Unravelling polytectonism using *in situ* Th-Pb dating of monazite

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Despite the high U and low common Pb contents of monazite, interpretation of conventional U-Pb monazite ages is complicated by problems including inheritance, isotopic disequilibrium, recrystallization, and other open system behaviors. These problems can be circumvented by Th-Pb dating of monazite using an *in situ* method which provides two capabilities with unique potential to assess polymetamorphism: prograde thermochronometry and continuous thermal histories. Monazite is unstable in most pelitic rocks at low grades but reappears in prograde terranes of normal Ca and/or Al contents at the aluminosilicate isograd permitting direct dating of the isograd. Although recent experimental results indicate that diffusive loss of Pb* is unlikely under amphibolites conditions, the Th-Pb system can be reset in matrix monazites by dissolution/reprecipitation reactions. However, neoformed monazites included in garnet immediately following growth are shielded from fluid alteration. By using an *in situ* analysis method, one can recognize the various misbehaviors described above and identify domains that have escaped post-crystallization exchange. We have evaluated this approach in a number of deeply exhumed settings within the Indo-Asian collision zone (e.g., Main Central Thrust zone, Red River Shear Zone, Kongur Shan detachment fault, South Tibetan Detachment, Nyainqentanglha Shan) and found it, in conjunction with thermobarometry, to be a powerful strategy with which to obtain *P-T-t* histories of crustal scale fault systems. The approach, however, can be problematic where protoliths have previously attained amphibolite grade. Ion microprobe depth profiling permits measurable gradients of Pb/Th to be observed over sub-μm length scales in separated monazites. Where these gradients can be shown to be due to diffusive Pb loss, they contain continuous *T-t* information that can be used to constrain numerical models of heat flow adjacent a fault ramp from which quantitative slip histories can be obtained. Routine application of this approach is limited by uncertainty in extrapolation of experimental diffusion data but results from geologically well-constrained environments are being used to 'anchor' the empirical results in geological time.

Geochronology of the Western Gneiss Region UHP terrane

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Geochronology and petrology of new UHP and HP eclogites define three discrete UHP domains within the Western Gneiss Region of Norway that are separated by HP rocks. $^{40}Ar/^{39}Ar$ muscovite ages show that these UHP domains are gentle antiforms that are younger than 375 Ma. The UHP antiforms range in size from ~2500 km^2 to >100 km^2 and are overlain by a HP veneer that extends over more than 60,000 km^2. If continuous at depth, the UHP terrane underlies at least 11,000 km^2. Eclogite U/Pb and Sm/Nd ages, combined with characteristic thermal diffusion distance, imply that the northern UHP domain and the two southern domains are separate crustal blocks that experienced and were exhumed from UHP conditions at different times.

Petrologic studies show that the UHP rocks underwent isothermal decompression to 0.5 GPa in ~5 Myr; this implies adiabatic exhumation of a UHP body 20–30 km in diameter or thickness. Discrepancies in anticipated and observed flattening magnitude and sinking magnitude suggest that either the UHP terrane was more viscous when it ponded at the Moho or that it did not pond at the Moho. The combined geochronologic, structural, and petrological dataset suggest that the UHP slab rose coherently from mantle to crustal depths and was exhumed through the crust progressively from east to west between 400 and 390 Ma.

Petrotectonics-geochronology of ultrahigh-pressure (UHP) crustal and upper mantle rocks — implications for Phanerozoic orogeny

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UHP metamorphic terranes worldwide reflect descent of continental crust to depths of ~90-140 km in now-imbricated contractional orogens. For documented UHP belts thus far recognized, formation took place in Phanerozoic time. Rocks are strongly retrogressed to low-P mineral assemblages; relict UHP phases are retained under kinetically inhibiting circumstances, mainly in tough, refractory host minerals. Many UHP complexes consist of thin, allochthonous sheets, but the two largest, in China and Norway, are ≥10 km thick. They are made up chiefly of quartzofeldspathic rocks ± serpentinites; mafic-ultramafic lithologies comprise less than 10 % of each exhumed subduction complex. Some UHP garnet peridotites and eclogites reflect crustal emplacement; others are mantle-wedge derived. SHRIMP dating of zoned zircons in gneissic and eclogitic rocks constrains the timing of protolith, peak, and retrograde recrystallization. Roundtrip P-T paths are completed in ~10-20 Myr; ascent rates to mid-crustal levels approximate descent velocities. Late-stage domical uplifts characterize some UHP complexes. Sialic crust may be carried to great depth because it is attached to a largely oceanic downgoing plate. Exhumation typically involves near-adiabatic decompression through the P-T fields of much lower P metamorphic facies. Thin-aspect-ratio, ductiley deformed nappes, generated by subduction-zone shear forces, allow heat to be conducted away as UHP complexes rise, cooling the sheets. Ascent along the subduction channel is driven chiefly by the positive buoyancy of a mainly continent-crust slab relative to the surrounding mantle. Rapid exhumation prevents establishment of a more normal geothermal regime in the subduction-zone. Return to mid-crustal levels does not require wholesale removal of the mantle wedge. Combined with vigorous erosion, late-stage underplating, contraction, tectonic aneurysms and/or lithospheric plate shallowing may elevate mid-crustal UHP décollements in domical uplifts. Where these situations are not satisfied, UHP complexes are totally transformed to low-P mineral assemblages, obliterating evidence of past profound burial.

Temporal constraints on the juxtaposition and exhumation of deep crustal domains, East Athabasca region, Western Canadian Shield

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The nature and rates of processes that juxtapose and exhume crustal domains are of central importance for understanding continental evolution. Although innumerable studies have investigated these problems in mid- and upper crustal rocks, the scarcity of orogen-scale lower crustal exposures has hindered study of these processes at deeper crustal levels. A spectacular exposure of granulites, composed of several distinct lithotectonic domains, occurs in the East Athabasca area in northern Saskatchewan. The high temperatures achieved by these granulites during ca. 1.9 Ga peak metamorphism, and their subsequent protracted cooling histories, provide a superb opportunity to reconstruct the detailed T-t paths of these rocks by exploiting the full temperature range permitted by the U/Pb (zircon, monazite, titanite, apatite, rutile), $^{40}Ar/^{39}Ar$ (hornblende, muscovite, biotite), and (U-Th)/He (zircon, apatite) isotopic systems. These data record several distinct post-1.9 Ga thermal histories that can be combined with existing thermobarometric and structural data to place constraints on domain juxtaposition and exhumation. The southern domain records cooling from peak 1.9 Ga conditions of 12-19 kbar, >800 °C to <450 °C by ca. 1.87-1.88 Ga, with biotite dates of ca. 1.8 Ga. In contrast, following peak 1.9 Ga metamorphism (10-12 kbar, >800 °C), parts of the Chipman and Northwestern domain record cooling to < 450 °C by ca. 1.83-1.86 Ga, with $^{40}Ar/^{39}Ar$ mica dates of 1.75-1.76 Ga. The cooling history of the southern domain suggests early exhumation linked to the 1.9 Ga event, and subsequent juxtaposition with the other granulite domains. The more protracted cooling histories of the Chipman and Northwestern domains may be attributable to both early ca. 1.9 Ga exhumation and subsequent regional unroofing by the ca. 1.84 Ga Legs Lake shear zone. Proterozoic (U-Th)/He dates on apatite and low U zircons are among the oldest ever reported for terrestrial rocks, and suggest the maintenance of a stable cratonic geotherm since the Proterozoic.

Geochemical characteristics and ion microprobe age of the mafic granulites from the Larsemann Hills, East Antarctica

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The mafic granulites in the Larsemann Hills play an important role in the understanding of the development of proterozoic high-grade gneiss from East Antarctica. Oriented distributed mafic granulite lenses, pods and occur in metapelitic and felsic neiss in the area. The geochemical characteristic of the rocks imply that they are chemically similar to mafic cumulate. They probably represent remnants of mafic dykes. It indicates that the mafic granulite was emplaced in the extensional environment. A combined cathodoluminescence (CL) and sensitive high-mass resolution ion microprobe (SHRIMP) single-zircon study has revealed a relict igneous zoning, metamorphic overgrowths. These new U-Pb SHRIMP zircon of the mafic granulites indicate that the basement rocks of the region are Mesoproterozoic in age. The crystallization ages of metavolcanic rocks were determined at c.1100Ma, Syn-tectonic enderbite give ages of c.990Ma, contemporaneous with metamorphic zircon growth at granulite facies conditions. No conclusive evidence of the mafic-felsic composite orthogneiss represents an Archaean basement complex to the metasedimentary sequence of the Larsemann Hills, Which based on the lithological similarity with mafic-felsic orthogneiss from the southeastern Rauer Group of the Archaean orthogneiss basement.

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The active margin of Gondwana in Peru – Isotopic and geochronologic constraints

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The basement underlying the Peruvian Andes is considered to consist of various blocks largely different in age and composition. The Eastern Cordillera is underlayin by old continental crust while the Western Cordillera and the Cretaceous Coastal Batholith are build upon young and juvenile arc crust. Initial $^{87}Sr/^{86}Sr$ and epsilon Nd values are in the range of 0.703-0.704 and +2 to +7, respectively, for the Western Cordillera, whereas the eastern Cordillera basement has Sr isotopic values as high as 0.716 and epsilon Nd values as low as –7. The Sr, Nd isotopic data are in perfect agreement with intial Hf isotopic compositions of dated zircon crystals. The lacking old continental basement underneath the Western Cordillera is tentatively interpreted to be a product of rifting-off of an Arequipa-type terrane during a Mesozoic, possibly Triassic, rifting period.

