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The geology of the Belledonne massif: an overview (External crystalline massifs of the Western Alps)

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Abstract

Recent petrological and geochronological data allow to reappraise the structure and the geology of the Belledonne massif. This paper includes a description of the different formations and a subsequent synthesis of the Paleozoic evolution in this region. It emphasizes the geological heterogeneity of the Belledonne massif which is built up by the late orogenic juxtaposition ("collage") of three orogenic domains. As these domains are significantly different regarding their lithology, magmatism and tectono-metamorphic evolution they can be considered as terranes (KEPPIE, 1985). They are representative of more or less internal parts of the Hercynian orogenic zonation.

Keywords: Variscan terranes, collision zone, strike-slip tectonics, metamorphism, granitisation, Belledonne massif, Western Alps.

Introduction

The Belledonne massif belongs to the external crystalline massifs (ECMs), which make up the pre-triassic basement of the Western and Central Alps: from south to north, Argentera, Ht Dauphiné, Belledonne-Gdes Rousses, Mt Blanc-Aiguilles Rouges and Aar-Gotthard. The pre-mesozoic fragments are separated from each other by their Mesozoic cover belonging to the Dauphiné or Helvetic realm.

Correlations among the different massifs have been proposed. They point, on the one hand, to the lithologic continuity of the various formations (KRUMMENACHER et al., 1965; VON RAUMER, 1981) and, on the other hand, to similarities in their tectono-metamorphic evolution (VON RAUMER, 1984a and b).

However, the unambiguous situation of the ECMs within the Variscan belt is still largely hypothetical (BARD et al., 1980; VON RAUMER, 1981). The largest part of the different ECMs can be compared to the innermost areas of the fold belt (VON RAUMER, 1981, 1984; MATTE, 1986; MÉNOT, 1987). Some correlations with the Eastern Massif Central (Cévennes, Lyonnais-Brévenne) have been put forward (CARME, 1971, 1975a and c;MÉNOT, 1987).

The Belledonne Massif

The contribution of strike-slip movements to the structure of the Belledonne chain is known since long time (LORY, CH., 1891). In spite of these tectonics, some correlations, within the massif, were drawn out through the definition of lithological or lithotectonic series ("séries vertes, brunes, etc.": BORDET and BORDET, 1963 or "complexe de Belledonne": CARME, 1970a). Recent petrological and geochronological data allow us to reappraise the orogenic significance of the Variscan strike-slip tectonics and to propose a new interpretation of the Belledonne geology in relation to the Variscan context.

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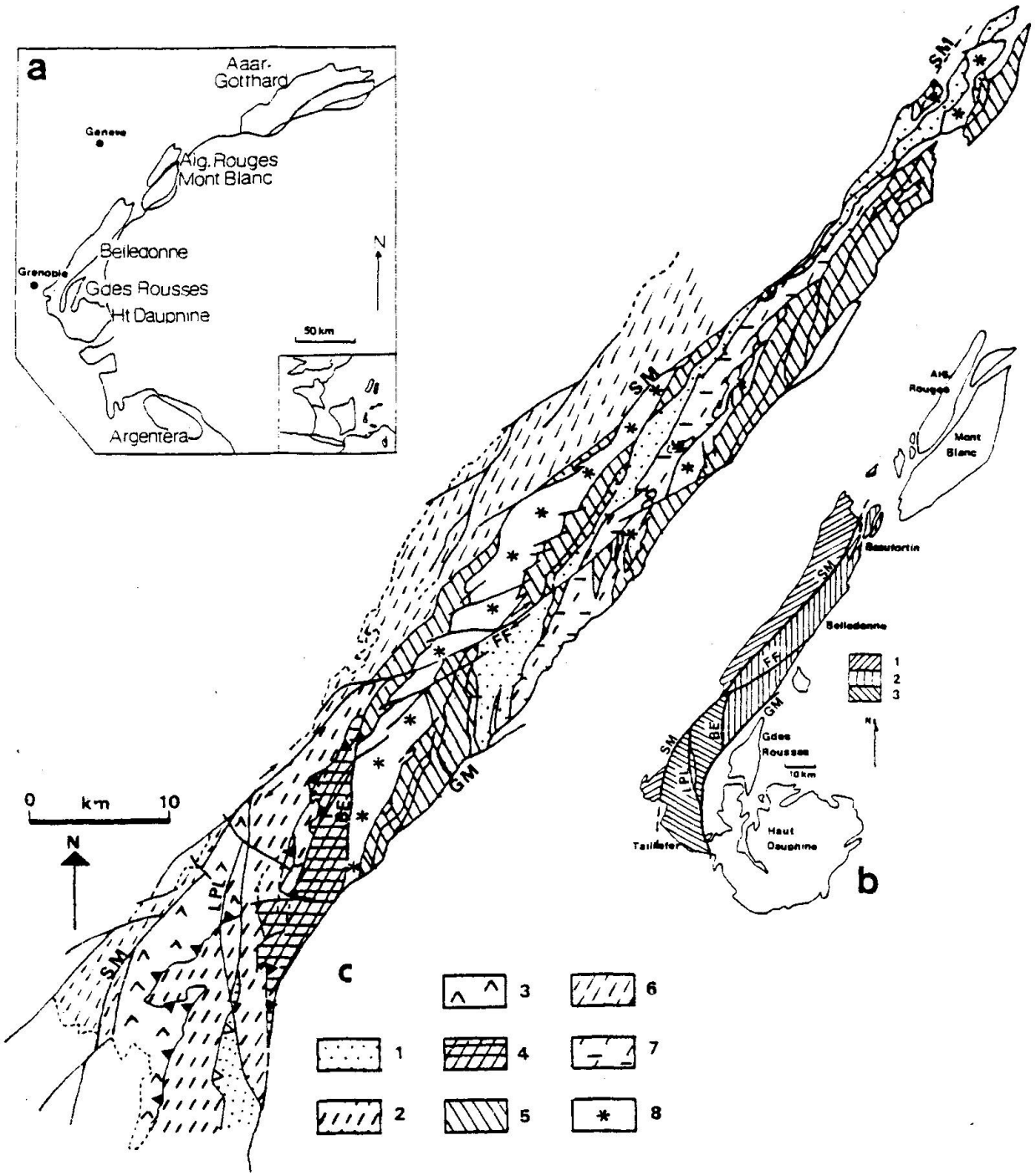

