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Ferrogabbroic and basaltic meta-eclogites from the Antrona mafic-ultramafic complex and the Centovalli-Locarno region (Italy and Southern Switzerland) - first results

by *Alberto Colombi*[1] and *Hans-Rudolf Pfeifer*[1]

Abstract

Between the Antrona and the Anzasca Valley in the west and the Centovalli-Locarno region in the east of the southern steep belt of the Pennine zone of the Central Alps, several zones of mafic-ultramafic rocks outcrop almost continuously. They can in part be attributed to well-known ophiolite nappes, such as Antrona and Zermatt-Saas. At about 10 localities mafic meta-eclogites, containing garnet, symplectite, amphibole and often relictic pyroxene have been identified and looked at in detail. Samples from the west (Antrona-Anzasca) contain omphacitic pyroxene and the assemblage garnet-clinopyroxene ± quartz indicates minimum pressures of 14 kbar and temperatures ranging for 500 to 700 °C for the Eoalpine high pressure event. Samples from the eastern part of the section (Centovalli–Maggia–Locarno) contain garnet, symplectite, sodic diopside, amphibole and oligoclase and are interpreted as a transitional stage of retrogressive decomposition of an eclogite paragenesis. In both regions, half of the samples have TiO_2 contents of 4 to 7 wt% and total FeO contents of up to 17 wt%, indicating a ferro-gabbroic origin. Yet, no meta-eclogites have been found in the middle part of the section. Nevertheless, it seems probable that also the eastern occurrences belong to an Eoalpine event, the relics of which survived the later Tertiary Mesoalpine amphibolite facies metamorphism.

Keywords: meta-eclogites, eoalpine metamorphism, pressure-temperature estimates, ophiolites, Central Alps.

1. Introduction and geologic frame

This note reports on some meta-eclogitic rocks sampled in connection with a systematic study of the metamorphism and origin of the Zermatt-Saas and the Antrona zone and their eastern continuation between Saas Fee, the Antrona

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and the Anzasca Valley and the Centovalli-Locarno region (fig. 1). An increasing number of investigations indicate that the Eoalpine high pressure event can be recognized even in areas strongly affected by the Tertiary amphibolite facies metamorphism, like the central and eastern Ticino area (TROMMSDORFF et al., 1975; ERNST, 1977; EVANS, TROMMSDORFF and RICHTER, 1979; VOGLER and VOLL, 1981; EVANS, TROMMSDORFF and GOLES, 1981; HEINRICH, 1982, 1983; IROUSCHEK, 1983, 1985; FREY et al., 1983; AURISICCHIO et al., 1985; BOCCHIO et al., 1985).

In the western and southern part of the central Ticino area meta-eclogites have been mentioned by severel authors (WANG, 1939; FORSTER, 1947; KOBE, 1956, 1966; WETZEL, 1972; LADURON, 1976; KLEIN, 1978; MARTIN, 1982; GRELLER, in prep.), but detailed mineralogical descriptions and exact locations are largely missing. *This* paper contains some mineral and rock analyses and investigates a possible Eoalpine pressure-temperature gradient between the Antrona-Anzasca-Valleys in the west and the Centovalli-Maggia-Locarno-region in the east. The samples come from the Antrona and Zermatt-Saas ophiolite zone and from more northern zones of the southern steep belt, normally attributed to the Contra and Cardada zones respectively (fig. 1, table 1).

Isograds of the Tertiary Mesoalpine metamorphic event in the study area are not known in detail und usually based on relatively few observations (BEARTH, 1958; RHEINHARDT, 1966; WENK and KELLER, 1969; WENK and WENK, 1984). They seem to indicate an upper greenschist facies zone close to the mylonites of the Insubric fault (SCHMID, ZINGG and HANDY, 1986), with an increasing grade northward, reaching the sillimanite grade amphibolite facies close to the Centovalli fault (cf. fig. 1).

Tab. 1 Geographic locations, tectonic units and country rocks of the different meta-eclogite occurrences described in this note (cf. fig. 1).

