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Manganese Ore Deposit of Monte del Forno
Its Stratigraphic and Structural Implications

By *Alfredo Ferrario**) and *Attilio Montrasio***)

With 3 figures and 1 table

Abstract

The Monte del Forno Mn-ore deposit (Western Val Malenco, Central Alps) is related to amphibole-pyroxene greenschists (probably metatuffites) in quartzitic rocks that we call "Basal Quartzites". The latter represent the basal levels of the metasedimentary cover of the Monte del Forno amphibolites that show, in the upper levels, pillow structures, pillow breccias and hyaloclastites containing Fe-Cu-Zn mineralizations. The upper levels of metasedimentary cover consist of andalusite-garnet biotitic schists and diopside-plagioclase quartzschists.

The mineral association of the Mn stratabound deposit includes: spessartitic garnet, Mn-Ca carbonate, tephroite and rhodonite. Psilomelane and pyrolusite are present as secondary minerals.

Fe-Cu-Zn and Mn-Fe mineralizations and associated rock types, show many similarities to "unmetamorphosed" volcano-sedimentary sequences and their mineralizations of Mesozoic ophiolite complexes in the Mediterranean Basin (Northern Apennine, Corsica, Cyprus).

The attribution of the stratigraphic sequence and their mineralizations of Monte del Forno area, to a particular structural unit (Suretta or Margna nappe) is unsatisfactory, as we consider them to constitute a structural independent unit: the Monte del Forno Series.

INTRODUCTION

Sedimentary rocks directly overlying ophiolitic complexes in many cases include Mn-Fe ore deposits connected mainly with radiolarites and cherts. These stratabound mineralizations are in close relationship with Fe-Cu-Zn mineralizations in the upper levels of pillow lavas and basal sediments (Northern Apen-

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nine, Corsica, Cyprus). Accordingly Mn-Fe and Fe-Cu-Zn ore deposits are stratigraphic markers for volcano-sedimentary sequences in Mesozoic ophiolites (FERRARIO, 1973; BRIGO and FERRARIO, 1974).

The Monte del Forno amphibolites and associated metasediments contain Fe-Cu-Zn and Mn-Fe mineralizations respectively. Stratigraphical, structural and paragenetic evidence suggests that these ore deposits belong to an ophiolite complex involved in the alpine metamorphism.

In this paper we will concentrate on the mineralogy and the stratigraphic meaning of Monte del Forno Mn-ore deposit and its paleogeographic and structural implications.

GEOLOGICAL SETTING

The investigated Mn-ore deposit is located 1 km SE of Monte del Forno (Western Val Malenco, Central Alps, Italy), near the point 2761 (Italian coord. 5658.3142; sheet 18 I NO, I.G.M.).

R. STAUB (1946) distinguished three structural units in this area; from E to W these are: Margna nappe, Suretta nappe and Bergell Massif. In the Margna Crystalline (pre-Paleozoic) he included two interesting lithologic units: "Muretto-Quarzite" and "Tiefere Fedoz-Serie". The Suretta nappe consists of a crystalline basement, Triassic and Jurassic metasediments and ophiolites (in particular Monte del Forno Amphibolites and Malenco Serpentinites).

TH. GYR (1967) agreed with STAUB's interpretation of lithologic and structural units apart from the amphibolites and serpentinites which "... cannot be attributed to a particular nappe with certainty. ..." At least this author recognized a possible stratigraphic relation between Andalusite-garnet biotitic schists (= "Tiefere Fedoz-Serie" p.p., STAUB, 1946), and Diopside-plagioclase quartzschists (= "Muretto-Quarzite" p.p., STAUB, 1946), and between these formations and Monte del Forno amphibolites.

H.-R. WENK (1973) considered the surrounding rocks of the granite (including andalusite-garnet biotitic schists and, presumably, diopside-plagioclase quartzschists) to be of unclear tectonic position: "... They underlie the Margna nappe and most likely also the Suretta nappe." Nevertheless stratigraphic relationships do not exist between these lithologic units and the other surrounding rocks of the Bergell granite, in particular the Monte del Forno amphibolites.