Fig. 1 Location (a), structural subdivisions (b) and lithology (c) of the Belledonne massif.
(b) and (c): main late-Variscan strike-slip faults: SM: "Synclinal Médian"; LPL: La Pra-Livet; BE: Belle Etoile; GM: Grand-Maison; FF: Fond de France.
(b): main structural domains: 1: "rameau externe", domain A; 2: NE part of the "rameau interne", domain B; 3: SW part of the "rameau interne", domain C.
(c): Main formations: 1: Taillefer (domain C) and "schistes verts" (domain B), L. Carbon.; 2: Rioupéroux-Livet (domain C), Devon.; 3: Chamrousse (domain C), U. Camb.-L. Ordov.; 4: Allemont-Rochetaillée (domain C), L. Paleoz.; 5: gneissic and amphibolitic basement (domain B), L. Paleoz.; 6: "série satinée" (domain A), L. Paleoz. (?); 7: orthogneisses (domain B), U. Devon.-L. Carbon.; 8: granites (domain B), L. and M. Carbon.

The massif is subdivided into three main domains A, B and C (Fig. 1) which are characterized by distinct lithological, magmatic, tectonic and metamorphic features and which have been emplaced side by side by late orogenic, carboniferous strike slips faults (MÉNOT, 1987):

- Domain A, exposed in the "rameau externe", includes a sub-vertical meta-pelitic series.
- Domain B, exposed in the NE part of the "rameau interne", consists of a gneissic and amphibolitic basement intruded by orthogneisses and granites and of green and black schists associated with acid and basic meta-volcanics. All metamorphic formations show a sub-vertical mylonitic foliation.
- Domain C, exposed in the SW of the "rameau interne", is built up by the tectonic superposition of four formations, the age, the geodynamic significance and the tectono-metamorphic evolution of which are significantly distinct. The structures of these formations are monoclinal or broadly folded.

2.1. LITHOLOGY

2.1.1. Pre-Variscan cycle

It is rather badly known and no reliable datations are available. In the Argentera, Haut Dauphiné, Aig. Rouges and Gotthard, some granitic gneisses have been considered as remnants of an older basement (VON RAUMER, 1984a). Perhaps some orthogneisses of the domain B of Belledonne could belong to this pre-Variscan cycle.