Sample	Locality	Tectonic unit	Country rock	Geologic map	Coordinates
A 28	A. Moro, Val Loranco	Furgg	Gneiss	Lobrinus/Beglé (1985)	650.54/106.21
MA 24	Passo del Mottone	Antrona	Amphibolite	--	652.47/97.76
MA 25	A.Lavazzero/P.Vallar	Antrona	Amphibolite	Baumann(1979)	651.87/95.86
LO 22	Auressio, V.Onsernone	Cardada	Gneiss	Kobe(1956,1966,1984)	696.95/116.90
MA 3	A. Cardada, Locarno	Cardada	Gneiss	Forster (1947)	705.02/117.39
MA 4	Valleggia, V.Maggia	Cardada	Amphibolite	Forster (1947)	702.13/117.21
LO 41	Cavigliano, Centovalli	Mergoscia	Gneiss	Kobe (1966,1984)	698.76/115.90
UM 75	Ri del Vo, V.Onsernone	Mergoscia	Ultramafics	Kobe (1956,1966,1984)	696.00/118.68
UM 11	Capoli,Dunzio/V.Maggia	Mergoscia	Ultramafics	Kobe (1956,1966,1984)	699.20/118.80

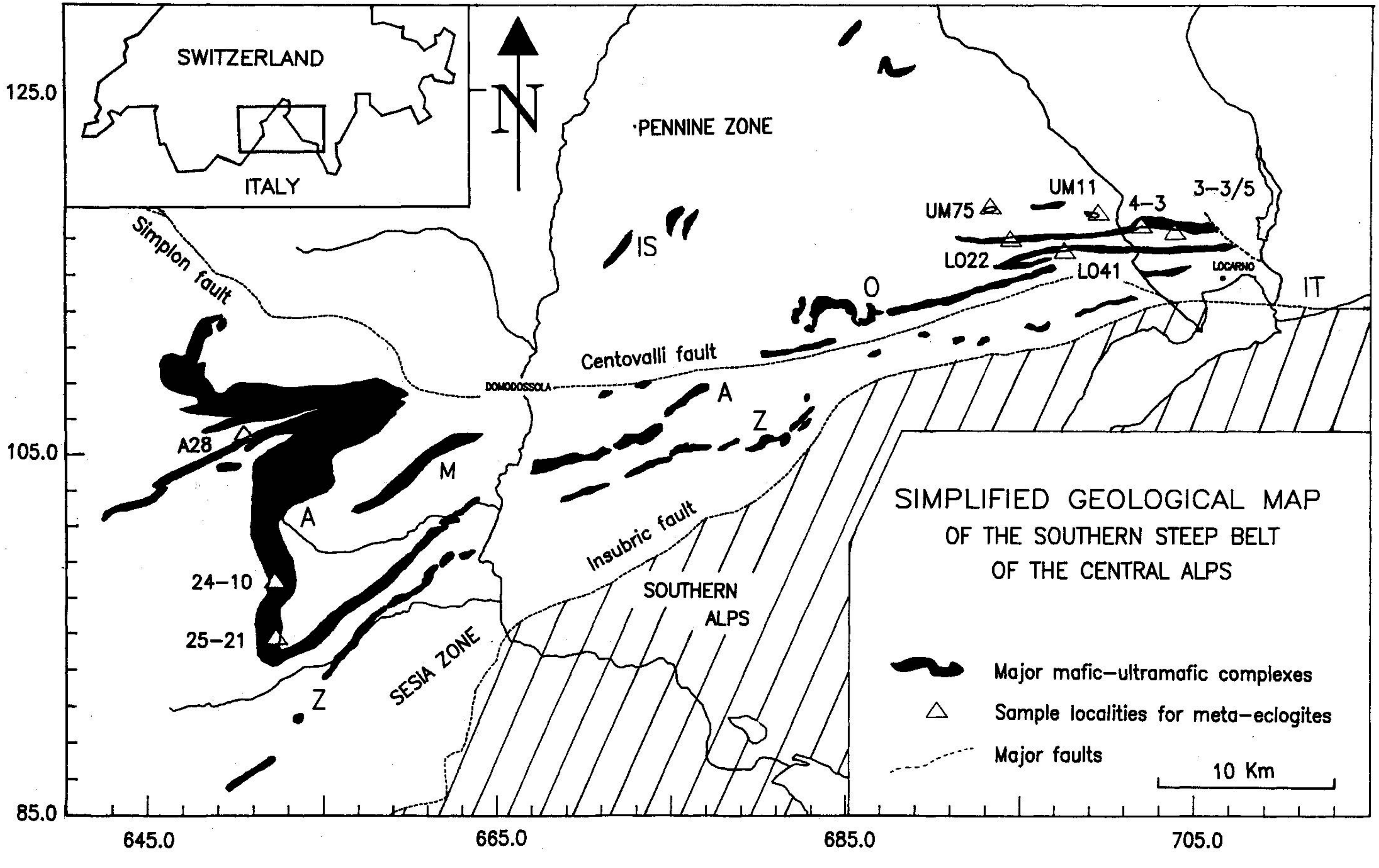

Fig. 1 Simplified geological map of the region between the Antrona and the Anzasca Valleys in the west (left) and the Maggia Valley-Locarno region in the east (right), showing major mafic-ultramafic rock units of the southern steep belt of the Pennine zone (Sesia zone excluded). Note the eastern extension of the Zermatt-Saas zone beyond Val d'Ossola, which has recently been confirmed by careful mapping near Locarno.
Abbreviations: A = Antrona zone, Z = Zermatt-Saas zone, O = Orselina zone, IS = Isorno zone, M = Moncucco zone, IT = Iorio-Tonale fault.

2. Petrography and bulk rock composition

All of the samples are clear relics, that is typically occur in the center of boudin-shape masses, most often situated within massive common amphibolites. Sampling criteria used were the presence of garnet and a slightly lighter green colour than normal amphibolites. Of course, only part of the rocks sampled in this manner were really meta-eclogites. For our study we defined meta-eclogites as clearly mafic rocks, containing, aside from amphibole and plagioclase, garnet