Zeitschrift: Archives des sciences [1948-1980]
Herausgeber: Société de Physique et d'Histoire Naturelle de Genève
Band: 33 (1980)
Heft: 1-3

Artikel: The mélange zone of the col du Chenaillet (Montgenèvre ophiolite, Hautes-Alpes, France)

Autor: Bertrand, J. / Steen, D. / Tinkler, C.

DOI: https://doi.org/10.5169/seals-739484

THE MELANGE ZONE OF THE COL DU CHENAILLET (MONTGENÈVRE OPHIOLITE, HAUTES-ALPES, FRANCE)

BY

J. BERTRAND [1], D. STEEN [1], C. TINKLER [1] and M. VUAGNAT [1]

ABSTRACT

The Montgenèvre massif is a slightly metamorphic partly dismembered ophiolite preserved from strong alpine regional metamorphism and deformation by its tectonic position as a downfaulted block between two transverse faults. Ultramafites (strongly serpentinized lherzolites), gabbros, diabase dikes and masses, rare albitites and thick pillow lavas, pillow breccias and hyaloclastites are found.

The massif is separated into several thick tectonic slices by serpentinitic zones. One of these zones, between the Chenaillet and the Grand Charvia summits, appears to be a typical melange. The matrix is a serpentinite breccia to microbreccia with a groundmass grading from a serpentinitic to calcitic cement. Elements of all sizes are included in this matrix: massive serpentinite with relicts of primary minerals, coarse diabases, pillow breccias with some intact pillows, other breccias, and ophispherites. Rares detritic sediments are also associated with the melange material. Some of the inclusions, mainly the ophispherites, have been submitted to metasomatic processes similar to those leading to classical rodingites. Ophispherites derive mainly from pillow lava fragments, diabases and gabbros. In their core, augite is frequently the only primary mineral preserved accompanied by chlorite and/or by various lime-silicates: hydrogarnet, garnet, prehnite. The outer shell is generally entirely chloritized.

It is believed that this melange corresponds to a fracture zone in the ocean floor along which peridotite-serpentinite was intruded in a solid state and finally reached the bottom of the sea.

RÉSUMÉ

Le massif du Montgenèvre est constitué par une séquence ophiolitique partiellement démembrée et plus ou moins préservée du métamorphisme régional alpin du fait de sa position tectonique particulière. Il s'agit en effet d'un compartiment effondré limité par deux failles transversales.

Des ultramafites (lherzolites fortement serpentinisées), des gabbros, des diabases (dykes et masses bien individualisées), de puissantes coulées de basaltes en coussins, de brèches de pillow et de hyaloclastites, et de rares albitites le constituent.

Le massif est divisé en plusieurs importantes écailles tectoniques délimitées par des zones serpentineuses.

---

[1] Department of Mineralogy, University of Geneva, 13, rue des Maraîchers, 1211 Genève 4, Switzerland.

Entre les sommets du Chenaillet et du Grand Charvia, l'une de ces zones apparaît comme un mélange typique. La matrice de ce dernier consiste en une brèche à microbrèche de serpentinite à ciment serpentineux à calcitique. Des éléments de toutes tailles sont inclus dans cette matrice: serpentinite massive avec reliques de minéraux primaires, diabases grossières, brèche de pillows avec quelques pillows bien préservés, diverses autres brèches et des ophisphérites; de rares sédiments détritiques s'observent aussi.

Certaines de ces inclusions, principalement les ophisphérites, ont été affectées par des phénomènes de métasomatose tels ceux conduisant à la formation des rodingites. Les ophisphérites sont formées principalement de fragments de basaltes en coussins, de diabases et de gabbros. Elles comprennent un cœur et une enveloppe externe. Dans le premier, l'augite est souvent le seul minéral primaire préservé accompagné de chlorite et/ou divers silicates de chaux: hydrogrenat, grenat, prehnite. Dans la seconde, la chloritisation est généralement totale.

Ce mélange est interprété comme un vestige d'une zone de fractures dans la croûte océanique, fractures selon lesquelles la péridotite-serpentinite, à l'état solide, aurait fait intrusion pour atteindre finalement le fond de la mer.

INTRODUCTION

The Montgenèvre ophiolite is located on both sides of the French-Italian border at the latitude of Briançon, just South of the pass of Montgenèvre (Hautes-Alpes, France) (Pusztaszeri, 1969).

The North-South extension of the massif in a direction parallel to the general trend of the Alps in this region, is about 4-5 km; from West to East it stretches approximately 8 km, from the Replatte du Gondran to the Mont Cruzeau. The highest point, the Chenaillet peak, culminates at 2650 m and the lowest point is near Cesana Torinese (Province of Torino, Italy) at about 1350 m.

The Montgenèvre complex is a typical partly dismembered and moderately metamorphosed ophiolite (Geotimes, 1972; Dietrich *et al.*, 1974). Penetrative alpine deformation appears only in the Easternmost part (Mont Cruzeau). This massif represents the largest of the so-called "unmetamorphic" ophiolites of the Western Alps, covering about 30 sq. km and exposing a sequence more than one thousand meters thick. The poor development of the regional alpine metamorphism is due to the fact that the whole massif occurs as a down-faulted block between two approximately East-West trending normal faults: the Montgenèvre fault to the North and the Cerveyrette Valley fault to the South (Lemoine, 1964) (see Figs. 1 and 2 for location). Due to down-faulting, the higher levels of the alpine edifice, showing only a moderate metamorphic imprint, have been preserved. In the Western part assemblages of pumpellyite-actinolite facies are found whereas near the Eastern border minerals of the blue-schist facies begin to appear (lawsonite, Na-rich pyroxene, blue amphibole).

Structurally the Montgenèvre massif is part of the "domaine piémontais" or, more exactly, part of a nappe which corresponds to the highest tectonic unit of the Alps in this region. This nappe is made up of ophiolitic rocks covered with a rather thin sedimentary sequence (Lemoine *et al.*, 1970).

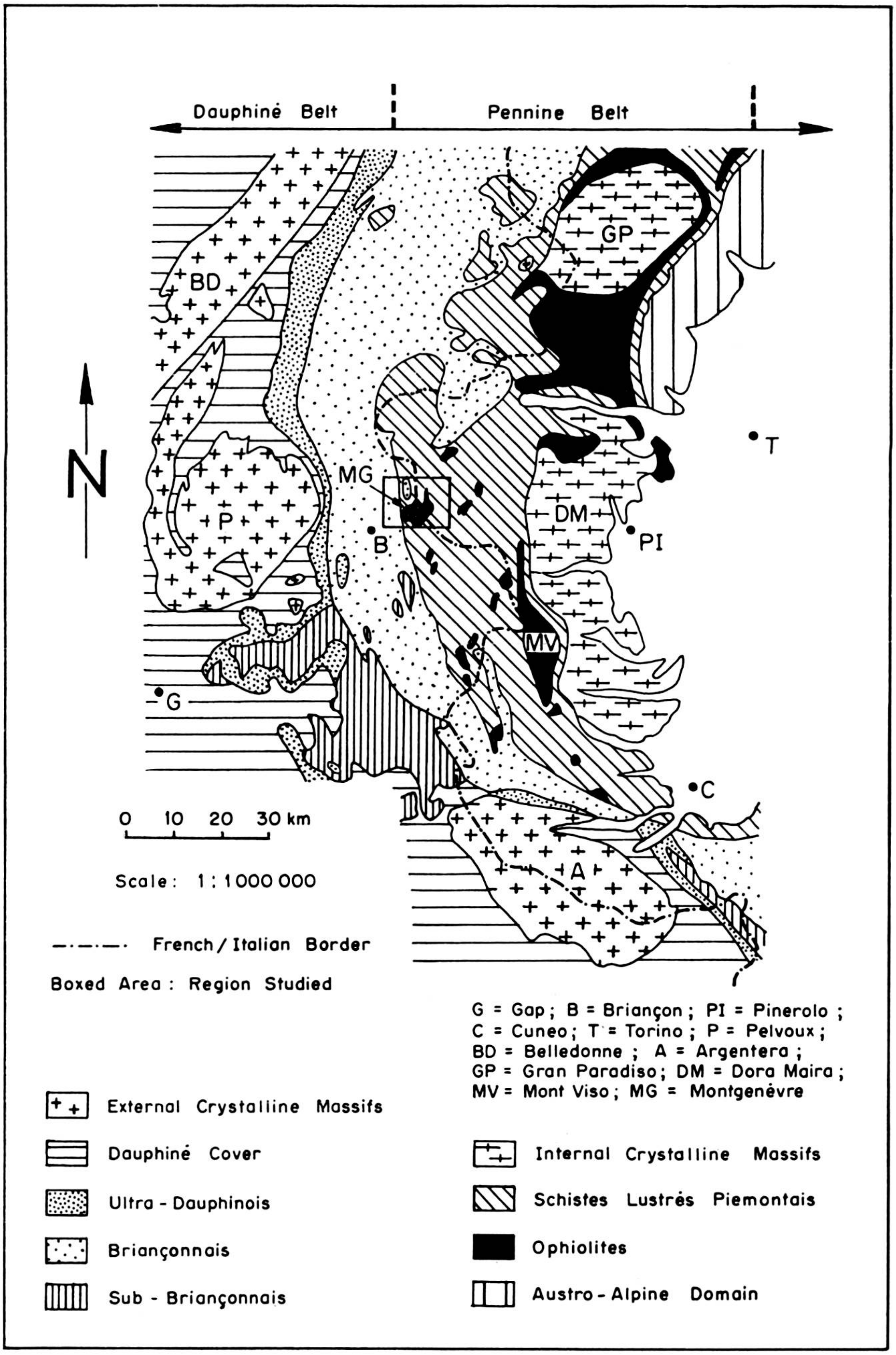

FIG. 1.—Geographical and Geological Location of the Montgenèvre Ophiolite.

