

Diss. ETH 7282

Die regionale Hochdruckmetamorphose der Aduladecke, Zentralalpen, Schweiz

ABHANDLUNG

zur Erlangung des Titels eines
DOKTORS DER NATURWISSENSCHAFTEN

der

EIDGENOESSISCHEN TECHNISCHEN HOCHSCHULE ZUERICH

vorgelegt von

Christoph A. Heinrich

dipl. Natw. ETH

geboren am 8. September 1953

von Thalwil ZH

Angenommen auf Antrag von

Prof. Dr. V. Trommsdorff, Referent

Prof. Dr. A. B. Thompson, Korreferent

1983

SUMMARY

In the Central Alps two main events of Alpine metamorphism have been described. A Barrow-type facies series reaching sillimanite grade is Tertiary in age and forms a dome of steeply dipping isograd surfaces. These cut discordantly through flatter-lying nappes consisting of pre-Mesozoic continental basement and intercalated Mesozoic metasediments and ophiolites (Fig.1.1, Heinrich 1982, Fig.1). Mineral assemblages of eclogites and blueschists are older than nappe emplacement and do not follow the zonal distribution of the Tertiary isograds, but occur in two separate areas east and west of the so called "Lepontine dome". Eclogites in the eastern area are essentially restricted to one tectonic unit, the Adula - Cima Lunga Nappe, and form the subject of this study.

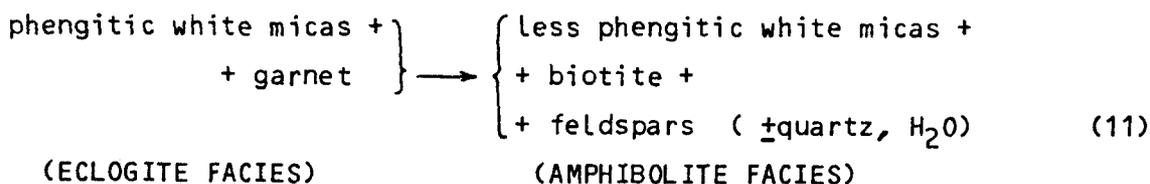
Eclogitic assemblages formed predominantly in rocks of the prealpine basement of the Adula Nappe that had probably been metamorphosed to amphibolite facies already during an Hercynian (Upper Carboniferous) orogeny. Locally garnet + omphacite occur in ophiolites and metasediments of the Mesozoic cover of the nappe, suggesting an Early Alpine rather than a prealpine formation of at least some of the eclogitic assemblages.

Chapter 3 contains detailed information on textural relationships of eclogites with their country rocks. Except for pre-eclogitic amphibolite minerals occurring as inclusions in cores of garnet porphyroblasts, well recrystallized eclogitic assemblages are interpreted to be texturally oldest in all areas. They apparently survived Tertiary overprinting only at sites of low strain, mainly in cores of competent eclogitic boudins. At contacts to their predominantly pelitic country rocks they were overprinted to amphibolite assemblages which can be texturally distinguished from primary hydrous silicates (amphiboles, white micas, epidote minerals) which are present in most of the unaltered eclogites. The country rocks usually contain amphibolite facies assemblages that have recrystallized completely during intensive post-eclogite-facies folding. Only few localities show a textural continuity of mafic eclogites with pelitic rocks, allowing a textural identification of rare eclogite facies metapelitic assemblages. These are always free of plagioclase and contain paragonite + phengite + garnet ± kyanite ± omphacite (3.4) or talc +

phengite + chlorite + garnet \pm kyanite (3.7). In chapter 4 the mineral chemistry of eclogitic phases is described. Throughout this thesis, vector notation after J.B.Thompson (e.g.1981) is used to discuss mineral compositions (definitions see Tab.4.1). Amphiboles in stable textural coexistence with omp + gar + qtz range in composition from glaucophane through barroisite and common hornblende to sodic tremolite. Compositions of coexisting clinopyroxenes vary concomitantly in a continuous series from jd₇₀ to jd₂₀. Garnets are almandine-rich in samples from the northern Adula Nappe (to which area blue glaucophane is restricted) and have compositions typical of type-C-eclogites (Coleman et al. 1965). In the kyanite bearing eclogites of the southern Adula Nappe garnet compositions are more magnesian, similar to other type-B-eclogites.

