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Alpine Metamorphism of Mafic Rocks

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With 2 figures, 1 table and 1 plate

Abstract

Metamorphosed mafic rocks in the Alps exhibit many characteristic mineral assemblages. They are used to study different phases of alpine metamorphism. The great variety of alpine metamorphosed mafic and ultramafic rocks is illustrated with a map of their distribution (plate I) and a listing showing their localities, size and thickness, metamorphic grade and tectonic situation. The localities: Préalpes romandes, Préalpes du Chablais, Versoyen, Haut Val de Suse, Montgenèvre and Haute-Ubaye in the Western Alps and a N-S profile (Arosa-Oberhalbstein-Upper Engadine) in the Rhetic Alps are described in detail. The petrographic data could fit into a plate-tectonic model yielding different metamorphic events: a Jurassic to lower Cretaceous oceanic metamorphism, an upper Cretaceous to Eocene subduction metamorphism (low temperature and high pressure) and a postkinematic upper Eocene-Oligocene high temperature-metamorphism.

INTRODUCTION

This article introduces the reader to the problems of alpine metamorphism of mafic rocks. The main emphasis is on geologic and tectonic interpretation. The region considered includes the Western, Central and Rhetic Alps. Four main groups of mafic rocks can be distinguished:

I. Ophiolites (pillow lava + gabbro + serpentinite) associated with Jurassic and Cretaceous sediments.
II. Mafic volcanic rocks (late Paleozoic to early Mesozoic age).
III. Mafic-ultramafic rocks (pre-Mesozoic origin).
IV. Mafic rocks in the Taveyanne graywackes formation (Eocene/Oligocene) (for a review see Kübler, Martini and Vuagnat this volume, p. 461).

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I. Ophiolites are a distinctive assemblage of mafic to ultramafic rocks. In this paper we refer to the statement on ophiolites given at the G.S.A. Penrose Conference 1972 (*Geotimes*, 17/12, 1972). We also use the name ophiolite not as a rock type nor as a lithologic unit in mapping.

For the ophiolitic occurrences in the Western and Rhetic Alps we give a generalized sequence which may differ from many other ophiolites in the world. From the top to the bottom:

Mafic volcanic complex (commonly pillowed; sheeted mafic dikes are missing).
Gabbroic complex.
Ultramafic complex (mostly lherzolitic composition, containing pyroxenitic layers and rodingitized gabbroic and diabasic dikes).

The mafic volcanics are associated, but not always in true stratigraphic contact, with Mesozoic sediments: Bündnerschiefer (Schistes lustrés), radiolarian cherts, limestones and flyschtype shales. According to stratigraphic and radiometric data it seems that the volcanics and subvolcanics are of Jurassic to lower Cretaceous age. However, it is quite possible that the age of consolidation of the ultramafic members and pyroxenites is older, as they are probably slices of the Upper Mantle.

In many cases the ophiolitic sequence is incomplete and dismembered (in table 1: d. ophiolite = dismembered ophiolite and i. d. = incomplete dismembered.) Faulted contacts between mappable units are common. In the listing we have tried to estimate the maximum outcrop thickness for the different rock types, which, in some cases might have been either reduced or thickened by alpine deformation.

There are no completely unmetamorphosed ophiolites in the Alps. All stages of transformation are found from very low grade to high grade assemblages. Furthermore these rocks have been affected by *different phases of the alpine metamorphism* (Jurassic to Tertiary) – BEARTH (1959), VAN DER PLAS (1959), DIETRICH and PETERS (1971), DAL PIAZ, HUNZIKER and MARTINOTTI (1972), ERNST (1973), JÄGER (1973) and BEARTH (this volume, p. 385).

In table 1 we distinguish between *5 categories of metamorphism* according to the grade of transformation in mafic-ultramafic rocks. For the Central Alps we include the metamorphic zones (NIGGLI, 1970).

1. Completely undeformed ophiolites, probably in the *prehnite-pumpellyite facies.*
2. Undeformed to slightly deformed ophiolites, with the *pumpellyite-actinolite-chlorite assemblage* defined as facies (HASHIMOTO, 1965).

In rocks of low metamorphic grade primary structures and textures have been more or less preserved.

3. In some areas a transition from slightly deformed into deformed ophiolites also exist (flattening, elongation of the structures). Primary features are still recognizable. Typical *greenschist facies* mineralogy.
4. Ophiolites with *blue schist* or *transitional blue schist* assemblages, with primary features still detectable.
5. High grade metamorphic ophiolites; here, in most cases the primary structures have disappeared. There are however some exceptions, for instance preserved pillow structure with *eclogitic assemblages* (BEARTH, 1959 and 1967).

In large parts of the Penninic nappes, especially in the Western Alps, high grade assemblages occur. P. BEARTH reviews in this volume the problems related to these metamorphosed ophiolites.

Two different Penninic belts have been distinguished for Jurassic and lower Cretaceous times on the basis of tectonic and paleogeographic reconstructions (TRÜMPY, 1960, 1971 and 1973). These are: the northern Valaisian belt and the southern Piemontais belt separated by the Briançonnais platform. However, this subdivision of alpine ophiolites into two belts is hypothetical and up to now has not yet been confirmed by petrographic data.

In the *Valaisian* belt huge masses of Jurassic to Cretaceous Bündnerschiefer (Schistes lustrés) occur. The setting of volcanics and subvolcanics intercalated in the Bündnerschiefer (Binn, Hohsandhorn, Vals, Safien, Tambo, and Avers) seems to be different from the typical ophiolitic sequence (ANTOINE et al. 1973). Only fragmentary and strongly deformed serpentinites occur. In the *Piemontais* belt typical ophiolitic sequences are developed but often tectonically dismembered. The typical Schistes lustrés of the Western Alps are missing in the Arosa zone and Platta nappe (Grisons). Radiolarian cherts, Calpionella limestones and shales (Aptian) are common. Ophiolites of low metamorphic grade belonging to the *Piemontais* are found:

A. In the Iberg klippes, Arosa zone and Platta nappe (Eastern Switzerland, Liechtenstein and Allgäu).

B. In the more external westerly parts of the Pennine (Montgenèvre and Queyras).

C. As small tectonic slices and/or olistolites in the upper Prealpine units and in the Helminthoid Flysch of south-eastern France. A great part of the Corsican ophiolites and most of the Apennine ones belong to this type of slightly metamorphic ophiolites.

II. Mafic volcanic rocks of Permian to lower Mesozoic age are found intercalated in the sediments of the Helvetic and Autochtone zone. They include spilitic "melaphyres" of the Verrucano of Central and Eastern Switzerland (BEDER, 1909; AMSTUTZ, 1954), spilitic basalts of the Triassic and lower Liassic sediments covering the Pelvoux Massif in France or its southern "satellite", the Dôme de Remollon (TERMIER, 1898; ALSAC, 1961; TANE, 1962).

III. Mafic-ultramafic rocks of pre Mesozoic origin occur in the "crystalline" basement of the Alps (external Hercynian Massifs, Austroalpine nappes, Dent Blanche nappe – Sesia Lanzo zone, Mont Emilius, Ivrea zone and Southern Alps) and in the cores (?) of the Pennine nappes.

In the Sesia Lanzo zone and Mont Emilius, the mafic rocks have suffered different phases of metamorphism overprinting each other (1. for the amphibolites of the "second diorite-kinzingite zone": pre-Mesozoic; 2. for the eclogites: eoalpine = early Mesozoic and 3.: Eocene). For detailed information see NOVARESE (1931), BEARTH (1962), BIANCHI and DAL PIAZ (1963), REINHARDT (1966), CALLEGARI and VITERBO (1966), DAL PIAZ (1967), VITERBO and BLACKBURN (1968), HUNZIKER and BEARTH (1969), MAFFEO (1970), MARTINOTTI (1970), BORTOLAMI and DAL PIAZ (1970), BERTOLANI (1971), DAL PIAZ et al. (1972) and ISLER and ZINGG (1974).

In the Dent-Blanche nappe, in the Southern Alps and in the Austroalpine nappes a pre-Mesozoic metamorphism is evident. The influence of an eoalpine and/or an Eocene phase is possible but not clear.

The map (plate I) shows large ultramafic bodies in the mafic complex of the Ivrea zone. The metamorphism is pre-Mesozoic; a complete bibliography has been published in CARRARO and SCHMIDT (1968). For ultramafics see LENSCH (1971), ETIENNE (1971) and LENSCH and ROST (1972).

IV. Of very great interest for modern interpretation of alpine orogenesis and metamorphism are occurrences of calcalkaline volcanism during the early Mesozoic and Tertiary. Along the northern rim of the Western and Central Alps large amounts of andesitic and basaltic volcanic detritus were deposited into the Helvetic region during the uppermost Eocene and lower Oligocene. These graywacke formations (Taveyanne, Val d'Illiez and Altdorf) were studied in detail by NIGGLI (1922), DE QUERVAIN (1928), VUAGNAT (1943, 1952), MARTINI and VUAGNAT (1965, 1970), MARTINI (1968, 1972) and ELTER et al. (1969).

Between the Sesia-Lanzo and the Ivrea zones SCHEURING et al. (1973) could establish a Tertiary age for the unmetamorphosed volcano-detrital cover of the "Micaschisti eclogitici" which in 1972 still was believed to be of late Carboniferous age (CARRARO and CHARRIER). From the Southern Alps we know early Mesozoic and Tertiary volcanics (PICCOLI, 1965 and PICCOLI et al. 1971). Porphyrite bearing pipes and dikes crosscut the basement and the Mesozoic cover (DE SITTER and DE SITTER-KOOMANS, 1949).