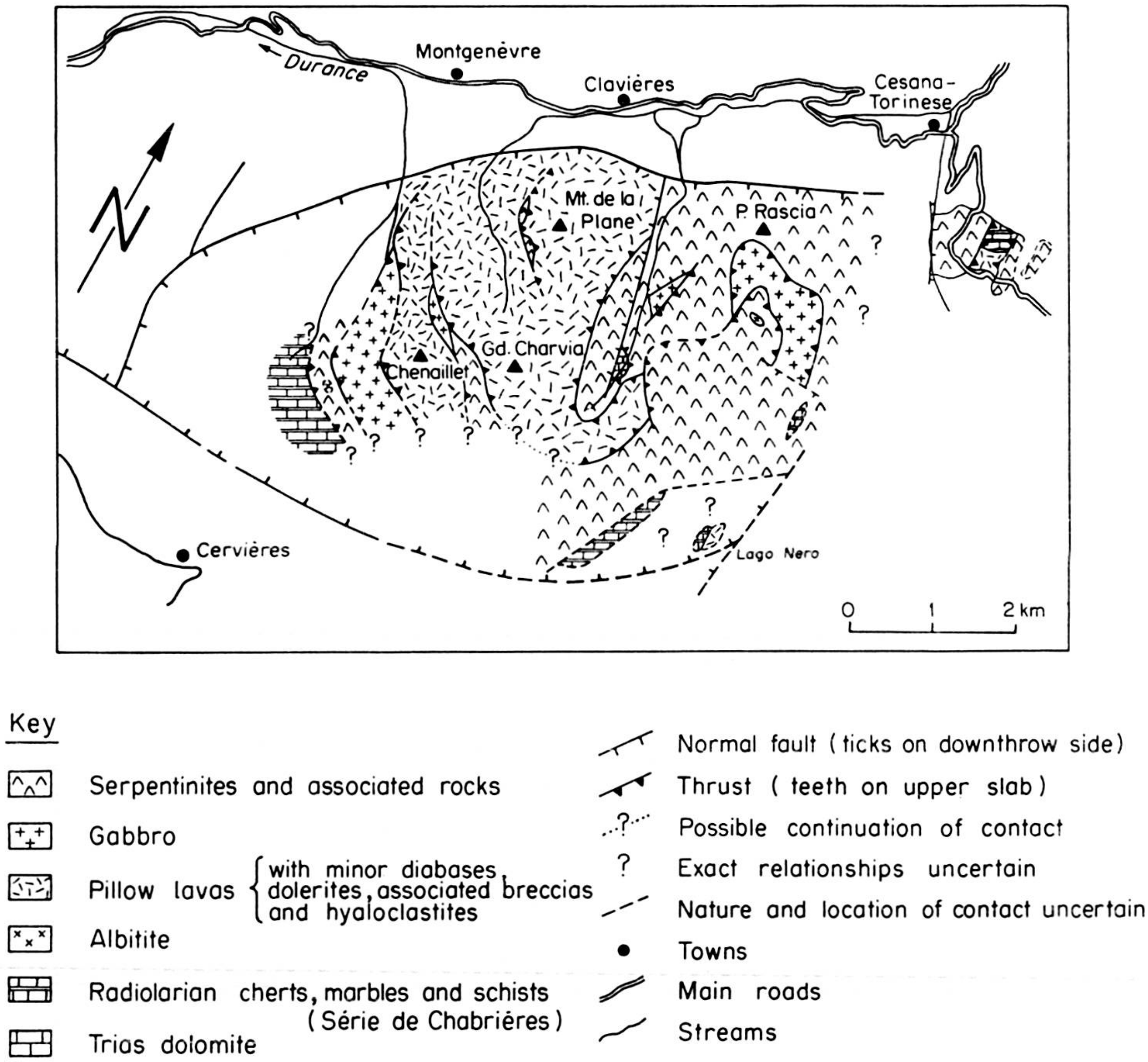

FIG. 2.—Geological Sketch of the Montgenèvre Ophiolite.

The main members of ophiolitic complexes are recognized;—*serpentinized ultramafics* of the "tectonite" type (mostly lherzolites),—*gabbros* with mafic cumulates near the base and numerous diabase dikes higher up. These gabbros show zones of strong penetrative deformation leading to typical flasergabbros. This deformation has been accompanied by recrystallization in the amphibolite facies and formation of amphibole. As these flasergabbros are cut by completely undeformed dikes of diabase, it is believed that the deformation and metamorphism took place very early in the deep oceanic crust.—Thick *pillow basalt flows* with intercalated pillow breccias and hyaloclastites are also well represented. Some of these pillow basalts and pillow breccias show a typical spilitic character with high soda, low lime and abundance of albite. This type of spilitisation can be tentatively ascribed to metasomatic processes in the upper part of the oceanic crust. Rocks of the plagiogranite group are represented only by rare lenses and dikes of albitites.

The whole massif has been folded and dismembered into several thick slices. The Westernmost of these constitutes the Chenaillet Peak, the next one to the East is that of the Grand Charvia (or Souréou) Peak. In the saddle between these two summits, there is a crushed serpentinite zone: we call this the "melange zone of the col du Chenaillet" (Fig. 3).

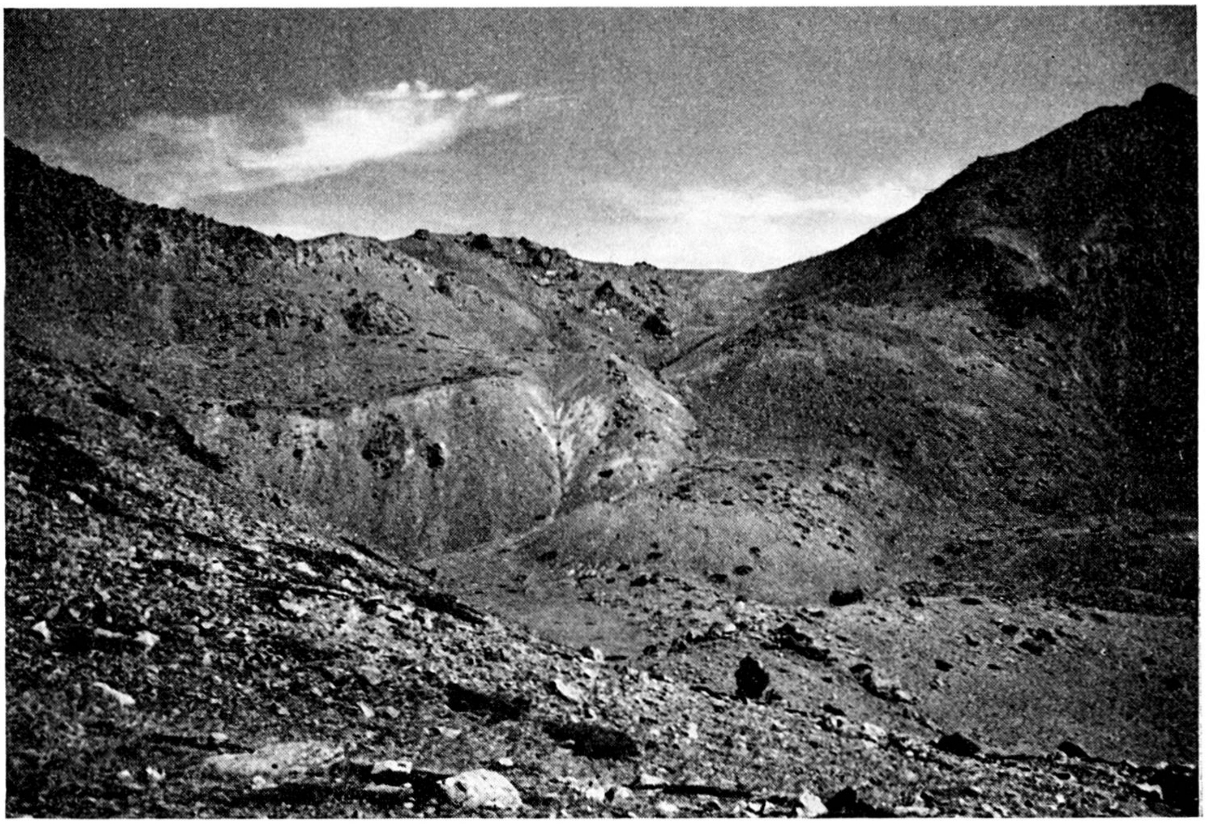

FIG. 3.—The col du Chenaillet Melange Zone seen from the South.

