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The post-Triassic sediments of the ophiolite zone Zermatt-Saas Fee and the associated manganese mineralizations

By PETER BEARTH and HANS SCHWANDER[1])

ABSTRACT

The post-Triassic sediments of the Zermatt-Saas area are reviewed. Four lithostratigraphic sequences can be distinguished. The paleogeographically northernmost (external) one is represented by marine sediments of the Briançonnais platform, whereas the southernmost (internal) sequence, called the Oceanic series, is connected with the former oceanic crust, now represented by the ophiolites of Zermatt-Saas Fee. Two different series, both probably derived from the distal continental margin in the north, intervened between these.

The second part of this paper deals with the manganese and iron concentrations characteristic of the oceanic series. Their areal distribution and the chemical composition of the most important minerals are presented.

The Mn-bearing outcrops are separated by Mn-poor sediments, which can easily be confused with Triassic sediments or with Paleozoic basement rocks.

The distribution of the Mn-bearing sediments demonstrates that the ophiolites of the Zermatt-Saas area form a north-vergent recumbent fold with a west-plunging axis. The position of this fold within the nappe pile of Zermatt is illustriated by Figure 15. The scetch shows clearly the tectonic independence of the ophiolite zone.

ZUSAMMENFASSUNG

Die folgende Arbeit befasst sich zunächst mit den posttriassischen Sedimenten der Region von Zermatt. Hier können vier verschiedene Entwicklungen unterschieden werden. Die Reihe beginnt im Norden (extern) mit der Schwellenfazies des Briançonnais und endet im Süden (intern) mit den Tiefseesedimenten, die an die Ophiolithe gebunden sind (sogenannte ozeanische Serie). Zwei brekzienführende Schichtfolgen - die Serie des Gornergrates und diejenige der Combinzone - vermitteln zwischen diesen zwei Extremen.

Im zweiten Teil der Arbeit werden die für die ozeanische Serie typischen Anreicherungen von Mangan und Eisen besprochen, Beispiele für den Chemismus der wichtigsten Mineralien aufgeführt und die sporadisch auftretenden Mn-Knollen beschrieben.

Die im Felde leicht erkennbaren Mn-führenden Vorkommen werden streckenweise durch Mn-arme abgelöst, was leicht zu Verwechslungen mit Trias- oder Paragesteinen des Grundgebirges führen kann.

Die Verteilung der Mn-führenden Sedimente zeigt, dass die Ophiolithe von Zermatt-Saas eine westwärts einfallende, nordvergente liegende Falte bilden. Die Situation dieser Falte im Deckenbau von Zermatt ist in Figur 15 dargestellt. Deutlich kommt dabei die tektonische Unabhängigkeit dieser Ophiolithzone zum Ausdruck.

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Introduction

Four lithologically distinct post-Triassic sedimentary sequences may be dinstinguished within the southern and central Penninic zone of the Valais. Their stratigraphic sequences are schematically sketched on Figure 1 and labeled with *A*, *B*, *C*, *D* respectively. They correspond to a palaeogeographic profile from the north to the south. Sequence *A* represents a northern continental margin series, corresponding to the submerged platform of the Briançonnais zone. The southernmost sequence *D* is an oceanic pelagic sequence and was deposited directly on mesozoic crust of the former Tethys ocean. This oceanic crustal material represents the main constituent of the ophiolite zone Zermatt-Saas Fee. The sequence *B* is intermediate between *A* and *D* and derived from the distal continental margin. The origin of sequence *C* is not well established. It could be derived from the distal southern continental margin, south of the oceanic area, or it could be emplaced in its present structural position above the ophiolites by back-thrusting from the north. In contrast to the sequence *D* the Jurassic to younger sediments of the sequences *A*, *B* and *C* are underlain by Triassic sediments.

The post-Triassic sequence *A* is characterized from bottom to top by: dark limestones and quartzitic schists of the middle Jurassic. Liassic sediments are missing. Sediments of late Jurassic to possibly early cretaceous age occur as coarse-grained marbles with thin chert bands (now quartzite). These are overlain, with a hiatus, by greenish chlorite-sericite marbles probably representing upper Cretaceous to lower Tertiary pelagic limestones. These marbles grade continuously into a sequence of calcareous sandstones and black shales. This formation is regarded as an Eocene flysch deposit (ELLENBERGER 1952, BEARTH 1978).

The oceanic sequence *D* was deposited directly on the ophiolites. The sequence begins with very finely laminated reddish quartzites (metaradiolarites) alternating with yellowish marbles. These beds may be regarded as equivalent of the well-known radiolarites and associated Calpionella limestones of the Ligurian Apennines (STEINMANN 1926). The higher levels of the succession are iron-magnesian rich metapelites. Garnet + chloritoide + quartz + mica is the characteristic mineral assemblage of these rocks. The metapelites are overlain by calcschists and micaceous quartzites. In the upper part of the sequence thin layers and bands of greenschists (prasinites) may be found as intercalations within the metasediments. This sequence presumably represents Cretaceous sedimentary and volcanic rocks (BEARTH 1976).

Series *B* is derived from between the continental margin sequence *A* and the pelagic sequence *D*. Sequence *C* occurs in allochthonous position above the sequences *A* and *D*. *B* shows a certain analogy to *A* whereas *C* comprises some lithologies typical of *D*.

The rocks of the sequence *B* (like those of *A*) rest on a Variscan basement of plutonic and high grade metamorphic rocks, capped by Permo-Triassic quartzites and conglomerates (BEARTH 1953, 1957, 1964, 1967, 1973). The Permo-Triassic rocks are covered in turn by remnants of Triassic limestones and dolomites, sedimentary breccias containing components of Triassic carbonate rocks and of dark grey limestones (ressembling lower Liassic crinoidal calcarenites) in a limestone matrix.