and abundant symplectic masses of amphibole, plagioclase and possibly pyroxene. All of the samples we measured in detail contain pyroxene which is sufficiently large that it can be identified by optical means. Table 2 contains the mineralogical composition of some representative samples and fig. 2 shows typical textures of these rocks.

Tab. 2 Mineralogic composition of selected samples of meta-eclogite. Location of samples: fig. 1 and tab. 1.

Mineral	Sample number									
	28	24-10	25-21	22-10	3-3	3-5	4-3	41-3	75-5	11T
Garnet	●	●	●	●	●	●	●	●	●	●
Clinoyroxene	●	●	●	●	●	●	●	●	●	
Quartz		●	●	●			●		●	●
Amphibole	●	●	●	●	●	●	●	●		
Symplectite	●	●	●	●	●	●	●	●	●	●
Plagioclase	●		●		●	●	●			●
Rutile	●	●	●	●	●	●	●			●
Sphene	●			●	●			●		
Opaque	●	●	●	●	●	●	●	●	●	●
White mica	●	●		●						
Epidote	●	●		●		●				
Biotite				●					●	

A look at the bulk rock compositions of table 3 shows that half of the analyzed samples exhibit typical ferrogabbroic compositions with total FeO contents of 14 to 17 weight percent and values of TiO_2 typically between 4 and 7 weight percent. It is interesting to note that mafic eclogite relics often have a ferrogabbroic composition (cf. Cortesogno et al., 1977; Cimmino and Messiga, 1983; Baldelli, Dal Piaz and Lombardo, 1985; Morten, Bocchio and Mottana, 1985; Pognante, 1985). Such compositions conceivably survive more easily a later metamorphism. The essential major element composition is summarized in fig. 3. The trace element composition of the meta-volcanics corresponds to that of modern mid ocean ridge or back arc basalts (MORB) of transitional character (cf. Beccaluva et al., 1983a, b).

3. Mineral chemistry and pressure-temperature estimations

Figs. 4 to 6 show the compositional variation of the major minerals of five selected samples. It is interesting to note that only the samples from the Antrona