An attempt to describe eclogitic phase relations within the condensed NCMASH - System (4.1) indicates apparent reaction relationships between assemblages that are believed to have crystallized at the same p-T-conditions. These relationships can be interpreted as a consequence of internal control of a(H₂O) during crystallization of some hydrous eclogites (4.9,eq.8). In other cases bulk compositional effects along condensed components can explain the phase incompatibilities apparent in NCMASH: An example is the stabilization of glaucophane assemblages by high Fe³⁺AL₋₁ relative to the (omphacite-) epidote - amphibolite assemblage more common in the northern part of the Adula Nappe (eq.10; Tab.4.2).

Most of chapter 5 has been published along with a summary of some other results of this thesis (Heinrich 1982). The overprinting behaviour of metapelitic and mafic bulk compositions during unloading from eclogite to amphibolite facies conditions are compared. A kinetic explanation is proposed for the apparently incompatible pressures estimated from mafic eclogite and their predominantly amphibolite facies pelitic country rocks. Quantitative mass balance modelling based on corona textures is used to show that overprinting of metapelites during unloading involved dehydration reactions of the general type.



The relatively rapid rate of dehydration reactions led to nearly complete reequilibration of metapelites to amphibolite facies assemblages.

After the formation during high-pressure metamorphism of mafic eclogites, later lower-pressure reequilibration by hydration to amphibolites was slow, and therefore incomplete, because it depended on large scale transport of H₂O from adjacent, dehydrating metapelites to mafic eclogites.

Conventional methods to estimate p-T-conditions of eclogite equilibration from mineral chemical data are applied to Adula eclogites in chapter 6. The results indicate a tendency of regional increase in p and T of eclogite formation from north to south. The most likely estimates are

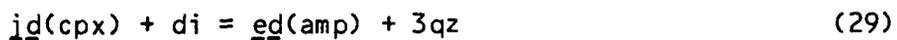
Northern Adula Nappe	Vals	450-550°C	11-13 kbar
Central Adula Nappe	Trescolmen,		
	Confin	500-650°C	14-22 kbar
Southern Adula Nappe	Gagnone	650-750°C	17-27 kbar
	Arami, Duria	800-900°C	20-35 kbar

The calibration of the Fe²⁺/Mg-exchange equilibrium between garnet and clinopyroxene by Ellis and Green (1979) corrects for all mineral compositional effects within cofacial samples from Arami and Gagnone. However, within the samples from Trescolmen and Confin an increase of apparent temperature with increasing jadeite content in pyroxene remains even after applying the compositional correction by Ellis and Green. This remaining effect could be explained by ordering of Fe and Mg on the two M-sites of clinopyroxene (Fig.6.3). It is concluded that the most reasonable T-estimates can be expected from assemblages with high total Fe/Mg and moderate NaAl-content. Even higher uncertainty is involved in the p-T-estimates for Vals where compositional relations indicate primary growth of omphacite with an ordered NaAl- CaMg- distribution. This is expected to preferentially stabilize jd₅₀-omphacites down to lower pressures than predicted by barometers that are based on experimental calibrations of the equilibrium $ab = jd(omp) + qz$ with synthetic disordered omphacites.

In chapter 7 an attempt is made to separate bulk compositional effects upon the mineral compositions of amphibole - quartz - eclogites from effects of continuous reactions due to different p-T-conditions of eclogite equilibration. To do this, empirically defined mass action expressions (K_D

for exchange, K_N for continuous net-transfer reactions) are calculated from analytical data.

