Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 78 (1998)

Heft: 2

Artikel: The high-pressure ultramafic-mafic-carbonate suite of Cima Lunga-Adula, Central Alps : excursion to Cima di Gagone and Alpe Arami

Autor: Pfiffner, Marcel / Trommsdorff, Volkmar

DOI: https://doi.org/10.5169/seals-59292

SCHWEIZ. MINERAL. PETROGR. MITT. 78, 337–354, 1998

The high-pressure ultramafic-mafic-carbonate suite of Cima Lunga-Adula, Central Alps: Excursions to Cima di Gagnone and Alpe Arami

by *Marcel Pfiffner*[1] and *Volkmar Trommsdorff*[1]

Abstract

Several prominent outcrops of high-pressure rocks in the Cima Lunga (Adula) nappe are described. They comprise garnet lherzolites with poikiloblastic texture at Cima di Gagnone and with porphyroclastic texture at Alpe Arami. Accompagnying metarodingites, eclogites and meta-ophicarbonate rocks at Cima di Gagnone reveal the high-pressure suite as former association along a rifted oceanic margin. Comparison of observed features at Alpe Arami and Cima di Gagnone makes an ultra-high-pressure origin of the former unlikely.

Keywords: high-pressure rocks, field excursion, eclogite, Cima di Gagnone, Alpe Arami, Central Alps.

Introduction

The Alpine arc (Figs 1, 2 and 3) was formed by subduction and subsequent continental collision with successively more external, i.e. Tethyan and European, lithosphere subducted under the internal Adriatic plate during the Cretaceous and Tertiary.

In the Alps remnants of at least two belts of the Tethyan ocean are exposed (TRÜMPY, 1960, 1980). They are derived from the older, Jurassic, more internal Piemontese ocean bordering the Adriatic continent and from the younger, Cretaceous and more external Valais trough bordering the European continent. Between the two oceanic basins, a spur of continental lithosphere (STAMPFLI, 1993), i.e. the Briançonnais domain, existed during the Cretaceous. From internal to external the paleogeographic domains that are distinguished in the Alps are (Fig. 1): the Austroalpine realm comprised of continental basement and sediments of the Adriatic margin; the Penninic realm comprised of the Piemontese ocean basin, the Briançonnais, the Valais basin and adjacent European margin; and the Helvetic realm comprised of more external elements of the European margin. The present sequence of paleogeographic domains became superimposed during subduction

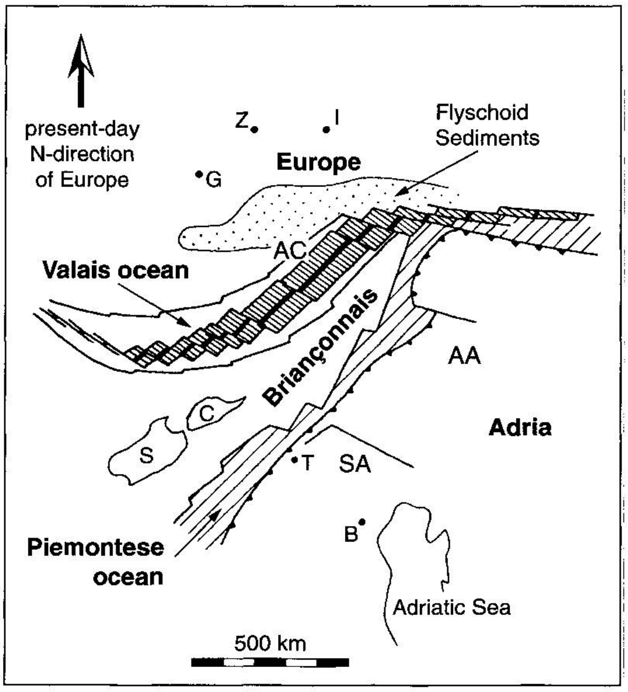

Fig. 1 Paleogeographic situation at about 110 Ma (Abtian to Albian) for the Alpine domain, modified after STAMPFLI (1993) and SCHMID et al. (1997). Abbreviations are as follows: AA: Austroalpine; SA: Southern Alps; AC: Adula-Cima Lunga unit; B: Bologna; C: Corsica; G: Geneva; I: Innsbruck; S: Sardinia; T: Torino; Z: Zürich.

[1] Institut für Mineralogie und Petrographie, ETH-Zentrum, CH-8092 Zürich, Switzerland.
<marcel@erdw.ethz.ch//vtro@erdw.ethz.ch>

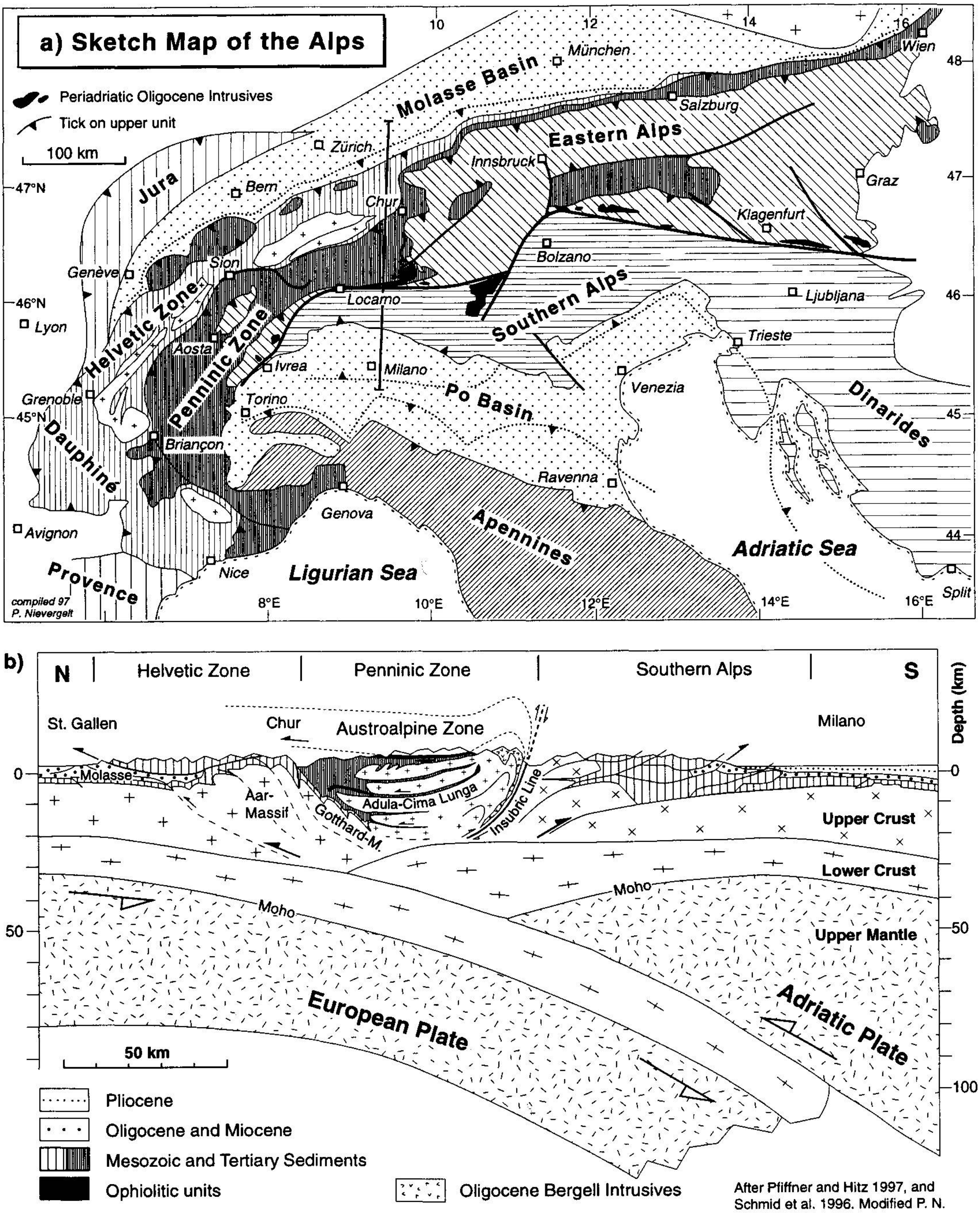

Fig. 2 (a) Simplified sketch map of the Alpine arc, from Nice to Vienna. Locarno is indicated to the west of the center of the map. Trace of profile corresponds to figure 2b. (b) Schematic tectonic section across the Central Alps. The Adula-Cima Lunga unit is situated in the middle of the Penninic nappe stack.

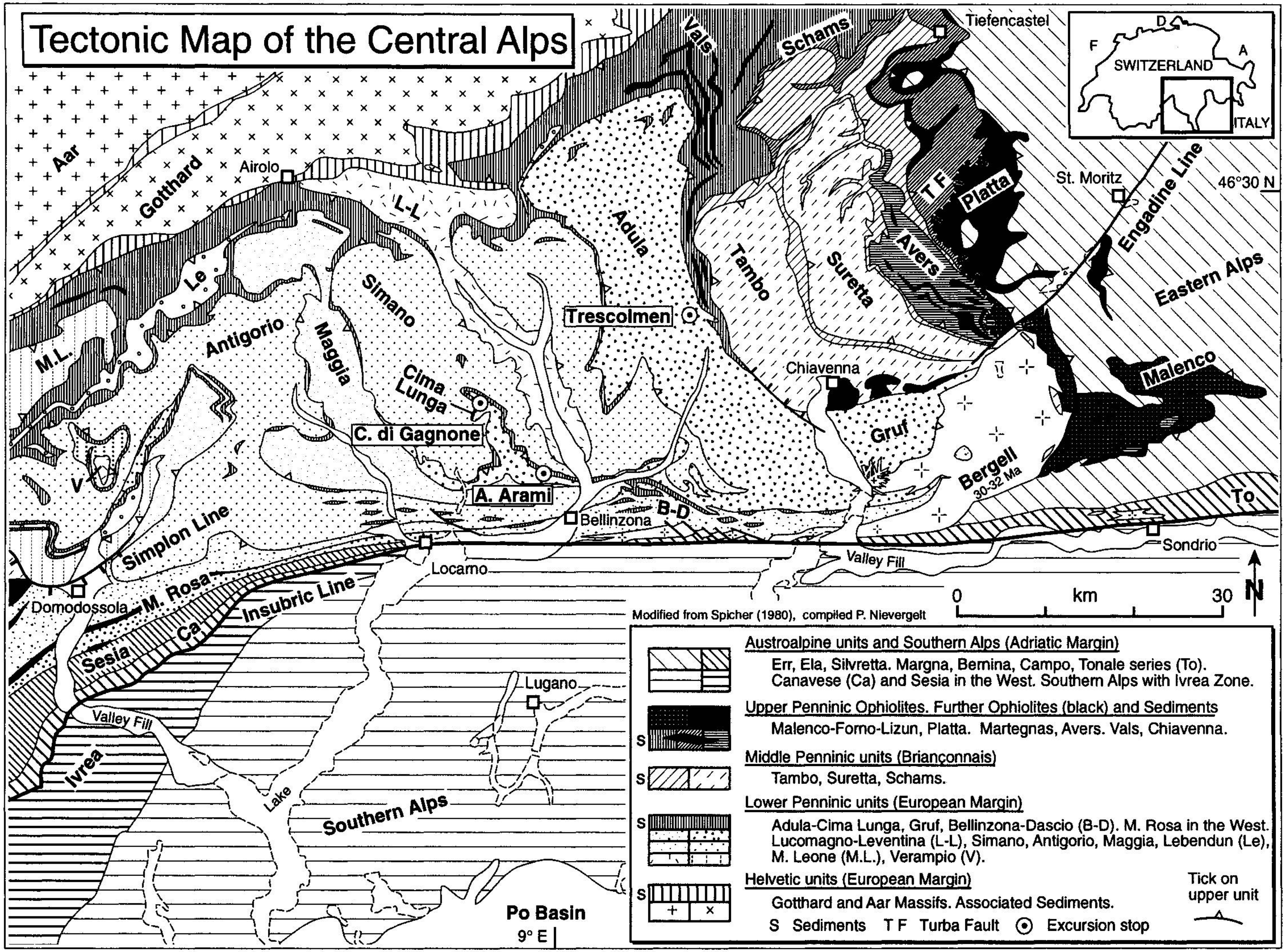

Fig. 3 Tectonic map of the Central Alps, modified from SPICHER (1980). The destinations of the three excursions are indicated: Cima di Gagnone, Trescolmen and Alpe Arami.

and continental collision in the Cretaceous and Tertiary with the internal, Austroalpine, nappes on top, a middle stack of Penninic nappes and the Helvetic zone as the tectonically deepest element (Figs 2 and 3).