2.1.2. Variscan cycle

Lower Paleozoic formations:

The "série satinée": it only occurs in the "rameau externe" (domain A). It represents a thick flysch-derived formation (8000 m, GASQUET, 1979) including the following alternating facies: chloritic, sericitic and graphitic schists associated with subordinate quartzites. It includes some scarce igneous intercalations considered as basaltic meta-tuffs. The "série satinée" has undergone two metamorphic events both in greenschists facies conditions (CARME, 1970b; SIMÉON, 1979) (Fig. 2). The second event is related to the Lower-Middle Carboniferous strike slip tectonics (KALSBEECK, 1962; CARME, 1970b; GASQUET et al., 1981). The deposition age of this meta-sedimentary formation is unknown but it has been considered as Lower Carboniferous (LE FORT and EHRSTROM, 1969), or as Brioverian (CARME, 1970a). But a Lower Paleozoic age is also commonly admitted owing to analogies with other metapelitic series of Massif Central (Cévennes and Pilat) and Vosges (Villé sch.).

The gneissic and amphibolitic formations of Belledonne: They make up the framework of the NE domain (B). They include many different facies resulting from the diversity of the protoliths and from more or less extended secondary events such as migmatization and late mylonitic deformations: biotite and amphibole-rich terms, migmatitic, protomylonitic, mylonitic and phyllonitic textures. Locally massive and fine-grained amphibolites are more abundant and some samples present mineralogical and textural evidences of an early, pre-migmatization eclogitic stage.

The gneissic and amphibolitic formations arise from supracrustal series, mainly including immature detritic materials (graywackes) and subordinate volcanic and sub-volcanic intercalations of basaltic composition. The chemistry of amphibolites, T- and N-MORB tholeiites with a weak crustal-contamination (PAQUETTE, 1987), also suggests an ensialic setting within an attenuated crust of Lower Paleozoic age (PAQUETTE, 1987).

The metamorphic polyphased evolution comprises three successive stages (Fig. 2): 1) an eo-Variscan HP event (Acadian: Upper Silurian-Lower Devonian, PAQUETTE, 1987); 2) a Barrovian stage of Devonian age leading to kyanite-staurolite assemblages and subsequent regional cordierite-bearing anatexites; 3) a mylonitic retromorphic stage generating the penetrative and generalized sub-vertical foliation, during Lower Carboniferous times (VIVIER et al., 1987).

In the SW domain (C) of Belledonne, the *Allemont-Rochetaillée series* represents a lithologic analogue of the previous gneissic and amphibolitic formations (MÉNOT, 1987; CARME and PIN, 1987). However, some differences should be retained: no relics of the HP event; only limited extension of the anatexis and development of the late mylonitic vertical foliation restricted to narrow shear zones.

The Chamrousse-Séchilienne ophiolitic complex: It outcrops at the SW end of Belledonne (domain C) as a monoclinal series (25 km length and 5 km width) that corresponds to a meta-plutonic sequence (Chamrousse formation) growing into a metavolcanic and sedimentary formation (Séchilienne formation). Metamorphic recrystallizations highlight epidote-amphibolite and amphibolite facies conditions. The ophiolite complex is actually upside down as evidenced by the cumulates succession, the chemical evolution of their igneous minerals and the polarity of the dyke complex (CARME, 1975b; MÉNOT, 1979, 1987). The more significant features are summed up below:

a) the cumulate rocks crystallized according to the sequence ol-cpx-plg-opx-hn, as in the E- and T-MORB and in island arcs basalts (MÉNOT, 1987; PIN and CARME, 1987).

b) field observations and geochemical characters point out the polyphased nature of the ophiolitic magmatism. Several models have been proposed to explain this diversity. PIN and CARME's data (1987) favour a mixing model between three end-members of N-MORB, E-MORB and supra-subduction zone basalt affinities. According to BODINIER et al. (1981), the three successive influxes of respectively E-, T- and N-MORB compositions are related to an increasing rate of mantle partial melting. But in addition, this evolution is also marked by a decrease of the Th and lithophile elements contents (MÉNOT et al., 1988a) and can express the transition from attenuated continental lithosphere to oceanic lithosphere (MÉNOT, 1987). Moreover, the magmatic complexity is emphasized by other processes such as open system fractionation and local increase of the H_2O pressures leading to secondary differentiation trends (MÉNOT, 1987; MÉNOT et al., in press).

c) the ophiolite has undergone a multiphased tectonic activity (DEN TEX, 1950; CARME, 1975b; BODINIER et al., 1981). The earliest events consist of an intra-oceanic syn-accretion tectonics (MÉNOT, 1987). They induce the flasering and the shear zones of the cumulate gabbros and the high-temperature mylonites and ultramylonites of the banded complex. Only the last tectonic event, where the complex was overthrusted upon Devonian and Lower Carboniferous terrains (Fig. 2), is related to the Variscan orogeny (MÉNOT et al., 1987). The associated mesozonal recrystallizations are extensive in the lower geometric part of the ophiolite (Séchilienne formation) but less marked in the plutonic sequence (Chamrousse formation).

d) the Late Cambrian-Lower Ordovician age of the ophiolite accretion was defined by the U/Pb method on zircons of plagiogranites (MÉNOT et al., 1984a, 1988a) and confirmed by a Sm/Nd isochron on gabbros (PIN and CARME, 1987).