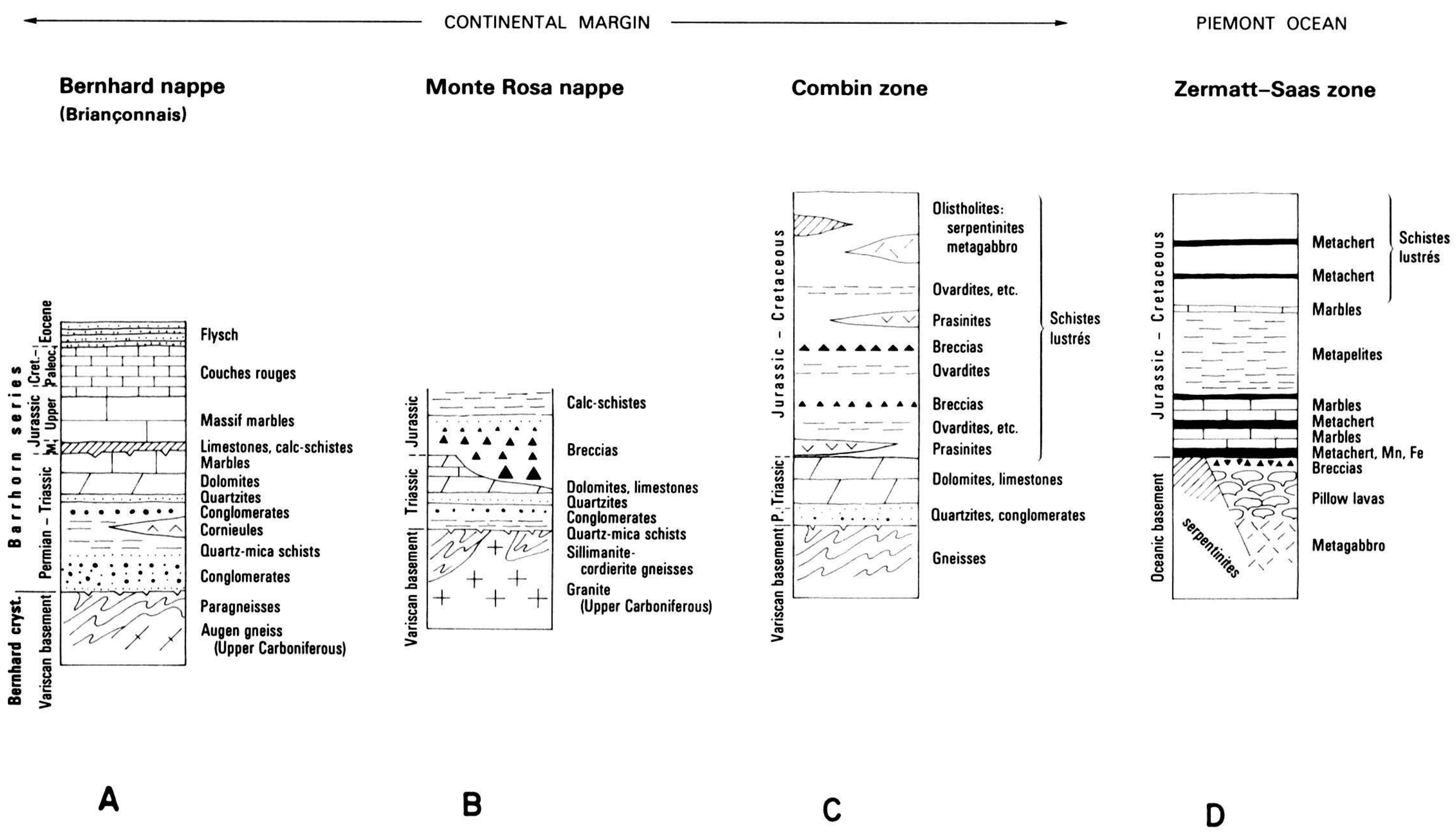

Fig. 1. Schematic sections of the four different stratigraphic sequences of the Zermatt area (see text).

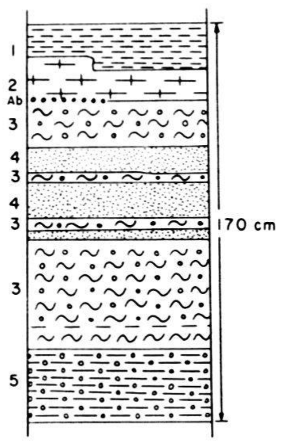

Fig. 2. Detail from the section through the Combin zone (along the path Zermatt-Trift, altitude 1970 m). 1 = Calcschists, 2 = marbles, 3 = albite-rich micaschist, 4 = muscovite quartzite with intercalations of 3, 5 = chlorite-phengite-albite gneiss.

This sequence is well exposed on the ridge and the southern slopes of the Gornergrat. Consequently it was named the Gornergrat zone (BEARTH 1953). It represents the original sedimentary series overlying the Monte Rosa crystalline basement.

The rocks of the facies *C* (called the Combin zone) occur between the ophiolites of Zermatt-Saas Fee and the thrust plane of the Lower Austro-Alpine Dent Blanche nappe. The entire series is strongly folded and sheared (WILSON 1978). Defined as above, the term "Combin zone" describes a tectonic unit. This unit is composed of a number of different slabs of "schistes lustrées" (calc-micaschists) and metabasic rocks (of sedimentary of volcanic origin) separated by thin bands of strongly deformed Triassic quartzites, limestones and dolomites (see Fig. 2 and BEARTH 1953). Pillow structures have been found in metabasic rocks (mainly prasinites and ovardites) outside the region of Zermatt (DAL PIAZ 1971). Meta-radiolarites represent an additional but rare rock type of the Combin zone. Strongly deformed lenses of serpentinites, metagabbros (fuchsite-schists) and other ophiolitic rocks frequently occur in the upper part of the Combin zone.

We interpret these ophiolitic rocks either as tectonic slices or as olistoliths.

The critical mineral assemblages found in the rocks of the Combin unit are diagnostic for greenschist-facies metamorphism (BEARTH 1953, 1959, 1973). This is in contrast to the zone of Zermatt-Saas Fee where eclogitic high pressure assemblages have been found. Hence it may be concluded that the Combin unit was separated from the ophiolite nappe prior to the late Cretaceous subduction event.

The manganese and iron mineralization in the zone *D*

A sketch of the frontal part of the ophiolite nappe of Zermatt-Saas Fee is presented in Figure 3. As already described, the ophiolites are often covered by sedimentary quartzites yielding manganese minerals. It is interesting to note that the sedimentary layering typically found in radiolarites is still preserved in these rocks. This layering consists of an alteration of originally silica, Mn- and clay-rich layers that were not destroyed by the subsequent deformation and recrystallization. Therefore, the original contact between sediments and ophiolites may still be preserved in places. We believe this to be the case at several localities in the area, for instance on the east ridge of the Oberrothorn.

Table 1: *List of the hitherto determined minerals of the Mn-bearing outcrops. The most important minerals are in italics.*

Actinolite	Calcite	Ilmenite	Rhodochrosite
Albite	Chlorite	*Magnetite*	Richterite
Ankerite	*Epidote*	*Manganophyllite*	Rutile
Apatite	Glaucophane	*Piemontite*	*Spessartite*
Braunite	Hematite	Phlogopite	Titanite
			Tourmaline

