The Les Essarts eclogite-bearing metamorphic Complex (Vendée, southern Armorican Massif, France):

Pre-Variscan terrains in the Hercynian belt?

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Le complexe métamorphique à éclogites des Essarts (Vendée, Massif armoricain méridional) : un témoin de terrains pré-varisques au sein de la chaîne hercynienne ?

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Mots-clés : Serpentinite, Eclogite, Leptynite, Amphibolite, Métamorphisme rétrograde, Protolithe, Métagabbro, Gneiss, Métamorphisme polycyclique, Faciès éclogite, Vendée.

Key words: Serpentinite, Eclogite , Leptynite, Amphilobite, Retrograde metamorphism, Protolith, Metagabbro, Gneiss, Polymetamorphism, Eclogite facies, Vendée, France.

Résumé

Dans cet article, nous présentons des données qui permettent de préciser l'origine de l'unité à éclogites des Essarts (Vendée, Massif armoricain). Lors des trois dernières décennies, ces éclogites furent considérées comme des reliques d'une vieille croûte océanique, éclogitisées lors d'une subduction éo-varisque puis intégrées à la chaîne varisque. Nous présentons ici les divers terrains métamorphiques et les linéaments tectoniques qui encadrent cette unité ("Geological framework", p. 22), puis nous donnons une description pétrologique et structurale des éclogites ("Eclogite and related rocks", p. 29) et de leurs gneiss encaissants ("Surrounding gneiss", p. 38).

L'unité de haute pression des Essarts est encadrée par le Sillon houiller de Vendée au nord-est et la ligne tectonique Sainte-Pazanne-Mervent au sud-ouest. Ces deux failles délimitent un couloir d'environ 150 km de long et quelques kilomètres de large, qui comporte trois unités métamorphiques distinctes : (i) l'unité à éclogites des Essarts, (ii) l'orthogneiss Chantonnay-Mervent, et (iii) l'unité épizonale de Roc-Cervelle. Des similitudes avec la région du Bas-Limousin permettent d'envisager que ces terrains fussent translatés tectoniquement du Limousin en Vendée au Carbonifère, par le jeu dextre des failles liées au serrage varisque.

Une partie des gneiss encaissant les éclogites a conservé la mémoire de deux épisodes métamorphiques (pp. 39-43). Ce sont des gneiss migmatitiques à cordiérite (premier épisode, de haute température) affectés par le métamorphisme éclogitique (second épisode, de haute pression). Ces deux stades métamorphiques sont séparés par un épisode de rétromorphose, de sorte que ces roches semblent avoir subi deux cycles orogéniques distincts, pré-varisque et varisque. Elles pourraient appartenir à une croûte continentale ancienne entraînée dans la même subduction éo-varisque que les éclogites, qui seraient d'origine océanique.

Les éclogites ont des caractères géochimiques de roches océaniques. La lignée tholéitique inclut des péridotites altérées (vraisemblablement à grenat), des éclogites à disthène, des éclogites à quartz, des éclogites ferro-titanées et des ortho-leptynites dérivant de plagiogranites. La roche anté-éclogitique était un gabbro amphibolitisé et saussuritisé. Le large éventail des compositions isotopiques de l'oxygène peut être attribué à un métamorphisme et une altération océaniques. Le principal épisode de déformation ductile est contemporain des conditions éclogitiques.

L'unité de Saint-Martin-des-Noyers s'étend sur le côté sud-ouest de la ligne tectonique Sainte-Pazanne-Mervent. Elle comporte un ensemble de roches à amphibole, qui constituent une lignée magmatique tholéitique, et dérivent de roches volcaniques ou hypovolcaniques qui pourraient avoir appartenu à un arc insulaire ou à un bassin arrière-arc. Cette unité est elle-même limitée au sud-ouest par une ceinture d'orthogneiss intrusifs dans le domaine ouest-vendéen. La même séquence d'unités géologiques semble se répéter sur les rives de l'estuaire de la Loire, dans la région de Paimbœuf.

L'unité de haute pression des Essarts apparaît comme constituée de terrains pré-varisques d'origine océanique probable (éclogites) et continentale (ortho- et para-gneiss), impliqués dans la même convergence éo-varisque.

Abstract

We present data that aims to clarify the origin of the Les Essarts eclogite-bearing

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Complex that, for the last three decades, has been considered to represent remnants of an old oceanic crust eclogitized during an eo-Variscan subduction stage and subsequently incorporated into the Variscan orogenic belt. We give an overview of the various metamorphic units and tectonic lineaments that occur close to the Les Essarts eclogite-bearing Unit (“Geological framework”, p. 22), as well as petrological and structural descriptions of the eclogite (“Eclogite and related rocks”, p. 29) and its surrounding gneiss (“Surrounding gneiss”, p. 38).

The eclogite and its surrounding gneiss occur between the Vendée coal belt and the Sainte-Pazanne-Mervent tectonic lineament, within an elongate NW-SE-trending zone about 150 km long and a few kilometres wide. Three units with contrasted features and histories occur in this zone: (i) the Les Essarts eclogite-bearing Unit, (ii) the Chantonnay-Mervent orthogneiss, and (iii) the Roc-Cervelle low-grade Unit. Similarities with the Bas-Limousin area suggest that these terrains were tectonically translated from Limousin to Vendée by the combined dextral displacements of faults related to Variscan compression during the Carboniferous.

Some of the surrounding gneiss shows evidence for two high-grade metamorphic stages separated by a retrograde stage (pp. 39-43). These comprise migmatitic cordierite-bearing gneiss (first high-T stage) that was later affected by an eclogite-facies metamorphism (second high-P stage). These rocks are thus likely to have been subjected to two distinct orogenic cycles, i.e. pre-Variscan and Variscan. They could belong to an old pre-Variscan continental crust that was involved in the same eo-Variscan subduction as the eclogite, which probably has an oceanic origin.

The eclogite has the geochemical characteristics of oceanic rock. The tholeiitic suite includes altered peridotite (possibly garnet-bearing), kyanite eclogite, quartz eclogite, Fe-Ti eclogite, and ortholeptynite derived from plagiogranite. The pre-eclogite protolith was an amphibolitized and saussuritized gabbro. The wide range of O isotope compositions can be attributed to ocean-floor metamorphism and alteration. The main deformation event took place during eclogite-facies metamorphism.

The Saint-Martin-des-Noyers Unit extends along the southwest side of the Sainte-Pazanne-Mervent tectonic lineament. It contains a set of amphibole-rich rocks that correspond to a tholeiitic magmatic suite. They derive from volcanic or hypovolcanic rocks that might have belonged to an island-arc or fore-arc system. This unit is bounded to the southwest by an orthogneiss belt intrusive into the West-Vendée domain. A similar sequence of geological units apparently occurs on the banks of the Loire estuary, near Paimbœuf.

The Les Essarts high-pressure Unit probably represents remnants of pre-Variscan continental (ortho- and paragneiss) and oceanic (eclogite) terrains that were involved in the eo-Variscan convergence.

Introduction

The eclogite-bearing metamorphic complex of the Vendée (southern Armorican Massif, Western France) is a typical example of eclogite-facies metamorphism in the Variscan belt of Europe. It is well known for the abundance and variety of its eclogite, but is difficult to study because of very poor exposure conditions. Over the last three decades, the eclogite has been interpreted in terms of plate tectonism, and considered as being remnants of an old oceanic crust eclogitized during an eo-Variscan subduction stage and subsequently incorporated into the Variscan orogenic belt during a continental collision (cf. Montigny and Allègre, 1974; Godard, 1981, 1983, 1988; Peucat *et al*., 1982a, 1982b; Bernard-Griffiths and Cornichet, 1985). The oceanic origin of the Vendée eclogite has been widely accepted. However, further investigations tend to show that the reality is probably much more complex than the simplistic hypotheses proposed a few years ago, and have recently raised some awkward questions:

(a) The Vendée eclogite did not derive directly from a gabbroic protolith, since the pre-eclogite rock was an amphibolitized gabbro (see Fig. 13; Godard, 1988).

(b) The surrounding ortho- and paragneiss, some of which record two orogenic cycles (see pp. 39-43; Godard, 1998), are typical of a continental crust, so we need to explain how oceanic eclogite came to be intimately interleaved within such gneiss.

(c) Neighbouring units have received various interpretations in terms of plate tectonism: island arc (Saint-Martin-des-Noyers Unit; Thiéblemont *et al*., 1987, 1988), back-arc basin (La Meilleraye metabasalts; Thiéblemont and Cabanis, 1986; Thiéblemont, 1988), some other subduction zone (Bois-de-Cené: Guiraud *et al*., 1987). The consistency between these various assumed geodynamic environments is far from being established.

In this paper, we present data that aims to clarify the origin of the Vendée eclogite-bearing Complex. Detailed petrological descriptions, as well as the pressure(P)-temperature(T) paths of the eclogite and surrounding gneiss, are presented elsewhere (Godard, 1988, 1998), and are only summarized here. On the other hand, we pay particular attention to field observations, which are for the most part unpublished. After a historical section, we present an overview of the various metamorphic units that occur close to the Les Essarts eclogite-bearing Unit, which with petrological and structural descriptions of the eclogite (“Eclogite and related rocks”, p. 29) and its surrounding gneiss (“Surrounding gneiss”, p. 38). The origin and geological history of this metamorphic complex are discussed in the last section.

Previous studies

Auguste Rivière discovered the Vendée eclogite in the 1830s and described it together with amphibolite and gneiss of the same region (Rivière, 1835a, 1835b, 1844a, 1844b, 1851; see Godard, 1984). This finding was one of the very first discoveries of eclogite, a few years after René-Just Haüy (1822) had coined the term “eclogite” (see Godard, 2001). François Dubuisson (1830) also knew of some eclogite in “Loire-Inférieure” (now Loire-Atlantique), but he did not identify it with Haüy’s “eclogite”. All these studies were rather rudimentary because they were performed without the microscope, and so were soon forgotten and ignored.

It was Alfred Lacroix (1891a, 1893-1913) and Charles Baret (1882, 1898, 1900) who made the first petrographic descriptions of the Armorican eclogite. Lacroix (1891a) classified it into two

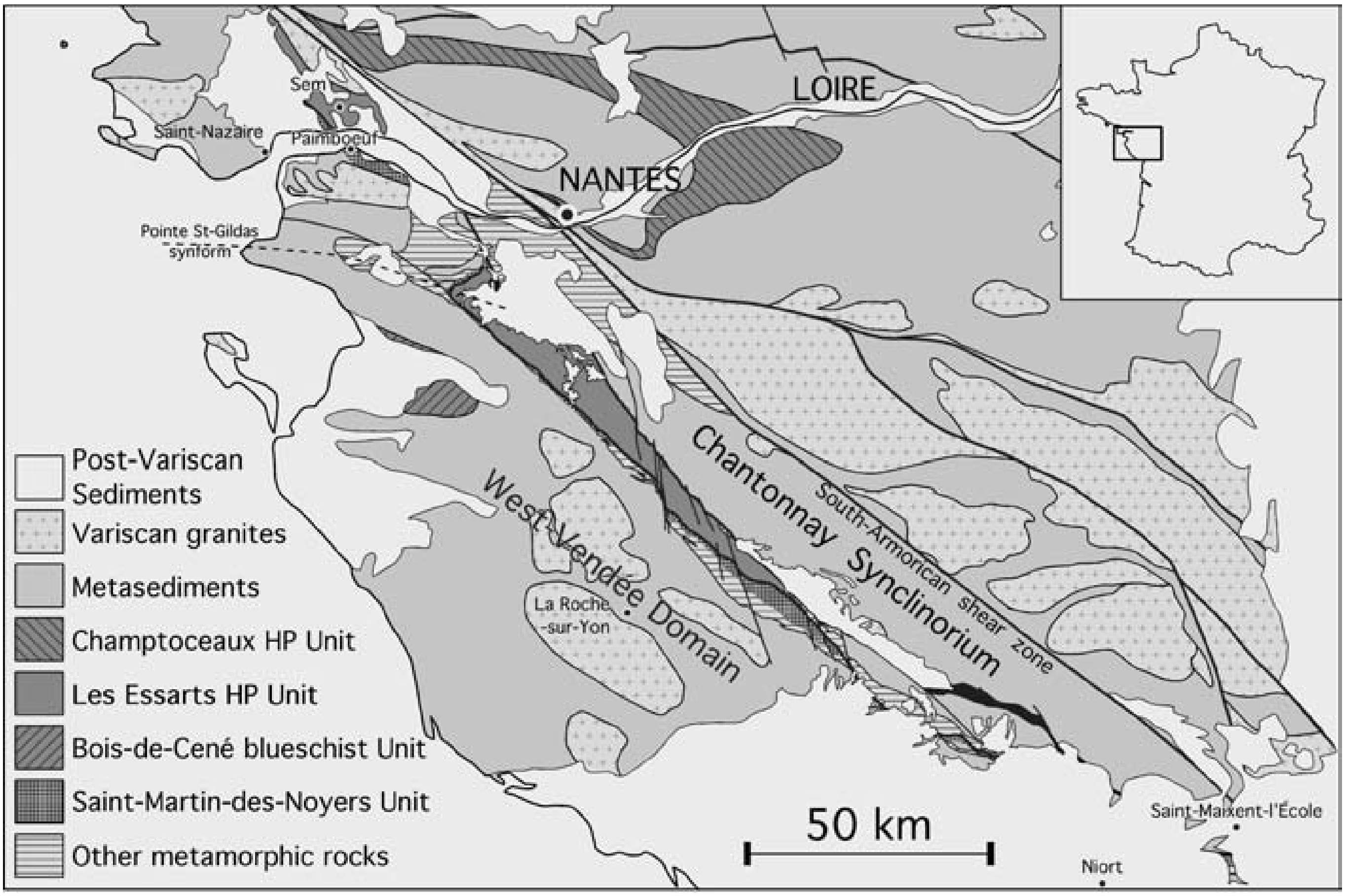


Fig. 1.- Geological sketch map of Vendée.

Fig. 1.- Carte géologique simplifiée du Massif Vendéen.

types, according to its texture and structure: (i) type I: coarse-grained eclogite, highly abundant in the Les Essarts Complex (Vendée) where it occurs as long (several kilometres) bodies; (ii) type II: very fine grained eclogite, with common atoll garnets, highly abundant in the Champtoceaux Complex (Fig. 1) where it occurs as small lenses generally ranging from a few decimetres to a few metres wide. Lacroix entrusted Marcel Brongniart, one of his students, with the task of making a detailed study of these rocks. Brongniart published a short abstract (Brongniart, 1908), but gave up his studies. Yvonne Brière, another of Lacroix's students, later took charge of the work. Brière's thesis (1920) was dedicated to the study of all the eclogite in France and the colonies, but was mainly concerned with the Armorican and Limousin eclogite. In addition to describing the main occurrences of eclogite, she also made a detailed mineralogical study of them. She concluded that these rocks had resulted from the metamorphism of gabbroic rocks. Such an origin is nowadays widely accepted, but the members of Brière's thesis examining board at La Sorbonne University severely criticised this conclusion at the time (Brière, pers. comm.).

Meanwhile, several researchers carried out fieldwork and geological mapping (e.g. Wallerant, 1882; Boisselier, 1889, 1892; Bureau, 1900; Le Verrier, 1903; Bureau and Ferronnière, 1927; Mathieu, 1937a, 1944, 1949, 1957; Mathieu and Waterlot, 1940). They provided evidence that the Vendée eclogite, amphibolite and associated gneiss belong to a NW-SE-directed terrain that is bounded by mica schist to the southwest, and by mica schist and Carboniferous sediments to the northeast. Thus, the eclogite-bearing terrain came to be considered as the core of an anticline that was believed to be one of the southern extensions of the *Anticlinal de Cornouailles* (cf. Jourdy, 1909; Cogné, 1960).

For a long time after Brière's classical work, few studies were undertaken on the eclogite (Christophe-Michel-Lévy, 1962; Velde, 1970; Velde and Sabatier, 1972). In the 1970s, plate tectonism produced a huge revival of interest in eclogite because of the geotectonic implications. Thus, on the basis of rare-earth element patterns, Montigny and Allègre (1974) proposed that the Vendée eclogite was remnants of an old oceanic crust metamorphosed in a paleo-subduction zone. Javoy and Allègre (1967) and Javoy (1971), studying O isotopic compositions, reached a similar conclusion. Petrological monographs (Godard, 1981, 1988) and geochemical studies (Bernard-Griffiths and Cornichet, 1985) also strengthened this hypothesis. Concomitant geochronological work (Peucat *et al.*, 1982a, 1982b; Peucat, 1983; Postaire, 1983; Paquette *et al.*, 1985) provided a date of 436 ± 15 Ma (U-Pb method on zircon; lower intercept age) that was interpreted as the age of the high-P metamorphism (i.e. eo-Variscan subduction), whereas the upper intercept age (1297 ± 60 Ma) was considered as representing the age of either inherited zircons or the gabbroic protolith. Further mineralogical and structural studies were performed on the eclogite (Godard and Smith, 1984, 1999; Godard and Van Roermund, 1995; Mauler *et al*., 2001). Because of these studies, the Vendée eclogite came to be considered as fragments of an oceanic paleocrust metamorphosed during subduction and subsequently involved in a Variscan continental collision.

Fieldwork and geological mapping performed in addition to the eclogite studies (e.g. Ters, 1979; Wyns, 1980; 1984a; Godard, 1981; Godard *in* Wyns *et al*., 1987; Meidom, 1991) show this area to be much more complex than the so-called anticline of the earlier authors. However, until recently, a lot of confusion arose from the grouping together of eclogite, amphibolite and gneiss of various origins, the whole being referred to as the *Complexe Les Essarts[-Mervent]* and considered, in the 1980s, as being a *complexe leptyno-amphibolique*, a term whose meaning was confused but designated Variscan suture zones (e.g. Santallier *et al*., 1988; Ménot *et al*., 1988). The recent recognition of different units bounded by tectonic lineaments and showing specific metamorphic histories helps to clarify the structure of this “complex”. We should now consider it as composed of several tectonic slices. Among these different units, the eclogite-bearing terrain displays very particular features, and we propose to call it the “Les Essarts high-pressure Unit”, and to retain the name “Les Essarts Complex” for the whole area.

Geological framework

In this section, we give an overview of the various geological units and tectonic lineaments in proximity to the Les Essarts high-P Unit (See geological map of Fig. 2, in pocket on inside back cover). These terrains are presented from the northeast to southwest. For the sake of convenience, location co-ordinates (longitude and latitude) are given in the Lambert II extended grid reference system.