Preliminary U-Pb zircon ages from a variety of magmatic rocks from the Eastern Cordillera suggest a polyepisodic evolution with crust-forming events at 480, 320-330, and 240 Ma. These ages were obtained on calc-alkaline and S-type granitoid intrusions and high-grade gneisses along the La Oroya – Tarma – San Ramón transect, a granite to the east of Laguna de Junín and on the calc-alkaline Pataz batholith in the northen part of Peru (La Libertad). The involvement of Proterozoic crust is demonstrated by inherited zircon cores pointing to upper intercept ages of 1.3 Ga. Preliminary therobarometric data from metabasaltic rocks from the northern portion of the Eastern Cordillera yield PT conditions of ~ 700º C, 11.5 kb for the last major orogenic event.

We tentatively conclude that the eastern Cordillera represent part of the active continental margin of Gondwana in the early Paleozoic, which underwent rifting and departure of a continental domain during the Triassic and onto which younger and more juvenile terranes and material were accreted after this rifting, now forming the Western Cordillera basement.

Reactivation of Precambrian fault networks: A K-feldspar $^{40}Ar/^{39}Ar$ study

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Our working hypothesis is that Ancestral Rocky Mountain (320-290 Ma) and Laramide (70-50 Ma) faults in New Mexico and Colorado reactivated zones of crustal weakness that formed during the Precambrian. We are testing this with $^{40}Ar/^{39}Ar$ K-feldspar thermochronology analyses. In Arizona, the Grand Canyon Supergroup sedimentary package is well exposed and provides an unambiguous example of development of a Laramide monocline due to reverse slip reactivation of a Neoproterozoic normal fault. However, because there are limited Precambrian sediments exposed or remaining in the more deeply exhumed Rocky Mountains it is difficult to directly observe reactivation of Precambrian structures. Because $^{40}Ar/^{39}Ar$ K-feldspar age data record the time when rocks cooled from about 300 to 150°C it is the only available thermochronometric system that allows quantitative evaluation of Neoproterozoic or Ancestral Rocky Mountain basement exhumation histories. The basement of New Mexico and Colorado is defined by a complex polygonal network of ~10 km scale blocks that were differentially exhumed between ~1.4 Ga to 0.5 Ga. Emerging K-feldspar data show that different blocks had distinct and variable cooling histories. Thermal histories of Precambrian basement rocks across specific Phanerozoic structures are revealing divergent exhumation histories that began during the culmination of the Grenville orogeny at about 1.1 Ga. These data support our hypothesis that many young fault systems are reactivating older structural weaknesses. Thermal history analysis also records a period of regional cooling (exhumation) between 850 to 750 Ma that coincides with the onset of Neoproterozoic rifting of the Rodinia supercontinent. Additionally, in Colorado the K-feldspar data appear to record cooling related to basement removal during the Ancestral Rocky Mountain orogeny. Continued work across distinct faults, with different orientations (NW versus NS) may reveal which segments of the Paleozoic to Laramide fault network were active at different times in the Proterozoic and hence may help decipher the geometry and kinematics of intracratonic Proterozoic fault systems.

Constraining the slip history and initial dip of low-angle normal faults using $^{40}Ar/^{39}Ar$ K-feldspar thermochronology: A case study from the Sierra Mazatán core complex, Sonora, Mexico

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Introduction

Sierra Mazatán, located in northwestern Mexico, is the southernmost core complex in the Cordillera and accommodated large-magnitude extension in the Mexican portion of the southern Basin and Range. The core complex was primarily exhumed by top-to-the-WSW slip on a major low-angle (10-15°) normal fault. We present $^{40}Ar/^{39}Ar$ K-feldspar thermochronologic data from the footwall that yield insight on the slip history and initial dip of this low-angle normal fault and compare these results with geologic constrains.

Results and discussion

Modeled thermal histories of the K-feldspar data reveal two distinct pulses of rapid footwall cooling implying a poly-phase slip history with early slip from 25-23 Ma followed by a major slip event from 21-16 Ma. Rapid hanging wall sedimentation from 18-15 Ma supports this later slip event. The footwall was rapidly cooled ~75 °C during the 25-23 Ma event and >200 °C during the 21-16 Ma event, implying slip of 3-7 km and 15-35 km for the earlier and later slip events respectively (depending on the geothermal gradient and fault dip). The low end of these slip estimates are supported by the offset of marker units across the fault that constrains the total slip to ≤20 km. These data imply average slip rates of ~3-4 mm/yr during major slip.

Finally, the thermochronologic data indicate that a ~300 °C temperature difference existed across 25 km of the footwall in the slip direction prior to major slip (21 Ma), implying 25-50° of footwall tilt depending on the paleogeothermal gradient (15-30 °C/km). Geologic data, including moderately NE dipping footwall sediments and moderately SW dipping footwall dikes, support ~40° of footwall tilt. This would restore the presently low-angle normal fault to a steep initial dip of 50-60°.

Conclusions

Thermochronologic and geologic data demonstate that the Sierra Mazatán core complex was exhumed by poly-phase Oligo-Miocene extension involving 15-20 km of total slip at rates of 3-4 mm/yr on an initially steep normal fault. Poly-phase unroofing, moderate slip amounts, and initially steep faults may be common to some, if not many, core complexes.

Inherited zircon and the magmatic construction of oceanic crust

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The presence of magmatic zircon in oceanic crust provides an exceptional opportunity for understanding crustal accretion history at mid-ocean ridges. High-resolution Pb/U ion microprobe zircon ages permit the absolute dating of magma emplacement, with typical uncertainties of <1-2%. This technique provides unprecedented resolution of magmatic construction of oceanic crust.

Here we present new Pb/U ion microprobe zircon ages of in-situ lower crustal gabbro from Atlantis Bank, Southwest Indian Ridge. Pb/U zircon ages range between 11.9 ± 0.2 and 12.2 ± 0.3 Ma, with some zircon revealing inheritance (core ages ~1.5 myr older than their corresponding rims). This age range is significantly greater than anticipated by simple plate spreading models. We suggest that the inherited zircons originally formed in gabbroic bodies emplaced at depths of ~14 km in the cold, axial mantle lithosphere beneath the ridge. These gabbro bodies and surrounding mantle were then uplifted, intruded and assimilated by voluminous, shallow-level, crust-forming magmas during the creation of Atlantis Bank.

U-Pb dating of hydrothermal zircon: Fracturing and fluid flow in mantle peridotite at the MAR

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The recognition of hydrothermal zircon porphyroblasts from meta-peridotite collected along the mid-Atlantic Ridge (MAR) provides a new methodology for understanding the temporal history of fluid flow and faulting in slow spreading mid-ocean ridges.

Serpentinized mantle peridotite is commonly exposed on the seafloor at or near ridge segment ends in slow-spreading environments. Atlantis Massif, located at the ridge–transform intersection at 30°N on the MAR, forms a domal exposure of gabbro, diabase and peridotite denuded to the sea floor along a detachment fault system. Peridotite exposed to seawater, due to cracking along the detachment fault system, reacts strongly through exothermic chemical reactions to form hydrated mineral species and magnetite, and produce warm, alkaline fluids rich in hydrogen and methane. Circulation of the fluids drives hydrothermal systems with focused venting from brucite/aragonite chimneys like those in the Lost City vent system found atop the massif. Focused or diffuse hydrothermal systems may also allow mobilization and concentration of less mobile elements including Zr, U, Th, La, Nd, Ce, and Ti.

Here we report hydrothermal zircon with a wide range of U (7 - 2827 ppm) and Th (4 – 4003 ppm) concentrations, in addition to apatite, monazite, and xenotime porphyroblasts from *in situ* meta-peridotite collected from Atlantis Massif. The host rocks for these trace minerals comprise tremolite, talc, serpentine, chlorite, magnetite and chromite. We present high-resolution Pb/U SHRIMP zircon ages that permit the absolute dating of fluid flow events and serpentinization associated with fracturing of mantle peridotite denuded to the seafloor. These ages range from 0.68±0.21 to 1.69±0.05 Ma in a transect normal to the ridge axis.

Multi-stage evolution of the orthogneiss from Baizhangyan, North Dabie, China

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Orthogneiss is a wildspread rock type in Dabie ultrahigh-pressure (UHP) orogen. Previous dating results suggested that the orthogneiss in North Dabie Complex (NDC) experienced multi-stage metamorphism. The protolith was formed in about 700 to 800 Ma; and then experienced the UHP meta-morphism when the Yangtze craton was subducted under the North China craton at Triassic. During the large-scale Cretaceous thermal event, the isotopic systems of the orthogneiss were reset, showing similar ages to intrusions. The above age information was derived from isotopic dating of gneisses from several localities, and its interpretation is therefore ambigous. For example, some authors explained the Cretaceous ages as the formation time of gneisses in NDC.