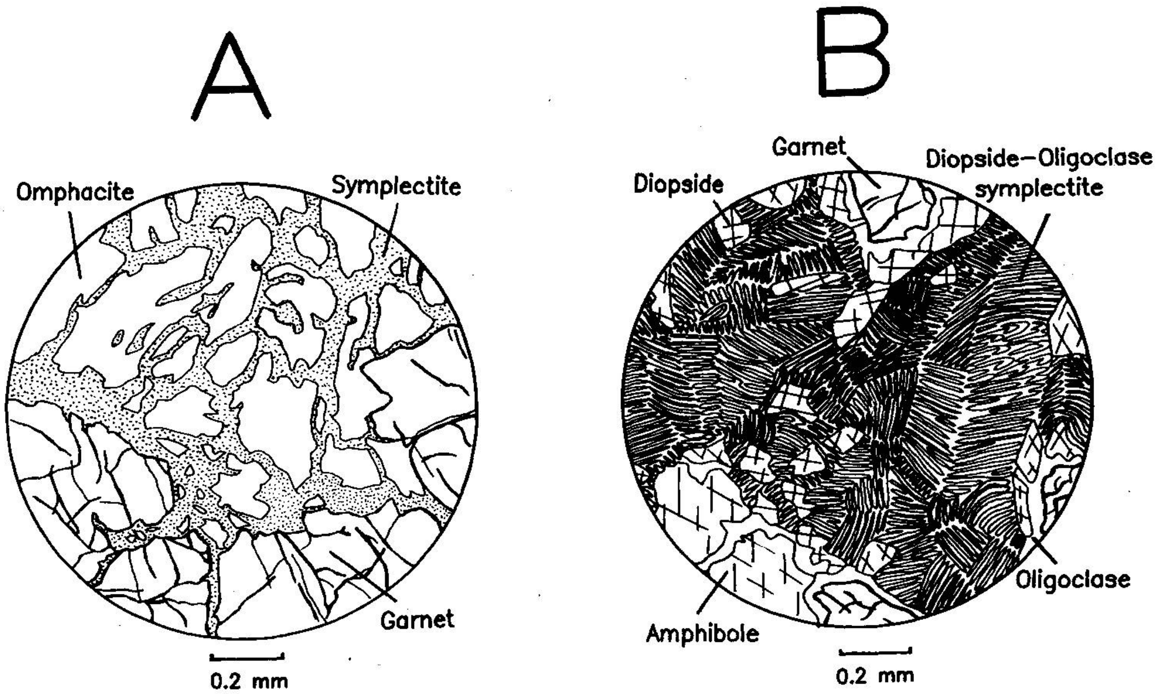

Fig. 2 Typical microstructures of meta-eclogites: A. Well preserved example from the Antrona-zone (sample MA 24-10). B. Original paragenesis to a large degree replaced by symplectite which seems to form pseudomorphs after sodic pyroxene (sample MA 3-3, from A. Cardada, Locarno).