Chantonnay Synclinorium

The Chantonnay Synclinorium is located between two major late-Variscan tectonic lineaments, namely the South Armorican Shear Zone (*i.e. Zone de cisaillement sud-armoricaine*) and the Vendée coal belt (*i.e. Sillon houiller de Vendée*) (Fig. 1). It was first defined and studied by Mathieu (1934, 1936c, 1937a, 1944), but its stratigraphy has since been completely revised by Wyns (1979, 1980, 1984a, 1984b), Wyns *et al*. (1989) and Bouton (1990). Since a detailed description of this domain is beyond the scope of the present study, we shall give only a brief summary of it here. The basement, to the north-northeast, is a meta-ophiolite sequence of serpentinized peridotites (Saint-Georges-de-Montaigu, Montbert, Bouaye, Le Pellerin) overlain by a kilometre-thick amphibolite-bearing zone (Pont-Léger, Boufféré, Pont-Saint-Martin). The sequence also includes Cambrian(?) greywacke and metapelite, ignimbrite (Lapparent, 1909; Berre, 1967; Boyer, 1968, 1972, 1974, 1976), Ordovician(?) quartzite, Silurian-Devonian phthanite and shale (Wyns, 1979; Wyns *et al*., 1989; Bouton, 1990). The core of the syncline is composed of Devonian(?) metabasalt with back-arc affinity (Thiéblemont and Cabanis, 1986; Thiéblemont, 1988), in which pillow-lavas have been observed (Boyer *et al*., 1976). Metamorphism is late-Variscan since it affects Devonian rocks, and ranges from low to medium grade (chlorite- to biotite-bearing mica schist). Two main deformation phases have been identified in this domain (e.g. Bouton, 1990). This volcano-sedimentary domain is far different from the eclogite-bearing complex, from which it is separated by a late-Variscan tectonic lineament, the Vendée coal belt.

Vendée coal belt

Geological setting

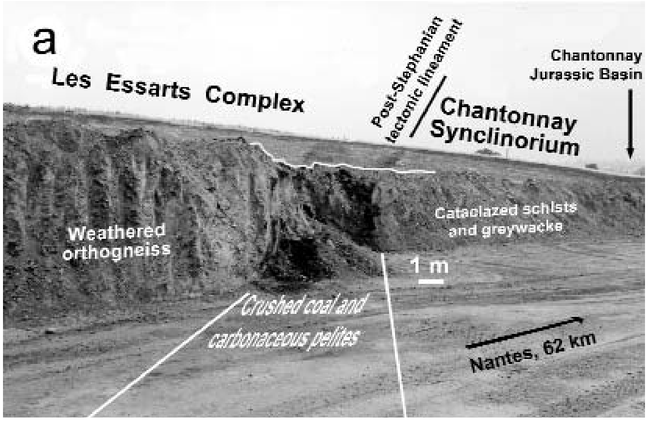
The Vendée coal belt extends over 120 km, from Port-Saint-Père near Grand-Lieu Lake (NW) to Saint-Laurs (SE), where it disappears under the Jurassic cover of the Aquitaine Basin. This belt delineates an important late-Variscan tectonic lineament that separates the Chantonnay Synclinorium (NE) from the Les Essarts eclogite-bearing Unit (SW). Along this line, unmetamorphosed Carboniferous continental deposits occur within a narrow zone, whose width usually ranges from a few metres (Fig. 3a) to a few hundreds of metres. It attains a width of 2 km towards the southeast, in the old mining district of Faymoreau (Fig. 2).

The Vendée coal belt was mined for coal from 1775 to 1958, notably at Faymoreau, Chantonnay and Saint-Mars-de-Coutais. For this reason, it has been described by many authors: e.g. Mercier (1834), Fournel (1836), Paret (1840, 1841), Lechatelier (1841), Cacarrié (1842-43), La Fontenelle de Vaudoré (1844), Devillaine (1881), Fournier (1887), Saint-Quentin (1899), Bureau (1900), Laromiguière (1907), Bergeron (1910), Picquenard (1918), Péneau (1921, 1923), Mathieu (1935, 1936a, 1936c, 1936d, 1937a, 1937c), Greigov (1937), Gautier (1950), Wyns (1980, 1984a), Godard (1981), Bouton (1990).

Fossil flora and sediments

The continental fossil flora preserved in the sediments indicates two episodes of sedimentation, namely Namurian and Westphalian-Stephanian (Upper Carboniferous: Grand’Eury, 1877; Bureau, 1914; Welsch, 1916; Picquenard, 1918, 1920a, 1920b, 1923, 1924; Péneau, 1920, 1921; Mathieu, 1936a, 1937a). Both Namurian and Stephanian sediments occur in the southeastern area, near Faymoreau, together with Givetian (Upper Devonian) marine limestone (La Villedé d’Ardin: Dollfus, 1903; Mathieu, 1936b, 1937b; Lemaître and Mathieu, 1937; Camuzard *et al*., 1968, 1969; Bouton, 1990). On the other hand, in the northwestern part of the belt, at the contact with the high-P eclogite-bearing unit, the sediments apparently belong only to the Stephanian.

Coarse clastic deposits (conglomerate, brownish psammitic and arkosic sandstone: Fig. 3b) constitute the main part of the succession (e.g. Lambert co-ordinates: 311.30-2224.75; 341.35-2191.42; 372.20-2176.67), which also includes intercalations of carbonaceous pelite and some metre-thick coal seams (e.g. Faymoreau: 372.91-2176.22 [dangerous], 373.16-2176.01). All these sediments are clearly post-metamorphic. The conglomerate pebbles are primarily quartz (Fig. 3b), but there are also pebbles of schist, sandstone and gneiss, particularly orthogneiss. Pebbles of weathered amphibolite and



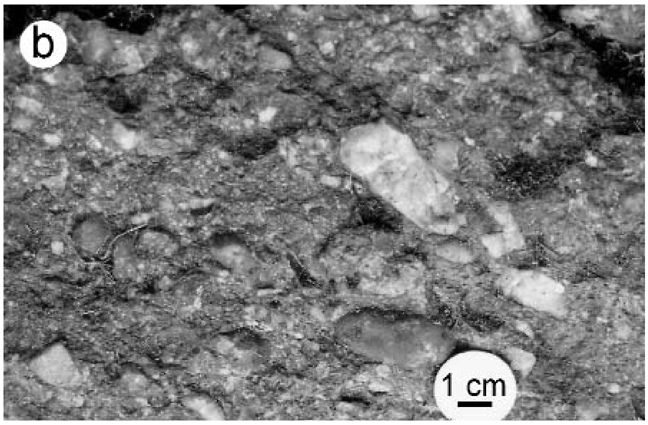


Fig. 3.- Vendée coal belt.
a) Section across the Vendée coal belt along the A83 Nantes-Niort motorway, near Le Fraigne, 5 km to the southeast of Les Essarts (332.6-2200.4).
b) Stephanian conglomerate from the disused coal mine of L'Effeterie, near Saint-Mars-de-Coutais (292.02-2241.76). Most of the pebbles are quartz, although gneiss, schist and weathered eclogite also occur (see text).

Fig. 3.- Sillon houiller de Vendée.
a) Coupe à travers le Sillon houiller le long de l'autoroute A83 Nantes-Niort, près du Fraigne, à 5 km au sud-est des Essarts (332.6-2200.4).
b) Conglomérat stéphanien de l'ancienne mine de charbon de l'Effeterie en Saint-Mars-de-Coutais (292.02-2241.76). La majorité des galets sont du quartz, mais il existe aussi des galets de gneiss, de schistes et d'éclogite altérée (voir texte).

eclogite are observed at one locality, La Barrelière near Saint-Philbert-de-Bouaine (310.45-2225.33). This observation indicates that some of the eclogite had reached the surface by the Stephanian (around 300 Ma). In the northwestern part of the belt, the pebbles originate primarily from the Les Essarts high-P Unit (Godard, 1981), whereas, in the south, some of them also come from the Chantonnay Synclinorium (Bouton, 1990).

Structure and tectonics

While the southeastern area of Faymoreau shows a complex folded and faulted structure (Bergeron, 1910; Bouton, 1990), the structure is more simple towards the northwest, where stratification in the Stephanian sediments is monoclinal, dipping northeast at angles ranging from around 80° near Chantonnay to 50° near Saint-Philbert-de-Bouaine (Figs. 2 and 4). Although rarely exposed, the contact between the Carboniferous and the Les Essarts high-P Unit seems to be a sedimentary unconformity that has been partly reworked by tectonics. A few years ago, this unconformity was well exposed near Chantonnay (340.00-2193.65; see Wyns, 1984a). On the other hand, the contact between the Carboniferous and the Chantonnay Synclinorium is clearly tectonic, being marked by a 100-m-wide zone of cataclased schist, greywacke and gneiss (Fig. 3a; e.g. 308.91-2227.95; 310.53-2225.61; 310.86-2225.23, near Saint-Philbert-de-Bouaine). In this zone, a lense of listwaenite (dolomitized serpentinite; L'Écotais, near Malabrit: 311.15-2225.00) could result from the tectonic reworking of some serpentinite originating from the basement of the Chantonnay Synclinorium. Mathieu (e.g. 1961) strangely considered this rock as a Devonian dolomite, although several authors had observed chromite and "chromocre" in it (Dufour, 1877; Baret, 1884, 1898, 1905).

Several recent studies on the Vendée coal belt (e.g. Godard, 1981; Wyns, 1984a; Bouton, 1990) have led to the following conclusions about its tectonic features: (i) the main tectonic episode was late- or post-Stephanian (<290 Ma), since it affects Stephanian sediments; (ii) it is characterized by a brittle cataclastic deformation; (iii) the regime was transpressive, with a NW-SE tightening component, and an important dextral shearing component; and (iv) stratification in the Carboniferous was tilted towards the northeast at angles ranging between 40° to 90°; it was even overtilted between Chantonnay and Les Essarts (La Marzelle, Le Fraigne: Figs. 3a and 4). If the contact with the Les Essarts high-P Unit is really an unconformity, as proposed here (see above), we should expect that this tilting also affected the units that bound the coal belt towards the southwest.

The Les Essarts high-pressure Unit, Chantonnay-Mervent orthogneiss and Roc-Cervelle low-grade Unit

Between the Vendée coal belt, to the northeast, and the Sainte-Pazanne-Mervent tectonic lineament, to the southwest, there is a narrow NW-SE-trending zone about 150 km long and a few kilometres wide (Figs. 1 and 2), which coincides with a strong positive magnetic anomaly (B.R.G.M., 1998). Three different metamorphic units occur in this zone: (i) the Les Essarts high-P eclogite-bearing Unit (from Port-Saint-Père to Chantonnay), (ii) an orthogneiss (around Chantonnay), and (iii) the Roc-Cervelle low-grade Unit (from Chantonnay to Saint-Laurs). The two bounding tectonic lineaments intersect these three units at low angles.

Les Essarts high-pressure Unit

This unit is made of eclogite and eclogite-derived amphibolite, as well as ortho- and paragneiss with high-P relics. It is the main subject of this study, and the reader is referred to the next sections for further descriptions. A similar serpentinite- and eclogite-bearing terrain occurs on the northern bank of the Loire, near Sem-en-Donges (Lasnier, 1968) (Fig. 1). The latter terrain could be either an equivalent or an extension of the Les

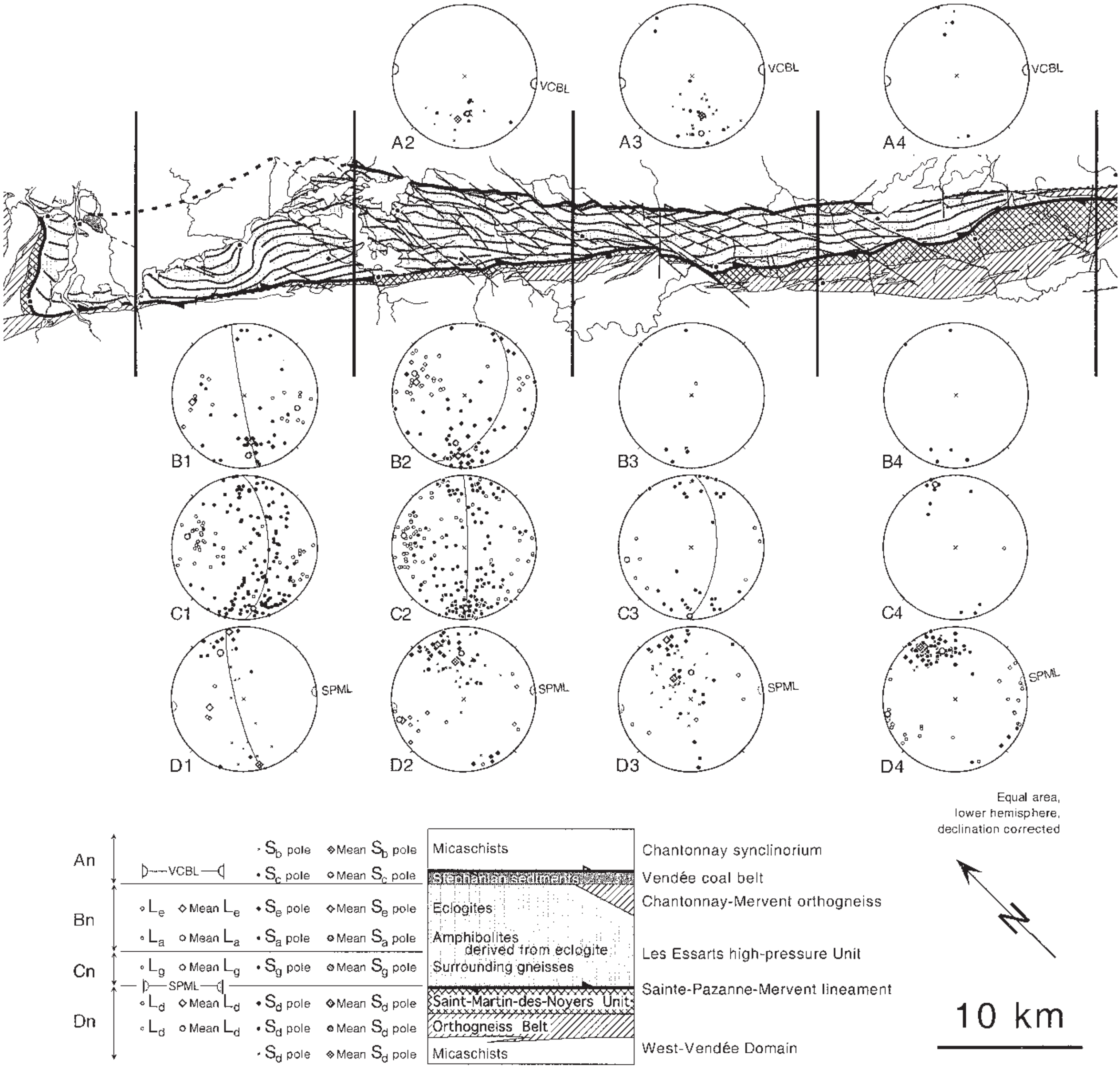


Fig. 4.- Structural data.
Equal area projection in the lower hemisphere, after correction of the declination. Sb: (Devonian?) schistosity (Chantonnay Synclinorium); Sc: Stratification in the Stephanian sediments of the Vendée coal belt (Upper Carboniferous); Le and Se: eo-Variscan syn-eclogite-facies lineation and foliation in the eclogite; La and Sa: post-eclogite lineation and foliation in the eclogite-derived amphibolite; Lg and Sg: syn-eclogite to post-eclogite lineation and foliation in the surrounding gneiss; Ld and Sd: eo-Variscan lineation and foliation in the West-Vendée domain. VCBL: mean strike of the Vendée coal belt tectonic lineament; SPML: mean strike of the Sainte-Pazanne-Mervent tectonic lineament.

Fig. 4.- Données structurales.
Projections à aires égales dans l'hémisphère inférieur après correction de la déclinaison. Sb : schistosité (dévonienne ?) dans le Synclinorium de Chantonnay ; Sc : Stratification dans les sédiments stéphaniens du Sillon houiller de Vendée (Carbonifère supérieur) ; Le et Se : linéation et foliation minérales syn-éclogitiques éo-hercyniennes dans les éclogites ; La et Sa : linéation et foliation minérales post-éclogitiques dans les amphibolites dérivant d'éclogite ; Lg et Sg : linéation et foliation minérales syn- à post-éclogitiques dans les gneiss encaissants ; Ld et Sd : linéation et foliation principales dans le domaine ouest-vendéen. VCBL : direction moyenne de la ligne tectonique du Sillon houiller de Vendée ; SPML : direction moyenne de la ligne tectonique Sainte-Pazanne-Mervent.

Essarts Unit towards the northwest. However, the area is obscured by faults and overlying Cenozoic sediments, so there is no clear evidence for such continuity. On the other hand, the so-called eclogite of the Saint-Nazaire region (Fig. 1) that has been shown on several geological sketch maps in the literature is not eclogite but calc-silicate rocks made up of jadeite-free diopside, garnet (grossular-andradite), plagioclase and scapolite (e.g. Lacroix, 1889, 1891b).

Foliation in the Les Essarts Unit is almost subvertical, while stretching lineation dips slightly NW (Bn and Cn *in* Fig. 4). Foliations in the eclogite and gneiss are similar (Bn versus Cn *in* Fig. 4). Where contact between eclogite and gneiss is visible, the structures seem parallel in both rock types, suggesting that they were deformed simultaneously. Strong unconformity between the two rock types, as seen at the northwestern end of La Gerbaudière quarry (Figs. 10 and 11b), seldom occurs. Such unconformity is certainly due to differences in rheology between the eclogite and gneiss, resulting in a boudinage effect.

Chantonnay-Mervent orthogneiss

This metagranite formation, which has been tectonically stretched in a NW-SE direction, occurs over a distance of more than 80 km between Chauché, Chantonnay and Mervent. It separates the Les Essarts high-P Unit (NW) from the Roc-Cervelle low-grade Unit (SE). Outcrops can be seen along a few rivers (La Mozée, near Moinet; Grand Lay, between La Vildé and Pont Charron; La Mère, near Pierre Brune), and in a few disused quarries (e.g. 333.72-2199.28; 334.04-2199.00; 343.60-2189.91; 347.16-2184.08; 349.00-2182.15; 349.83-2179.33; 351.1-2178.6; 364.7-2172.4). The rock is generally leucocratic, rich in alkali feldspar, and has a sodi-potassic composition (see analyses 1622-1626 *in* Wyns, 1980, and Q22, P4, *in* Wyns *et al*., 1987). Quartz grains are strongly stretched parallel to foliation. They display numerous subgrains and a clear crystallographic preferred orientation ([c] axis normal to foliation). Foliations and stretching lineations are subvertical and almost horizontal, respectively (Wyns, 1980; Wyns *et al*., 1987).

C. Guerrot (unpubl. data) obtained an inaccurate age of 495 +37/-14 Ma for the protolith (U-Pb method on zircon; Chantonnay; large inaccuracies are due to both Pb memory and loss), whereas an Ordovician age of 446 ± 12 Ma was obtained by Vidal (1980) (Rb-Sr; age recalculated using a λ^{87R}b value of 1.42 10-11; La Guière, near Mervent). We can expect that the U-Pb system better retained the granite age than the Rb-Sr system.