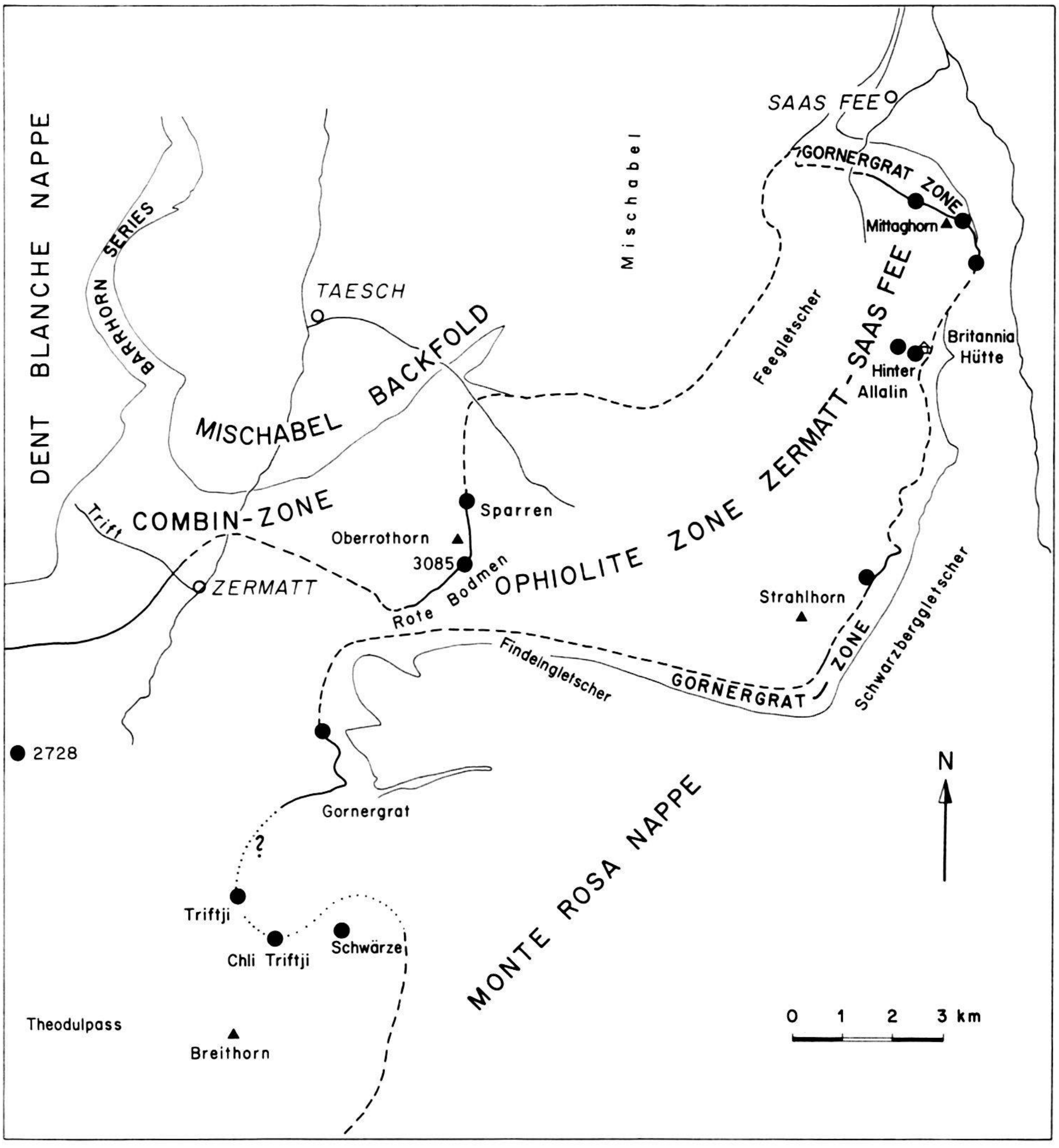

Fig. 3. Map showing the major outcrops with Mn- and Fe-mineralizations in the Zermatt-Saas Fee area.

At a number of localities, enrichments of manganese (rarely of iron as well) have been found. Figure 3 shows these outcrops as solid circles. The most frequently observed Mn-minerals are: braunite, spessartite, piemontite and mangano-phyllite. Commonly all these Mn-minerals are present. For additional minerals see Table 1. A number of very rarely observed minerals have not been identified yet. (See also CORTESOGNO et al. 1979, DAL PIAZ 1969, DAL PIAZ et al. 1979, DEBENEDETTI 1965, ELTER 1971.)

Chemical composition of minerals[2])

A large number of microprobe analyses of minerals has been performed by H. Schwander. Most of them are represented in the diagrams (Fig. 4, 5, 6, 7 and 8) and in the Tables 2 and 3.

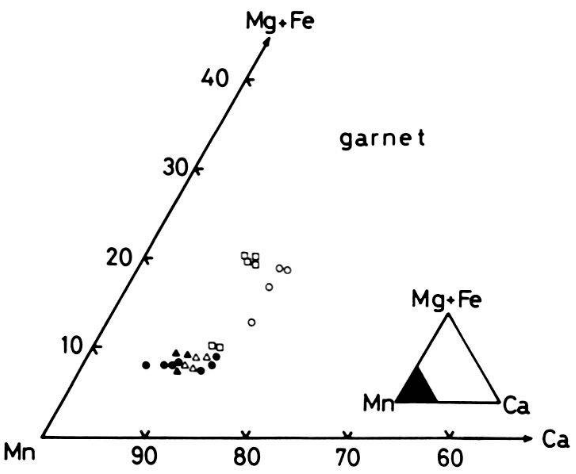

Fig. 4. Composition of spessartite in a Mn-Ca-(Mg + Fe) diagram.

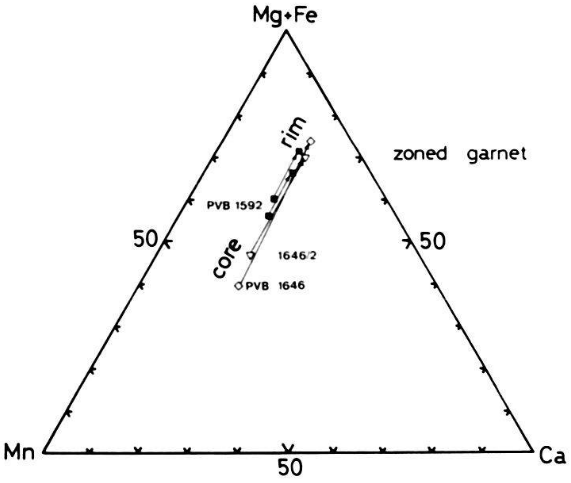

Fig. 5. Zonation in garnet from metapelite represented in a Mn-Ca-(Mg + Fe) diagram.

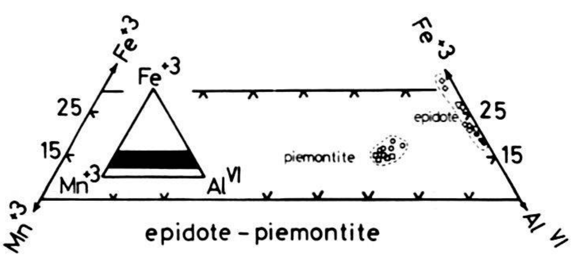

Fig. 6. Composition of epidote and piemontite in a Mn^{3+}-Fe^{3+}-Al^{VI} diagram.

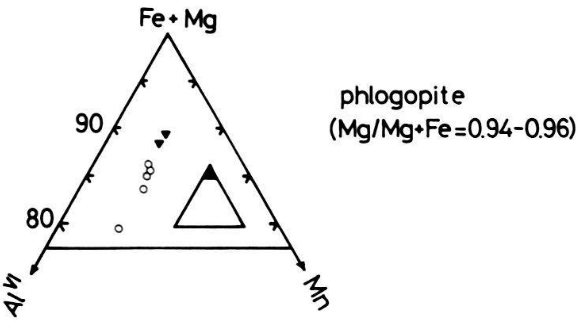

Fig. 7. Composition of phlogopite in a (Fe + Mg)-Mn-Al^{VI} plot.