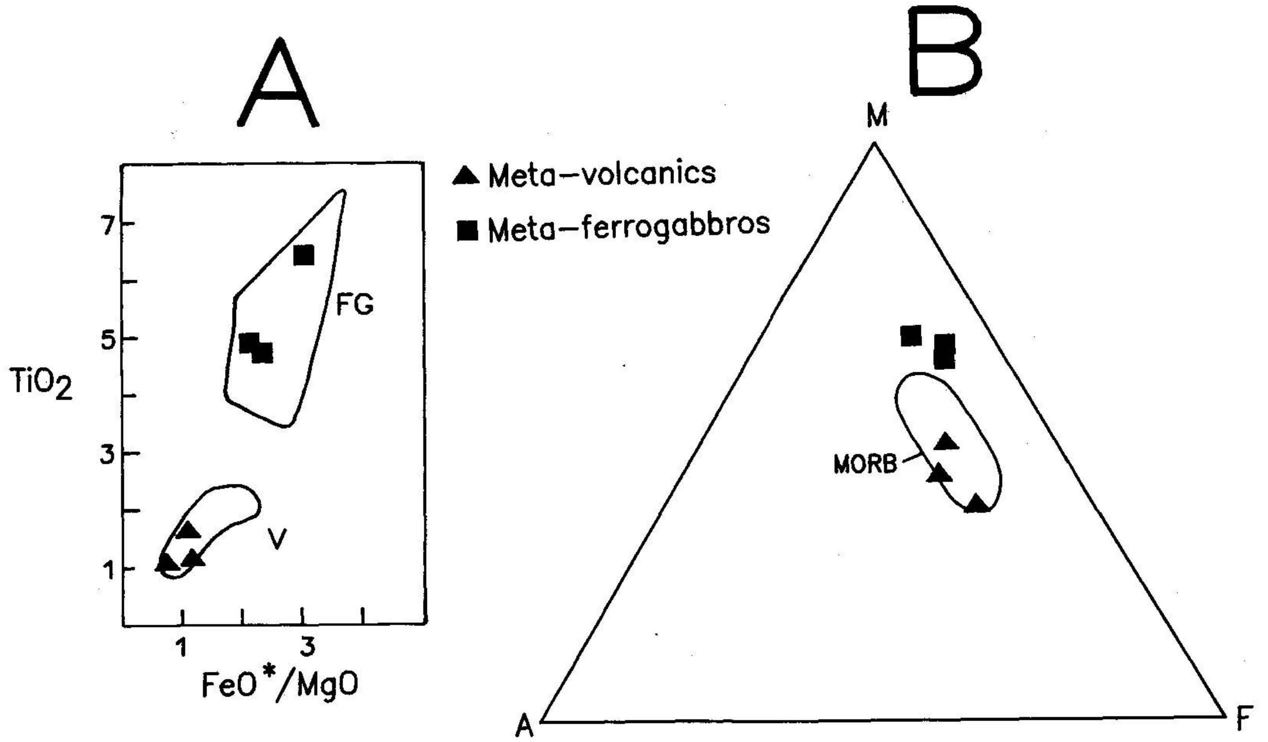

Fig. 3 Major element rock composition of selected meta-eclogites: A. FeO* / MgO versus TiO_2 diagram (FeO* = total iron as FeO). For comparison, several mafic rocks from Liguria are shown as well (PICCARDO, 1983): FG: ferrogabbros, V: volcanics. B. AFM-diagram (A = $Na_2O + K_2O$, F = FeO_{tot}, M = MgO, all as wt%, MORB-field after HÖCK, 1983).

Tab. 3 Selected bulk rock analyses of meta-eclogites in weight percent and ppm respectively. For sample location see fig. 1, for the mineralogical composition, tab. 2. Sample MA 17-15 is a garnet-amphibolite of ferrogabbroic composition from Alpe Ciape/Antrona Piano, for comparison. Analytical methods: XRF, colorimetry (FeO) and coulometry (CO_2). Analysts: J.-M. Favre and J.-C. Lavanchy. -: below detection limit (Nb: 4 ppm, U: 8, Rb: 4, Pb: 7, Cu: 4, Nd: 25).

	25-17	24-10	A-28	17-15	3-3	25-21
SIO2	49.04	49.51	49.03	41.77	44.06	43.82
TIO2	1.03	1.69	1.16	4.81	4.93	6.42
AL2O3	16.53	14.61	15.36	13.50	15.13	11.21
FE2O3	2.03	3.46	2.95	5.13	3.29	5.39
FEO	6.23	5.19	7.46	12.90	11.42	12.71
MNO	0.16	0.11	0.19	0.47	0.23	0.27
MGO	9.97	7.43	7.67	7.37	6.65	5.75
CAO	9.45	12.90	10.58	9.26	10.78	9.93
NA2O	3.52	3.81	2.91	1.92	1.96	3.05
K2O	0.14	0.01	0.51	0.09	0.06	0.00
P2O5	0.02	0.07	0.06	0.79	0.39	0.07
H2O+	1.78	0.99	1.64	1.58	1.29	1.18
CO2	0.12	0.05	0.18	0.06	0.03	0.02
CR2O3	0.04	0.07	0.03	0.00	0.01	0.01
NIO	0.02	0.01	0.00	0.00	0.00	0.00
TOTAL	100.08	99.91	99.73	99.65	100.23	99.83
TRACE ELEMENTS IN PPM						
NB	-	-	-	8	7	5
ZR	70	134	63	144	72	124
Y	23	30	24	73	25	43
SR	172	143	210	54	144	37
U	0	0	0	0	-	0
RB	-	-	17	-	7	-
TH	0	0	0	0	0	0
PB	-	-	-	-	-	10
GA	16	16	19	6	23	31
ZN	70	32	101	126	98	166
CU	61	-	54	131	6	59
NI	197	65	64	20	33	53
CO	40	34	45	48	50	73
CR	348	288	197	17	44	50
V	130	183	214	404	270	492
CE	309	197	187	308	178	308
ND	-	-	-	-	-	-
BALb	32	11	139	47	45	58
BALa	16	27	148	80	41	85
LA	0	0	0	153	81	219
SC	29	39	52	60	38	66
S	0	0	0	57	0	1955
TOTAL	1488	1182	1390	1670	1117	3762

and Anzasca Valleys (belonging to the Antrona und Furgg zones respectively) show typical pyroxene compositions of real eclogites, that is omphacite. The samples from Locarno (belonging to the Cardada zone) contain relatively sodium-rich *diopsidic* pyroxene (average 0.9 wt% Na_2O) as compared to pyroxene from *amphibolites* of the southern steep belt (average 0.6 wt% Na_2O). In contrast to the latter, these meta-eclogites contain a much more sodic plagioclase (An 15–25, typical values in amphibolites: 40–50, WENK and KELLER, 1969). Similar mineral compositions have been mentioned by WENK and KELLER (1969, p. 189), ERNST (1977) and BOCCHIO et al. (1985) in eclogitic rocks containing omphacite relics of the Alpe Arami-Cima Lunga nappe E of our study area.