The boundaries between this orthogneiss and the Les Essarts and Roc-Cervelle units are poorly exposed. It is not clear whether they are tectonic or represent the deformed intrusive limits of the former granite. Bouton (1990) mentioned cataclastic rocks between the orthogneiss and the Roc-Cervelle Unit, whereas Wyns (1980, p. 99) and Meidom (1991, p. 9) observed biotite in the Roc-Cervelle Unit close to the gneiss (e.g. Villeneuve en La Jaudonnière), which seems in favour of an intrusive relationship. We also observed mylonitic rocks near Chauché, at the boundary between the orthogneiss and the Les Essarts Unit, but this could be a local circumstance.

The Roc-Cervelle low-grade Unit

The Roc-Cervelle Unit was defined by Bouton (1990), although previously studied by other workers (e.g. Mathieu, 1937a; Wyns, 1980, 1984a). It is mainly composed of monotonous sequences of marine sandstone, greywacke and pelite, affected by a low-grade metamorphism that developed sericite and chlorite. Wyns (1980) attributed the unit to the Precambrian. Bouton (1990) suggested that it could be Cambrian, because of lithologic similarities with formations of the Chantonnay Synclinorium, but there is no paleontological evidence to support this hypothesis. Wyns (1980), Bouton (1990) and Meidom (1991) gave detailed descriptions of the deformation structures, which are dominantly coaxial with two syn-metamorphic schistosities, S1-2.

Metamorphosed doleritic rocks, composed of actinolite + albite + chlorite + epidote + calcite + sphene, are observed at Roc-Cervelle (380.3-2169.5; Bouton, 1990), to the northeast of Mervent (e.g. 363.45-2174.20), and near Saint-Philbert-du-Pont-Charrault (La Vildé: e.g. 343.70-2189.76; Fig. 5) where such rocks are abundant. Where the rock is slightly deformed, subhedral phenocrysts of albitized plagioclase and amphibole, set in a mafic microcrystalline matrix, represent relics of a preserved magmatic microgranular porphyritic texture (Fig. 5). In the past, these rocks have been confused with amphibolite derived from eclogite. Until the last generation of geological maps, no clear distinction was made between the Les Essarts and Roc-Cervelle units, although their metamorphic histories are very dissimilar. The preserved porphyritic (or volcanic) texture and the evidence for low-grade greenschist-facies metamorphism indicate that the so-called amphibolites of the Roc-Cervelle Unit have a quite distinct origin compared with those of the Les Essarts and Saint-Martin-des-Noyers units.

Sainte-Pazanne-Mervent tectonic lineament

This tectonic lineament was described by Godard (*in* Wyns *et al*., 1987) as representing a tilted overthrust of the Les Essarts eclogite-bearing Unit over the subautochthonous terrains of the West-Vendée Domain. This idea is no longer topical nowadays, since further fieldwork has shown that the so-called allochthonous unit is itself made of several units (see the previous section). Moreover, this lineament is subvertical almost everywhere and seems deep rooted. The lineament is picked out by mylonite and by the Saint-Martin-des-Noyers formation, which extends all along its southwestern side.

Following the line from Mervent (SE) to Sainte-Pazanne (NW), a progressive change in dip occurs from about 70° SW to 40° NE (see the sections in Fig. 2). Because of this shallow dip, the E-W-oriented Pointe-Saint-Gildas synform (Figs. 1 and 2) has a strong effect on the trace of the lineament which, near Sainte-Pazanne, turns towards the northeast, in the direction of Port-Saint-Père (Fig. 2). Here, the Vendée coal belt (Figs. 1 and 2) apparently intersects the lineament, but field evidence is not clear due to late faults and to the poor exposure. Such a relationship would indicate that the Vendée coal belt post-dated the Sainte-Pazanne-Mervent lineament, which would thus be of pre-Stephanian age.

Mylonite and ultramylonite, with a thickness of around 100 m, are exposed in a few places (e.g. 294.6-2232.4; 318.60-2208.56; 319.68-2207.67; 320.67-2206.45; 331.75-2198.13; 336.25-2195.65; 336.95-2195.94; 340.85-2190.75, 362.95-2173.50). The most remarkable of these localities are La Petite-Vallée (banks of the Petit-Lay river: 334.90-2196.65) and L'Orbrie (small quarry near Saint-Laurent-de-la-Salle: 349.50-2179.60) where a complete section of 150 m is visible across the Sainte-Pazanne-Mervent tectonic lineament (Fig. 6). Cataclased and mylonitized

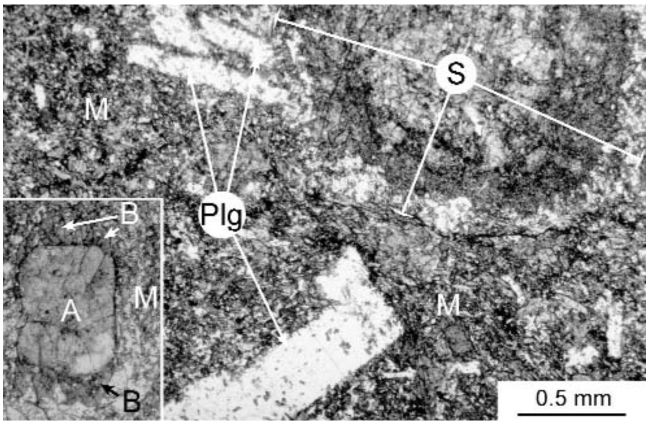


Fig. 5.- Metamorphosed porphyritic dolerite (or microdiorite) from the Roc-Cervelle Unit.
Pautay, near La Vildé, Saint-Philbert-du-Pont-Charrault (343.70-2189.76); plane-polarized light; A: actinolite after a euhedral phenocryst of clinopyroxene or amphibole; B: actinolite overgrowth over the same phenocryst; M: microcrystalline matrix of actinolite+pistacite+albite; Plg: albitized phenocrysts of plagioclase; S: pistacite-rich spherulite resulting from pseudomorphism or devitrification.

Fig. 5.- Metadolérite (ou méta-microdiorite) à structure porphyrique de l'Unité de Roc-Cervelle.
Moulin de Pautay, près de la Vildé en Saint-Philbert-du-Pont-Charrault (343.70-2189.76) ; lumière analysée ; A : actinote ayant remplacé un phénocristal automorphe de clinopyroxène ou d'amphibole ; B : surcroissance d'actinote sur le même phénocristal ; M : matrice microcristalline d'actinote, pistacite et albite ; Plg : phénocristaux albitisés de plagioclase ; S : sphérolite riche en pistacite résultant d'une pseudomorphose ou de dévitrification.

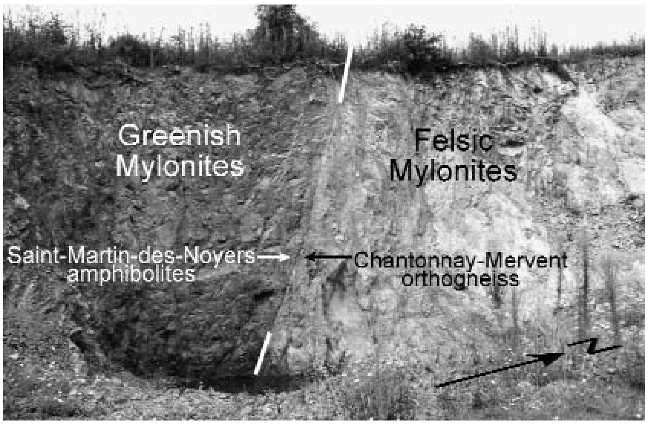


Fig. 6.- Sainte-Pazanne-Mervent tectonic lineament.
The small quarry of L'Orbrie, near Saint-Laurent-de-la-Salle (349.5-2179.6: see Fig. 2), shows a complete 150-m section across the Sainte-Pazanne-Mervent lineament, bringing mylonitized amphibolite (Saint-Martin-des-Noyers Unit) into contact with mylonitized gneiss (Chantonnay-Mervent orthogneiss).

Fig. 6.- Ligne tectonique Sainte-Pazanne-Mervent.
La petite carrière de L'Orbrie, près de Saint-Laurent-de-la-Salle (349.5-2179.6 : voir fig. 2), montre une coupe de 150 m de long à travers la ligne tectonique Sainte-Pazanne-Mervent. Celle-ci met en contact des amphibolites (unité de Saint-Martin-des-Noyers) et des gneiss (orthogneiss Chantonnay-Mervent) mylonitisés.

amphibolite of the Saint-Martin-des-Noyers Unit can also be seen at the northern edge of the Moulin d'Albert quarry (7 km northeast of Fontenay-le-Comte: 365.0-2171.7), which is only 100 m away from the lineament. A similar situation is observed in the disused quarry of Écoutard (364.3-2172.4) in the same region.

Saint-Martin-des-Noyers Unit

Geological setting

The Saint-Martin-des-Noyers Unit, which is mainly made up of amphibole-bearing rocks, extends along the southwestern side of the Sainte-Pazanne-Mervent lineament, between Port-Saint-Père (NW) and the Moulin d'Albert quarry near Fontenay-le-Comte (SE), where it disappears under the Jurassic cover. It appears again farther to the southwest, at the Rocher du Diable, close to the viaduct of the A10 motorway, near Saint-Maixent-l'École, owing to a window cut into the Jurassic cover by the L'Hermittain river (SE corner of Fig. 1; e.g. Rivière, 1839; Mathieu, 1942). While it extends over more than 200 km, its width ranges from a few tens of metres to about 3 km near Saint-Martin-des-Noyers. On the banks of the Loire River, near Paimbœuf (Fig. 1), an amphibolite-rich formation presents many similarities with the Saint-Martin-des-Noyers Unit, of which it could be an equivalent or a northwesterly extension. Similarly to the latter, it extends along the southwest edge of terrains that enclose eclogite and serpentinite lenses (Sem-en-Donges: Fig. 1).

Although the Saint-Martin-des-Noyers amphibolite does not contain any eclogite relics, it has long been confused with the neighbouring amphibolite and eclogite of the Les Essarts Unit (e.g. Mathieu, 1949; Ters, 1979). Godard (1981, 1988) distinguished and defined the Saint-Martin-des-Noyers Unit, which was further studied by Wyns (1984a), Thiéblemont *et al.* (1987, 1988), Thiéblemont (1988), Wyns *et al.* (1987) and Meidom (1991).

Petrology and geochemistry

For detailed information on geochemistry and petrology, the reader is referred to Thiéblemont *et al.* (1987, 1988). This unit contains a set of rocks corresponding to a tholeiitic magmatic suite, with compositions ranging from mafic to felsic and a concomitant increase in Fe/(Fe+Mg). Separate mapping of these rocks is not possible, however, because of the poor outcrop conditions and close intercalation of the various facies, which commonly alternate on the scale of a metre. The main minerals, whose abundances vary according to the chemical trend, are amphibole (actinolite to ferro-hornblende) + albite (Ab_{99}) + pistacite + chlorite (ripidolite) ± garnet (almandine-grossular) ± quartz ± sphene ± ilmenite (± pyrite ± chalcopyrite…).

Five rock-types have been distinguished, despite the existence of intermediate members between them (Thiéblemont *et al.*, 1987, 1988):

(a) The first member of the tholeiitic trend is a massive and homogeneous dark amphibolite of basaltic composition. Some relics of a doleritic structure are unevenly distributed and scarcely visible, with albite+pistacite aggregates occurring more-or-less as pseudomorphs after former magmatic plagioclase crystals that were probably labrador-andesine. This rock is visible in several quarries at Pont Charron near Chantonnay (341.1-

2189.5), and Les Loges near Mervent (362.0-2173.5). It also crops out along the Grand Lay river between Pont Charron and Moulin Neuf (Wyns, 1980).

(b) Garnet amphibolite has features intermediate between dark [(a)] and mesocratic [(c)] amphibolite and commonly occurs with them.

(c) In some mesocratic amphibolite, amphibole and chlorite are elongate in a microcrystalline matrix of quartz and albite with some millimetre-size garnet crystals. Thiéblemont *et al*. (1987, 1988) mentioned outcrops of these rocks in the Petit-Lay valley. This facies is also visible, together with the others, in the northern part of the Moulin d'Albert quarry (364.8-2171.6), near Fontenay-le-Comte.

(d) Leucocratic banded gneiss represents the most differentiated member of the tholeiitic suite, with a rhyolitic or sodic-dacitic composition. It is made up of garnet, amphibole, pistacite and ilmenite crystals scattered in a felsic, microcrystalline and granoblastic matrix. The rock is strongly banded with a centimetric-to-decimetric layering (S0) that has been transposed parallel to the foliation (S1-2). In some cases, we can observe millimetre-scale albite phenocrysts flattened parallel to the (010) crystallographic plane and twinned according to albite and Carlsbad laws. These crystals are most likely of magmatic origin, but their euhedral shape has been destroyed by deformation. The best outcrop of this rock is in a quarry located 1.5 km northwest of Saint-Hilaire-le-Vouhis (334.35-2194.75). This facies is also visible, as metre-thick layers, in the Petit-Lay valley near Saint-Hilaire-le-Vouhis, at Les Revêtissons near Chantonnay (railway cutting: 337.75-2191.75), at Le Châtaignier to the south of Chantonnay (Wyns, 1980) and at Corcoué-sur-Logne (303.0-2225.5).

(e) Some mica schist is included within the previous rock types and can be observed in a very few places (Belle-Vue near Corcoué-sur-Logne: 304.45-2223.75; Raballe: 325.0-2202.5; Gué-Joubert: 333.5-2195.5). It is composed of quartz, phengitic muscovite (e.g. Gué-Joubert: $Musc_{69}$ $Celad_{19}$ $Parag_{6}$), albite (Ab_{100}), a little chlorite and, in places, garnet and magnetite. Some garnet ± chloritoid mica schist described by Wyns (1984a, p. 30) could be ascribed to this facies.

Finally, the retrograde metamorphic evolution of the above facies is expressed by (i) the appearance of micro-exsolutions in amphibole due to a miscibility gap (Thiéblemont *et al*., 1988), (ii) chloritization of garnets and, more markedly, (iii) the development of ferri-stilpnomelane. Thus, many amphibolites were transformed into schistose amphibolites, to which stilpnomelane gives a typical green brownish colour. This retrograde facies is the most abundant of the whole formation (e.g. disused quarry of Passe-moi-l'eau near Saint-Laurent-de-la-Salle: 350.5-2178.2).

Petrogenesis

The physical conditions of the amphibolite-facies metamorphism were estimated by Thiéblemont *et al.* (1988) who proposed values of about 7 kbar at 470 to 550 °C, followed by a clockwise P-T path during retrograde metamorphism. These P-T conditions, typical of a medium-grade metamorphism, are clearly distinct from those that affected the neighbouring eclogite domain.

Wyns (1980) and Thiéblemont *et al.* (1987) have published various discriminant diagrams and rare-earth element patterns. They demonstrated that the range from mafic to felsic members corresponds to a tholeiitic magmatic differentiation. They proposed that the whole formation was derived from volcanic or hypovolcanic rocks that might have belonged to an island-arc or fore-arc system.

Structures

Two syn metamorphic foliations (i.e. S1 more-or-less transposed parallel to S2) have been observed in this unit (Wyns, 1980; Meidom, 1991). The magmatic layering (S0) was totally transposed parallel to the main foliation S2. The latter dips towards the southwest, and its mean strike is oblique relative to the average trend of the unit on a map (Dn in Fig. 4; Godard, 1981), indicating a strong dextral shear component. On the other hand, the L2 lineation is poorly defined (Fig. 4; see also Wyns, 1980). From the C2 shear planes, dextral displacements dominate over sinistral (Meidom, 1991).

Orthogneiss belt

Geological setting

An orthogneiss belt extends all along the western edge of the Les Essarts Complex (Figs. 1 and 2), between Chauvé (NW) and Moulin d'Albert (SE), where it disappears under Jurassic sediments. It appears again farther to the southeast, near Saint-Maixent-l'École, in the L'Hermittain valley (SE corner of Fig. 1). This eo-Variscan granite, which underwent Variscan regional metamorphism and deformation, is well exposed at several places such as, from northwest to southeast: L'Ennerie (269.9-2247.0), Pont-Berranger (284.2-2245.5), Sainte-Pazanne (284.5-2243.8), Les Airables (311.5-2215.4) and La Faubretière (330.20-2194.25) quarries; banks of the Petit-Lay (335.85-2191.30) and Grand-Lay (339.6-2189.7) rivers; railway cutting near L'Angle (336.90-2190.60); disused quarry near La Chapelle-Thémer (348.9-2178.65); base of the Mervent dam (360.8-2172.8); southern part of the Moulin d'Albert quarry (365.0-2171.4; Meidom, 1991).

Petrology

This orthogneiss strongly resembles the Chantonnay-Mervent orthogneiss (see above), and confusion frequently arose in the past between the two. Much of the orthogneiss has the composition of a sodi-potassic leucogranite, with relatively high contents of Si, K, Na and low contents of Ca, Fe, Mg (see analyses 1636-1638 in Wyns, 1980; Chalet, 1985; Table 2 in Wyns *et al*., 1987). These geochemical characteristics can be correlated with certain mineralogical features, such as an abundance of quartz and microcline, a commonness of K-feldspar augen, a scarcity of biotite and an alkali-rich composition of the original plagioclase.

Under the microscope, we can observe the following minerals:

(a) Quartz: long ribbons of quartz commonly recrystallized into granoblastic aggregates.

(b) Plagioclase: where the rock has been little deformed, the old magmatic plagioclase crystals are still recognisable and dotted with small blades of white mica ("damourite") and scarce rods of clinozoisite ("saussurite"). At L'Angle (336.90-2190.60), a reconstruction of the magmatic plagioclase before the exsolutions of mica and clinozoisite yields compositions close to anorthoclase (Ab_{90-85} Or_{10-15} An_{1-2}: Wyns *et al.*, 1987). Generally, deformation was intense enough to make the plagioclase recrystallize as long trails of a microcrystalline mosaic of almost pure albite, with minor interstitial "damourite".

(c) Microcline: old centimetre-scale K-feldspar phenocrysts were stretched during deformation. They show Carlsbad twinning and display well-developed perthite. At L'Angle, the compositions and relative proportions of the exsolved perthite (Ab_{98} $Or_1 An_1$; 15-20%) and host microcline (Or_{95} Ab_5; 75-80%) made it possible to reconstruct the K-feldspar composition before exsolution: Or_{80-75} Ab_{20-25}. During deformation, the K-feldspar of the matrix and the phenocryst rims recrystallized as non-perthitic millimetre-scale crystals of microcline (Or_{94} Ab_6). Applying the solid-solution models for alkali-feldspars (e.g. Fuhrman and Lindsley, 1988) to L'Angle metagranite, the reconstructed compositions of the coexisting magmatic plagioclase and K-feldspar indicate T of the order of 600-650 °C, while compositions of the two feldspars recrystallized during deformation have given inaccurate T estimates around 400 °C.