In this work we used SHRIMP technique to examine zircons from a single orthogneiss sample from Baizhangyan, NDC, and obtained an evidence of multi-stage evolution of this orthogneiss. BSE images of zircons from this gneiss reveal four different domains: the dark gray and metamict domains are generally cores, whereas the grayish and white domains are inner and outer rims. The total of 32 spots were measured in the four domains. Seven measurements in the dark gray domain give weighted mean $^{206}Pb/^{238}U$ age ($t_{^{206}Pb/^{238}U}$) of 729±42 Ma, with Th/U ratios of 0.37 to 1.4, and low U and Th concntration of 35 - 138 ppm, and 19 - 121 ppm, respectively. Four spots in the grayish domain give $t_{^{206}Pb/^{238}U}$ = 215±21 Ma, Th/U ratio = 0.013 to 0.028, [U] = 1047 - 1699 ppm, [Th] = 22 - 32 ppm. Seven spots in the white domain give $t_{^{206}Pb/^{238}U}$ = 127±10 Ma, Th/U ratio = 0.012 to 0.035, [U] = 322 - 5203 ppm, [Th] = 4 - 184 ppm.

The rock clearly experienced a multi-stage evolution history. Th/U ratios higher than 0.4 in the dark gray domains suggest a magmatic origin. The date for the dark gray domain therefore represents the time of the protolith formation. The grayish and white domains give Th/U ratios within the range of fluid-precipitated zircons (lower than 0.1), so the ages obtained from the rims represent the timing of a later thermal event involving fluids. The grayish domains are formed during exhumation of the UHP slabs at Triassic, whereas the white domains were produced by the thermal event at Early Cretaceous.

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The geochemical characteristics during mylonitization in Tan-Lu fault belt, East China

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Introduction

The area for this study is in the joint part of Tan-Lu fault belt with the East Qinling-Dabie orogenic belt in east part of China (Mattauer et al., 1985; Yang et al., 1998). In this study the author chose ductile shear zones for chemical and isotope compositions from the mylonites and wall rock gneiss in order to characterize the relationship of deformation and fluid-rock interaction during mylonitization.

Results

The mylonites are enriched by factors of 1.32-1.87 in elements such as TiO_2, P_2O_5, MnO, Y, Zr and V and depleted in SiO_2, Na_2O, K_2O, Al_2O_3, Sr, Rb and light REE compared to their protolith gneiss. The immobile element enrichments are attributed to enrichments in residual phases such as ilmentite, zircon, apatite and epidote in mylonites and are interpreted as due to volume losses from 15-60% in ductile shear zone. Modeling calculated results of the ratio of the fluids to rocks flowed through the ductile shear zone ranges from 196 to 1192 by assuming different degree of fluid saturation. With the increasing differential flow stress, the mylonites show the increase of $\delta^{18}O$ in quartz, K-feldspar and fluid.

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References

Mattauer M., Matte Ph., Malavielle J., Tappomier P., Aluski, Xu Z., Liu Y. and Tang Y., (1985), *Nature*, **317**, 496-500.

Yang X.Y. Yang X.-M., Liu D., Wang K. and Dai J., (1998), *Acta Geophysica Sinica*, **41(sup)**,123-132(In Chinese with English abstr).

Detrital mineral thermochronology in active fluvial systems and the evolution of modern orogenic landscapes

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In order to explore the relationship between tectonics and climate in active orogenic systems, it is important to establish short-term erosional histories. At present, some of the most powerful tools available for such studies are the $^{40}Ar/^{39}Ar$, (U-Th)/He, and fission-track cooling ages that can be obtained for detrital minerals in stream channels and young river terraces. The $^{40}Ar/^{39}Ar$ method is well-suited to such studies; the micas (particularly muscovite) are relatively resistant to grain-size comminution and alteration during erosion and transport and yield information pertaining to the cooling of source regions through the ~375-325˚C temperature range. Modern laser microprobe systems permit the routine determination of 100 single-grain $^{40}Ar/^{39}Ar$ dates – enough for statistically significant characterization of the age population in most detrital samples – in 24-36 hours. Himalayan case studies will be presented to show how such data may be used to model both catchment-wide and regional erosion rates, and to monitor the kinematics of recent deformation.

Unlike most $^{40}Ar/^{39}Ar$ thermochronometers, the (U-Th)/He and fission-track thermochronometers – zircon, monazite, xenotime, titanite, and apatite – have closure temperature ranges (~225-65˚C) sufficintly low that that the geometry of their closure isotherms mimic surface topography in rapidly eroding orogens. As a consequence, these low-temperature thermochronometers can be extremely valuable indicators of changes in the landscape during orogenesis. Unfortunately, most detrital fission-track and (U-Th)/He studies involve analytical protocols that are much more time consuming than those used for laser microprobe $^{40}Ar/^{39}Ar$ studies. As a consequence, generating a sufficient number of single-grains dates to achieve a representative sampling of the total population in a detrital sample is a major undertaking. For (U-Th)/He work, laser microprobe technologies offer great promise for improving sample throughput. Early applications of this emerging tool will be reviewed at the presentation.

UV-laser ablation $^{40}Ar/^{39}Ar$ geochronology of tectonic processes

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One way that $^{40}Ar/^{39}Ar$ geochronology can be applied to understand better the temporal evolution of tectonic processes of both local and regional scale is through the identification and *in situ* dating of K-bearing mineral growth ages. In some cases, documenting mineral growth is relatively straightforward such as during near-surface pseudotachylyte formation. For example, pseudotachylyte associated with exhumation of UHP rocks in the Dora Maira massif, Italy, contain microcrystallites of K-feldspar and biotite neocrystallized from the frictional melt generated during a seismogenic event. *In situ* ultraviolet (UV) laser ablation $^{40}Ar/^{39}Ar$ geochronology of the pseudotachylyte yields an age of 20.1 ± 0.5 Ma for this event, consistent with field observations and other geochronological data. Geological examples of tectonic processes from deeper levels in the crust yield geochronological results reflecting longer, and sometimes divisable, time scales. Muscovite fish in greenschist facies extensional mylonites in southern Norway show textural, compositional, and $^{40}Ar/^{39}Ar$ evidence for distinct growth histories. UV-laser $^{40}Ar/^{39}Ar$ ablation ages of muscovite cores interpreted to have formed during high-grade metamorphism record $^{40}Ar/^{39}Ar$ cooling ages approximately 10 to 12 m.y. older than compositionally distinct muscovite overgrowths. The muscovite overgrowth ages are interpreted to record a subsequent regional extensional event. Even deeper levels within the crust can yield meaningful $^{40}Ar/^{39}Ar$ growth histories. Phengitic white mica from blueschist and eclogitic rocks from the Greek island of Syros, have subtle and irregular compositional zoning barely resolvable with X-ray mapping. Such compositional variations are interpreted to reflect the response of white mica to changes in external changes in pressure, temperature, and fluid conditions. *In situ* UV laser ablation $^{40}Ar/^{39}Ar$ geochronology of individual white micas reveals a distribution of ages not only consistent with the observed compositional variations but also spanning a time range that is interpreted to record mica growth during blueschist and eclogite metamorphism *including* the period of subduction. While such an interpretation is predicated upon the assumption that these mica ages record mineral growth and not cooling, additional geochronological data from other systems including Lu-Hf support such an interpretation.

Growth and rate of deformation of an accretionary thrust wedge, western Lachlan Orogen

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Quantifying deformation rates or orogenic strain rates has been more challenging than determining the timing of discrete geological events in ancient orogens. It is possible to determine strain rates across the low-grade (~280-350˚C), external parts of orogens by $^{40}Ar/^{39}Ar$ dating metamorphic white mica from cleavage bands in slates and phyllites lacking detrital muscovite, and from syntectonic quartz veins. White mica closes to argon loss at 350˚±50˚C so that at low greenschist and prehnite-pumpellyite facies, grow occurs at or below the closure temperatures, and apparent ages reflect the timing of growth. In polydeformed zones this requires some early metamorphic mica to be preserved in low-strain domains through episodes of transposition cycling. Timing of mica growth combined with measured finite strains and/or palinspastic restorations can be used to estimate time-averaged strain and displacement rates. Dating mica growth in the basal decollement gives the rate of fault propagation, and dating micas defining cleavage growth gives the rate of fold propagation. Deformation of a turbidite dominated, accretionary-style thrust wedge in the western Lachlan Orogen occurred by chevron folding and faulting over an eastward propagating decollement. Based on $^{40}Ar/^{39}Ar$ dates of white micas, this deformation started at ~455 Ma in the western part and ended at ~385 Ma in the eastern part, with distinct "pulses" of deformation at about 440, 420 and 390 Ma. These data suggest a time-averaged decollement propagation rate on the order of 10 mm/yr or a strain rate of 10^{-14} to 10^{-15} s^{-1} at the orogen scale. The rates were probably higher than average during the deformation pluses. At the scale of two individual thrust sheets in the western Lachlan $^{40}Ar/^{39}Ar$ dating of micas from (1) bedding-parallel cleavage and veins, (2) sub-vertical cleavage and folded viens, (3) and cross-cutting veins on late thrust faults, defines the duration of tectonic shortening as it evolved from open folding, to chevron fold lock-up, finally to thrusting over 10-15 million years.

Continental-scale tectonics: Zircon He-FT-Pb triple-dating of modern river sediment

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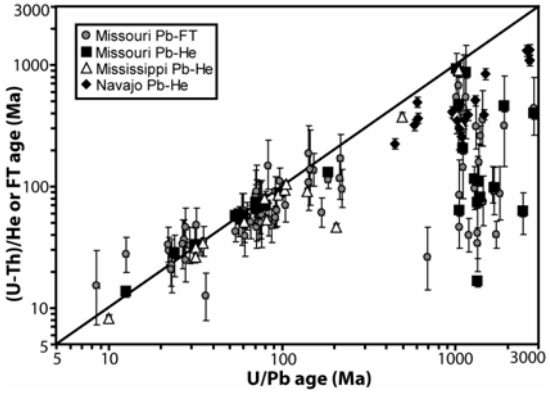
U/Pb, fission-track, and (U-Th)/He systems provide independent formation and cooling ages on single zircons. We measured He-FT-Pb triple-dates on single detrital zircons from modern sediment in the Mississippi and Missouri rivers, to interpret Precambrian through Recent tectonic and volcanic histories of a large region of North America.



