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Lead isotope geochemistry of Bambuí Group carbonate rocks, São Francisco Basin, Brazil.

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Pb isotopic compositions and U and Pb concentrations determined for carbonate rocks of Bambuí Group, São Francisco Basin, Brazil show 4 distinct types of Pb, called types I, II, III and IV. Type I is present in samples with relatively low-Pb and high-U; it is variably radiogenic, depending on the U/Pb ratios. Type II is present in samples with relatively high-Pb and low-U; this is non-radiogenic Pb with composition ($\alpha = 18.8$, $\beta = 15.75$) similar to that of average crustal Pb at ca. 600 Ma. Type III is also found in samples with high-Pb and low-U, but it is radiogenic crustal Pb and can be divided into types IIIa ($\alpha = 36.0$, $\beta = 18.3$) and IIIb ($\alpha = 34.0$, $\beta = 17.8$), etc. according to isotopic compositions. Type IV is intermediate in composition between type III and type I.

Type I Pb represents in situ growth of radiogenic Pb and yields a Pb-Pb isochron age of 672 ± 95 Ma. Type II Pb falls on the lower extension of the isochron for type I Pb, suggesting that it represents the initial Pb composition; regression of type I and type II data yields a Pb-Pb age of 651 ± 43 Ma. We interpret this isochron age for Type I Pb as the minimum age of deposition for carbonates of the Bambuí Group, and we infer that rock hosting Type I Pb, in this case, was not affected by subsequent alteration.

Type III Pb plots on a line where Type II Pb falls on the lower end of this line which intersects the Stacey and Kramers (S&K) growth curve; the regression of type II and type III data yields S&K intercepts at about 520 and 2050 Ma. We interpret type III Pb and type II Pb as crustal Pb extracted between 650 and 520 Ma from 2.1 Ga (Transamazonian) crustal sources; type II Pb represents average crust, whereas type III Pb represents crustal sources with higher U/Pb ratios. This Pb was introduced into some of the Bambuí Group carbonates during low-grade metamorphism or hydrothermal alteration associated with the ca. 600 Ma Brazilian orogeny. The mobility of Pb isotopes shows that this basin was not totally stable, especially on its borders, during the Brazilian Cycle.

Type IV Pb appears to be a mixture of type I Pb and type III Pb; it formed as a result of introduction of type III Pb into the rocks during the 600 Ma alteration, but in quantities insufficient to dominate subsequent growth of radiogenic Pb.

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Old and Crusty: Cenozoic Accumulation History of a Pacific Ferromanganese Crust

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Variations in the composition and rate of accumulation of slowly growing hydrogenetic ferromanganese crusts are suggested to record long-term paleoceanographic events. Although thick, well-preserved, and presumably old crusts are found on Cretaceous seamounts, previous ^{10}Be and $^{87}\text{Sr}/^{86}\text{Sr}$ dating of these deposits suggest they are no older than Miocene, a finding that is suggested to coincide with relatively oxic conditions in the global ocean that began in the Oligocene and intensified in the Neogene. However, we felt that it is doubtful oxic conditions were so low throughout the water column of the Paleogene ocean that precipitation of ferromanganese oxides was inhibited. To investigate this hypothesis, we performed a variety of chemical and isotopic analyses of a ~9.5 cm-thick ferromanganese crust, dredged from Schumann Seamount in the Hawaiian Archipelago. These analyses included ^{10}Be profiling, $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ age determinations of included phosphatised limestone debris and vein inclusions, and Co chronometry. Together with microfossil stratigraphy (Cowen et al., 1992), our results indicate that some seamount crusts greatly exceed Miocene age, probably approaching the Cretaceous seamount age. Phosphatised limestone inclusions between 40 to 51 mm depth yield $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ dates near Eocene microfossil ages reported in overlying layers, whereas a substrate vein infilling represents Middle Miocene phosphatisation. Seamount paleocracking indicates equatorial divergence cannot explain the Middle Miocene phosphogenesis, and suggests N.E. trade wind transport of aluminosilicates in the Cenozoic, the latter consistent with other evidence for the antiquity of this ferromanganese crust.

Cowen, J. et al., *Eos* 72, 73 (1992).

V51A-5 0815h POSTER

Investigation of Strontium Isotopic Dating of FeMn Oxides in Ferromanganese Crusts

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In order to further evaluate the proposed $^{87}\text{Sr}/^{86}\text{Sr}$ dating method for ferromanganese oxides (Futa et al. 1988; Ingram et al. 1990; and Hein et al. 1992), four subsamples representing lithic end-members of an ~9.5 cm thick ferromanganese crust from Schumann Seamount were chosen for $^{87}\text{Sr}/^{86}\text{Sr}$ analyses. These subsamples represent crust material with a large aluminosilicate fraction (L4), a layer with high Fe oxide and aluminosilicate content (L7), a layer containing abundant francolite (L12), and a layer rich in Mn oxide (L17).

