PETROLOGIC LABORATORY ALPS: A KEY FOR GEODYNAMICS, EXPERIMENTAL INVESTIGATIONS AND THEORY

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Plate tectonics are the ultimate cause for most metamorphism. Conversely the significance of metamorphism as a monitor for geodynamic processes has been stressed since the early days of the plate tectonic concept. In this context, in post-Variscan times the Alpine region was subjected first to divergent and subsequently to convergent plate tectonic regimes. Correspondingly the most common types of metamorphism that can be recognized in the Alps correlate with these regimes as follows:

Divergent plate regime

- Extensional metamorphism
- Oceanic metamorphism

Convergent plate regime

- Subduction zone metamorphism
- Collisional, ultra high pressure metamorphism
- Decompressional metamorphism
- Contact metamorphism about Alpine Intrusives
- Metamorphism associated with thrusting

Table 1 is a tentative scheme presenting a summary overview of these kinds of metamorphisms as function of time and occurence in the Alps. The Alps are thus a huge petrological laboratory. The products of this laboratory are metamorphic rocks that provide useful tools for unraveling a complex tectonic history, or on the other hand, may give information on critical investigations in experimental petrology or even on the evaluation of thermodynamic data. It usually can not be expected that all these three goals can be obtained through the analysis of one kind of metamorphic terrain: tectonicists require rocks with a history as complex as possible, whereas experimental petrologists and theorists need rocks with simple metamorphic histories.

In the Alps, ultramafic upper mantle rocks are suitable candidates to obtain information concerning geodynamics, experimental petrology and thermodynamic data of minerals. These relatively common rocks have simple chemistries and record much of the Alpine geologic history. In their Variscan time, ultramafic rocks cycled from a stable subcontinental mantle condition through first exhumation and then denudation in the Tethyan ocean; oceanic serpentinization to later subduction; high-pressure collisional metamorphism and subsequent near isothermal decompression with prograde metamorphism. We will follow this path and try to obtain the various kinds of key information from the different stages.

Ma	Geological period/epoch	Processes (overlapping in time)	kinds of metamorphism (overlapping)	Occurrences
	PERMIAN	EXTENSION		LOWER ADRIA CRUST
245 ———		UNDERPLATING	GRANULITES	(IVREA, SESIA ZONES
	TRIASSIC			DT. BLANCHE, MALENCO)
	Norian	———	———	———
210 ———		RIFTING	GRANULITE -> AMPHIBO-	
	JURASSIC		LITE -> GREENSCHIST,	ADRIA MARGIN
190	Toarcien	———	RETROGRADE	
		OCEAN FORMATION	———	———
144 ———			OCEANIC	ALPINE OPHIOLITES
120		———	———	———
				INTERNAL OCEAN
	CRETACEOUS	SUBDUCTION	BLUESCHIST/ECLOGITE	MARGINS
			ABOVE SUBDUCTION	UPPER AA-BASEMENT
			ZONE: GREENSCHIST	PLATTA/MALENCO
66,4 ———				SESIA/MARGNA
			———	———
	EOCENE	COLLISION	ULTRA HIGH	INTERNAL MASSIFS
			PRESSURE	ADULA, TAUERN-S
36,6 ———			———	———
			PROGRADE GREENSCHIST	CENTRAL ALPS, TAUERN
	OLIGOCENE	DECOMPRESSION	/AMPHIBOLITE BELTS	
			CONTACT METAMORPHISM	ALPINE INTRUSIVES
23,7 ———			———	———
	MIOCENE	GLIDING APART WITH	LOW PT, TRANSPORTED	HELVETIC NAPPES
		CONVERGENCE BELOW		SIMPLON, BRENNER
				FAULTS

Table 1
Tectonics and Metamorphism Alps, Permian to Miocene

A fossil, undisturbed granulitic crust to mantle section (TROMMSDORFF, 1993, HERMANN et al., 1996) belonging to the former Adria plate is exposed in Val Malenco. The section consists of lherzolitic mantle and a gabbroic and pelitic lower crust. Gabbro underplating occurred in an early extensional phase during the Permian (HANSMANN et al., 1995). Granulite metamorphism outlasted the crystallization of the underplated gabbro (MÜNTENER & HERMANN, 1996) and led to equilibration of all rock types. In a second extensional phase the sequence of crust to mantle rocks was exhumed during Jurassic rifting and was exposed on the Tethyan ocean floor. The retrograde path of extensional metamorphism from granulite to oceanic conditions remained always in the kyanite stability field, which is typical for »IBC granulites« in the sense of HARLEY (1989). Three main implications from the analysis of the section are 1. extremely high densities (3.2–3.3, HERMANN et al., 1996) of the lower crustal granulites which place the Moho at least one kilometer above the petrological crust to mantle boundary; 2. Mantle rocks emplaced in the Tethyan ocean basin are of subcontinental origin and thus atypical of classic ophiolite suites. 3. The emplacement of granulites at the Adria continental margin of Val Malenco can be considered as a model for the exhumation of many other granulite terrains along passive margins.