WESTERN ALPS

by *M. Vuagnat* and *J. Bertrand*

Préalpes romandes (Table 1, No. 38)

The Prealps are divided into two main regions: A southern one located south-west of the Rhône valley ("Préalpes du Chablais") and a northern one extending from the Rhône to the lake of Thoune ("Préalpes romandes"). The tectonic relation of the ophiolites to the "Nappe de la Brèche" or to the "Nappe de la Simme" is uncertain.

In the "Préalpes romandes", 19 small outcrops (max. 150 m wide and few meters thick) of completely undeformed diabases and pillow lavas, located between Saanen-Gstaad and Jaunpass-Zweisimmen, are known. Stratigraphically these mafics are intercalated in upper Cretaceous flyschtype sediments (mostly black shales but also sandylime-shales). Contacts between diabases and radiolarian cherts or shales are rarely visible.

The mafic rocks may be grouped according to their occurrence:

1. *Sills.* Most of the outcrops show textures characteristic of such intrusions (chilled margins, Na-metasomatism of sediments and breccias). One K/Ar age determination of 76 ± 4 m. y. on augites from a diabase sill is in agreement with the Maestrichtian-Campanian age of the flysch. It is however possible that this diabase sill could have been an olistolite which has lost some argon during a low grade metamorphism.
2. *Pillow lavas and breccias.* In one (Jaunpass) of the two known outcrops the volcanic breccia contains detrital fragments of gneisses, granites and albitites. An age determination made by total lead on granite gave 340 ± 20 m.y. (SALAMI, 1965).
3. *Detrital diabasic breccias.* The two outcrops are related to the Niesen nappe.

Mineralogy: Albite and chlorite are the major constituents. Augite is also present in some diabases. The accessory minerals are hematite, sphene, calcite, amphibole (uralite or hornblende as an alteration of the Ti-bearing augite), biotite, ferristilpnomelane, sericite, quartz, apatite, ilmenite, pyrite and magnetite.

Primary textures are well preserved, suggesting that any metamorphism must have been of very low grade. The chemical composition of the diabases and pillow lavas is spilitic.

Préalpes du Chablais (Table 1, No. 39)

In the Chablais (Haute-Savoie, France) 17 outcrops of ophiolitic rocks occur in the Col des Gets area. These outcrops are small, between 50 and 400 m in length. The undeformed diabases, pillow lavas and gabbros as well as lizardite-chrysotile-serpentinites are regarded as a completely dismembered ophiolite sequence probably embedded as olistolites in upper Cretaceous flysch. Recent studies

(Elter et al., 1966; Bertrand, 1970) have indicated that these rocks belong to an independant unit, the "Nappe des Gets" (? "Nappe de la Simme s. l."), which was carried over the "Nappe de la Brèche". In the Chablais area, the "Nappe des Gets" is the highest tectonic unit of the Préalpes.

The *diabases and pillow lavas* are the most common mafic rocks and may be divided into four main groups:

1. Pillow lavas, pillow breccias, meta-hyaloclastites and shallow sills (Le Vuargne).
2. Diabases and especially diabase breccias, more or less hematitic. These rocks show in some places primary contacts with granitic lenses (La Rosière, Le Plenay), which yielded Hercynian age according to total lead radiometric data (Bertrand, 1970).
3. Sedimentary rocks with detrital diabasic fragments: conglomerates, microconglomerates and breccias. Some of these are made up of diabasic fragments only, some of diabasic and sedimentary fragments (cherts and phyllites), and finally some of diabasic, granitic and sedimentary fragments.

The textures of the diabases and pillow lavas vary from intersertal to variolitic, with a predominance of intersertal, diverging, arborescent and spherolitic types. The chemical composition is spilitic.

Mineralogy. Albite and chlorite are the main constituents. Accessory minerals are hematite, calcite, sphene, quartz, sericite, tremolite-actinolite, biotite, stilpnomelane, apatite, ilmenite and pyrite.

4. Diabases (La Mouille-Ronde) and diabasic fragments as inclusions in serpentinites or in ophiolitic breccias.

These mafic rocks are characterized by diabasic to gabbroic textures and variable mineral composition (plagioclase-chlorite, plagioclase-amphibole or, less frequently, plagioclase-pyroxene assemblages).

Mineralogy: Albite, plagioclase relics (sometimes up to 40% An), chlorite, basaltic hornblende and Ti-bearing augite. The accessory minerals are actinolite-tremolite, epidote and clinozoisite, sericite, calcite, blue amphibole (very rare and in ophiolitic breccia only), apatite and ore minerals. It is also possible that some very fine-grained pumpellyite is sometimes associated with clinozoisite in plagioclase crystals.

In the Col des Gets region, *gabbros* are much less common than diabases and serpentinites. They occur as more or less independant masses, as inclusions in the diabases (La Mouille-Ronde), as components of ophiolitic breccias or as small inclusions in serpentinites.

Textures are fine or coarse-grained, even pegmatitic. The degree of alteration and of tectonization varies from place to place.

Mineralogy: Plagioclase (0–10% An and also with relics up to about 30–40% An), basaltic hornblende, Ti-bearing augite-diallage and chlorite replacing augite or hornblende.

Accessory minerals are sericite, epidote, clinozoisite, actinolite-tremolite, calcite, sphene, biotite, apatite, ore minerals and, sometimes, probable fine-grained pumpellyite associated with clinozoisite.

One of the most interesting features of the ophiolites in the "Col des Gets" region is the abundance of *mafic inclusions in the serpentinites*. Their size ranges between 5 and 30 cm. They are common in strongly tectonized serpentinites. Different petrographic types are present. In order of decreasing frequency:

1. Diabases containing plagioclase, hornblende, pyroxene and chlorite.
2. Gabbros with generally fresh or altered hornblende, or more rarely, with augite.
   Probably these inclusions are relics of dismembered dikes.
3. Ophiolitic breccia.

Mineralogy: Plagioclase (0–10 or sometimes up to 30–40% An), chlorite, clinozoisite, pumpellyite, and sericite. Zoisite, prehnite, calcite and actinolite-tremolite are rare. Accessories are apatite, sphene and ore minerals.

Part of these inclusions, with concentric shapes due to chloritisation, have been called ophispherites (Vuagnat and Jaffe, 1952) and are a special kind of rodingites (for more details see the description in No. 54).

Thirteen K/Ar age determinations ranging from 180 to 140 m. y. were carried out on diabases and gabbros related to serpentinites (Bertrand, 1970).

Versoyen (Table 1, No. 47)

The Versoyen zone lies on both sides of the French-Italian border, between the Mont-Blanc-Massif and the Petit-Saint-Bernard pass. Its tectonic position is still controversial. Hermann (1938) considered that it was a frontal part of the Dent-Blanche nappe involuted under deeper Pennine units. The more commonly accepted hypothesis now is that it belongs to the "Nappe des Brèches de Tarentaise", the ophiolites having been emplaced in the Valaisian geosyncline. However, some geologists argue that these mafics and antigorite-serpentinites are part of a huge "ophiolite nappe" which originated at the internal margin of the Pennine domain.

The degree of metamorphism of the ophiolites corresponds to the greenschist and to the blueschist facies (Schoeller, 1929 and Loubat, 1968).

Pillow lavas are present in many places. Some of the flows are almost undeformed (for instance near the Chalets de Prainan, north of Bourg-Saint-Maurice) while others are more or less laminated (Aiguille-de-Prainan). On the Italian side of the border the degree of deformation and of metamorphism increases and it is often difficult to recognize a pillow structure.

Mineralogy: Albite, chlorite, actinolite, epidote, sphene and calcite.

Massive greenstones, probably diabase sills, are fairly common in the Beaupré-Mont Miravidi zone; some may be very thick (about 150 m). Coarse diabasic textures are still recognizable in a few thin sections.

Mineralogy: Albite, relic-augite, actinolite, epidote, chlorite, ilmenite, sphene. In some specimens, sericite, stilpnomelane, and a blue-brown amphibole are also found.

In the Pointe du Clapey *large masses of glaucophane and stilpnomelane rich rocks* occur, very probably derived from diabases and gabbros. Few typical primary textural features have been preserved. The mineral assemblages are more varied than in the pillow lavas or in the massive greenstones.

Mineralogy: Albite, augite, green amphibole, blue amphibole, epidote, zoisite, garnet, sericite, chlorite, stilpnomelane, ilmenite, sphene, apatite, tourmaline, quartz have been described from these rocks. Some varieties are coarse-grained glaucophanites.

Haut Val de Suse (Table 1, No. 52)

In the Haut Val de Suse ophiolites associated with the Schistes lustrés have been extensively metamorphosed. However, there is no doubt that these are remnants of the different parts of a dismembered ophiolitic sequence.

Some of the mafic rocks have lost their primary textures (prasinites and glaucophanites). Other mafic rocks with partly preserved primary structures and textures are described as metagabbros, metadolerites and metabasalts (Gay, 1971).

In some of the latter pillow and pillow breccia structures are very well preserved.

These metamorphic pillow lavas outcrop near Ulzio (Gay, 1968).

Mineralogy: Albite, sericite, chlorite, glaucophane, epidote/clinozoisite, lawsonite, pumpellyite, calcite, sphene and rutile. In some thin sections an actinolitic amphibole is present.

