Forward modeling of P-T-deformation paths of regional metamorphic rocks at convergent plate boundaries

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Regional metamorphic belts and rocks are thought to be products of remarkable geological events, such as collision and subduction of plates at convergent plate boundaries. Therefore, it is possible to extract the events and processes from the regional metamorphic rocks. Analysis of P-T(-time) paths of the rocks is one of the main approaches of metamorphic petrology, in order to understand ultimately the evolution of the Earth's crust (e.g., Spear, 1995). Regional and structural geology also provide fundamental information on flow and deformation of the crust, especially the forearc region of the arc and continent (e.g., Platt, 1986). In spite of accumulation of the information on physico-chemical conditions recorded in the metamorphic rocks, the corresponding global field to produce such conditions has been poorly constrained at present. In this paper, we will discuss forward modeling of such global field.

Results of modeling on the temperature field and the flow field of metamorphism and deformation of a forearc region (e.g., Iwamori, 2000; 2003) suggest that (1) high-P type metamorphism, together with high-T type, requires a high-T condition compared to the average thermal structure of forearc region in subduction zone, when both heat and water are supplied to the forearc region associated with ridge subduction, supporting "paired metamorphism" (Miyashiro, 1961), (2) a 3-D corner flow in a forearc wedge can account for observed deformation recorded in Cretaceous regional metamorphic belts in SW Japan, suggesting that a large-scale viscous flow and deformation of the forearc region occurred associated with the metamorphism. These results suggest that the P-T paths and deformation should be strongly coupled, hence combined analyses of P-T paths and deformation will provide tight constraints on the global temperature and flow field.

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Pressure and temperature controls on slab-derived fluid chemistry

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The composition of slab-derived fluid in a subduction zone is determined by the residual mineral assemblage following pressure-induced dehydration reactions in the subducted oceanic crust. The residual mineral assemblage, in turn, is determined by the trajectory of the slab through pressure-temperature space as it descends into the mantle. Recent experimental studies of phase equilibria in subducted oceanic crust have shown that the presence of zoisite in the residual slab following amphibole breakdown is strongly dependent on temperature (Forneris and Holloway 2003). We have combined new mineral-fluid trace element partitioning data for zoisite and mica with existing data for garnet, cpx, and rutile to generate bulk eclogite-fluid trace element partition coefficients for both zoisite-bearing (cold) and zoisite-free (hot) assemblages. We find that fluids in equilibrium with zoisite-bearing slabs are strongly depleted in Sr and Pb, and to a lesser extent Ba, Th, and U relative to fluids in equilibrium with zoisite free slabs. Rare earth and high field strength elements in the fluid are not affected by zoisite in the slab.

The cold and hot slab-derived fluids are numerically combined with sediment melts and added to the mantle, which is susequently melted 10-20% to generate arc basalt. We find that model arc besalts generated from cold slab-derived fluids have Sr concentrations of about half what is observed in natural arc basalts. Therefore, either most subducting slabs are at temperatures outside the range of zoisite stability beneath the volcanic front, or there is an additional Sr input to arc basalts not accounted for in our model. Our results help constrain thermal conditions beneath subduction zones and the processes responsible for determining arc basalt geochemistry.

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Fluid or melt? Constraining the slab component of arc magmas using high-pressure hydrothermal experiments on subducted sediment