If we look at figures 4 and 5, we see that the melange zone is about 1000 m long varying in width from 100 to 300 m. It is limited to the West by the diabases, pillow basalts, pillow breccias and hyaloclastites of the Chenaillet. In the North-West corner the serpentinite abuts against an outcrop of flasergabbro. To the East the pillow basalts of the Grand Charvia mark the limit of the zone. To the North the zone pinches out between volcanics and to the South it seems also to pinch out but the outcrops are covered by scree and landslid masses.

If we follow the divide line along the crest of the saddle (see Fig. 5) between Chenaillet and Grand Charvia, we find from West to East: the coarse diabase of the Chenaillet, then a first serpentinitic zone containing ophispherites, serpentinite breccias and massive serpentinite followed by a large mass of pillow breccias with

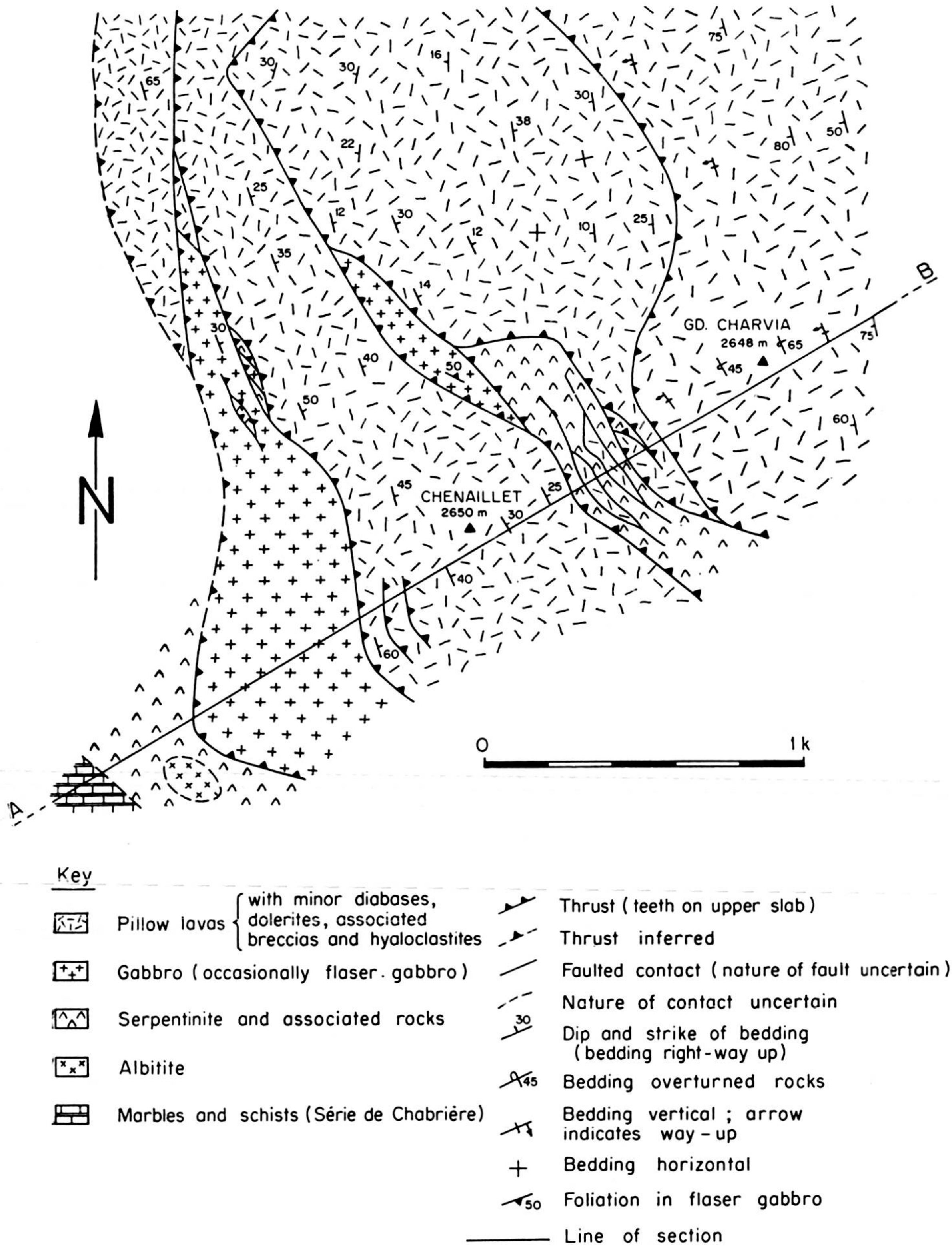

FIG. 4.—Simplified Map of the Chenaillet-Grand Charvia Area.

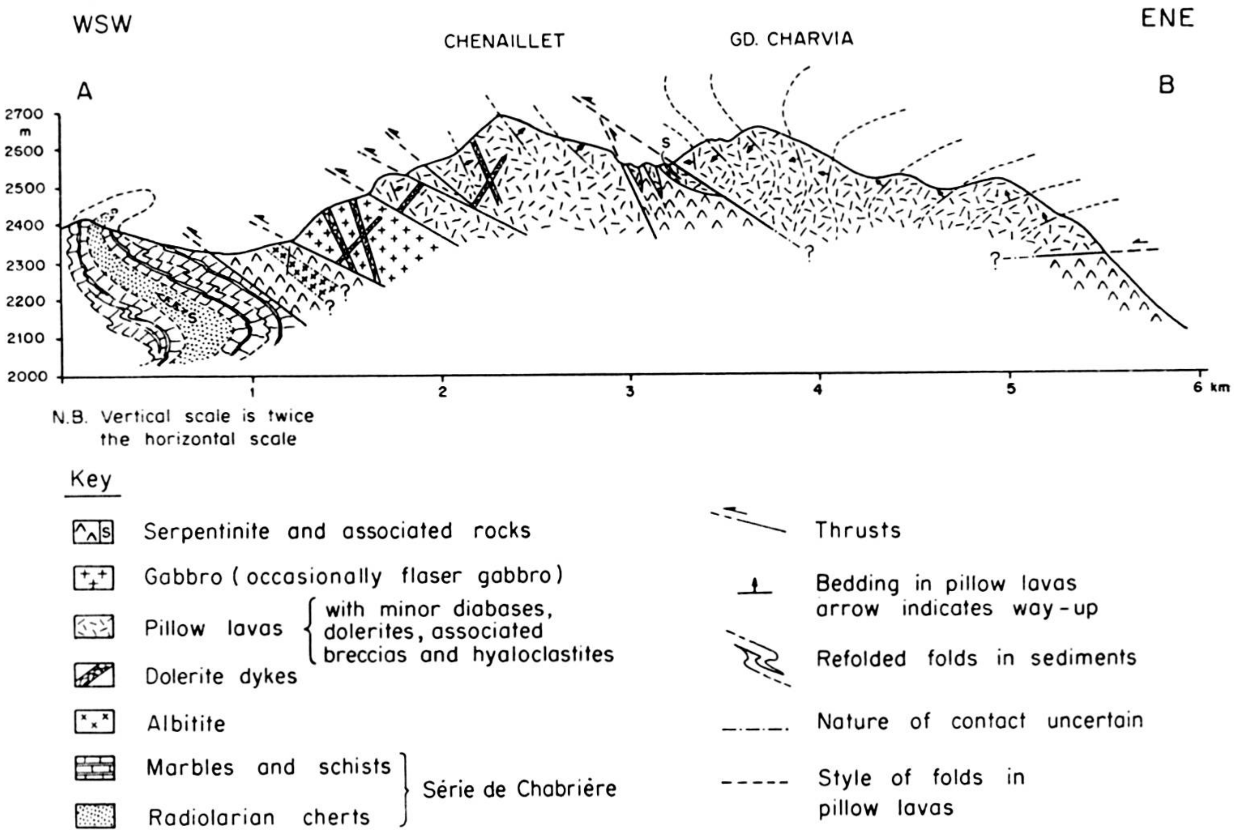

FIG. 5.—Section across the Western Part of the Montgenèvre Ophiolite.

some isolated pillows. Further to the East we again enter the crushed serpentinite with intercalations of diabases and pillow breccias. Finally we arrive at the pillow basalt flows of the Grand Charvia, showing in some places small and rare relics of sediments between the pillows.

Summing up, we encounter the serpentinite four times near or along the divide line. The intercalations of volcanics or subvolcanics are not continuous along the strike but form slices or lenses embedded in the serpentinite breccia matrix; some of these intercalations are probably segments of dismembered dikes. These mafic rocks, being harder than the serpentinitic matrix, have resisted better to erosion and stand out as large blocks in the landscape leading to a geomorphology reminiscent of the "knocker terrain" of melange zones in the Franciscan of California and in the South Island of New Zealand.