It can be shown from paragenetic relationships that there have been *two stages of metamorphism.* The first, and main one being characterized by high pressures producing the glaucophane-lawsonite association; the second one of retromorphic character corresponding to a partial transformation to greenschist facies assemblages.

Montgenèvre (Table 1, No. 54)

The Montgenèvre massif is the largest remnant of slightly metamorphosed ophiolites in the Alps between the Mediterranean Sea and Vienna. It straddles the French-Italian border at the latitude of Briançon with a north-south extension of about 5 km and an east-west extension of some 6 km. From the bottom of the Bousson Valley to the top of the Chenaillet there is more than 1200 m of relief.

The Montgenèvre ophiolites are thrust on the "série prépiémontaise" of Mesozoic sedimentary rocks of the Gondran zone (LEMOINE, 1971); they appear to plunge eastward under the Schistes lustrés of the region around Sestrière. These schists, the equivalent of the Bündnerschiefer of Eastern Switzerland, are typical of the alpine geosyncline. Most geologists agree that they are marly sediments of Jurassic to Cretaceous age transformed to calcareous schists during the alpine metamorphism. For a long time, the ophiolites were thought to be intercalated stratigraphically in the Schistes lustrés, however, there are now some indications pointing to the possibility of tectonic contacts between ophiolites and Schistes lustrés in the Pennine domain (LEMOINE, 1971; G. ELTER, 1971).

It is important to mention that the whole Montgenèvre massif is a down-faulted block limited to the north and to the south by major transverse faults (LEMOINE, 1964). The extent of the dip-slip movement is unknown but must be at least several hundred meters as, at the Prairial for instance, we see pillow lavas of upper Jurassic or lower Cretaceous age in faulted contact with dolomitic limestones. It is probably due to this down-faulting that the ophiolites of the greater part of this massif have been preserved in an apparently unmetamorphosed condition. To the north and south this high tectonic level has long ago been removed by erosion. Another structural pecularity of the Montgenèvre block is the absence of "backthrusting" (rétrocharriage); this late thrusting toward the east of more westerly tectonic units on the Pennine zone is very important elsewhere in the internal French Alps.

The stratigraphic position of the Montgenèvre ophiolites is somewhat uncertain. There is a true primary contact with radiolarian cherts at Mont Cruzeau. These cherts are supposed to be of upper Jurassic to lower Cretaceous age. On the other hand a K/Ar age determination of a diabasic rock indicates a middle Cretaceous age of 100 m. y.

Petrography and Mineralogy. The members of an ophiolitic sequence are all well represented with well preserved primary textures and structures in the Montgenèvre massif.

Pillow lavas constitute the main part of the massif; they are often extremely well preserved in shape and microscopic textures. Several structural varieties may be distinguished (porphyritic pillows, non-porphyritic pillows with coarsely or finely variolitic rind, etc.). In contrast to many other apparently unmetamorphic pillows in the Alps, those of Montgenèvre do not exhibit a strongly spilitic trend, except in the vicinity of Lago Nero we find typical spilite with albite, chlorite and hematite as main constituents.

Associated with the pillow lavas are *coarse-grained diabases*, probably dikes, with subophitic to intergranular textures. The common paragenesis is altered plagioclase, augite and some chlorite. Here again some diabases have a spilitic composition with apparently fresh albite.

The *gabbros* are typical alpine gabbros. The most common assemblage is diallage and more or less saussuritized plagioclase. Some albite-hornblende gabbros are also found. Melanocratic and leucocratic "schlieren" are common, the composition may thus vary from pyroxenitic to anorthositic. The grain size changes very rapidly from one point to another and pegmatitic textures are fairly common. In some places there is a distinct orientation of the crystals and a trend toward flasergabbros. The gabbros are cut by numerous diabase dikes with distinctly chilled margins. Their thickness vary from few cm to a few m. This is similar to sheeted complexes but here the dike density is much lower. Good outcrops of gabbros are found in the lower part of the Southwestern ridge of the Chenaillet and in the Monti della Luna between Sagna Longa and Colle Bercia.

The lizardite-chrysotile bearing *serpentinites* and *ophicalcites* contain a suite of rocks, some of uncertain origin:

1. *Albitite:* The most interesting of these is found at the Replatte du Gondran (Pusztaszeri, 1969). It is probably a dismembered dike in highly sheared serpentinites.
2. *Rodingites:* Typical rodingites in dikes and in lenticular inclusions in serpentinites are found in the Italian part of the massif, on the ridge above Colle Bercia and in the Lago Nero region. The gabbroic texture of these rocks can still be seen in many examples.
3. *Ophispherites:* These are found in several outcrops, as inclusions in crushed serpentinite, at and near the Col du Chenaillet (Vuagnat, 1953). They usually have a hard core showing the textures of pillow lava, diabase or gabbro. Whereas the pyroxene of these rocks has often been well preserved, the plagioclase has been transformed to various calcium silicates among which hydrogarnet is conspicuous. The core is surrounded by a softer and darker shell of the same rock entirely transformed to an aluminous chlorite where the primary texture may still be recognized as it is outlined by fine grained iron oxides. There is no doubt that ophispherites are akin to rodingites in their mineral assemblages and genesis.

As elsewhere in the Alps, it is difficult to see the relations between the serpentinites, gabbros, diabases, and pillow lavas. The least disturbed sequence is to be found on the southwestern ridge of the Chenaillet. From the Replatte du Gondran to the top of the Chenaillet, there is a thin slice of sheared serpentinite with a large albitite inclusion, gabbros cut by numerous diabase dikes, pillow lavas, and some hyaloclastites. However, the contact serpentinite-gabbro is certainly faulted.

Metamorphism. Important parts of the Montgenèvre region are apparently unmetamorphosed, particularly the Chenaillet massif and in the surroundings of Lago Nero. At one time, undeformed rocks with even such delicate textures as the variolitic arrangement of needle-like plagioclase crystals were considered as having escaped the effect of alpine regional metamorphism. Now we know that completely undeformed rocks found outside the classical zone of metamorphism, i. e. the Pennine zone, may have suffered extensive mineral and even chemical transformations. This is the case for instance in the highly volcanic graywackes of the Taveyanne formation in the High Calcareous Alps where assemblages of zeolite and of prehnite-pumpellyite facies are well developped (Martini and Vuagnat, 1965 and also Kübler, Martini and

VUAGNAT, this volume, p. 461). The presence of some prehnite, epidote and a few needles of actinolite indicate that, notwithstanding their very good structural preservation, the Montgenèvre ophiolites have been submitted to light regional metamorphism.

In the easternmost part of the Montgenèvre region, in the small Mont Cruzeau massif between Cesana and Sestriere, the pillows have been distinctly deformed and the originally spherical varioles present now an ellipsoidal shape. In some places there is the development of a blue amphibole in beds of radiolarian cherts near the lava contact. A jadeitic pyroxene has been observed in pillow lavas and lawsonite in pebbles of hyaloclastite found as elements of an ophiolitic breccia (KOEHN and VUAGNAT, 1970).

Haute-Ubaye (Table 1, No. 56)

Important masses of a partly dismembered ophiolite have been discovered and described recently in the upper part of the Ubaye Valley (Southern French Alps) (LEMOINE, STEEN and VUAGNAT, 1970; STEEN, 1972).

Pillow lavas which outcrop on both sides of the Vallon de Chabrière are undeformed or slightly flattened.

On the west side of the Vallon they are associated with ophiolitic breccias some of which are heterogenous with fragments of pillow lavas, of pegmatitic gabbros and, rarely of limestones and calcareous schists. The mechanism of formation of these breccias seems akin to that of olistostromes.

The crossection of the Pelvat peaks ophiolite complex (east side of the Vallon de Chabriere) exhibits the following sequence from top to bottom: coarse diabase to gabbro often rich in glaucophane; transition zone made up of fine-grained diabase, igneous breccia of coarse-grained diabase containing fragments of finer-grained diabase and pillow lavas; hyaloclastite; pillow lavas; pillow breccias; cherts and siliceous schists; recrystallized limestones; Replatte Formation (phyllitic schists and limestone beds).

Several "*inclusions*" of various *mafic rocks* are found embedded in lizardite-chrysotile- and antigorite-serpentinites: fragments of pillow lava, diabases, albitites and sediments. All these rocks have been rather extensively metamorphosed. The most interesting ones are probably the meta-albitites, which are characterized by a high soda content (up to more than 11%).

Mineralogy (STEEN, 1972):

a) Jadeite (main constituent), albite and lawsonite (variable), aegirinic augite, Fe-Mg-chlorite and analcite; pumpellyite in veinlets.
b) Albite and blue amphibole (main constituents), Fe-Mg-chlorite and stilpnomelane; jadeite and aegirinic augite as relics.
c) Albite and Mg-Fe-chlorite (main constituents), actinolite and stilpnomelane.

Accessory minerals in a), b) and c) are sphene, zircon, apatite and epidote-allanite.

It is very likely that at least some of the meta-albitites were derived from albitites of the "Replatte du Gondran" type. If some of these inclusions can be explained as dismembered dikes in the ultramafite from which the serpentinite was derived, others, like the metasediments, are no doubt, of tectonic origin.

Metamorphism. The ophiolites in the Haute-Ubaye region have been submitted to several metamorphic events. STEEN (1972) assigns the spilitization of many diabases, pillow lavas and pillow breccias to an pre-orogenic transformation in the oceanic crust. A first stage of truly alpine metamorphism was characterized by high pressures and moderate temperatures. Two assemblages developed: jadeitic pyroxene with lawsonite and glaucophane with lawsonite (and/or pumpellyite); it is possible that the second assemblage formed toward the end of the first stage under slightly lower pressures and slightly higher temperature. During a second stage of alpine metamorphism, greenschist facies assemblages developed. This stage has a retromorphic character; however, equilibrium was not reached and numerous relics of the blueschist assemblages are still well preserved.