Combined formation-cooling age distributions in these rivers show distinct populations corresponding to different magmatic and exhumation events. About 85% of U/Pb ages fall within 25-35 Ma (~10%), 55-100 Ma (~25%), 140-220 (10%), 1.0-1.1 Ga (~20%), and 1.3-1.8 Ga (~20%), with pronounced magmatic age gaps at 35-55 Ma, 100-140 Ma, and 0.2-1.0 Ga. Nearly all zircons younger than 100 Ma are first-cycle volcanic, with indistinguishable He and Pb ages. Most Grenville zircons have Appalachian cooling ages, reflecting continental-scale disperal of Appalachian detritus. Most 1.3-1.8 Ga zircons have 17-150 Ma cooling ages, reflecting Cordilleran exhumation. Some 1.0-1.1 Ga zircons have nearly identical (~0.9-1.0 Ga) cooling ages, which may represent dispersed Grenvillian volcanics or other ancient eroded sources. Abundant volcanic zircons younger than 100 Ma reflect the strong magmatic character of the Cordilleran orogen, whereas abundant cooling ages coupled with a near absence of formation ages between 0.2 and 0.6 Ga reflect the weak magmatic but strong exhumational signature of the fundamentally tectonically different Appalachian orogen.

Laser microprobe (U-Th)/He thermochronometry of monazite

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Monazite, with it's high U and Th contents (up to a few wt.%), is an excellent candidate for high-precision low-temperature thermochronometry on the young rocks found in orogenic systems such as the Himalayas. However, strong parent-element zonation common in natural monazites, in combination with their typically small size (<100μm) would likely result in large, poorly constrained recoil corrections. In addition, preliminary diffusion data suggests closure temperature (T_c) variations in excess of 50C°, possibly due to variations in composition (Farley and Stockli, unpublished, and our data, to be presented here). These issues combine to make conventional furnace or laser-heating ages difficult to interpret. An alternative is excimer laser-ablation (U-Th)/He chronometry (ExLA-He), which enables all of the above problems to be minimized or avoided completely.

We present the first ExLA-He of monazite from the Nanga Parbat massif, Pakistan. Our preliminary data demonstrate the excellent reproducibility of ExLA-He, with 5 individual laser dates from one monazite crystal yielding a mean closure age of 1.020 Ma ± 0.044, (<5% at 2σ), while another yields an apparent age of 0.413 Ma ± 0.011 (<3% at 2σ, N=2). As would be expected, these ages are younger than 0.6-1.5 Ma U-Pb ID-TIMS ages for the same samples (Crowley et al., this volume), and are also consistent with existing apatite fission track data (e.g. Zeitler et. al, 1985, summary in Treloar et al., 2000).

Using existing diffusion data for He in monazite, the spatially variable T_c corresponding to the individual ExLA-He dates range from ~100 C° to ~250 C°. The wide range in modeled exhumation rates that would be derived from this data is in large part due to the uncertainty in T_c for these specific samples, emphasizing the need for more detailed diffusion studies, as well as chemical characterization of individual grains used for (U-Th)/He chronometry. Step-heating experiments in progress will further constrain the closure temperature for these specific monazite crystals, thereby providing more precise exhumation rate constraints.

As methodological refinement continues, ExLA-He of monazite should prove to be a useful chronometric tool for leucogranites and other appropriate lithologies.

Evidence for underestimation of long-term FT annealing in apatite from natural FT and (U-Th)/He data

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Apatite Fission Track (AFT) data from cratons have commonly been interpreted in terms of major episodes of sedimentary burial and subsequent denudation, often in the absence of any remaining sedimentary sequences or other supporting geological evidence. Reconciling these interpretations with geologically documented episodes of denudation or outcropping regional stratigraphy can be problematic. Also, repeatable apatite (U-Th)/He ages from cratonic igneous rocks that are older than paired AFT ages are commonly discarded as 'too old.' For example, AFT data from Finland and central Sweden have been interpreted to reflect, first, burial by a Caledonian foreland basin several kilometres in thickness and, subsequently, its denudation. However, there is no supporting geological evidence that such a deep, extensive foreland basin ever existed in this area and indeed some geological evidence points to the contrary. Repeatable apatite (U-Th)/He ages from this area are in many cases older than their AFT pairs but have been interpreted by their authors as 'too old' relative to the AFT ages and not geologically meaningful. Additionally, extreme local variation between AFT ages exists, which cannot be attributed to variations in apatite chemistry or structural offset.

We demonstrate that AFT data from Finland and central Sweden are largely a function of the apatite uranium content. Studies related to nuclear waste disposal have shown radiation-enhanced lattice repair (α-annealing) is dominant over thermal annealing at sub-APAZ temperatures. Increased uranium content enhances lattice repair, and thus may be expected to reduce AFT ages and MTLs. Existing annealing models would compensate by predicting excess *thermal* annealing, which would be conventionally interpreted as a heating-cooling cycle. Thus we suggest that 1) AFT ages in cratons are 'too young' rather than that the (U-Th)/He ages are 'too old'; 2) repeatable sequences of (U-Th)/He ages are more likely to record the true denudation history of cratons, and 3) interpretations of cratonic AFT data based on conventional FT annealing models significantly overestimate sedimentary burial and subsequent denudation. Where apatite uranium concentrations are sufficiently high, young AFT data are potentially also compromised.

Constraining denudation in Scotland by using a combination of low temperature thermochronometers

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Mantle plumes may influence patterns of denudation of the crust underneath which they impinge. In Scotland the offshore record indicates that sedimentation was enhanced in several pulses at around 60 Ma. The correspondence of these pulses with volcanic activity related to the ancenstral Icelandic plume has been taken to indicate that erosion and hence sedimentation in the Palaeogene was dominated by the mantle plume activity.

Here we present new apatite fission track and (U-Th)/He data from two vertical profiles and one about 1300 m deep borehole from the Scottish Highlands and the outer Hebrides. Both apatite (U-Th)/He and fission track ages from the vertical profiles are at least 30 Myr older than the Tertiary magmatic activity. We have combined the two thermochronometers in a novel way that provides a precise estimates of the palaeotemperatures experienced by the samples at the time of the plume activity. Exploiting the fact that the samples lie on vertical profiles we are able to constrain the palaeogeothermal gradient and, thus, to calculate the amount of denudation since the Tertiary. Also by modelling apatite fission track and (U-Th)/He together we have constrained timing, amount and rates of denudation in Scotland through time. We conclude that the Scottish Highlands have experienced a period of rapid denudation between 80 and 40 Ma during which between 1.3 and 1.8 km of crust were removed.

The low temperature thermochronological data do not show a Neogene rapid denudational event, suggested by geomorphological and sedimentological records in other areas of the North Atlantic. We conclude that either northern Britain was not affected by this event, or its magnitude was not enough (less than 1 km) to affect the fission track and/or the (U-Th)/He systematic.

Timing of accelerated glacial denudation constrained by $^4He/^3He$ thermochronometry

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The thermal structure of the uppermost few kilometers beneath the surface responds to major changes in the topographic relief of mountain ranges. A record of this thermal structure through time permits testing of tectonic and geomorphic hypotheses, and quantification of rates of topographic evolution. $^4He/^3He$ thermochronometry of apatite constrains the set of possible time-temperature (*t-T*) histories that individual samples experienced between ~80°C and ~20°C. Unlike conventional "(U-Th)/He age-elevation" relationships, the *t-T* paths do not depend on the He ages or relative positions of other samples; each sample provides independent information on its own thermal history. By combining the *t-T* paths of multiple samples (e.g., along a vertical or horizontal transect), the evolving subsurface thermal structure is revealed. For instance, a vertically stacked set of *t-T* paths reveals the near-surface geothermal gradient through time. Likewise, major changes in the thermal field should be recorded in proximate samples.

We present the application of this approach to test a hypothesis recently proposed by Ehlers et al. (*Nature* in review) on the southern Coast Mountains in British Columbia, Canada. Using conventional (U-Th)/He ages and a thermal-kinematic model, they concluded that 1.0 to 2.2 km of exhumation occurred along the western flank of present day Mt. Waddington sometime since ~7.5 Ma. Our results independently corroborate their hypothesis and constrain the onset of accelerated denudation at the present location of the Klinaklina river valley to have initiated at ~1.8 ± 0.2 Ma. At least 2 km must have been removed from that location at a rate of > 5 mm/yr. The timing of this accelerated denudation correlates with enhanced Pleistocene glaciation in the region.

Using thermochrometry to image topographic evolution in the Northern Apennines, Italy

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Shallow isotherm surfaces tend to follow the overlying surface topography, with the degree of smoothing increasing with depth. The closure isotherms for (U-Th)/He and fission-track (FT) apatite are shallow enough (< ~3 km) that they are strongly affected by surface topography. Thus, these cooling ages should provide information about the surface topography at the time of closure. We exploit this concept here using a dense suite of (U-Th)/He and fission-track apatite ages from the northern Apennines, and numerical inverse methods that allow estimation of the evolution of surface topography from the cooling ages.