Acetic acid leaches (2N) were followed by H_2O_2 leaches, then subsequently stronger HCl leaches from 0.25N up to 2N and finally total dissolution of the HCl residues. The supernatant from each dissolution was analyzed for $^{87}\text{Sr}/^{86}\text{Sr}$. The acetic acid and H_2O_2 leaches have a predominantly modern seawater signature. Francolite is also partially dissolved by the acetic acid, which explains the deviation from modern seawater values in L12. The $^{87}\text{Sr}/^{86}\text{Sr}$ for the HCl leaches vary considerably with the strength of the acid, the 0.25N HCl leach giving the lowest values for three of the four layers. Layers 4, 7, and 17 had values ranging between 0.708216 to 0.708276, while the francolite-rich L12 exhibited a ratio of 0.708650. These values clearly cannot be interpreted as ages of

ferromanganese formation, because this would mean that several layers ranging in depth from 9-68 mm were precipitated virtually at the same time. This is corroborated by ^{10}Be and micro-fossil dating, Co chronometry, and $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ dating of francolite inclusions in this crust. Residues from L4 and L7 exhibit a continental $^{87}\text{Sr}/^{86}\text{Sr}$ signature whereas residues from L12 and L17 have an altered basal signature. Our results show that ferromanganese oxide material must be effectively separated from all detritus or francolite to have any hope of obtaining reliable formation ages using Sr isotopes, and cast doubt upon previous age interpretations using this method.

Futa et al., *Geochim Cosmochim Acta* 52, 2229 (1988).
Ingram et al., *Geochim Cosmochim Acta* 54, 1709 (1990).
Hein et al., *Paleoceanography* 7, 63 (1992).

V51A-6 0815h POSTER

Testing Models of Fission Track Annealing in Apatite in a Simple Thermal Setting: ODP Site 800, Leg 129

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Four models of fission track annealing in apatite are compared with measured fission track lengths in samples from Site 800 in the East Mariana Basin, ODP Leg 129, given an independently determined temperature history. The temperature history of Site 800 was calculated using a one-dimensional, compactive, conductive heat flow model assuming two end-member thermal cases: one for cooling of Jurassic ocean crust that has experienced no subsequent heating, and one for cooling of Cretaceous ocean crust. Because the samples analyzed were only shallowly buried and because the tectonic history of the area since sample deposition is simple, resolution of the temperature history is high. The maximum temperature experienced by the sampled bed is between 16°C and 21°C and occurs at 96 Ma; temperatures since the Cretaceous have dropped in spite of continued pelagic sediment deposition because heat flow has continued to decay exponentially and bottom water temperatures have dropped. Fission tracks observed within apatite grains from the sampled bed are $14.6 \pm 0.1 \mu\text{m}$ (1 σ) long. Given the proposed temperature history of the samples, one unpublished and three published models of fission track annealing predict mean track lengths from 14.8 to 15.9 μm . These models require temperatures as much as 40°C higher than the calculated paleotemperature maximum of the sampled bed to produce the same degree of track annealing. Measured and predicted values are different because annealing models are based on extrapolation of high temperature laboratory data to geologic times. The model that makes the closest prediction is based on the greatest number of experiments performed at low temperature and on an apatite having composition closest to that of the core samples.

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Evaluating the role of inclusions in U-Pb and Sm-Nd Garnet Geochronology: Stepwise Dissolution Experiments and Induced Fission Track Distributions

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U-Pb and Sm-Nd dating of garnet are important tools for improving our understanding of the dynamic aspects of metamorphism. Yet both systems suffer from possible contamination by inclusions of phases such as monazite or zircon which are rich in these elements. A stepwise dissolution technique, combined with measurement of induced fission track distributions can be used to identify the presence of monazite, allanite or zircon inclusions, and also determine the impact of these inclusions on U-Pb and Sm-Nd ages.

Inclusion free grossular-andradite garnets from Cascade Slide Adirondacks, N.Y. produce a homogeneous distribution of fission tracks, and show limited variation in U/Nd (0.022-0.023), Th/U (2.08-2.15), and Sm/Nd (0.241-0.247) between dissolution steps. Dissolution steps yield a $^{207}\text{Pb}/^{206}\text{Pb}$ isochron age of 1027 ± 5 Ma, in agreement with previously determined ages for this sample.

In contrast, almandine-pyrope garnets from the Archean core complex of the Wind River Range, Wyoming, have a heterogeneous distribution of fission tracks with U being located both in the garnet itself, and in ca 20 μm monazite inclusions. Stepwise dissolution reveals correlations of Sm/Nd (0.2-1.2), U/Nd (0.02-0.20) and U/Th (0.15-0.83), consistent with the observed presence of monazite inclusions. The $^{207}\text{Pb}/^{206}\text{Pb}$ age defined by nine garnet aliquots from the same sample (2747 ± 20 Ma) is older than U-Pb ages on groundmass monazites (2659 ± 1 Ma) suggesting a higher closure temperature for the U-Pb system in garnet. Both U-Pb and Sm-Nd garnet-whole rock ages (2598 ± 13 Ma) appear to be unaffected by the presence of monazite inclusions. The younger Sm-Nd age suggests that the Sm-Nd system in garnet is reset at temperatures of ca 600°C .