(d) Mica: biotite is not abundant, and is even absent in places. It is usually retrograded into chlorite. White mica is flattened parallel to the foliation and has a metamorphic origin. At L'Angle, it is a phengitic muscovite ($Musc_{56}$ $Celad_{38}$ $East_5$ $Parag_1$; Fe/[Fe+Mg] = 0.54). The equilibrium celadonite (*s.s.*) = muscovite (*s.s.*) + K-feldspar + biotite + quartz gives a P estimate close to 10 kbar (Wyns *et al.*, 1987).

(e) Other minerals: garnet, a grossular-almandine (e.g. $Gross_{56}$ Alm_{42} $Spess_1$ Pyr_1), occurs as small but common crystals. Though they have a metamorphic origin, they do not show any clear reaction structure, such as coronas around biotite. Clinozoisite, zircon, sphene, myrmekite are commonly observed.

A metamorphic paragenesis (recrystallized microcline and albite, quartz, phengitic muscovite and minor epidote) partly replaced the magmatic association during deformation. The moderate-P-T conditions of this metamorphism (see (c) and (d)) could be compatible with those of the Saint-Martin-des-Noyers amphibolite (see above), but are far removed from the high-P conditions that prevailed in the eclogite-bearing unit, from which the orthogneiss is isolated by the Sainte-Pazanne-Mervent tectonic lineament.

Structures

The orthogneiss is coarse grained with a strong foliation (S1-2, i.e. S1 transposed parallel to S2) and a less obvious stretching lineation (L2). The average foliation dips southwestward, whereas lineation is almost horizontal (Dn *in* Fig. 4). Because the intensity of the deformation was heterogeneous, strongly deformed rocks occur alongside weakly deformed rocks. At one locality (328.30-2197.25), the rock is even totally non-deformed. Deformation produced a strong petrofabric with a clear preferred orientation of white micas flattened parallel to S1-2. The quartz crystals of the granitic protolith have been stretched into long ribbons with many subgrain boundaries and a preferred orientation of the [c] axes more-or-less normal to S1-2. These quartz bands commonly recrystallized, forming aggregates with a granoblastic texture. The dextral shearing component is strongly expressed by the shape of the orthogneiss apophyses of the southwestern edge that are systematically stretched towards the northwest (Fig. 2). Meidom (1991) has given some other details on the structure of the southeastern part of the orthogneiss belt.

Intrusive relationship with the West-Vendée Domain

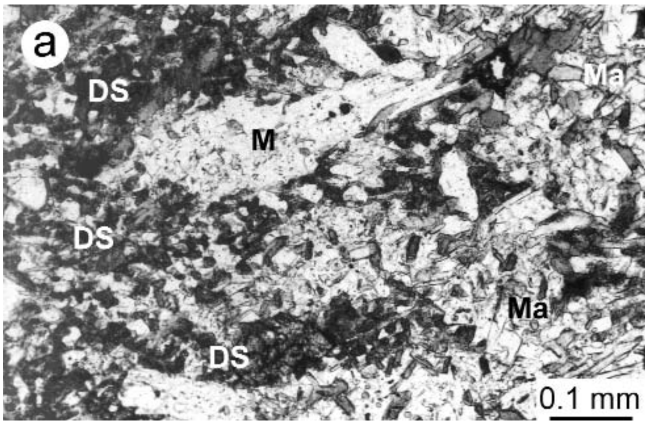
Several features of the southwestern edge of the orthogneiss belt indicate that the granite protolith was intrusive into the Palaeozoic formations of the West-Vendée Domain. The orthogneiss shows apophyses stretched in the Palaeozoic mica schist and, reciprocally, mica schist is enclosed and elongated within the orthogneiss (Fig. 2). Phthanite, similar to that occurring in the West-Vendée Domain, is observed within one enclave (325.55-2197.75). There is also some evidence of contact metamorphism in the mica schist at the contacts with the orthogneiss, producing hornfels and spotted schist that were further deformed during metamorphism and deformation.

Enclaves of metamorphosed hornfels within the orthogneiss can be well observed in outcrops near La Merlatière (321.35-2204.20; 321.35-2203.95; 324.15-2201.05; 325.25-2200.40; 325.40-2199.85) and Saint-Sulpice-le-Verdon (314.1-2214.2). The hornfels is fine grained, light grey and commonly dotted with dark spots a few millimetres in size. These spots were originally equant and have been slightly foliated together with the surrounding orthogneiss. This slight foliation is picked out by secondary white mica lamellae. Under the microscope (Fig. 7a), we observe a microcrystalline and almost equant matrix composed of quartz, biotite and plagioclase (albite-oligoclase). The dark spots are linked to the presence of a brownish garnet-bearing cryptocrystalline felting that probably replaced cordierite. The late-stage white mica growing parallel to the incipient foliation is a sodic muscovite (e.g. $Musc_{74}$ $Parag_{13}$ $Celad_8$ $East_5$). It forms poikiloblastic millimetric blades that enclose other minerals, mainly quartz (Fig. 7a).

Apart from hornfels, the paleo-granite intrusion produced a contact aureole made up of spotted mica schist. A few hundred metres from the southwestern edge of the orthogneiss, brownish spots appear in the enclosing mica schist (e.g. railway cutting at L'Angle: 336.90-2190.60; Boulogne valley near Saint-Denis-la-Chevasse: 317.13-2210.53; Le Pas Clavier near Saint-Lumine-de-Coutais: 289.80-2236.15). These spots are chlorite-bearing pseudomorphs of biotite (with a flattened shape) or garnet (globular shape: Fig. 7b). Another non-identified prismatic mineral has resulted in rod-shaped pseudomorphs (e.g. 329.95-2194.05). The protominerals were produced by contact metamorphism and replaced by chlorite after temperature relaxation. Because their original shapes are preserved, the replacement likely occurred after deformation.

Relationship with the Saint-Martin-des-Noyers Unit

The northeastern contact between the orthogneiss and the amphibolite-bearing formation of Saint-Martin-des-Noyers is apparently not intrusive. This boundary is rectilinear, with no orthogneiss apophyses



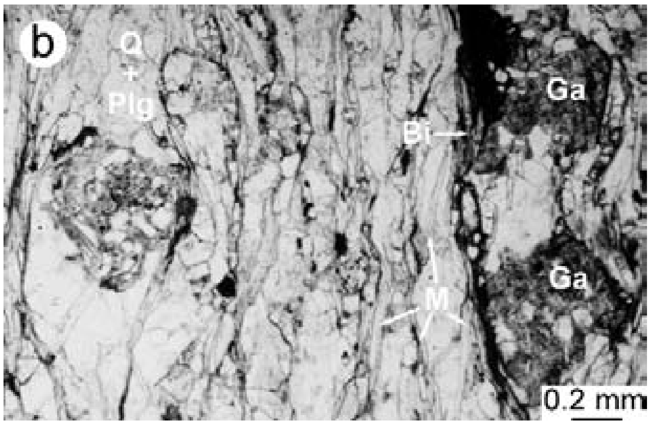


Fig. 7.- Contact metamorphism at the southwestern edge of the orthogneiss belt.
a) Metamorphosed hornfels. 321.35-2203.95; plane-polarized light. Ma: almost equant matrix of biotite (grey), quartz and plagioclase (white); DS: garnet-bearing cryptocrystalline felting that probably replaces cordierite spots (i.e. the "spotted schists" structure); M: poikiloblastic white mica.
b) Mica schist. 317.13-2210.53; plane-polarized light. Q+Plg: matrix of quartz+plagioclase; M: muscovite; Bi: chloritized biotite; Ga: chloritized garnet.

Fig. 7.- Métamorphisme de contact sur la bordure sud-ouest de la ceinture d'orthogneiss.
a) Métacornéenne. 321.35-2203.95 ; lumière non analysée. Ma : matrice microcristalline et quasi-équante à biotite (gris), quartz et plagioclase (blanc) ; DS : feutrage cryptocristallin à grenat ayant vraisemblablement remplacé de la cordiérite en tache (i.e. structure de "schistes tachetés") après le métamorphisme de contact ; M : mica blanc poecilitique.
b) Micaschistes à blastes. 317.13-2210.53 ; lumière non analysée. Q+Plg : matrice à quartz+plagioclase ; M : muscovite ; Bi : blaste de biotite chloritisé ; Ga : blaste de grenat chloritisé.

intruding the amphibolite, and no amphibolite enclaves included within the orthogneiss. In addition, there is no trace of contact metamorphism. Therefore, this contact should have a tectonic origin. However, we find no post-metamorphic mylonite comparable with that of the Sainte-Pazanne-Mervent lineament, and the tectonic juxtaposition of the two formations must have occurred before or during the metamorphism of the protoliths to form the gneiss. This contact is well exposed in the Moulin d'Albert quarry, where a 30 m-thick vertical band of mica schist separates the orthogneiss from the Saint-Martin-des-Noyers amphibolite (see Fig. 1-2 in Meidom, 1991).

West-Vendée Domain

The above orthogneiss belt actually belongs to the West-Vendée Domain, since the metagranite is intrusive into it. The tectonic and metamorphic history of this domain is primarily eo-Variscan, involving the stacking of structural units affected by tangential tectonism with a westerly transport direction (e.g. Burg, 1981; Burg *et al*., 1987). It is mainly composed of acid metavolcanic rocks (porphyroids) and metasediments intruded by late-Variscan granite. A detailed description of this domain is beyond the scope of this work, and the reader is referred to the following studies: Talbert (1971); Stussi (1976); Burg (1981); Maillet (1984); Chalet *et al*. (1983); Chalet (1985); Wyns *et al*. (1987); Meidom (1991); Goujou (1992); Ballèvre *et al*. (1994). Among the various units of this domain, we should draw attention to the Bois-de-Cené blueschist-bearing Unit (Anthonioz and Brillanceau, 1969; Guiraud *et al*., 1987; Triboulet, 1991). As a southeastern equivalent of the well-known Île de Groix blueschist, it is considered in the literature as one of the numerous candidates for the Variscan suture zone.

Sedimentary cover

Superficial sediments obscure parts of the studied area. Jurassic limestone is preserved in a collapsed zone (Chantonnay Basin) located along a Cenozoic normal fault known as the Chantonnay Fault (Fig. 2), which reactivated the Variscan tectonic lineament of the Vendée coal belt. Ypresian (Early Eocene) deltaic sediments are common in the northwestern part of the area (Godard *et al.*, 1994). During the Eocene, tropical weathering affected the rocks down to a depth of about 10 m. Weathering commonly involves the eclogite, amphibolite and, most of all, the gneiss, especially where it is close to the Ypresian palaeosurface (e.g. Fig. 10 in the pocket on inside back cover). Finally, Pliocene "faluns" and Quaternary sediments occur in the Grand-Lieu area.

Les Essarts high-pressure Unit: Eclogite and related rocks

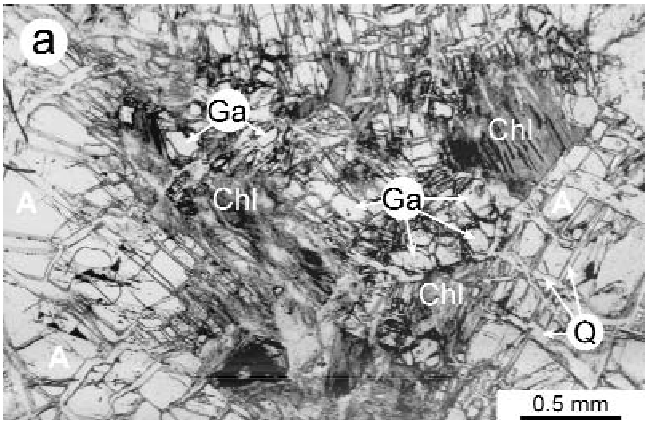
This section not only concerns the eclogite, but also other rocks that are derived from eclogite (i.e. amphibolite) or that are closely associated with eclogite in the same lenses (silicified serpentinite, ortho-leptynite derived from plagiogranite). After a description of the various rock types, we present the various stages of their evolution, from the protoliths, through the pre-eclogite and eclogite metamorphic stages, to retrograde metamorphism.

Rock types

The eclogite and associated rocks form several-kilometre-long lenses that are stretched and slightly boudinaged within the surrounding gneiss (Figs. 2 and 10). These lenses, elongated parallel to the foliation and almost vertical, are composed of silicified serpentinite (1.5%), eclogite (10.5%), amphibolite derived from eclogite (79.0%) and ortho-leptynite (9.0%).

Silicified serpentinite (birbirite)

Some altered, silicified peridotite (Fig. 2) is associated with the eclogite and amphibolite (e.g. 289.7-2243.3; 308.9-2223.4), whereas others occur as indepen-



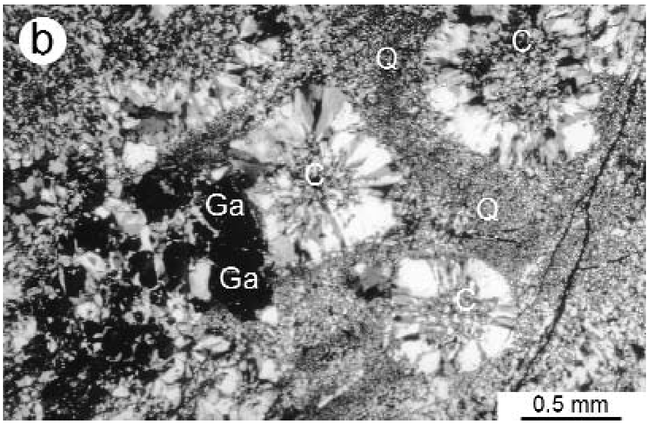


Fig. 8.- Silicified ultramafic rock (birbirites) with garnet relics.
Moulin des Pouzinières (302.0-2231.5), near Saint-Colomban.
a) Garnet-bearing anthophyllite rock. plane-polarized light; A: anthophyllite; Ga: garnet relics; Chl: chlorite corona around garnet; Q: microveins of quartz and chalcedony, resulting from an incipient birbiritization.
b) Birbirite (silicified ultramafic rock). cross-polarized light; Q: microcrystalline quartz; C: spherulites of chalcedony; Ga: garnet relics.

Fig. 8.- Roches ultramafites silicifiées (birbirites) à reliques de grenat.
Moulin des Pouzinières (302.0-2231.5), près de Saint-Colomban.
a) Roche à anthophyllite et reliques de grenat. Lumière non analysée ; A : anthophyllite ; Ga : reliques de grenat ; Chl : couronne de chlorite autour du grenat ; Q : micro-veines de quartz et de calcédoine, résultant d'un début de "birbiritisation".
b) Birbirite (ultramafite silicifiée). Lumière analysée ; Q : quartz microcristallin ; C : sphérolites de calcédoine ; Ga : reliques de grenat.

dent lenses (288.2-2243.1; 288.1-2238.5; 298.25-2232.40; 298.75-2232.55; 300.55-2231.85; 300.8-2231.2; 302.0-2231.5; 302.15-2230.30; 304.8-2228.3; 305.18-2225.85; 310.80-2219.45; 311.18-2219.25). This former peridotite was totally serpentinized and silicified, and thus transformed into "birbirite". Birbirite is a brownish, iron-bearing, quartzitic rock named by Duparc *et al.* (1927). It is characterized by colloform textures in which chalcedony and fine quartz crystals occur alongside colloform masses of limonite. It results from alteration, hydration and Mg-leaching of peridotite or serpentinite during weathering (e.g. Augustithis, 1965, 1967; Plyusnina *et al*., 1983). In the Vendée, birbiritization likely occurred during the Palaeogene, a period of tropical weathering in this region. The ultramafic protolith can be recognized in the form of a few rare mineral relics (serpentine, anthophyllite, fuschite: e.g. 302.0-2231.5; 305.18-2225.85; 308.9-2223.4; 311.18-2219.25). Baret (1905) mentioned talc at L'Aujardière near Saint-Philbert-de-Grand-Lieu. A snakeskin (*peau-de-serpent*) cellular structure is preserved in places, resulting from the pseudomorphism of olivine grains (e.g. 298.25-2232.40; 300.55-2231.85; 311.18-2219.25).

Near Moulin des Pouzinières (302.0-2231.5), 800 m to the north of Saint-Colomban, some loose blocks of an ultramafic rock essentially made up of anthophyllite (Fig. 8b; X_{Mg} = 0.85) occur among the birbirite. They contain relics of garnet (Fig. 8; Pyr_{54} Alm_{33} $Gross_7$ $Spess_2$ $Uvar_2$ $Andr_2$) that is partly replaced by a kelyphitic corona of chlorite (penninite: Fig. 8a). Although proper P-T estimates are not possible due to the high degree of retrograde metamorphism, we can infer that the rock likely derived from an eclogite-facies garnet-bearing pyroxenite or peridotite.

Eclogite

The Vendée eclogite has been described in detail elsewhere (e.g. Godard, 1988). This section, therefore, merely presents a synthesis of previous work. For the sake of convenience, a distinction is made between four varieties of eclogite, ranging from the magnesian to the ferrous end-members of the differentiation trend:

(a) Mg-rich kyanite-bearing quartz-free eclogite: the light-green clinopyroxene [Cpx] matrix of this eclogite is studded with pink garnet crystals, whose size can reach several centimetres. Kyanite, zoisite and syn-eclogite light-coloured amphibole are also abundant. The two main occurrences of this beautiful rock are at La Compointrie (Fig. 9; 295.38-2234.07; 295.10-2234.15), discovered by Baret (1900), and Saint-Denis-la-Chevasse (318.0-2209.5; abandoned quarry: 317.75-2209.70). Loose blocks also exist in some other small occurrences (307.00-2225.05; 306.20-2224.55; 308.90-2223.05; 313.20-2216.90).

(b) Kyanite-bearing quartz-poor eclogite: this type of eclogite commonly occurs together with the previous one. It was abundant in the former Pied Pain quarry (295.55-2233.30), and metre-thick bands of such eclogite exist in the La Gerbaudière quarry. Its petrological features are intermediate between the quartz-free [(a)] and kyanite-free [(c)] eclogite.

(c) Quartz-bearing eclogite: this is the most abundant variety as it accounts for more than 95% by outcrop area of all the eclogite. The best outcrops are the two quarries of La Gerbaudière near Saint-Philbert-de-Bouaine (305.8-2227.8; 305.4-2227.6; Figs. 10 and 11). This variety is also visible in old small disused quarries: 308.24-2225.03; 304.63-2230.30; 301.65-2230.45; 299.95-2231.30. The rock contains garnet crystals, commonly subhedral with an average size of 0.4 cm, set in a foliated matrix consisting of quartz and mainly omphacite. Dark syn-eclogite-facies amphiboles delineate trails parallel to the syn-eclogite foliation. Zoisite, clinozoisite, rutile, ilmenite, sulphides and calcite (possibly former aragonite) are accessory minerals.