DESCRIPTION OF THE MELANGE ZONE

The list below gives a compilation of the different types of rocks found in the melange zone:

Serpentinitic rocks

1. Massive serpentinites
2. Serpentinite breccias
   a. Consolidated serpentinite breccias to microbreccias without an appreciable amount of carbonate.
   b. Consolidated serpentinite breccias to microbreccias with a carbonate cement.
   c. Unconsolidated soft mushy mixture of serpentine minerals.
   d. "Ophicalcites" of variegated colors with a variable ratio of carbonate to serpentine minerals.
   e. Various more polygenic breccias where the serpentinites fragments are accompanied by elements of other compositions.

Diabasic (doleritic) rocks

1. Coarse diabase West of the melange zone.
2. Blocks of diabase near the crest of the col du Chenaillet.
3. Dismembered spilitic diabase dike.

Pillow basalts and pillow breccias

Ophispherites

1. Fragments of pillow basalts.
2. Fragments of diabase.
3. Fragments of gabbroic rocks.
4. Miscellaneous fragments.

Sedimentary rocks

1. Banded detritic rock.
2. Limestone.

We shall briefly give some data on the mineralogy, texture and chemistry of these different types of rocks.

SERPENTINITIC ROCKS

They occur both as matrix material and as individual elements of the melange either in rather large masses, several meters in size, or as finer material, down to grains of a few mm of diameter.

1. MASSIVE SERPENTINITES

Relics of primary minerals are preserved in some specimens. Clinopyroxenes are the most common of these relics; in a few exceptional cases orthopyroxenes (sometimes with clinopyroxene exsolution lamellae) and olivine may be found. As accessory minerals a dark brown spinel and magnetite were observed. These relics point to a lherzolitic composition for the primary peridotite. The absence of cumulate textures may mean that these ultramafics were of the "tectonite" type. The secondary phases are mainly chrysotile and lizardite accompanied by some chlorite and occasionally by a metasomatic garnet, carbonate, talc and tremolite. Antigorite was never observed under the microscope.

The serpentinites exhibit typical mesh textures with rather large lizardite crystals and numerous veinlets of chrysotile.

2. SERPENTINITE BRECCIAS

Serpentinite breccias are quite varied; we may tentatively group them in 5 categories but it should be noted that gradations exist between these subdivisions:

a. *Consolidated serpentinite breccias to microbreccias without an appreciable amount of carbonate.* Angular or rounded elements of serpentinites are cemented by a mixture of serpentine minerals and chlorite.

b. *Consolidated serpentinite breccias to microbreccias with a carbonate cement, mostly calcitic.* There is a complete gradation from breccias of type 1., with a moderate amount of carbonate, to rocks where the carbonate is abundant, and finally to limestones with fragments of serpentinites.

c. *Unconsolidated soft mixture of serpentine minerals* where inclusions of hard serpentinites or ophispherites are found. It is likely that this mush derives from breccias of types a. or b. Some hydromagnesite has been found.

d. "*Ophicalcites*" *of variegated colors with a variable ratio of carbonate to serpentine minerals.* The serpentinitic material is more diffusely distributed than in the breccias of type b.

e. *Various more polygenic breccias where the serpentinites fragments are accompanied by elements of other compositions: gabbros, dolerites, pillow basalts, chloritites, tremolitites.* The cement of these breccias is composed either of finely ground material derived from the clasts of the breccia or of calcite; there is sometimes an extensive development of garnet. Stratified detritic sediments of this type are described under the heading: sedimentary rocks.

In these various types of breccias it is not unusual to observe fragments which themselves have a breccia structure, for instance, serpentinite breccias. Such complex rocks certainly were formed in several stages; this is also confirmed by the coexistence of fragments unaffected by metasomatic processes with others which have been more or less strongly transformed. Among the latter, elements invaded by various associations of carbonate, talc and garnet are noteworthy.

Diabasic (doleritic) rocks

Diabases i.e. slightly metamorphosed dolerites are common in the Col du Chenaillet area where they occur either bordering the melange zone or within the melange zone. In the latter we may find them as large blocks corresponding, in some cases at least, to fragments of dikes or as small, more or less metasomatized inclusions forming many ophispherites.

The following main types may be distinguished:

1. Coarse diabase west of the melange zone.

This rock is well exposed at the base of the slope leading to the summit of the Chenaillet. It is either part of a large dike or a mass of diabase in the pillow basalt flows. Under the microscope we see wide laths of saussuritized plagioclase and larger crystals of augite showing a subophitic relationship. Other primary minerals are sphene and ilmenite, partly transformed to leucoxene. The main secondary minerals are chlorite, prehnite and very fine needles of actinolite which have developed on the rims of the augite crystals. The grain size is quite coarse for a diabase, up to several mm. The difference in aspect between this rock and the typical ophiolitic gabbros nearby and its gradation to finer grained diabases clearly indicate a rather shallow subvolcanic level of consolidation.

2. Blocks of diabase near the crest of the Col du Chenaillet

In the serpentinite melange we find several large blocks or slices of diabase. They frequently contain phenocrysts of plagioclase and the texture is either subophitic or intergranular. The plagioclase has been transformed to albite. Grains of ilmenite are partly replaced by leucoxene. Chlorite, prehnite and pumpellyite appear as secondary minerals.

3. Dismembered spilitic diabase dike

In the Southern slope of the Chenaillet pass, about 15 m below the crest, there is a crag of harder rock. It consists of a variety of diabase finer grained than the one described above. Toward the margin it becomes brecciated but this is probably only a pseudo-breccia resulting from the presence of a network of reddish hematite-rich veinlets. There are also numerous amygdules. Under the microscope the fabric is made up of albite laths exhibiting a rapid variation of grain sizes and shapes, with textures ranging from intersertal to arborescent. The interstitial augite is quite fresh. There are also some ilmenite grains. Secondary minerals are abundant including chlorite, well developed pumpellyite, prehnite and calcite.

This rock is probably part of a disrupted shallow dike. It has a strong spilitic character which is confirmed by the chemical analysis: high Na_2O content, rather low CaO, especially if one substracts the CaO needed to form calcite.

Pillow basalts and pillow breccias

These rocks are found either in large wedges in the melange or in smaller fragments in ophispherites. In addition they form the major part of the two peaks, Chenaillet and Grand Charvia, on either sides of the melange zone.

The largest mass of volcanics is found just East of the main ophispherite zone. It extends for tens of meters and is made up mostly of pillow breccias with fragments of pillow basalts ranging mainly from 2 up to 10 cm in size. These fragments are polyhedral with blunt edges. There is almost no cement. Occasionnally a larger piece of pillow or a "whole" pillow is found.

The basalt fragments exhibit all the classical textures found in pillows but there is a predominance of arborescent and spherulitic textures. The main mineral is a slightly brownish augite which occurs as thin microlites. Fine comb structures are developed. The plagioclase, which occurs as thin needles, is difficult to distinguish; it seems to be albite. Some sphene appears in minute grains. Secondary minerals are chlorite, prehnite and pumpellyite. Noteworthy are spherical amygdules partly or wholly filled by very fine grained augite.

This large mass of volcanics is in contact with a serpentinitic rock containing ophispherites. It is interesting to note that it shows a metasomatic alteration: a thin chloritic margin and a more internal zone where only the plagioclase has been chloritized, the pyroxene being preserved. This is similar to the phenomenon observed in some rodingites. It is difficult to estimate the exact thickness of the metasomatic zone but it seems to be at least 10 cm thick.

Ophispherites

Ophispherites are more or less rounded fragments set in a serpentinite matrix. The matrix may be either a consolidated or unconsolidated breccia to microbreccia. These ophispherites, varying in size from 1-2 cm to about 50 cm, exhibit a concentric structure with an outer shell generally darker than the core. This peculiar zoning results from metasomatic processes which have strongly affected the primary nature of the inclusion. Some elements may show similar metasomatic transformations but without a zoned structure; they could be named *paraophispherites*.

Ophispherites were observed first in the Chenaillet massif (Vuagnat, 1952, 1953) and at about the same time in the Col des Gets area (Haute-Savoie, France) (Vuagnat and Jaffé, 1953, 1954).

The ophispherites may be classified either according to the nature of the primary rock or according to the type of metasomatic transformations.

Categories of primary rock

Four categories may be distinguished:

1. *Fragments of pillow basalts.*

These fragments may be easily recognized by their textures which range from intersertal/divergent to variolitic. This means that the fragments may be derived from any part of a pillow. These elements are structurally identical to those found in the pillow breccias; if not too transformed they are also very rich in augite. It is probable that these fragments are the result of tectonic dislocation of a pillow breccia which was in contact with the ultramafics (see below).

2. *Fragments of diabase*

Diabasic ophispherites are a little less common than basaltic ones. They show various types of doleritic textures, some as coarse as the Chenaillet diabase previously described. Augite is often very well preserved in the cores of these ophispherites, whereas the plagioclase, with few exceptions, has entirely been transformed; however, the shapes of the laths are still easily recognized.