Conclusions for the Western Alps

In the "classical view", alpine ophiolites are intercalated as sills or flows in the thick sequence of Mesozoic Schistes lustrés of the alpine geosyncline as a result of some initial magmatism. During the last ten years facts have accumulated, mostly in the Alps of southern France and in the Apennine, pointing to a different story.

There is now a rather strong evidence (LEMOINE et al., 1970; LEMOINE, 1971; ELTER, 1971; BOCCALETTI et al., 1971 and BEZZI and PICCARDO, 1971) in favor of considering that the ophiolites, at least in the regions mentioned, are part of a tectonic unit quite separate from the Schistes lustrés. In this unit, called "Nappe des ophiolites" or "Nappe Ligure" or, in the Préalpes "Nappe des Gets", the mafics and ultramafics are the basis of the stratigraphic sequence, they do not rest on an older basement. The sediments on top of the upper part of the ophiolites (pillow lavas and their breccias) have a pronounced pelagic character beginning with radiolarian cherts followed by fine-grained limestones. This thin series is quite different from the Schistes lustrés. However, above the limestones there is a progressive increase of the pelitic component leading to flyschtype shales (or sericitic schists depending on the degree of metamorphism) not unlike some of the Schistes lustrés.

Although this new interpretation was arrived at independently from any assumption of sea-floor spreading and plate tectonics it is in agreement with these new theories. The ophiolites can be considered as greatly dismembered and more or less metamorphosed slabs of an oceanic crust with a part of the subjacent uppermost mantle. The progressively increasing terrigenous character of the sediments capping the volcanics is well explained by gradual approach to a continental block as a result of sea-floor spreading and subduction.

In this view the metamorphism of the ophiolites may be ascribed to three main phases.

Phases of Alpine Metamorphism. The *first phase* predates entirely the alpine orogenesis. It is characterized by load metamorphism in the oceanic crust. It may have begun already near the active oceanic ridge as a response to the thickness of the volcanic pile and to the high thermal gradient near the ridge. It may also have happened further from the ridge when the weight of the Cretaceous pelitic sediments added to that of the volcanic rocks. It is possible that the spilitization of many pillow lavas, pillow breccias and dolerites is related to this first phase (VUAGNAT, 1974).

The *second phase* began with the subduction that initiated the alpine orogenesis. It was a high-pressure low-temperature phase with the development of blue amphibole, jadeite or jadeitic pyroxenes and lawsonite.

The *third phase* corresponds to the paroxysm of alpine orogeny and, in the more external zone of the ophiolite domain (Versoyen, Montgenèvre, Haute-Ubaye) gave birth to greenschist assemblages.

The prehnite-pumpellyite and pumpellyite-actinolite assemblages could be related either to the second or to the third phase. The peculiar mineral association of rodingites and ophispherites may result from processes operating during the first phase and be concomitant with the tectonic ascent of ultramafic slices along faults in the oceanic crust. It could however also be in relation with a much younger event.

RHETIC ALPS

by *V. Dietrich*

Arosa-Oberhalbstein-Upper Engadine (Table 1, No. 4–8)

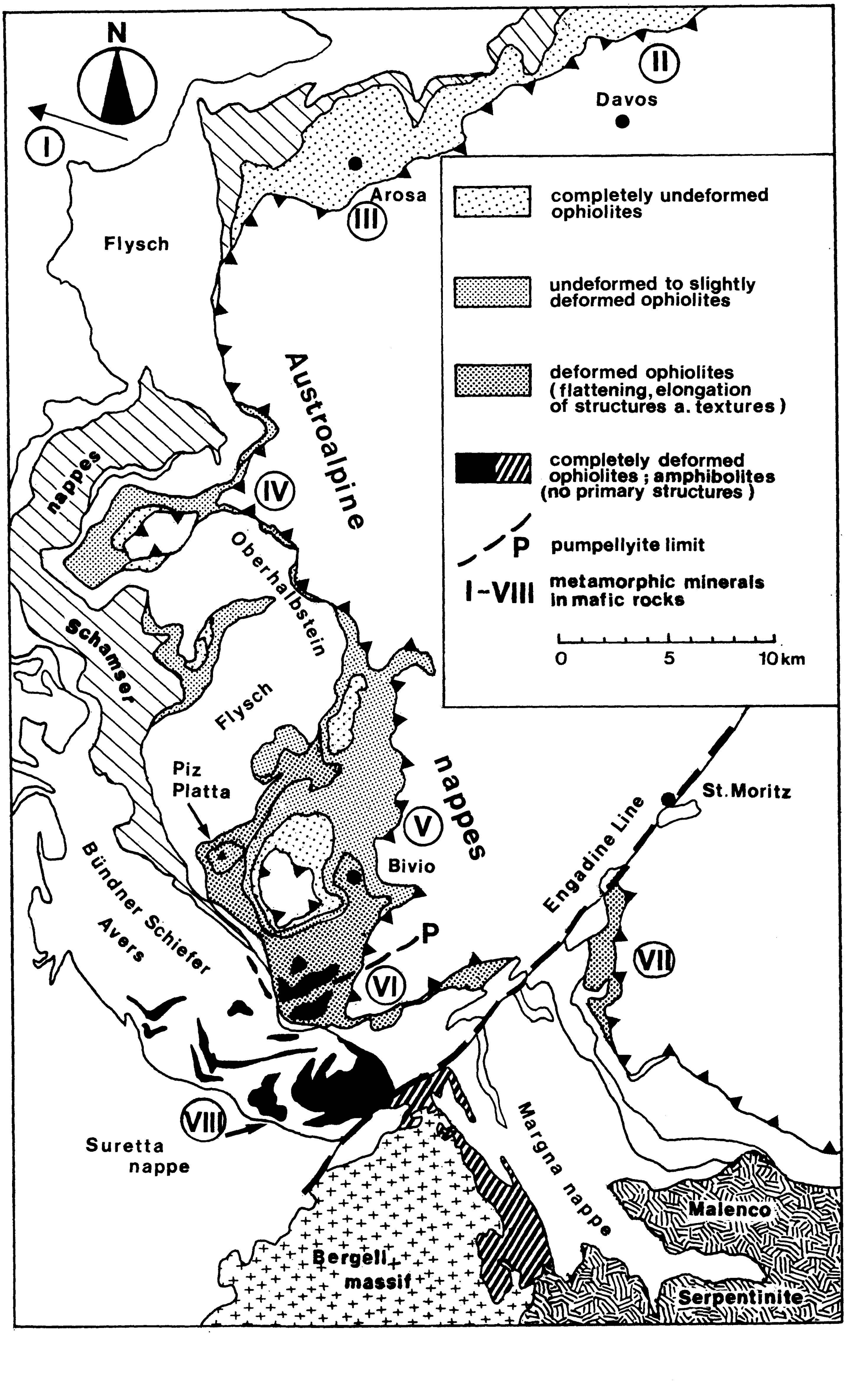
The pillow lavas, diabases, diallage-gabbros, lherzolitic serpentinites, ophicalcites and oceanic sediments in the Arosa zone and Platta nappe are regarded as a typical dismembered ophiolitic sequence (references in Table 1). Relics of an ultramafic-mafic transition zone and sheeted dikes do not exist. A part of ophicalcite breccias, mylonitic fabrics in serpentinites (partly preserved peridotites) and gabbros as well as the oceanic-tholeiitic (in many cases spilitic) chemistry of pillows and diabases indicate the development of a complex oceanic crust (e. g. ridge with transform faults) and oceanic lithosphere during the Jurassic and lower Cretaceous (Fig. 2).

Today the upper Penninic ophiolite nappe (Arosa-Platta) overlie Jurassic-Cretaceous Bündnerschiefer and upper Cretaceous-lower Tertiary flysch (Fig. 1). The ophiolites are overlain by the large ophiolite-free Austroalpine nappes (basement with Mesozoic cover).

Within the ophiolite nappe different types of mélange and intensive alpine thrust tectonics occur. The shearzones are filled with serpentinites, gabbros and ophicalcites. Remnants of Triassic and Jurassic sediments are sandwiched in serpentinite thrust zones, while usually upper Jurassic radiolarites, cherts, marbles and lower Cretaceous slates and phyllites show primary contacts with the volcanics.

Fig. 1. Mineral assemblages of metamorphosed mafic rocks in the profile Arosa-Oberhalbstein-Upper Engadine (Rhetic Alps). Abbreviations: Act = actinolite, Alb = albite, Cct = calcite, Chl = chlorite, Clz = clinozoisite, Dpd = diopside, Ep = epidote, Glauco = glaucophane, He = hematite, Law = Lawsonite, M = muscovite, Pump = pumpellyite, Pr = prehnite, Rieb/Cr = riebeckite and crossite, Qz = quartz, Ti = titanite = sphene.