(d) Ferro-titanian quartz-bearing eclogite: the omphacite of this eclogite has an unusually dark-green colour, and the garnet is bright red. These distinctive colours, still visible in thin section, are due to the high Fe-content of the minerals. Moreover, we observe a relatively high abundance of rutile, as much as 4 vol.%. This ferro-titanian eclogite mainly occurs near Rocheservière (306.50-2225.00; 308.45-2224.15), Boulogne (320.85-2207.90; 322.00-2207.05), and at other minor localities (e.g. 317.82-2209.45; 313.15-2219.00). It could account for about 2 to 3% of the Vendée eclogite.

Other atypical varieties of negligible volume occur sporadically within the eclogite, corresponding either to peculiar compositions or origins: centimetre-thick layers of garnet + quartz (+ rutile) ; quartz+kyanite-rich eclogite with abundant zircon (La Gerbaudière); fine-grained eclogite with microscopic atoll garnets (e.g. sample H6 *in* Godard, 1988) belonging to the “Le Cellier” facies, common in the Champtoceaux complex (see Brière, 1920; Godard, 1988). Finally, some centimetre-thick veins are made up of quartz + phengitic muscovite (La Gerbaudière), quartz + kyanite ± rutile (La Gerbaudière; Saint-Denis-la-Chevasse: Brière, 1920), quartz + zoisite (Pied Pain: Baret, 1882; Brière, 1920), or calcite (La Teurdeau: 301.65-2230.45). They presumably resulted from fluid mobility during the high-P metamorphism, since they are parallel to the syn-eclogite foliation and their minerals were partly retrograded during the post-eclogite metamorphism.

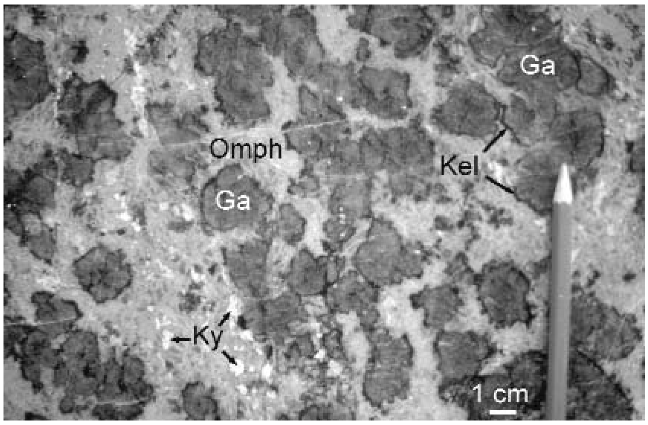


Fig. 9.- Mg-rich kyanite eclogite.
The kyanite eclogite of La Compointrie (295.38-2234.07), Saint-Philbert-de-Grand-Lieu. Ga: pyrope-rich pink garnet; Omph: matrix of omphacite (+ zoisite + magnesio-hornblende); Ky: kyanite partly replaced by pseudomorph; Kel: late amphibole coronas at the contact between garnet and omphacite (i.e. kelyphite).

Fig. 9.- Eclogite magnésienne à disthène.
Éclogite à disthène de La Compointrie (295.38-2234.07), Saint-Philbert-de-Grand-Lieu. Ga : grenat rose riche en pyrope ; Omph : matrice à omphacite (+ zoïsite + magnesio-hornblende) ; Ky : disthène partiellement pseudomorphosé ; Kel : couronne d’amphibole secondaire à l’interface entre grenat et omphacite (i.e. kélyphite).

Ortho-leptynite derived from plagiogranite

These leucocratic and banded rocks are commonly interlayered with eclogite and amphibolite (Fig. 12a). They mainly occur near La Limouzinière, Corcoué-sur-Logne and to the west of Grand-Lieu Lake (“keratophyre” of Ters, 1979). Outcrops can be seen near La Limouzinière and Corcoué-sur-Logne (e.g. 299.95-2228.55; 301.52-2228.65 and disused quarries nearby; 304.1-2227.5; 302.37-2226.30). Decimetre-thick bands of this rock within eclogite are also visible as blocks in the walls of La Brosse house and in vineyards nearby (south of Saint-Philbert-de-Bouaine: 306.5-2226.0).

Millimetre-scale grains of garnet and amphibole, which account for less than 20% of the rock volume, occur in a quartz + plagioclase matrix (Fig. 12b). The strongly banded structure is due to variations in mineral proportions and sizes on the scale of a few centimetres. Small layers of coarse quartz and plagioclase resemble leucosomes and could have resulted from partial fusion. This strong layering (S0) was transposed parallel to the foliation (S1), which is hardly visible because of the lack of phyllosilicates. These structures are parallel to those in the host eclogite and amphibolite.

Under the microscope (Fig. 12b), quartz and plagioclase display an isogranular structure, without any clear preferred orientation. Oligoclase (e.g. An_{12} $Or_{0.3}$ $Ab_{87.7}$) is abundant, but K-feldspar has nowhere been observed. Garnet (e.g. Alm_{63} Pyr_{10} $Gross_{26}$ $Spess_{1}$) is xenomorphic and encloses numerous inclusions. Amphibole, a ferro-tschermakitic hornblende, occurs as dots of less than a millimetre scattered in the rock; it also exists as irregular coronas around garnet. Micrograins of epidote are common. Biotite, rutile, ilmenite, sphene and apatite are observed as accessory minerals.

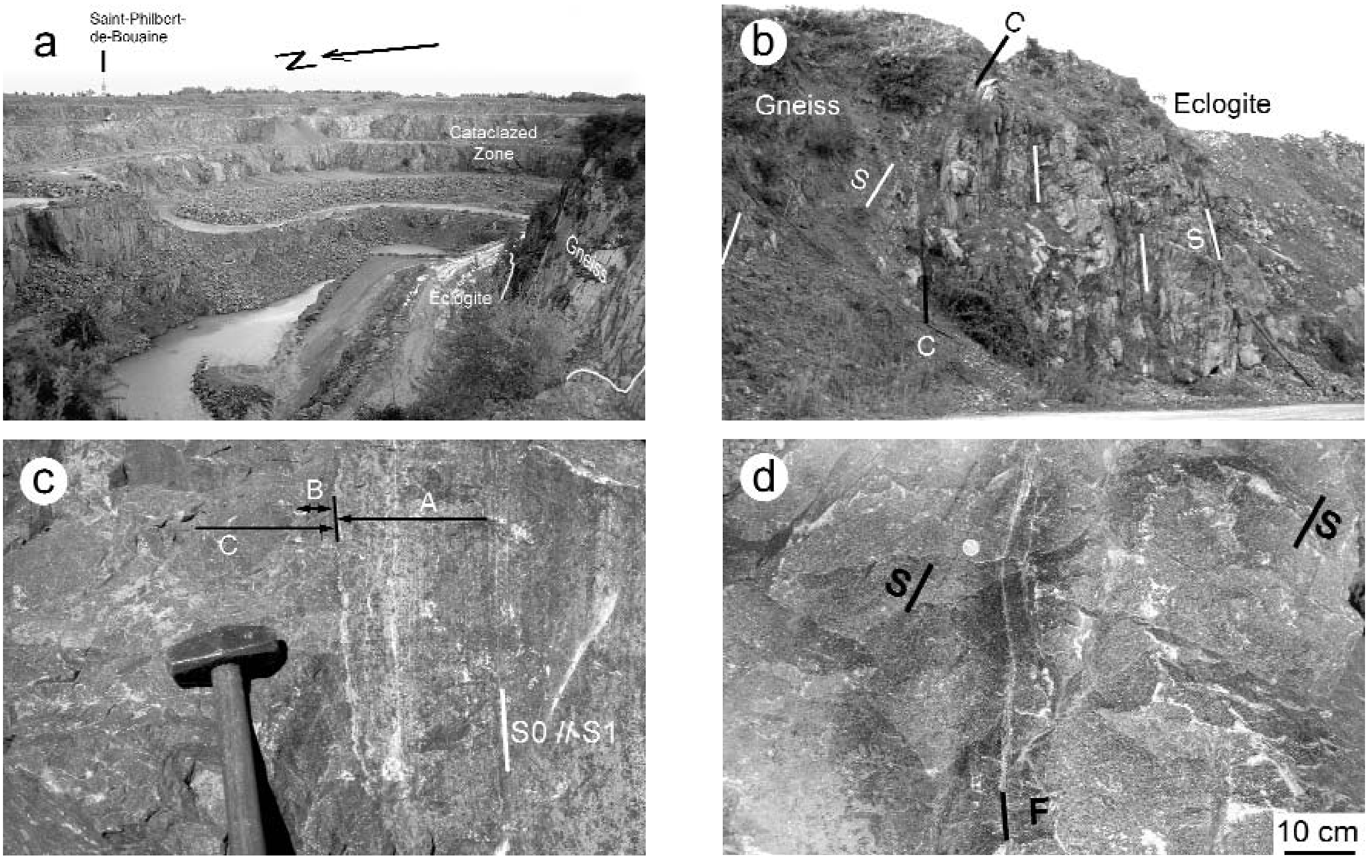
These rocks are closely associated with eclogite and related amphibolite. They have the composition of a plagiogranite and could represent the ultimate differentiates in the tholeiitic suite that also produced the eclogite protolith (see below). However, they do not show evidence of high-P metamorphism (see discussion on p. 39).

Amphibolite

Around 90% of the eclogite has been retrograded into amphibolite, and all intermediate members exist between these two rock types which one finds associated in the same occurrences. Most of the amphibolite is made up of green hornblende + plagioclase + garnet (0.3 mm in size, on average) ± zoisite ± quartz ± sphene. Relics of the former eclogite paragenesis are not rare: rutile partly transformed into sphene; Cpx+plagioclase and amphibole+plagioclase symplectites after omphacite; corroded garnet crystals. In a few places, zoisite is concentrated in millimetre-size clusters that could be pseudomorphs after kyanite (e.g. 282.2-2231.6; 297.65-2231.45). Finally, where retrograde metamorphism was extensive, the resulting amphibolite recrystallized into a paragenesis of green hornblende + plagioclase ± zoisite, without eclogite-facies relics.

Protoliths

The bulk compositions of the Vendée eclogite show that the gabbroic protoliths



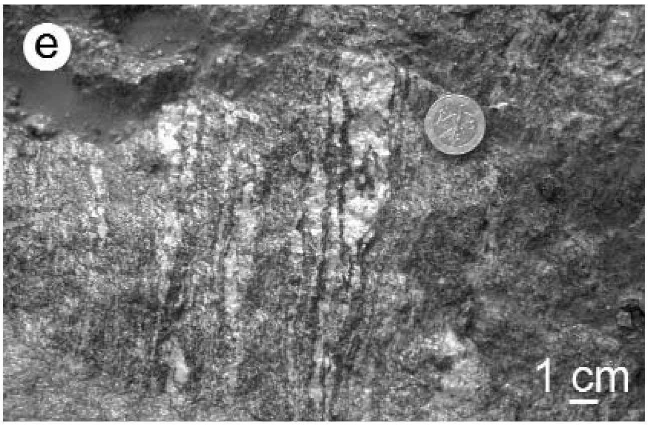


Fig. 11.- La Gerbaudière quarry (Saint-Philbert-de-Bouaine).
a) General view from the northwest. The quarry is elongate parallel to the eclogite lens; foliations are subvertical.
b) Contact (C) between gneiss and eclogite, at the northwestern corner of the quarry. S: foliation in the gneiss and eclogite.
c) Compositional layering (S0) in the eclogite. A: coarse-grained banded eclogite; B: fine-grained garnet-rich eclogite; C: fine-grained massive eclogite; B resembles a "chilled margin" structure that could be inherited from the pre-eclogite rock; the layering (S0) was transposed parallel to the syn-eclogite-facies foliation (S1).
d) Amphibolitization (dark zone) occurring along a late fracture (F) cutting across the syn-eclogite-facies foliation (S).
e) Migmatitic paragneiss interleaved within the eclogite. Leucosomes are parallel to foliations in the gneiss and surrounding eclogite. Incipient migmatization seems to have occurred after the eclogite-facies metamorphism.

Fig. 11 - Carrière de La Gerbaudière (Saint-Philbert-de-Bouaine).
a) Vue générale depuis le nord-ouest. La carrière est allongée parallèlement à la lentille d'éclogite ; les foliations sont sub-verticales.
b) Contact (C) entre gneiss et éclogite, dans le coin nord-ouest de la carrière. S : foliation dans le gneiss et l'éclogite.
c) Structure rubanée (S0) dans l'éclogite. A : éclogite rubanée à grain grossier ; B : ruban d'éclogite à grain fin, riche en grenat ; C : éclogite massive à grain fin; le niveau B évoque une structure de "bordure figée" héritée de la roche anté-éclogitique ; le rubanement (S0) a été transposé parallèlement à la foliation syn-éclogitique (S1).
d) Zone sombre riche en amphibole s'étant développée à partir d'une fracture tardive (F) séquante sur la foliation syn-éclogitique (S).
e) Paragneiss migmatitique intercalé dans l'éclogite. Les leucosomes sont parallèles aux foliations du gneiss et de l'éclogite encaissante. La migmatisation semble s'être produite après le métamorphisme éclogitique.

belonged to a tholeiitic suite, as indicated by a strong increase in the Fe/(Fe+Mn+Mg) ratio and a Ti enrichment correlated with differentiation (Fig. 8.8 and Table A.8.2.1 *in* Godard, 1988). Leaving aside the amphibolite derived from eclogite, the above rock types correspond to different stages in the differentiation trend:

(a) Altered peridotite (birbirite: see above) could possibly represent ultramafic cumulates in the magmatic suite, but it could also have a mantle origin.

(b) The least differentiated eclogite in the compositional trend is Mg-rich kyanite eclogite ("Eclogite" section above, [(a)] and [(b)] with the chemical characteristics of cumulates. Its gabbroic C.I.P.W. norms, converted into modal percentages of minerals (Godard, 1988), indicate that it was derived from Mg-rich troctolitic leucogabbro that cumulated at the plagioclase [An_{62}] + diopside + olivine cotectic stage, and whose composition is close to the

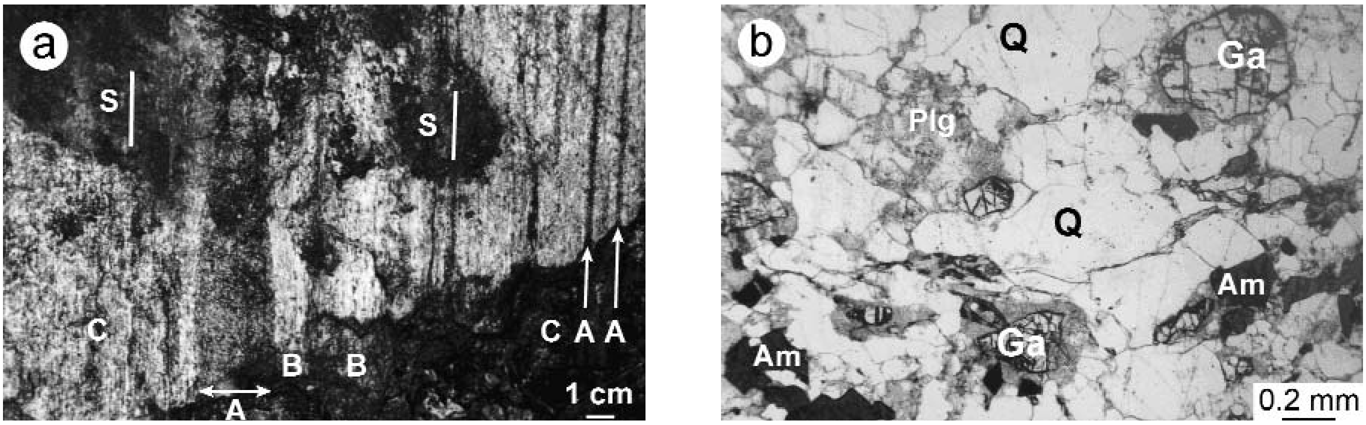


Fig. 12.- Banded ortho-leptynite.
The banded leptynite is interlayered with eclogite and derives from plagiogranite (see text).
a) Banded leptynite. Corcoué-sur-Logne (302.45-2226.16); A: amphibolite bands derived from eclogite; B: felsic leptynite; C: garnet and amphibole-bearing mesocratic leptynite; S: compositional layering transposed parallel to the foliation.
b) Leptynite. La Brosse (306.5-2226.0), near Saint-Philbert-de-Bouaine; plane-polarized light; Ga: garnet; Plg: plagioclase; Q: quartz; Am: green amphibole.

Fig. 12.- Ortho-leptynites rubanées.
Ces leptynites sont intercalées avec des éclogites et dérivent de plagiogranite (voir texte).
a) Leptynite rubanée. Corcoué-sur-Logne (302.45-2226.16) ; A : rubans d'amphibolite dérivant d'éclogite ; B : rubans felsiques ; C : leptynite mésocrate à amphibole et grenat ; S : rubanement transposé parallèlement à la foliation.
b) Leptynite. La Brosse (306.5-2226.0), près de Saint-Philbert-de-Bouaine ; lumière non analysée ; Ga : grenat ; Plg : plagioclase ; Q : quartz ; Am: amphibole.

critical plane of silica undersaturation. It is rich in Cr and Ni (up to 1180 ppm and 200 ppm, respectively: Godard, 1988), and has a low REE abundance and a positive Eu anomaly (Eu/Eu* = 1.76: Bernard-Griffiths and Cornichet, 1985), which support a cumulate origin.

(c) The typical rock type of the tholeiitic trend, by far the most abundant, is quartz-bearing eclogite ("Eclogite" section, [(c)], which, according to its norms, was derived from olivine gabbronorite. The gabbroic protolith was layered since an inherited compositional layering (S0) can quite commonly be observed in this eclogite (Fig. 11c). Its REE distribution patterns are identical to those of N-type Mid-Oceanic-Ridge-Basalt [MORB], and show a slight negative Eu anomaly (Eu/Eu*=0.9-1.0) (Montigny and Allègre, 1974; Bernard-Griffiths and Cornichet, 1985; Godard, 1988). MORB-normalized trace-element patterns also support the relationship with MORB (Fig. 8.5 *in* Godard, 1988).

(d) The most evolved eclogite in the trend is the ferro-titanian eclogite ("Eclogite" section, [(d)]. It is Ti- and V-rich (e.g. 4.20 wt.% TiO_2; 986 ppm V: sample H49 *in* Godard, 1988), shows a high Fe/(Fe+Mg) ratio, and is enriched in REE, particularly LREE (Bernard-Griffiths and Cornichet, 1985).

(e) The ortho-leptynite intercalated within the eclogite has the composition of plagiogranite: high SiO_2-content (around 65 wt.%); low FeO+MgO (about 10 wt.%) and very low K_2O-content (<1%). It could represent even more evolved rocks in the tholeiitic differentiation trend.

The geochemical features of the eclogite and related rocks clearly indicate a tholeiitic differentiation of their protoliths. Moreover, the most abundant eclogite type, namely the quartz-bearing variety, accounting for more than 90% of all the eclogite, exhibits the geochemical characteristics of MORB. Several authors have proposed that this eclogite might represent fragments of a metamorphosed old oceanic crust (Montigny and Allègre, 1974; Godard, 1981, 1983, 1988; Bernard-Griffiths and Cornichet, 1985; Thiéblemont, pers. comm.).