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A series of novel hydrothermal piston-cylinder experiments have been performed to determine the composition of representative fluids and fluid/melt/rock interaction in subduction zones. Experiments were conducted under H_2O saturated conditions at 2.2 GPa over a temperature range from 600-750 ºC. The experiments contained synthetic, trace-element-doped pelitic starting material and fractured quartz chips to trap and preserve synthetic fluid/melt inclusions. Pelite residues from the subsolidus experiments (600-650 ºC) consist of a stable mineral assemblage of quartz, phengite, epidote, rutile, garnet, apatite, and zircon. Analysis and quantification of trapped fluid inclusions from these experiments indicate that subsolidus hydrous fluids released from subducted sediments are relatively dilute. The wet solidus for the pelitic starting material is located at 675 ºC (±10 ºC) at 2.2 GPa. At temperatures above the wet solidus, fluid and melt coexist as immiscible phases at least up to 750 ºC, indicating that the second critical end-point for pelitic rocks is located above 2.5 GPa at around 700 ºC. Residue phases in the supersolidus experiments (700-750 ºC) are garnet, rutile, and zircon, which suggest that HREE and HFSE are retained in slab residues, even under conditions of very-high degrees of melting. Nonetheless, Nb is fractionated from Ta during slab melting and dehydration, leading to a high Nb/Ta flux from the slab into the mantle wedge.

The experimental results are used to show that subducting sedimentary rocks do not undergo significant element loss during metamorphic dehydration. Furthermore, the trace-element contents of subsolidus fluids in subduction zones are too low to significantly contribute to arc magmas, regardless of the volume of fluid considered. Instead, sediment-derived melts can completely account for the slab component of arc magmas, which implies that slab surface temperature must be 700 ºC or higher at sub-arc depths.

^{238}U-^{206}Pb geochronology of eclogite-facies metamorphism, Monte Rosa massif, Western Alps, Italy

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High precision ^{238}U-^{206}Pb geochronology of rutile from Qt+Carb+Rt+white mica veins in eclogite boudins and schist and gneiss within the Monte Rosa massif near the Indren glacier, Val di Gressoney, Western Alps, Italy, indicate that eclogite-facies metamorphism may have lasted from 49 to 38 Ma, which is contemporaneous with eclogite-facies metamorphism in the structurally overlying Zermatt-Saas ophiolite. The veins in eclogite are usually oriented at high angles to the long axis of the boudins and are likely synchronous with boudinage of more coherent tracts of metabasite. The veins in eclogite cross-cut eclogite facies minerals with little or no associated retrogression, suggesting that vein formation occurred under eclogite-facies conditions. Veins near the boudin necks typically contain inclusions of surrounding schist and gneiss, texturally linking them with the eclogite boudins. The age data indicate that the emplacement of the veins, likely associated with fluid pulses, represents a possible age range of eclogite facies conditions of the metabasic boudins as well as the schist and gneiss. Rutile-clinozoisite pairs from assemblages within eclogite-facies metagabbro boudins unfortunately have insufficient spread in $^{206}Pb/^{204}Pb$ to yield meaningful ages, likely reflecting the low U/Pb ratios of the basic protoliths.

Near the terminus of the eastern Lys glacier, upper Val di Gressoney (~6 km west of the Indren glacier), metabasic boudins typically contain greenschist-facies minerals with locally preserved eclogite-facies assemblages. Tension veins in these metabasic boudins are texturally similar to those near the Indren glacier but are typically composed of Qt+ Carb+Ttn+Amp+white mica. U-Pb data from Ttn-Carb and Ttn-Amp pairs from two samples ~10 m apart yield $^{206}Pb/^{204}Pb$ ratios within error of each other, indicating that the fluid that deposited the veins, presumably after eclogite-facies metamorphism, had a very low U/Pb ratio. The initial $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios of these veins suggest local variability in the Pb isotope composition of vein producing fluids, perhaps indicating that the fluids were derived from sources proximal to the veins.

Does fluid-induced eclogitization of slab crust generate arc signatures?

