collected from the footwall of the Main Central Thrust (MCT), a crustal-scale shear zone long thought to be inactive since the Miocene, yield 1.0±0.5 Ma and 0.8±0.2 Ma Th-Pb ion microprobe ages. If the ages time hydrothermal monazite growth due to slip within the zone at a speculated temperature of $\sim$400°C, the MCT accommodates 40-54% of the total convergence rate between the Indian and Eurasian plates and has faster shortening rates (>16 mm/yr) than those estimated for the seismically active Himalayan Main Frontal Thrust. In western Turkey, a monazite grain collected from the surface of the Kuzey Detachment, a low angle normal fault that bounds the

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Central Menderes Metamorphic Core Complex to the north, is 4.5±1.0 Ma. The grain is in reaction with allanite, and its age is within 1σ of the apatite fission track result of 3.7±0.6 Ma from a rock collected along the same detachment. This result raises questions of the P-T conditions and paths required for the allanite to monazite reaction. The presence of these young monazite grains in two type localities of contraction and extension is significant, producing rapid exhumation and slip rates, and elevating the structures they were collected from to major roles. The rates they produce, however, have large uncertainties because of the currently speculative P-T conditions of monazite formation.

V32C-1027 1330h POSTER

Double-dating single-grain zircons by (U-Th)/He and U/Pb

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Dating of single zircon crystals by both the (U-Th)/He and U/Pb methods (He-Pb* double-dating) provides high-temperature (crystallization or high-grade metamorphism) and low-temperature (~180 °C) ages. Advantages of He-Pb* double-dating of detrital zircons includes greatly improved resolution of source terrain provenance, as well as constraints on depositional ages of active-margin sedimentary rocks by identification of first-cycle (e.g., volcanic) zircons of the youngest-age population. Although several analytical methods can be used for He-Pb* double-dating, our work shows that measurement of U/Pb ages by laser ablation ICP-MS, followed by bulk He extraction/measurement and U-Th measurement provides the best results, with several additional advantages. Besides U/Pb age determination, LA-ICP-MS provides spatial and depth resolution of U/Pb ages and U-Th concentration variations. Variations in single-grain U/Pb ages can date post-formation metamorphic or overgrowth events that further constrain the high-temperature history of the zircons. Depth-resolved U-Th zonation from LA-ICP-MS can also be used to customize alpha-ejection corrections, which commonly improves accuracy of (U-Th)/He ages by 5-10% (or more, for extremely zoned grains). We have applied the He-Pb* double-dating technique to a variety of detrital and volcanic zircons (the latter as standards), including samples from the Mississippi River delta, Navajo sandstone, Kamchatkan flysch, and alluvium from the Ganges and Indus rivers. Ganges and Indus zircons have U/Pb ages ranging from 25 to 2700 Ma, but 60% of grains have (U-Th)/He ages between 0.30 and 4.3 Ma, with most of the rest between 15-30 Ma. Some zircons with relatively old U/Pb ages also preserve rims with U/Pb ages of 15-30 Ma. These data suggest that most sediment draining the Himalayas originates from regions exhuming at rates greater than ~1-2 km/myr, containing crust of a wide variety of pre-Himalayan formation ages that was metamorphosed in the mid-Tertiary.

V32C-1028 1330h POSTER

The present status and not-too-distant future of laser ablation (U-Th)/He geochronology

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The development of effective protocols for laser-ablation (U-Th)/He geochronology enables a new way of exploring many important problems in the earth sciences. Here we review the preliminary results of several research projects actively being pursued in our laboratory. The high spatial resolution of laser ablation (U-Th)/He geochronology allows for unique and exciting analytical opportunities not possible with conventional (U-Th)/He techniques. In addition, blank measurements are kept consistently low because the sample chamber is not heated during ablation, allowing for very small (near blank level) amounts of gas to be measured reproducibly. As a consquence, ablated volumes as small as 8 x 8 x 0.125 μm (8μmm^3) yield sufficient helium for a successful analysis of a sample of Jurassic age. This permits the measurement of core ages of very small or heterogeneous accessory mineral grains, in many cases effectively eliminating the need for alpha-ejection corrections that can contribute significantly to the uncertainty of a conventional (U-Th)/He age. The laser microprobe permits the analysis of monazite, xenotime, and other accessory mineral inclusions too small to otherwise date easily. In addition, it permits the dating of individual crystals in petrographic context, a boon to the study of samples with complex thermal histories. In raster mode, with a nominal minimum depth of 0.125 μm per pass, high-resolution depth profiles can be generated with the laser microprobe. This enables the quantification of experimental diffusion profiles, natural ejection profiles, and the effect of intra-grain parent element heterogeneities on cooling profiles.

V32C-1029 1330h POSTER

Effects of Wildfires on (U-Th)/He Ages

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Apatite and zircon (U-Th)/He thermochronometry yield valuable constraints on the timing and rates of bedrock exhumation through shallow crustal depths. However, the low closure temperatures of these systems (about 70 and 180 degrees C, respectively) raise the possibility that high-temperature (>300 degrees C) surficial thermal events unrelated to exhumation, such as wildfires, may significantly influence He ages near exposed rock surfaces. To test this possibility, we measured replicate single-crystal apatite and zircon He ages from 1-cm thick intervals in a depth profile of granodiorite bedrock from a recently burned area of the Washington Cascades. We also measured apatite He ages in modern colluvium in the same region. Apatite and zircon He ages have been reset by as much as 90% and 15%, respectively, in the outermost cm of exposed bedrock, and asymptotically increase, over about 3 cm, to regionally consistent ages measured in interior slabs. In addition, apatite He ages from thin (< 3 cm) flakes exfoliating from a nearby boulder show up to 50% He loss compared to ages from nearby interior bedrock. These results agree well with a simple He diffusion model that predicts that "moderate" wildfire heating of rock surfaces (5-10 minutes at 500-600 degrees C) can substantially reset apatite He ages to 3 cm below rock surfaces, and partially reset zircon He ages in the outermost 1 cm. These results are important for several reasons. 1) This significant loss of He near rock surfaces indicates that the outermost 3-5 cm of bedrock samples should routinely be removed prior to AHe or ZHe analysis. 2) He ages of detrital apatites derived from wildfire-prone regions may be substantially lower than the crustal exhumation ages, particularly if wildfires themselves generate a significant portion of sediment through mechanical weathering processes. 3) Wildfires likely also significantly disturb fission-track and cosmogenic He systems in bedrock rims and some exfoliated (potentially detrital) fragments. 4) Modeling the observed AHe and ZHe profiles through the bedrock surface allows us to constrain the recent thermal history of the sample; the model and data indicate that He loss from our sample likely resulted from the thermal equivalent of a 5-10 minute, 575-650 degrees C heating event. This technique may be useful for delineating wildfire zones or estimating wildfire intensities.