Thus, the ophiolitic complex appears as a well-preserved witness of the Lower Paleozoic extensional period. It represents either an oceanic back-arc basin (PIN and CARME, 1987) or an ensialic basin upon an attenuated passive margin (MÉNOT, 1987).

Middle and Upper Paleozoic formations:

The Rioupéroux and Livet formations: they are exposed on both sides of the lower Romanche valley (domain c: fig. 1) and consist of leptynitic and micaceous gneisses, amphibolites, acid and basic meta-volcanics and siliceous intrusives.

They are considered as a single plutonic and volcanic complex, which is now dismembered into five main tectonic units (SCARENZI, 1984; MÉNOT, 1986). The units A and B of the Rioupéroux formations respectively include volcanic and volcano-sedimentary rocks, with subordinate plutonites, and represent the upper part of the complex. Trondhjemitic sills and stocks are more abundant in the Livet units C and E, interpreted as deeper levels of the same complex, and they intrude an amphibolitic-leptynitic series that testifies an older bimodal igneous event (MÉNOT, 1986).

Trondhjemites of both Rioupéroux and Livet formations have been dated using the U/Pb method on zircons and have similar ages (352 ± 56 and 365 ± 17 ma: MÉNOT et al., 1984b, 1988b).

All magmatic rocks belong to the same cycle (CARME, 1975a). With respect to chemical characteristics, the geotectonic significance of the plutonic and volcanic complex is still badly defined: CARME (1975a) and CARME and PIN (1987) argue for an active margin environment whereas MÉNOT (1987) infers for an ensalic rift. According to the latter author and SCARENZI (1984), the chemistry of amphibolites and metabasalts arise from both an enriched mantle source and a continental contamination. The siliceous volcanics and intrusives, like the metabasites, also present this twofold chemical

character. But the wider compositional range of the acidic rocks points out their diversity of origin: some represent the differentiated terms of a basaltic source by fractional crystallization and others are issued from the partial melting of amphibolites. Secondary magmatic processes emphasize this complexity: more or less intensive crustal contamination and hybridization.

Following the previous interpretation, the magmatic evolution through time, from a bimodal stage to a more siliceous stage, bears evidence of an aborted mechanism of continental distension and thinning.

The tectono-metamorphic evolution corresponds to Variscan events (Fig. 2) (MÉNOT, 1986; MÉNOT et al., 1987). Mineralogical assemblages attest greenschist and amphibolite facies conditions (CARME, 1973a; MÉNOT, 1986). The early metamorphic recrystallizations, that affect the amphibolitic-leptynitic series prior to the intrusion of trondhjemites can be related either to a continental rift metamorphism or to the preliminary compressive stresses of the tectogenesis (MÉNOT, 1987).

Orthogneisses and granites: The orthogneisses form an elongated outcrop 80 km in length and 1 to 5 km in width in the domain B ("complexe de Saint Colomban" and "gneiss à mégacristaux"). They arise from heterogenous biotitic and amphibolitic porphyroid granitoids, diorites and leucogabbros and are associated with migmatitic gneisses. Igneous acid and basic associations and magmatic flow textures are locally preserved (VIVIER et al., 1987).

Biotitic orthogneisses belong to the alumino-potassic sub-type (PLOQUIN and VIVIER, 1984) and present a spacial field association and genetic relationships with cordierite-bearing migmatites. The intermediate and basic plutonic facies have sub-alkaline monzonitic characteristics (PLOQUIN and VIVIER, 1984).

Subsequent deformations lead to protomylonitic, mylonitic and phyllonitic textures, the later being well-developed at the margins of the plutonic bodies and in localized shear zones.

No geochronological data are available for the orthogneissic formation, but a Devonian age seems to be likely: orthogneisses are contemporaneous or late compared with the Devonian anatectic stage (see below) and older than the intrusion of the Carboniferous granites (322 ± 43 ma: DEMEULEMEESTER, 1982). This early plutonic event succeeds to the orogenic crustal thickening of the NE domain (VON RAUMER, 1984b).