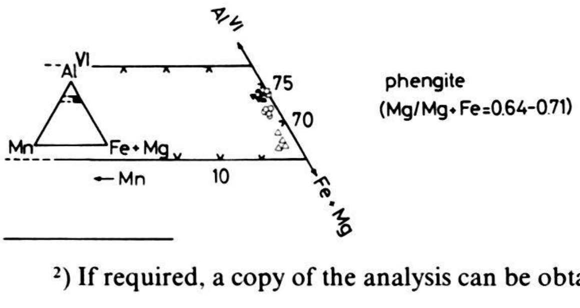

Fig. 8. Composition of phengite in a (Fe + Mg)-Mn-Al^{VI}plot.

[2]) If required, a copy of the analysis can be obtained from the second author.

Table 2: *Analysis of amphiboles.*

PVB	1411	1617	1617	1623	1623	1623	1623	1621	1621	1621
	Actinolites			Ferro-actinolites				Richterites		
SiO_2	53.51	55.71	54.96	52.70	50.99	49.33	51.03	52.81	52.70	53.02
Al_2O_3	2.77	0.59	0.89	2.10	2.54	2.63	2.23	4.63	4.57	4.08
FeO	7.95	7.52	8.10	17.54	15.80	19.38	16.32	13.77	13.92	13.30
MnO	0.42	3.19	3.89	2.98	4.65	3.21	4.61	1.20	1.33	1.97
MgO	18.05	18.58	18.06	8.66	11.82	9.51	11.69	13.08	12.87	13.85
CaO	10.58	10.23	10.24	9.48	7.78	9.84	7.78	5.34	5.46	5.60
Na_2O	1.62	0.50	0.38	1.26	1.65	1.10	1.63	5.02	5.35	4.48
K_2O	0.16	0.03	0.02	.11	.10	.16	.11	.18	.19	.16
TiO_2	0.12	-	0.12	.08		.16		.08	.15	
	95.18	96.35	96.66	94.91	95.33	95.32	95.40	96.11	96.54	96.46

number of ions on the basis of 23(O)

	1411	1617	1617	1623	1623	1623	1623	1621	1621	1621
Si	7.74	7.98	7.91	8.04	7.75	7.65	7.78	7.75	7.73	7.76
Al	.26	.02	.09		.25	.35	.22	.25	.27	.24
Al	.21	.08	.07	.38	.21	.13	.17	.55	.52	.46
Ti	.01		.02	.01		.02		.01	.02	
Mg	3.89	3.97	3.87	1.97	2.68	2.20	2.65	2.86	2.81	3.o2
Fe^{+2}	.88	.90	.98	2.24	2.01	2.51	2.08	1.51	1.65	1.51
Mn		.05	.06	.38	.10	.14	.09			
Ca				.02						
Fe^{+2}	.10							.12	.06	.11
Mn	.05	.33	.41		.50	.28	.50	.15	.17	.24
Ca	1.64	1.57	1.58	1.53	1.27	1.63	1.27	.84	.86	.88
Na	.21	.10	.01	.37	.23	.09	.23	.90	.92	.76
Na	.24	.04	.09		.25	.24	.26	.53	.60	.51
K	.03	.01	.01		.02	.03	.02	.03	.04	.03

←

The analysed minerals have been taken from the following rocks:

PVB		rock-type	locality
1411	▼	Magnetite-Albitegneiss	Rote Bodmen,P.3085
1592	■	Garnet and Chloritoid bearing-schist	Ober Rothorn
1615	△	Spessartite-quartzite	Sparren
1617	▲	Spessartite-quartzite	Sparren
1618	▼	Albite-Spessartite-quartzite	Sparren
1621		Carbonate-Hornblende-Garnet-quartzite	Sparren
1623	●	Spessartite-quartzite	Sparren
1629	□	Piemontite-quartzite	Hörnligrat,P.2728
1638	◓	Spessartite-Piemontite-quartzite	Saas Fee
1646	◇	Magnetite-Albitegneiss	Kessiengletscher,Saas Fee
1646/2	▽	Magnetite-Albitegneiss	Kessjengletscher,Saas Fee
1731	○	Spessartite-Piemontite-quartzite	Saas Fee

Table 3: *Microprobe analysis of tourmaline and chloritoid.*

	tourmaline PVB 1731	chloritoid PVB 1592
SiO_2	35.89	23.73
Al_2O_3	29.89	41.76
FeO	2.83	24.10
MnO	3.25	0.30
MgO	9.61	2.33
CaO	.66	.02
Na_2O	3.02	
TiO_2	.12	
B_2O_3*	10.49	
total	75.76	92.24
	29(O)	12(O)
Si	5.94	
B	3.00	
Al	5.83	
Ti	.02	
Fe	.39	
Mn	.46	
Mg	2.37	
Ca	.12	
Na	.98	
	4.32	

* calculated on the basis of 3 B

Remarks to the chemical composition of the minerals

In the following the compositional range of some minerals is given: *Garnet* (in the quartzites): spessartite 70–84 mol%, almandite 1–8 mol%, pyrope 1.6–7.1 mol%, grossularite 6.6–12.2 mol%. These garnets are idiomorphic, colorless and zoned.

The garnet from the chloritoid-bearing metapleites (PVB 1592) turned out to be almandite with 5.2–11 wt% MnO whereas the associated chloritoid and phengite contain only a few tenth percent of MnO. A few examples of the zoning in these garnets are shown in Figure 5. A chloritoid analysis is presented in Table 3.

The dominant *mica* in the Mn-bearing quartzites is a Mn-poor phengite with 0.5–0.8 MnO and 2.2–4.2 FeO (Fig. 7). It is often overgrown by phlogopite.

The *epidotes* in the quartzites have 11–13 wt% Fe_2O_3, whereas the associated piemontite has only 7–7.5 Fe_2O_3 but 10–12% Mn_2O_3. Colorless epidote and piemontite could be found in the same thin-section.

Amphiboles (Table 2): Following the classification of Leake they are either actinolites, ferroactinolites or richterites. The MnO content varies from 0.42 to 4.65 wt%, the higher values belonging to the actinolitic amphiboles.

Tourmaline (Table 3) has been found in all examined quartzitic rocks. In several outcrops highly abundant tourmaline gives a black color to the rock (e.g. Sparren and Hinter Allalin).

The occurrence of B is probably due to submarine hydrothermal activity. Following the work of HARDER (1970) the concentration of *B* is mainly caused by the adsorption on illitic clay.

The manganese nodules

Metamorphic manganese nodules sporadically occur in the Zermatt area. They are always related to the Mn-rich sediments of section *D*.

A large number of fossil Mn-nodules were found at the locality Sparren in the outer Täsch valley (BEARTH 1976). The size of the nodules varies considerably at this locality, several of them exceeding 10 cm in diameter; however, most of the nodules are much smaller (Fig. 9, 10, 11, 12).

The nodules were flattened by the Alpine deformation and partly deformed to ellipsoids whose long axes are parallel to the main direction of fold axes in the Zermatt area (f_2, WILSON 1978). In cross sections through the nodules a concentric mineralogical zonation can be observed (Fig. 9, 10 and 11).