V32C-1030 1330h POSTER

Long-term Landscape Evolution of the Ligurian Alps (NW Italy)

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The long-term landscape evolution of the Ligurian Alpine system (NW Italy), covering the onshore Ligurian Alps and the offshore Ligurian basin, has been reconstructed integrating detrital apatite (U-Th)/He and fission track (AFT) data with results from seismic studies. Three transects, covering the onshore western, central and eastern Ligurian Alps have been investigated. Both apatite He and AFT ages become older eastwards, documenting late Miocene cooling in the western Ligurian Alps (Foeken et al., 2003), while early to middle Miocene cooling is recorded in the eastern Ligurian Alps. Cooling is interpreted to result from exhumation accommodated along a north dipping thrust front emerging oblique to the Ligurian margin. Three seismic lines describe the offshore evolution of the Ligurian basin. Main results from the seismic study are that the late Miocene to recent sequences are characterised by continuous reflectors that lack deformation. The apparent discontinuity between the ongoing exhumation onshore and the tectonic quiescence offshore suggest that the two systems are detached. Analysis of the seismic lines shows that following the Pliocene, the Liguro-Provençal basin experienced subsidence, resulting in a deepening of the basin. Reconstruction of the Pliocene to recent morphology of the Ligurian Alpine system shows that the long-term evolution is directly related to movement along the thrust front. The western Ligurian Alps, evolving from moderate relief in the Pliocene to steep relief with well-incised valleys at present day, is located close to the actual thrust front and experiences active exhumation. The eastern Ligurian Alps, located northwards and away from the thrust front, is characterised by low to moderate relief from the Pliocene to present day. Foeken, J.P.T., Dunai, T.D., Bertotti, G., and Andriessen, P.A.M., 2003, Late Miocene to present exhumation in the Ligurian Alps (southwest Alps) with evidence for accelerated denudation during the Messinian salinity crisis: Geology, v. 30, p. 797-800.

V32C-1031 1330h POSTER

(U-Th)/He Dating of Merrillites and Chlorapatites From Martian Meteorite Los Angeles

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Los Angeles (LA), one of the basaltic shergottitic Martian meteorites, has an igneous formation age of ~170 Ma, and is thought to have been ejected from Mars by collision at ~3.1 Ma. The medium to high temperature thermal history of LA is documented based on Rb/Sr and Sm/Nd chronometers, but essentially no thermochronologic data are available to constrain its low temperature thermal history. To understand the thermal effects of collision-related shock metamorphism and subsequent low-T thermal history of LA, we measured (U-Th)/He ages of single crystal phosphates (igneous merrillite and chlorapatite) from the meteorite. Merrillites and chlorapatites yielded distinctive U and Th concentrations (~2 ppm and ~13 ppm for merrillites; ~4 ppm and ~5 ppm for chlorapatites) with apparently different U/Th ratios. Thirteen merrillite grains have ages between 0.8-3.5 Ma with a weighted mean age of 3.1 Ma. Five other merrillite ages are widely distributed between 5.1-32 Ma. Six chlorapatite grains yielded ages clustering in the range of 1.9-2.9 Ma (alpha-recoil uncorrected) with a weighted mean of 2.2 Ma, and three other grains produced older and scattered ages up to 5.8 Ma. The cumulative probability plots show highest peaks at 2.3 Ma and 3.3 Ma for chlorapatites and merrillites, respectively. The peak age or weighted mean age of merrillite is indistinguishable from the cosmogenic exposure ages (3.1 ± 0.2 Ma) previously determined from ^{3}He, ^{10}Be, ^{21}Ne, ^{38}Ar and ^{81}Kr systems, suggesting that the timing of the shock metamorphism is represented by the merrillite (U-Th)/He system. The average age difference between the merrillite and chlorapatite ages is probably due to the typically smaller grain size of apatite crystals and therefore greater proportion of alphas lost by recoil ejection. Assuming a peak shock temperature of 450 °C (consistent with previous studies), the observed complete He degassing for most of the phosphates by shock metamorphism suggests that the radius of the original body ejected from Mars was probably larger than ~100 cm. The few old and variable ages observed may be due to exceptionally large (>600 micrometers) phosphate grains found in the LA, or incomplete He degassing during the shock metamorphism caused by heterogeneous heating as revealed in the other Martian meteorites. This study shows that phosphate (U-Th)/He thermochronometry can be used to understand the timing and dynamics of collision-related shock metamorphic processes in other meteorites, such as ALH84001.

V32C-1032 1330h POSTER

Garnet, zircon, and apatite (U-Th)/He thermochronometry of the Ocna de Fier (Romania) skarn ore district

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The Ocna de Fier (ODF)- Dognecea ore district in SW Romania, formed at the contact of Upper Cretaceous granodiorites (75.5 ± 1.6 Ma SIMS U-Pb zircon age; 76.6 ± 0.3 Ma Re-Os molybdenite age) with Upper Jurassic - Lower Cretaceous limestones, has been continuously mined for more than 4000 years, and is part of the group of deposits first recognized as being of contact-metasomatic (skarn) origin. Due to its ore reserves, mineral wealth (in excess of 140 valid minerals, including three new mineral species) and genetic type, for the last 250 years the deposits have been the focus of a wide interest in the scientific community, resulting in close to 300 district-related papers published to date. To better constrain the medium- and low-temperature thermal history of the ODF and examine the utility of skarn minerals for (U-Th)/He dating, we have measured He ages of garnet, epidote, zircon, and apatite from this deposit and for zircon and apatite from the adjacent (4 km north) Bocsa intrusive. Replicate zircon U-Th/He (ZHe) ages of 76 ± 6 Ma for the ODF intrusive and 71 ± 6 Ma for the related Bocsa intrusive, are indistinguishable from or slightly less than U/Pb, Re/Os, and zircon fission track (ZFT) age of 72 ± 6 Ma, suggesting very rapid cooling (∼83° C/Myr) through ∼200° C. However, for apatite the difference between fission track (AFT) and U-Th/He (AHe) ages is significant: 68 ± 5 Ma vs. 36 ± 2 Ma respectively, suggesting a protracted cooling through low temperatures. These data suggest that following intrustion and skarn formation, the region experienced extremely slow cooling (< 2° C/Myr) until at least ∼30 Ma. We have also developed analytical methods for (U-Th)/He dating of garnet, involving laser He extraction in Nb foil that is subsequently dissolved along with post-degassing garnet residue for U-Th measurement. Multiple replicates of interior cores of large (∼1 cm) grandite garnets using this method yielded strongly contrasting U contents (20 vs. 0.3 ppm), but similar (U-Th)/He ages of 75.2 ± 2.5 Ma and 77.9 ± 4.3 Ma, respectively. Due to the apparently rapid cooling of this system, we cannot estimate a He-in-garnet closure temperature from these results, except to say that it is greater than about 200° C. Preliminary data on hydrothermal epidote from the deposit, using the same procedures, show poor reproducibility. Epidote He ages on six aliquots range from 15-29 Ma. Although we currently have no explanation for the discrepant epidote results, analyses are ongoing, and preliminary indications suggest a relatively low closure temperature for this phase.