Based on our detailed geological field work and studies of Mn-Fe and Fe-Cu-Zn mineralizations, we think that the andalusite-garnet biotitic schists, the diopside-plagioclase quartzschists, the Monte del Forno amphibolites and a new lithological unit, the "Basal Quartzites", can be attributed to the same stratigraphic sequence, of ophiolitic type, that we call: Monte del Forno Series (Fig. 1).

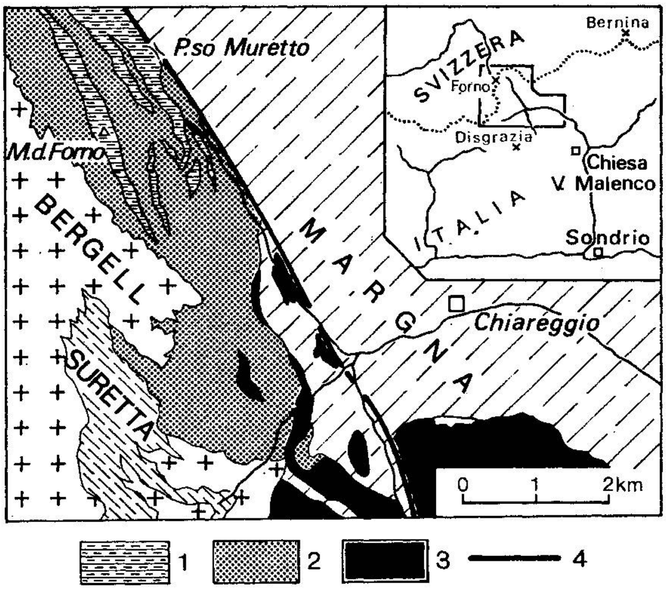

Fig. 1. Geological sketch map of Monte del Forno-Monte Disgrazia area. Metaophiolites and their metasedimentary cover: (1) Diopside-plagioclase quartzschists + Andalusite-garnet biotitic schists + Basal Quartzites; (2) Monte del Forno Amphibolites; (3) Malenco Serpentinites; (4) Muretto-Ventina Line.