I.	Chl, Alb, Cct, Qz, Ti, M	
	Alb, He, Cct	
	Chl, Pump, Ti	
II.	Pr, Pump, Act, Ti, Alb	
	Pr, Ep, Ti	
	Pr, Ep, Act	
	Ep, Act, Ti	
	Alb, Act, Ep, Chl, Qz	Gees (1955 und 1956)
	Alb, He, Chl, Cct, Ti, Ep	
III.	Alb, Chl, Ep, He, Cct, Ti, Qz	Grunau (1947)
	Pump, Chl, Cct, Qz	
IV.	Alb, Chl, Ep, Act, Ti±He	Streiff (1939)
	Alb, Chl, Act	
	Ep, Alb, Act, Cct, Chl, Ti	
	Ep, Pump, Chl, Act	
V.	Alb, Chl, Ti	
	Alb, Chl, M, He	
	Alb, Act, Chl, Ep±Cct, Ti	
	Alb, Cct, Chl±Qz	
	Chl, Pump, Act±Dpd	
	Chl, Pump, Ti±Cct, Qz	
	Pump, Chl, Ep, Act, Cct, Qz	
	Pump, Dpd, Chl	
	He, Alb, Qz, Cct, Chl	
	Qz, Cct, Law, He	
VI.	Alb, Chl, Ti	
	Alb, Chl, Ep, Act, Cct±Qz, Glauc.	
VII.	Alb, Chl, Cct	
	Alb, Act, Chl, Ep, Clz, M, Ti±He	D. Dietrich (1971)
	Alb, Chl, Ep, Ti	
	Act, Alb, Chl, Ep, Ti	
	Alb, Cct, Chl, Ep, Ti	
VIII.	Alb, Ep, Act, Rieb/Cr, Ti, Carbonates	Staub (1920)
	Alb, Ep, Law, Glauc, Chl, Act	


N
I
II
Davos
Arosa
III
Flysch
completely undeformed ophiolites
undeformed to slightly deformed ophiolites
deformed ophiolites (flattening, elongation of structures a. textures)
completely deformed ophiolites; amphibolites (no primary structures)
P pumpellyite limit
I-VIII metamorphic minerals in mafic rocks
0 5 10km
Austroalpine
nappes
IV
Oberhalbstein
Schamser
Flysch
Piz Platta
nappes
V
Bivio
St. Moritz
Engadine Line
P
VI
VII
Bündner Schiefer
Avers
VIII
Suretta nappe
Margna nappe
Malenco
Serpentinite
Bergell massif

Metamorphism

In Fig. 1 we have divided the N-S profile, Arosa-Upper Engadine into seven areas (II–VIII) and have listed the paragenetic assemblages of the metamorphic minerals of the mafic rocks. In the ophiolitic remnants of the Iberg klippes (I. 73 km WNW of Arosa, No. 9, plate 1), in the Arosa area and in the highest tectonic units of the Platta nappe completely undeformed primary structures and textures are perfectly preserved. From the upper part of the Oberhalbstein Platta nappe down and to the south there is a change into deformed ophiolites. In the "Upper Platta thrust sheets" the undeformed to slightly deformed volcanic structures and textures are macroscopically and microscopically visible while in the "lower Platta units" they are transformed by progressive flattening, schistosity and foliation. In the "Forcellina thrust sheet" they are completely deformed (Dietrich, 1969), and all primary structures and textures have disappeared.

In the areas I–V *pumpellyite* is a common mineral in the mafic rocks. Within the Forcellina thrust sheet and south of it pumpellyite is absent. *Prehnite* has only been found in some contact rocks between the "Totalp serpentinite" and overlying gneisses (Davos, II). *Lawsonite* occurs submicroscopically in the matrix of a completely undeformed pillow lava together with quartz, calcite and hematite. Only in the area VIII (prasinites, greenschists and blueschists within the tectonically lower "Averser Bündnerschiefer"), Staub (1920) described lawsonite together with glaucophane. *Glaucophane* (unzoned and without lawsonite) is common in the greenschists and prasinites of the Forcellina thrust sheet. *Alkali-amphiboles* (riebeckite and crossite, partly zoned around actinolite; ? post-kinematic) occur in gabbros, diabases and cherts in the areas IV–VI. *Stilpnomelane* seems to be post-kinematic. It occurs in diabases and gabbros throughout the Oberhalbstein.

From experimental data (Hinrichsen and Schürmann, 1969 and Nitsch, 1971) it seems that pumpellyite bearing assemblages in metabasalts show a trend towards higher pressures. Increase in grade (increase in temperature between 300 and 400° C) may be inferred from the following sequence of assemblages: chorite + pumpellyite; actinolite + chlorite + pumpellyite ± epidote; actinolite + epidote + pumpellyite ± chlorite; actinolite + chorite + epidote.

Petrographic data in the Arosa-Platta mafics suggest a progressive increase of grade in the field. In some places tectonic mixing within the ophiolite thrust sheets may have destroyed that picture. On the large scale from N to S, especially with the disappearance of pumpellyite and occurrence of glaucophane as well as with serpentine minerals (Dietrich and Peters, 1971) and with manganese minerals (Trommsdorff et al., 1970) the increase in grade is proven.

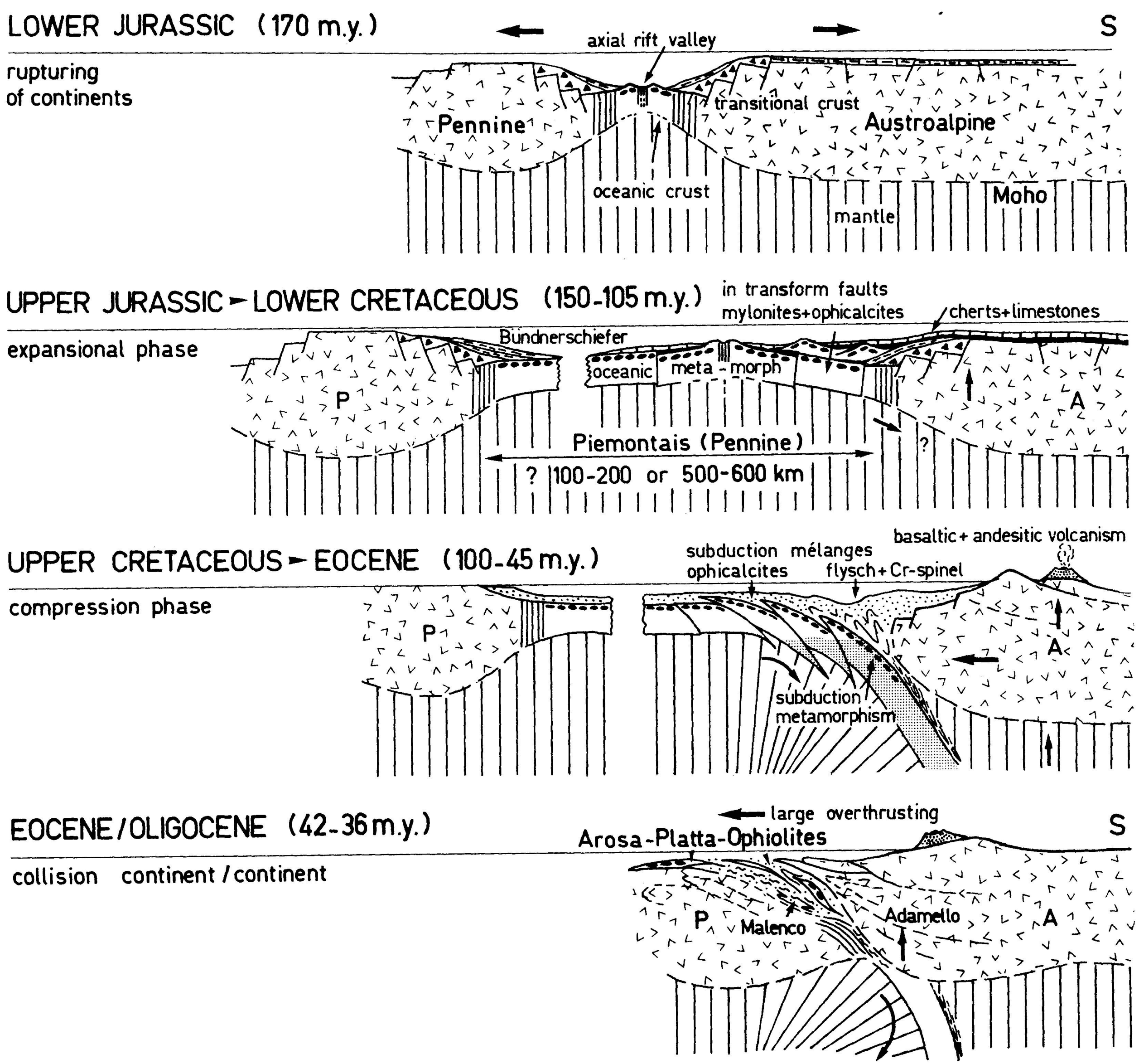


Fig. 2. Development of oceanic crust in the Pennine from Jurassic to Oligocene.

The role of Na_2O, H_2O and CO_2 in the mafics, and the influence of a possible earlier metamorphic event are not clear. It seems likely that a part of the mafic assemblage underwent a primary oceanic metamorphism, which produced actinolite and/or epidotite-chlorite-albite (MIYASHIRO et al., 1970).

Phases of Alpine metamorphism

According to the geological evidence (tectonic setting, rock types, structures, textures and dated oceanic sediments) and metamorphic mineral assemblages we suggest different phases of the Alpine metamorphism using the model of plate tectonics (ISACKS et al., 1968; DEWEY and BIRD, 1970 and LAUBSCHER, 1970) (Fig. 2).