To describe any continuous H_2O -conserving reaction among amphibole, pyroxene, garnet and quartz within NCMASH, three independent reactions are sufficient, each of which in principle controls the exchange vectors $j_d(\text{amp})$, $e_d(\text{amp})$ and $t_s(\text{amp})$ in amphibole as a function of p, T , and the composition of the coexisting phases. The large number of uncertainties, however (unknown thermodynamics of multi-site solid solutions; partial equilibration; incomplete analysis by microprobe, notably Fe^{3+}) makes at least at this stage any conclusions highly uncertain: Shifting of the reaction



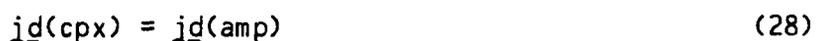
from more jadeitic clinopyroxenes in the central Adula Nappe to more edenitic amphiboles in the southern part of the Nappe could explain the systematic rotation of tie-lines observed in compositional plots of coexisting amphiboles and pyroxenes. The shift is probably due to regional differences in eclogite equilibration temperatures.

Zoning trends in individual grains indicate that reaction



played an important role during the crystallization history of many Adula eclogites. Theoretically, equilibrium (30) is expected to be pressure sensitive but the available data do not allow further interpretations.

Various empirical ways were used to calculate distribution coefficients K_D for the exchange reaction



from the compositional data. A very regular behaviour is observed, illustrating that compositions of coexisting minerals can contain important information about ordering of cations in natural multi-site solid solutions during their inter-crystalline equilibration. The analytical data from the central and southern Adula Nappe are tentatively interpreted to indicate that Na, Al and Ca, Mg were essentially disordered on the M2, M1 sites of clinopyroxenes, whereas in the corresponding M4, M2 sites of coexisting amphiboles the same cations were probably more strongly ordered, at least by forming local next-neighbour CaMg and NaAl pairs.

In chapter 8 the regional distribution of eclogite assemblages in the Adula Nappe are discussed. The restriction of albite in textural equilibrium with hbl + klz (+ Qtz + gar ± omp) to the Vals area (northern

Adula Nappe) and of kyanite + omp + qtz (+ gar ± minor hydrates) to the central and southern Adula Nappe defines an "albite/kyanite - isograd" of Early Alpine (?) regional high - pressure metamorphism (Fig.8.1) which can be represented by the reaction



This dehydration reaction, textural evidence, the general geological situation, the ubiquitous occurrence of the product assemblage of (41) in eclogitic veins, and estimated reaction volumes are all compatible with the interpretation that the kyanite eclogites of the Adula Nappe formed by progressive dehydration of more hydrous, probably amphibolitic protoliths during regional high - pressure metamorphism. High - pressure dehydration of mafic rocks has important consequences for the kinetics of mineral reactions and the preservation of metamorphic assemblages through erosion, depending critically on both the bulk compositions (chapter 5) and on the p-T-path (Fig.8.2) undergone by the rock suite. Incompatible p-T-estimates obtained from mafic eclogites and their gneissic country rocks in many terrains (S-Adula Nappe, SW-Norway) can thus be regarded as a kinetic consequence of the general tendency of metamorphic rocks to retain the most dehydrated mineralogy of their p-T-history as their final recorded state.

Chapter 9 summarizes the consequence of regional eclogite facies metamorphism upon the tectonic history of the eastern Central Alps. In the absence of radiometric dates, geological evidence for an Early Alpine age of the eclogite facies metamorphism are reviewed. The absence of eclogites in tectonic units over- and underlying the Adula Nappe and the p-T-paths estimated for Adula rocks necessitate a complex history with initial subduction of a slice of continental basement and some ophiolitic material, followed by uplift (isostatic?) that must have occurred earlier than, and independent of, final emplacement of the present nappe structures with subsequent amphibolite facies metamorphism in Mid-Tertiary time.