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A suite of co-genetic gabbros and eclogites from central Zambia has been used to investigate fluid-induced transformation processes and associated trace element mobilization. These rocks are relics of subducted lower oceanic crust and gradual stages of the prograde gabbro-to-eclogite transformation are preserved by disequilibrium textures of incomplete reactions. No evidence for prograde blueschist- or amphibolite-facies mineral assemblages was found in the eclogites. Instead, fine-grained intergrowths of eclogite-facies minerals replacing plagioclase indicate the direct eclogitization of gabbroic precursors. Eclogitization occurred at 630-690°C and 2.6-2.8GPa and was accompanied by a channelized fluid flow which lead to vein formation. The aqueous fluids had variable salinities, ranging up to brine compositions. Based on textural and geochemical evidence, we hypothesize that these mafic rocks were subducted as a coherent slab, but gabbros were only eclogitized if they were infiltrated by fluid under eclogite-facies conditions. Hence, the eclogites and their veins represent relict fluid pathways through subducted oceanic crust, providing direct evidence of channelized fluid flow within a slab. The gabbros and eclogites have MORB-like trace element patterns and initial Nd and Hf isotope compositions. In some eclogites, however, the LREE have been strongly fractionated from the HFSE and HREE, an effect that cannot be of magmatic origin but must have occurred during metamorphism. Eclogitization was limited by fluid availability, and the fluid flow through the rock is the most likely mechanism for LREE fractionation. Model fluid-rock ratios suggest that the rocks depleted most in LREE reacted with an amount of fluid equal to 20-80% of their mass. The lower gabbroic part of the oceanic crust is an unlikely source for such a large volume of fluid and thus we hypothesize that the fluid originated in the underlying serpentinised lithospheric mantle. If, after triggering eclogitization, the resulting LREE-rich, HFSE+HREE-poor slab fluid reaches the zone of partial melting in the mantle wedge, it may contribute significantly to the arc signature. We will evaluate whether the trace element mobilization during fluid-induced eclogitization could be generally responsible for producing the slab component in arc magmas.

Sr-Nd-Pb isotopic systematics of basaltic oceanic crust subducted into the subarc mantle

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Numerous geochemical models have been proposed to estimate the integrated trace element and isotopic compositions of a hypothetical slab-derived ‘component’ in arc and OIB lavas. However, contributions from individual sources are difficult to assess from lava compositions alone, because element fractionations during slab dehydration and mass fluxes from the various subducted ‘lithologies’ are poorly constrained. Therefore, an understanding of trace element and isotopic compositions of individual rock types subducted into the subarc mantle is indispensable for constraining the geochemical models for subduction-zone material recycling.

In this paper, we focus on eclogite xenoliths from the Colorado Plateau, interpreted as representing fragments of the subducted Farallon plate, in order to infer Sr, Nd and Pb isotopic compositions of oceanic crust subducted into the subarc mantle. Based on the mass balance calculations and mineralogical observations, the whole-rock chemistry of the xenoliths was contaminated by near-surface processes after eruption and limited interaction with the serpentinized ultramafic microbreccia host magma. Thus, Sr, Nd and Pb isotopic compositions of separated minerals from the xenoliths were measured to avoid these secondary effects; these separates yield distinctively enriched isotopic compositions in the range of 0.70502 to 0.70590 for $^{87}Sr/^{86}Sr$, -1.5 to -3.1 for εNd and 18.928 to 19.052 for $^{206}Pb/^{204}Pb$. This suggests that the xenoliths were metasomatized by a fluid equilibrated with the sedimentary layer probably covering the Farallon plate in the forearc region. This metasomatism resulted in the xenoliths acquiring distinctively enriched isotopic compositions compared with those of altered MORB.

Some of the distinct isotopic signatures observed in OIBs and arc lavas compared to those from MORBs have been interpreted as a result of oceanic sediment subducted deep into the mantle. Our results, on the contrary, suggest an alternative possibility that these anomalous isotopic reservoirs in the mantle are formed by the subduction of oceanic crust modified by the metamorphic fluid from the covering sedimentary rocks.