V32C-1033 1330h POSTER

Micaschist and Impure Marble - two Examples for Lithology Related Constraints to Rb-Sr Microsampling Analysis

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Retrograde overprinted calcite-bearing micaschists and mica-containing marbles from the northern part of the Cycladic blueschist belt on South-Evia, Greece, have been investigated to understand the interplay between bulk rock chemistry, mineral assemblage and resetting of the Rb-Sr isotope system during deformation. White mica represents two optical distinguishable microstructures, isoclinal folds (S1) and axial plain cleavage (S2) induced by flattening and elongation episode of isothermal exhumation. The varying Si content of phengites is not related to microstructures. Due to microstructural complexity and grain size variation the application of Rb-Sr microsampling method was expected effective investigation of Rb and Sr rich mineral phases to elucidate constraints for geochronological and isotope geochemical imprint in microstructures. Drilling out calcite, albite and mica samples with weights down to 200g each out of 30m thick sections realized textural controlled separation. Calculated Rb-Sr mica ages show lithology-related scattering but totally not microstructural induced variation. Particulary, S1 and S2 phengites in micaschist yield similar age values around 31 Ma. In contrast, impure marble mica within similar S1 and S2 have Rb-Sr mica ages widely scattering between 34 and 50 Ma. Therefore, structural elements formed by these phengites are not distinguishable in terms of geochronolgy. Explaining the scatter of age values, principally, two possibilities were taken into account, (i) the fluid flux neccessary to homogenize Sr isotope composition in mica and calcite (albite) might have been less effective in impure marble than in micaschist due to the generation of CO2. In constrast to this possibility, calcite 87Sr/86Sr in both specimen are quite homogeneous at least on cm-scale, e.g. values of 0.712125 ± 66 (2s) for impure marble and of 0.721419 ± 42 for micaschist were meassured. Albite 87Sr/86Sr corroborate Sr homogenisation on scale this study was focussed on. So far, (ii) we would assume calculated age values date moments of growth of single mica crystals. However, the image of microstructure by crystals may be realized by new growth, recrystallization or just reorientation, e.g. by passive rotation of preexisting grains. To interpret the mineral age values, it must be scrutinized, which process is responsible for current mineral position in the structure. Additionally, duration of (prograde) exumation induced contineous deformation and the contribution of fluid influx can be prospected by further investigation of south-Evian blueschist facies units on other mineral phases by Rb-Sr microsampling technique.

V32C-1034 1330h POSTER

From the nm to the Mm

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Tectonic models for the evolution of an orogen start at the Mm scale, and use field work on smaller subunits at the km scale and rocks collected at the m scale. At the mm scale, minerals are identified, analyzed by mass spectrometry, their "cooling ages" assigned to a specific closure temperature, a cooling rate attributed to a particular tectonic regime, and a large body of self-referential literature is the product of an oiled machinery. Problems become apparent if one attempts to harmonize mm-scale science with the nasty little details at even smaller scales. Atoms are invisible to the naked eye (unlike the minerals mentioned above) and their actual behavior is, or was, only accessible to indirect argumentations and simplified calculations. Increased computing power now allows calculating the transport of atoms in a crystal from the Schrödinger equation: results do not fit 19th century continuum physics for infinitely dilute solutions (Fick's and Arrhenius' "laws"). Moreover, improved nanochemical analyses allow characterizing the supposedly homogeneous mineral matrix. TEM images show how layers or chains in pristine minerals are substituted in a non-periodic way by alteration products. EMP analyses show the almost ubiquitous presence of razor-sharp boundaries rather than Erf profiles. Disequilibrium recrystallization textures thus prevail over diffusive reequilibration; diffusion sensu stricto is shown to be a much slower process than heterochemical replacement. Alterability sequences are well known to surface scientists: e.g. halite, olivine, biotite, muscovite, zircon. Such sequences are reflected in the isotopic retentivity. The link only becomes clear at the nm scale: isotopic exchange occurs during the replacement reactions that affect all rocks on their retrograde P-T evolution. This is sufficient to explain why zircons record higher isotopic ages than muscovites, which in turn undergo less isotope exchange than biotites etc. While there is a vague dependence on temperature (hydrothermal waters affect biotite more thoroughly than meteoric ones) this dependence does not allow to quantify a purely thermal evolution in neglect of more efficient isotope exchange promoters such as the availability of fluids. What consequence should tectonic modellers draw? In their past, tectonicists have abandoned well-charted waters (e.g. an exceedingly vast body of literature on geosynclinals) just because it wasn't true. As mineralogy and nanoscience make constant progress, their insights should not be fought against in the name of old paradigms, but should instead be the starting-point for new paradigms blending petrology, fluid inclusion studies, and molecular dynamics to understand the coupling of major and trace element mobility in minerals. As a consequence of this change in paradigms, what is the meta-information that needs to be reported so as to interpret a mass spectrometer output? Certainly not just the parent/daughter ratio, as this would tacitly imply that only Fickian diffusion controls isotope mobility. This is clearly not the case: REE patterns in CL-zoned zircons and monazites, BSE maps of patchy micas and feldspars, and oxygen isotopes of Sr-bearing carbonate crusts all demonstrate the importance of heterochemical disequilibrium as the most important atomic-scale process. Disequilibrium textures also mean that a rock does not "have an age", it rather records a history. Trivializing the microchemical-microtextural information by reducing it to one number does not do justice to the knowledge accumulated by petrologists on the nano-scale processes on which the whole of geochronology rests.

V32C-1035 1330h POSTER

Lu-Hf and U-Pb Chronology of a Possible Triassic Franciscan High-Grade Block, Healdsburg, California

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The chronology of high-grade metamorphic blocks hosted by the Franciscan Formation of California has been defined in previous studies largely by the K-Ar and Ar-Ar systems, which consistently yield 150-160 Ma on hornblende and phengite. A U-Pb age on sphene from a high-grade blueschist gives 162 ± 3 Ma. The Sm-Nd system has had mixed results for chronology in the Franciscan, but has yielded one 190 ± 10 Ma, garnet-hornblende isochron, which is significantly older than other ages. It is possible that Ar results are, in some cases, cooling ages, and that the older Sm-Nd age represents earlier, possibly pre-Franciscan, crystallization. Eclogite from Healdsburg, California contains abundant small (< 25 μm) zircons that can be separated into two different textural populations. Anhedral zircon contains abundant inclusions of quartz and epidote and usually occurs as an inclusion phase in garnet or omphacite. Euhedral zircon contains no inclusions and occurs along the margins of matrix minerals. Little or no zoning in either BSE or CL imaging is visible in either population. Preliminary results of in-situ ion probe U-Pb dating of these zircons suggest that the two morphological groups have different ages. Euhedral zircons (n=5) yield a concordant age of 178.2 ± 7.2 Ma. Anhedral zircons (n=4) are reversely discordant and yield a $^{206}Pb^{*}/^{238}U$ age of 218.9 ± 6.0 Ma, significantly older than most of the previously published ages for similar blocks. If these data, now being verified with additional analyses, are correct, they have significant implications regarding the initiation of the Franciscan subduction zone and the provenance of Franciscan high-grade blocks. They may also provide insight in the retentive behavior of zircon during HP metamorphism. Lu-Hf dating of the peak metamorphic assemblage of garnet, omphacite, and rutile produces isochrons that may have a higher closure temperature, and may be more resistant to resetting than the Sm-Nd system. Zircon results will be compared with Lu-Hf mineral isochron data for the Healdsburg eclogite, and the effects of a late phengite-glaucophane overprint will be evaluated. If the high-grade blocks were metamorphosed exclusively during the Franciscan event, then subduction must have begun 60-70 My before current estimates and well before the crystallization ages of Coast Range Ophiolite rocks. Alternatively, the older zircons may represent a crystallization age of a basaltic protolith that crystallized at an oceanic spreading zone in the Triassic; however, older zircons do not possess typical igneous morphology. The Healdsburg eclogite and possibly other blocks may have undergone peak metamorphism in the late Triassic, well before the onset of subduction at 150-160 Ma in the late Jurassic, and only acquired an overprint at that time.