From the large scale nappe stacking, from the metamorphic patterns and from the sedimentary record, it is evident that subduction was directed toward the internal parts of the edifice (TROMMSDORFF, 1990). High-pressure metamorphism occurred in several stages during the Cretaceous and Tertiary and prograded from the internal parts of the arc towards external parts and from east to west. During steep continental collision in the Eocene the deepest burial of continental basement and ophiolites led to ultra-high-pressure metamorphism, which is especially well documented in the Penninic arc of the Western Alps.

Much of the Penninic nappe stack later became overprinted by Oligocene greenschist to amphibolite facies metamorphism when the Central Alps (Fig. 3) were rapidly exhumed. The classic metamorphic belt of the Central Alps (TROMMSDORFF, 1966, 1980; NIGGLI, 1970; WENK, 1970), with isograds crosscutting the nappe boundaries (Fig. 5) is a consequence of this exhumation.

The Central Alps

The Central Alps are built up by a sequence of nappes derived from the Penninic area. This nappe stack has two culminations in which the deepest elements are exposed (Fig. 3): The Verampio (V) dome in the west and the more eastern Leventina (L-L) dome (PREISWERK, 1921). These domes are separated by the synformal (BÄCHLIN et al., 1974) NNW trending Maggia zone (NIGGLI et al., 1936; WENK, 1955; GRUJIC and MANCKTELOW, 1996). To the north and to the south of these three structural elements, steeply dipping belts are exposed that run parallel to the trend of the Alpine chain (MILNES, 1974; SCHMID et al., 1987; GRUJIC and MANCKTELOW, 1996); the steep dips are a consequence of collisional to post-collisional back folding. This led to intense mylonitisation in the southern steep belt along the Insubric Line (FUMASOLI, 1974) – actually a belt – which separates the Penninic edifice of the Central Alps from the Southern Alps belonging to the Adriatic plate. In Oligocene times (32–28 Ma, VON BLANKENBURG, 1992) the calc-alkaline Bergell granitoid rocks intruded the southern steep belt and adjacent areas to the north. In its higher portions the intrusion crosscuts several nappe boundaries (TROMMSDORFF and NIEVERGELT, 1983). Later dextral strike slip movements (SCHMID et al., 1987) along the steeply north plunging Insubric mylonite zone displaced the Southern Alps about 50 km with respect to the Central Alps (FUMASOLI, 1974; FISCH, 1989).

The Cima Lunga-Adula nappe complex

The Cima Lunga unit (Fig. 3) occurs to the west of the Leventina dome and is tectonically equivalent to the higher and more southern parts of the Adula nappe. Paleogeographically the Adula and Cima Lunga nappe complexes have been considered as part of the former European margin (TRÜMPY, 1980; SCHMID et al., 1990, 1996). The deeper seated Simano and Leventina nappes then would correspond to more external European basement; the units above the Adula nappe, i.e. the Tambo and Suretta nappes, are of more internal provenance (Briançonnais).

ROCK TYPES

Like other nappes of the Central Alps, the Adula-Cima Lunga nappe complex consists of a crystalline, continental basement with pelitic, mafic and granitoid rocks. This basement is partly overlain by mesozoic quartzite and dolomite which in some places are still autochthonous in the northern parts of the Adula nappe. In general, however, the higher part of the nappe has an imbricated structure containing slices of basement tectonically intercalated with carbonaceous metasediments of possible, but paleontologically not proven, Mesozoic age (MITTELHOLZER, 1936; DAL VESCO, 1953). Closely associated with the carbonaceous metasediments are mafic, eclogitic rocks in the northern Adula nappe and increasingly ultramafic rocks in the southern Adula and Cima Lunga nappes. In the Cima Lunga unit ultramafic boudins and lenses of kilometer to meter size form a continuous marker horizon from Alpe Arami (AA) in the south to Cima di Gagnone (CDG) in the north (Fig. 3). Amongst these ultramafic rocks are several occurrences of garnet peridotite, many enstatite-olivine-chlorite rocks and, to the north, talc-olivine rocks (TROMMSDORFF and EVANS, 1974). At least a part of the ultramafic rocks at CDG went through a serpentinite stage during their history (EVANS and TROMMSDORFF, 1978). The ultramafic rocks are accompanied by mafic metamorphic rocks that occur as eclogites and amphibolites outside and at CDG as metarodingite and eclogite boudins inside the ultramafic rocks (EVANS et al., 1979). The chemical composition of these mafic rocks corresponds to that of low-pressure tholeiites with typical MORB characteristics (EVANS et al., 1981) and with well preserved magmatic fractionation trends. The mafic-ultramafic rock suite beween AA and CDG is further accompanied by metacarbonate rocks of unknown sedimentation age. Some of these metacarbonate rocks have typical characteristics of ophicarbonate rocks (PFIFFNER and TROMMSDORFF, 1997).

In contrast to the abundant evidence for a precursor oceanic stage in ultramafic, mafic and carbonate rocks from Cima di Gagnone no such evidence (rodingitized mafic dykes, meta-ophicarbonate rocks) has been detected at the classical garnet lherzolite locality of Alpe Arami. However, the mafic rocks surrounding the Arami body show chemical features identical with those from Cima di Gagnone (EVANS et al., 1981) indicating a low-pressure origin.

PRE-ALPINE SCENARIO FOR CIMA DI GAGNONE AND ALPE ARAMI

From the evidence referred to in the foregoing chapter a tentative scheme of the paleogeographic situation prior to Alpine subduction can be reconstructed as shown on figure 4. CDG could correspond to an oceanic domain near a continental margin, with ophicarbonates and rodingitized basaltic dykes in an exposed lithospheric mantle, AA to a subcontinental situation near the crust to mantle interface. The whole suite of CDG and AA then became subducted during the Alpine orogenesis.

ALPINE METAMORPHISM AND RADIOMETRIC AGES

In the upper parts of the Adula nappe and in the Cima Lunga unit a regional high-pressure metamorphism has been mapped in mafic rocks by HEINRICH (1983, 1986); pressure and temperature increase from north to south (Fig. 5). This high-pressure metamorphism has not been found in the other nappes of the Central Alps overlying and underlying the Adula-Cima Lunga unit. A prograde transition from albite-epidote amphibolites through omphacite amphibolites to kyanite eclogites occurs in the northern part of the Adula nappe. The southern Adula and the Cima Lunga units are dominated by kyanite eclogites. For the latter areas, the petrogenesis of garnet peridotites (AA and CDG) has been summarized by EVANS and TROMMSDORFF (1978). Mineralogically the garnet lherzolites from AA and CDG are identical, but texturally they differ considerably. Garnet at AA is more or less equant, anhedral and occurs in a porphyroclastic matrix of olivine and pyroxenes (MÖCKEL, 1969). Garnet at CDG is poikiloblastic and overgrew a folded matrix of mimetically crystallized olivine, pyroxenes and pargasitic magnesian amphibole (Fig. 10). The survival of amphibole during garnet growth is consistent with an upper pressure limit for CDG of about 3.0 GPa (MYSEN and BOETTCHER, 1975; NIIDA and GREEN,

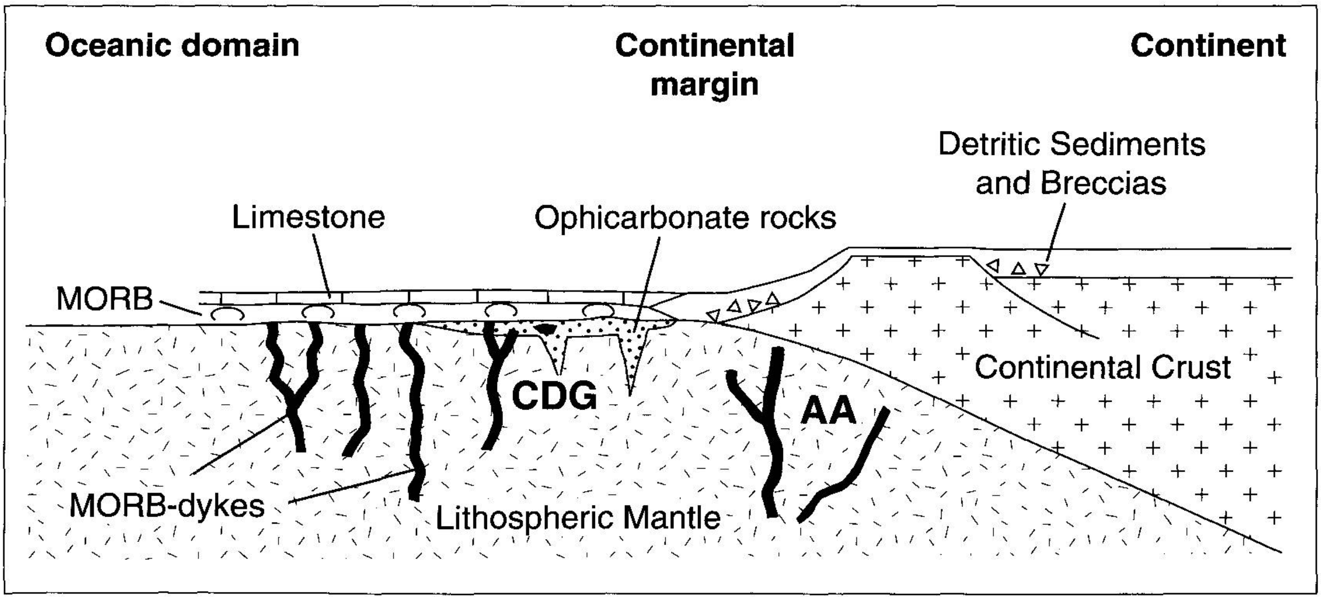

Fig. 4 Paleotectonic setting of Alpe Arami (AA) and Cima di Gagnone (CDG) at the ocean to continent transition prior to Alpine subduction and high-pressure metamorphism.