Pre-eclogite metamorphism: oceanic metamorphism?

The pre-eclogite paragenesis: an amphibolitized gabbro

Garnet crystals in the eclogite are poikiloblastic. They enclosed numerous mineral inclusions during their growth, i.e. during eclogite formation. These inclusions consist mainly of quartz, zoisite (or clinozoisite), amphibole, rutile, and seldom clinopyroxene, calcite, plagioclase and K-feldspar. The included minerals could represent either by-products of the eclogite formation process, or pre-eclogite minerals enclosed in garnet during its growth. Zoisite and amphibole, for example, likely belong to a pre- or early-eclogite paragenesis, since, in many cases, they are present as inclusions in garnet but have disappeared from the matrix. On the other hand, quartz and rutile are typical eclogite minerals, and likely appeared during eclogite formation.

Two distinct groups of inclusions are ordinarily observed in garnet (Fig. 13a):

(a) Zoisite-bearing rutile-free zones: rods of zoisite (occasionally clinozoisite) are concentrated in zones that also contain quartz, but which lack amphibole and rutile (Fig. 13a). These zones display regular shapes. In places, zoisite is preferentially concentrated at their core (Fig. 13a).

(b) Rutile-bearing zoisite-free zones: large numbers of hair-like rodlets of rutile are concentrated, together with rutile grains, in "dusty clouds" that display clear outlines. Only clearly visible under the microscope at high magnification, the rodlets lie in parallel orientations that correspond to crystallographic axes of the

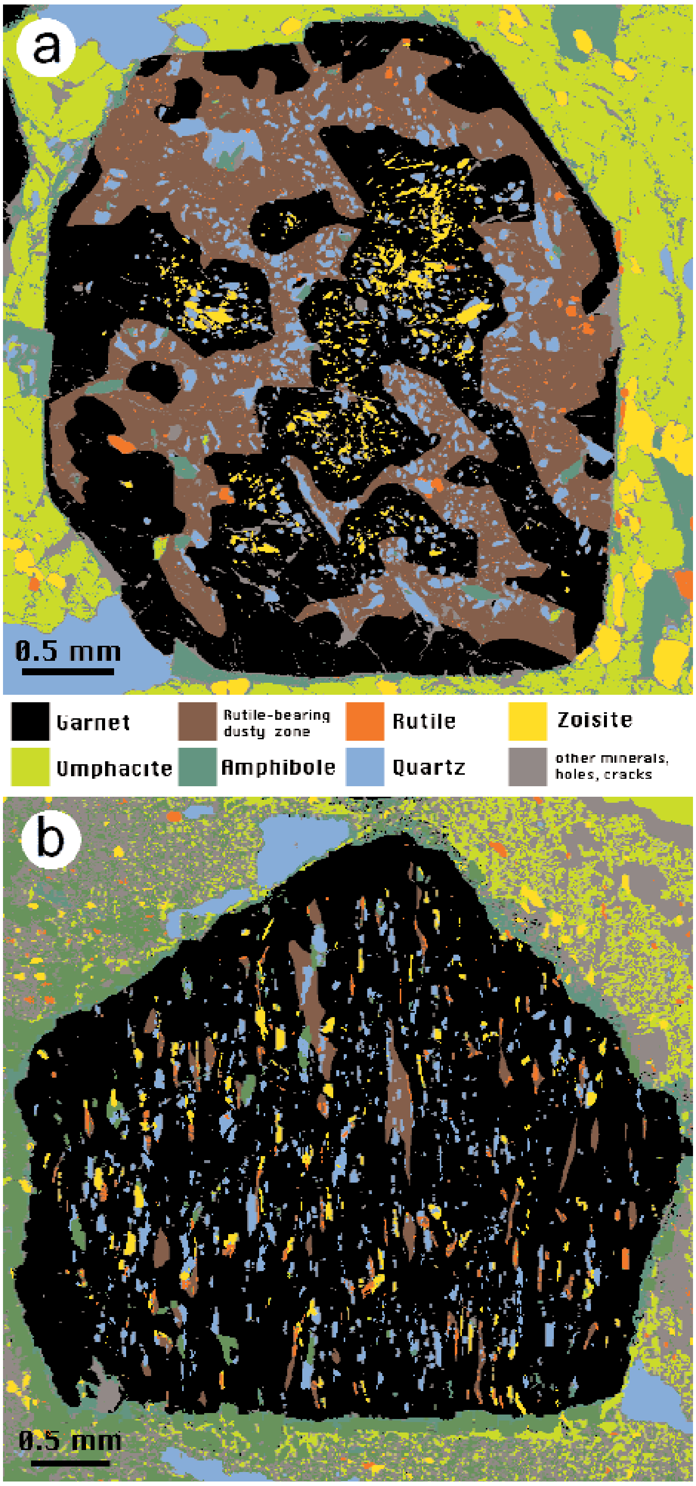


Fig. 13.- Relics of pre-eclogite metamorphosed gabbro.
(a)- Mineral inclusions in a single garnet crystal preserve the ophitic structure of the pre-eclogite gabbro. They show that the latter was amphibolitized and saussuritized (see text); 306.97-2224.95.
(b)- In a few samples, the same inclusions define well-arranged linear trails that are relics of a pre- or eo-eclogite foliation (see text); 310.75-2222.87.
The images were produced by multispectral image analysis of X-ray element maps obtained using a scanning electron microscope.

Fig. 13.- Reliques du métagabbro anté-éclogitique.
(a)- Les inclusions minérales contenues dans un même cristal de grenat ont conservé la structure ophitique du métagabbro anté-éclogitique. Elles montrent que ce dernier était amphibolitisé et saussuritisé (voir texte) ; 306.97-2224.95.
(b)- Dans quelques échantillons, ces mêmes inclusions dessinent des alignements qui sont les reliques d'une foliation anté- ou éo-éclogitique (voir texte) ; 310.75-2222.87.
Les images ont été générées par analyse d'images multispectrale de cartes d'éléments chimiques obtenues au microscope électronique à balayage.

host garnet (Fig. 14). Quartz and less-abundant amphibole are also present in these zones. The amphibole composition (pargasitic hornblende or ferroan pargasite) is richer in Fe than the syn-eclogite amphibole of the matrix. In a few samples, we can also observe omphacite, which seems restricted to garnet rims, whereas amphibole occurs in the cores of the same garnet crystals (Fig. 13a). This indicates that omphacite most likely replaced amphibole during garnet growth.

The zoisite-rich and rutile-rich zones commonly show sharp and regular boundaries that resemble the ophitic texture of a gabbroic rock (Fig. 13a). This suggests that the zoisite- and rutile-rich zones are pseudomorphs after the felsic and mafic parts of the pre-eclogite rock, respectively. Zoisite-rich zones could be relics of zoisite+albite pseudomorphs after magmatic plagioclase (i.e. “saussurite”), a common structure in amphibolitized gabbroic rocks. Moreover, preferred concentrations of zoisite in the core of the zones could reflect a zonation of the former magmatic plagioclase, with an anorthite-rich core. On the other hand, the rutile-rich zones are certainly pseudomorphs after pre-eclogite mafic minerals, most likely amphibole, some of which was enclosed in these zones during garnet growth. The replacement of Ti-bearing amphibole (e.g. 0.53 wt.% TiO_2 in the included amphibole of sample H24l [Fig. 13a]) by an almost Ti-free garnet can produce rutile. The latter could also result from the recycling of former ilmenite-bearing “Schiller structures” that are common in amphibolitized augite.

In some samples, the above inclusions display well-arranged linear trails within each garnet crystal (Fig. 13b). Quartz inclusions show a crystallographic preferred orientation, with the [c] axis perpendicular to the trails (Fig. 22 *in* Godard, 1981). Indeed, these trails are relics of a pre- or eo-eclogite foliation that destroyed the distribution of the inclusions in the above zoisite- and rutile-rich zones. However, such oriented inclusions are not common, and the pre-eclogite protolith was little foliated or undeformed in most cases.

The main conclusion we can draw from the above observations is that the pre-eclogite protolith was an amphibolitized and saussuritized gabbroic rock, generally undeformed. Similar amphibolite commonly occurs in the oceanic crust and ophiolites, where it results from oceanic metamorphism (e.g. Mevel *et al.*, 1977; Stern and Elthon, 1979; Sivell and Waterhouse, 1984; Harper *et al.*, 1988; Peters *et al.*, 1991). However, we cannot exclude that the pre-eclogite protoliths resulted from an amphibolite-facies metamorphism of continental gabbroic rocks.

Oxygen isotopes: possible evidence for oceanic alteration

Oxygen isotope compositions also provide information on the pre-eclogite history. The Vendée eclogite shows a strong dispersion of the $\delta^{18}O$ values (Javoy and Allègre, 1967; Javoy, 1971; Agrinier, unpubl. data), which range from 2.9 to 7.4 (Agrinier, unpubl. data: n=20; average=5.01; σ=1.48; min=2.88±0.10; max=7.38±0.13). Unaltered gabbroic rocks usually show a very narrow range of $\delta^{18}O$ values from 5.5 to 5.8, whereas oceanic hydrothermal alteration and amphibolitization modify these values, inducing either an increase at low T ($\delta^{18}O$ up to 10; T < 250 °C) or a decrease at high T ($\delta^{18}O$ down to 3; T >250 °C) (e.g. Muehlenbachs, 1986; Harper *et al.*, 1988; Philippot and Rumble, 2000). Dehydration during eclogite metamorphism and rehydration during late amphibolitization could also have some effects on $\delta^{18}O$, but this has never been proved important (e.g. Barnicoat and Cartwright, 1997; Philippot and Rumble, 2000). Moreover, the samples selected for the O isotope study were of well-preserved non-amphibolitized eclogite. Therefore, a pre-eclogite alteration and amphibolitization, at various temperatures, may well explain the wide range of $\delta^{18}O$. This metamorphism likely occurred in an oceanic environment, although a few authors have inferred pre-eclogite continental alteration to explain such variations in the Chinese Sulu-Dabie eclogite and gneiss (see discussion *in* Liou *et al.*, 2000). Finally, oceanic alteration could also be responsible for some erratic fluctuations of the alkali contents observed in the Vendée eclogite (Peucat, 1983; Godard, 1988).

Eclogite metamorphism

Petrology

The eclogite-facies parageneses have been described by Lacroix (1891a), Brière (1920), Velde and Sabatier (1972), Schmidt (1980), Godard (1981, 1988), and Lorand and Godard (1982 [sulphides]). Godard (1988) reports the mineral compositions and garnet zonations. The tholeiitic differentiation of the protolith is reflected in modal and mineralogical variations that are summarized in Figure 15. The eclogite formation process is governed by a multivariant sliding reaction that produces garnet and omphacite at the expense of amphibole, as shown in Figure 15. Since the degree of completion of a sliding reaction depends on the bulk composition, particularly on the Fe/Mg ratio if mafic minerals are involved, certain features of the most magnesian eclogite, such as the persistence of amphibole and zoisite and the relatively low jadeite-content of the omphacite, are explained by an incomplete eclogitization of these rocks (Fig. 15; see discussion *in* Godard, 1988, p. 474).

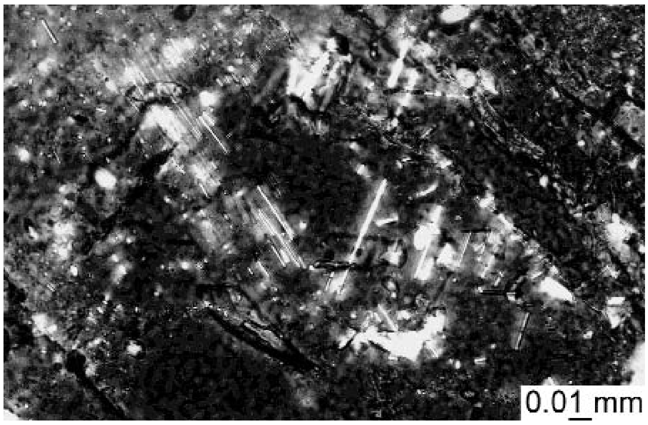


Fig. 14.- Rutile rodlets in garnet.
Hair-like rodlets of rutile, concentrated in “dusty zones”, define parallel orientations. Cross-polarized light; same garnet crystal as in Figure 13a.

Fig. 14.- Aiguilles de rutile dans un grenat.
Les aiguilles de rutile, concentrées en zones, sont orientées selon des directions parallèles. Lumière analysée ; même cristal de grenat que la figure 13a.

Eclogite-facies P-T conditions were estimated by Godard (1981, 1988) and Godard and Van Roermund (1995) on the basis of the (Fe,Mg)-exchange between garnet and omphacite, and the jadeite-content of omphacite. The results were: T=650-750 °C and P >14 kbar. The Jd_{30}+kyanite+H_2O=paragonite equilibrium also provides a minimum P value of the order of 15 kbar, if we assume that $P_{H_20}=P_{tot}$. Godard (1988) proposed a maximum P value of about 20 kbar, assuming that isolated oligoclase inclusions in garnet or kyanite were pre-eclogite relics preserved during eclogite metamorphism. These inclusions are very rare, as they were observed in only four samples. They could have been included in garnet and kyanite during their growth, but could also be related to late retrograde metamorphism, although it is impossible to produce a sodic plagioclase from garnet or kyanite alone.

Geochronological studies (Peucat *et al.*, 1982a, 1982b; Peucat, 1983; Postaire, 1983; Paquette *et al.*, 1985) provided a date of 436 ± 15 Ma (U-Pb method on zircon; lower intercept) that was interpreted as the age of the high-P metamorphism, whereas the upper intercept (1297 ± 60 Ma) was considered as being either an inheritage zircon age or the gabbroic protolith age.

Structures

The eclogite displays clear mineral foliation (S1) and lineation (L1), which appear in thin section as a strong orientation of the omphacite crystals. The pre-eclogite compositional layering (S0) has been totally transposed parallel to S1 (Fig. 11c). Several observations indicate that garnet crystals clearly acted as rigid bodies during this deformation, whereas omphacite, quartz and rutile deformed plastically: (i) the pyroxene-rich foliation wraps around the garnet crystals, which have preserved their subhedral shape (Fig. 16a); (ii) unlike the omphacite crystals, the garnets show a chemical zoning that would not have survived a diffusion-dependent plastic deformation; (iii) where inclusions in garnet define trails, their orientation varies from garnet to

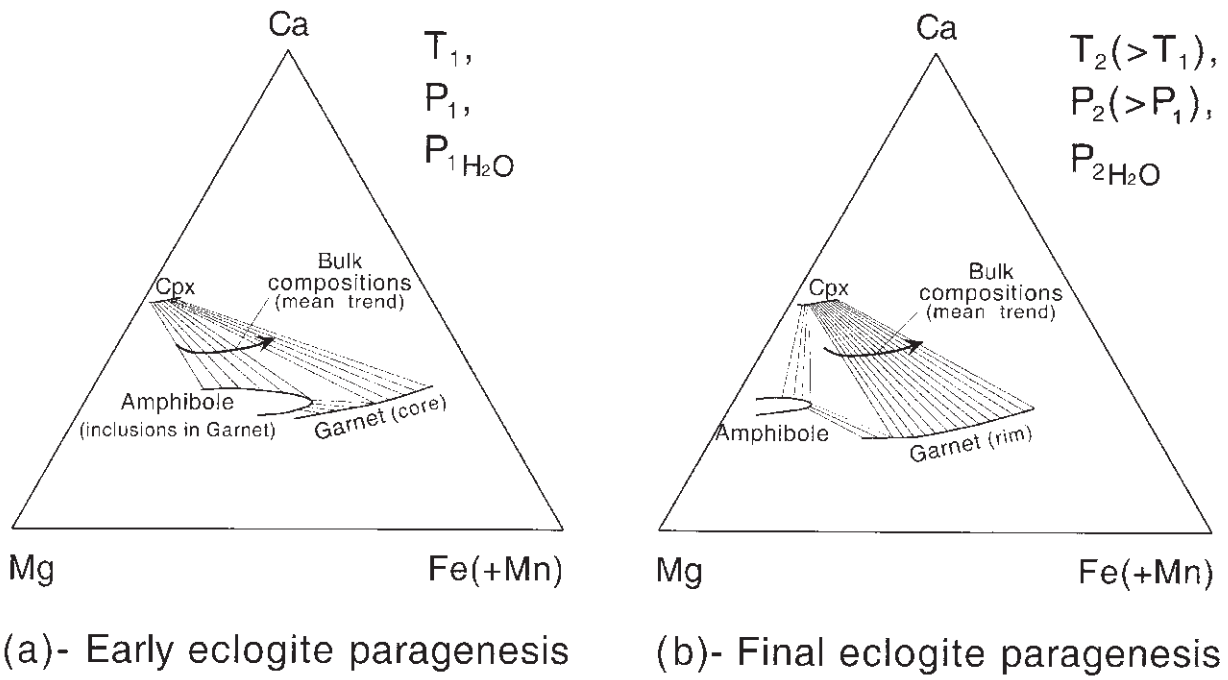


Fig. 15.- Eclogite formation process.
Eclogite formation is explained by a sliding reaction that produces garnet and omphacite at the expense of amphibole (see text).
The above barycentric diagram provides a qualitative representation of the eclogitization sliding reaction, but the reader should be aware that it does not respect the phase stoechiometric coefficients. Eclogite parageneses have few phases, and therefore a high variance. For this reason, it is not possible to represent them correctly in a ternary phase diagram. Projections from rutile, phengite and quartz are not sufficient to reduce the number of independent components to 3, and other projections would eliminate major phases such as omphacite or garnet.

Fig. 15.- Processus d'éclogitisation.
L'éclogitisation est expliquée par une réaction "glissante" qui produisit grenat et omphacite aux dépens d'amphibole (voir texte).
La représentation barycentrique utilisée ici permet de visualiser le processus d'éclogitisation d'une manière qualitative, mais elle ne respecte pas les coefficients stœchiométriques des phases. En effet, les paragenèses éclogitiques possèdent un nombre de phases réduit et donc une variance élevée. Pour cette raison, il n'est pas possible de les représenter correctement dans un diagramme de phases ternaire. Les projections depuis les pôles rutile, phengite et quartz ne sont pas suffisantes pour réduire le nombre de constituants indépendants à 3, et des projections supplémentaires feraient disparaître des phases majeures, telles que grenat et omphacite.

garnet showing that the garnets rotated passively during subsequent deformation (Fig. 16b); (iv) in a few samples, some garnet crystals have been broken and dispersed as fragments within the omphacite matrix (Fig. 16d).