The granites: They define two axes ("Sept-Laux" and "Lauzière") intruding the pre-Carboniferous gneisses, migmatites and orthogneisses of the NE Belledonne domain (B) (Fig. 1).

The Sept-Laux massif represents a multistage intrusion. The earliest and dominant facies, a coarse-grained, biotite-albite-oligoclase-microcline bearing granite, is characterized by a strong magmatic planar fabric and is locally enriched with mafic enclaves. The younger facies, fine-grained hololeucocratic granite and dykes of aplitic and pegmatitic nature, are equant. However the different granitic terms have very close compositions similar to that of sub-alkaline monzonites (VIVIER et al., 1987). The age of the Sept-Laux granite is not well defined (322 ± 43 ma, Rb/Sr on whole rocks isochron with an initial ratio of 0.7066), but it suffered the Lower to Middle Carboniferous strike slip shearing as evidenced by foliated borders and intrabatholitic shear zones (see below).

The syntectonic character of the earliest facies and the chemical affinities with the orthogneisses suggest that the Sept-Laux granite could represent a late and more evolved term of a single plutonic event (VIVIER et al., 1987).

The Lauzière massif consists of a monzonitic association including early mesocratic syenites, more differenciated syenites, granites and late hololeucocratic facies. In this complex, acid-basic emulsions, sharp contacts between the various terms and different chemical imprints respectively attest to the polyphased nature of the intrusions and to the control of the magma genesis by several stages, or degrees, of continental contamination and by several, mantle and crustal, sources (NEGGA, 1984; AUMAITRE et al., 1985). The Lauzière plutonites are the latest pre-Stephanian intrusives as they cross-cut both the orthogneisses and the Sept-Laux granitoids.

The Taillefer formation: it outcrops in the SW domain (C) (Fig. 1) and consists (a) of various sedimentary facies, pelites, arenites and conglomerates with local occurences of carbonates and (b) of volcanic and volcanigenic rocks, spilites, keratophyres and tuffs (CARME, 1965). Epizonal metamorphic recrystallizations are weak and a well-marked foliation only appears in the shear zones. This tecton-

ometamorphic evolution is contemporaneous with the major thrusting event of Upper Visean age (MÉNOT et al., 1987) (see below).

The chemical character of the meta-volcanics is ambiguous and might present affinities with orogenic tholeiites (CARME and PIN, 1987). But our recent and unpublished work favours a tholeiitic intraplate nature and this bimodal magmatism shows striking similarities with that of the Devonian Rioupéroux-Livet formations. Consequently, the Taillefer formation could represent a Dinantian (Visean ?: GIBERGY, 1968) intracontinental basin of pull-apart type (MÉNOT, 1987).

The "schists verts" formation is exposed in the NE domain of Belledonne (B) as a longitudinal belt, tectonically inserted within the gneissic basement (cf. 1.2) (Fig. 1). It closely resembles the Taillefer formation (domain C) with regard to lithological composition: epizonal black and green schists, metaconglomerates and siliceous and basaltic metavolcanic and metavolcanogenic material (BORDET and BORDET, 1963; GROS, 1974; VERJAT, 1980; NEGGA, 1984). No precise data about the igneous rocks are yet available.

The regional mylonitic foliation rubs out an older epizonal assemblage. It corresponds to the late retromorphic stage recorded in the surrounding gneisses (CARME, 1970b; VIVIER et al., 1987).

The age and the relationships between the "schistes verts" and the gneissic formation are ambiguous: The "schistes verts" are either autochthonous and Visean (BORDET and BORDET, 1953) or allochthonous and of undefined age (Lower Paleozoic (?): VERJAT, 1980). They are never intruded by the Lower Carboniferous granites (2.2) but are older than Stephanian sediments.

2.1.3. Post-Variscan Cycle

The post-Variscan formations are exposed as tectonic coins along the major longitudinal accidents (especially "Synclinal Médian", Fig. 1) and as horizontal or gently dipping deposits, unconformly lying upon the crystalline basement. They represent Upper Carboniferous, Permian, Triassic and Liassic terrains.

The Upper Carboniferous and Permian ("grès d'Allevard") formations consist of conglomerates, sandstones and multi-coulored shales with local coal-bearing layers. The oldest sediments are dated Westphalian D and Stephanian A and are the lateral analogues of the exploited basin of La Mure (South of Belledonne).