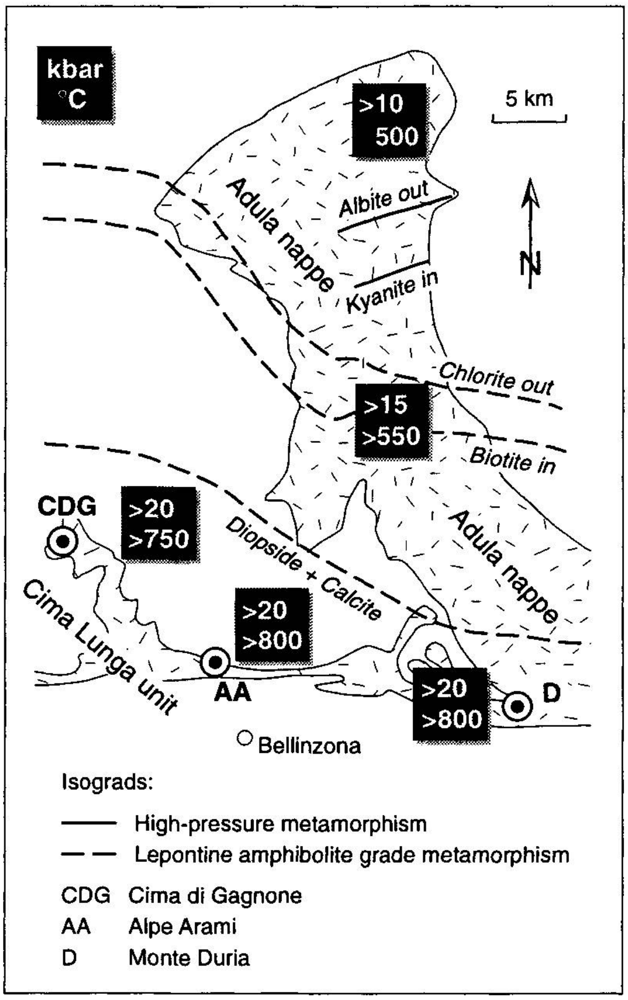

Fig. 5 The Adula nappe and Cima Lunga unit in the Central Alps. Isograds of high-pressure metamorphism within mafic rocks of the Adula nappe are after HEINRICH (1986) with increasing grade to the south. Isograds crosscutting the nappe boundaries are for the main Alpine metamorphic event. Approximate p-T values are after HEINRICH (1986) and EVANS and TROMMSDORFF (1978).

submitted). For AA EVANS and TROMMSDORFF (1978) obtained similar pressures using various conventional thermobarometers, consistent with p-T determinations on the eclogites by HEINRICH (1986). However, on the basis of a detailed study of oriented, unmixed $FeTiO_3$ inclusions in olivine from AA DOBRZHINETSKAYA et al. (1996) obtained pressures of > 10 GPa, possibly 20 GPa. These values should be taken with caution, because RISOLD et al. (1996, 1997) were able to prove that $FeTiO_3$ rods identical in size, quantity, orientation and composition to those from AA are also observed in olivine from CDG garnet lherzolite.

Radiometric ages for the high-pressure metamorphism of the Adula-Cima Lunga nappe system have been published by BECKER (1993) and GEBAUER (1996). These data scatter from 43 Ma (Eocene) to 35 Ma (Eocene to Oligocene) and were obtained with the Sm–Nd method on garnet from the garnet lherzolites and eclogites and with the U–Pb SHRIMP method on zircons from the same rock types. Zircons from AA, however, contain inherited cores of up to 2.5 Ga (GEBAUER et al., 1992; GEBAUER, 1996).

In the southern Adula and Cima Lunga nappes the high-pressure parageneses were frequently overprinted by upper amphibolite facies assemblages during the rapid decompression of the Central Alpine nappes. Only in domains with no fluid access are high-pressure assemblages preserved. The overprint led to the formation of blackwalls around the ultramafic bodies and around the metarodingite boudins (e.g. EVANS et al., 1979; PFEIFER, 1979, 1987) and to partial melting of felsic lithologies at Alpe Arami (GEBAUER, 1996). Pressure-temperature determinations for the second metamorphic event at Cima di Gagnone by GROND et al. (1995) resulted in conditions of 6–8 kbar and 600–660 °C for pelitic gneisses that show no relics of the high-pressure event.

The second metamorphic event in the Central Alps is believed to have occurred during decompression caused by the exhumation of the Central Alpine nappe pile in Oligocene times. For this regional metamorphism a wealth of age determinations exists as summarized by HUNZIKER et al. (1992, 1997). The Oligocene metamorphism reached a first climax around 32 Ma when felsic rocks surrounding the AA garnet lherzolite were partially melted (GEBAUER, 1996), and a second, later climax around 25 Ma when aplites and pegmatites intruded the steep belt. Despite the construction of various p-T-t loops for the Cima Lunga high-pressure metamorphism (HEINRICH, 1986; GEBAUER, 1996) it is likely that the high-pressure event, that is proven for ultramafic, mafic and carbonaceous lithologies of the lithospheric mélange (as defined by TROMMSDORFF, 1990), was not shared by the surrounding felsic rocks (GROND et al., 1995). The p-T history of both rock suites was joined after 32 Ma according to GEBAUER (1996).

ALPINE STRUCTURES

A pre-high-pressure deformation (D_0) is preserved in microfolds included in garnet porphyroblasts of Cima di Gagnone garnet peridotites. Deformation under high-pressure conditions (D_{HP}) caused the formation of a weak foliation and rare lineation in eclogites, metarodingites and garnet peridotites. These features are reflected by aligned omphazite and zoisite in eclogite and by garnet, pyroxenes and olivine in garnet peridotite of Cima di Gagnone. GROND et al. (1995) have discussed the subsequent structural evolution at Cima di Gagnone and recognized four phases of deformation that are all later than the high-pressure metamorphism. These phases are shared by all rock types of the area, which therefore were in juxtaposition. The first deformation phase D_1 is related to nappe stacking with strong isoclinal folding. The second phase corresponds to the main schistosity and stretching lineation with a top to the SSE sense of shear. D_2 produced a series of flat lying, isoclinal, megafolds homoaxial to D_1. These two phases reenforced the boudinage of ultramafic lenses at Cima di Gagnone. The later D_3 developed more open folds with an axial plane dipping to SW. D_1 to D_3 took place under amphibolite facies conditions. D_4 corresponds to local crenulation during retrogression and may be linked to the formation of the northern steep zone along the internal Gotthard and Aar massifs (MILNES, 1974; GRUJIC, 1992; GRUJIC and MANCKTELOW, 1996).

Excursion to Cima di Gagnone

Itinerary

The excursion starts at a little helicopter airport at 850 m elevation south of Frasco in Val Verzasca. The over 1500 m climb to the Cima di Gagnone region is mastered by helicopter in a five minute flight. On the excursion are visisted four outcrops along a four kilometer walk with a total climb of 200 m and descent of 450 m to Capanna Efra at Corte di Cima in Val Efra (see Fig. 6). Most of the itinerary follows a marked footpath with a total walking time of 2 hours. From Capanna Efra the final descent to Frasco requires a 2 hour 1200 m descent following a footpath.

Useful topographic maps (Schweiz. Landeskarte): 1 : 100'000 N° 43 "Sopra Ceneri", 1 : 25'000 N° 1293 "Osogna".

Overview of the structure

Figure 6 gives a geological overview of the area to be visited with the four stops planned. The overall structure (Fig. 7) is formed by a series of flat lying isoclinal D_2 megafolds with amplitudes of one kilometer or more. These folds have been mapped using the ultramafic-mafic-carbonate mélange as a marker horizon. Ultramafic bodies are concentrated near the fold hinges and form boudins of 10 m to over 100 m size. Eclogites occur as small bodies associated with their retrograde products, garnet amphibolites and plagioclase amphibolites (Fig. 6). Metacarbonates form individual layers or are coarse calcsilicate rocks representing metaophicarbonate rocks associated with the metaperidotites. The matrix rocks of the lithospheric mélange at Cima di Gagnone are semipelitic gneisses and micaschists. The boundary between the Cima Lunga nappe and the Simano nappe can only be traced approximately and seems to be deformed by D_2 (GROND et al., 1995). Taking into account the thickening of the Cima Lunga nappe by D_2, the actual thickness of the lithospheric mélange at Cima di Gagnone is in the order of 100 to 200 m.

Eclogites, metarodingites, metaophicarbonate rocks and metaperidotites

STOP 1

Ultramafic lens (Mg 163) at 2400 m, ca. 500 m to the south of Cima di Gagnone (Swiss Coordinates 708'350/131'100), figure 8 and profile figure 9.

Suggested reading: EVANS et al. (1979, 1981); PFEIFER (1979, 1987); PFIFFNER and TROMMSDORFF (1997).

Layers of variably amphibolitized eclogite occur along the margin of a 200 m long ultramafic body (Fig. 8) and in the nearby semipelitic gneisses. Metamorphosed rodingites and rocks transitional between eclogite and metarodingite occur inside the ultramafic body. They form boudins of decimeter to meter size, almost everywhere parallel to the compositional banding and foliation in the ultramafic rocks. Irregular veins of former titanian clinohumite and diopside, now olivine-tremolite-chlorite-ilmenite-magnetite veins, are locally found in the ultramafic body. Several generations of late veins, consisting of talc, enstatite and magnesite or anthophyllite and magnesite, demonstrate metasomatic alteration of the ultramafic rocks due to fluid infiltration. Coarse- to fine-grained calc-silicate rocks outside the metaperidotites and as wedges within them represent former ophicarbonates.

The metaperidotite is a ferrit-chromite bearing enstatite ($X_{Mg} \approx 0.9$) -forsterite ($X_{Mg} \approx 0.9$) -chlorite schist with enstatite forming slender prisms up to several centimetres in lengh oriented parallel to the foliation. A second generation of enstatite is of millimeter size forming part of the