The main plastic deformation event in the eclogite took place before retrograde metamorphism, since post-eclogite symplectites and coronas are undeformed. Nevertheless, it occurred under eclogite-facies conditions after eclogite formation, since the garnet crystals generally enclose undeformed pre- or eo-eclogite minerals (Fig. 13a). Near La Compointrie (295.18-2234.12), some loose blocks found in vineyards show centimetre-scale skeletal hollow garnet crystals that have included undeformed omphacite during their growth, i.e. during eclogite formation (Fig. 16c). The polycrystalline omphacite isolated in the cavity of a single hollow garnet is fine grained and very weakly oriented, whereas the omphacite in the matrix is coarse grained and strongly deformed. The crystallographic preferred orientation of omphacite is much stronger outside than inside the garnet (Godard and Van Roermund, 1995; Mauler *et al.*, 2001). This indicates that omphacite inside the garnet escaped syn-eclogite-facies plastic deformation, because of the rigidity of the garnet. Occasionally, such hollow garnets were broken during deformation, whereupon a transition occurs between undeformed and deformed omphacite (Fig. 16d).

Godard (1981, 1988), Van Roermund (1992), Godard and Van Roermund (1995) and Mauler *et al.* (2001) studied the crystallographic preferred orientations and microstructures of omphacite and rutile. The results made it possible to constrain the shape of the strain ellipsoid. The [001] axis of the omphacite is preferentially oriented parallel to the lineation, while [010] is normal to the foliation plane. However, this pattern varies with the axis ratios of the shape fabric ellipsoid: in strongly lineated samples, the maximum of [001] forms a point maximum parallel to the lineation and [010] spreads out in a great circle normal to the lineation, whereas in strongly foliated samples, the maximum of [010] describes a point maximum normal to the foliation plane, while [001] is dispersed within the foliation plane. The observed fabric types range from strongly foliated to strongly lineated, but planar fabrics are by far the most common. The relative obliquity between the crystallographic axes of the omphacite and rutile was proposed as an indicator of the sense of shear (Mauler *et*

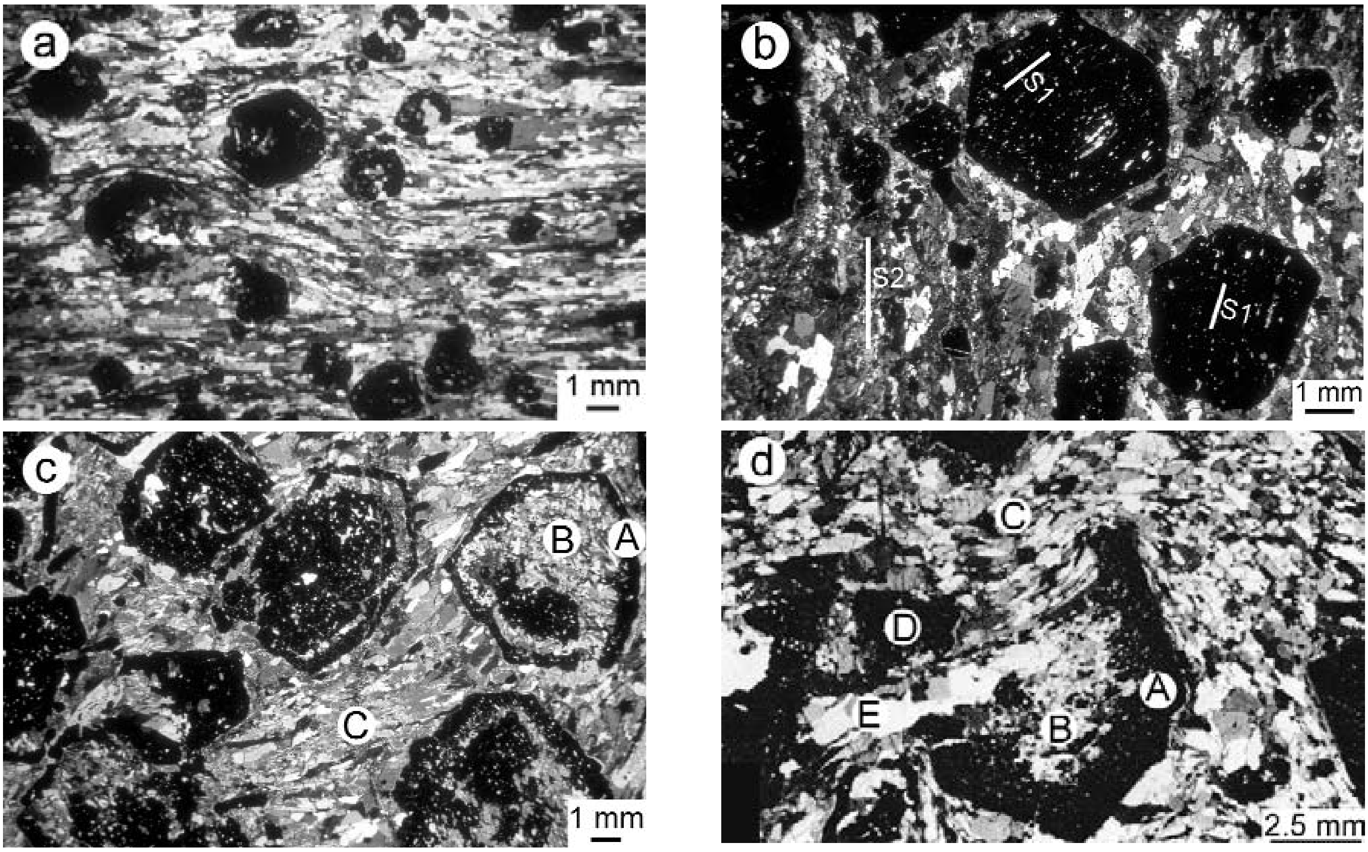


Fig. 16.- Syn-eclogite-facies deformation structures in eclogite.
Black: garnet; grey: matrix of omphacite and quartz; cross-polarized light.
a) Deformed omphacite (grey) wrapping around the garnet crystals (black), which have preserved their subhedral shape; Pied Pain, Saint-Philbert-de-Grand-Lieu; 295.40-2233.25.
b) The inclusion trails in garnet are relics of a pre- or eo-eclogite foliation (S1). S1 varies from garnet to garnet showing that the garnet crystals rotated passively during the syn-eclogite-facies deformation that produced the foliation in the matrix (S2); same sample as in Figure 13b.
c) Relics of omphacite sheltered from the syn-eclogite-facies deformation. A: skeletal hollow garnet; B: poorly deformed micro-granular omphacite, which has been sheltered from deformation by garnet A; C: strongly deformed coarse-grained omphacite; La Compointrie (295.18-2234.12).
d) Brittle behaviour of garnet during plastic deformation. A: broken hollow garnet; B: poorly deformed micro-granular omphacite, which has been sheltered from deformation by garnet A; C: strongly deformed coarse-grained omphacite, showing foliation wrapping around garnet A; D: fragment of a garnet; E: quartz; note that a transition exists between B and C; La Compointrie (295.18-2234.12).

Fig. 16.- Structures de déformation syn-éclogitique dans les éclogites.
Noir : grenat ; gris : matrice à omphacite et quartz ; lumière analysée.
a) L'omphacite déformée (gris) moule les cristaux de grenat (noir) qui ont préservé leurs formes subautomorphes ; Pied Pain, Saint-Philbert-de-Grand-Lieu ; 295.40-2233.25.
b) Les alignements d'inclusions dans les grenats sont les reliques d'une foliation anté- ou éo-éclogitique (S1). Celle-ci varie d'un grenat à l'autre, montrant que les grenats ont été roulés au cours de la déformation syn-éclogitique qui produisit la foliation S2 de la matrice ; même échantillon que dans la figure 13b.
c) Relique d'omphacite préservée de la déformation syn-éclogitique. A : grenat creux à croissance squelettique ; B : omphacite à grain fin peu déformée, qui fut protégée de la déformation par le grenat A ; C : omphacite à gros grain fortement déformée ; La Compointrie (295.18-2234.12).
d) Comportement fragile du grenat au cours de la déformation plastique. A : grenat creux fragmenté ; B : omphacite à grain fin peu déformée, qui fut protégée de la déformation par le grenat A ; C : omphacite à gros grain fortement déformée, dont la foliation moule de grenat A ; D : fragment de grenat ; E : quartz; on notera qu'une transition existe entre B et C ; La Compointrie (295.18-2234.12).

al., 2001). Finally, Godard and Van Roermund (1995) and Mauler *et al*. (2001) argued that diffusion creep is clearly a major mechanism during omphacite deformation.

Retrograde metamorphism

Various retrograde metamorphic reactions are visible in the eclogite. They have been described and balanced by Godard (1988) and Godard and Smith (1999). We only list them here:

a) Omphacite decomposition into a symplectite made up of oligoclase and Jd-poor Cpx [i.e. 1 omphacite (Jd_x) + y quartz $\rightarrow$ 1 Cpx (Jd_{x-y}) + y albite] (Fig. 17a).

b) Biotite+plagioclase symplectite after phengite [i.e. phengite + omphacite $\rightarrow$ biotite + plagioclase (+ quartz); see Franz *et al*., 1986].

c) Kyanite decomposition into spinel ± corundum + anorthite symplectites [see Godard and Mabit, 1998].

d) Kyanite + amphibole $\rightarrow$ preiswerkite + Na-(Mg, Fe)-margarite + plagioclase [La Compointrie eclogite; Godard and Smith, 1984, 1999;

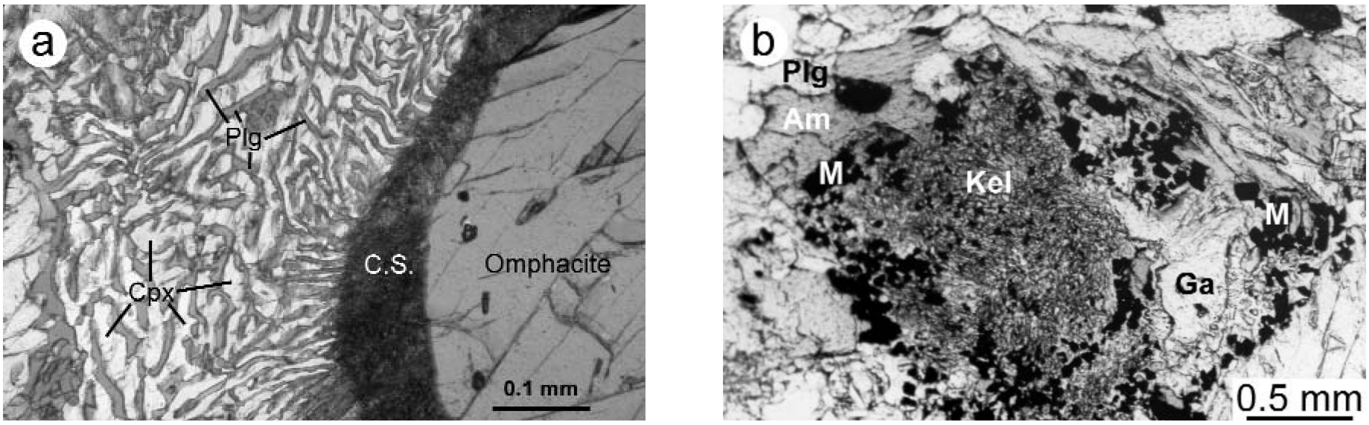


Fig. 17.- Main retrograde reactions in the eclogite.
a) Omphacite → symplectite of Jd-poor clinopyroxene (Cpx) + oligoclase (Plg); C.S.: cryptocrystalline Cpx+Plg symplectite; cross-polarized light; 313.55-2216.58.
b) Amphibolitization. Kel: kelyphitic association of amphibole + plagioclase + magnetite (M) after garnet (Ga); matrix of plagioclase (Plg) and amphibole (Am); plane-polarized light.

Fig. 17.- Principales réactions rétrogressives dans les éclogites.
a) Omphacite → symplectite à clinopyroxene pauvre en jadéite (Cpx) et oligoclase (Plg) ; C.S. : symplectite cryptocristalline à Cpx+Plg ; lumière analysée ; 313.55-2216.58.
b) Amphibolitisation. Kel : association kélyphitique à amphibole + plagioclase + magnétite (M) corrodant le grenat (Ga) ; matrice à plagioclase (Plg) et amphibole (Am) ; lumière non analysée.

preiswerkite is a very unusual trioctahedral Na-mica].

e) Sphene coronas around rutile and ilmenite.

f) Amphibolitization (Fig. 17b): late dark-green amphibole (mostly, edenitic or pargasitic hornblende) occurs in three main forms: (i) amphibole-bearing coronas around garnet ("kelyphite": Fig. 17b), with or without other amphibolitization products (plagioclase, epidote, magnetite, etc.); (ii) amphibole + plagioclase ± epidote symplectite in the matrix; (iii) large poikiloblastic crystals of amphibole that enclose corroded syn-eclogite minerals (mostly garnet) and amphibolitization by-products (lobed crystals of plagioclase). During retrograde metamorphism, most of the eclogite was transformed into amphibolite, with a final paragenesis of dark-green hornblende + plagioclase + quartz ± epidote ± garnet + sphene. This amphibolitization everywhere affects the margins of the eclogite lenses (e.g. La Gerbaudière quarry: Fig. 10). It also develops from fractures that intersect the syn-eclogite foliation (Fig. 11d). Both phenomena can be explained by the percolation of aqueous fluids.

The above processes indicate (i) rehydration (growth of hydrated minerals such as mica, sphene and, mainly, amphibole), and (ii) a drop in P (growth of plagioclase, Jd-poor Cpx, etc.). When observed in eclogite, retrograde metamorphism is always static, without any apparent deformation. Strong deformation occurring during retrograde metamorphism would induce a recrystallization and erase any trace of eclogite paragenesis. Therefore, foliation in amphibolite may reflect a post-eclogite deformation stage, whereas earlier structures were preserved in less ductile, metastable eclogite. Nevertheless, foliation in the amphibolite is subparallel to that in eclogite (Bn *in* Fig. 4), although more scattered, suggesting that the stress field was rather constant during retrograde metamorphism. It is also likely that the rigid and already elongated eclogite lenses could not rotate to an angle notably different from the tensional direction.

The Rb-Sr isochron of phengite from the La Gerbaudière quarry would place the final cooling age at 322 ± 30 Ma (Carboniferous; Peucat, 1983). Finally, some of the eclogite was at the surface by the end of the Carboniferous (around 300 Ma), since pebbles of eclogite are found in the Stephanian deposits of the Vendée coal belt (see above).

Les Essarts high-pressure Unit: surrounding gneiss

The petrological features of the gneiss that surrounds the Vendée eclogite are only summarized here; they will be presented in detail in a future publication by the present author. Most of these rocks do not display any evidence of eclogite-facies metamorphism. However, where deformation and retrograde metamorphism are less intense, relics of two consecutive high-T and high-P parageneses are visible in both ortho- and paragneiss. Various other rock types that also occur are described.

Schistose and retrograded gneiss

Most of the rocks that enclose the eclogite are schistose and rich in white mica, so they resemble mica schist, although they show evidence of a gneissic paragenesis with biotite, garnet, plagioclase, quartz and microcline. White mica, a phengitic muscovite, is abundant and the rocks resemble some phengite-bearing eclogite-facies mica schist, such as the so-called *micascisti eclogitici* of the Alps. However, jadeite and other high-P minerals are lacking, whereas plagioclase is ubiquitous. Foliation and lineation are parallel to the structures in eclogite (Figs. 4 and 10), so both rocks seem to have undergone the same eclogite-facies deformation event. However, these structures are also similar to those in the eclogite-derived amphibolite, and it is difficult to relate them clearly to a particular stage of the metamorphic history.

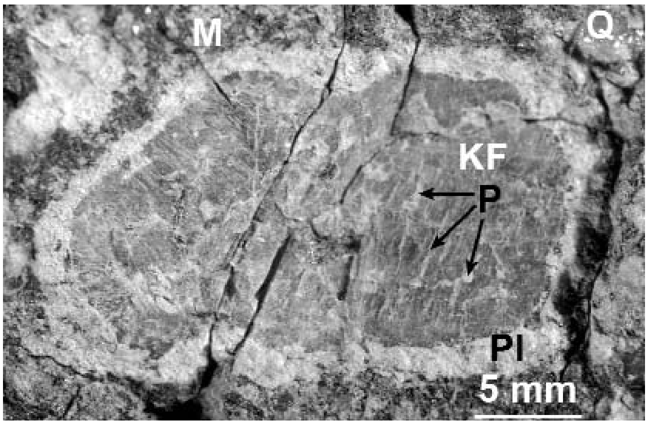


Fig. 18.- Coronitic metagranite.
KF: K-feldspar (microcline) porphyroblast; P: perthite; Pl: plagioclase rim around microcline (i.e. Rapakivi texture); Q: quartz; M: microcrystalline matrix of biotite + plagioclase, with garnet coronas; loose block: 308.3-2225.5.

Fig. 18.- Métagranite coronitique.
KF : Porphyroblaste de feldspath potassique (microcline) ; P: perthites ; Pl : enveloppe de plagioclase autour du microcline (i.e. structure Rapakivi) ; Q : quartz ; M : matrice microcristalline à biotite + plagioclase, avec couronnes de grenat ; pierre volante : 308.3-2225.5.

Fig. 19.- Coronitic paragneiss (La Ruffelière).
The walls of La Ruffelière manor (XVth century), near Saint-Philbert-de-Bouaine, provide one of the best exposures of coronitic paragneiss. The hearth stone of the courtyard entrance, noticeably, displays dark pseudomorphs of cordierite several centimetres in size.

Fig. 19.- Paragneiss coronitiques (La Ruffelière).
Les murs du manoir de La Ruffelière (XVe siècle), près de Saint-Philbert-de-Bouaine, constituent l'un des meilleurs gisements de paragneiss coronitique. La dalle du seuil de la cour, notamment, montre des pseudomorphes foncées de cordiérite de plusieurs centimètres de taille.

Gneiss associated with eclogite, but lacking evidence of eclogite-facies metamorphism, is well exposed at La Gerbaudière. In the quarry, paragneiss is so intimately interlayered with the eclogite (Figs. 10 and 11f) that we cannot escape the conclusion that both rocks underwent the same history. The gneiss is mainly made up of quartz + plagioclase + biotite + garnet ± muscovite, with very scarce K-feldspar. Leucosomes seldom occur, indicating an incipient migmatization (Fig. 11f). Foliation is parallel to the syn-eclogite foliation of the neighbouring eclogite. However, evidence for high-P metamorphism is lacking, and an amphibolite zone of a few tens of centimetres in thickness everywhere occurs at the interface between gneiss and eclogite. The ortho-leptynite described on p. 31 displays a similar relationship with the eclogite.