Stratigraphic evidence indicates that the Apennines emerged above sea level at ~5 Ma. Our expectation was that topography and relief would have increased over the last 5 m.y., reaching the maximum elevations observed today of ~2500 m. Age-elevation relationships show a linear increase in age with elevation at the local scale. However, at the regional scale, the cooling ages are inversely correlated with elevation. This relationship is diagnostic of a *decrease* in relief with time. We have analyzed both the FT and He apatites ages using a finite-element routine (PECUBE) and also a fourier-based routine. The best-fit solution was found by numerical search. We find that the relief of the range has decreased since emergence, by a factor of 2 or 3 starting at ~8 Ma. This result makes sense given that the Apennines started at ~30 Ma as a large submarine subduction wedge. The large relief before 8 Ma reflects the large submarine relief of the wedge at that time and the relatively constant sea floor tempetures in the Mediterranean (~14 C). This wedge was reduced in size when it emerged as it overrode the passive margin of the Adriatic platform.

Geodynamic implications of rapid denudation of the granitoids at about 50 and 20 Ma in the Eastern Pontides, Turkey: Apatite fission-track results

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The Cretaceous to Recent geological evolution of the Turkish eastern Pontides has been governed by the fate of two "Neo-Tethyan" ocean basins. The northern branch of the "Neo-Tethys" was bounded by the Eurasian plate (EP) in the north and the Tauride-Anatolide platform (TAP) in the south, and the southern branch was limited by the TAP in the north and by the Arabian plate (AP) in the south. In the eastern Pontides, the northern "Neo-Tethyan" convergence between the EP and TAP seems to have been responsible for the widespread Cretaceous to late Palaeocene extensional arc magmatism, the late Palaeocene to early Eocene denudation-accompanied, post-collisional magmatism, and the middle to late Eocene within-plate extensional magmatism. The closure of southern "Neo-Tethys" was followed by Oligo-Miocene intra-continental convergence that maintained regional shortening and crustal thickening in the eastern part of Turkey, from the eastern Pontides in the north to the BZS in the south. This ongoing convergence between the EP and AP has also governed the neotectonics of Turkey. The apatite fission-track age versus elevation profile of the Dereli-Sebinkarahisar granitoids, in the eastern central Pontides reveals rapid (>1 mm a^{-1}) denudation between 48 and 57 Ma, which is interpreted as a result of the late Palaeocene-early Eocene collision between the EP and TAP along the IAES zone. The age versus elevation profiles along a N-S transect from the Black Sea coast to the Coruh river valley through the composite Kackar batholith in the eastern Pontides indicate tectonic exhumation between 17 and 23 Ma at rate of 0.4 – 0.5 mm a^{-1}. This episode is interpreted as related to the Oligo-Miocene collision between the EP and AP.

Subduction times of oceanic crust along the Jinshajiang suture zone, Tibetan plateau, SW China

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Introduction

The central part of the Tibetan Plateau is consists of the Kunlun Terrane, Bayanhar Terrane, Qiantang Terrane and Lhasa Terrane . The Jinshajiang suture zone lies between the Bayanhar Terrane and the Qiantang Terrane. For a long time, the subduction times of oceanic crust along the Jinshajiang suture zone have been disputed. We try to give a times limit for the subduction of oceanic crust by dating of the ophiolite, IAG and CCG type granite using Ar-Ar and SHRIMP U-Pb isotope geochronological methods.

Results, Discussion and Conclusions

In the Jinshajiang suture zone, it lasted only a span of 9 Ma from the start of subduction (marked by the eruption of andesitic magmas and intrusion of intermediate rock of IAG type at about 227 Ma) to the end of subduction, consumption of oceanic crusts and the collision of terranes (marked by the fast cooling of intermediate-acid rocks at about 218 Ma). This implies that either the oceanic crusts between the Qiangtang and Bayan Har terranes were small sized, or they subducted at a very fast speed along the Jinshajiang suture zone. It also explains why there were isotope chronological records in the intrusive rocks of the Kunlun terrane for such large tectonic events like collisions between the Lhasa and Qiangtang terranes and between the Himalayas and Lhasa terranes, and why very few evident chronological records were left in it for the collision between the Qiangtang and Bayan Har terranes along the Jinshajiang suture zone. Because the collisions between these three terranes took place almost simultaneously or even overlapped at a time, chronological information on the collisions in the Jinshajiang suture zone became blurred or indistinct.

Acknowledgements

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Ar-Ar dating for greenschist-facies metavolcanics in the Dabie orogen: Implication for the accretionary wedge of continental subduction

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It has hotly been debated whether sporadic low-grade metamorphic rocks in the interior of UHP metamorphic zones experienced the same history of subduction to mantle depths. Greenschist-facies metavolcanic and metasedimentary rocks were discovered to occur within UHP eclogite-facies zone in the Dabie orogen of east-central China, with the dyke-like intrusion of coesite-bearing eclogite. The metavolcanic rocks are mainly interbedded with metaconglomerate, sericite phylite, sericite-feldspar-quartz schist and silty slate. The occurrence of dyke-like coesite-bearing eclogite within the metavolcaniclastics resulted in the controversial conclusion that the eclogite and host metavolcanics shared the same UHP metamorphic history. This is in conflict with the fine-grain nature of metavolcanics. Whole-rock Ar-Ar dating for these low-grade rocks may provide a resolution.

Two metavolcanic samples were selected from ash-bearing metasilicate layers at Ganghe in the Dabie terrane. Ar-Ar isotope data on sample GH-1 yield a reasonable isochron with an age of 785.0±4.7 Ma (MSWD = 0.37) and an initial $^{40}Ar/^{36}Ar$ ratio of 280.2±31.7. The main plateau is composed of 5 to 10 steps with 91.86% of total released ^{39}Ar, corresponding to a plateau age of 783.3±0.9 Ma. The other sample (BX-1) yields an Ar-Ar isochron age of 769.5±3.1 Ma (MSWD = 0.57) with an initial $^{40}Ar/^{36}Ar$ ratio of 308.9±16.7. The main plateau is composed of 3 to 10 steps with 97.36% of total released ^{39}Ar and corresponds to a plateau age of 771.0±0.6 Ma. Because of the low closure temperature of Ar diffusion in silicates, these mid-Neoproterozoic ages indicate that in the process of the Triassic continental subduction, the low-grade metamorphic rocks did not suffer the high-grade metamorphism under UHP eclogite-facies conditions, so that the Ar isotopic system was not disturbed since the volcanic eruption at the mid-Neoproterozoic. Therefore, the volcanic rocks were scraped off from the upper part of subducting Yangtze Block by obduction of the North China Block, and suffered only the greenschist-facies dynamic metamorphism. They essentially correspond to the accretionary wedge of continental subduction.

Ar-Ar chronology study of the Qiugemingtashi-Huangshan ductile shear zone, Xinjiang, NW China

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The Qiugemingtashi-Huangshan ductile shear zone, situated in the middle Tianshan orogenic belt, Xinjiang, NW China, is believed to be the product of the subduction and collision of the two plates in the north and south of the East Tianshan during the late Paleozoic. It is the important part of the orogenic belt and also an important metallogenic belt, containing copper, nickel and gold deposit. According to the involved ductile deformed strata and Rb-Sr and K-Ar dating results, the shear zone age is inferred to be the late Carboniferous to the early Permian by the former researcher. Obviously, this is too extensive and we need further study. We use $^{40}Ar/^{39}Ar$ method, which is the most suitable method to date the shear deformation age, to date the Qiugemingtashi-Huangshan ductile shear zone and define the age of the early nappe shearing and the late strike-slip shear deformation.

Ar-Ar isotope chronology study reveals that the activity of Qiugemingtashi-Huangshan ductile shear zone show different time in the different area of the shear zone. In the early, the shear zone show nappe shearing and its upper limit on the age is 280Ma. In the late, it shows strike-slip shear deformation. In the Kanggur, situated in the middle-western shear zone, the $^{40}Ar/^{39}Ar$ age of the mylonites is mainly ~260Ma while in the southern Tuwu, situated in its east, the $^{40}Ar/^{39}Ar$ age of the mylonites is mainly 240-250Ma. Because the metal deposits of the East Tianshan are mostly located in this shear zone, the above results not only deepen the study on the tectonic history of the East Tianshan but also provide new age evidence for the further understanding the controlling of the shear deformation on the mineralization.

Acknowledgements

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Laser-ablation ICP-MS zonation-dependent α-ejection correction of zircons in (U-Th)/He chronometry

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We use LA-ICP-MS depth profiling of standards and zoned zircon samples together with a new LabVIEW-based numerical model to examine whether U-Th zonation is responsible for overdispersion and age bias observed in some (U-Th)/He data sets. Our model uses integration over 3-D matrix with isotropic grid spacing to determine zonation-dependent bulk retentivty, F_{ZAC}, as the relative-α-productivity-weighted average of local α-retentivity values. Integration occurs over three spatial dimensions and all relevant α-producing isotopes. Modeling of bipyramidal prisms with synthetic, geologically realistic zonation demonstrates that crystal morphology and zonation can conspire to create >30% α-ejection-corrected age bias when homogeneity and simplified geometries are assumed *a priori*.

In practice, our approach uses laser-ablation ICP-MS depth profiling on whole, unmodified zircons in grain-mount. Internal fragments of Sri Lankan detrital zircons are used as external concentration standards, and to monitor depth-dependent Th/Zr and U/Zr fractionation. Fractionation-corrected data for unknowns are used in the zonation-dependent bulk retentivity model to populate 3-D α-productivity matrices assuming self-similar crystal growth.