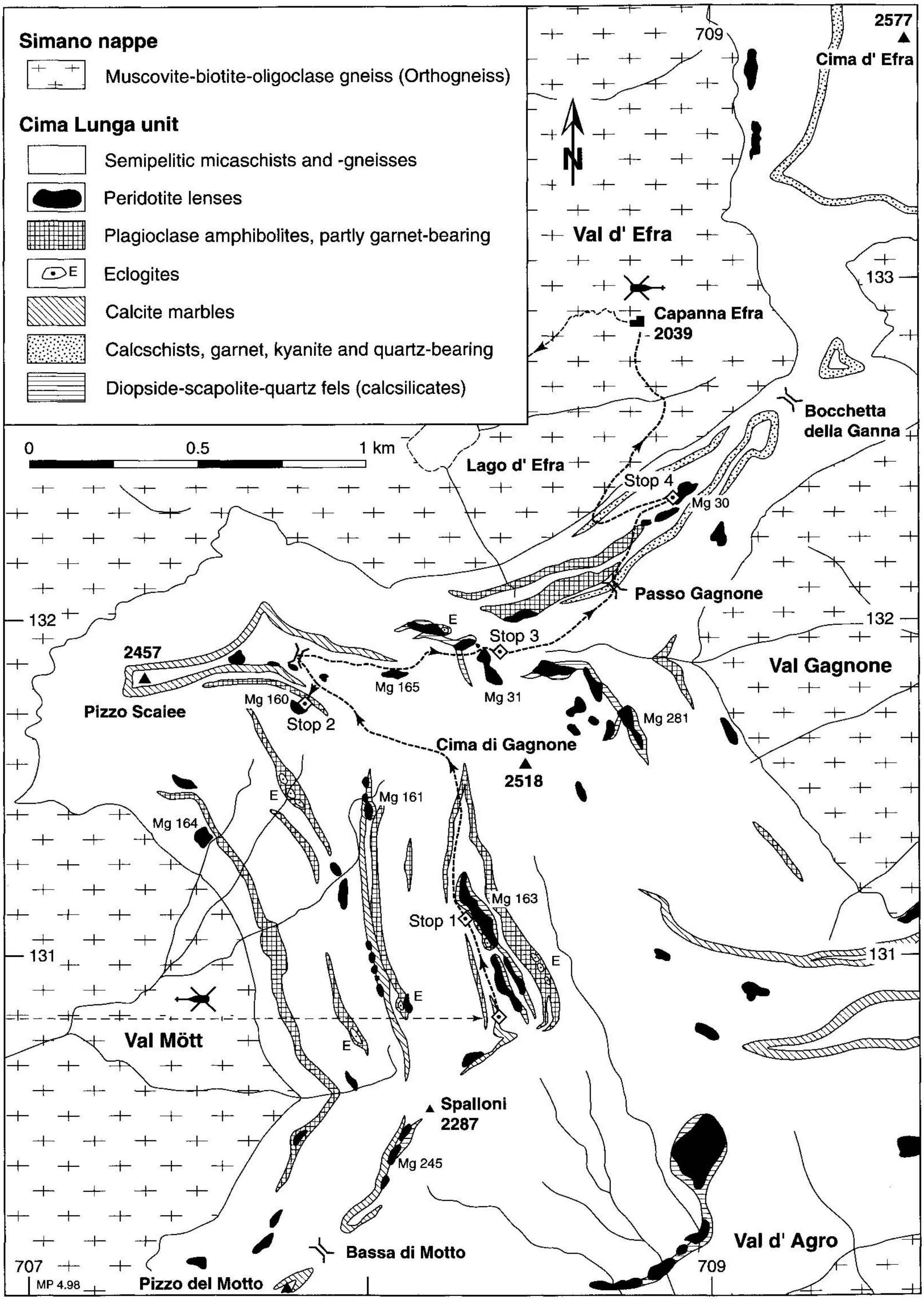

Fig. 6 Geological map of the Cima di Gagnone region (after GROND et al., 1995) with excursion stops 1 to 4 indicated.

matrix of the rock. Late alteration of enstatite to talc is commonly observed.

The eclogites, consisting of pyralspite and pyroxene with more than 10% jadeite component, are generally banded rocks forming layers typically one to three meters thick and tens of meters long. The banded appearance is due to variations in the relative amounts of the eclogitic mineral paragenesis and of later formed amphibole, epidote and symplektite. A weak foliation parallel to the banding is marked by the alignment of pyroxene, hornblende and zoisite.

The metarodingites are pink, relatively fine-grained highly calcic grossularite-diopside rocks, in places faintly banded, and are commonly crosscut by irregular thin veins of garnet, pyroxene (less common) and secondary hornblende. Compared to the eclogites, the metarodingites form thinner bodies, seldom exceeding one meter in thickness and are strongly boudinaged. Recognizable metarodingite boudins may be as small as one or two centimeters across. Dark, amphibole-rich blackwalls surround all metarodingite boudins. There are normally three reaction zones around each boudin; from metarodingite to ultramafic rock, these are: (1) a green zone consisting of hornblende-epidote symplektite and diopside sharply bounded against the metarodingite (inner blackwall), (2) a black zone of hornblende and epidote, locally with megacrysts of sphene (outer blackwall), and (3) a coarse-grained heterogeneous zone of actinolite and chlorite, with chlorite becoming more abundant outwards. Reaction zones between eclogite and ultramafic rock are not so simple and clear as those around metarodingite. From eclogite to ultramafic rock, they are made up of the sequence: (1) garnet and symplektite (after omphacite), (2) hornblende, passing outwards into actinolite, and (3) chlorite and actinolite.

The principal difference between the reaction zones against metarodingite and eclogite is the abrupt disappearance at the beginning of zone 1 of garnet in the former and omphacite in the latter. A sizeable fraction of the garnet-bearing mafic boudins in the region possesses structural and textural characteristics transitional between eclogite and Ca-rich metarodingite. These rocks have correspondingly intermediate bulk chemical and mineralogical properties. They are interpreted as rocks in which the original process of rodingitization was incomplete.

The coarse-grained calc-silicate rocks consist of up to 80% of coarse-grained diopside (up to 10 cm), minor scapolite (75% meionite), secondary amphibole (after diopside) and oligoclase/andesine (after scapolite), quartz and some sphene. The fine-grained calcsilicate rocks consist predominantly of diopside and plagioclase with some minor amphibole. They are higher in Na_2O-content (up to 3 wt%), show pseudomorphs of albite-rich plagioclase and diopside after former

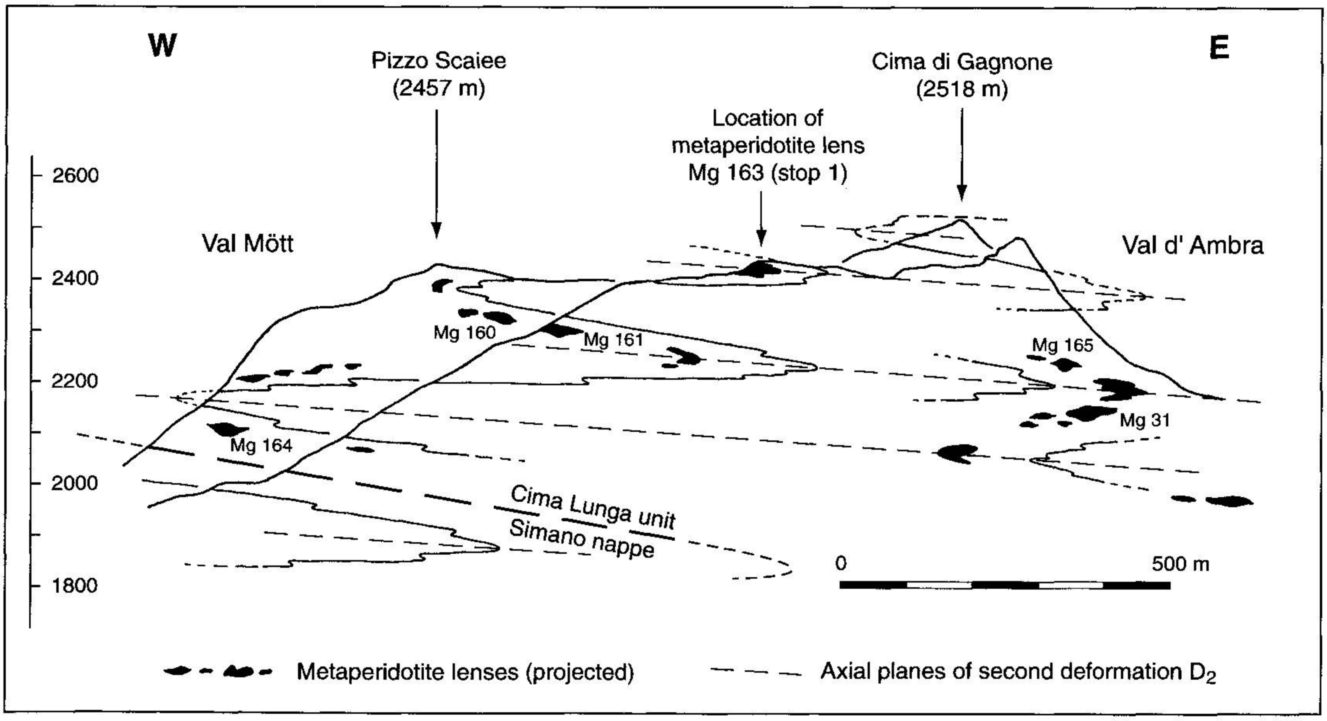

Fig. 7 Structural cross section of the northern Cima Lunga unit. Metaperidotite lenses are preferentially concentrated within the fold hinges of D_2 megafolds as for example the ultramafic body Mg 163 (excursion stop 1).

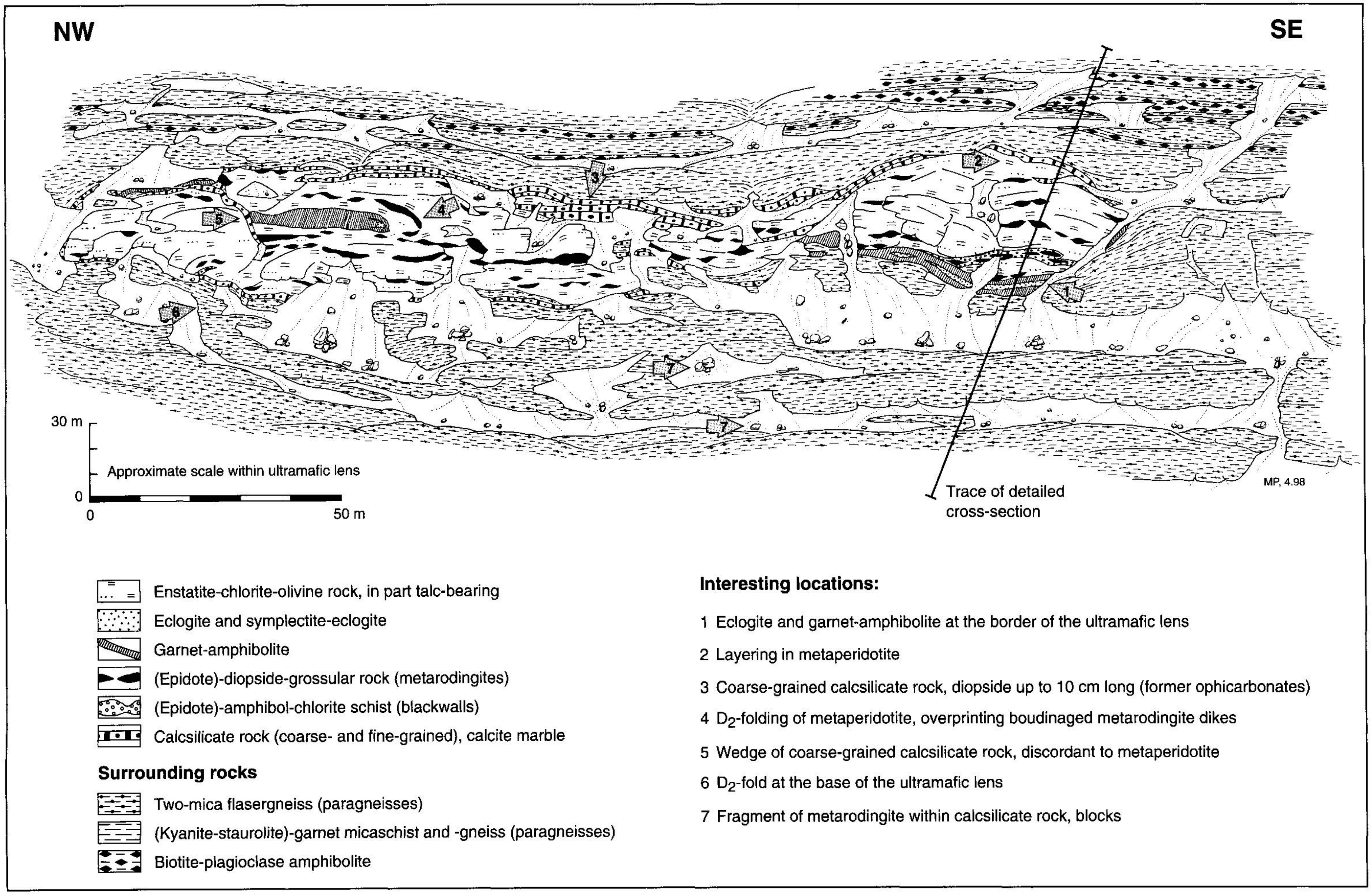

Fig. 8 Detailed sketch map of metaperidotite lens Mg 163 and the surrounding gneisses, with eclogites and boudinaged metarodingite dykes indicated. Some interesting locations recommended to visit are marked by arrows. The trace of cross section figure 9 is indicated.

omphazite and demonstrate a precursor high-pressure event. Both coarse- and fine-grained calcsilicate rocks are high in Cr- and Ni- but low in Zr- and TiO_2- contents with proportions similar to those in the ultramafic rocks and differ markedly from those of the mafic suite in the outcrop. The bulk chemical data of the calc-silicate rocks perfectly fall on mixing lines between calcite marbles and the ultramafic rocks. They are interpreted as former ophicarbonate rocks deposited as fracture fillings and sedimentary cover on top of ultramafic rocks exposed at an ocean floor.