1. *Jurassic to lower Cretaceous*
   - Expansion phase with an accretion of oceanic crust and lithosphere (PETERS, 1969). Mylonitization in fracture zones, tectonic mixing of various rock types. Formation of cataclastic gabbros, serpentinites and ophicalcites.
   - *Low grade oceanic metamorphism* (in mafics Ep-Chl-Alb or Act-Plag; in ultramafics lizardite and chrysotile) in the oceanic crust.
   - ? Beginning of a subduction towards south (Fig. 2). Only few indications of a very weak calc-alkaline volcanism in the Austroalpine and Southern Alps (BERNOULLI and PETERS, 1970 and 1974 and DIERSCHE, 1973).

2. *Cenomanian to Eocene*
   - Compression phase. Subduction towards south along a suture zone parallel to the Austroalpine. Possible obduction of oceanic crust with sediments (first thrust tectonics and/or olistolites into flysch) towards north and south forming parts of the Iberg-Arosa-Platta ophiolites. Mélange of the Arosa-Zone.
   - *Influence of a high pressure and low temperature metamorphism;* detectable only in relics: parts of the Platta mafics with pumpellyite and lawsonite; Forcellina thrusts sheets and southern units containing glaucophane (lawsonite) and rock forming antigorite (DIETRICH and PETERS, 1971). Few radiometric data (80–65 m. y.) are available from blue amphibole and micas (JÄGER, 1973).
   - Calc-alkaline volcanism in the Austroalpine and Southern Alps (DE SITTER and DE SITTER-KOOMANS, 1949; PICCOLI, 1965 and 1967; PICCOLI et al., 1971 and GANSSER, 1973).
   - A low grade thermal metamorphism is possible for the Austroalpine and Southern Alps according to the model of paired metamorphic belts (MIYASHIRO, 1961 and 1972).

3. *Eocene-Oligocene*

- Main tectonic event due to the collision of Pennine and Austroalpine continental crust. Large overthrusting of the Austroalpine nappes over Penninic nappes. Erosion of the Austroalpine surface (basaltic/andesitic volcanoes) and deposition of the Taveyanne graywackes.
- Possible flip towards north of the subducted lithosphere causing the:
- emplacement of the Bergell and Adamello granites, granodiorites and tonalites;
- *high temperature metamorphism in the Central Alps* with possible formation of postkinematic stilpnomelane in the mafics of the Arosa-Platta ophiolites.

4. *Oligocene-Miocene*

- Unroofing and cooling of the Central Alps. Uplift of the external massifs (Aar, Gotthard).
- Re-equilibration of fissure silicates and sulfides.

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Eclogae = Eclogae geologicae Helvetiae

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Table 1. *Metamorphosed mafic and ultramafic rocks (explanation to Plate I)*

No.	Locality	Rock-Types	Max. Thickness Outcropping	Metamorphism Categories 1–5 (p. 292); Mineral Zones	Tectonic Units	References * Major Petrographic Investigations
			Eastern Penninic Nappes			
1	Engadine window (d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite	~ 400 m traces lenses (200 m)	2, 3	Penninic	Züst (1905) * Grubenmann & Tarnuzzer (1909) Vuagnat (1946) * van Loon (1960) * Cadisch et al. (1963) Vuagnat (1965) Wenk (1968) Heugel (1974) *
2	Arosa zone Allgäu-Liechtenstein (i. d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite Ophicalcite	few meters, strongly tectonized	1, 2	highest Penninic nappe = Arosa-Platta-nappe	Seidlitz (1906) Schaetti (1952) Richter (1957) Jacobshagen & Otte (1968) Schidlowski (1969) Schidlowski & Stahl (1971) Otte (1972)
3	Arosa zone Liechtenstein-Klosters (i. d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite Ophicalcite	few meters, max. 100 m, partly tectonized	1, 2	Arosa-Platta-nappe	Häfner (1924) Allemann et al. (1951) Gees (1956) *
4	Arosa zone Klosters-Davos (d. ophiolite)	Diabase/Gabbro Contact felses Serpentinite Peridotite Garnet-Pyroxenite Ophicalcite	traces 0.1–1 m ~ 500 m (Serpentinite, Peridotite) 2–3 m ~ 300 m	1, 2	Arosa-Platta-nappe	Ball (1897) * Cadisch (1921) Gees (1955, 1956) * Peters (1963, 1965, 1968, 1969) *
5	Arosa zone Arosa (d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite Ophicalcite	100 m traces (Gabbro, Serpentinite, Ophicalcite)	1, 2	Arosa-Platta-nappe	Steinmann (1895, 1897, 1906, 1926) Bodmer-Beder (1898) * Vuagnat (1944, 1946) * Grunau (1947) * Niggli, P. (1950)

6	Northern Oberhalbstein-Avers (d. Ophiolite)	Diabase/Pillow lava Gabbro Serpentinite	500 m 150 m 150–200 m	2	Platta nappe s.l. Curver Serie, Martegnas Serie Livizung Zug Lower- and Upper Platta-Schuppen	Escher & Studer (1839) Studer (1851, 1853) Arbenz & Tarnuzzer (1923) Frei & Ott (1926) Wilhelm (1929) Streiff (1939) * Ziegler (1956) *
7	Southern Oberhalbstein-Avers (d. Ophiolite) Piz Forcellina	Rodingite dike Ophicalcite Serpentinite Greenschist	1–5 m 50 m 50 m 200–300 m	3, 4	?	Buch (1816), Bonney (1880) Staub (1920, 1921, 1926, 1928, 1958) Cornelius (1912, 1935) * Geiger (1948) * Vuagnat (1948, 1951) Ziegler (1952) Müller (1959, 1962, 1963, 1964) * Dietrich (1969, 1970, 1972) * Dietrich & de Quervain (1968) * Dietrich & Peters (1971) *
8	Upper Engadine Val Fex (d. Ophiolite)	Diabase Greenschist Serpentinite Ophicalcite	100 m 50 m few meters	3	Platta nappe s.l.	Staub (1914, 1915, 1916, 1934, 1946, 1952) * Trommsdorff et al. (1970) * Dietrich, D. (1971) * Seger (1971) Wanner (1971)
9	Iberg klippes (i. d. ophiolite)	Diabase/Pillow lava ? Gabbro	? 50–100 m ? traces	1	? Arosa-Platta-nappe	Quereau (1893) Trümpy (1967) Dietrich (unpublished)
10	Southern Avers	Greenschist Prasinite Blueschist Meta-Gabbro Serpentinite	few meters, max. 50–100 m, strongly tectonized	3, 4	Averser-Bündnerschiefer = Suretta nappe	Staub (1920, 1921, 1926) Wilhelm (1921) Streiff (1939) * Kruysse (1967)

No.	Locality	Rock-Types	Max. Thickness Outcropping	Metamorphism Categories 1–5 (p. 292); Mineral Zones	Tectonic Units	References * Major Petrographic Investigations
11	East of Bergell	Greenschist Amphibolite	> 100 m	3, ? 4 + Bergell contact metamorphism	? Suretta, Margna- or Platta nappe	Staub (1921, 1946) Gyr (1967)
12	Val Malenco	Amphibolite Meta-Gabbro Cpx-Antigorite-Serpentinite Pyroxenite Ol-Antigorite-Serpentinite	~ 2000 m	3, ? 4 + Bergell contact metamorphism	? Suretta, Margna- or Platta nappe	de Quervain (1938, 1945, 1963) * Fagnani (1958), Gerber (1966) * Dietrich & de Quervain (1968) Evans & Trommsdorff (1970) Trommsdorff & Evans (1972) * Bucher (1972) * Pfeifer (1972) * Bucher & Pfeifer (1973) Engi (1973) *
13	Vals-Safien	Greenschist Prasinite	1–50 m	3, 4	Bündnerschiefer	Schmidt (1891) Rothaan (1919) * Wilhelm (1929)
		Serpentinite	strongly tectonized		Adula-Tambo nappe	Nabholz (1945) * van der Plas (1959) *
14	Adula-Tambo	Greenschist Prasinite Blueschist	1–350 m	3, 4	Bündnerschiefer	Gansser (1937) *
		Serpentinite	few meters strongly tectonized		Adula-Tambo nappe	
15	Chiavenna, Val Bondasca	Amphibolite Meta-Gabbro Fo-Tc-Chl-Hbl-Ant (±En, Anth, Sp) Ultramafics	150–200 m 150 m 200 m	sillimanite zone + contact metamorphism	tectonic basis of the Tambo nappe	Ferrini (1964) * Schmutz (1973) *

