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Anatomy of Mélange Zones in Tectonic Accretion Channels: Relation to the Mixing Zones Predicted by Numerical Models

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Model predictions of the scale and degree of tectonic mixing need to be compared to pertinent observations from exhumed orogenic units. We report on examples from the Central Alps and Cyclades.

Predicted mixing

Recent thermomechanical models of convergent margins predict a spatially extensive *mixing zone* to evolve along the margin of a continental (upper) plate and a subducting plate. Such scenarios have been simulated by Gerya et al. (2002), Pysklywec et al. (2002), and Vanderhaeghe et al. (2002), among others. Some of these numerical models suggest a tectonic intermingling of lower crustal rocks from the upper plate with fragments of previously subducted (oceanic) crust and hydrated upper mantle slices formerly situated above the subducting plate. Mechanisms in the proposed mixing zone are expected to govern the rapid exhumation (and thus likely preservation) of (U)HP fragments.

Evidence in mÈlange zones

Qualitatively, these predictions show certain similarities with the characteristics of mÈlange units present in the tectonic accretion channel (TAC) in the Central Alps. TAC properties documented there and in other collisional orogens include:

(a) eclogite and other HP-lenses of variable sizes occur confined to the TAC-mÈlange,

(b) TAC-units show fragments of extraordinarily variable petrographic composition,

(c) supracrustal rock types predominate, hence TAC-units are highly radiogenic (>2 μW/m^3),

(d) high-strain patterns and mylonites are ubiquitous in the TAC, with foliations around the HP-fragments being stringently parallel.

A late-orogenic metamorphic overprint of the mÈlange units is common, thus many of the early (U)HP characteristics were obliterated under Barrovian conditions, which vary in grade (up to migmatite).

Critical observations

We are characterizing (at μm- to km-scales) several TAC-related mÈlange zones in the Central Alps and Cyclades. Our aims are to identify relevant mechanisms of fragmentation, to recognize the types of deformation, and to document the extent of mixing in mÈlange units. A particular focus is on the geometric relations of HP fragments (size, shape, spacing), on their petrogenetic record, internal strain, and extent of geochemical interaction with a variety of *matrix types*. These host rock types for HP-fragments include quartz-feldspar gneiss (granitic or tonalitic), mica schist, silicate marble, mafic gneiss (blueschist or amphibolite), and serpentinite. Mafic or ultramafic fragments occurring as boudins and lenses typically preserve their HP-record, even in mÈlange zones that experienced a strong Barrovian overprint. Where the latter was weak (e.g. on Syros, Cyclades) angular to ovoid eclogite fragments, cm- to m-sized, are but faintly overprinted in supracrustal matrix types, except where hydrous fluids retrograded them marginally. The size and shape parameters of fragments tend to be fairly uniform within one mesoscopic mÈlange band, but they can be substantially different in adjacent layers. PT-paths documented for several HP-fragments in the Central Alps vary strongly, even within one and the same mÈlange unit, indicating substantial relative mobility of these fragments prior to their exhumation as part of a coherent TAC sheet.

Mixing is evident at scales from mm to km. At mesoscopic scale, most *mÈlange bands* (deci- to a few dekameters thick) are basically binary mixtures, few of them are ternary, i.e. one or two petrographic types of fragments occur in one type of matrix. In many areas, extended *mÈlange slices* ($\sim$40 to 350 m thick, up to several km long) of a fairly uniform spectrum of mÈlange bands can be recognized; in the Central Alps these have traditionally been mapped as *ìzonesî* (e.g. the Mergoscia-Arbedo Zone which hosts the HP-fragments of Alpe Arami). The spacing and relative position of adjacent mÈlange zones varies: some of them occur isolated, strung out as trails, which partially separate complex crystalline nappes (within which HP-relics are missing); others form stacks of mÈlange-slices and build up a coherent thrust sheet (e.g. the Adula ìnappeî) which has experienced multistage deformation as a unit.

Within the TAC, ductile lithotypes (i.e. quartz- or phyllosilicate-rich varieties, impure marbles) typically show sheet-like shapes (length/width $\sim$10 to $>$100); amphibolite and silica-poor marbles have L/W $\sim$3-8; HP-lenses (eclogite or garnet peridotite) typically show L/W $\sim$1.2-2.5. The spectral frequency of rock types shows slight to moderate differences amongst the mÈlange zones of one TAC. The fragmentation process itself is difficult to characterize, but there are several lines of evidence pointing to a protracted multi-stage evolution, both under prograde and HP-conditions, and probably again during extrusion. Observations on Syros commonly suggest mechanical abrading of single minerals from eclogite fragments.

First results on the metasomatic interaction at the interface between eclogite fragments and matrix indicate variable exchange, much of it late (under Barrovian conditions), but the significance of the limited earlier metasomatism is difficult to interpret, as the position of fragments relative to the matrix is likely to have continually changed due to deformation.

Comparison with numerical predictions

This study is ongoing, and results obtained so far allow but a few preliminary conclusions. Compared with patterns predicted by numerical (continuum) models, much of the ìmixingî in orogens apparently ocurred along preestablished geological boundaries and structures. The incomplete homogenization of the spectra of rock types at the 100 m scale is likely due to differences of the accretion history. The preservation of such differences sets first (weak) limits to the efficiency of mixing during the time span the TAC evolved, but the amount of mixing within individual mÈlange-zones needs further quantification. Some amount of mixing at orogenic scale is indeed indicated by the regional distribution of mÈlange, where TAC-remnants occur along the boundaries of crystalline nappes and km-sized slices. There is no indication that the TAC as a whole extended tens of km into the (lower crust of the) upper plate.

It thus appears that numerical models may overestimate the extent and scale of mixing, but TAC-units and the distribution of mÈlange zones with HP-fragments lend support to the mixing process proposed by some of the numerical models.

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