In the semipelitic gneisses surrounding the ultramafic body no signs of high-pressure metamorphism have been detected. A detailed account of these rocks is given by GROND et al. (1995).

STOP 2

Garnet peridotite (Mg 160) south of Passo Scaiee (Swiss Coordinates 707'800/131'740), figure 10.

Suggested reading: EVANS and TROMMSDORFF (1978, 1983); HEINRICH (1983); RISOLD et al. (1996).

This is a 40 m by 50 m macroboudin of brown weathering lherzolitic peridotite outcropping 700 m WNW of Cima di Gagnone in steep south-sloping talus just below the "Strada alta" (EVANS and TROMMSDORFF, 1978). Garnet peridotite constitutes only a small fraction of the body, perhaps less than 10%. It may be found in situ and in large fallen blocks below. The main mass of peridotite is an amphibole-bearing chlorite-enstatite-olivine rock. Except for occasional clots of megacrysts, garnet does not occur as idiomorphic porphyroblasts but tends to be concentrated in thin layers or schlieren typically 5 mm in thickness. It is accompanied by olivine, dark green clinopyroxene, reddish brown lineated prisms of orthopyroxene and patchily distributed pale green magnesiohornblende.

In thin section garnet is poikiloblastic and overgrows preexisting folds (D_0) with diopside, olivine, enstatite, pargasite to Mg-hornblende and spinel (Fig. 10). Olivine frequently contains inclusions of oriented rods of ilmenite with similar dimensions, orientation and quantity as at Alpe Arami. Pseudomorphs after titanian clinohumite of olivine plus ilmenite and local relics of titanian clinohumite complete the mineral assemblage of the garnet peridotite. From the center of the lens towards outside, the rock passes into garnet free peridotite. Passage into garnet-free peridotite in-

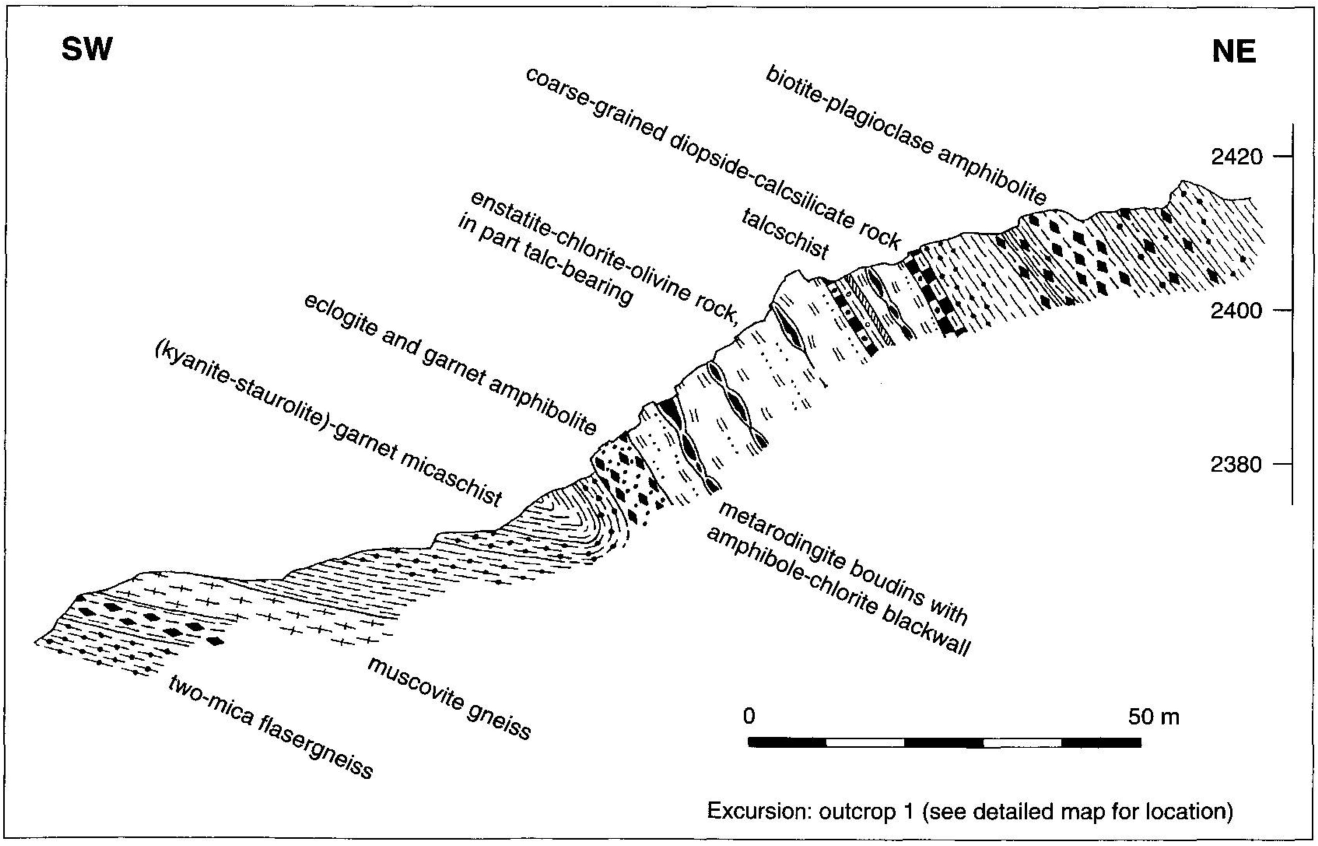

Fig. 9 Detailed section across the metaperidotite body Mg 163. Note the near isoclinal fold of the second deformation phase D_2 in the footwall of the ultramafic body.

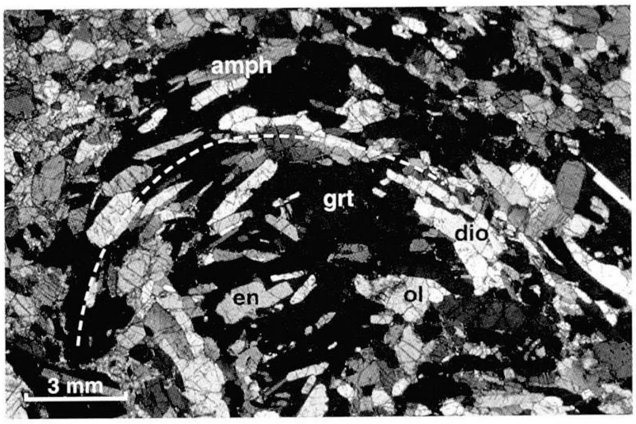

Fig. 10 Photomicrograph of garnet peridotite. Poikiloblastic garnet (grt) overgrows a preexisting microfold with diopside (dio), olivine (ol), enstatite (en) and pargasitic amphibole (amph).

volved the disappearance also of the clinopyroxene and hornblende, but not necessarily any structural change. Both garnet-bearing and garnet-free peridotites are foliated and lineated, the schistosity is best developed in tremolite plus cummingtonite-rich rocks from near the margin of the body. A possible primary layering in the form of pyroxene-rich and pyroxene-poor bands is parallel to the foliation. Both foliation and layering are folded, often nearly isoclinally. Abundant chlorite-rich seams probably represent sheared-out reaction zones. Olivine, garnet, clinopyroxene, hornblende and chlorite occur occasionally in clots of megacrysts. Like most ultramafic lenses in the Cima di Gagnone area the garnet peridotite containing lens encloses boudins of mafic rock, but other than in most peridotites of the area these boudins are only mildly rodingitized. This garnet lherzolite body probably represents a part of upper mantle plus mafic dykes that underwent little serpentinization and rodingitization.

STOP 3

Ultramafic lens (Mg 31) north of Cima di Gagnone (Swiss Coordinates 708'360/131'880), figure 11.

Suggested reading: RICE et al. (1974); TROMMSDORFF and EVANS (1974).

The outcrop is formed by a 150 × 30 m macroboudin (detailed map Fig. 11) of schistose ultramafic rocks which, in addition to the common enstatite-forsterite-chlorite assemblage, contain tremolite with magnesiocummingtonite overgrowths. The ultramafic rocks are folded by D_3 with a steeply SW dipping axial plane which resulted in a multiple repetition of strings of metarodingite boudins along the ultramafic lens. As a special feature in this outcrop discordances between the metarodingites and the compositional layering of the metaperidotites are visible, underlining the dyke-character of the mafic rocks. Part of the ultramafic rocks are in direct contact with meta-ophicarbonate rocks. In the pelitic gneisses underlying the ultramafic body aluminium silicate-quartz-nodules can be studied showing nice andalusite crystals overgrowing deformed kyanite, related to the decompressional history of the area (see KLEIN, 1976).

STOP 4

Ultramafic lens (Mg 30) at Guglia (Swiss Coordinates 708'930/132'380).

Suggested reading: EVANS and TROMMSDORFF (1974).

Measuring approximately 50 × 50 m, the boudin at Guglia forms a prominent outcrop of red brown weathering, largely schistose, ultramafic rock. The boudin possesses an internal structure involving a large recumbent fold of the second deformation phase D_2 closing to the northeast and a minor, presumably earlier, shallow syncline on the east side of the body. The body is overlain by a sequence of interlayered garnet-staurolite-kyanite schist, garnetiferous amphibolite, actinolitic calc-silicate rock, and a one meter layer of diopside marble underlain by hornblendic semi-pelitic schist.