3. *Fragments of gabbroic rocks*

Gabbroic ophispherites are rather scarce. The most common are coarse grained gabbros with some preserved augite but entirely transformed plagioclase. A few of these ophispherites have an anorthositic core made up almost entierly of altered basic plagioclase.

From their textural aspect it seems that the primary rock, in many cases, was not derived from the main bodies of gabbro (like that which outcrops on the South-western ridge of the Chenaillet) but from dismembered mafic dikes or layers in the peridotites.

There are some very rare examples of microgabbro and flasergabbro. Both types may be observed in the gabbro bodies of the Chenaillet.

It is noteworthy that in the gabbroic ophispherites the boundary between core and dark chloritic outer shell is less well defined and more irregular than in the diabasic or basaltic ones.

4. *Miscellaneous fragments*

In this category we group a few ophispherites of uncertain origin. For instance, nephrite rocks probably derived from a pyroxenite layer or vein in the ultramafites.

THE METASOMATIC TRANSFORMATIONS OF THE OPHISPHERITES

In typical ophispherites we may distinguish a *core*, where the minerals are generally less transformed, and a *rim* or *outer shell* which shows very pervasive metasomatism. The composition of rims is quite homogeneous but cores show various associations. It is possible to distinguish three main categories of cores:

1. *Fresh cores where both pyroxene and plagioclase have been preserved.* This case is extremely rare; one good example of a diabasic ophispherite with fresh zoned basic plagioclase in the core has been observed. Up to now, this is the only clear instance of basic plagioclase well preserved in the whole Montgenèvre ophiolite.

2. *Cores where the pyroxene has been at least partly preserved but the plagioclase transformed to secondary minerals.*

   The augite is thus accompanied by one or several of the following minerals: chlorite, pumpellyite, prehnite, tremolite-actinolite, garnet-hydrogarnet, carbonate (mostly calcite), vesuvianite (?).

3. *Cores where the pyroxene has also disappeared.*

   Various associations are observed with one or several of the following minerals: garnet-hydrogarnet, chlorite, pumpellyite, tremolite-actinolite, carbonate, sphene-leucoxene, ore minerals.

   It should be noted that chlorite and garnet-hydrogarnet may replace both pyroxene and plagioclase.

The outer shell of ophispherites are all very similar: the main primary minerals have been transformed to chlorite. Despite extreme metasomatism, the primary textures are generally well preserved, except in the case of gabbros. This is due to the fact that very finely divided opaque or semi-opaque minerals (magnetite, ilmenite, sphene, leucoxene) outline the contours of the former plagioclase crystals which thus appear as "ghosts". Sometimes there is also formation of pyrite grains which are occasionally large; these are often arranged in an externally concentric zone. Another common phenomenon is the presence of a thin shell rich in calcite at the contact of core and rim; these thin calcitic bands may appears several times within the chloritic margin.

The thickness of the outer chloritic shell is variable; it depends, among other factors, on the size of the inclusion and on the intensity of the metasomatic processes. In a few cases it seems that the core has entirely disappeared, the whole fragment being chloritized.

In many ophispherites we can only distinguish two main zones: a *core* and an *outer shell*. However, quite a few of these inclusions exhibit some multiple zoning. This is particulary conspicuous in the core. The difference between these zones may be due either to the disappearance of a primary mineral, or to the presence of secondary minerals. It is rather common for an inner core to contain well preserved augite accompanied by chlorite, sometimes garnet, while in the outer core pyroxene has been replaced; however, the outer core itself may show a zoning due to differences in the nature of the secondary minerals. Up to four of five zones have been observed in some ophispherites.

The external chloritic shell may also exhibit some inconspicuous zonations which may be due either to the presence of varieties of chlorite, differing mostly by their dispersion colors, and/or to the proportion and mode of distribution of the opaque and semiopaque minerals; finally the zonal distribution of calcite and pyrite mentioned above may also contribute to this subsiduary zoning.

Some photomicrographs of these rocks are shown in plate I.

In Table 1 we give some chemical analyses of typical ophispherites. They can be compared with analyses of non-metasomatic rocks similar to those from which the inclusions have been derived (Table 2). This comparison shows that the cores of ophispherites are generally quite depleted in alkalis; this is due mainly to the complete transformation of the plagioclase. The degree of enrichment in lime is variable; some cores do not show appreciable increase in calcium, others are strongly enriched; this is particulary noticeable in the cores where garnet-hydrogarnet is well developed.

Analyses of outer shells show that they are mainly composed of an aluminous Mg-Fe chlorite and that there is little variation from one inclusion to another. This reflects the mineralogical homogeneity of these outer shells. It is important to emphasize the fact that the composition of this dark green outer shell is substantially different from that of the serpentinite matrix (either the brecciated cement or the fragments of massive serpentinite) (analyses S 3 and S 1 and S 2, table 2).

Many problems concerning the ophispherites are still unsolved. Due to exceptionally fine grain size the exact nature of some minerals remains, in a few cases, uncertain.

There is some evidence that there have been two main types of metasomatism. The first one, exhibited in the cores, is recognized by the almost complete or total depletion in Na_2O and K_2O and very often by a strong enrichment in CaO. The second one, represented by chloritization of the external part of the ophispherite, is characterized by the loss not only of the alkalis but also of the lime and of a part of the alumina and by a strong enrichment in magnesium and water. Are these two processes synchronous or successive phases? If we admit the first hypothesis it means that leaching of alkalis, with or without a substantial increase in lime, occurred in the inner core at the same time as magnesium metasomatism producing almost complete loss of lime in the outer core. In the second hypothesis there are two stages of formation: a phase where there is leaching of alkalis accompanied by calcium metasomatism, followed by a phase where the calcium-bearing minerals are destroyed by magnesium metasomatism (see Fig. 6).

Table 1: Chemical analyses of ophispherites

(wet analysis; results in weight %)

	Go 1a	Go 1b	Go 1c	Go 2a	Go 2b	Go 3a	Go 3b	Bo 1a	Bo 1b
SiO_2	43.46	42.25	31.07	33.65	31.59	37.00	33.25	34.02	30.73
TiO_2	0.85	0.70	0.99	0.12	0.10	0.06	0.07	1.38	1.66
Al_2O_3	14.65	12.43	14.25	19.74	18.93	20.70	15.19	14.33	13.34
Fe_2O_3	2.78	3.13	2.85	0.32	1.35	0.80	2.15	5.77	4.76
FeO	2.27	1.63	2.75	0.80	1.14	1.72	2.06	2.13	3.98
MnO	0.12	0.17	0.52	0.16	0.26	0.17	0.16	0.48	1.38
MgO	6.94	6.73	33.59	13.49	32.93	16.57	30.36	13.85	30.53
CaO	24.39	30.14	0.55	23.53	0.60	14.63	2.96	20.29	0.61
Na_2O	0.11	-	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)
K_2O	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)
P_2O_5	0.11	0.11	0.12	0.01	0.01	0.01	0.01	0.14	0.19
H_2O^+	3.41	1.71	12.68	5.76	13.28	8.36	12.97	6.96	12.04
H_2O^-									
CO_2	1.13	1.93	0.12	1.66	-	-	0.24	-	-
	100.22	100.93	99.49	99.24	100.19	100.02	99.42	99.35	99.22

	Do 2a	Do 2b	Bo 3a	Bo 3b	Bo 4a	Bo 4b	Bo 5a	Bo 5b	Bo 5c	Bo 5d	Bo 5e
SiO_2	35.52	31.92	32.22	30.35	34.92	29.87	34.13	35.15	31.74	31.39	33.76
TiO_2	1.84	1.80	2.06	2.32	1.80	1.85	1.34	1.33	1.19	1.26	1.34
Al_2O_3	12.58	13.55	11.74	12.76	15.18	12.80	15.17	14.45	17.69	14.46	13.93
Fe_2O_3	5.72	3.83	5.70	4.38	1.79	5.57	3.82	3.70	3.69	7.16	4.20
FeO	1.86	3.54	3.45	4.92	6.44	3.35	4.71	5.02	3.46	2.83	3.42
MnO	0.30	0.70	0.24	1.09	0.30	0.65	0.37	0.36	0.29	0.64	0.99
MgO	17.61	30.52	20.42	30.15	20.05	32.95	20.06	20.24	13.85	30.58	28.46
CaO	16.94	0.62	12.76	0.98	9.27	-	8.87	8.83	19.71	1.52	1.46
Na_2O	0.11	(<0.10)	1.22	1.26	1.22	1.28	0.17	0.19	0.15	0.10	0.10
K_2O	(<0.10)	(<0.10)	0.25	0.17	(<0.10)	0.29	(<0.10)	(<0.10)	(<0.10)	(<0.10)	(<0.10)
P_2O_5	0.14	0.16	0.19	0.23	0.17	0.18	0.18	0.17	0.25	0.20	0.17
H_2O^+	7.10	12.43	9.61	10.94	8.54	11.10	10.11	9.60	6.93	10.11	12.46
H_2O^-	(0.15)	(0.51)	(0.26)	(0.36)	(0.46)	0.16	(0.44)	(0.51)	(0.49)	(0.57)	(1.06)
CO_2	-	-	-	0.25	-	-	0.38	0.16	0.19	0.47	0.26
S^{-2}		0.29					0.60	0.60	0.70	traces	traces
	99.72	99.36	99.86	99.80	99.68	99.89	99.91	99.80	99.84	100.72	100.55
O ≡ S		0.14					0.30	0.30	0.35		
		99.22					99.61	99.50	99.49		

TABLE 1. — *Chemical analyses of ophispherites*

Analyses Go 1: Fine grained gabbroic ophispherite.

a: *Core:* plagioclase totally replaced mostly by garnet-hydrogarnet, pyroxene.

b: *Intermediate zone:* very similar to the core, but garnet-hydrogarnet more developed.

c: *Rim:* completely chloritized (pyroxene and replacement minerals of plagioclase).