V51A-8 0815h POSTER

Responses of Rb-Sr and Sm-Nd Isotopic Systematics to Metamorphism and Deformation: Examples From the Crossore-type Plutons in the Southern Appalachian Blue Ridge

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The Blue Ridge thrust complex in the southern Appalachians consists of several thrust sheets with thick shear zones bounding

and within the thrust sheets. The Beech Mountain thrust sheet within the Blue Ridge complex is one of the four thrust sheets recognized west of the Grandfather Mountain window. Progressively deformed metagranite and along shear zones within the Beech Mountain thrust sheet was analyzed to evaluate the effects of deformation and metamorphism on isotopic systematics.

Seven whole-rock analyses of Beech metagranite, including protomylonitic to mylonitic samples of the pluton, give a Sm-Nd isochron (MSWD=0.04) with an age of 755 ± 81 Ma, which is consistent with U-Pb zircon results (Su and others, 1992). Data indicate that the Sm and Nd were relatively immobile during Paleozoic greenschist-facies metamorphism and subsequent late Paleozoic deformation. In contrast, Rb-Sr analyses of whole-rock Beech metagranite do not yield an isochron and show random and small variations in the $^{87}\text{Rb}/^{86}\text{Sr}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, suggesting limited and incomplete Rb and Sr migration. Seven thin slices cut from one ultramylonite hand specimen yield a Rb-Sr isochron (MSWD=1.5) with an age of 307 ± 10 Ma and an initial ratio of 0.7891 \pm 0.0019, reflecting isotopic re-equilibration (complete resetting) on a cm scale during mylonitization. This late Carboniferous age agrees with an earlier date obtained for the Linville Falls fault mylonite (Van Camp and Fullagar, 1982) and is interpreted as the timing of mylonitization, suggesting that northward thrusting of the Blue Ridge complex occurred during the Alleghanian orogeny. Rb-Sr isotopic results for sheared metagranite from the Lansing and the Warrenville plutons constitute an errorchron and a geologically meaningless pseudo-isochron, respectively, which are considered to be the result of interaction between the granite and a fluid phase with high Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios.

V51A-9 0815h POSTER

Geochronology of Granites in the Cherskii Range, Yakutia and Implications for Accretion of Terranes to the Siberian Craton

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Jurassic to Cretaceous granitic plutons form linear belts which are parallel to (e.g. the Main Belt) and perpendicular to (e.g. the Transverse granites) both the axis of the Cherskii mountains and the Verkhoyansk fold system located in eastern Yakutia, Russia. Russian K-Ar ages of these plutons span a range from 60 Ma to 200 Ma, with the majority of ages being between 120 Ma and 150 Ma. The large age range has been interpreted to record a protracted period of magmatism reflecting the duration of the collision of Kolyma-Omolon composite terrane with the Siberian craton.

Critical examination of published Russian data indicates that the age range for the Main Belt granites may in fact be an artifact of dating mineral phases and whole rock samples which have been exposed to various degrees of partial thermal resetting or retention of excess argon. Other ages included in the Russian compilations may reflect later or mineralization events. Our analysis indicates that the Main Belt granites show a single age mode of 130-135 Ma, while the Transverse granites show two age modes at 90-110 and 135 Ma. These data suggests that two discrete events occurred, with 135 Ma being indicative of the time of accretion of the Kolyma-Omolon superterrane to the Siberian craton. The University of Alaska Geochronology Laboratory has begun $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the Main Belt and Transverse granites. Preliminary results have been obtained for the granitic Chibagalakh massif, one of the largest plutons in the Main Belt. Biotite and muscovite separates show age plateaus of 142.93 ± 0.65 Ma and 142.25 ± 0.65 Ma respectively. These ages are older than the whole rock K-Ar ages for this pluton reported in Russian compilations.

V51A-10 0815h POSTER

Timing of Collision of the Sino-Korean and Yangtze Cratons, China

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The northwest trending Qinling-Dabie suture zone between the north and south China cratons extends >2000 km across central China. The eastern part of the suture is a high-grade metamorphic belt marked by a series of fault-bounded belts composed of crustal protholiths. This zone is offset 450 km to the north by the Tanlu fault. The subduction-related metamorphic rocks range from low greenschist facies in the southwest to ultrahigh-pressure eclogite facies in the northeast. The ultrahigh-pressure belt is coesite and diamond-bearing, indicating subduction to depths of approximately 120 km as a result of continental collision. The ultrahigh-pressure belt is mostly composed of quartzofeldspathic gneiss, but also contains boudins of eclogites. Timing of the continental collision has previously been inferred as upper Triassic from regional geological relations, or Caledonian from $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the adjacent and possibly related Qinling metamorphic belt. Direct dating of ultrahigh-pressure eclogites from the Dabie Mountains using U-Pb analyses on zircons yields a metamorphic age of 209 ± 2 Ma. U-Pb zircon analyses on the surrounding quartzofeldspathic gneiss also renders ages of 201 ± 10 Ma, indicating subduction and exhumation of large, coherent slabs of continental crust. These metamorphic cooling ages coincide with the later stages of collision, and thereby give a minimum estimate of the time of collision. Despite extreme metamorphic conditions, zircons