By analogy (JENKYNS 1970) it is believed that the Mn-nodules of Zermatt have formed on the Tethys seafloor during middle to late Jurassic time. Despite Alpine polyphase metamorphism and deformation the Mn-nodules preserved characteristic primary structures (i.e. concentric shell structure, Fig. 9, 10 and 11). The structures found in the Zermatt Mn-nodules are remarkably similar to those recently described by SOREM (1979) and HUBRED (1975) from the present ocean floor.

W. B. Stern made two analyses of the black core of samples PVB 1663 (Fig. 9) and 1664 (Fig. 10) by X-ray diffractometry. Both gave identical results (Table 4). The black central part of the analyzed specimens (see Fig. 9 and 10) shows an

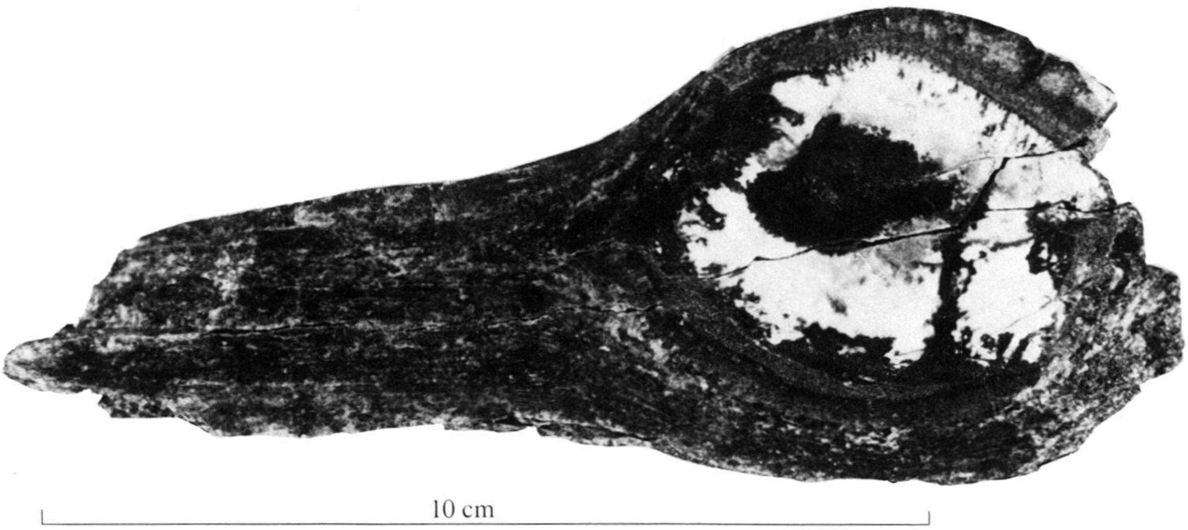

Fig. 9. Manganese nodule (PVB 1663). The black core consists of garnet and spessartite, the surrounding light coloured shell is composed of spessartite and quartz. The nodule is embeded in a fine laminated schist with alternating quartz-rich bands and spessartite and (or) mica-rich bands. Notice the manganese dendrites along the boundary of the light shell.

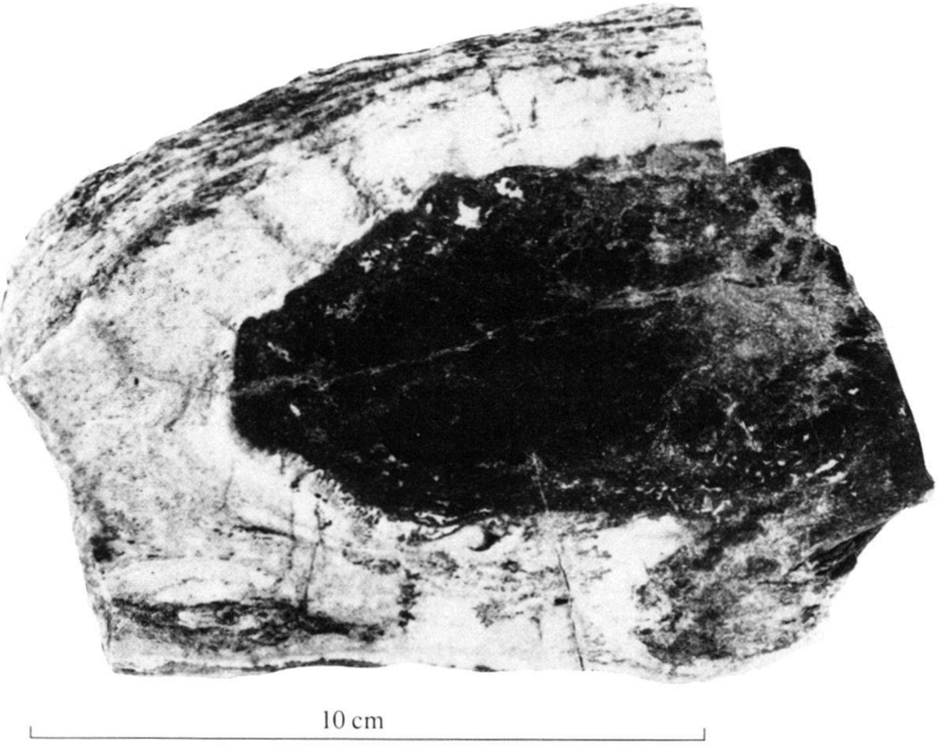

Fig. 10. Manganese nodule (PVB 1664). The core consists of braunite and spessartite. The border zone shows Mn-dendrites on radial fissures.