V32C-1036 1330h POSTER

Timing of Magmatism and Metamorphism in the Lower Crust Beneath the Colorado Plateau From Coupled U-Pb and Lu-Hf Isotopic Analysis of Zircon From Xenoliths

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A major uncertainty in models for Proterozoic evolution of the southwestern U.S. is whether lower crust that formed and accreted at 1.8-1.6 Ga was substantially modified ca. 1.4 Ga by mafic underplating that produced voluminous granitic magmatism and associated low P - high T metamorphism (0.35-0.6 GPa, 500-700 C) preserved in middle and upper crustal basement rocks. A regionally extensive high-velocity (7.xx) lower crust has been interpreted as evidence of underplated magmas. We undertook a U-Pb and Lu-Hf isotopic study of zircons from lower crustal xenoliths to constrain the timing of magmatism and metamorphism beneath the Colorado Plateau. Xenoliths of mafic and felsic granulite from the Navajo volcanic field are interpreted as lower crustal samples based on the primary mineralogy of Cpx-Grt-Pl +/- Qtz and P-T estimates of ca. 1.3 GPa and 800 C. CL imaging of the internal zoning in zircon guided our attempts to isolate homogeneous, moderate sized (50-100 microns) domains through grain fragmentation and air-abrasion. Fragments of grains from eight xenoliths were dated by the ID-TIMS U-Pb method and the solutions from many of these fragments were analyzed for Lu-Hf isotopes by MC-ICPMS. Weak, curved, and sector zoning that is typical of metamorphic zircon is prominent in the mafic xenoliths yet sparse in the felsic ones. Fragments

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from these zoned domains yielded U-Pb dates that define groups at 1420-1414, 1410-1395 (most prevalent dates), 1385, and 1360 Ma. There is substantial variability in the initial Hf isotope compositions of these grains (Epsilon Hf = -0.7 to +13.6; TDM = 1.8-1.3 Ga), from the same xenolith as well as between xenoliths. This dispersion suggests growth of metamorphic zircon from a variety of introduced fluid compositions or from protolith minerals with diverse time-integrated Lu/Hf ratios. Many of the felsic and mafic xenoliths have zircon cores or whole grains with zoning that may indicate magmatic crystallization. Four felsic granulites have oscillatory-zoned grains with U-Pb dates of 1710 and 1640-1620 Ma, and unradiogenic Hf isotope compositions with depleted mantle model ages of 1.8-1.6 Ga; this concordance of crystallization and source extraction ages supports an igneous protolith interpretation. Three mafic xenoliths have sector- and oscillatory-zoned grains that crystallized at ca. 1435 Ma, however their unradiogenic Hf isotope compositions and model ages of 1.7-1.6 Ga complicate interpretation of the ca. 1435 Ma dates as representing mafic magmatic crystallization, unless these melts were substantially contaminated by older crust. Further petrologic and geochemical studies of the mafic xenoliths are necessary to evaluate this hypothesis. The results suggest a complex lower crust beneath the Colorado Plateau with ca. 1435 Ma mafic magmatism in ca. 1.7-1.6 Ga felsic rocks followed by episodic metamorphism that coincided with regional granitic magmatism and metamorphism in exposed basement rocks. This coincidence suggests a link between ca. 1.4 Ga mafic magmatism and metamorphism in the lower crust and tectonothermal events in the middle crust. The 1.7-1.6 Ga Hf model ages from many metamorphic zircons and all igneous zircons in the mafic xenoliths indicate that they are crustally contaminated ca. 1.4 Ga mafic magmas or restites from ca. 1.4 Ga granite extraction.

V32C-1037 1330h POSTER

Pb-Pb geochronologic study on the carbonaceous rocks in the Krai area, Altai, Russia: V-C boundary or Snowball Earth event?

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We have analyzed the limestones occurred in the Kurai area, Altai district, Russia to define Pb-Pb isochron age and examine their variation of Sr isotopic compositions through time. The limestones are inferred to have deposited at the boundary of the Vendian-Cambrian from stratigraphic analyses. In this study, We have newly collected samples for the purpose of the present Pb isotopic study on the basis of the reinvestigated stratigraphic map. Samples are also available from various horizons to examine isotopic variation of Sr through time. We made a minor modification on the method of Pb extraction process from the samples to maintain a stable and higher yield, which made it possible to obtain reliable Pb isotopic data. At present, we have obtained an isochron age of 598 +- 25 Ma (MSWD=1.06) for 9 samples. The present age is evidently older than the boundary of the Vendian-Cambrian, and seems to be correlated with the snowball Earth event. Sr isotopes show substantial variation from 0.7059 to 0.7077 which is interpreted in terms of environmental change during the snowball Earth event. Besides the Pb isotopic age, homogenous 208Pb/204Pb ratios of the samples are suggestive that Th/Pb ratio had been uniform within the seawater or through the formation process of the limestone.

V32C-1038 1330h POSTER

Combining SHRIMP, TIMS U-Pb and Ar-Ar to Resolve Magmagenesis, Metamorphism and Fluid Flow in Three Coincident Magmatic Arcs (Yukon-Tanana Terrane, Western Yukon)

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Multi-method geochronology has been instrumental in resolving the tectonic evolution within the Stewart River portion of the Yukon-Tanana Terrane in west-central Yukon Territory. Two short-lived and distinct arc assemblages of Paleozoic age are now manifest as highly strained, polydeformed metasedimentary, metavolcanic and metaplutonic rocks. These assemblages, as dated by SHRIMP and TIMS show the presence of an early 360-345 Ma arc, marked by 360 Ma augen granites carrying a strong transposition foliation. This same foliation is also manifested in the later arc assemblage as marked by a 263.6±2.6 Ma, highly deformed felsic volcanic rock interlayered with amphibolite-grade mafic metavolcanics and second suite of augen granites, dated at 259.1±0.4 Ma. SHRIMP dating of zircon overgrowths on detrital zircons from a metamorphosed and deformed arkosic conglomerate give an age of 259.3±3.4 Ma, coeval with emplacement of the deformed Permian augen granites. These overgrowths are demarcated by a thin band of inclusions that are trapped between the core and new zircon growth. Furthermore, there is evidence for severe dissolution of zircons in the felsic volcanic rock, but no such effect on the detrital zircons cores, despite having a range of morphology, U content and age. This suggests that fluid-rock interaction is the primary driver for transport and regrowth of new zircon in the conglomerate, likely during a time of peak metamorphism at 259 Ma. However, dating of metamorphic titanite provides evidence of an amphibolite grade metamorphism and deformation concomitant with the earlier arc assemblage. This titanite, formed within a package of mixed amphibolite (mafic volcanic rocks?) and calc-silicates rocks, gives an age of 345-360 Ma. This age shows that the pervasive Permian metamorphism was insufficiently hot enough to reset the titanite U-Pb systematics. These two arc sequences were intruded by weakly to undeformed Triassic-Jurassic granites. Detailed sampling for CO2 laser Ar-Ar geochronology took place on two transects across the area. Samples along both transects (including a sample set co-located with the metamorphic titanite sample) give relatively uniform 180±7 Ma ages on hornblende, muscovite and biotite. There is no correlation of age with distance from Mesozoic plutonic bodies, showing that it is a regional thermal event. When taken in concert with titanite data, it is apparent that an episodic Jurassic cooling event was likely driven by rapid uplift of the entire block. Furthermore, these ages are in accord with previously reported Ar-Ar ages across the Alaska border within the FortyMile River assemblage.