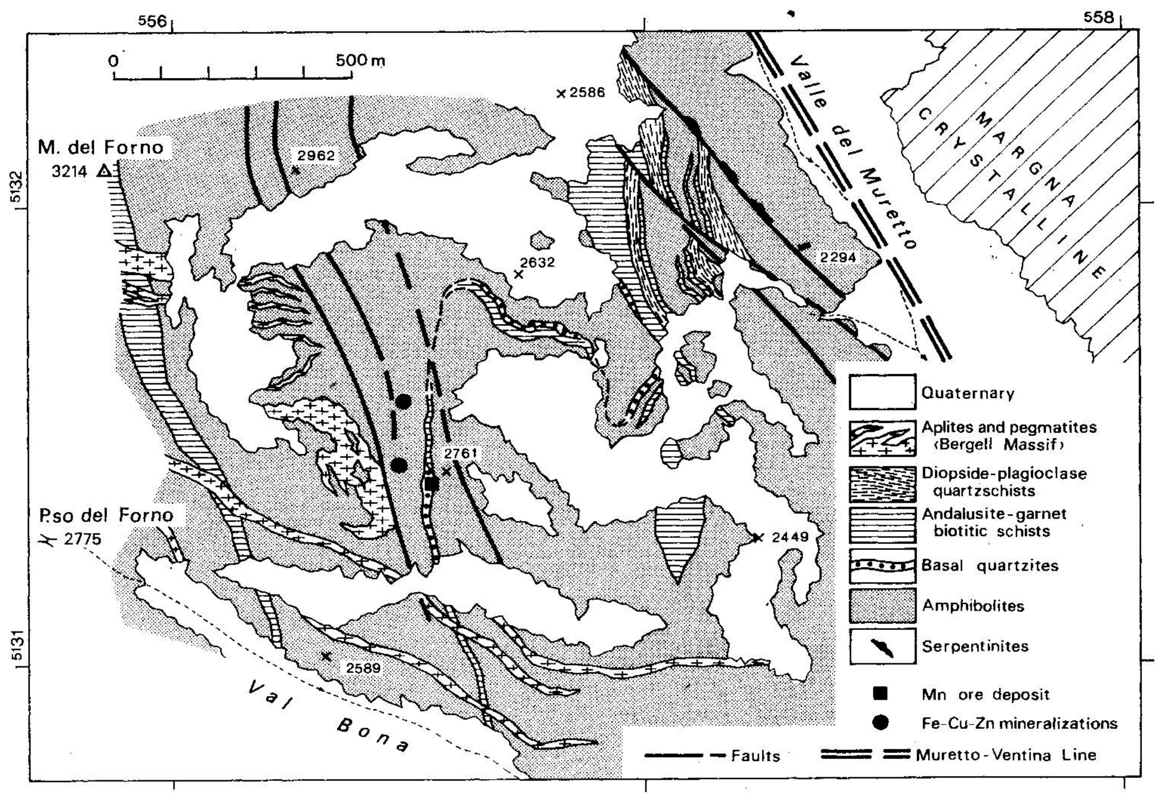

Fig. 2. Geological map of Valle del Muretto, SE of Monte del Forno (Val Malenco, Central Alps).

THE MONTE DEL FORNO SERIES

The Monte del Forno Series (Montrasio, in prep.) consists of folded metamorphic rocks grouped in two genetically different units (Fig. 2):

Metavolcanic rocks, mainly composed of amphibolites of different kinds, with, locally, well preserved metapillow lavas (Montrasio, 1973), metapillow breccias and, probably, metahyaloclastites; these volcanic features are found in the upper part of the Monte del Forno amphibolites and contain small stratiform Fe-Cu-Zn mineralizations mined in the past (Ferrario and Montrasio, in preparation).

Metasedimentary cover, composed, from bottom to top, of: "Basal Quartzites" (a new lithologic unit) with local intercalations of amphibole-pyroxene greenschists and marbles, andalusite-garnet biotitic schists (= Andalusit-Granat-Biotitschiefer, Gyr, 1967; = Tiefere Fedoz-Serie p.p., Staub, 1946), diopside-plagioclase quartzschists (= Diopsid-Plagioclase-Quarzschiefer, Gyr,, 1967; = Muretto Quarzite p.p., Staub, 1946). Mn-silicates and carbonates are associated with amphibole-pyroxene greenschists in "Basal Quartzites".

Serpentinitic slices are tectonically included in the Monte del Forno Series.

The boundaries between the metasedimentary formations and between these and metavolcanic rocks are frequently gradual or alternating and seem to be primary.

THE MANGANESE ORE DEPOSIT

In the area of the Mn ore deposit (Fig. 3), the Monte del Forno Series is incompletely exposed; amphibolites and "Basal Quartzites" show the best outcrops:

The *amphibolites*, with schistose texture, are composed of green actinolitic hornblende (Table 1, column I), plagioclase (45% An), epidote, diopsidic pyroxene (Table 1, column II); other common minerals are: quartz, sphene, ilmenite, apatite and pyrrhotite. All these minerals are metamorphic, except pyroxene which shows relict, probably primary, structures (Montrasio, 1973). Close to the boundary with the "Basal Quartzites" amphibolites increase gradually in biotite and quartz content and two kinds of plagioclase are present, the first one deeply saussuritized, the second one (48% An) clear but weakly zoned. Granular magnetite and tourmaline are widespread in this lithotype.

The "*Basal Quartzites*" form a layer up to 25 m thick; they consists of beds (millimeter to centimeter thick, max. 1–2 dm) of quartz, biotite (Table 1, column XV) and, less commonly, zoned garnet (Table 1, columns XIII and XIV), alternating regularly, that give to the rock its typical compositional banding. Epidote, magnetite, pyroxene, tourmaline, amphibole and white mica are variously associated with the above minerals. Particularly interesting is the almost