A great number of triassic outcrops can be observed in the Belledonne massif. These relics of the early Mesozoic peneplain include arkosic sandstones, cavernous limestones and mainly dolomites. The sediments contain intercalations of spilites.

Some liassic marls and limestones also occur as slices in the "Synclinal Médian".

Alpine metamorphic transformations are restricted to a phengitic slaty cleavage (DONDEY, 1960). But the occurence of such Upper Paleozoic-Lower Mesozoic formations as tectonic slices gives evidence of the reactivation of the main Variscan faults during the Alpine orogeny.

2.2. GEOLOGICAL EVOLUTION

2.2.1. Magmatism

According to the chemical characteristics of igneous rocks, three main Paleozoic tectono-magmatic settings are considered:

Cambro-Ordovician distension-related magmatism:

Lower Paleozoic magmatites occur in both the domains B and C and respectively correspond to a bimodal suite (amphibolitic and leptynitic formation) and to the ophiolitic complex of Chamrousse-Séchilienne.

The chemistry of the NE Belledonne amphibolites is characterized by both MORB affinities and a slight continental contamination component (PAQUETTE, 1987; MÉNOT, unpublished data). Thus they are strictly comparable with the Aiguilles Rouges metabasites (LIÉGEOIS and DUCHESNE, 1981; VON RAUMER et al., in press). According to their specific chemical characters and to their intimate association with supracrustal gneisses, the amphibolites are considered to be representative of an ensialic distension episod (attenuated crust-related magmatism).

The Chamrousse ophiolite is representative of a true oceanic domain and is considered as a marginal basin (bakc-arc basin; PIN and CARME, 1987, or ensialic basin on a passive and then active margin; MÉNOT, 1987).

With respect to the age and the geotectonic significance of both igneous formations mentioned above, they are comparable with Appalachian, Scottish and Scandinavian ophiolites, with the mafic ultramafic complexes of NW Spain and of the southern border of the French Massif Central (NAJAC; BODINIER et al., 1986), and finally with the bimodal igneous formations (i.e. "complexes leptyno-amphiboliques" of the western Europe Variscan belt (CARME and PIN, 1987; MÉNOT et al., 1988a and b).

Devono-Carboniferous distension-related magmatism:

The corresponding igneous rocks belong to the Devonian formations of Rioupéroux and Livet and to the Lower Carboniferous formations of the Taillefer and, may be, of the "schistes verts".

The plutonic and volcanic complex of Rioupéroux-Livet (domain C) is interpreted as a witness of an ensialic rift-zone (MÉNOT, 1987) or of an active margin (CARME and PIN, 1987). These different interpretations arise from the geochemical analogies shown by the siliceous materials produced in both contexts (SHENK, 1978; SIVELL and FODEN, 1985). A distension-related magmatism seems to be more appropriate as the Rioupéroux-Livet formations are closely comparable with the Brévenne series where ensialic ophiolitic members have been described (SIDER and OHNENSTETTER, 1986) or with the Mid-Armorian intracontinental basins. Moreover, the existence of effective subduction-zones, during the Upper Devonian and in this region, is unlikely according to the recent syntheses of the Variscan framework (MATTE, 1986; WEBER, 1985).

The Lower Carboniferous spilites and keratophyres are associated with clastic materials attesting that the sedimentation occurred in narrow, syn-orogenic intracontinental basins.

Devono-Carboniferous compression-related plutonism:

The Devono-Carboniferous plutonism of the NE domain (B) succeeds to the barrovian metamorphic event and its earliest terms, orthogneisses, are closely related to the anatectic melts. Thus, it originates within a thickened crust and bears evidence of the Devono-Carboniferous PT evolution (increasing T together with declining P) after the eo-Variscan HP stage (VON RAUMER, 1984b).

Conclusions:

During the Lower Paleozoic, igneous relics of a major extensional episod are demonstrated in both the NE and SW domains (B and C) of Belledonne. But the distension has reached to a true oceanic crust in the SW domain (Chamrousse ophiolite) and only to an attenuated continental crust environment in the NE domain (amphibolitic formation).

During Devonian and Lower Carboniferous, the igneous characteristics highlight the opposition between a mesocrustal orogenic domain (B) (orthogneisses and granites) and more supracrustal formations (Allemont-Rochetaillée) and even anorogenic superficial formations (volcano-plutonic complex of Rioupéroux-Livet) (domain C).