The boudin is composed of roughly equal amounts of locally magnesite-bearing chlorite-talc-forsterite schist, a texturally homogeneous rock, and a coarse- to extremely coarse-grained inhomogeneous chlorite-forsterite-magnesite-talc-enstatite rock. By means of an increase in grain size of the chlorite-talc-forsterite schist and growth in it of schlieren and veins of the enstatite-bearing rock, the two rock-types irregularly grade into one another. Since the schlieren and veins in places intersect the schistosity of the talc-forsterite schist, the enstatite-bearing rock is interpreted as later in origin. Furthermore, it has formed by replacement. The talc-enstatite rock becomes dominant toward the margins of the body, particularly on the uppermost side. Minor amounts of enstatite-chlorite (± phlogopite) schist are also present. Other rock types occur as sharp, cross-cutting veins. Most frequent are composite replacement veins, sometimes as little as 10 cm apart. They are vertical, trend NNE, and consist of an outer, light coloured 1 to 2 cm wide zone of talc and magnesite and a thin 1 to 3 mm central zone of anthophyllite. A later set of very

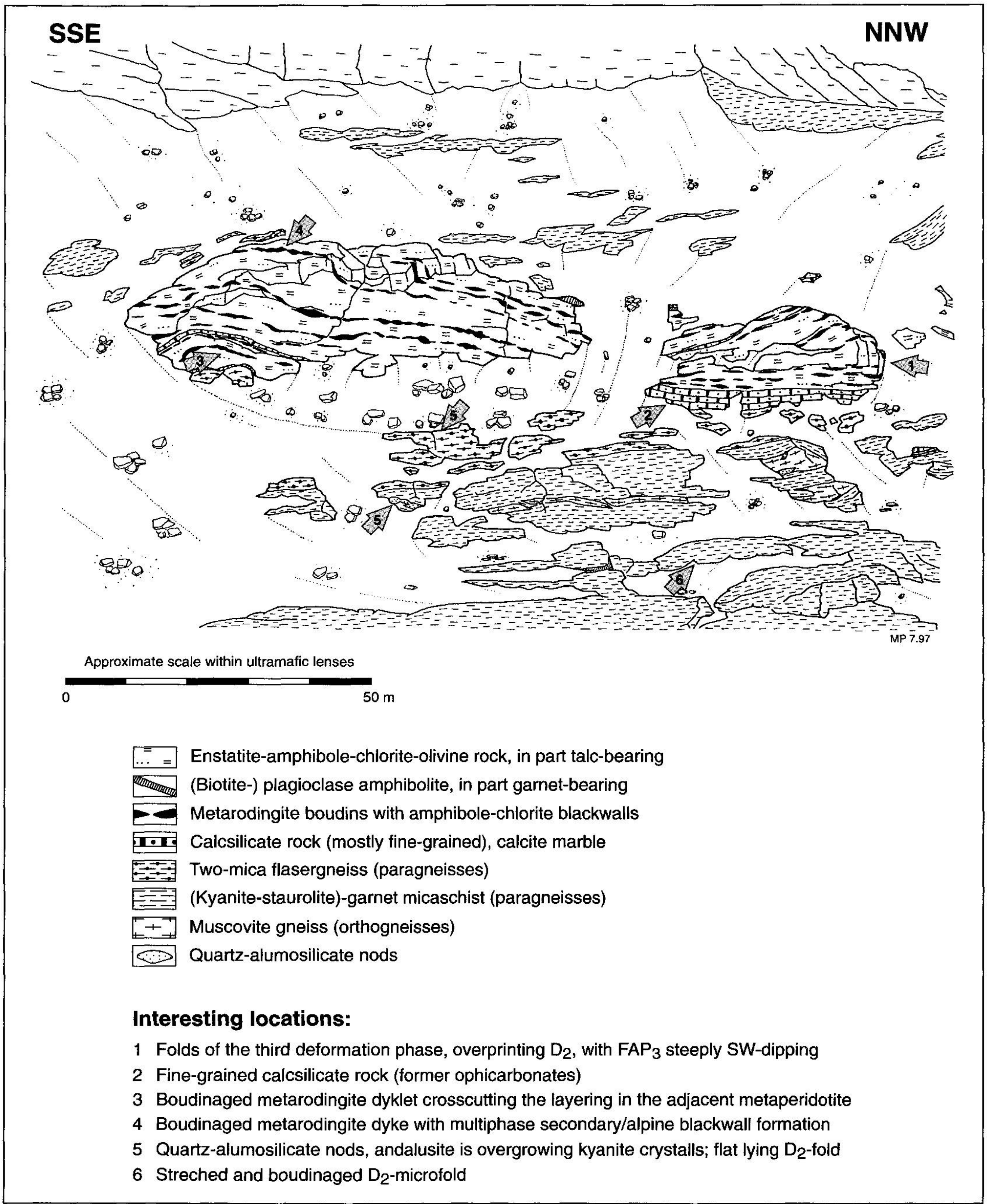

Fig. 11 Detailed sketch map of metaperidotite body Mg 31. Recommended locations are indicated by arrows.

thin NNW-trending alteration veins is composed of red weathering fibrous anthophyllite. Finally, coarse, cross-oriented actinolite, together with chlorite, forms a broad vein following the curved axial plane of the shallow syncline. This vein is inferred to be earlier than the other two varieties. Similar material is present as a thin zone along the poorly exposed contacts of the body. The entire sequence of rock types therefore formed in the following order: talc-forsterite schist, forsterite-magnesite-talc-enstatite rock, actinolite vein, composite veins, anthophyllite veins. The sequence of assemblages is consistent with increased fluid input during uplift and decompression of the Cima Lunga unit. Early diffuse veins formed when the rock was still ductile at high temperatures and pressures. The late sharp cross-cutting veins formed when the body behaved brittle.

Excursion to Alpe Arami

Introduction

Selected suggested reading: GRUBENMANN (1908); MÖCKEL (1969); BUISKOOL TOXOPEUS (1976); EVANS and TROMMSDORFF (1978); ERNST (1977, 1978, 1981); DOBRZHINETSKAYA et al. (1996); GEBAUER (1996); RISOLD et al. (1996, 1997); BRENKER and BREY (1997).

Total walking time: 1½ hours.

Since the times of GRUBENMANN'S (1908) pioneering work, the garnet lherzolite and the eclogites at Alpe Arami, near Bellinzona (Fig. 3) constitute a prominent locality of high-pressure metamorphic rocks in the Central Alps. Later studies of this classic occurrence have been petrographic (DAL VESCO, 1953; ROST et al., 1974), structural (MÖCKEL, 1969; BUISKOOL TOXOPEUS, 1976), geochemical (O'HARA and MERCY, 1966; ERNST, 1978; OTTONELLO et al., 1984), petrological (EVANS and TROMMSDORFF, 1978; DOBRZHINETSKAYA et al., 1996; BRENKER and BREY, 1997) and geochronological (BECKER, 1993; GEBAUER, 1996). In recent times the depth of origin of the garnet lherzolite at Alpe Arami (DOBRZHINETSKAYA et al., 1996; BRENKER and BREY, 1997; cf. RISOLD et al., 1996, 1997) has caused discussions as outlined in the introductory part of this paper.

The ultramafic body of Alpe Arami is situated in the Cima Lunga unit (Fig. 3). It is separated from the underlying Simano nappe by a sequence of metamorphosed carbonate rocks that occur in several layers just north of Alpe Arami. All the units are steeply south-dipping and E-W-striking, but farther to the north they rapidly become flat-lying (as at Cima di Gagnone).

Leucocratic microcline gneisses and oligoclase-two mica gneisses together with narrow marble beds envelop the ultramafic lens at Alpe Arami that measures about one by one half kilo-

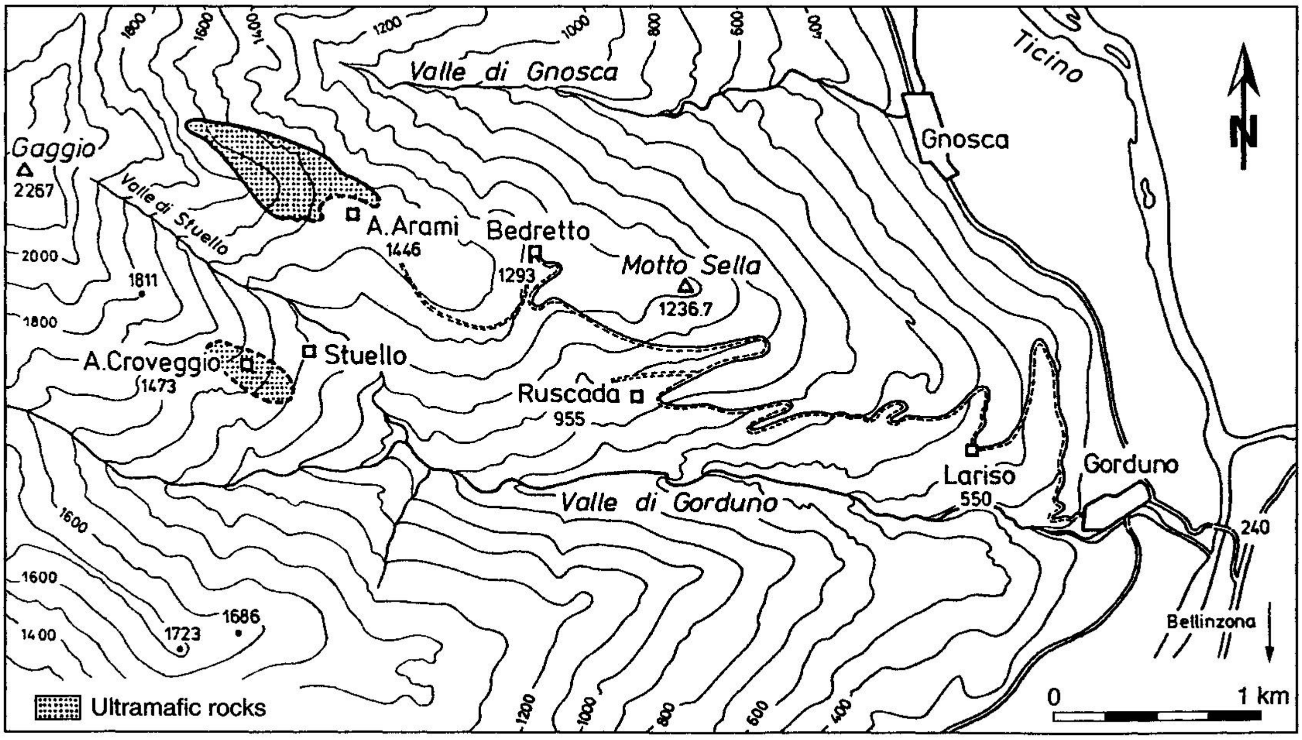

Fig. 12 Outline map of the area around Alpe Arami.

meters. The ultramafic body consists of chlorite peridotite and garnet peridotite and is accompanied along its margins by variably amphibolitized eclogite and locally by clinopyroxenite and hornblendite (Fig. 13). A thin mylonite rim around the peridotite has been described by some authors. Within the peridotite, the compositional layering is commonly preserved and transected at acute and locally at obtuse angles by the Alpine foliation (Fig. 13). The latter constitutes the major structural element outside the peridotite. Within the peridotite body it caused flattening of chlorite knobs pseudomorphic after garnet.

Eclogite and garnet peridotite assemblages yield equilibrium conditions at temperatures and pressures (> 800 °C and > 25 kbars, Fig. 5; ERNST, 1977; EVANS and TROMMSDORFF, 1978; HEINRICH, 1986) higher than those of the main Alpine metamorphism which is at sillimanite grade. This metamorphism caused chloritisation of the garnets in the peridotite and amphibolitisation of eclogite. The Arami garnet peridotite has been interpreted as derived from the mantle transition zone (e.g. DOBRZHINETSKAYA et al., 1996). On the other hand, in the Cima di Gagnone area garnet peridotite and eclogite are found that have cycled from surface conditions through a deep subduction metamorphism during Alpine collision (e.g. EVANS et al., 1979; review in TROMMSDORFF, 1990).