The following mass balances, which consider the real mineral compositions, could account for the transition from eclogite to amphibolite: (1) breakdown of omphacitic clinopyroxene and formation of diopside and oligoclase:

$$\underbrace{10\,\mathit{jadeite} - 6\,\mathit{pl} - 5\,\mathit{tk}}_{\text{omphacitic pyroxene}} + 5\text{ quartz} = 5\text{ diopside} + \underbrace{5\,\mathit{albite} - \mathit{pl}}_{\text{oligoclase}}$$

(2) Breakdown of garnet and formation of tschermakitic amphibole:

$$4\text{ diopside} + \underbrace{5\,\mathit{pyrope} + 4\,\mathit{mc}}_{\text{garnet}} + 4\text{ quartz} + 4\,H_2O = \underbrace{4\,\mathit{tremolite} + 5\,\mathit{tk}}_{\text{amphibole}}$$

Exchange vectors (Thompson et al., 1982): *mc* = $CaMg_{-1}$, *pl* = plagioclase: $NaSiCa_{-1}Al(IV)_{-1}$, *tk* = tschermak: $Al(IV)Al(VI)Mg_{-1}Si_{-1}$.

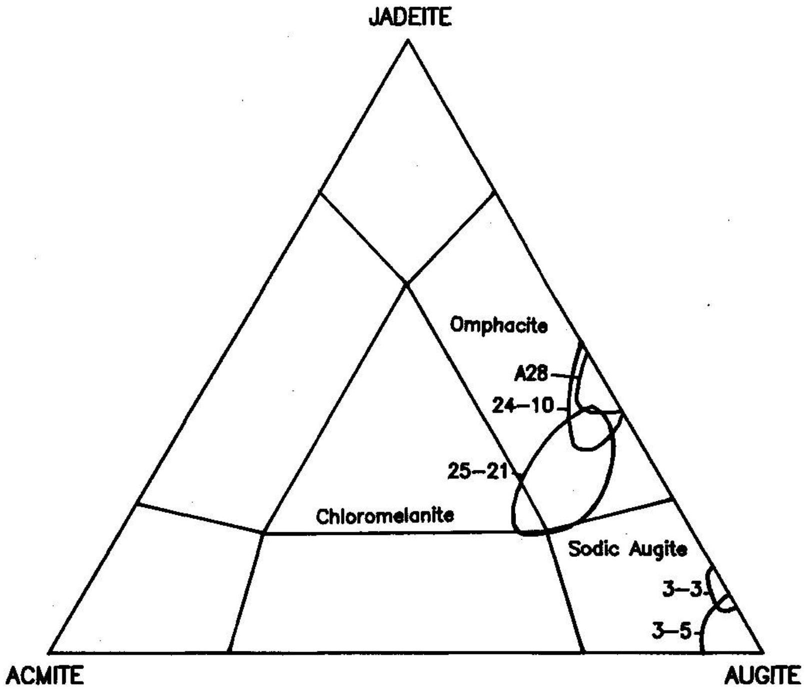

Fig.4. Pyroxene compositions. Fe^{3+} has been calculated, using charge balance and site saturation arguments (LAIRD, 1977, 1978). No zoning has been observed.