V32C-1039 1330h POSTER

$^{40}Ar/^{39}Ar$ and U/Pb chronology of the Green Lake Pluton (Eastern Sierra Nevada, California)

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The aim of this study is to understand the cooling (and emplacement) history of the Cretaceous Tuolumne Intrusive Suite (TIS, eastern Sierra Nevada, California) by studying its thermal effects on adjacent plutonic bodies such as the Green Lake pluton (GLP), which is a small granodioritic intrusion 5 km to the east of the TIS (ca. 5 km in diameter). Nine samples were collected from the center of the GLP towards the TIS. U/Pb zircon single-crystal analyses display an upper intercept age of 168 ± 5 Ma (uncertainties are given at the 2σ level). $^{40}Ar/^{39}Ar$ analyses were performed on two different biotite and hornblende grain size fractions (800-900 μm and 150-180 μm) from each sample. Step heating experiments on large biotite and hornblende as well as total fusion analyses on 20 (biotite) to 25 (hornblende) single grains yield the following ages (relative to FCs at 28.02 Ma): (1) Biotite plateau ages (100 to 95% ^{39}Ar) display a trend between 118.2 ± 0.8 Ma in the center of the GLP to 83.9 ± 1.5 Ma closest to the TIS. (2) Total fusion analyses of the 150 to 180 μm biotite fractions yield younger ages ranging from 89 to 82 Ma. We interpret these ages as the result of partial and/or total resetting of the K/Ar system at the time of TIS emplacement at around 90 Ma (Coleman et al, 2002). (3) Age spectra from large hornblende crystals are highly discordant due to "younger" (i.e. degassed) biotite inclusions. Hornblende (150 to 180 μm) total fusion experiments display a wide range of ages (92 to 172 Ma) with most of the ages ranging from 164 to 170 Ma (Ca/K of 15, weighted mean age of 166.2 ± 1.6 Ma). This age is in agreement with the above reported U/Pb age and interpreted to be the "true cooling age" of hornblende devoid of biotite inclusions and unaffected by the TIS intrusion. The results demonstrate the possibility for erroneous conclusions if techniques are used which fail to reveal these spatial complexities and partial resetting of the K/Ar system. The western margin of the pluton is obviously affected by the TIS but only the biotite seems to be partially reset. The central part of the pluton is only marginally affected and probably records the primary cooling history of the GLP; the TIS, which intrudes at less than 5 km from the margin of the GLP, has a significant thermal effect. The temperature probably reaches more than 350°C in the area of the western edge of the GLP. Our new data indicate that, during the reheating by the TIS, the temperature never reaches more than 350°C in the center of the GLP and not more than 500 to 550°C at the western edge of this pluton. Coleman, D.S., Glazner, A.F., and Gray, W., 2002, U-Pb geochronologic evidence for incremental filling of the Tuolumne Intrusive Suite magma chamber. Geol. Soc. Am. Abstr. w/Progs, vol. 34, no. 6, 269.

V32C-1040 1330h POSTER

Basalt Chronostratigraphy of NE Iceland: Implications for the Geomagnetic Polarity Time Scale

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The flood basalts exposed in the Jökulsáá dal valley in northeast Iceland show normal magnetic field directions consistent with emplacement during the Gauss Chron, and reversed magnetic field acquired during the Matuyama Chron. In the lower Matuyama basalts, an apparently continuous horizon containing normally magnetized flows has been recognized that was defined as belonging to the Olduvai event (Wensink 1964). A separate normal flow above the Olduvai was interpreted as the Gilsá event. The age of this event was established at 1.61 ± 0.05 Ma by K-Ar dating of samples from the Hnjuksá valley, a small streambed draining into the main river from the basalt plateau to the west (McDougall and Wensink 1966). This age was revised to 1.62 ± 0.08 Ma in a subsequent study (Watkins et al. 1975. Both results have been recalculated to be consistent with current conventions concerning the decay constant and isotopic abundance of ^{40}K). Based on the original paleomagnetic field work and the K-Ar results McDougall and Wensink (1966) suggested an average periodicity in the rate of basalt eruptions of once per 40 kyr, and implied regional continuity of individual flows. In a more recent paper, Udagawa et al. (1999) dated normally magnetized flows in the lower Matuyama in the main Jökulsá á dal river bed ca 10 km upstream from the original Hnjuksá section applying the conventional K-Ar dating technique. They found ages of 1.61 Ma for the normal flows, which they interpreted to be consistent with the Watkins et al. (1975) results from the Hnjuksá section, and thus belonging to the Gilsá event. We independently resampled the Hnjuksá section and a second, parallel section along the Hnappá streambed 3 km north of the Hnjuksá section. Paleomagnetic analysis indicates that both sections contain normal flows in the lower Matuyama at ca 500 - 550 m altitude, which could be interpreted as confirmation of the Olduvai subchron. There is no evidence for a separate normal flow above the Olduvai indicating a younger Gilsá event. We applied high resolution $^{40}Ar/^{39}Ar$ laser incremental heating to selected flows of both the Hnjuksá and the Hnappá sections. We found that the normally magnetized flows of the Hnjuksá valley yielded ages of 1.82 ± 0.03 Ma and 1.71 ± 0.04 Ma. This age is consistent with emplacement of these basalts during the Olduvai Normal Subchron. As our results are based on well defined plateaus and isochrons, we conclude that in the original type section of the Gilsá Subchron, our new $^{40}Ar/^{39}Ar$ ages of the normal flows disproves the existence of a separate Gilsá event. The ages of the normal flows in the adjacent Hnappá section turned out to be even older: 2.01 ± 0.05 Ma and 2.26 ± 0.06 Ma, which would be at a 95 percent confidence level consistent with the Réunion

Subchron. From our analysis we draw two main conclusions: 1. In the type section, the normal flows previously attributed to the Gilsá event, can be reconciled with emplacement during the Olduvai Subchron, and 2. Event at short distances the flood basalt flows in the Jökuldalur area are discontinuous, and cannot be correlated using magnetostratigraphy alone. This questions the conclusion of Udagawa et al. (1999) who argue that they identified flows belonging to the Gilsá Subchron at much larger distances from the type section.

V32C-1041 1330h POSTER

An Astronomically Dated Standard in $^{40}Ar/^{39}Ar$ Geochronology?