Itinerary

GENERAL REMARKS

From Bellinzona through Gorduno on a narrow paved mountain road to Bedretto, 1283 m a.s.l., one kilometer east of Alpe Arami (Fig. 12). The road above Gorduno crosses steeply south plunging migmatitic gneisses which in places contain boudins of variably amphibolitized eclogite. At Bedretto spectacular blocks of leucocratic migmatitic gneisses can be studied with leucosomes crosscutting the Alpine foliation. Zircons of the leucosome yield an age of 32.4 Ma (GEBAUER, 1996). East of Bedretto a viewpoint can be visited which gives a nice overview of a profile to the east that reaches from the Southern Alps to the south through the southern Steep Belt into the flat lying parts of the Lower Penninic gneiss nappes to the north. From Bedretto Alpe Arami can be reached in a half hour walk on a gravel mountain road. This road is closed to the public traffic just above Bedretto by a barrier. From the end of the road the huts of Alpe Arami are visible 250 m to the northwest. From Alpe Arami walk on a narrow horizontal footpath towards north, first through meadow and forest, then through blocky talus into a narrow valley 250 m NNW of the Alp. Along the footpath blocks and outcrops of amphibole-chlorite-enstatite-olivine rock can be observed, with flattened chlo-

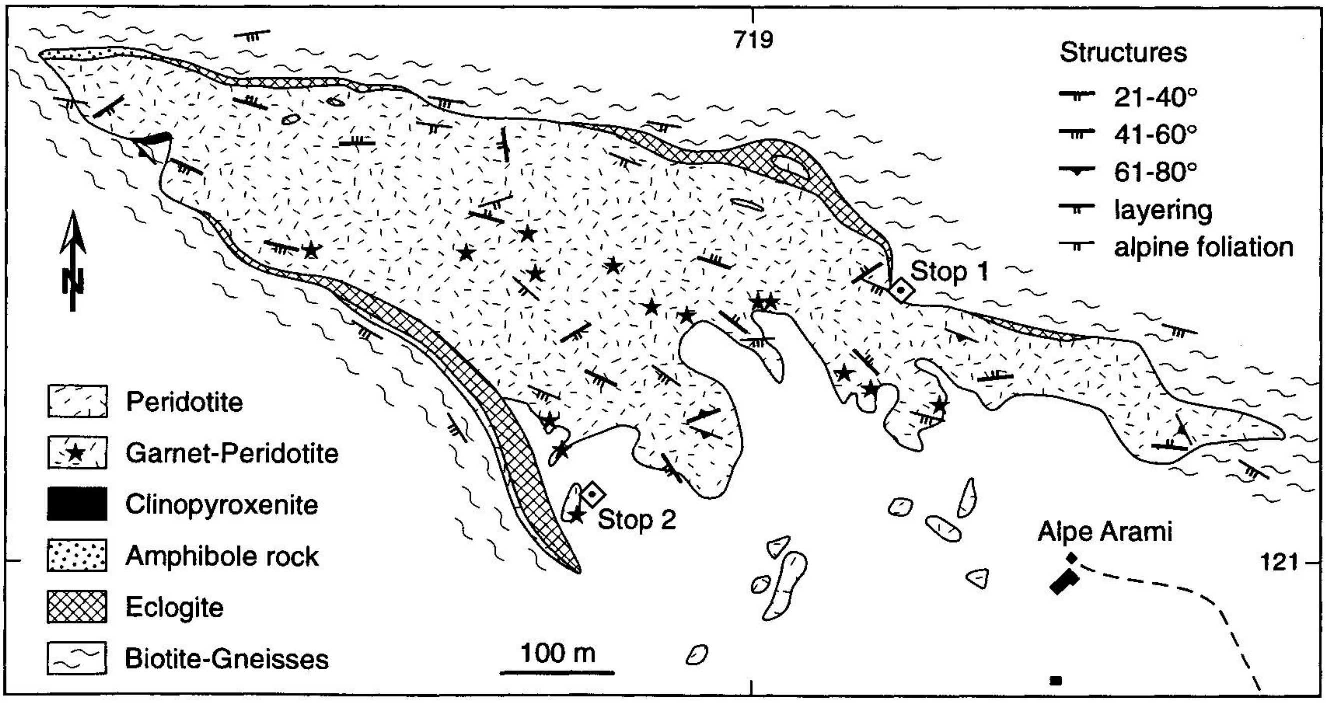

Fig. 13 Detailed map of the ultramafic body at Alpe Arami (after MÖCKEL, 1969).

rite knobs pseudomorphic after garnet (Swiss Coordinates 719'200/121'175; Fig. 13).

Useful topographic maps (Schweiz. Landeskarte): 1:100'000 N° 43 "Sopra Ceneri", 1:25'000 N° 1313 "Bellinzona".

STOP 1

Blocks and outcrops of fresh garnet peridotite (Swiss Coordinates 719'150/121'220).

In contrast to the poikiloblastic garnet lherzolite of Cima di Gagnone the Alpe Arami rocks have a porphyroclastic texture. Garnet (~ py 66.5, alm 19, gross 13.7) is rounded with sometimes concave grain boundaries and relatively poor in inclusions. It occurs in a matrix with two generations of olivine (fa 9–10, fo 90), a porphyroclastic generation with up to 2 mm big crystals and a recrystallized generation with small subhedral grains that form the mortar between the porphyroclasts. Apple green chromian clinopyroxene of up to 5 mm in diameter is easily recognized in hand specimen. It is frequently concentrated near garnet (DOBRZHINETSKAYA et al., 1996), that is, in calcium rich domains of the rock. Its composition varies from center (jd 6.7, di + he 88.9, en + fs 4.0) to edge (jd 0.7, di + he 93.2, en + fs 4.0) in terms of jadeite component. Minor enstatite (en + fs 97.3, di + he 1.0) is dark grey, up to 2 mm large and sometimes kinked. The gradual transition from garnet lherzolite through spinel-amphibole peridotite into chlorite peridotite is recognized by means of an increase in kelyphite margins around garnet and its final replacement by chlorite. Late serpentine alteration is recognized by increasing softness of the rock accompanied by a darkening in colour. Not uncommonly late brittle shear planes with a serpentine cover can be observed in the rock.

Special features of the rock that have not been or cannot be recognized in hand specimen are: (i) occurrence of titanian clinohumite and olivine plus ilmenite pseudomorphs after titanian clinohumite (MÖCKEL, 1969); (ii) local inclusions of spinel in garnet; (iii) the occurrence of about 20 μm by 2 μm rods of $FeTiO_3$ (ilmenite) exsolved from olivine porphyroclasts. MÖCKEL (1969, p. 79) interpreted these inclusions as rutile. The ilmenite rods gave rise to the ultra-high-pressure interpretation of the Arami garnet peridotites by DOBRZHINETSKAYA et al. (1996) as outlined in the introduction.

STOP 2

Outcrops of spinel-amphibole peridotite with spinel-amphibole kelyphite after garnet, garnet peridotite, pyroxenite, garnet-diopside rock and eclogite with profile across the margin of the Arami ultramafic body (Swiss Coordinates 718'840/121'050).

From Alpe Arami 200 m climb along traces of the trail to the mountain Gaggio towards WNW. At 400 m distance from the Alp, close to the margin of the ultramafic body outcrops of spinel-amphibole peridotite. The peridotite contains pseudomorphs of spinel and amphibole after garnet and spinel, amphibole and orthopyroxene after clinopyroxene. In the vicinity garnet pyroxenite layers with apple-green chromiferous clinopyroxene and several cm big garnet crystals are found. Somewhat to the west, between 1600 and 1700 m elevation a profile across the margin of the ultramafic body can be studied. From inside to outside of the peridotite lens the following sequence is recognized: garnet peridotite, chlorite peridotite, mylonite, eclogite becoming progressively amphibolitized, biotite plagioclase gneiss.

For lazy climbers all these rock types are displayed in blocks on and above a little horizontal meadow only about 200 m west of Alpe Arami (elevation 1500 m). At the eastern margin of the meadow a block of garnet peridotite contains a nice layer of garnet pyroxenite. **Do not hammer!**

Somewhat more extended masses of clinopyroxenite are outcropping at an elevation of 1640 m, 500 m nothwest of stop 2 (Swiss Coordinates 118'500/121'350) at the southwestern border of the Arami ultramafic rocks.

Acknowledgements

The authors like to thank Peter Nievergelt for help in computer drawing of figures 2 and 3, Jörg Hermann and George Skippen for careful reviews of the manuscript and Sven Girsperger for taking excellent aerial photographs of various outcrops at Cima di Gagnone which greatly facilitated detailed mapping.

References

BÄCHLIN, R., BIANCONI, F., CODONI, A., DAL VESCO, E., KNOBLAUCH, P., KÜNDIG, E., REINHARD, M., SPAENHAUER, F., SPICHER, A., TROMMSDORFF, V. and WENK, E. (1974): Geologischer Atlas der Schweiz 1:25'000, Blatt 1313 Bellinzona. Schweiz. geolog. Komm.

BECKER, H. (1993): Garnet peridotite and eclogite Sm–Nd mineral ages from the Lepontine dome (Swiss Alps): New evidence for Eocene high-pressure metamorphism in the Central Alps. Geology 21, 599–602.

BRENKER, F.E. and BREY, G.P. (1997): Reconstruction of the exhumation path of the Alpe Arami garnet-peridotite body from depths exceeding 160 km. J. metamorphic Geol. 15, 581–592.

BUISKOOL TOXOPEUS, J.M. (1976): Petrofabrics, microtextures and dislocation substructures of olivine in a peridotite mylonite (Alpe Arami, Switzerland). Leidse Geol. Meded. 51, 1–36.

DAL VESCO, E. (1953): Genesi e metamorfosi delle rocce basiche e ultrabasiche nell'ambiante mesozonale dell'orogene Pennidico. Schweiz. Mineral. Petrogr. Mitt. 51, 329–348.

DOBRZHINETSKAYA, L., GREEN, H.W. and WANG, S. (1996): Alpe Arami: A Peridotite Massif from Depths of more than 300 Kilometers. Science 271, 1841–1845.

ERNST, W.G. (1977): Mineralogic Study of Eclogitic Rocks from Alpe Arami, Lepontine Alps, Southern Switzerland. J. Petrol. 18, 371–398.

ERNST, W. G. (1978): Petrochemical study of some lherzolitic rocks from the Western Alps. J. Petrol. 19, 341–392.

ERNST, W.G. (1981): Petrogenesis of eclogites and peridotites from the Western and Ligurian Alps. Amer. Mineralogist 66, 443–472.

EVANS, B.W. and TROMMSDORFF, V. (1974): Stability of Enstatite + Talk, and CO_2-Metasomatism of Metaperidotite, Val d'Efra, Lepontine Alps. Amer. J. Sci. 274, 274–296.

EVANS, B.W. and TROMMSDORFF, V. (1978): Petrogenesis of garnet lherzolite, Cima di Gagnone, Lepontine Alps. Earth Planet. Sci. Letters 40, 333–348.