2.2.2. Orogenic evolution: tectonics and metamorphism

The main tectonometamorphic features are summed up in Fig. 2. They emphasize the distinction between the three domains of the Belledonne massif.

Domain A: All the successive stages of the polymetamorphic evolution of the "Série Satinée" consist in low-grade assemblages. Such an evolution for this Lower Paleozoic (?) pelitic series can be compared with that of the external zones of the Variscan belt.

Domain B: It is characterized by a long-lived polyphased evolution VIVIER et al., 1987):

- late-Silurian-eo-Devonian HP stage,
- Devonian stage of barrovian type and subsequent anatexis,
- Lower Carboniferous epi- to mesozonal mylonitic stage.

Thus, the NE domain of Belledonne appears to represent a part of the axial Devonian fold belt (Moldanubian or Ligerian zone: AUTRAN and COGNE, 1980; innermost crystalline nappes: MATTE, 1986).

This evolution clearly points out the successive orogenic processes: eo-Hercynian collision with deep-seated thrusts (HP event), Devonian crustal thickening and basement uplift (MP stage and anatexis) and finally development of a regional shear-zone (CARME, 1970b, VIVIER et al., 1987), arising from the ultimate compressive stresses in the upper crust.

		S	S_1 - - - - - - - - →	S_2 - - - - - - - - - - →	S_3 - - - - - - - - - - →
R. EXTERNE	Domain A "Série satinée" (Lower Paleozoic) ?	?	epi-mesozone	epizone	Albite + Biot. + Musc. strain-slip (s-s) cleavage Ductile strike-slip faults and open kilometric folds
RAMEAU INTERNE	Domain B North-Eastern (a): Gneissic and amphibolitic F. (Cambrian-Ordovician)	HP Eclogites	MP - - → anatexis Staur. Kyan. Orthogneisses	Meso-epizone - - - - - →	Biot. (East) Actin. Chlor. (West) Sept Laux - Lauzière granites - → mylonitic sub-vertical and generalized foliation Shear zone Localized ductile strike-slip faults
	Domain C South-Western (b) Allemont-Rochetaillée F. (Cambrian-Ordovician) ?	?	+ - - - Kyan. - - → Staur. Gt. local anatexis (cord.)	Epi - mesozone Biot. + Musc. + Hn. Late-metamorphic thrust	Biot. + Musc. Chlor. Hn. s-s cleavage Ductile strike-slip faults and related folds
	(c) Chamrousse-Séchilienne F. (Cambrian-Ordovician)		? + - - Equant. recryst. (Hn. + Plg)	Mesozone Hn. + Plg. + Gt.) Late-metamorphic thrust	Hn./Actin. s-s cleavage Equant. recryst. strike-slip faults
	(d) Rioupéroux and Livet F. (Dévonian)		Sn Mesozone Trondhj. and related volcan	Sn + 1 Epi-mesozone Late-metamorphic thrust Intra-formation dismembering (?)	Sn + 2 (Actin.-Biot. Chlor.) Equant. recryst. strike-slip faults
	Taillefer F. (Lower Carboniferous)			? + - - (Biot. - Musc. Actin. - Chlor.)	
Datings		≈ 400 Ma HP event, eclogites Beaufortin Aig. Rouges (Domain NE)	367 - 352 Ma Intrusion, Trondjemites Rioup-Livet (Domaine SW)	324 ± 12 Late-metamorphic thrust, Romanche (domain SW) 323 ± 18 Syn-metamorphic, mylonitic event, Belledonne NE 322 ± 43 Intrusion, granite des Sept Laux (domain NE)	

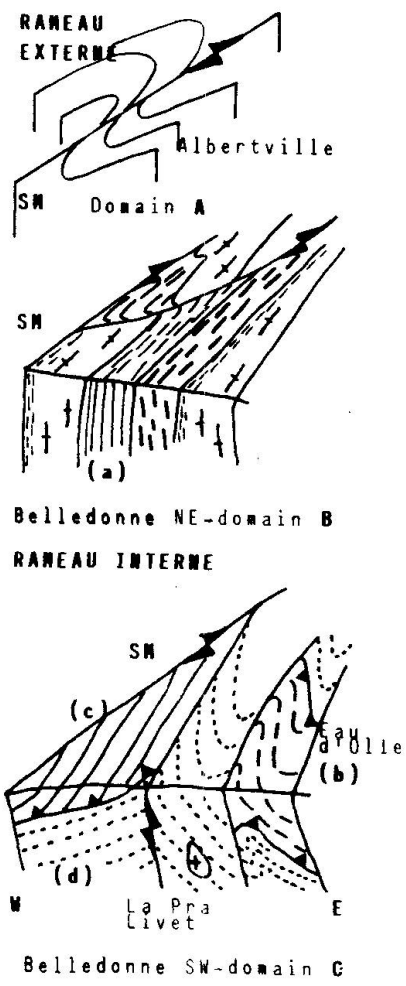

Fig. 2 Paleozoic evolution of the different formations and structural domains of Belledonne.