During the oceanic stage a great part of the ultramafic rocks was serpentinized and the mafic rocks in their immediate contact, i.e. Permian gabbros and Jurassic MORB dykes, became rodingitized. Ophicarbonate rocks were deposited in fractures and on top of the denudated subcontinental mantle. With onset of the convergent plate regime in the Alps the ultramafic-mafic-ophicarbonate (UMOC) suites of the Adria margin became subducted to variable depths. Antigorite rocks remained stable to eclogite conditions during this subduction (BEARTH, 1967, SCAMBELLURI et al. 1995). In the Cima Lunga nappe of the Central Alps UMOC rocks were subducted to conditions of garnet-peridotite facies (EVANS & TROMMSDORFF, 1978) during the Eocene to Oligocene (BECKER, 1993, GEBAUER, 1996). Recent discoveries of unmixing phenomena in olivine from garnet lherzolites at Alpe Arami in the Cima Lunga nappe have been interpreted by DOBRZHINETSKAYA, GREEN & WANG (1996) as consequence of exhumation from the mantle transition zone (400–670 km). As the phenomena described by these authors are, however, quite common in subducted metaultramafic rocks of the Central Alps alternative explanations may be more plausible.

In the Malenco section, which avoided deep subduction because of its position in a marginal wedge, only greenschist conditions were reached during the collisional phase. The UMOC rocks of Val Malenco then underwent partly Oligocene contact metamorphism within the Bergell aureole up to conditions, where titanian OH-clinohumite and antigorite break down (at 3.5 kbar and 500–550 C) with enstatite plus olivine stable at the highest grade.

The high-pressure stability of natural antigorite, as observed in the Alps, makes this mineral, that contains 13 wt% H_2O, an interesting candidate for transport of H_2O to mantle depths in subduction zones. Experimental investigations on natural antigorite from Val Malenco (ULMER & TROMMSDORFF, 1995) confirmed its high-pressure, high-temperature stability to 720°C at 20 kbar, 690°C at 30 kbar and 620°C at 50 kbar. The H_2O released under these conditions is in an ideal position for ascent into the hotter, overlying mantle above subduction zones to cause partial melting in the source region of calc-alkaline melts at 100–130 km depths.

A further experimental investigation on natural titanian OH clinohumite (WEISS & ULMER, 1996) results in an even higher pressure stability for this mineral, which is common in ultramafic rocks of the Alps. It can thus be regarded as an additional source for H_2O in deeply subducted mantle rocks.

The results of experimental petrology are the main source for thermodynamic data bases, which in turn are used to calculate phase relations and conditions of metamorphism as encountered in the field laboratory. In the case ot the contact metamorphosed Malenco ophicarbonate rocks it has been possible to map in detail a phase diagram topology for CaO-MgO-SiO_2-CO_2-H_2O that is experimentally inaccessible because of the narrow spacing of equilibrium curves. This topology has been used to resolve inconsistencies in the DGf for magnesite on the order of 3 kj/mole. These inconsistencies arose between the data base of BERMAN (1988), experimental results on magnesite breakdown (PHILIPP, 1988) and calculated phase relations (CHERNOSKY et al., 1988). The field mapped phase diagram is only in agreement with Philipps data. A more recent calorimetric determination of the free energy of magnesite (CHAI & NAVROTSKY, 1993) and experimental data on various reactions in the system (KOZIOL & NEWTON, 1995) confirmed the choice based upon field mapping. For the anhydrous system CaO-MgO-SiO_2-CO_2 an analogous discrepancy has been resolved on the basis of mapping the prograde sequence of decarbonation reactions in ultramafic carbonate rocks of the Central Alps. Using the field tested data a P–T projection for the mixed volatile CaO-MgO-SiO_2-CO_2-H_2O system has been calculated that has the advantage to represent in addition to fluid composition, pressure and temperature simultaneously, and in contrast to the commonly used XCO_2-diagrams is also appropriate for rocks that are fluid-undersaturated. This diagram is a useful basis for selecting mineral assemblages for field mapping that have restricted fields of stability on the projection and are thus P–T indicators (CONNOLLY & TROMMSDORFF, 1991).

The use of the petrological laboratory Alps is only possible because of the very detailed geological data base in this region. The principal goal in using the laboratory must in turn be a geological one.

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