Results from two analytical systems are compared: 1) New-Wave 193 nm excimer laser– Element2 magnetic sector ICP-MS (Yale); and 2) Merchantek 213 nm Nd:YAG laser – VG PQ ExCell quadropole ICP-MS (BU). Reproducibility of unbiased ages from un-zoned Fish Canyon Tuff zircon standards with multiple depth profiles indicate that helium is not quantitatively lost from the remaining volume during laser ablation. This method can be used to pre-screen candidate aliquots to identify homogeneous grains, or to calculate customized F_{ZAC} α-ejection corrections for zoned grains. A demonstrably un-zoned Tardree Rhyolite zircon produces a homogeneous α-ejection corrected age of 59.7 ± 4.8 (2σ) Ma in agreement with the accepted emplacement age of 58.4 ± 0.7 Ma, whereas the F_{ZAC} α-ejection correction for a Tardree zircon with a factor of ~40 U-depleted rim, yields an F_{ZAC}-corrected age of 57.8 ± 4.6 Ma (2σ) compared with a F_T-corrected age of 64.5 Ma assuming U-Th homogeneity.

Shear deformation ages of the Xianshuihe fault zone in SE Tibetan plateau

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The NWW-SEE striking Xianshuihe fault zone slices the southeastern Tibetan plateau and connects southeastward with the Anninghe-Zemuhe-Xiaojiang fault zone, they together forming a huge, active sinistral strike-slip fault zon.The total late Cenozoic left-lateral offset along the Xianshuihe fault is estimated to 100~78 km. However, the onset of these offset accumulations and cooling ages for left-lateral shear of the Xianshuihe fault has been poorly studied. Based on field geological survey, structural measurements and classical $^{40}Ar/^{39}Ar$ dating techenique, we obtain cooling ages for Miocene left-lateral shear along the Xianshuihe fault zone.

$^{40}Ar/^{39}Ar$ stepwise heating dating of mica, biotite and K-feldspar from both the shear zones and undeformed granites show a complex cooling history. Two cooling events can be identified. The early event occurred at 12~10 Ma and corresponds to emplacement and rapid cooling from 700°C to near 350°C of the Zheduoshan granitic massif. The late event took place at 5.5~3.5 Ma with emplacement of fine grained granites along the megmatite zone.

This study confirms that emplacement and rapid cooling of the Zheduoshan granitic massif and left-lateral shear along the Xianshuihe fault zone were synchronous. Moreover, structural and thermochronology data reveal a late shear event occurred at 5.5~3.5 Ma, possibly synchronous with emplacement and cooling of fine grained granites along the eastern side of the Xianshuihe fault zone. One of the important conclusions we can drawn is that the eastward extrusion of the Chuan-Dian Block started at 16~12 Ma and occurred episodically.

Acknowledgements

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Provenance of the Middle Jurassic strata of the Tornquist Shear Zone in southern Sweden

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Aim and used provenance techniques

The aim of this study is to investigate the provenance of the Jurassic Glass Sand Member and the underlying Fuglunda Member of the Tornquist Shear Zone in the south-western parts of the Baltic shield and to compare the provenance of the two different strata. The provenance techniques used are SIMS U-Pb and Pb-Pb dating of single detrital zircon grains (Whitehouse et al., 1999) and Ar-Ar dating of detrital muscovite grains. Chemical zoning and inclusion patterns in garnet, rutile and other heavy minerals, and trace element data, are also considered as these may give important information on the metamorphic source terrain.

Discussions of preliminary results

Preliminary SIMS U-Pb and Pb-Pb dating of detrital zircon grains shows trends of provenance of a western source, such as the Sveconorwegian Orogen. The preliminary results also show a difference in provenance between the two studied members of the informal Mariedal Formation (Ahlberg et al., 2003). Rutile is present in all samples while garnet is only found in the Glass Sand Member.

References

Ahlberg A., Sivhed U. and Erlström M., (2003) *The Jurassic of Denmark and Greenland.* pp. 527-541.

Whitehouse M.J., Kamber B.S and Moorbath S., (1999), *Chemical Geology*, 160 (3), 201-224.

U-Pb zircon and Sm-Nd data for rocks of the Murmansk domain (Kola Peninsula, NE Baltic Shield)

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The Murmansk domain is located in the eastern part of the Kola Peninsula (NE Baltic Shield) and consists mainly of plagiogranitoids and plagiomicrocline granites. Plagiogranites contain a plenty of xenoliths of amphibolites, amphibole-biotite gneisses, diorites, and two-pyroxene schist which are considered to be xenoliths of the basic rocks in primary - crust granitites or relicts of more ancient magic basement, altered by granitization or a product of structural - metamorphic reorganization of the uniform stratified complex of primary - crust granitoids. To understand a geological history of this structure we need careful geological study with the modern geochronological data for the subsequent opportunity of correlation of the Murmansk domain with similar Archaean structures of the Kola Peninsula, the Canadian Shield and Greenland. New geochronological results (U-Pb zircon and T(DM) Sm-Nd) are obtained for some rock complexes spatially placed in the eastern part of the Murmansk domain. U-Pb zircon age for biotite gneisses is 2724 +/-7 Ma; T (DM) Sm-Nd is 3068 Ma. The age of zircon from xenolith of amphibolites is determined as 2739 +/-7 Ma, T (DM) Sm-Nd is 2638 Ma. Plagiogranites from different parts of the investigated territory gave U-Pb ages 2771 +/-10 Ma and 2748 +/-7 Ma, T (DM) Sm-Nd - 2936 Ma and T (DM) Sm-Nd - 2868 Ma, respectively. For diorites U-Pb zircon age is obtained - 2717 +/-7 Ma, T (DM) Sm-Nd - 2862 Ma. The given data testify to the Late Archaean time of formation of the investigated rocks of the Murmansk domain with ages, limited by an interval of 2.7-2.8 Ga. The work is supported by scientific school N 2305.2003.5.

Combined (U-Th)/He and U-Pb thermochronometry of rift-flank exhumation in east-central Africa

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A thermochronologic study combining U-Pb and (U-Th)/He analysis of apatite and zircon was conducted up the eastern slope of the Rwenzori Massif in Uganda to characterize the timing and rate of rift-flank exhumation related to continental rifting in east-central Africa. Rising more than 4 km above the adjacent Albertine Rift Basin floor, the Rwenzori represent an extreme example of basement rift-flank uplift, a phenomenon common throughout the East African Rift System and characteristic of continental rift systems in general. New thermochronologic work coupled with field and remote sensing observations makes the case for recent and non-steady state uplift of the massif. U-Pb apatite results indicate that, prior to Neogene rifting, the rocks of the Rwenzori experienced a protracted history of slow cooling without major tectono-thermal perturbation since at least the Paleoproterozoic (>1550Ma). Comparably old (U-Th)/He zircon and apatite (>400Ma, >70Ma respectively) ages reflect a transient lag period before sufficient exhumation has occured to remove the inherited pre-rift thermal structure. This non-steady state condition of rapid uplift outpacing erosion has resulted in preservation of relict landsurfaces, truncated spurs, hanging valleys, vast stranded bogs and uplifted river terraces at high elevation. Given the typical continental geothermal gradient prior to rifting implied by U-Pb thermochronology, no more than 2km of erosion could have accompanied uplift on the order of 5km in the Rwenzori region. This requires a minimum average uplift rate of 1.6km/Myr based on biostratigraphic evidence suggesting the range rose from beneath local baselevel within the last 2.5Ma. Regardless of the active rock uplift rate of the Rwenzori, net exhumation can not yet have exceeded the depth of the (U-Th)/He closure isotherm in apatite (~2km). These results highlight the danger of modeling young orogenic systems using the simplifying assumption of topographic steady state.

Lu-Hf geochronology of eclogites from Pfulwe, Zermatt-Saas ophiolite, western Alps, Switzerland

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Major-element zoning patterns in garnets from eclogite-facies metabasalts of the Zermatt-Saas ophiolite complex, western Alps, record large segments of the prograde P-T-t path to HP/UHP conditions. Ca, Fe, Mg, and Mn contents in garnet from core to rim are indicative of prograde growth zoning. Core to rim trace element analyses and 3-D imaging of garnet by laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) and x-ray tomography indicates strong HREE (Er, Yb, Lu) zoning, where the highest concentrations occur in the garnet core. Lu zoning is typically characterized by a very sharp, narrow spike in concentration (50 to 170 ppm) in the garnet core flanked by concentration values of 10 to 20 ppm that decrease toward the rim. Zr, and by proxy Hf, concentrations are typically constant across garnet traverses.

Lu and Hf garnet zoning patterns have important implications for Lu-Hf geochronology because they indicate that the Lu/Hf ratios are highest in the garnet core, though we note that the very highest values are in a very small volume of the garnet (1-2%). Therefore, if bulk garnet separates are used for geochronology, the measured Lu-Hf ages are strongly skewed toward the early prograde growth because the majority of the Lu is within the first 30% (by volume) of grown garnet.

Five ages from samples collected along the trail to the Pfulwe pass and from the famous Pfulwe pillow locality (near Zermatt, Switzerland) range from 46.5 to 54.5 Ma, as determined by MC-ICP-MS. These Lu-Hf ages, which overlap within error, reflect early garnet growth during subduction and prograde metamorphism, not the peak P-T conditions. Sm-Nd ages obtained on the same samples are very imprecise or undeterminable due to the presence of LREE inclusions in garnet. The relative insensitivity of Lu/Hf ratios to common LREE rich inclusions in eclogitic garnet highlights one advantage of Lu-Hf geochronology over Sm-Nd.