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The standard geological time scale of Berggren et al. (1995) and Cande and Kent (1995) is calibrated with different absolute dating techniques, i.e. the Plio - Pleistocene relies on astronomical tuning, and older parts of the time scale are based on radio-isotopic ($^{40}Ar/^{39}Ar$ and U/Pb) calibration methods. In the new edition of the standard geological timescale (Lourens et al., to be published in 2004) the entire Neogene will rely on astronomical dating. Therefore, it is of crucial importance that all dating methods produce equivalent absolute ages when the same geological event is dated. The Mediterranean Neogene provides an excellent opportunity to compare different dating methods by isotopic dating ($^{40}Ar/^{39}Ar$, U/Pb) of volcanic ash layers intercalated in astronomically dated sediments. Here we will show that in spite of potential errors in all methods, we succeeded to intercalibrate the $^{40}Ar/^{39}Ar$ and astronomical methods, arriving at astronomically calibrated age of 28.24 ± 0.01 Ma for the in $^{40}Ar/^{39}Ar$ geochronology commonly used standard FCT sanidine. The advantage of an astronomically calibrated FCT above a K/Ar calibrated standard is a smaller error in the absolute age due to the lack of uncertainties related to ^{40}K and radiogenic ^{40}Ar contents in the primary standard and a decreasing influence of errors in the decay constant (branching ratio is not required). In addition to an astronomically calibrated FCT age we propose to introduce an astronomically dated standard. A direct astronomically dated standard can be regarded as a "primary" standard and does not require intercalibration with other standards, thus reducing analytical (and geological) uncertainties. Ash layers intercalated in sedimentary sequences in the Melilla Basin, Morocco appear to be the most suitable for this purpose. A reliable astronomical time control is available and intercalated ash layers contain sanidine phenocrysts up to 2 mm. Four ash layers are not or barely affected by xenocrystic contamination. Further, two of these ash layers (Mes-9 and Mes-4) can easily be recognized in the Messadit section due to their thickness of respectively 0.6 m and 5.0 m. The other two can also easily be recognized, but require inspection of the cyclostratigraphic framework. To avoid any confusion about the location of the ash layers we propose either Mes-9 or Mes-4 as potential $^{40}Ar/^{39}Ar$ dating standards. Before this standard can be introduced additional work (e.g. microprobe analyses to confirm homogeneity of the populations) will be done in the near future to decide on the "best" standard.

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V32C-1042 1330h POSTER

Neutron Irradiation Using A Deuteron-Deuteron (D-D) Fusion Source: Benefits for $^{40}Ar/^{39}Ar$ Dating

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Irradiation of samples for $^{40}Ar/^{39}Ar$ dating, traditionally achieved in a fission reactor, carries the necessary evils of recoil, interference corrections, radiological concerns, and lengthy turnaround time. Alternative high-flux neutron sources with appropriate energies (1-6 MeV) to drive the $^{39}K(n,p)^{39}Ar$ reaction have been little explored. The deuteron-deuteron (D-D) fusion reaction $D(d,n)^3He$, which can produce essentially monoenergetic 2.45 MeV neutrons, has been achievable for decades albeit with neutron fluxes far too low to be of interest for $^{40}Ar/^{39}Ar$ dating. D-D neutrons at 2.45 MeV are in many ways ideal for $^{40}Ar/^{39}Ar$ dating and recent developments in fusion research foreshadow the realization of adequately high neutron fluxes. A toroidal geometry plasma source with axial, self-loading target and central sample placement appears especially promising. Modeling argon isotope production from K, Ca, and Cl shows reductions in all unwanted reaction rates relative to a fission spectrum. Production of ^{36}Ar and ^{38}Ar from Ca and ^{37}Ar from K are negligible from 2.45 MeV neutrons. The production ratios $^{40}Ar/^{39}Ar$ and $^{38}Ar/^{39}Ar$ from K and $^{39}Ar/^{37}Ar$ from Ca are reduced by two, four, and one order(s) of magnitude respectively compared with their production rates in a fission spectrum, reducing these conventionally important interference corrections to the point of negligibility. Additionally, the $^{24}Al(n,\alpha)^{24}Na$ reaction, which has important radiological consequences due to the β^- activity of ^{24}Na, is essentially eliminated, allowing safer/quicker handling of samples irradiated in Al containers. Eliminating higher energy neutrons, unavoidable in a fission spectrum, also reduces the recoil energy, hence recoil distance, of ^{39}Ar and ^{37}Ar atoms produced chiefly from K and Ca respectively. With fission spectrum neutrons, ^{39}Ar recoil severely limits the applicability of the $^{40}Ar/^{39}Ar$ method to fine-grained materials such as clay minerals. Modeling of recoil effects using the SRIM ion transport code reveals significant benefits of D-D neutrons in reducing recoil effects. For example, in 1 micron diameter illite crystals, fission spectrum neutrons produce ^{39}Ar with a mean recoil energy of 177 KeV, resulting in ∼17% loss of ^{39}Ar by displacement from the crystals. In contrast, D-D neutrons produce ^{39}Ar with a mean recoil energy of 30 KeV, resulting in only ∼3% loss. Thus, irradiation by D-D neutrons will significantly broaden the scope of problems uniquely addressable by $^{40}Ar/^{39}Ar$ methods.

V32C-1043 1330h POSTER

Argon isotopes as recorders of magmatic processes

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Argon isotopic ratios vary enough between different reservoirs (atmosphere, crust, mantle) and diffuse fast enough through most minerals at magmatic temperatures (700-1200 C) to make them ideal for looking at magma chamber dynamics. Indeed, diffusion is sufficiently fast to allow short time scales to be deciphered, setting argon apart from many other isotopic methods. A mineral's ability to retain “excess” argon (40Ar/36Ar ratios greater than the atmospheric value and apparent ages older than the known eruption age) during post-eruption cooling is key to Ar studies. Previous work shows that both phenocrysts (crystallizing in the magma chamber; e.g. Mt St. Helens; Layer and Gardner, 2001) and xenocrysts (introduced into the magma chamber; e.g Toba; Gardner et al., 2002) preserve excess argon, which enables magma chamber processes to be deciphered through the variable diffusion rates between crystal phases. Single crystal 40Ar/39Ar step-heating of biotite from the 10.5 ka eruption of Nevado de Toluca volcano, Mexico indicates that they are xenocrystic and resided for only a short (< 1 year) time in the magma before it erupted. The biotite has reaction rims of hornblende, orthopyroxene and plagioclase, and failed to grow experimentally at pressure-temperature conditions of the magma, confirming the xenocrystic nature of this phase. Single-step fusion of plagioclase phenocrysts from eruptions of El Chichon volcano, Mexico, shows evidence of excess (mantle) argon, whereas hornblende from the same eruptions contains little or none. In this case, faster diffusion of Ar in plagioclase than in hornblende allow plagioclase to incorporate excess argon during magma recharge; hornblende does not. Combining such results with other isotopic systems may in fact better determine magma chamber processes. At El Chichon, Sr isotopes suggest magma recharges ocurred (Tepley et al., 2000), whereas the argon isotopes suggest such pulses occurred just before each eruption. The fast and variable diffusion of argon thus allows it to record events that other systems may miss or smear out with time. Gardner, J.E., P.W. Layer and M. Rutherford, 2002, Geology, 30, p. 347-350. Layer, P.W., and J.E. Gardner, 2001, Geophys. Res. Lett., 28, 4279-4282. Tepley, F. J., III, J.P. Davidson, R.I. Tilling, J.G. Arth, 2000, J. Petrol., 41, 1397-1411.