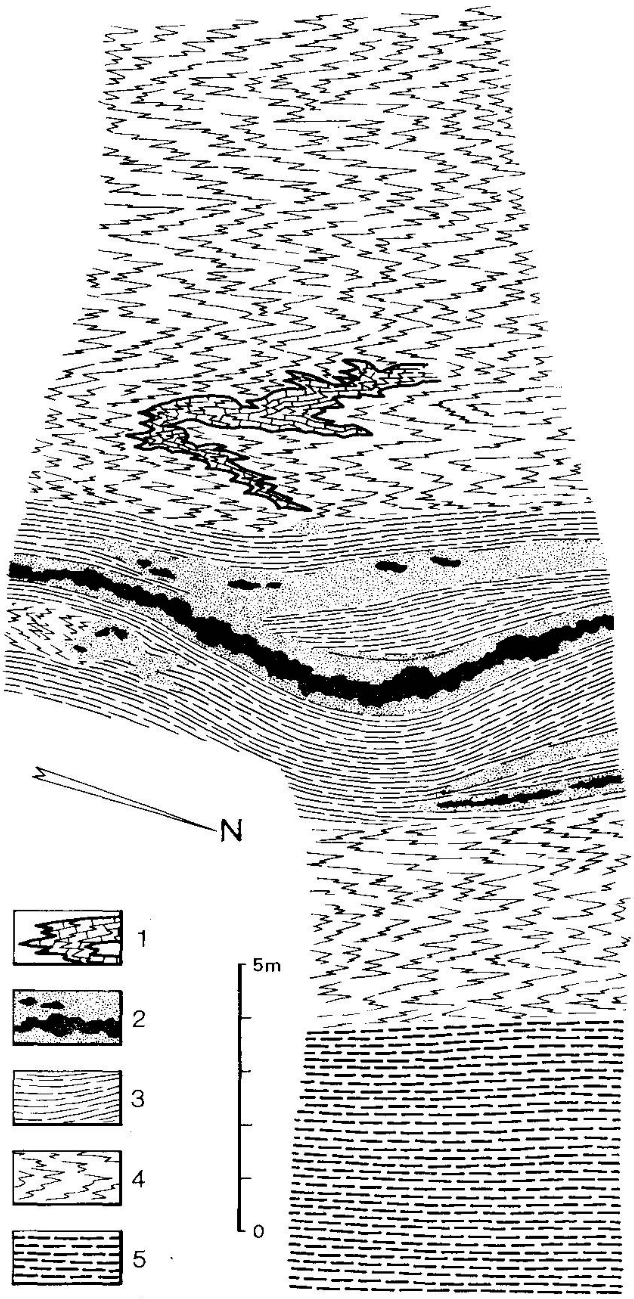

Fig. 3. Stratigraphic sequence including Mn-ore deposit, 1 km SE of Monte del Forno (see Fig. 2): (1) Ca-silicate bearing marble; (2) Ore-body: Tephroite + rhodonite + spessartite + Ca-Mn carbonate (black), and Spessartitic rock of the salbands (dotted); (3) Amphibole-pyroxene greenschists; (4) Basal Quartzites; (5) Monte del Forno Amphibolites.

ubiquitous presence, in the quartzites, of magnetite scattered either as granules or in form of nodules (max. 7 mm sized), invariably rimmed by quartz.

The banded quartzites are intensely folded and this feature, together with the mineralogical composition, lithological association and stratigraphic position, distinguishes them from diopside-plagioclase quartzschists. Folded compositional banding is discordant to schistosity and lithologic boundaries of the other rocks (see Fig. 3).

Two greenschists layers (5 m and 1 m thick) are intercalated in the "Basal Quartzites" (in Fig. 3 only the 5 m thick unit is represented). They consist of

Table 1. *Microprobe analysis*[1]) *of rock forming minerals from series including*

		MD-500		MD-505		MD-510			
	[2])								
	[3])	amph.	pyrx.	plag.	garn.	garn.	teph.	rhon.	carb.[4])
		I	II	III	IV	V	VI	VII	VIII
SiO_2		39.92	51.99	67.00	36.53	35.44	29.31	45.88	–
TiO_2		0.79	–	0.03	0.11	0.01	0.06	0.06	0.03
Al_2O_3		11.79	0.79	20.16	18.98	18.98	0.06	0.04	0.05
Cr_2O_3	[5])	–	–	–	–	–	–	–	–
FeO	[5])	19.00	11.69	0.15	13.78	1.92	1.35	0.20	0.07
MnO	[5])	0.35	0.49	0.05	20.65	42.54	65.95	45.61	21.82
NiO	[5])	–	–	–	–	–	–	–	–
MgO		8.55	11.25	–	1.22	0.05	0.89	0.56	0.49
CaO		11.81	24.01	1.79	8.47	1.65	0.21	5.16	74.39
Na_2O		1.55	0.39	11.06	–	–	–	–	–
K_2O		0.75	–	0.25	–	–	–	–	–
Total		94.51	100.61	100.48	99.74	100.59	97.84	97.52	97.02
						Numbers of ions on the basis of n oxigens			
		n = 23	n = 6	n = 8	n = 12	n = 12	n = 4	n = 15	
Si		6.316	1.969	2.918	2.986	2.955	0.999	5.025	
Al		1.684	0.031	1.069	0.014	0.045	0.002	0.005	
Al		0.514	0.004	–	1.813	1.820	–	–	
Fe'''		–	–	0.005	–	–	–	–	
Ti		0.094	–	–	0.007	–	0.001	–	
Cr		–	–	–	–	–	–	–	
Mg		2.017	0.635	–	0.149	0.006	0.045	0.091	
Ni		–	–	–	–	–	–	–	
Fe''		2.514	0.370	–	0.942	0.134	0.038	0.018	
Mn		0.047	0.016	0.002	1.430	3.004	1.904	4.230	
Ca		2.002	0.974	0.081	0.741	0.147	0.008	0.605	
Na		0.475	0.029	0.928	–	–	–	–	
K		0.151	–	0.013	–	–	–	–	