Central Alps

16	Valle della Mera Borgo, Val Darengo	Peridotite Peridotite and kelyphitic Peridotite	lenses ~ 100 m lenses	sillimanite zone sillimanite zone	Adula nappe Bellinzona zone	TROMMSDORFF & EVANS (this issue) BLATTNER (1965) * EVANS & TROMMSDORFF (1970) FUMASOLI (1973) *
17	Monte Duria	Garnet-Peridotite Eclogite	lenses few meters, max. 100 m	sillimanite zone	Adula nappe	FUMASOLI (1973) *
	Gana Rossa	Peridotite Eclogite Amphibolite }	lenses	sillimanite zone	Bellinzona zone	
18	Alpe di Mea, Val Cama	Peridotite Eclogite	~ 100 m	sillimanite zone	Adula nappe	BRUGGMANN (1965) * TROMMSDORFF & EVANS (1969) *
19	Cima di Giù, Val Carassina	Ol-Antigorite- Serpentinite + pyroxenitic layers } Amphibolite	200–300 m few meters	chloritoid zone	Adula nappe	EGLI (1966) *
20	Loderio	Peridotite Amphibolite	30 m lenses	staurolite zone	Simano nappe	HEZNER (1909) *
21	Alpe Arami	Garnet-Peridotite Eclogite	320 m 2 m	sillimanite zone	Cima Lunga- Lappen	GRUBENMANN (1908) * DAL VESCO (1953) *
	Alpe Alai	Peridotite Amphibolite	150 m 50 m	sillimanite zone	Cima Lunga- Lappen	O'HARA & MERCY (1966) MÖCKEL (1968) *
22	Val Verzasca	Garnet-Peridotite Eclogite	lenses lenses	staurolite zone	Simano nappe	DAL VESCO (1953) * TROMMSDORFF (unpubl.)
	Cima di Gagnone	Peridotite	lenses	sillimanite zone	Simano nappe	EVANS & TROMMSDORFF (1974)
23	Upper Maggia Region	Amphibolite Serpentinite	lenses (50–300 m) lenses (few meters)	staurolite zone	Maggia zone	GÜNTHERT (1954) * WENK & KELLER (1969)
24	Val Peccia	Anthophyllite fels Amphibole-Peridotite	lenses lenses (few meters)	staurolite zone	Orsaglia Serie	FEHLMANN (1919) GÜNTHERT (1954)

No.	Locality	Rock-Types	Max. Thickness Outcropping	Metamorphism Categories 1–5 (p. 292); Mineral Zones	Tectonic Units	References * Major Petrographic Investigations
25	Bosco Gurin	Peridotite-Tr-Tc-Ol-Antigorite Amphibolite	lenses (10–20 m) 100 m	staurolite zone	Bosco Gurin	Grütter (1929) *
26	Monte Larone	Greenschist Prasinite Serpentinite	lenses few meters max. 30 m	staurolite zone	Bündnerschiefer Lebendun Serie	Schmidt & Preiswerk (1908)
27	Agaro, Valle dell Isorno	Tr-Tc-Ol-Antigorite-Serpentinite } Amphibolite	~ 300 m ~ 100 m	staurolite zone	Isorno Serie	Wieland (1966) * Keusen (1972)
28	Valle Vigezzo, Centovalli	Peridotite Amphibolite	lenses (100–200 m) lenses ~ 500 m	sillimanite zone	Orselina zone	Knup (1958) *
	For further information on Amphibolite occurrences, on ultramafic and eclogitic inclusions					Wenk & Keller (1969) * Kündig (1926) * Evans & Trommsdorff (1970) Wang (1939)*, Forster (1947)*, Kobe (1956)
			External Massifs			
29	Gotthard-Massif	Amphibolites		stilpnomelane zone	Gotthard-Massif	Geolog. Generalkarte der Schweiz 1 : 200 000 Geolog. Karte d. Schweiz 1 : 500 000 Geotechn. Karte d. Schweiz 1 : 200 000
30	Goms-Hospental-Disentis	Serpentinite Talcschist	lenses, few meters, max. 200 m	stilpnomelane zone	Gotthard-Massif Tavetscher-Massif	Stapff (1878, 1880) Schneider (1912) * Heim (1918), Fehlmann (1919) Parker (1921) *
31	Aar-Massif	Greenschist Amphibolites	lenses	stilpnomelane zone in the southern part	in paragneisses of the Aar-Massif	Geolog. Generalkarte der Schweiz 1 : 200 000 Geolog. Karte d. Schweiz 1 : 500 000 Geotechn. Karte d. Schweiz 1 : 200 000

40	Aiguilles-Rouge-Massif	Greenschist Prasinite Amphibolite Gabbro Peridotite	3000 m basic-acid volcanics with associated lenses of gabbros and ultramafics	north of stilp-nomelane zone	Aiguilles-Rouge-Massif	Geolog. Generalkarte der Schweiz 1 : 200 000 LAURENT (1973) *
			Western Penninic Nappes			
32	Turbhorn,	Greenschist Amphibolite Gabbro-Amphibolite	100–150 m	3 or stilp-nomelane zone	Bündnerschiefer	PREISWERK (1907) * SCHMIDT & PREISWERK (1908)
	Hohsandhorn, Banhorn	Antigorite-Serpentinite	lenses (few meters)			
33	Binn-Tschampigen-keller	Greenschist Gabbro-Amphibolite	~ 500 m	3 or stilp-nomelane zone	Bündnerschiefer	PREISWERK (1907) * SCHMIDT & PREISWERK (1908)
34	Geisspfad	Ol-Tr-Antigorite-Serpentinite Rodingite dike	500–700 m few meters	3 or staurolite zone	Monte Leone nappe	PREISWERK (1901) SCHMIDT & PREISWERK (1908) SCHNELL (1921) KEUSEN (1970, 1972) *
35	Visp (i. d. ophiolite)	Greenschist/Pillow lava Prasinite Ovardite Serpentinite	50–100 m 100–150 m	3 or stilp-nomelane zone	Bündnerschiefer	PREISWERK (1903, 1907)* SCHMIDT & PREISWERK (1908) WERENFELS (1924) VUAGNAT (1947)
36	Antrona-Val Loana,	Prasinite Flasergabbro Serpentinite	> 500 m < 100 m < 100 m	4, 5	Bündnerschiefer Ophiolite nappes	BEARTH (1954, 1956, 1972)
	Furgg-Zone	Amphibolite	?			BEARTH (1954) WETZEL (1972) *
37	Moncucco	Amphibolite Talc-Peridotite	lenses ~ 500–800 m	4, 5	Camughera-Moncucco complex	BEARTH (1956)
			Prealpine Nappes			
38	Gstaad-Jaunpass (i. d. ophiolite)	Pillow lava Diabase	5–10 m 5–10 m	1	within Cenomanian flysch of Simmen nappe s.l.	VUAGNAT (1944) GRUNAU (1945) ARBENZ (1947) SALIMI (1965) * ELTER et al. (1966)

No.	Locality	Rock-Types	Max. Thickness Outcropping	Metamorphism Categories 1–5 (p. 292); Mineral Zones	Tectonic Units	References * Major Petrographic Investigations
39	Les Gets (d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite	~ 50 m 1–5 m 5–10 m	1	within Cenomanian flysch of Simmen nappe s.l.	Michel-Levy (1892) Schroeder (1939) Vuagnat & Jaffe (1954) Jaffe (1955) Bertrand (1970) *
			Western Penninic Nappes			
41	Mt. Vélan-Fionnay-Turtmanntal	Prasinite, Ovardite Amphibolite Blueschist (? pre-Mesozoic)	horizons lenses > 5 m	3, 4	Bernard nappe	Woyno (1912) Schürmann (1953) Tschopp (1923) Vallet (1950) Gilleron (1946) Schaer (1959)
42	Zone du Combin (Zinal-Mauvoisin) (d. ophiolite)	Prasinite, Amphibolite, Blueschist } Gabbro Serpentinite Ophicalcite	> 100 m 300–500 m > 20 m few meters	? 3, 4	Ophiolite nappe	Argand (1908) Preiswerk (1926) Dias (1920), Witzig (1948) Zimmermann (1955)
43	Zone du Combin Val d'Ollomont (d. ophiolite)	Prasinite, Amphibolite, Blueschist } Gabbro, Serpentinite	> 200 m > 20 m	? 3, 4	Ophiolite nappe Zone du Combin Val d'Ollomont	Diehl (1938) * Diehl et al. (1952) Dal Piaz (1974)
44	Mt. Collon	Diallage-Gabbro, Olivine-Gabbro }	> 500 m	? 1 or 2	Dent Blanche nappe Ophiolite nappe Valpelline	Brun (1892, 1894) * Argand (1908, 1934) Bartholomès (1920) * Stutz (1940)*, Masson (1938), Diehl et al. (1952)
	Valpelline	Amphibolite	lenses (20–100 m)			
45	Zermatt-Saas zone (d. ophiolite)	Prasinite, Blueschist, Eclogite = (pillow lava) } Flasergabbro Antigorite-Serpentinite, Rodingite dikes }	~ 500 m ~ 1000 m ~ 500–900 m (? 3000 m)	3, 4, 5	Ophiolite nappe Complex between Mt. Rosa and Gran Paradiso (45–46)	Bearth (1953, 1954, 1959, 1962, 1964, 1965) * Bearth (1967, 1973) * Güller (1948) Schäfer (1895) Dal Piaz (1965, 1966, 1967, 1974)
46	Grivola zone (d. ophiolite)	(rock-types as for 45)		4, 5		Dal Piaz (1928) * Pelloux (1946) Rigault (1961)