Grenville-age metamorphism on the western margin of Laurentia, northern Idaho: Evidence from Lu-Hf garnet geochronology

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Lu-Hf geochronology of garnet-bearing amphibolite facies rocks in northern Idaho reveal a complex multistage metamorphic history. We determined Lu-Hf ages on amphibolite and pelitic schists from the Clearwater complex of northern Idaho and on a pelitic schist more proximal to the Cretaceous Idaho batholith. The core and rim of the garnet amphibolite have Lu-Hf ages of 1149±4 and 118±4 Ma, respectively. Very high Lu/Hf ratios in the garnet core ($^{176}Lu/^{177}Hf$ up to 17.83) result in extraordinary present day $^{176}Hf/^{177}Hf$ ratios as high as 0.688932 (ε_{Hf} = +13,656). Grenville ages of 1056±57 and 1006±5 Ma are recorded in the pelitic schists samples. In contrast, the pelitic schist near the Idaho batholith yields a well-defined age of 89.6±2.6 Ma.

The ~1.1 Ga metamorphic ages combined with polyphase penetrative structures observed in metamorphic tectonites and metasedimentary rocks north of the Idaho batholith strongly suggest that Grenville-age tectonism in the northwestern U.S. Cordillera was widespread and reflects a period of Proterozoic crustal thickening prior to or during the assembly of Rodinia. Thus Early and Middle Proterozoic basins of western Laurentia may record deposition and contraction in an intracontinental setting or may have developed during a history of both passive margin and convergent margin tectonism. The younger Lu-Hf ages are consistent with widely observed evidence for Cretaceous metamorphism in the region.

The presence of domains within a single garnet that record ages differing by over a billion years clearly supports a complex tectonic history for these rocks. This juxtaposition of ages demonstrates the potential of the Lu-Hf isotope system in garnets to see through younger metamorphic overprints and resolve an earlier metamorphic history. Taken together with regional structural analysis, this work illustrates the utility of the Lu-Hf system in dating complex, polymetamorphic histories associated with regional deformation.

Tectonic basement of South China

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Our researches on pre-Mesozoic rocks of South China suggest that a Precambrian continental block had ever occurred in the Wuyishan-Wugongshan-Nanling-Yunkaidashan region according to middle-high grade metamorphic rock assemblages, structural deformational styles and newer data of isotopic ages. This oldland, with the oldest isotopic age of 2100 Ma, named the Cathaysian Oldland, is characterized by large scale of schist, gneiss and migmatic rocks dated at 1800Ma to 1200 Ma, which consist of a continental crustal basement. About 1100−900Ma, the Cathaysian Oldland collided with the Yangzi continental plate to form the Shaoxing-Jiangshan-Dongxiang-Pingxiang Suturing Zone. Not long time, about 800 Ma, the Cathaysian Oldland was dispersed into three blocks with different striking and distinct outline, that is, the NEE striking southeastern Zhejiang-northwestern Fujian block, the sub-N-S-striking central Jiangxi-southern Jiangxi block and the NE striking Yunkaidashan block, respectively. The Sinian-Early Paleozoic sedimentary materials with a large thickness were filled among these three blocks, which, together with three blocks,. consist the tectonic basement of Late Mesozoic (mainly Cretaceous) volcanic-intrusive complexes. Study proposes that this Old-land had subjected to three phase tectonic-thermal events at least, that is, Luliang event (1800−1600Mha), Jinning event (1100−900Ma) and Caledonian event (420−400Ma). The tectonothermal event during Silurian-Middle Devonian time is a strong compressure-thinckening work to form the South China Caledonian folding-orogenic belt marked by numerous granitic bodies, folded greenschist facies metamorphic and mylonitic rocks. This ancient tectonic framework constrains large scale of Mesozoic tectonic-magmatism, difference of magmatic compositions and distributrion.

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Apatite fission track and (U-Th)/He thermochronometers contraints on the development of two high elevation passive margins

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Apatite fission track (AFT) and (U-Th)/He thermochronometers are used to constrain continental rifting and escarpment development of the high elevation Eritrean and south-eastern Australian passive margins.

AFT and (U-Th)/He data have been determined from four coast perpendicular traverses. Along both margins the He and AFT ages at the present coast broadly correspond to the time of sea-floor spreading and they increase approaching the foot of the escarpments. On the plateau, He and fission track ages are much older than breakup time and the track length distributions indicate that denudation has been slow and constant since at least mid-Mesozoic times.

The combination of AFT ages, track length distributions and He ages indicates that both margins were rapidly eroded by in-situ excavation of a pre-existing plateau rather than parallel escarpment retreat. A comparison of the measured He ages from the coastal plain with He ages predicted by a forward model indicates that the main phase of denudation in the Eritrean margin started at around 15 Ma, closer to the initiation of seafloor spreading in the Red Sea than previously thought. In the south-eastern Australian case, the forward modelling suggests that denudation was enhanced at 120 Ma, some 35 Myr before sea-floor spreading, in agreement with the hypothesis that magma-poor margins evolve more slowly than magmatic ones.

The comparison of the Eritrean and eastern Australian margins indicate that they evolved in much the same way, despite differences in climate, lithology and modes of rifting. This study suggests that the primary control on syn-rift denudation is exherted by the topography.

Petrogenesis of Mesozoic strongly peraluminous granites in South China: Implication for tectonic domains transform

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Geological background

The number of strongly peraluminous granites (SPGs) is more than 1/3 of total number of all granite bodies in South China. All SPGs from South China bear strongly peraluminous minerals such as muscovite, Al-rich biotite, tourmaline, garnet. 13 representative granite bodies are studied though petrography, geochemistry, Sr-Nd isotope and zircon U-Pb isotopic dating.

Results and discussions

The results show that these granites formed in two stages: late Indosinian (228.0~207.6 Ma, ~T_3) and early Yanshanian (173.0~155.4 Ma, ~J_{2-3}). These SPGs have low CaO/Na_2O ratio and $\varepsilon_{Nd}(t)$ (-11.9~-8.9) values, high Al_2O_3 value and Rb/Ba, Rb/Sr ratios, and high $TE_{1,3}$ (1.13~1.34) of REE tetrad effect and $Nd(t)_{DM}$ values of 1.9 Ga~1.7 Ga,. The geochemistry of high aluminous minerals show that these SPGs were crystallized from primary peraluminous magmas. We suggest that these Mesozoic SPGs were generated though partial melting of early Proterozoic pelitic metamorphic rocks.

Conclusions

Indosinian SPGs were formed under post-collision extensional tectonic setting which was constrained by Tethyan Tectonic Domain. Whereas the early Yanshanian SPGs were formed under back-arc extensional tectonic setting which was controlled by Pacific Tectonic Domain. Therefore, the transform of Tethyan to Pacific Tectonic Domains happened during early Jurassic in South China.

Reference

Barbarin B., (1996), Geology 24, 295-298.
Chappell B.W., (1999), Lithos 46, 535-551.
Carter A., Rogues D., Bristar C., King P., (2001), Geology 29, 211-214.
Sylvester P.J., (1998). Lithos 45, 29-44.
Zhou X.M., Li W.X., (2000), Tectonophysics 326, 269-287.

SHRIMP zircon U-Pb dating for impure marbles in the Jiaobei terrane of east-central China: Implication for its tectonic affinity

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The application of carbonate Pb-Pb and U-Pb dating has contributed a lot to timing of limestone deposition or marble metamorphism. However, difficulties were encountered in obtaining reasonable isochrons because the U-Pb isotopic system of carbonate rocks is prone to disturb by diagenesis or retrograde alteration. As a result, the carbonate U-Pb or Pb-Pb ages sometimes do not provide a definite dating with the geological meaning. SIMS zircon U-Pb dating coupled with CL imaging is proven to be a successful way to date the impure marble for its ages of both protolith deposition and metamorphism. This is illustrated for impure marbles from the western part of Shangdong Pennisula (i.e. the Jiaobei terrane) in east-central China.

SHRIMP zircon U-Pb dating and CL imaging for two samples of impure marble from the Fenzishan Group in the Jiaobei terrane yield consistent ages of 786±67 Ma and 240±44 Ma for igneous and metamorphic zircons, respectively. Both detrital and metamorphic zircons are identified in the samples of interest. Oxygen isotope fractionation between calcite and garnet from one sample gave a temperature of 680ºC, pointing to upper amphibolite-facies metamorphic conditions. Positive $\delta^{13}C$ values as high as +5.6‰ are measured for both pure and impure marbles, consistent not only with the worldwide Neoproterozoic limestones in connection with the global glaciation, but also with the marbles associated with UHP metamorphic eclogites in the Dabie orogen. These results indicate that protolith of the marbles is a kind of limestone that was synchronously deposited with volcaniclastic rocks in the mid-Neoproterozoic rift basin of continental margin. Like the UHP metamorphic rocks in the Dabie-Sulu orogenic belt, both mid-Neoproterozoic magmatism and Triassic metamorphism occurred in the hotly debated region. Therefore, the Jiaobei terrane belongs to the South China Block, corresponding to the seaward flank of rift shoulders during the mid-Neoproterozoic rift magmatism along the continental edge of the South China Block.