Mantle and crustal metasomatism of garnet-bearing peridotite in the Western Gneiss Region of the Norwegian Caledonides

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The trace element and isotope geochemistries, Re-Os model ages and Sm-Nd mineral ages of garnet-bearing orogenic peridotite bodies in the Western Gneiss Region, Norwegian Caledonides indicate an episode of mantle metasomatism and a later episode of crustal metasomatism re-fertilized dunite and harzburgite that had formed during a melting depletion event in the Archean. The early metasomatism occurred when melts passed through the sub-Baltic mantle. The oldest Sm-Nd mineral age determined (1.64 Ga) is a minimum age for recrystallization in the garnet stability field, which in turn is the minimum age for the transit of the melts. Contiguous peridotite and pyroxenite show parallel trace element patterns, enriched in LREE and some LIL elements and depleted in the HFSE, suggesting the melts metasomatized the host peridotite. Sr and Nd isotope ratios define show large variation in $^{143}Nd/^{144}Nd$ but very limited increase in depleted $^{87}Sr/^{86}Sr$ ratios as $^{143}Nd/^{144}Nd$ decreases. The second metasomatism occurred during the closure of Iapetus, (420-400 Ma) when the western edge of the Baltic Shield was subducted into the mantle and invaded by the peridotite bodies from the overlying mantle wedge. It was associated with the development of exsolved micro-assemblages including microdiamonds. Metasomatism was heterogeneous with depleted patterns persisting in some assemblages whereas others are enriched in LREE and some LILE, but not HFSE. The depleted assemblages display the Proterozoic isotopic patterns described above while the enriched assemblages show an increase to very high (>0.715) $^{87}Sr/^{86}Sr$ ratios. The patterns are consistent with metasomatism in the mantle wedge above subducting ocean crust or with metasomatism by fluids derived by dehydration reactions from the host crust.

Water content in eclogite from the ultrahigh-pressure terrane

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Water is introduced into the mantle by hydrated oceanic lithosphere at subduction zone, but most of hydrous minerals become unstable at high pressure and temperature. However, nominally anhydrous minerals can dissolve substantial amounts of hydroxyl as reported in mantle xenoliths (e.g., Bell and Rossman, 1992) and high-pressure experiments (e.g., Kohlstedt et al., 1996). In this study, we measured hydroxyl components of major constitute minerals of eclogites from the Kokchetav ultrahigh-pressure metamorphic terrane, using infrared spectroscopy and secondary ion mass spectrometry, and report how much water can be carried to the deep subduction zone.

The diamond-grade eclogite is mostly composed of omphacite and garnet with minor amounts of coesite and rutile, and yields P-T conditions of ca. 60 kbar and 1000°C. Infrared spectra reveals three hydroxyl absorption bands for the omphacite in the regions of 3440-3460 cm^{-1}, 3500-3530 cm^{-1} and 3600-3625 cm^{-1}, and ion micro-probe analysis yields 840 ppm H_2O (by weight). The garnet has a single peak at 3580-3630 cm^{-1}, and contain up to 120 ppm H_2O. The hydrogen concentrations of these minerals increase systematically with the metamorphic grade. Ca-Eskola component in the omphacite have a positive correlation with the OH content, which suggests that the M2 vacancy is most likely mechanism to incorporate hydroxyl in the omphacite. According to modal proportion of the rocks, the eclogites contain approximately 430 ppm H_2O at depths greater than 150 km. This indicates that subducting oceanic crust transports considerable amounts of water into the deep upper mantle beyond stability field of hydrous minerals. Such water may be stored in the deep mantle and have an important influence on dynamics in the Earth's interior.

Trench to subarc: Metamorphic chemical flux in subduction zones

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The compositional effects of subduction-zone metamorphism are not yet sufficiently understood for *quantitative* inclusion in models of subduction-zone chemical cycling. Further study of subduction-related metamorphic rocks is required to better reconcile seafloor sediment-crust inputs with subduction outputs (arcs, forearc fluids, serpentinite seamounts) and elucidate chemical contributions of subduction to the mantle beyond subarcs.

Prograde subduction P-T paths, related to subduction-zone thermal structure, dictate depths and extents of devolatilization and related element release. Most modern subduction zones are sufficiently cool to promote deep subduction of even relatively fluid-mobile components. Today, warmer subduction results in greater forearc release of fluid-mobile components, a pattern likely to have affected older-Earth efficiency of volatiles recycling into the mantle and thus long-term mantle-surface budgeting.