[1]) *Analyst:* G. D. TAYLOR, Department of Geology and Mineralogy, Marischal College, University of Aberdeen, Scotland.

[2]) MD-500: epidotic amphibolite; MD-505: amphibole-garnet greenschist; MD-510: Mn-mineralization; MD-513: amphibole-garnet greenschist; MD-520: Ca-silicate marble; MD-521: "Basal Quartzites"; MD-524: andalusite-garnet biotit schist.

fine-grained, schistose rock, characteristically showing a rhythmic compositional banding (0,1 to 10 mm circa) with green hornblende, hedenbergite (Table 1, column IX), quartz, biotite, and garnet (Table 1, column IV) each alternatively being the main component. Magnetite, locally occurring as macroscopic nodules, sphene and ilmenite are widespread in the rocks, whereas postcinematic albite (Table 1, column III) is distributed irregularly. These greenschists (cropping out for 150 m), which are supposed to have a tuffitic origin because of their stratigraphic position, lithologic association with metavolcanic rocks, and mineralogical assemblages, are the host rocks of Mn mineralization.

Intercalations of Ca-silicates bearing marbles are also included in the "Basal Quartzites"; their mineralogical composition consists of equigranular calcite (Table 1, column X), idioblastic grossular (Table 1, column XI), xenoblastic

Mn-ore deposit, SE of Monte del Forno (Val Malenco, Italy; see figs. 2 and 3)

	MD-513	MD-520			MD-521			MD-524	
	pyrx.	carb.[4])	garn.	pyrx.	garn. core	garn. rim	biot.	amph.	garn.
	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
	52.50	–	37.71	52.34	36.62	36.20	36.26	45.08	38.60
	0.02	0.22	1.11	–	0.07	0.07	1.56	0.08	0.17
	0.98	–	13.68	0.54	19.13	18.74	17.07	10.50	21.34
	0.02	–	–	–	–	–	–	–	–
	9.57	0.10	9.10	7.06	13.87	14.99	16.22	15.96	22.54
	2.02	1.01	2.60	2.21	20.54	23.27	0.93	0.78	5.30
	0.05	–	–	–	–	–	–	–	–
	11.40	0.24	0.15	12.24	1.59	1.60	12.05	11.18	1.00
	23.34	98.65	33.41	25.67	4.33	4.63	0.05	12.18	11.48
	0.07	–	–	0.16	–	–	0.10	0.72	–
	0.02	–	–	0.01	–	–	9.43	0.70	–
	100.62	100.22	97.76	100.23	96.22	99.57	93.75	97.18	100.43

	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
	n = 6		n = 12	n = 6	n = 12	n = 12	n = 22	n = 23	n = 12
	1.978		3.077	1.971	3.068	2.990	5.530	6.745	3.050
	0.022		–	0.024	–	0.010	2.470	1.255	–
	0.022		1.315	–	1.889	1.814	0.598	0.697	1.987
	–		–	–	–	–	–	–	–
	0.001		0.068	–	0.005	0.005	0.179	0.009	0.010
	–		–	–	0.001	0.001	–	–	–
	0.640		0.018	0.687	0.199	0.197	2.639	2.494	0.118
	0.002		–	–	–	–	–	–	–
	0.301		0.628	0.222	0.971	1.035	2.069	1.997	1.489
	0.064		0.180	0.070	1.457	1.627	0.120	0.099	0.355
	0.942		2.919	1.036	0.389	0.410	0.008	1.953	0.972
	0.051		–	0.012	–	–	0.029	0.209	–
	0.001		–	–	–	–	1.834	0.134	–