Tectonothermal evolution of Olkhonskaya collision system: Constraints from $^{40}Ar/^{39}Ar$ data on granite veins sealed inside ultramafic bodies

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A mobility of K/Ar system depends on deformations and presence of fluids. When a rock is protected from access of deformations and fluids micas can retain radiogenic argon during superimposed metamorphic events. Such protection can often be observed inside rigid bodies of magmatic origin. We present results of $^{40}Ar/^{39}Ar$ dating of granitic veins which are sealed inside ultramafic-mafic massifs of the Olkhonskaya collision system. Metamorphic framing of massifs was also investigated.

Phflogopite of granitic vein sealed inside dunite body (Shidinskaya zone of Olkhonsky region) yielded $^{40}Ar/^{39}Ar$ age of 497.1±1.2 Ma. It is concordant with U/Pb zircon data on age of metamorphism of granulite facies [Bibikova et al., 1990; Letnikov et al., 1990; Gladkochub, 2004; Khromyh et al., 2004]. At the same time biotites from metamorphic framing of dunite bodies yielded age of 432 Ma. Thus metamorphic event characterized by intense strike slip deformations and amphibolitic PT-conditions is shown to be noticeably (about 70 Ma) distant from granulitic metamorphic stage. It is remarkable that K/Ar of phlogopite of granite vein sealed inside dunite body preserved information about the age of early granulitic stage. Using numerical modeling of phlogopite K/Ar system behavior essential constraints on duration of late metamorphic event have been obtained. If we assume that volume diffusion mechanism promoted argon loss, digital modeling results show that duration of event should be noticeably shorter than 1 Ma. This limitation should be taken into account in regional tectonic reconstructions.

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$^{40}Ar/^{39}Ar$ cooling ages from a vertical transect through the Patagonian batholith 46° S, Chile

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Mesozoic-Cenozoic granitoids of the North Patagonian Batholith in southern Chile have been key to understanding magmatism associated with subduction processes and tectonic uplift of the Southern Andes. Although Rb-Sr and Sm-Nd and fission track (FT) results have revealed the origin and timing of emplacement of several intrusions, and the denudation history of the Andes, thermochronology of the ~ 500–200°C history of this mountain range has not been explored. To better resolve the cooling history, particularly prior to the closure of zircon and apatite fission-track chronometers, we performed $^{40}Ar/^{39}Ar$ incremental heating analyses, using a defocused CO_2 laser beam, on amphibole, biotite, plagioclase and K-feldspar from granodioritic/ tonalitic plutons exposed on the south flank of 1924 m high Cerro Blanco, north of Lago General Carrera at 46° S. Six rocks were collected every 200 m along a vertical transect of 1.2 km through the intrusions between 200 and 1300 masl.

Concordant spectra from 1-3 crystal aliquots (1-2 mg) yield plateau ages as follows: (1) orthoclase correlates with elevation; ages at 410 and 1345 masl are 76 and 82 Ma, respectively, (2) biotite varies from 149 to 152 Ma and amphibole from 144 to 160 Ma; there is no correlation with the elevation. Discordant saddle-shaped spectra are common for plagiclase, and to a lesser degree, amphibole.

We interpret these plateau ages as the result of cooling following the intrusion. Age variations among individual biotite and horblende crystals in each sample are ascribed to disturbances imposed by the growth of minor secondary mineral phases and sub-solidus modifications during cooling. Using a simple linear T-t path and widely adopted closure temperatures for these minerals, the calculated cooling rate prior to 82 Ma was ~2-3°/myr, but this increased to ~4-5°/myr between 76 and 82 Ma. Combining with Rb-Sr ages (<160 Ma) indicates an early history of rapid cooling, followed by remarkably slow cooling for ~80 myr. Orthoclase ages overlap regional zircon FT closure between 73 and 96 Ma and predate apatite FT closure by up to ~70 myr, suggesting an average cooling rate of ~1°/myr from the Late Cretaceous to Miocene. Structural and tectonic evidence, however, led Thomson et al. (2001, *Tectonics*) to propose a non-monotonic cooling path that can only be fully evaluated via further vertically-controlled thermochronology in the #150° C range.

Radiometric dating for the timescale of UHP metamorphism in the Dabie orogen of China

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The peak age and duration of UHP metamorphism are very important issues with respect to geodynamic interpretation of continental collision. Triassic ages for UHP metamorphism in the Dabie-Sulu orogen have generally been accepted, but the exact timing of UHP event is still in controversy between Late Triassic and Early-Middle Triassic. While eclogite mineral O isotope studies suggest a short duration of 5 to 10 Ma for the peak UHP event, peridotite mineral Sr-O isotope studies indicate that a bulk recycling on the order of 12 to 26 Ma for continental subduction, UHP metamorphism at mantle depths and exhumation. A resolution to these necessitates comprehensive investigations concerning not only a combined study of zircon growth history and U-Pb dating but also a correct understanding of O, Pb, Sr and Nd diffusivity in radiometrically dated minerals during prograde and retrograde metamorphic processes. This study of zircon U-Pb, mineral Sm-Nd and Rb-Sr dating for low-T/UHP eclogite at Huangzhen has provided insight into these aspects.

The SHRIMP zircon U-Pb dating yielded two groups of age at 242±3 Ma and 222±4 Ma, respectively. In combination with petrologic study, these ages are interpreted to date zircon growth and overgrowth in the two episodes of dehydration, respectively, in response to decomposition of water-bearing minerals such as glaucophane, epidote and paragonite during deep subduction and lawsonite breakdown during initial exhumation. The mineral Sm-Nd and Rb-Sr isochron dates gave the concordant ages of Middle Triassic at 236.1±4.2 Ma and 230±7 Ma, respectively. O isotope equilibria were achieved and preserved between the isochron minerals, providing a test of Nd and Sr isotopic equilibria in them. Although the closure temperatures of O diffusion may not simply correspond to those of Sr or Nd diffusion in eclogite minerals formed at different P-T conditions, Sr and Nd isotopic equilibria are evident from the consistent ages. Thus the timescale of bulk continental subduction and exhumation in the HP-UHP-HP regimes may range from ca. 245~240 Ma to 225~220 Ma, on the order of 10 to 15 Ma, for the peak UHP event. The termination age of peak UHP metamorphism is probably different in different slices of deep-subducted slab in the Dabie-Sulu orogen.

The geochemistry and implications of clastic sedimentary rocks of the Baiyun-Zhashui subunit from the South Qinling orogenic belt

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The trace element, REE and Sm–Nd analyses of Middle and Late Devonian metasedimentary rocks from the Baiyun-Zhashui subunit along the Jinqian River section (South Qinling, China) in conjunction with previously published data are used to trace the crustal evolution. The εNd(t) values of the Middle Devonian are within the range of the metasediments from Qinling complex. In contrast, Late Devonian samples are above the ranges of the Qinling complex, being higher in Cr/Th ratios and lower in Th/Sc ratios. It allows us to speculate that samples from Late Devonian Formations were derived from the arc materials from the Erlangping Formation, north of the Qinling terrain. It is indicated that there is a significant provenance change between the Late Devonian and Middle Devonian clastic sediments in the Baiyun-Zhashui subunit. A further modeling using immobile elements Th, Co and REE were also made to calculate proportions of the DTT gneiss, mafic volcanic, granite as 3 possible source components, it shown that the Devonian metasediments from the Baiyun-Zhashui subunit are mainly the first-cycle erosion products of the 60% metasediments of the Qinling complex in the North Qinling. plus 30% of Early Paleozoic granites and 10% volcanics.

We propose that the South Qinling as the passive margin of the Yangtze Craton had been in a close proximity and accreted to the North China at least in the Middle Devonian times.

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Mesozoic-Cenozoic exhumation history of North Tianshan, Northwest China: Constrains from fission track analysis

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Fission track methods are used to examine at the exhumation history of North Tianshan, Northwest China.

Fifteen apatite samples and five zircon samples from volcanic rocks in Bogda mountains and granites in Harlik mountains were analysed. The apatite ages range from 109.3±6.1Ma to 11.9±4.1Ma and the zircon ages are within the range 81.7±7.8～56.8±5.1Ma. Results of calculation by paired-minerals indicate that the apparent exhumation rates range from 0.157km/Ma to 0.222km/Ma during the Late Cretaceous to Middle Cenozoic in above area. The thermal history modeled result shows four periods of exhumation in Bogda-Harlik mountains occurred in Early Cretaceous (119~105Ma), late Late Cretaceous (67~65Ma), Early-Middle Cenozoic (47~31Ma) and Late Cenozoic (12~7Ma) since Cretaceous.

Three apatite samples of Yandong pluton in Jueluotage mountains were analysed. The apatite fission track ages are within the range 94.7~87.4Ma which reveal that the uplift was initiated at least in Late Cretaceous. There is good relationship between the current altitude and the sample age, namely ages begin to increase with increasing elevation. The average uplift rate of 0.039km/Ma is calculated by extrapolation. Considering the uplift rate, the exhumation in Jueluotage mountains can be extremely slow since the Mesozoic.

Nine apatite samples are taken from Lianmuqin section in the central part of Turpan-Hami Basin and from both south and north piedmonts. Ages of seven Jurassic samples are distinctly younger than the depositional age, whereas ages of two Cretaceous samples are similar to or older than the depositional age. This indicates that annealing of the Jurassic samples is total or partial, whereas annealing of the Cretaceous samples is minimal. The thermal history modeled result shows that the samples experienced rapid tectonic uplift and cooling/exhumation during Late Cretaceous (120~100Ma) and were buried and heated up again during the Cenozoic, finally exhumed to the surface from 10 to 8Ma.

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