Integrated study of near-trench seafloor sediment sections and forearc metasediments subducted to 5-50 km indicates that chemical processing of sediment begins during early diagenesis and, for some elements (e.g., N, B, C, perhaps Cs, As, and Sb), can be profound at shallow levels in forearcs as pore fluids are mobilized and mineral reservoirs evolve. HP and UHP metasediments representing deeper subduction often show extreme exhumation-related overprinting of prograde assemblages and geochemistry. Compositions of HP and UHP metabasalts fall within the compositional range for altered oceanic crust, leading some to propose little or no element release and mobility during prograde metamorphism. However, uncertainty regarding protolith compositions could obscure element release and mobility that is significant when integrated over the large volumes of subducting oceanic crust. Yet unknown is the volumetric significance of mélange capable of impacting slab-mantle interface geochemistry.

Further work on texturally complex HP and UHP rocks must carefully distinguish between geochemical effects of prograde metamorphism and exhumation through use of microanalytical methods affording high spatial resolution. Hopefully, recently published consistencies between compositions of subduction outputs (notably, cross-arc trends) and geochemical records in subduction-zone metamorphic suites will drive more vigorous geochemical study of these important metamorphic lithologies.

On fluid and trace element mobility in eclogite-facies rocks

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Evidence for fluid mobility is omnipresent. Occurrence of high-pressure veins (qtz+omp±ky±phe±rt) are visible in most high pressure localities, documenting fracture-controlled fluid movement. Percolative fluid movement is also indicated by near-equilibrium trace element partitioning between minerals in a number of eclogite-facies rocks, at least on a thin section scale.

Trace element mobility on a meter to km scale is more difficult to prove in eclogite-facies rocks. The crucial point is that in environments with low fluid fluxes most trace elements are not mobile enough to be significantly depleted. Significant depletion can be defined as the depletion of a residuum remarkable beyond the expected scatter associated with the rock protolith composition. The clearest evidence is a general decrease in B concentration in metamorphic rocks with increasing grade (e.g., Moran et al. 1992).

With the exception of accretionary wedge environments, it should be recognized that fluid fluxes in high pressure rocks are mostly extremely low (e.g. blueschist-facies mafic rocks have only stored a few wt% H_2O). However, "trace element mobility" should not only be observed from a rock viewpoint, but also as a trace-element component in fluids. Simple mass balance calculations involving protolith concentrations, D(Min/Fluid) values and modal abundance of relevant minerals clearly demonstrate that trace element concentration of moderately mobile elements (e.g. Rb, Sr, Cs, Ba, Pb) can be 100x enriched in a fluid compared to primitive mantle values, while the residual rock has lost less than 10% of these elements. What is needed in the future are estimates of the trace element composition of high pressure fluids, either directly by measuring fluid inclusions in omphacite or indirectly by investigating minerals in the high pressure veins.

Contribution of oceanic gabbros to the N recycling in subduction zones

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Nitrogen content and isotopic composition together with major and trace element concentrations were determined in a sequence of metagabbros from the western Alps (Europe). These samples experienced (i) hydrothermal alteration on oceanic seafloor, followed by (ii) subduction to different depths (0 to ~70 km) along low geothermal gradient (~9°C/km) representative of a cold slab environment. A comparison of hydrothermally-altered metagabbros with their blueschist and eclogitic facies equivalent provides constraint on the evolution and behavior of N during progressive dehydration attending subduction zone metamorphism. Non-subducted and blueshists facies metagabbros are low-strain rocks from the Chenaillet massif and Queyras Valley, respectively. Eclogitic facies rocks include low-strain rocks, mylonites and veins collected in a major shear zones from the Monviso massif. Whole rock N content (between 2.6 and 28 ppm) and $\delta^{15}N$ (between +0.8 to +8.1 ‰) do not show any specific evolution with increasing metamorphic conditions. Low-strain rocks show a striking inverse linear correlation between Cu concentration and $\delta^{15}N$. It is argued that this correlation is most likely inherited from a pre-subduction stage such as magmatic differenciation or oceanic hydrothermalism. The preservation of this correlation implies that N remained in low-strain rocks during metamorphism although eclogitization was accompanied by ~90 % fluid loss. In contrast, Cu concentration estimates and $\delta^{15}N$ values obtained in veins and mylonites are not correlated. This indicates that dynamic re-crystallisation induced a release of N from the host rock to the fluid phase. Accordingly, deformation rather than metamorphism alone should be considered as a key factor for the preservation or loss of N in subducting metagabbros.