Analyses Go 2: Gabbroic ophispherite.

a: *Core:* pyroxene and plagioclase replaced, the first by garnet-hydrogarnet and chlorite, the second by garnet-hydrogarnet

b: *Rim:* replacement products of pyroxene and plagioclase totally chloritized.

Analyses Go 3: Gabbroic ophispherite.

a: *Core:* pyroxene replaced by actinolite-tremolite and chlorite, plagioclase replaced mainly by prehnite.

b: *Rim:* chloritization of actinolite-tremolite and lime-silicates.

Analyses Bo 1: Ophispherite derived from fragment of pillow basalt.

a: *Core:* plagioclase and pyroxene both replaced mainly by garnet-hydrogarnet with some chlorite, rare relics of pyroxene, sphene-leucoxene as accessories.

b: *Rim:* totally chloritized; fine grained leucoxene and ore minerals outlining the original texture.

Analyses Do 2: Diabasic ophispherite. Coarse intersertal texture.

a: *Core:* plagioclase totally replaced by garnet-hydrogarnet, pyroxene strongly chloritized, ilmenite and rutile.

b: *Rim:* totally chloritized with ilmenite as accessory.

Analyses Bo 3: Ophispherite derived from fragment of pillow basalt. Intersertal to arborescent texture.

a: *Core:* Garnet-hydrogarnet very abundant (replacement of plagioclase), chlorite, sphene-leucoxene.

b: *Rim:* totally chloritized with ore minerals grains.

Analyses Bo 4: Ophispherite derived from fragment of pillow basalt. Intersertal divergent texture.

a: *Core:* plagioclase totally chloritized, pyroxene more or less replaced by chlorite, sphene-leucoxene.

b: *Rim:* totally chloritized with numerous granules of ore minerals.

Analyses Bo 5: Ophispherite derived from fragment of pillow basalt. Intersertal divergent texture. Multiple zoning. From inside to outside:
Core:

a: plagioclase totally chloritized, pyroxene.

b: garnet-hydrogarnet replacing plagioclase, pyroxene more or less chloritized.

c: garnet-hydrogarnet abundant (replacing plagioclase and also pyroxene), subordinate chlorite.

d: chlorite with some fine grained ore minerals and calcite (subzonation due to distribution of these latter).

e: chlorite with granules of ore minerals and leucoxene as accessories.

TABLE 2.—*Chemical analyses of some non-metasomatic parent rocks from which the ophispherites are derived and of the serpentinitic matrix.*

Analysis Fg: Medium grained gabbro.
Plagioclase intensely saussuritized, pyroxene locally replaced by secondary amphiboles, chlorite.

Occurrence: Chenaillet.

Analysis Cd: Coarse diabase (dolerite).
Saussuritized plagioclase, pyroxene, chlorite, ore minerals and leucoxene.

Occurrence: West slope of the Chenaillet, just above the melange zone.

Table 2: Chemical analyses of non-metasomatic rocks from which the ophispherites are derived and of the serpentinitic matrix (wet analysis; results in weight %)

	Fg	Cd	Sd 1	Sb 2	S 1	S 2	S 3	Ps
SiO_2	50.50	50.47	50.00	53.80	39.20	37.10	38.50	45.88
TiO_2	0.49	1.05	1.51	1.44	0.16	0.07	0.11	0.06
Al_2O_3	15.00	16.59	15.50	15.00	2.51	2.04	1.70	0.67
Fe_2O_3	2.12	2.16	4.36	2.50	5.48	8.35	6.33	7.04
FeO	3.75	4.44	4.24	5.00	2.58	1.42	0.97	1.42
MnO	0.14	0.12	0.14	0.16	0.11	0.29	0.09	0.08
MgO	11.04	7.79	4.35	5.75	35.51	37.20	38.40	17.66
CaO	10.09	8.68	8.75	7.90	0.50	0.90	--	17.39
Na_2O	3.46	4.15	5.75	5.82	(<0.10)	(<0.10)	0.98	(<0.10)
K_2O	(<0.10)	0.62	0.17	0.19	(<0.10)	--	(<0.10)	(<0.10)
P_2O_5	0.02	0.13	0.18	0.14	--	--	--	0.01
H_2O^+	3.03	4.25	2.70	1.93	13.24	12.00	12.37	3.10
H_2O^-		(0.19)					(0.57)	
CO_2	0.06		2.60	0.10	--	--	--	6.17
S^{-2}						0.42		
	99.70	100.45	100.25	99.73	99.29	99.79	99.45	99.48
$O \equiv S$						0.21		
						99.58		

Analysis Sd 1: Spilitic diabase. Coarse intersertal texture.
Saussuritized plagioclase (with pumpellyite and actinolite), pyroxene, chlorite, carbonate, sphene-leucoxene.

Occurrence: Unmetasomatized part of a "sill" in the melange zone.

Analysis Sb 2: Spilitic pillow basalt. Arborescent to spherulitic texture. Element of a pillow breccia.
Saussuritized and chloritized plagioclase, pyroxene, chlorite, sphene-leucoxene; chlorite-pumpellyite veinlets and amygdules.

Occurrence: Unmetasomatized part of a large boulder of diabasic breccia in the melange zone.

Analysis S 1: Massive chrysotile-lizardite serpentinite.
Chrysotile, lizardite, some relics of pyroxenes, spinel, ore minerals.

Occurrence: Col du Chenaillet.

Analysis S 2: Massive serpentinite.
Chrysotile, ore minerals.
Rounded fragment in crushed serpentinite.

Analysis S 3: Consolidated serpentinitic breccia.
Chrysotile, lizardite and some ore minerals.
Matrix material attached to and surrounding some ophispherites.

Analysis Ps: Completely pseudomorphosed serpentinite.
Talc, garnet, carbonate, spinel, ore minerals.
Block in the serpentinitic melange.

Occurrences of analyses S 2, S 3 and Ps: Melange zone.