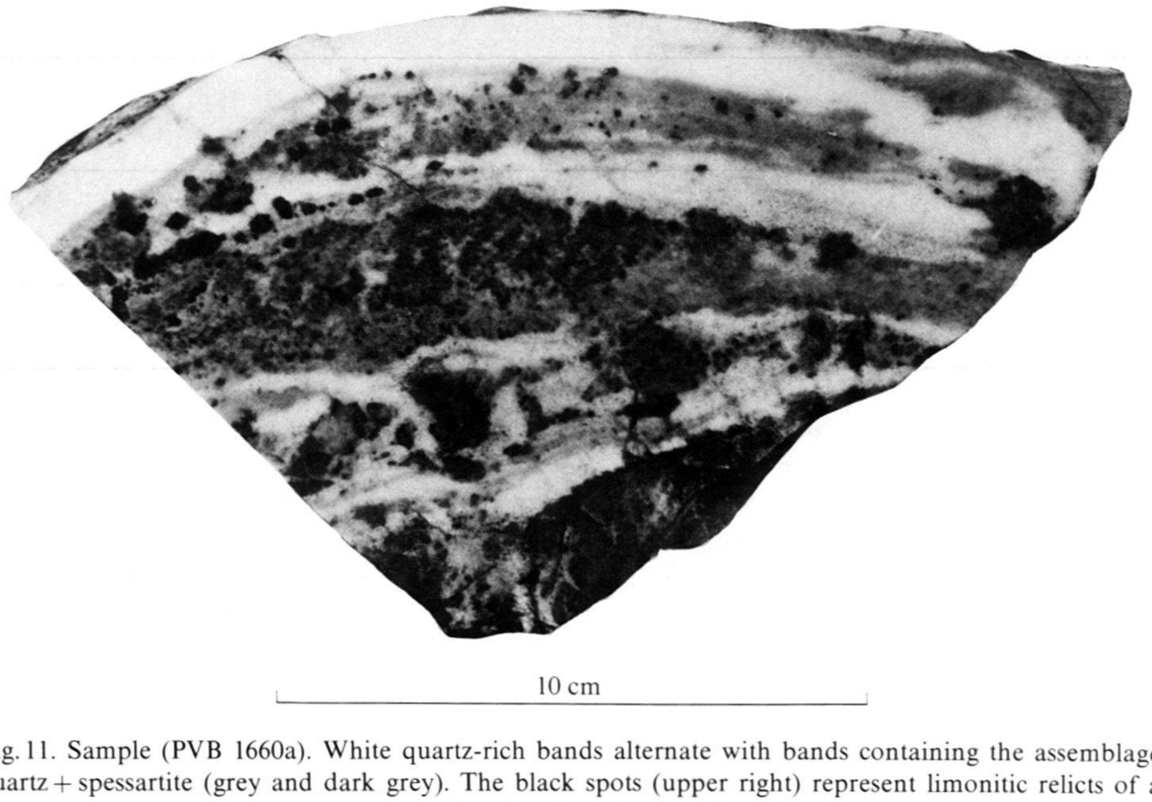

Fig. 11. Sample (PVB 1660a). White quartz-rich bands alternate with bands containing the assemblage quartz + spessartite (grey and dark grey). The black spots (upper right) represent limonitic relicts of a weathered carbonate mineral.

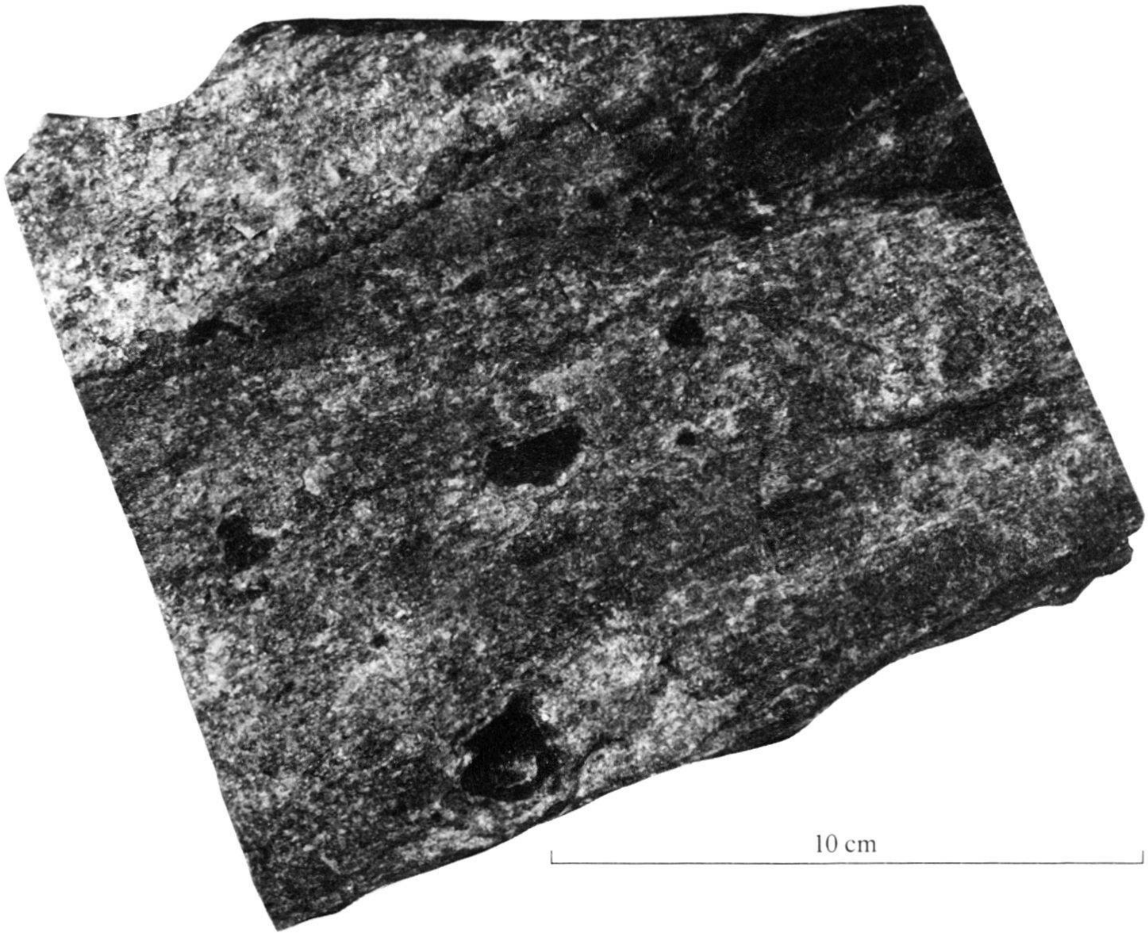

Fig. 12. Sample (PVB 1660c). Several Mn-nodules are present on a mica-rich schistosity plane. The finely laminated rock is made up of alternating bands rich in the assemblages spessartite, quartz, phlogopite and phengite respectively. Tourmaline is abundant in the rocks as well.

unfavourable peak/background (*p/b*) ratio, whereas the border zone shows a low background and a good *p/b* relation. In all the samples analyzed from core and border spessartite, quartz and rhodochrosite (the latter identified by Tj. Peters) were detectable, but no reflexes of other minerals. On the other hand the high background indicates a heavy groundmass, which can be due either to a small grain size or to a low cristallinity. Tj. Peters believes that the latter may be caused by weathering of the Mn-rich core. In one sample he could identify the Mn-oxyhydroxyd buserit.

Metabasaltic rocks closely associated with the Mn-nodule bearing metasediments display an eclogitic, amphibolitic or prasinitic mineralogical composition. From this field relation it may be concluded that the Mn-nodules have a metamorphic history similar to that of the metabasaltic rocks, i.e. late Cretaceous high-pressure metamorphic event was followed by Tertiary greenschist facies metamorphism (Lepontine event). This well established path of metamorphic evolution of the area does not find an expression in the mineral assemblages of the Mn-nodules. We did not examine if the zonation of the minerals reflects the changing metamorphic conditions. (See also Peters et al. 1973, 1978 and Trommsdorff et al. 1970, 1975.)

Table 4: *XRF analysis of Mn-nodule PB 1664* (analyst: Dr. W. B. Stern).