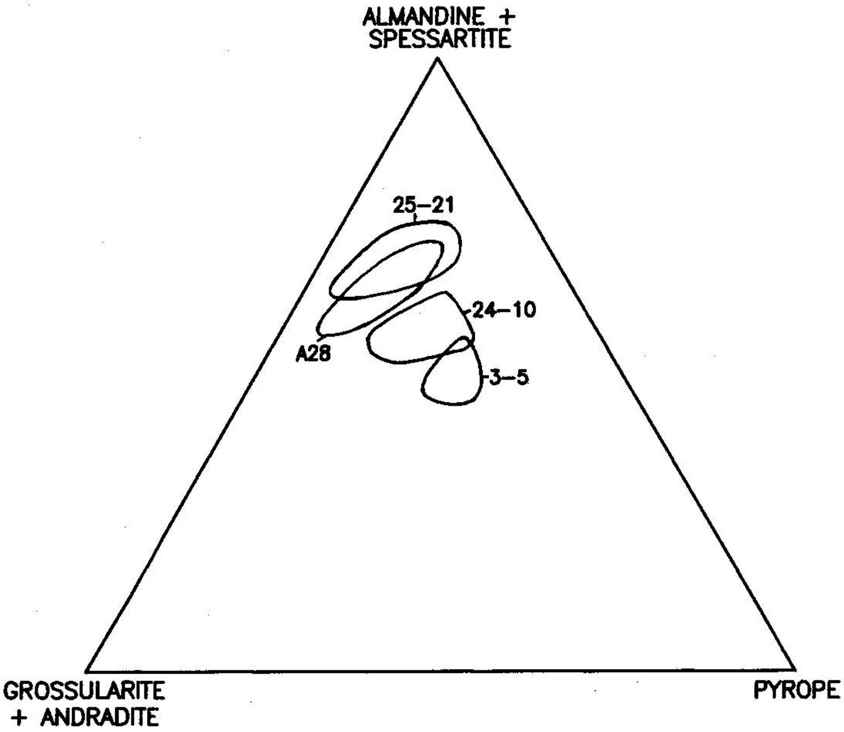

Fig. 5 Garnet compositions. Fe^{3+} has been calculated using charge balance and site saturation arguments. CaO decreases 2–3 wt% from the center towards the rims of the grains, whereas MgO and FeO increase by about the same amount.

We think therefore, that our samples from Locarno have once been real eclogites and that probably most of the "eclogites" described by FORSTER (1947) from this area are in fact transitional stages between eclogites and common amphibolites.

Using the Fe^{2+}-Mg partitioning between garnet and omphacite, a few temperature brackets have been determined for the Antrona-Anzasca samples with the geothermometer equation of ELLIS and GREEN (1979; even for the ferrogab-

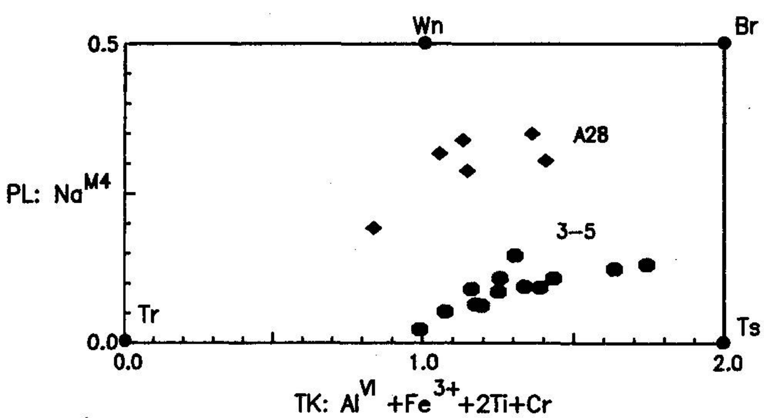

Fig. 6 Amphibole compositions: Fe^{3+} has been calculated using the charge balance and site saturation arguments of LAIRD (1977, 1978). Abbreviations: Br: barroisite, Ts: tschermakite, Tr: tremolite, Wn: winchite.

Tab. 4 Minimum and maximum temperatures of selected samples, calculated with the geothermometer equation of Ellis and Green (1979), together with corresponding garnet and omphacite compositions (Ga: garnet, Px: pyroxene, jd: jadeite component). The chosen 17 kb pressure to calculate the temperatures is an arbitrary value above the minimum pressure for all samples.

Sample	Temp. at 17kb		Fe2+/Mg Ga	Fe2+/Mg Px	$X_{Ca,Ga}$	$K_{D,Ga-Px}$	$X_{jd,Px}$
28	min.	512 °C	6.48	0.26	0.26	24.85	0.42
	max.	568 °C	3.96	0.25	0.20	16.12	0.45
24-10	min.	587 °C	1.85	0.14	0.20	13.08	0.34
	max.	780 °C	1.79	0.33	0.18	5.43	0.46
25-21	min.	545 °C	9.63	0.51	0.24	18.88	0.32
	max.	697 °C	3.39	0.52	0.15	6.42	0.37