EVANS, B.W. and TROMMSDORFF, V. (1983): Fluorine Hydroxyl Titanian Clinohumite in Alpine Recrystallized Garnet Peridotite: Compositional Controls and Petrologic Significance. Amer. J. Sci. 283, 355–369.

EVANS, B.W., TROMMSDORFF, V. and GOLES, G.G. (1981): Geochemistry of High-Grade Eclogites and Metarodingites from the Central Alps. Contrib. Mineral. Petrol. 76, 301–311.

EVANS, B.W. and TROMMSDORFF, V. and RICHTER, W. (1979): Petrology of an eclogite-metarodingite suite at Cima di Gagnone, Ticino. Amer. Mineralogist 64, 15–31.

FISCH, H. (1989): Zur Kinematik der südlichen Steilzone der Zentralalpen, E von Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 69, 377–392.

FUMASOLI, M.W. (1974): Geologie des Gebietes nördlich und südlich der Iorio-Tonale-Linie im Westen von Gravedona (Como, Italia). Unpubl. Ph. D. Thesis, ETH Zürich, 230 pp.

GEBAUER, D. (1996): A P-T-t Path for an (Ultra?-) High-Pressure Ultramafic/Mafic Rock-Association and its Felsic Country-Rocks based on SHRIMP-Dating of Magmatic and Metamorphic Zircon Domains. Example: Alpe Arami (Central Swiss Alps). In Earth Processes: Reading the Isotopic Code; Geophysical Monograph 95, Amer. Geophys. Union.

GEBAUER, D., GRÜNENFELDER, M., TILTON, G., TROMMSDORFF, V. and SCHMID, S. (1992): The geodynamic evolution of garnet-peridotites, garnet-pyroxenites and eclogites of Alpe Arami and Cima di Gagnone (Central Alps) from Early Proterozoic to Oligocene. Schweiz. Mineral. Petrogr. Mitt. 72, 107–111.

GROND, R., WAHL, F. and PFIFFNER, M. (1995): Mehrphasige alpine Deformation und Metamorphose in der nördlichen Cima-Lunga-Einheit, Zentralalpen (Schweiz). Schweiz. Mineral. Petrogr. Mitt. 75, 371–386.

GRUBENMANN, U. (1908): Der Granatolivinfels des Gordunotales und seine Begleitgesteine. Vierteljahresschr. der Naturf. Ges. Zürich 53, 129–156.

GRUJIC, D. (1992): Superposed folding: analogue models and comparison with natural examples from the Maggia nappe (Pennine Zone, Switzerland). Unpubl. Ph. D. Thesis, ETH Zürich, No. 9762, 233 pp.

GRUJIC, D. and MANCKTELOW, N.S. (1996): Structure of the northern Maggia and Lebendun Nappes, Central Alps, Switzerland. Eclogae geol. Helv. 89, 461–504.

HEINRICH, C.A. (1983): Die regionale Hochdruckmetamorphose der Aduladecke, Zentralalpen, Schweiz. Unpubl. Ph.D. Thesis, ETH Zürich, No. 7282, 214 pp.

HEINRICH, C.A. (1986): Eclogite facies regional metamorphism of hydrous mafic rocks in the Central Alpine Adula nappe. J. Petrol. 27, 123–154.

HUNZIKER, J.C., DESMOND, J. and HURFORD, A.J. (1992): Thirty-two years of geochronological work in the Central and Western Alps: a review on seven maps. Mémoires de Géologie (Lausanne), No. 13, 1–59.

HUNZIKER, J.C., HURFORD, A.J. and CALMBACH, L. (1997): Alpine cooling and uplift. In PFIFFNER, O.A., et al. (eds): Deep Structure of the Swiss Alps, Results of NRP 20; Birkhäuser, 260–265.

KLEIN, H.H. (1976): Alumosilikatführende Knauern im Lepontin. Schweiz. Mineral. Petrogr. Mitt. 56, 435–456.

MILNES, A.G. (1974): Structure of the Pennine Zone (Central Alps): a new working hypothesis. Bull. Geol. Soc. Amer. 85, 1727–1732.

MITTELHOLZER, A.E. (1936): Beitrag zur Kenntnis der Metamorphose in der Tessiner Wurzelzone mit besonderer Berücksichtigung des Castionezuges. Schweiz. Mineral. Petrogr. Mitt. 16, 19–182.

MÖCKEL, J.R. (1969): Structural petrology of the garnet-peridotite of Alpe Arami (Ticino, Switzerland). Leidse Geol. Meded. 42, 61–130.

MYSEN, B.O. and BOETTCHER, A.L. (1975): Melting of a Hydrous Mantle: I. Phase Relations of Natural Peridotite at High Pressures and Temperatures with Controlled Activities of Water, Carbon Dioxide, and Hydrogen. J. Petrol. 16, 520–548.

NIGGLI, E. (1970): Alpine Metamorphose und alpine Gebirgsbildung. Fortschr. Mineral. 47, 16–26.

NIGGLI, P., PREISWERK, H., GRÜTTER, O., BOSSARD, L. and KÜNDIG, E. (1936): Geologische Beschreibung der Tessiner Alpen zwischen Maggia- und Bleniotal. Beitr. geol. Karte der Schweiz, N.F. 71, 190 pp.

NIIDA, K. and GREEN, D.H. (submitted): Stability and chemical composition of pargasitic amphiboles in MORB pyrolite under upper mantle conditions. Contrib. Mineral. Petrol.

O'HARA, M.J. and MERCY, E.L.P. (1966): Garnet-peridotite and eclogite from Bellinzona, Switzerland. Earth Planet. Sci. Lett. 1, 295–300.

OTTONELLO, G., ERNST, W.G. and JORON, J.L. (1984): Rare earth and 3d transition element geochemistry of Peridotitic rocks: I. Peridotites from the Western Alps. J. Petrol. 25, 343–372.

PFEIFER, H.R. (1979): Fluid-Gesteins-Interaktion in metamorphen Ultramafititen der Zentralalpen. Unpubl. Ph.D. Thesis, ETH Zürich, No. 6379, 200 pp.

PFEIFER, H.R. (1987): A model for fluids in metamorphosed ultramafic rocks: IV. Metasomatic veins in metaharzburgites of Cima di Gagnone, Valle Verzasca, Switzerland. In: HELGESON, H.C. (ed.): Chemical transport in Metasomatic Processes, Reidel Amsterdam, 591–632.

PFIFFNER, O.A. and HITZ, L. (1997): Geologic interpretation of the seismic profiles of the Eastern Traverse (lines E1–E3, E7–E9): eastern Swiss Alps. In PFIFFNER, O.A. et al. (eds): Deep Structure of the Swiss Alps, Results of NRP 20; Birkhäuser, 73–100.

PFIFFNER, M. and TROMMSDORFF, V. (1997): Evidence for high-pressure metamorphosed ophicarbonate rocks, Cima di Gagnone, Central Alps. Terra Abstracts, suppl. No. 1 to Terra Nova 9, 26.

PREISWERK, H. (1921): Die zwei Deckenkulminationen Tosa–Tessin und die Tessiner Querfalte. Eclogae geol. Helv. 16, 485–496.

RICE, J.M., EVANS, B.W. and TROMMSDORFF, V. (1974): Widespread occurrence of magnesiocummingtonite in ultramafic schists, Cima di Gagnone, Ticino, Switzerland. Contrib. Mineral. Petrol. 43, 245–251.

RISOLD, A.-C., TROMMSDORFF, V., REUSSER, E. and ULMER, P. (1996): Alpe Arami and Cima di Gagnone Garnet Peridotites: Observations Contradicting the Hypothesis of Ultra Deep Origin. Suppl. to EOS, Transactions, AGU Vol. 77, 46, F761.

RISOLD, A.-C., TROMMSDORFF, V., REUSSER, E. and ULMER, P. (1997): Genesis of $FeTiO_3$ inclusions in garnet peridotites from the Central Alps. Terra Abstracts, suppl. No. 1 to Terra Nova 9, 28.

ROST, R., WANNEMACHER, J. and GRIGEL, W. (1974): Die Ultramafitite der Alpe Arami und Croveggio Tessin (Schweiz). Schweiz. Mineral. Petrogr. Mitt. 54, 353–369.

SCHMID, S.M., RÜCK, P. and SCHREUERS, G. (1990): The significance of the Schams nappes for the reconstruction of the paleotectonic evolution of the Penninic zone along the NRP 20-East traverse (Grisons, eastern Switzerland). Mém. Soc. géol. France 156, 263–287.

SCHMID, S.M., PFIFFNER, O.A., FROITZHEIM, N., SCHÖNBORN, G. and KISSLING, E. (1996): Geophysical-geological transect and tectonic evolution of the Swiss-Italian Alps. Tectonics 15, 1036–1064.

SCHMID, S.M., PFIFFNER, O.A. and SCHREURS, G. (1997): Rifting and collision in the Pennine zone of eastern Switzerland. In PFIFFNER, O.A., et al. (eds): Deep Structure of the Swiss Alps, Results of NRP 20; Birkhäuser, 160–185.

SCHMID, S.M., ZINGG, A. and HANDY, M. (1987): The kinematics of movements along the Insubric Line and the emplacement of the Ivrea zone. Tectonophysics 135, 47–66.

SPICHER A. (1980): Tectonic Map of Switzerland, 1:500'000. Edited by the Geological Commission of Switzerland.

STAMPFLI, G.M. (1993): Le Briançonnais, terrain exotique dans les Alpes? Eclogae geol. Helv. 86, 1–45.

TROMMSDORFF, V. (1966): Progressive Metamorphose kieseliger Karbonatgesteine in den Zentralalpen zwischen Bernina und Simplon. Schweiz. Mineral. Petrogr. Mitt. 46, 431–460.

TROMMSDORFF, V. (1980): Alpine metamorphism and Alpine intrusions. In TRÜMPY, R. (ed.): Geology of Switzerland, a guide-book. Schweiz. geolog. Komm., 82–87.

TROMMSDORFF, V. (1990): Metamorphism and Tectonics in the Central Alps: The Alpine Lithospheric Mélange of Cima Lunga and Adula. Mem. Soc. Geol. It. 45, 39–49.

TROMMSDORFF, V. and EVANS, B.W. (1974): Alpine Metamorphism of Peridotitic Rocks. Schweiz. Mineral. Petrogr. Mitt. 54, 333–352.

TROMMSDORFF, V. and NIEVERGELT, P. (1983): The Bregaglia (Bergell) Iorio intrusive and its field relations. Mem. Soc. Geol. It. 26, 55–68.

TRÜMPY, R. (1960): Paleotectonic Evolution of the Central and Western Alps. Bull. Geol. Soc. Amer. 71, 843–908.

TRÜMPY, R. (1980): An outline of the geology of Switzerland. In: Schweiz. Geol. Komm. (ed.): Geology of Switzerland, a guide-book, 1–104.

VON BLANKENBURG, F. (1992): Combined high precision chronometry and geochemical tracing using accessory minerals: applied to the Central-Alpine Bergell intrusion. Chem. Geol. 100, 19–40.

WENK, E. (1955): Eine Strukturkarte der Tessineralpen. Schweiz. Mineral. Petrogr. Mitt. 35, 311–319.

WENK, E. (1970): Zur Regionalmetamorphose und Ultrametamorphose im Lepontin. Fortschr. Miner. 47, 34–51.

Manuscript received November 30, 1997; revision accepted March 25, 1998.