SiO_2	39.9 wt%
Al_2O_3	7.2 wt%
Fe_2O_{3total}	4.5 wt%
Mn_2O_{3total}	41.5 wt%
MgO	1.7 wt%
CaO	1.3 wt%
Na_2O	0.0 wt%
K_2O	0.1 wt%
TiO_2	0.2 wt%
P_2O_5	0.1 wt%
H_2O	1.3 wt%
CO_2	1.0 wt%
Total	98.8 wt%

The iron mineralizations

Rocks substantially enriched in iron can be found at a number of localities (i.e. Sparren, P.3085, Rote Bodmen, Triftji). Hematite, magnetite and epidote group minerals are the principal carriers of the high iron content of these rocks. The oxides, dominantly magnetite, were found as euhedral inclusions in the albite crystals of the prasinitic rocks forming the basement of the metasediments. Rutile exsolved as blebs within the magnetite, testifies to an originally high Ti-content of the latter. The upper layer of metabasic rocks at the localitiy P.3085 contain unusually large nodules of this magnetite rich prasinites. Fresh fractured surfaces of such nodules show a distinct bluish luster. A high specific weight (3.03 ± 0.04) is a further characteristic of these rocks.

At the localities P.3085 (Rote Bodmen and Triftji) the quartzitic rocks typically contain abundant Fe-rich epidote (pistacite). The Fe-rich epidote represents an analogue to the Mn-rich piemontite mainly found at outcrops between the Britannia hut and Felskinn.

The observations made on the Mn- and Fe-rich rocks of the Zermatt-Saas Fee zone may be interpreted with a model recently developed by Bonatti et al. (1976) and Bonatti (1978): It is based on observations in the Ligurian Apennines and on results from recent deep sea research (see also Spooner & Fyfe 1973). The model proposes that convective seawater dissolves iron and manganese from the basaltic oceanic crust in a relatively high-temperature environment and precipitates these two elements in the form of various oxides at the contact with the oxidizing sea water (Krauskopf 1957).

The common association of manganese and iron mineralizations in the cover of the ophiolite nappe of Zermatt-Saas Fee suggests that similar hydrothermal processes in the oceanic crust as proposed by Bonatti are responsible for the observed Mn-Fe-mineral assemblages.

Rocks accompanying or substituting the post-Triassic quartzites

In the course of this study the oceanic metasedimentary series (profile *D*) turned out to be crucial for the structural interpretation of the ophiolitic zone (see next chapter). However, the identification of the oceanic series in the field as a clearly recognizable unit is complicated by the fact that the characteristic manganiferous schists and quartzites are frequently replaced by less distinct rocks.

There are two members of the metamorphic oceanic sequence which may be wrongly diagnosed in the field, namely the quartzites and the metapelites (Fig. 1).

Very often the quartzites of this sequence do not contain spessartite, piemontite or another easily determinable Mn-mineral, and therefore can be mistaken for Triassic (or Permian) sediments. However, the post-Triassic quartzites are never associated with dolomitic rocks or rauhwacke typical for the Penninic Trias. Moreover they contain garnet, epidote and other minerals which have never been found in Triassic quartzites.

The other candidate for a possible misinterpretation are the garnet and chloritoid-bearing metapelites, which are a characteristic member of the oceanic sequence. They can be mistaken for similar rocks of the basement. A description of such rocks can be found in BEARTH (1973).

In case of doubt, we should remember that the oceanic series is always on or near the border of the ophiolites, between the ophiolites and the basement or the Trias belonging to the basement. Exceptions are due to folding or other tectonic complications.

As an illustration of the above, one outcrop is described in some detail. This outcrop forms a part of the Mittaghorn fold (KLEIN 1978) and is situated above the path from Plattjen to the Britannia hut south of Saas Fee (BEARTH 1957). It shows a section of garnet- and chloritoid-bearing micaschists (Fig. 13, 3) which appear inserted between the ophiolites of the Egginer (amphibolites and prasinites) and the Triassic of the Gornergrat zone (rauhwacke, calcareous and dolomite marbles). We first interpreted these micaschists as a tectonic intercalation of basement rocks in the Mesozoic sequence. A closer examination reveals that the micaschists alternate with garnet-bearing quartzites which correspond to the post-Triassic quartzites. Hence the whole sequence labeled 2, 3 and 4 in Figure 13 is Mesozoic and represents a part of the sediments deposited on the oceanic crust.

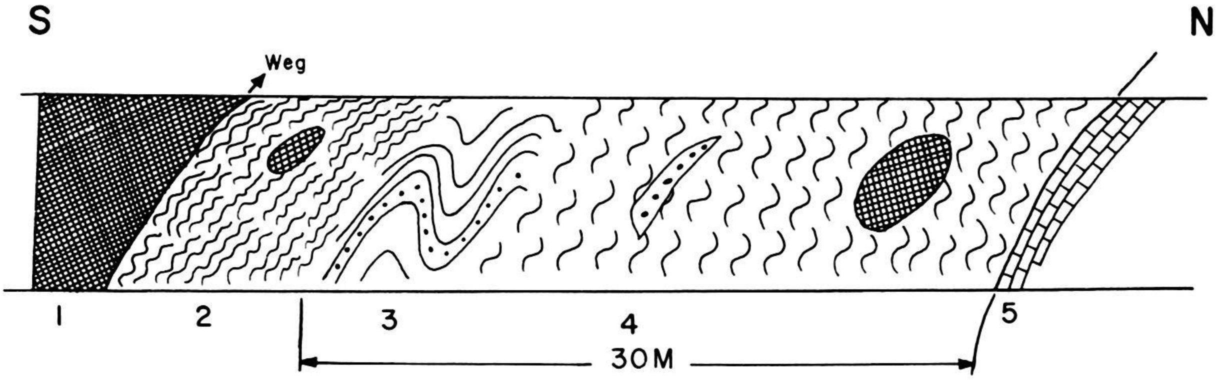

Fig. 13. Contact between Gornergrat zone and ophiolite zone Zermatt-Saas Fee, above path Plattjen-Britannia hut, along the ascend to the Mittaghorn, altitude 2720–2750 m.
1 = Prasinite and amphibolite, 2 = chlorite-muscovite schist with lenses of ovardite (= albite-chlorite schist), 3 = alternating bands of calcschist, quartzite and garnet bearing muscovite-quartzite, 4 = calc-schist and garnet-bearing muscovite-quartzites with lenses of ovardite, 5 = dolomitic marbles (Triassic).

The regional distribution of the oceanic metasedimentary series between the valleys of Zermatt and Saas Fee

Keeping the mentioned complications in mind, it is possible to follow the oceanic metasediments along the edge of the ophiolites as a nearly (see below) continuous unit from the Saas valley to the valley of Zermatt. To the north of the Findeln glacier, on the east-ridge of the Oberrothorn and in the Täsch valley (Fig. 3) the oceanic metasediments are laying on top of the ophiolites in a stratigraphically normal series, and are overlain by inverted Triassic or younger breccias of the Combin zone (series *C*).

In the Saas valley the situation is different. Here the oceanic sequence is inverted and the ophiolites are found on top of the metasediments. Both units together overlie a stratigraphically normal series of Triassic rocks or post-Triassic breccias (Gornergrat zone, series *B*). Hence, between the Saas and Zermatt valleys two different bands of oceanic metasediments can be distinguished, one of which is in normal stratigraphic position, whereas the other one is inverted. The two bands meet in the Mittaghorn fold south of Saas Fee (BEARTH 1967; see also section 5 in Plate 1 in BEARTH 1964 and 1967, KLEIN 1978).