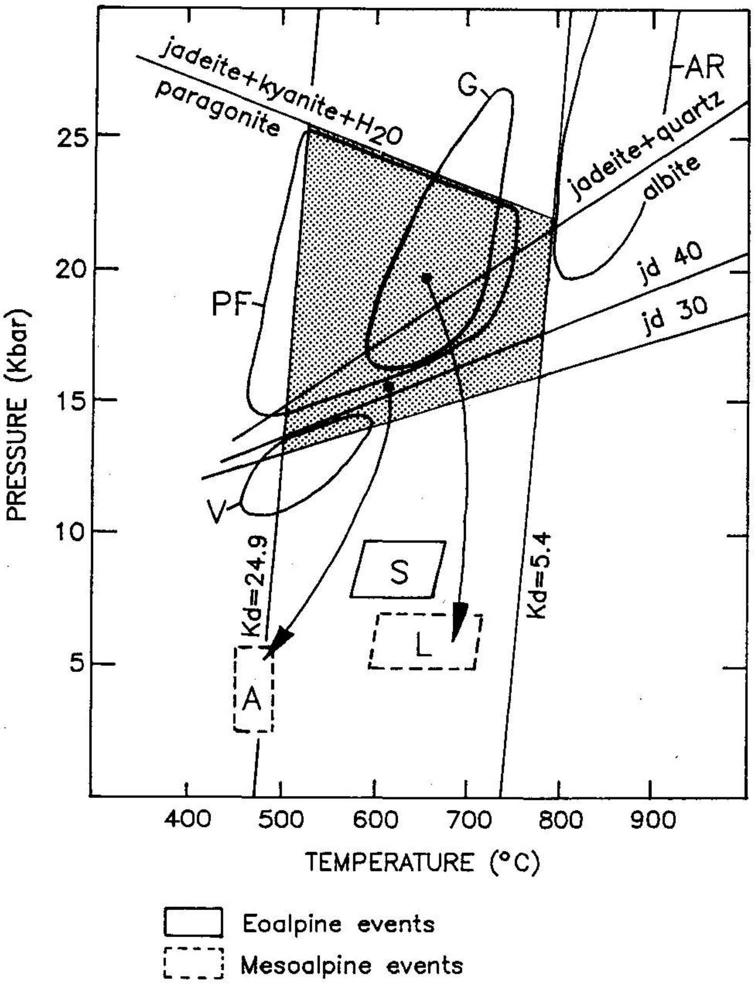

Fig. 7 Estimated pressure-temperature conditions for different meta-eclogites. The field coloured in grey corresponds to the *Eoalpine* P–T-field of the Antrona-Anzasca samples, based on the Fe^{2+}-Mg-partitioning of garnet-clinopyroxene (extreme K_D values are indicated) and the jadeite-content of the omphacite. The A- and the L-field mark *Mesoalpine* P-T-conditions for the Antrona-Loranco and the Locarno-region respectively (source of data: MEYER, 1983, and FREY et al., 1980). Other P–T estimations for the Eoalpine event are added for comparison: AR: Alpe Arami, G: Gagnoné, V: Vals (HEINRICH, 1983); PF: Pfulwe-Zermatt (OBERHÄNSLI, 1980); S: Simano (IROUSCHEK (1983, 1985). Arrows mark possible retrogression paths for the western and the eastern part of the study area.

broic compositions $Mg/Mg + Fe^{2+}$ ratios are within their experimental conditions and calculated Fe^{3+} in the minerals concerned is low. Minimum pressure estimates are based on the pair quartz-omphacite using the jadeite-contours of GASPARIK and LINDSLEY (1980). An upper pressure limit is given by the occasional presence of white mica and the absence of kyanite. Table 4 and fig. 7 summarize the results: minimum pressures lie around 14 to 16 kbar and calculated temperatures show a considerable spread between 480 and 720 °C.

4. Discussion

During this survey completely preserved eclogite assemblages of the Eoalpine event have only been found in the western part of the area studied, where the Mesoalpine metamorphism has greenschist to lower amphibolite facies grade. The tentative pressure-temperature estimates for the Antrona rocks based on three samples confirm a considerable temperature variation, as already detected by other authors for the nearby Zermatt-Saas zone (cf. OBERHÄNSLI, 1980; MEYER, 1983; fig. 7). No eclogite relics are known yet from the region Domodossola-Vigezzo Valley. However, we think that the symplectic diopside-oligoclase-garnet-meta-eclogites found in the amphibolite facies grade rocks of the Centovalli-Maggia-Locarno region represent additional remnants of the Eoalpine high pressure event, which might have affected large parts of the central Ticino area.

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