Metagabbros are a major component of the subducted oceanic crust. They represent mass flux of ~ 4×10^{16} g/yr (Peacock, 1990), being twice higher than basaltic crust flux. Considering the mean N content of mylonitic and low-strain metagabbros from this study (9.4 ± 7.0 ppm), the flux of subducted N associated with metagabbros is estimated at 3.8 (± 2.8) × 10^{11} g/yr. This value is half of the sedimentary N flux input in subduction zones, showing that gabbros may represent up to 30 % of the whole budget of recycled N.

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Partial dehydration of blueschist: Insights into the slab-wedge transfer

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The mafic high-pressure rocks of the Tianshan (NW China) display an interconnected network of eclogite-facies veins derived by prograde blueschist dehydration. They provide unique insights into fluid-rock interaction and element load during dehydration and long-distance fluid flow occurring during the major fluid release of subducting oceanic crust. The transition from blueschist- to eclogite-facies paragenesis is displayed as dehydration haloes around some veins. The vein-network consists of the dehydration veins – derived by dehydration of the immediate blueschist host– and veins which cross the blueschist host foliation and display sharp interfaces towards its wall rock. The latter ones show no evidence of dehydration reactions in the immediate blueschist host. In these cases the fluid source is regarded as being of external origin. These veins may represent high-pressure transport veins, thus potential channelways of fluid escape. This study focuses on such a transport-vein, its blueschist host and an eclogitized reaction zone (blueschist alteration zone), located in the central part of the vein. Textural evidence and the almost twice as high Li-concentration of the vein and the blueschist alteration zone in comparison to the blueschist host indicate the external origin of the vein forming fluid. This fluid triggered eclogitization and the associated devolatilization of the blueschist alteration zone. The low in trace element fluid caused a strong leaching of LILE, REE, and HFSE in those parts of the host rock with which the passing fluid reacted. The main difference between the blueschist host and the blueschist alteration zone is the replacement of glaucophane, dolomite and titanite by omphacite and rutile respectively, while garnet, rutile, phengite and clinozoisite occur in both parts of the rock. Therefore we regard the fluid-flow regime rather than the mineral assemblages and equilibrium partition coefficients as the main control of the trace element mobility. The mobilized trace elements reflecting those needed to create the ‘slab signature’ of arc magmas.

Interrelations between intermediate-depth earthquakes and fluid flow in subducting oceanic plates

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Hydrous fluid escape from the downgoing slab is widely believed to be the trigger that induces partial melting in the overlying mantle wedge, thereby producing the magmas erupted in arc volcanoes. Arc magmatism has a distinct chemical signature due to the addition of elements carried by initially hydrous slab-derived fluids. What is yet to be established are the mechanisms which are responsible for hydrous fluid flow from sources within the slab into the overlying wedge, and furthermore whether and how this fluid flow is linked to possible reactivation of normal faults and intermediate-depth earthquakes (70-300km). Two main but rival hypotheses have been proposed to explain intraslab seismicity; one, currently more in favor, suggests that high fluid pressures lead to dehydration embrittlement that triggers earthquakes, the other suggests that melt shear instabilities trigger seismic slip and may thereby produce permeabilities. Until now, testing these hypotheses has been restricted to theoretical investigations, lab experiments, and interpretations of seismic data. Unlike these more indirect approaches, we are able to directly investigate former slab rocks that experienced an earthquake during their burial in a subduction zone. We present so far unique field evidence indicating that intermediate-depth earthquakes produce frictional melts in subducting slabs and that the seismic failure was subsequently followed, not preceded, by infiltration of external fluid. We describe pseudotachylytes (quenched frictional melts) in eclogites from a fossil subduction slab in Zambia. Shortly after pseudotachylyte formation an external hydrous fluid infiltrated the rocks. Subsequent fluid flow leads to continuous vein formation during ongoing burial. The passing fluids mobilize those trace elements from the eclogites, which are characteristic of a 'hydrous slab component' in arc magmas. Since the fluids released by dehydrating slabs are believed to be the primary trigger for arc magmatism, we propose that intermediate-depth earthquakes have the potential to produce fluid-pathways within and out of the slab.