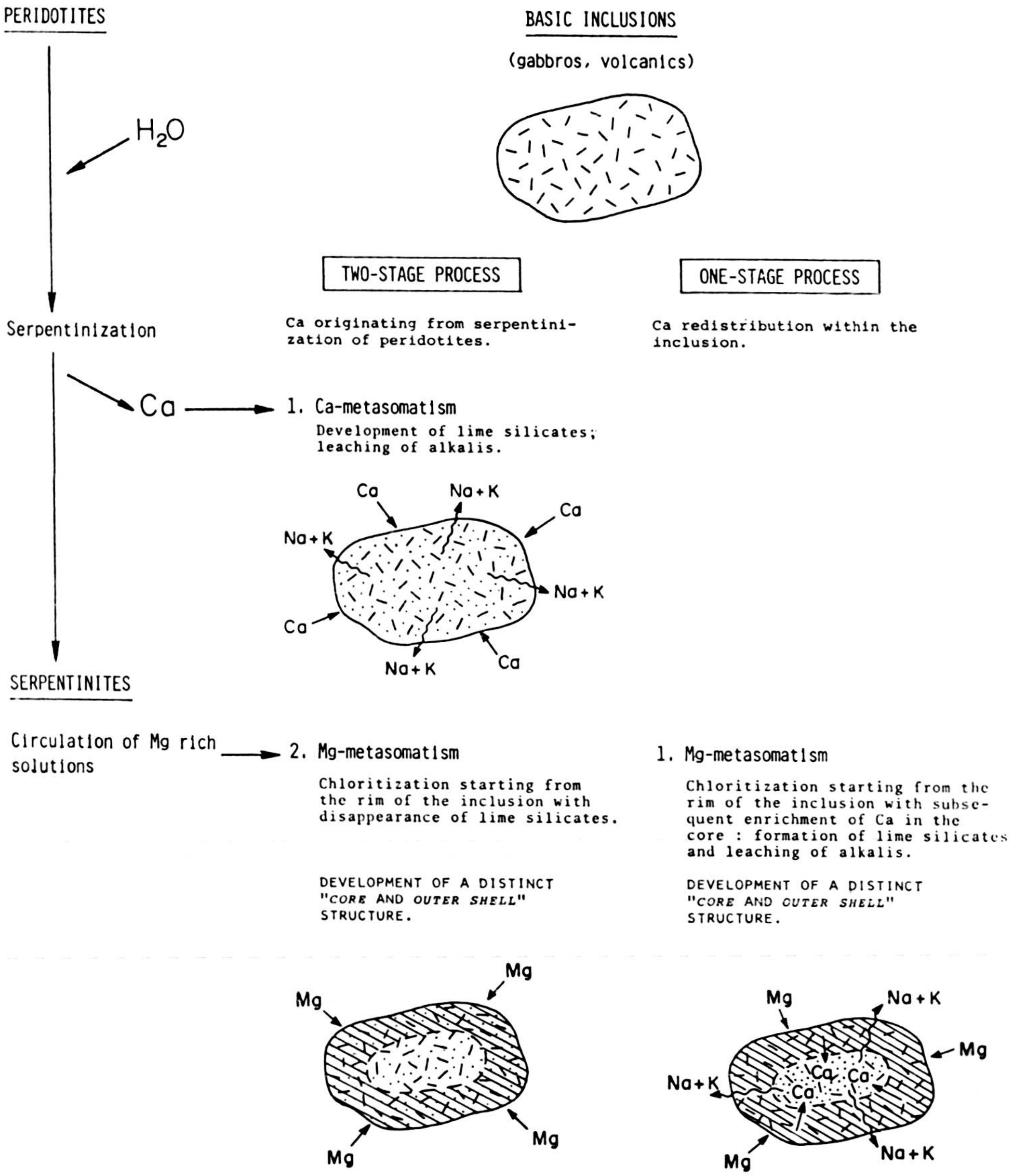

FIG. 6.—The two hypotheses proposed to explain the formation of the ophispherites of the col du Chenaillet melange zone.

At present it is difficult to choose between the two hypotheses. In some samples chlorite veins penetrate to the core: this tends to favour the second hypothesis. However, the delicate primary textures, which are generally preserved as "ghosts" in the outer shell, are often destroyed in the core affected by calcium metasomatism: this casts doubt on the significance of the second hypothesis. In addition, it may be quite possible that in some cases both mechanisms contribute to the phenomenon.

Another problem is that of the source of the different chemical elements which have been enriched either in core or in outer shell. It seems evident that the magnesium came from the serpentinite matrix but the origin of calcium is less obvious. It is widely admitted (Coleman, 1966, 1977*a*, *b*) that the excess calcium in rodingites has originated during the serpentinization processes by release of calcium from the clinopyroxenes. In the case of the ophispherites we could either retain this hypothesis or, alternatively, link the source of calcium to the chloritization of the outer shell. If we choose the latter then it would imply that in the external part of the inclusion there was a front of chloritization with magnesium metasomatism; the calcium so released could then be concentrated in the core. In many ophispherites the chloritized rim is sufficiently thick to have displaced enough calcium for such an enrichment. This potential for redistributing calcium within the inclusions has the added advantage that we no longer have to propose that the calcium originated from the host serpentinite, a proposal which could be difficult to accept if the rocks forming ophispherites were emplaced in the ultramafics after serpentinization.

SEDIMENTARY ROCKS

Some of the serpentinitic breccias previously described are probably of sedimentary origin. Two types of rocks in particular show good evidence of sedimentary origin.

1. BANDED DETRITIC ROCK

Outcropping near the North Eastern boundary of the melange zone, North of a small seasonal pond, a banded detritic rock is observed on top of the serpentinites, just under pillow basalts.

There are several small outcrops, the largest ones being of metric size. The rock is clearly stratified with thin laminae, of millimetric to centimetric thickness, varying in color from cream to pale green or pale pink; there is also some graded-bedding within this sediment which can range from a microconglomerate to graywacke or even siltstone. In the coarser samples we see, under the microscope, elements of diabases and pillow basalts, serpentinized peridotites and gabbros; the matrix between the fragments is polygenetic and contains some isolated grains of pyroxene, amphibole, plagioclase, calcite, spinel, ilmenite, epidote and pumpellyite. Between these grains there is also a very fine grained cement composed mainly of calcite and a semiopaque mineral which X-ray diffraction shows to be a hydrogarnet. It seems that garnet and calcite have been produced as a result of metasomatic effects on a pre-existing cement.

2. Limestone

It was shown earlier that the serpentinite breccias with calcareous cement grades to a limestone. This rock is white or grey, fine-grained, and contains a few angular clasts of serpentinite. Under the microscope, it resembles a finely recrystallized limestone containing dispersed grains of serpentine material with some associated ore minerals. There are numerous slightly coarser grained patches but no definite fossils have been found during the examination of many thin sections. Veins of coarser calcite are frequent.

This rock looks very much like a true sedimentary limestone; however, due to the lack of microfossils, it is impossible to eliminate the possibility that it represents a completely metasomatized serpentinite breccia. Moreover, a hydrothermal origin for such limestone would be possible.

FORMATION OF THE MELANGE ZONE

In the present state of our knowledge it is impossible to propose a single definite mechanism to explain the genesis of the melange zone. We may however imagine a plausible model.

Soon after the consolidation of the oceanic crust, fracture zones developed along which partly serpentinized peridotites intruded in a solid state. The serpentinization certainly began at this moment. Such fractures and diapiric intrusions of serpentinites have been demonstrated in the oceanic crust (Aumento *et al.*, 1974; Bonatti, 1976; Hall *et al.*, 1979).

The flasergabbros of the massif show evidence of an amphibolite facies metamorphism (Caby *et al.*, 1975; Steen *et al.*, 1977; Mevel *et al.*, 1978). It is noteworthy that the most deformed flasergabbros are found adjacent to the northern end of the melange zone; this disposition could be fortuitous or it could be significant. If it is reasonable to associate the deformation and metamorphism of the flasergabbros with the formation of the melange zone then perhaps the temperature could still have been quite high.

During uprise of the peridotite through the ocean crust there was further serpentinization which resulted in the formation of rodingites from the basic rocks enclosed within the ultramafite, e.g. culumate gabbroic layers and gabbroic, diabase and pyroxenite dikes. During this first phase of metasomatism the calcium required for rodingitization was certainly derived from the clinopyroxenes of the ultrabasic rocks. The layers or dikes of basic rocks which were transformed to rodingites were further boudinaged and dismembered to produce some of the ophispherites observed. The detatchement and inclusion, in the serpentinites, of some of the country rocks, e.g. dolerites, may have occurred during this stage of development or a little later on.

Higher in the crust the ultramafic diapir intruded the volcanics. At this stage there was extensive brecciation of the peridotite, possibly facilitated by strong serpentinization and decrease of pressure at shallow crustal levels. Brecciation would also increase the quantity of water, probably of oceanic origin, which was circulating through the ultrabasic rock. The resulting serpentinite mush could then be injected along fracture zones in the volcanics and cause a dismembering of the pillow basalt pile. The basalt fragments incorporated in the ultrabasic rock underwent a phase of magnesium metasomatism, probably accompanied by a concentration of calcium in the cores of the fragments, to produce some of the ophispherites.

On the ocean floor there were probably open fissures through which water, rich in dissolved calcium carbonate, circulated depositing calcite (Barnes *et al.*, 1969, 1972). Eventually the serpentinite diapir would reach the ocean floor. There were probably submarine fault scarps in the vicinity of the diapir and these would give rise to either tectonic or sedimentary breccias and microbreccias; siltstones and some limestone may also have been locally deposited.

The abundance of calcite in the serpentinite breccias raises some problems. One does not know if the ocean floor was above or below the calcite compensation depth. However, even if this surface had been below the calcite compensation depth it is possible that hydrothermal springs, rich in Ca^{+2} and CO_2, could have been responsible for calcium metasomatism and local deposition of calcite.

Later, during the alpine orogeny, the melange zone constituted a tectonically weak belt and was subject to further deformation. There is little doubt that the faults limiting the zone to the east and west are alpine in age. It also appears that all the rocks experienced a regional alpine metamorphism which reached pumpellyite-actinolite facies (Coombs *et al.*, 1970).

The problem of the association of serpentinites, ophicalcites and gabbros in the Piemont-Ligurian Domain of the Western Alps is discussed in detail by Lemoine (this volume).

Acknowledgments

The chemical analyses were made by the chemists of our Department, especially by Mrs G. Gulaçar to whom we would like to express our sincere thanks. Support of Swiss National Research Foundation (Project No. 2.005-0.78), is gratefully acknowledged.

BIBLIOGRAPHY

Aumento, F. and D. K. Sullivan (1974). Deep drill investigations in the oceanic crust in the North Atlantic. Geodynamics of Iceland and the North-Atlantic Area, 83-103 (Krisjansson, ed.) D. Reidel publ. Co. Dortrecht, Holland.

Bonatti, E. (1976). Serpentinite protrusions in the oceanic crust. *Earth Planet. Sci. Letters*, 32 107-113.

CABY, R. et M. GIROD (1975). Faciès amphibolite dans la croûte océanique: exemple des métagabbros du massif du Chenaillet (Hautes-Alpes). 3e réunion ann. sci. Terre, Montpellier.