V32C-1044 1330h POSTER

Comprehensive and systematic MC-ICP-MS/TIMS isotopic characterization of USGS Standards

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The Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the University of British Columbia has undertaken a systematic analysis of isotopic (Nd, Sr, Hf, Pb) composition and concentration of a broad compositional range of United States Geological Survey standards, including basalt (BCR-1, 2; BHVO-1, 2; BIR-1), dunite (DNC-1), andesite (AGV-1, 2), rhyolite (RGM-1, 2), syenite (STM-1, 2) and granite (G-2). USGS rock standards are geochemically well-characterized, but there is no systematic methodology nor database for radiogenic isotopic analyses, even for the widely used BCR-I. This investigation represents the first comprehensive, systematic analysis of the isotopic concentration and composition of USGS standards, and will provide an important database for the isotopic community. The wide range of equipment at PCIGR, including a Nu MC-ICPMS, a Triton TIMS, and an ElementII HR-ICPMS, permits a rigorous assessment and comparison of precision and accuracy in isotopic analyses. Our separation technique involves an HF/HNO3 dissolution in Teflon bombs, standard cation exchange elutriation for Sr and REE separation, and HDEHP Teflon columns for Nd separation. Samples are unspiked, and elemental concentration is determined by HR-ICPMS. Isotopic composition is determined by both thermal ionization mass spectrometry (Sr, Nd) and by multi-collector inductively coupled plasma mass spectrometry (Nd, Hf, Pb). Replicate runs of La Jolla Nd standard demonstrate excellent agreement between MC-ICPMS (143Nd/144Nd=0.511846±14 [n=100]) and TIMS (0.511850±16 [n=67]). Replicate analyses of strontium standard NBS987 yield 86Sr/87Sr values of 0.710256±15 [n=130]. Neodymium isotopic analyses (143Nd/144Nd values and Sm/Nd ratios) of previously characterized standards, such as BCR-1 (143Nd/144Nd=0.512623±2 [Nu; n=2]; 0.512627±8 [Triton; n=8]; Sm/Nd=0.1389) and BHVO-1 (0.512972±5 [Nu; n=2]; 0.512973±6 [Triton; n=14]; 0.1522-0.1532) are within error of published values. Replicate analyses of previously uncharacterized standards, such as AGV-1 (0.512776±4 [Nu; n=4]; 0.512781±7 [Triton; n=7]) and RGM-1 (0.512799±2 [Triton; n=2]), and second generation standards, such as BCR-2 (0.512639±6 [Triton; n=3]), BHVO-2 (0.512984±3 [Triton; n=3]), and AGV-2 (0.512792±1 [Triton; n=2]), provide the first reproducible data for these standards. Strontium analyses of BCR-1 (87Sr/86Sr= 0.705027±8 [Triton; n=4]) and BHVO-1 (0.703482±13 [Triton; n=6]) yield 86Sr/87Sr values that replicate known values. Replicate analyses of other standards, such as BCR-2 (0.705024±5 [Triton; n=3]), BHVO-2 (0.703487±9 [Triton; n=4]) and AGV-1 (0.703997±8 [Triton; n=7]) provide the first data for these standards. Hafnium and lead isotopic analyses on the same suite of samples are underway.

V32C-1045 1330h POSTER

The Enigma of the Ubiquity of ^{14}C in Organic Samples Older Than 100 ka

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An early expectation of the accelerator mass spectrometry (AMS) technique was that the dramatically improved AMS precision relative to beta counting methods would roughly double the range for ^{14}C dating from about 40 ka (7 times the half-life) to about 80 ka (14 times the half-life). Very soon it was discovered, however, that organic samples throughout the Phanerozoic record commonly display ^{14}C levels hundreds of times the AMS detection threshold. Thought to be contamination, AMS researchers mounted a major campaign to identify the source or sources of this ^{14}C. Although a few minor sources of contamination were identified and corrected, the majority of the ^{14}C in samples that should have been ^{14}C dead given their location in the geological record appeared to be intrinsic to the samples themselves. Studies on *insitu* production of ^{14}C from U and Th decay indicated this source to be too feeble to account for the elevated ^{14}C levels being detected. This situation motivated us to investigate this phenomenon in a more systematic fashion. We selected ten coal samples from the DOE Coal Sample Bank at Penn State University. These samples had been carefully collected and preserved in argon since collection. Our samples were selected for geographical diversity and to span a significant fraction of the geological record. They included three Eocene, three Cretaceous, and four Pennsylvanian coals. They were analyzed using AMS with multiple runs for high precision. After subtracting a standard background correction of 0.08 percent modern carbon (pMC), the results for these ten samples ranged from 0.10$\pm$0.03 pMC to 0.46$\pm$0.03 pMC with a mean of 0.25 and standard deviation of 0.11. In terms of radiocarbon ages, the range is between 44 ka and 57 ka with a mean of 50 ka. When averaged by geological interval, we obtained mean values of 0.26 pMC (49 ka) for Eocene, 0.021 pMC (51 ka) for Cretaceous, and 0.027 pMC (49 ka) for Pennsylvanian. These results match closely AMS determinations for coal reported in the radiocarbon literature by other investigators. This study indicates that ^{14}C levels in coal are indeed well above the background correction commonly used today and that there is little if any dependence of ^{14}C level on position in the geological column. We conclude the phenomenon of intrinsic ^{14}C in organic material throughout the Phanerozoic record is genuine and persists as an unresolved research question.

V32C-1046 1330h POSTER

Abundant Po Radiohalos in Phanerozoic Granites and Timescale Implications for Their Formation

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Radiohalos are significant as a physical, integral, historical record of the decay of radioisotopes in their tiny central mineral inclusions. In thin section the typical dark concentric rings in the host minerals are due to the α-emissions, with the ring radii related to the distinctive a energies of the different radioisotopes in the ^{238}U and ^{232}Th decay series. ^{238}U and ^{232}Th radiohalos typically form around zircon and monazite inclusions, respectively, commonly in biotite, within granitic rocks. Radiohalos are also observed without central mineral inclusions and consisting only of rings from the last three α-emitters in the ^{238}U series: ^{218}Po, ^{214}Po and ^{210}Po. Because rings for all the Po precursors are missing, one infers there may have been migration of a Po precursor, most likely ^{222}Ra, away from a ^{238}U source in the genesis of such halos. Early research to understand how Po radiohalos might have formed focused on Precambrian granitic rocks. Thus it was claimed that the Po radiohalos were largely confined to such rocks. Furthermore, their formation was described as "a tiny mystery", because the half-lives for ^{218}Po of 3.1 minutes, ^{214}Po of 164 μs, and ^{210}Po of 138 days place severe time constraints on the processes for separating the Po precursor from parent ^{238}U and concentrating it and/or Po prior to halo formation. We report new research which establishes that Po radiohalos are also common in Phanerozoic granites, for example, in the Lachlan Fold Belt of southeastern Australia and the Peninsular Ranges Batholith of southern California. Their abundance is approximately ten ^{210}Po radiohalos for every ^{214}Po radiohalo, while ^{218}Po radiohalos are rare. The frequency of ^{238}U halos in these rocks is typically comparable to that of the ^{210}Po halos. Po halos are usually found in the same biotite grains as ^{238}U halos. The zircon inclusions in the latter often contain >100 ppm U and therefore represent a potentially adequate source of precursor ^{222}Rn and Po for the Po halos. Hydrothermal fluids appear to play a critical role in the formation of these Po halos, both in nuclide transport and in chemical reactions to precipitate Po at localized sites. Because of α-track annealing, the halos can form only below 150° C. The time window for the required hydrothermal activity in the cooling granite hence would have been extremely short compared with the timescale of ^{238}U decay. As a consequence the amount of ^{222}Rn available during this brief cooling window falls far short of the amount required to generate the observed mature halos. We view this seeming paradox as a hint that nuclear decay processes may have been occurring more rapidly during the interval in which these granites were cooling.