[3]) amph. = amphibole; biot. = biotite; carb. = carbonate; garn. = garnet; plag. = plagioclase; rhon. = rhodonite; pyrx. = pyroxene; teph. = tephroite.
[4]) Calculated as total carbonate.
[5]) Cr_{tot} as Cr_2O_3; Mn_{tot} as MnO; Fe_{tot} as FeO (except structural formula of analysis III); Ni_{tot} as NiO.

pyroxene (Table 1, column XII), olivine, epidote, quartz and sphene. An epidote + garnet-rich reaction rim characterizes the quartzite-marble boundary.

In the vicinity of the Mn ore deposit, the "Basal Quartzites" are stratigraphically related (see Fig. 2) with andalusite-garnet biotitic schists whose principal minerals are: biotite, white mica, quartz, garnet (Table 1, column XVII), amphibole (Table 1, column XVI), andalusite, zircon, magnetite, pyrrhotite and ilmenite.

Although the *Mn-ore deposit of Monte del Forno* was in the past explored and mined (hauling shaft and scarce dumps) it has not been reported previously in the geological literature. The ore bodies (up to 20 m long and 1 m thick) have stratiform features and show marginal bands composed of spessartitic garnet (Table 1, column V), Mn-Ca carbonate (Table 1, column VIII), polygonal granoblastic tephroite (Table 1, columns VI) and rhodonite (Table 1, column VII; 2V = 77°, opt. +, lacking of twinning); this latter is present as granules inside carbonates minerals and in many cases shows a weak alteration; amphibole and quartz are rare. Psilomelane and pyrolusite are present as alteration minerals in the form of superficial crusts or late veins.

These mineral assemblages and metamorphic parageneses are quite similar to those described by PETERS et al. (1973), at Passo del Muretto, probably in the same stratigraphic position of the Monte del Forno Mn ore deposit. Furthermore many other Mn-mineralizations are present in different structural units in the Bernina Group (JAKOB, 1923; GEIGER, 1948; TROMMSDORFF et al., 1970; PETERS et al., 1973).

DISCUSSION AND CONCLUSION

The Monte del Forno Series is composed of metavolcanic rocks and its metasedimentary cover, made up of "Basal Quartzites", andalusite-garnet biotitic schists and diopside-plagioclase quartzschists.

The mineral assemblages in these lithotypes and in the Mn-ore body (actinolitic hornblende + plagioclase 48% An; rhodonite + spessartite + tephroite; andalusite + almandine + biotite; diopside + plagioclase 45% An) show a relatively high grade, predominantly thermal metamorphism, probably due, in this area, to the Bergell contact metamorphism (TROMMSDORFF, pers. comm.) overprinted on the Lepontine metamorphism.

Mn-Fe mineralization in the "Basal Quartzites" and Fe-Cu-Zn mineralizations in the upper levels of the Monte del Forno amphibolites have the same significance and, probably, the same age as the stratigraphic markers already mentioned for volcano-sedimentary sequences present in the "unmetamorphosed[1])" Mesozoic ophiolites of the Mediterranean Basin (i.e. Northern Apennine, Corsica, Cyprus) where associations of pillow basalts with Fe-Cu-Zn mineralizations and of cherty-radiolaritic formations with sporadically interbedded tuffites and Mn-Fe mineralizations, micritic limestone, pelitic and flysch-type formations, are common (FERRARIO, 1973; BONATTI et al., 1976; BRIGO et al., 1976).

For comparison we consider the Monte del Forno Series belonging to an ophiolite-sedimentary sequence, probably Mesozoic, involved in the alpine metamorphism.

In this context the attribution of the Monte del Forno Series to a particular structural unit (Suretta or Margna nappe) is unsatisfactory; in contrast our

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[1]) With "unmetamorphosed" ophiolites we mean also ophiolites involved in oceanic metamorphism.

data indicate that it should be considered a paleogeographically, and therefore structurally, independent unit.

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