COLEMAN, R. G. (1966). New Zealand serpentinites and associated metasomatic rocks. *New Zealand Geol. Survey Bull.* 76, 1-102.

—— (1977*a*). Emplacement and Metamorphism of Ophiolites. In: High Pressure-Low Temperature Metamorphism of the Oceanic and Continental Crust in the Western Alps. *Rendiconti Soc. Ital. Mineral. et Petrol.* 33, 3-32.

—— (1977*b*). *Ophiolites: ancient oceanic lithosphere?* Berlin; New-York: Springer.

COOMBS, D. S., R. J. HORODYSKI and R. S. NAYLOR (1970). Occurrence of Prehnite-Pumpellyite Facies Metamorphism in Northern Maine. *Am. Journ. of Sci.* 268, 142-156.

DIETRICH, V., M. VUAGNAT and J. BERTRAND (1974). Alpine metamorphism of mafic rocks. *Schweiz. Min. Pet. Mitt.*, 54, 291-332.

HALL J. M. and P. T. ROBINSON (1979). Deep Crustal Drilling in the North Atlantic Ocean. *Science*, 204, 4393, 573-586.

LEMOINE, M. (1964). Sur un faisceau d'accidents transversaux aux zones briançonnaise et piémontaise à la latitude de Briançon. *C. R. Acad. Sci. Paris*, 259, 846-847.

—— (1980). Serpentinites, gabbros and ophicalcites in the Piemont-Ligurian Domain of the Western Alps: possible indicators of oceanic fracture zones and of associated serpentinite protrusions in the Jurassic-Cretaceous Tethys, this volume.

LEMOINE, M., D. STEEN et M. VUAGNAT (1970). Sur le problème stratigraphique des ophiolites piémontaises et des roches sédimentaires associées: observations dans le massif de Chabrière en Haute-Ubaye (Basses-Alpes, France). *C. R. séances Soc. Phys. Hist. nat., Genève*, n. s. 5, 44-59.

MEVEL, C., R. CABY and J. R. KIENAST (1978). Lower amphibolite facies conditions in the oceanic crust: example of amphibolitized flasergabbro and amphibolites from the Chenaillet ophiolite massif (Hautes-Alpes, France). *Earth Planetary Sc. Letters*, 39, 98-108.

PUSZTASZERI, L. (1969). Etude pétrographique du massif du Chenaillet (Hautes-Alpes, France). *Bull. suisse minér. pétrogr.*, 49, 425-466.

STEEN D., VUAGNAT and J. J. WAGNER (1980). Early Deformations in Montgenèvre Gabbros. Colloques Internationaux du C.N.R.S., n° 272. Association mafiques-ultramafiques dans les orogènes (Grenoble, juin 1977).

VUAGNAT M. (1952). Sur une structure nouvelle observée dans les roches vertes du Montgenèvre (Hautes-Alpes). *Arch. Sci. Genève*, 5/3, 191-193.

—— (1953). Sur un phénomène de métasomatisme dans les roches vertes du Montgenèvre (Hautes-Alpes). *Bull. Soc. franç. Minér. Crist.*, 76, 438-450.

VUAGNAT M. et F. JAFFE (1953). Observations sur quelques ophisphérites de la région des Gets (Haute-Savoie). *Arch. Sci. Genève*, 6/6, 1 p.

—— (1954). Sur les ophisphérites de la région des Gets (Haute-Savoie). *Arch. Sci. Genève*, 7/1, 5-14.

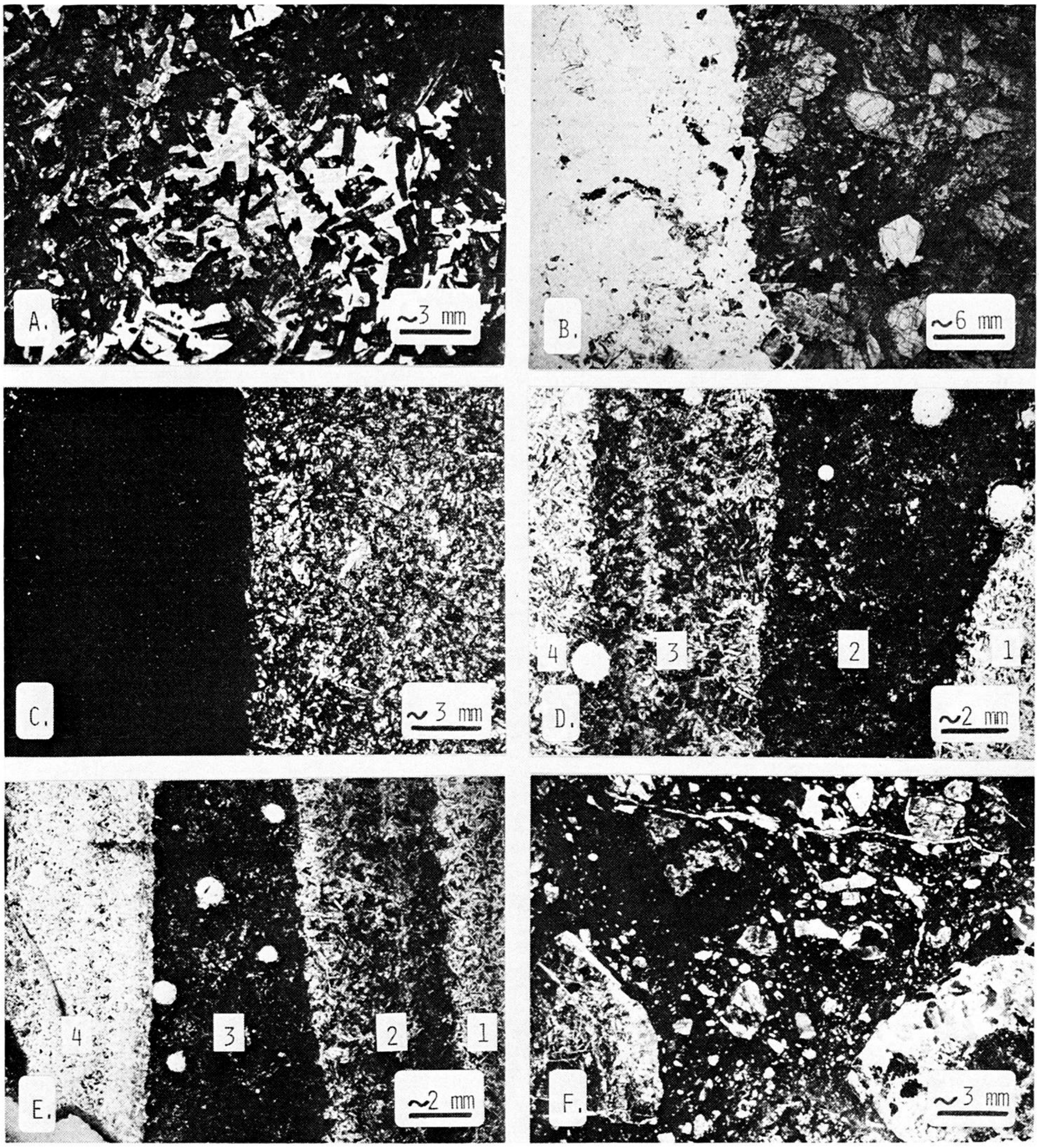
A.
~3 mm
B.
~6 mm
C.
~3 mm
4
3
2
1
D.
~2 mm
4
3
2
1
E.
~2 mm
F.
~3 mm

PLATE I

Photomicrographs of some rocks described

A. Coarse diabase (dolerite) (X-nicols). Pyroxene (dark) and saussuritized plagioclase (light). Sample from the West slope of the Chenaillet, just above the melange zone. Similar rocks, more or less rodingitized, may be found as inclusions in this latter.

From the melange zone:

B. Fine grained gabbroic ophispherite (plane light). *Core* (right): pyroxene (light) and plagioclase totally replaced mostly by garnet-hydrogarnet. *Rim* (left): pyroxene and replacement minerals of plagioclase completely chloritized.

C. Diabasic ophispherite (X-nicols). *Core* (right): pyroxene (light) and totally chloritized plagioclase. *Rim* (left): both pyroxene and plagioclase completely chloritized.

D. Diabasic ophispherite with multiple zoning (plane-light). From right to left: *Core* (two zones): 1. pyroxene and totally chloritized plagioclase; garnet-hydrogarnet with some chlorite. *Rim* (two main zones): 3. chlorite with ore minerals and some calcite; 4. chlorite only with scarce ore minerals.

E. Diabasic ophispherite with multiple zoning (plane-light). From right to left: *Core* (3 zones): 1. pyroxene and totally chloritized plagioclase; 2. pyroxene, garnet-hydrogarnet and chlorite (concentric sub-zonation due to distribution of these phases; 3. garnet with some chlorite. *Rim* (one main zone): chlorite with some calcite and ore minerals (concentric sub-zonation due to distribution of carbonate and ore minerals).

F. Serpentinite microbreccia (X-nicols). Fragments of serpentinite and peridotite more or less serpentinized in a cement mainly composed of abundant garnet and lesser carbonate.