V32C-1047 1330h POSTER

Recently Measured Helium Diffusion Rate for Zircon Suggests Inconsistency With U-Pb Age for Fenton Hill Granodiorite

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Gentry *et al.* (*GRL*, 9, 1129-1130, 1982) reported high levels of helium retention in zircons extracted from granodiorite core obtained from the 4300 m deep borehole GT-2 at Fenton Hill, NM, drilled as part of a Los Alamos geothermal research project. These investigators measured, for example, 27% retention at a depth of 2170 m and temperature of 151° C and 17% retention at a depth of 2900 m and temperature of 197° C. The U-Pb concordia age determination for this rock was 1500$\pm$20 Ma at a depth of 2900 m. They inferred the total helium production from the radiogenic lead in the zircons. These surprisingly high levels of radiogenic helium retention motivated us to determine the helium diffusion rate in zircon extracted from this same granodiorite. We contracted with a high precision laboratory for these determinations. We used the same zircon size as Gentry *et al.* (50-75 μm) and obtained diffusion rate measurements over the temperature range 50-500° C. At 200° C, for example, the measured diffusion coefficient was 1.42 x 10^{-17} cm^2/s. We also confirmed the high helium retention, finding 1320 nmol/cc (42% retention) in zircons from a depth of 1490 m and a temperature of 125° C. By contrast, the surrounding biotite had only 7 nmol/cc. Our determinations gave a U-Pb concordia age of 1440$\pm$2 Ma. Astonishingly, for the current borehole temperatures and measured diffusion coefficients, we find the zircons could have retained the observed levels of helium only if the time span were less than about 10 ka. Today, most of the rock column is well above the calculated zircon helium closure temperature of 128° C. According to published Los Alamos thermal models, temperatures in the region sampled by the borehole would have been much higher for the past 2 Ma, cooling down to today's levels only during the last 0.1 Ma. Even with present temperatures, our diffusion rates (which agree with published rates for other zircons) require retentions to be orders of magnitude lower than the observed levels to be consistent with the U-Pb age for these rocks.

V32D MCC: Level 2 Wednesday 1330h

Isotopic Constraints on Rates of Building Active Volcanoes II Posters

Presiding: **A Calvert,** U.S. Geological Survey, Menlo Park**; B Singer,** University of Wisconsin-Madison

V32D-1048 1330h POSTER

History and Eruptive Style of Mount Veniaminof, a Huge Alaskan Basalt-to-Dacite Volcano With Pleistocene and Holocene Caldera-Forming Eruptions

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The eruptive history of Mount Veniaminof, one of the largest and most active volcanoes in the Aleutian arc, is being established through geologic mapping, geochemistry, and $^{40}Ar/^{39}Ar$ and K-Ar geochronology. The Veniaminof edifice has a basal diameter of ~40 km, a volume of ~350 km^3, and an 8-km-diameter ice-filled caldera whose wall reaches an elevation of 2500 m. Glassy lava flow carapaces with polygonal and columnar joints are common and indicate widespread ice/lava interaction, which resulted in ice-marginal flows and tuyas. Exposures from deep glacial valleys to the caldera rim reveal a long history of dominantly basaltic and basaltic andesitic activity from at least 250 ka to 100 ka that produced lavas with compositions as primitive as 9.4% MgO and 130 ppm Ni at 50% SiO_2. Silicic magmas vented beginning ~100 ka are represented by virtually aphyric dacitic lavas (to 68% SiO_2) on the south and west flanks. Similarly, voluminous nearly-aphyric andesite and dacite were produced as recently as 36.4$\pm$6.5 ka (andesite) from a northwest-trending set of flank vents. Abundant dikes follow this arc-normal trend. Other abundant dikes have arc-parallel orientations and were emplaced prior to 100 ka pre-caldera lavas. Most lava compositions fall in the tholeiitic field on an SiO_2 versus FeO/MgO diagram. With the exception of a small volume hornblende dacite lava flow (79.0$\pm$1.4 ka), no hydrous phenocrysts are known in any Veniaminof juvenile eruptive products. Basalts and basaltic andesites carry olivine and plagioclase (to 1 cm) phenocrysts, joined by augite in some crystal-rich lavas. Andesites and dacites typically have few, small phenocrysts of plagioclase, augite, and low-Ca pyroxene $\pm$ Fe-Ti oxide. Caldera collapse may have initiated in the Pleistocene with eruption of dacitic magma locally preserved as pumiceous pyroclastic-flow and -fall deposits on the west side of Veniaminof (Miller et al. 2002) and capped by basaltic andesitic lava dated at 27.9$\pm$4.4 ka. Although the caldera may have collapsed further during two large Holocene andesitic explosive eruptions, eroded lava displaying ice-contact jointing drapes the caldera wall and indicates that a caldera was present in the late Pleistocene. The youngest dated Veniaminof lavas on the south, ice-blanketed side of the caldera are ~50 ka; a few south flank cinder cones may be latest Pleistocene/early Holocene. Despite the absence of an exposed southern caldera wall, no debris-avalanche-deposit evidence has been found for an alternative, sector-collapse origin of the caldera structure. Two voluminous andesitic Holocene pyroclastic eruptions (3700 yr BP and >4700 yr BP; Miller et al., 2002) emplaced pyroclastic-flow deposits on Veniaminof's flanks and in surrounding valleys. The younger deposited lithic breccia at higher elevations, including plutonic clasts with textures ranging from coarse-grained cumulate gabbro to medium-to-fine-grained miarolytic hornblende tonalite compositionally like Veniaminof dacite. A still younger (subplinian?), widespread dacitic (63.5% SiO_2) fall deposit up to ~30 cm thick suggests that this long-lived magmatic system may produce explosive silicic eruptions in addition to the historically-known basaltic andesitic strombolian and effusive eruptions from the intracaldera cone.

Miller, T.P., Waythomas, C.F., and Gardner, J.E., 2002, Possible multiple late Quaternary caldera-forming eruptions at Mount Veniaminof volcano, Alaska: Eos Trans. AGU 83(47), V11A-1376.