47	Versoyen (d. ophiolite)	Pillow lava Diabase Gabbro Serpentinite	~ 30 m ~150 m > 20 m lenses	3, 4, 5	Dent-Blanche nappe, Ophiolite nappe or Nappe des Brèches de Tarentaise	SCHOELLER (1929) VUAGNAT (1956) ANTOINE (1965) LOUBAT (1968) * ANTOINE (1972) ANTOINE et al. (1973)
48	Mont Jovet (i. d. ophiolite)	Prasinite Gabbro Serpentinite	few meters (Prasinite, Gabbro) ~ 50–100 m	? 3	Nappe des schistes lustrés	ELLENBERGER (1958) *
49	Stura d'Ala, Stura di Viù Avigliana	Prasinite, Blueschist, Eclogite (pillow lava) Amphibolite Flasergabbro Antigorite-Serpentinite Rodingite dike	~ 500–700 m (Prasinite … Amphibolite) ~ 300–400 m ~ 3000 m (Antigorite-Serpentinite, Rodingite dike)	4, 5 ? 3 4, 5	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	STRÜVER (1871) FRANCHI (1893) FRANCHI & NOVARESE (1895), GRILL (1921, 1922) MICHEL & NICOLAS (1961) DAL PIAZ (1965, 1967, 1971) * NICOLAS (1966, 1967) * CONTI (1966)
50	Val Susa (d. ophiolite)	(as 49)		4, 5	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	BORTOLAMI & DAL PIAZ (1970) DAL PIAZ et al. (1972)
51	Lanzo (ophiolite)	Lherzolite-Dunite Gabbro	> 2000 m lenses, dikes	?	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	NICOLAS (1968, 1969) * NICOLAS et al. (1971, 1972) BOUDIER (1972) * BOUDIER & NICOLAS (1972)
52	Haut Val de Suse (d. ophiolite)	Diabase/Pillow lava Gabbro Serpentinite	~ 100 m ? ?	3, 4	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	GAY (1968, 1971, 1972) CHATTERJEE (1971)
53	Mte. Rocciavrè (i. d. ophiolite)	Prasinite Blueschist Eclogite Gabbro Serpentinite	> 500 m	4, 5	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	FRANCHI (1897) DAL PIAZ (1965) PORADA (1966) BORTOLAMI & DAL PIAZ (1970) CHATTERJEE (1971)

No.	Locality	Rock-Types	Max. Thickness Outcropping	Metamorphism Categories 1–5 (p. 292); Mineral Zones	Tectonic Units	References * Major Petrographic Investigations
54	Montgenèvre (ophiolite)	Diabase/Pillow lava Gabbro Albitite dike Rodingite dike Ophispherite Serpentinite Ophicalcite	~ 500 m (Gabbro, Albitite dike) ~ 150 m (Rodingite dike – Ophicalcite) ~ 300 m	1, 2, 3, 4	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	Cole & Gregory (1890) Michel-Levy (1877) Masini (1929) Vuagnat (1953, 1967) Vuagnat & Pusztaszeri (1965) Vuagnat et al. (1966) * Koehn & Vuagnat (1970)
55	Queyras (ophiolite)	Diabase/Pillow lava Gabbro Serpentinite	~ 500 m	2, 3, 4	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	Routier (1945, 1946) Lemoine (1962) Lemoine, Steen & Vuagnat (1970)
56	Haute-Ubaye (ophiolite)	Diabase/Pillow lava Gabbro Albitite dike Serpentinite Ophicalcite	~ 200 m (Gabbro, Albitite dike) ~ 150 m (Serpentinite, Ophicalcite) ~ 300 m	3, 4, 5	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	Lemoine, Steen & Vuagnat (1970) Steen (1972) *
57	Monte-Viso (ophiolite)	Prasinite/Pillow lava Blueschist, Eclogite, Metagabbro Dikes Rondingite Serpentinite	> 2000 m	3, 4, 5	Ophiolite nappe, complex between Gran Paradiso and Dora Maira, Nappe des schistes lustres	Conti (1955, 1964, 1966), Franchi (1898, 1900) Bearth (1962, 1967) Dal Piaz (1965) Bortolami & Dal Piaz (1970) Mottana (1971)
58	Haute-Ubaye (i. d. ophiolite)	Pillow lava (Diabase)	20–25 m	1	within the Flysch à Helminthoïdes	Kerckhove (1961)
59	Alpes Maritimes (i. d. ophiolite)	Pillow lava (Diabase)	1,5 m	1	within the Flysch à Helminthoïdes	Haccard (1965)

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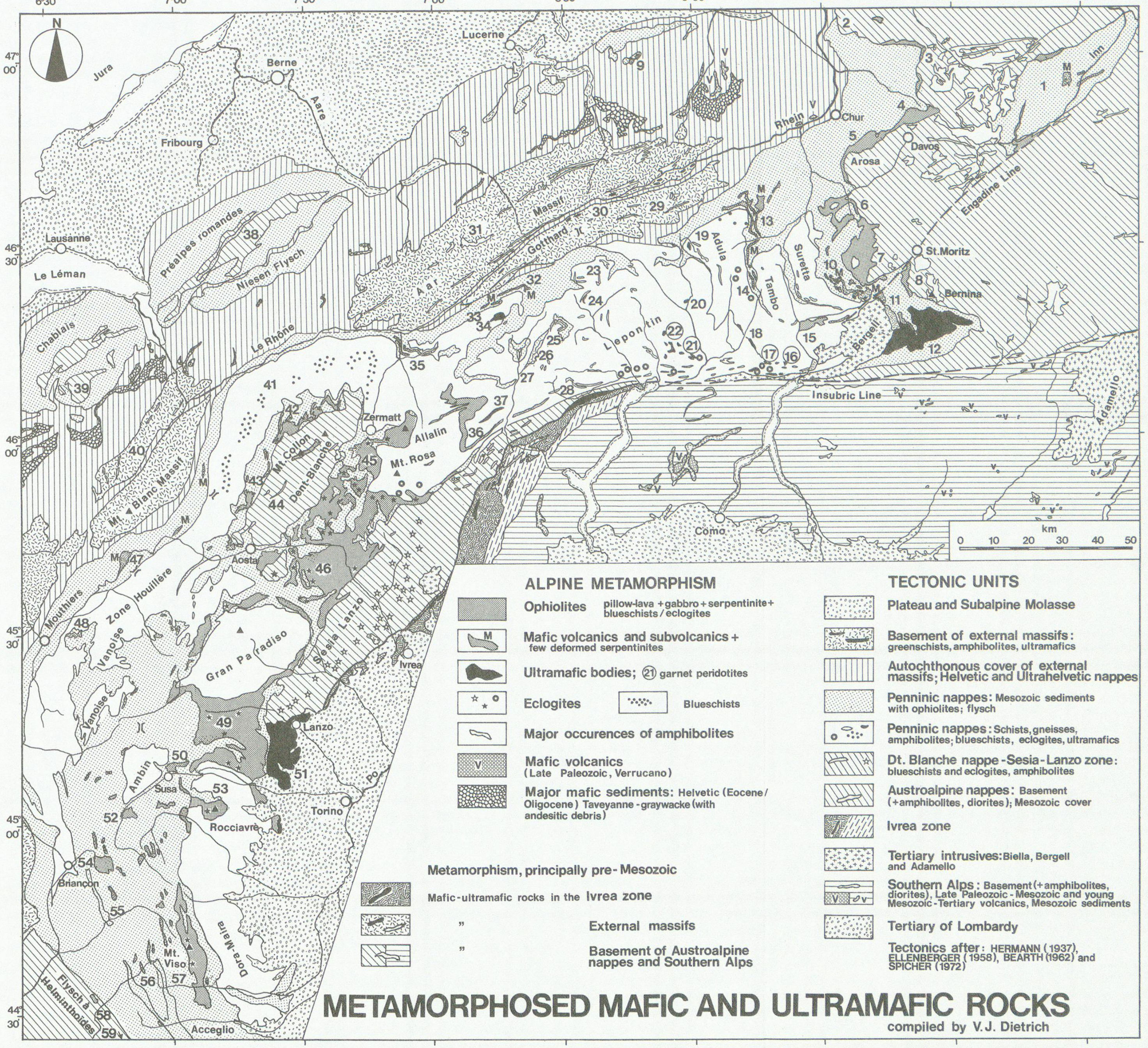

LOCALITIES

1 Engadine window
2 Arosa zone — Allgäu - Liechtenstein
3 Arosa zone — Liechtenstein - Klosters
4 Arosa zone — Klosters - Davos
5 Arosa zone — Arosa
6 Platta nappe — Northern Oberhalbstein - Avers
7 Platta nappe — Southern Oberhalbstein - Avers
8 Platta nappe — Upper Engadin - Val Fex
9 Iberg klippes
10 Southern Avers
11 East of Bergell
12 Val Malenco
13 Bündnerschiefer — Vals - Safien
14 Bündnerschiefer — Adula - Tambo
15 Chiavenna
16 Valle della Mera and Borgo, Val Darengo
17 Monte Duria and Gana Rossa
18 Alpe di Mea and Val Cama
19 Cima Giù, Val Carassina
20 Loderio
21 Alpe Arami
22 Val Verzasca, Cima di Gagnone
23 Upper Maggia region
24 Val Peccia
25 Bosco Gurin
26 Monte Larone
27 Agaro, Valle dell isorno
28 Valle Vigezzo, Centovalli
29 Gotthard - Massif
30 Goms - Hospental - Disentis
31 Aar - Massif
32 Turbhorn - Hohsandhorn - Banhorn
33 Binn - Tschampigenkeller
34 Geisspfad
35 Visp
36 Antrona - Valle Loana
37 Moncucco
38 Gstaad - Jaunpass
39 Les Gets
40 Aiguilles Rouges Massif
41 Mt. Vélan - Fionnay - Turtmanntal
42 Zone du Combin (Zinal - Mauvoisin)
43 Zone du Combin - Val d'Ollomont
44 Mt. Collon
45 Zermatt - Saas Fee zone
46 Grivola zone
47 Versoyen
48 Mont - Jovet
49 Stura d'Ala - Stura di Viù
50 Val di Susa
51 Lanzo
52 Haut Val de Suse
53 Monte Rocciavrè
54 Montgenèvre
55 Queyras
56 Haute - Ubaye
57 Monte - Viso
58 Haute - Ubaye — Flysch à Helminthoïdes
59 Alpes Maritimes — Flysch à Helminthoïdes