The tectonic complications along the northern rim of the Fee glacier (BEARTH 1964) and the Quaternary cover prevents a strictly continuous tracing of the oceanic series between Zermatt and Saas. However, the field relations are sufficiently clear to allow the conclusion that the frontal part of the ophiolite nappe between the valleys of Zermatt and Saas forms a large recumbent fold with a northern vergence and a westernly dip of 20–30°.

In the Zermatt area the inverted limb of this fold was found in outcrops north-east of the Untere Kelle (north of Hotel Gornergrat). Here the poorly preserved oceanic sedimentary series is wedged in between the inverted ophiolites of the Riffelberg zone (BEARTH 1967) and the Triassic metasediments of the Gornergrat zone (cover of the Monte Rosa basement, Fig. 14). It is uncertain whether the outcrops of oceanic sediments south of the Gorner glacier (Fig. 3) are linked with the inverted limb of the fold north of it.

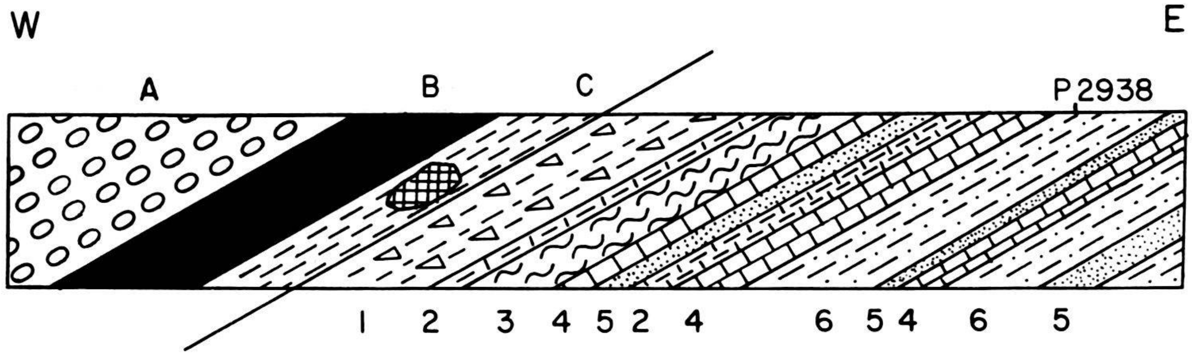

Fig. 14. Section through the tectonic contact of the ophiolites (*A*, *B*, *C*) to the metasediments (Untere Kelle, north of Hotel Gornergrat). *A* = Zone of Riffelberg, *B* = Serpentinites, *C* = carbonate- and magnetite-rich chlorite-talc schist, with lenses of hornblendites.

Sediments of the zone of Gornergrat: 1 = Laminated calcitic-dolomitic breccia (Liassic?), 2 = chlorite-muscovite schist, 3 = calcschist, 4 = calcite marble (Triassic), 5 = quartzite (Triassic), 6 = phengite-albite gneiss. The ophiolites (*A*, *B*, *C*) are separated from the metasediments (1–6) by a clearly tectonic surface.

Some remarks on the regional tectonics

Figure 15 shows the present setting of the recumbent fold of the ophiolite nappe between the large bodies of crystalline basement nappes. The Monte Rosa and the Bernhard nappes are correlated with the northern margin of the Mesozoic ocean. The corresponding oceanic crust is now represented by the zone of Zermatt–Saas Fee.

The scetch shows clearly the tectonic independence of this zone which has been wedged between the cover of the Monte Rosa nappe and the Combin unit.

The crystalline basement nappe of the Dent Blanche now found on top of the whole nappe pile can be regarded as the southern border of this Mesozoic ocean (Tethys) (ARGAND 1911, DAL PIAZ 1979).

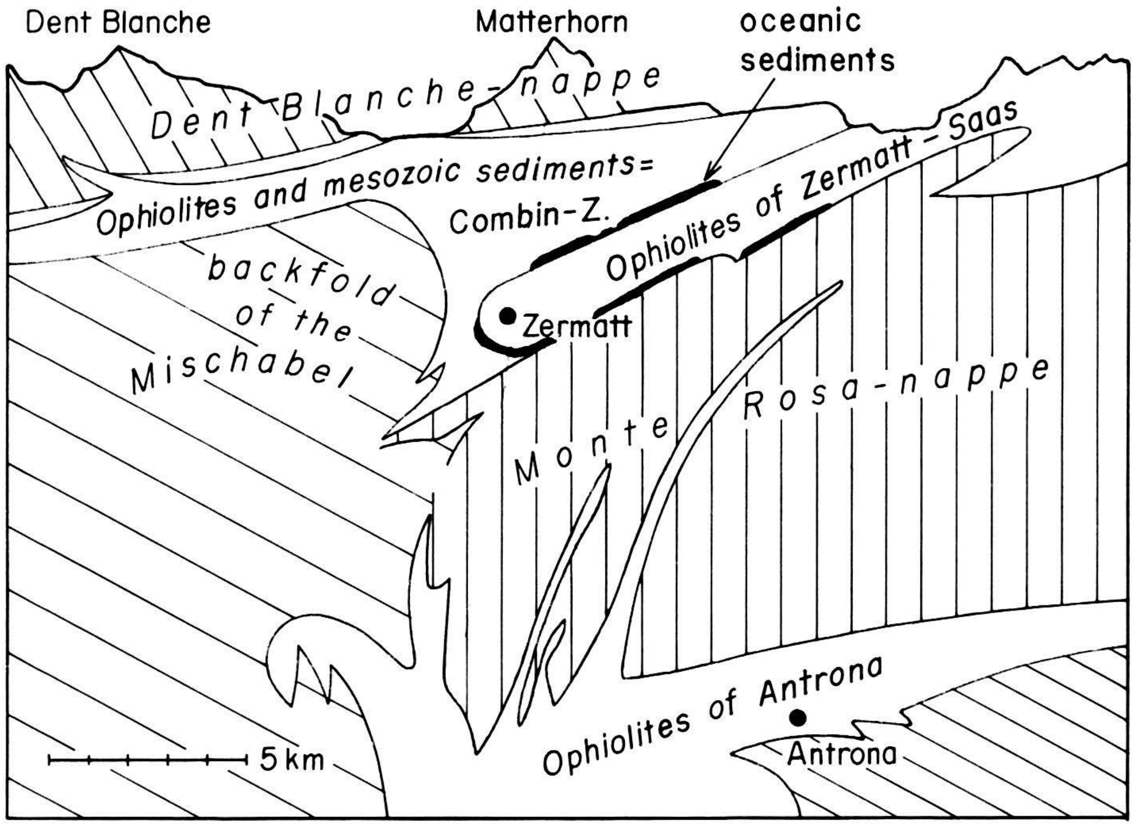

Fig. 15. Schematic N–S section through the nappes of the Zermatt area.

The geometric configuration of the nappes as shown in Figure 15 can be regarded as the complicated interference pattern of a long-lasting deformational history of the area. Large scale thrusting brought different tectonic units into contact and these were folded subsequently. Mineral assemblages indicating high pressure metamorphism during late Cretaceous times, recrystallized during and after Oligocene deformation to mineral assemblages characteristic of greenschist facies metamorphism (HUNZIKER 1974, DAL PIAZ 1978).

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