Domain C: Its organization results from the tectonic superposition of four main formations during the Lower Carboniferous tectonometamorphic events (MÉNOT et al., 1987) disturbing the normal distribution of the metamorphic zones (Sn+1: Fig. 2): the mesozonal formations of Chamrousse and Allemont are overthrusted upon epi- to mesozonal terrains of Rioupéroux and Livet (CARME, 1973b, MÉNOT, 1986). Before the nappe piling, each formation exhibits a specific evolution (MÉNOT, 1987):

- In the Allemont-Rochetaillée gneisses, the Sn+1 assemblages represent the latest stage of a retromorphic evolution after the barrovian paragenesis (Sn) and the related anatectic stage.
- In the Chamrousse ophiolite, the mylonitic foliation (Sn+1) is especially well-marked in the Séchilienne formation, in the lower part of the tectonic unit. The superimposition of the foliation upon earlier isotropic amphibolitic assemblages and the variation of the mineral chemistry suggest a prograde evolution and a change from static to dynamic conditions in relation with the thrusting (MÉNOT, 1987).
- In the Rioupéroux and Livet formations, the main recrystallizations also occur during late Devonian–Lower Carboniferous: after the trondhjemites intrusion (352–365 ma) (MÉNOT et al., 1984b and 1988b) and prior to the cooling age of the metamorphic basement (324 ma) (MÉNOT et al., 1987).
- The Taillefer formation of probably Visean age has only undergone the latest effects of this tectonometamorphic event (Sn+2).

In summary, in the SW domain of Belledonne, the different formations have been involved in the orogenic belt only during the late Devonian and Lower Carboniferous times. Thus they can be considered as representative of the Saxothuringian zone of the Variscan orogen. The particular evolution of the Allemont-Rochetaillée gneisses, with an earlier stage in more severe PT conditions, suggests that this unit initially belongs to an intermediate zone between the axial zone (Moldanubian id. domain B) and the outer zone (Saxothuringian, id. other formations of domain C).

Conclusions

1. The heterogeneity of the Belledonne massif results from the juxtaposition of three main distinct domains. Each of them exhibits specific structural characteristics but also a particular tectonometamorphic evolution. The three domains are representative of more or less internal zones of the hercynian belt:
   - Late Silurian to Devonian: domain B is a deep section of the collision zone (meso- to catazonal metamorphism, anatexis), as domain A represents an outermost area of the orogenic belt.
   - Lower Carboniferous:
   -- domain B acts as a meso and supracrustal section of the axial zone (syn-tectonic granitisation and regional strike-slip tectonics [hypercollision context])
   -- domain C results from the outwards extension of the collision zone (epi- to mesozonal metamorphism and nappe piling).
   - Mid-Carboniferous: tectonic association of the three domains along major late orogenic decrochement faults.

2. The different domains of Belledonne can be considered as, homogeneous (A and B) and composite (C) terranes (KEPPIE, 1985). The accretion occurs during the late-orogenic stages and is related to strike-slip tectonics leading to continental sutures. If so, the previously proposed correlations, based on lithological similarities, within the Belledonne massif and amongst the different external crystalline massifs of the Western Alps can be partially ruled out.

As compared with the Belledonne massif, the other external crystalline massifs seem to be homogeneous and their orogenic evolution is similar to that of the NE domain of Belledonne (VON RAUMER, 1984b) and comparable with the innermost sections of the belt and more specially with the "complexes leptyno-amphiboliques" (MÉNOT et al., 1988b). However, the western part of the Haut Dauphiné (Chaillol area) could probably represent the southward extension of the domain C and be correlated with more "external" zones.

3. Such a tectonic association of different orogenic domains allows some comparisons with other Variscan regions: the central and southern areas of Armorica, the northern and central Vosges. Moreover, the concepts of terranes and continental sutures could be used to successfully explain some still badly defined

tectonic contacts, as, for example, the relationships between the Brévenne and the Lyonnais units in the NE French Massif Central.

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