Mélange zones as a better source for the "slab" signature in arcs

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Common models for mass transfer from subducted slabs to arc sources generally hold that little modification of "slab" signatures occurs during transit into the mantle. However, developing data for metamorphic systems along the slab-mantle interface indicate that important mediation of fluid/melt chemistries occurs following their liberation from the slab and prior to their modification of arc mantle sources. Therefore, while "slab" signatures in arc volcanics certainly exist, it is questionable whether the last chemical reservoir equilibrated with these fluids/melts was actually the slab itself. One of the most likely sites for re-equilibration of the "slab" signature is within mélange zones formed along the slab-mantle interface.

The juxtaposition of the crustal lithologies of subducted slabs beneath the mantle wedge produces a dramatic contrast in chemical potentials for almost all elemental species, and these contrasts are resolved by a combination of mechanical and metasomatic mixing processes to form mélange. These hybridized rocks form a compositional gradient to chemically bridge the slab-mantle interface. Analytical data for exhumed tracts of mélange matrix from the Catalina Schist, CA, are remarkable in that they preserve the mixing processes and chemical gradients of the slab-mantle interface, but that pervasive fluid flow in mélange dominates some isotopic compositions. Sr and Nd isotopic data are heterogeneous in mélange and reflect a range in compositions expected for mixing between crustal and depleted mantle compositions. In contrast, Pb isotopic compositions for mélange are indistinguishable for a range of bulk compositions, are strongly radiogenic, and define an end-member composition that is predicted by a linear correlation of Pb data through modern arc volcanics from mantle compositions. Mélange B isotope data at a range of metamorphic temperatures agrees extremely well with models for B fractionation derived from arc volcanics, suggesting they are an ideal source for arc B. In summary, mélange isotopic compositions can explain numerous aspects of the "slab" signature observed from arcs, but are preferable to slab sources in that mélange integrates additional aspects of the physical and chemical processes occurring during subduction.

Geochemical structure of Pb isotopes in Tongbai-Dabie area

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Based on the Pb isotopic data of the core complex, ultrahigh-pressure (UHP) and high-pressure (HP) metamorphic rocks and associated foliated granites, the lower metamorphosed rocks from North Huaiyang tectonic belt, and Cretaceous granites in Tongbai-Dabie area, China, we have determined the Pb isotopic structure of the Tongbai-Dabie orogenic belt. The Pb isotopic map of the Tongbai-Dabie area shows that the Pb isotopic composition is similar within individual lithotectonic unit, but the Pb isotopic compositions of different lithotectonic units show systematic variations. The North Huaiyang tectonic belt contrasts strongly with the Tongbai-Dabie HP and UHP metamorphic belts in Pb isotopic compositions. It is suggested that the line along the Xiaotian-Mozitan fault, the north limit of the Tongbai-Dabie UHP and HP metamorphic belt, represents an important tectonic boundary and possibly marks the suture of Triassic deep continental subduction

Within the Tongbai-Dabie area, the vertical variation of Pb isotopic compositions in different units and the spatial relationship among different major lithotectonic units has been constrained. The tectonic stacking of units within the Tongbai-Dabie UHP-HP metamorphic belt has been established according to the vertical variation of the Pb isotopic compositions in different units.