The coexistence of eclogite with gneiss showing no evidence of eclogite-facies metamorphism is a complex, but rather common problem. It was at the origin of the "in-situ versus foreign" controversy about eclogite origin. Two main lines of argument may account for this apparent inconsistency:

a) eclogite and oligoclase-bearing gneissic parageneses can coexist in a divariant P-T field bounded by the Ab_{85}=Jd_{40}+Q and Ab_{85}=Jd_{100}+Q equilibrium curves (i.e. roughly between 15 and 20 kbar). In this field, oligoclase is unstable with omphacite but stable alone. In the Vendée, this is supported by the existence of few rare plagioclase inclusions enclosed in the kyanite or garnet of some eclogite (see "Eclogite metamorphism", p. 35), which apparently remained stable during eclogite metamorphism, whereas the matrix remained plagioclase-free. These inclusions can hardly be attributed to retrograde metamorphism, since it is difficult to produce oligoclase from kyanite or garnet in a closed system.

b) eclogite-facies gneiss and mica schist could have been entirely retrograded, whereas the eclogite has preserved its high-P paragenesis. Such a hypothesis is more and more accepted in the geological literature. The difference in behaviour between the two rocks during retrograde metamorphism could be due to (i) a more persistent metastability of the eclogite-facies parageneses in basic rocks, (ii) the necessity to rehydrate eclogite to produce amphibolite, (iii) incipient migmatization in pelitic rocks, and (iv) the strong difference in rheology between gneiss and eclogite, which could explain a preferential deformation and recrystallization of the gneiss.

In the Vendée, hypotheses (a) and (b) are both possible. The second hypothesis is now supported by the recent discovery of high-P relics in some gneiss that we describe in the next section.

High-pressure eclogite-facies ortho- and paragneiss

Although more than 95% of the surrounding rocks consist of the schistose and retrograded gneiss described above, some of them are less deformed. Early structures and parageneses are then preserved, and reveal a complex early metamorphic history. These structures, primarily garnet coronas around biotite, are visible in some orthogneiss as well as in paragneiss.

Coronitic orthogneiss

Coronitic orthogneiss is visible at a few localities (e.g. 305.2-2228.3; 305.55-2227.90; 308.3-2225.5; 308.60-2227.88; 309.95-2220.90; 308.9-2223.6). It displays the usual paragenesis of metagranite: quartz + oligoclase + biotite + phengitic muscovite + microcline. Perthitic microcline forms centimetre-scale augen. At one location (loose blocks: 308.3-2225.5), the augen are surrounded by plagioclase rims (i.e. Rapakivi texture: Fig. 18). The main feature of the orthogneiss is the presence of complex garnet-bearing coronas along the plagioclase-biotite interface, which results from the following metamorphic reaction:

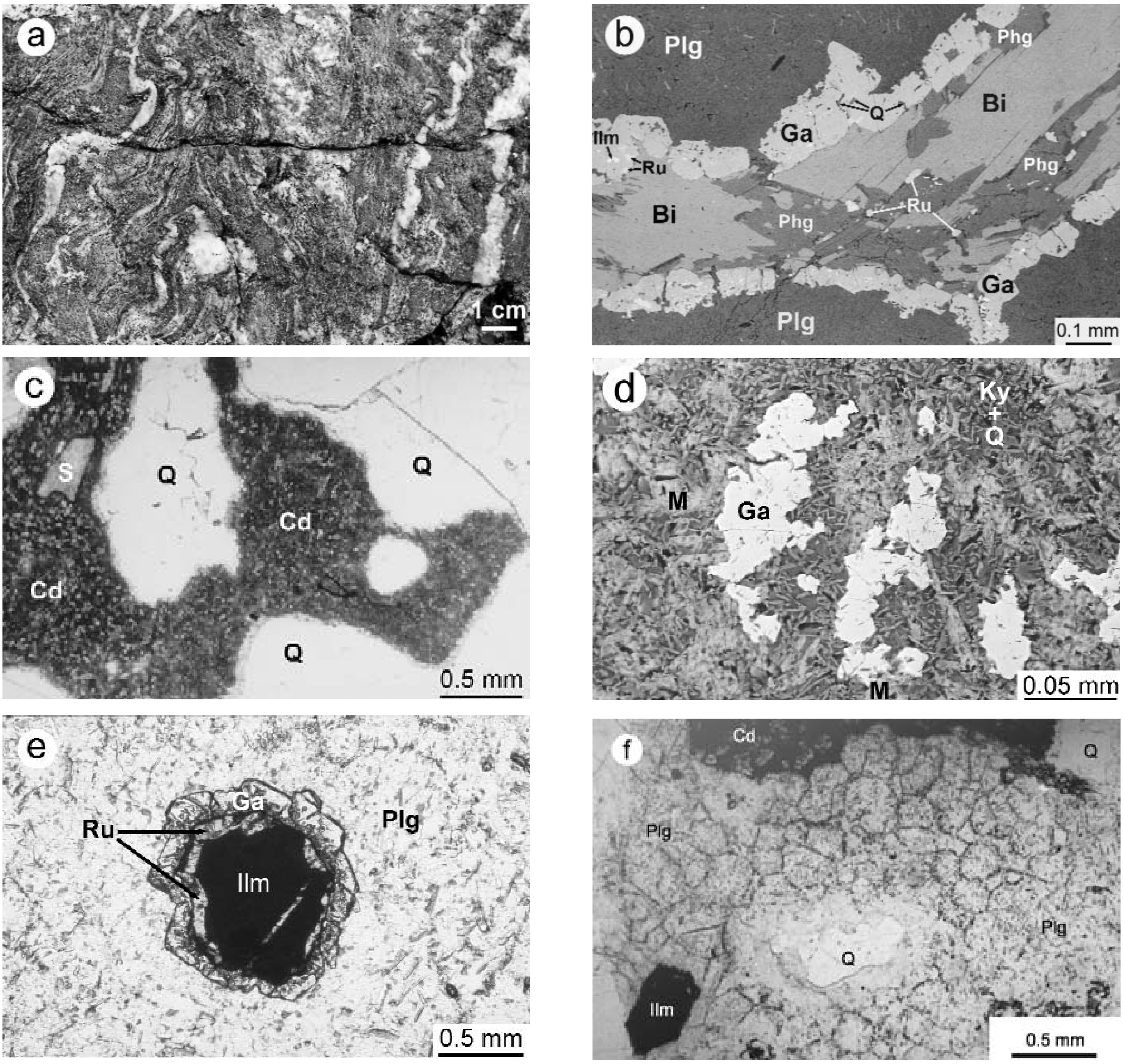


Fig. 20.- Coronitic paragneiss and migmatite (Grezay).
a) Coronitic migmatite. Cordierite-bearing leucosome veinlets provide the most favourable samples for petrological studies.
b) Garnet coronas at the contact between biotite and plagioclase: biotite (Bi) + polycrystalline oligoclase (Plg) → garnet (Ga) + phengite (Phg) + rutile (Ru) + ilmenite (Ilm) + quartz (Q); back-scattered electron image.
c) Cd: cordierite pseudomorph; Q: quartz; S: kyanite derived from fibroblastic sillimanite (i.e. fibrolite); plane-polarized light.
d) Cordierite pseudomorph: Ga: garnet; Ky+Q: kyanite rodlets (grey) and quartz (dark background); M: mica, mostly biotite; back-scattered electron image.
e) Garnet corona at the contact between ilmenite and plagioclase: ilmenite (Ilm) + polycrystalline oligoclase (Plg) → rutile (Ru) + garnet (Ga) + quartz (included in Ga); plane-polarized light.
f) Possible jadeite pseudomorphs. Cells of polycrystalline plagioclase (Plg: Ab_{91}) are picked out by minute kyanite rods. The cells could represent former plagioclase monocrystals that were replaced by jadeite+quartz+kyanite+zoisite cryptocrystalline aggregates in eclogite-facies conditions, but no jadeite relics have been preserved (see text); plane-polarized light.

Fig. 20.- Paragneiss et migmatites coronitiques (Grezay).
a) Migmatite coronitique. Des veinules de leucosome à cordiérite fournissent les meilleurs échantillons pour les études pétrologiques.
b) Couronnes de grenat à l'interface biotite-plagioclase: biotite (Bi) + oligoclase polycristallin (Plg) → grenat (Ga) + phengite (Phg) + rutile (Ru) + ilménite (Ilm) + quartz (Q) ; image en électrons rétrodiffusés.
c) Cd: pseudomorphe de cordiérite ; Q : quartz ; S : disthène ayant conservé la structure fibroblastique de la sillimanite (i.e. fibrolite) ; lumière non analysée.
d) Pseudomorphe de cordiérite ; Ga : grenat ; Ky+Q : cristallites de disthène (en gris) et quartz (fond foncé) ; M : mica, principalement biotite ; image en électrons rétrodiffusés.
e) Couronne de grenat à l'interface ilménite-plagioclase : ilménite (Ilm) + oligoclase polycristallin (Plg) → rutile (Ru) + grenat (Ga) + quartz (inclus dans le grenat); lumière non analysée.
f) Pseudomorphes hypothétiques de jadéite. Des cellules de plagioclase polycristallin (Plg : Ab_{91}) sont délimitées par de minuscules cristallites de disthène; elles pourraient représenter d'anciens monocristaux de plagioclase, remplacés lors du métamorphisme éclogitique par des aggrégats polycristallins à jadéite+quartz+disthène+zoïsite, mais aucune relique de jadéite n'a été préservée (voir texte) ; lumière non analysée.

biotite + plagioclase → garnet + phengite (+ quartz + rutile).

The reaction products are typical of high-P conditions and could be related to the eclogite-facies metamorphism. Similar metagranite is known in the Champtoceaux Complex (La Picherais metagranite: Lasnier *et al*., 1973) and the Malpica-Tuy Unit in Galicia (Spain; Gil Ibarguchi, 1995).

Coronitic paragneiss

Some coronitic paragneiss has proved to be more interesting. It shows evidence of a high-T low-P metamorphic stage (cordierite-bearing migmatite) followed by an eclogite-facies stage (garnet coronas) (Godard, 1998). These peculiar rocks can be seen in a few occurrences:

a) La Ruffelière (305.0-2225.3): La Ruffelière manor, near Saint-Philbert-de-Bouaine, was destroyed in 1417 during the Hundred Years' War, rebuilt in the 1420s by Aliette de Polhay and Jehan de Goulaine, and burnt again in 1794 during the Vendée War (Aillery, 1914). The walls are built of a rock that displays dark pseudomorphs of cordierite, several centimetres in size. The hearth stone of the courtyard entrance, which has been polished by the tread of feet over the centuries, shows spectacular pseudomorphs that present some of the shapes of pseudo-hexagonal cordierite (Fig. 19). The rock is also visible in the eastern moat, and in a few other outcrops nearby (e.g. deformed rock in 304.95-2225.40), notably on the opposite bank of the Boulogne river (304.60-2225.96). On the ground in the courtyard, the rock displays a layered migmatitic structure with leucosomes.

b) Boulogne valley, near Rocheservière: paragneiss with dark pseudomorphs of cordierite more-or-less elongated parallel to foliation occurs in a 2-km-long SE-NW-directed zone, from La Naulière, in the south, to La Touche, in the north. The gneiss occurs as loose blocks in the countryside, as well as in several outcrops near the river (e.g. 307.9-2220.92; 306.5-2222.4).

c) Grezay (325.50-2204.28), near Les Essarts, is by far the most interesting occurrence: nebulitic migmatite, later metamorphosed under eclogite-facies conditions, occurs in a small disused quarry. Some centimetre-scale dark spots represent pseudomorphs of poikiloblastic cordierite, as at La Ruffelière. The most favourable samples for petrological studies are provided by centimetre-thick veinlets of leucosome with small cordierite pseudomorphs (Fig. 20a-f). The walls of the nearby country house of Grezay display interesting samples of various coronitic orthogneiss, paragneiss and migmatite (Fig. 20a).

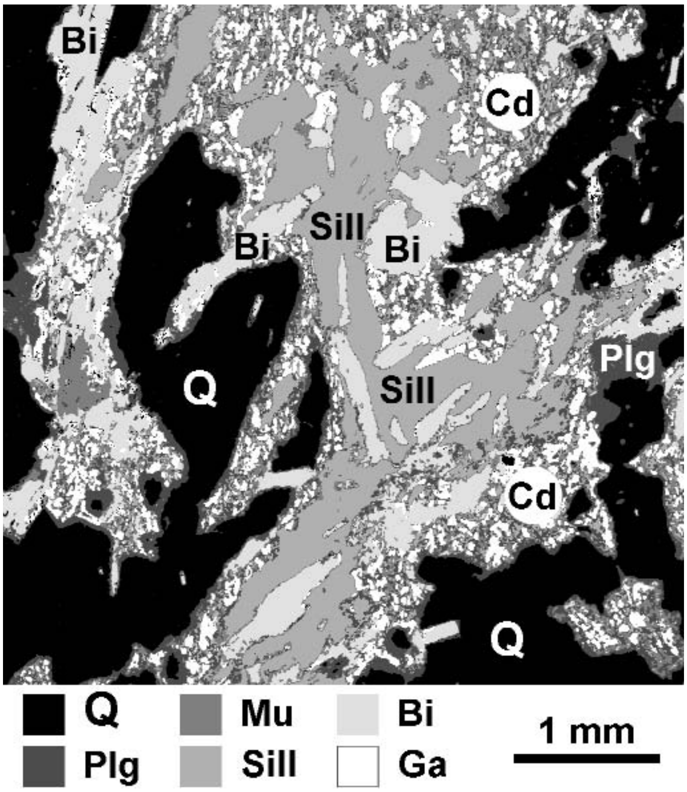


Fig. 21.- Migmatization reaction (Grezay).
Q: quartz [black]; Plg: plagioclase [dark grey]; Sill: former sillimanite [grey]; Bi: biotite [light grey]; Cd: cordierite pseudomorph (garnet [white] + kyanite [grey] + quartz [black]). Cordierite always occurs at the Bi-Q-Sill triple points, whereas Bi-Q and Bi-Sill contacts remain stable. Such a structure indicates that cordierite grew through the well-known migmatization reaction: biotite + quartz + sillimanite (± plagioclase) → cordierite + melt (± garnet ± K-feldspar). The image was produced by multispectral image analysis of X-ray element maps obtained using a scanning electron microscope.

Fig. 21.- Réaction de migmatisation (Grezay).
Q : quartz [noir] ; Plg : plagioclase [gris foncé] ; Sill : ancienne sillimanite [gris] ; Bi : biotite [gris clair] ; Cd : pseudomorphe de cordiérite (grenat [blanc] + disthène [gris] + quartz [noir]). La cordiérite apparaît aux points triples Bi-Q-Sill, alors que les contacts Bi-Q et Bi-Sill demeurent stables. Une telle structure indique que la cordiérite s'est développée selon la réaction de migmatisation: biotite + quartz + sillimanite (± plagioclase) → cordiérite + produit de fusion (± grenat ± feldspath potassique). L'image a été générée par analyse d'images multispectrale de cartes d'éléments chimiques obtenues au microscope électronique à balayage.

d) Small occurrences of similar paragneiss with cordierite pseudomorphs occur in several other localities: e.g. 296.1-2233.1; 297.1-2232.9; 311.7-2220.45; 317.63-2210.30. Commonly, the dark pseudomorphs after cordierite are more-or-less elongate parallel to an incipient foliation. In 294.4-2233.3, loose blocks in vineyards resemble cordierite-bearing spotted hornfels; they occur together with blocks of orthogneiss.

All these rocks show petrological evidence for two distinct metamorphic stages:

a) High-T/low-P stage: an early paragenesis, typical of high-T/low-P conditions, consists of biotite + garnet + quartz + plagioclase ± cordierite ± K-feldspar ± Al-silicate + ilmenite. The Al-silicate is now kyanite, as proven by Raman spectrometry, but it was evidently derived from sillimanite, of which it displays the typical fibroblastic structure (i.e. fibrolite). Cordierite was completely replaced by later cryptocrystalline minerals (Figs. 20c and 20d). It can form dark centimetre-scale poikilo-

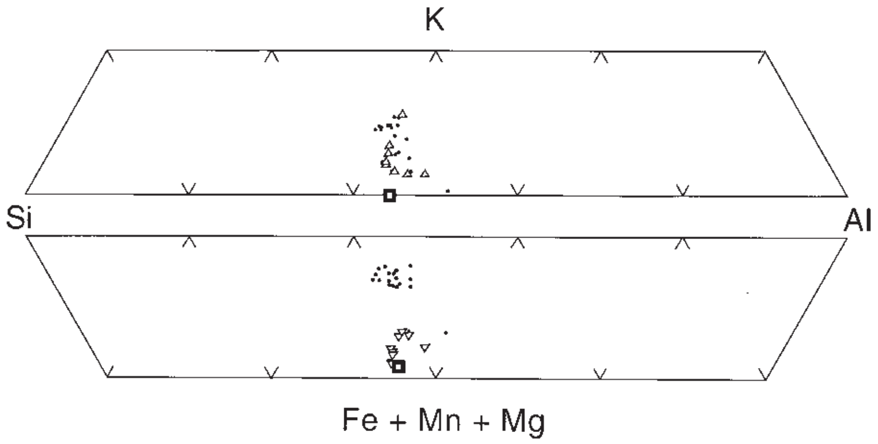


Fig. 22.- Composition of the cordierite pseudomorphs: evidence for cordierite pinitization (Grezay). Square: theoretical cordierite composition; dots: "pinite" composition from the literature; triangles: composition of the cordierite pseudomorph (garnet + kyanite + quartz ± mica), obtained by scanning electron microprobe.

Fig. 22.- Composition des pseudomorphes de cordiérite : indice en faveur de la pinitisation de la cordiérite (Grezay).
Carré : composition théorique de la cordiérite ; points : compositions de "pinite" d'après la bibliographie ; triangles : composition des pseudomorphes de cordiérite (grenat + disthène + quartz ± mica), obtenue par balayage à la microsonde électronique.

blasts (La Ruffelière [Fig. 19], Grezay). Biotite, quartz and the former sillimanite are always separated from each other by the cordierite pseudomorph (Fig. 21) which, moreover, completely surrounds and isolates the former sillimanite (Fig. 20c). Such a structure indicates that cordierite grew at the expense of biotite, quartz and sillimanite, according to a well-known migmatization reaction:

biotite + quartz + sillimanite (± plagioclase) → cordierite + melt (± garnet ± K-feldspar).

This process is known to operate around 3-7 kbar and 700-850 °C, depending on the fluids and mineral compositions (e.g. Vielzeuf and Holloway, 1988; Le Breton and Thomas, 1988; Stevens *et al*., 1997). Otherwise, migmatization is evident due to the common occurrence of leucosomes and nebulitic structures.

b) High-P eclogite-facies stage: during a second stage, these rocks underwent a high-P metamorphism that is indicated by several metamorphic reactions:

(i) cordierite → garnet + quartz + kyanite (+ micas) [i.e. cordierite pseudomorph: Figs. 20c and 20d];

(ii) sillimanite (fibrolite) → kyanite;

(iii) biotite + plagioclase → garnet + phengite + quartz + rutile [coronas around biotite; Fig. 20b];

(iv) ilmenite + plagioclase → garnet + rutile + quartz [coronas around ilmenite; Fig. 20e];

(v) monazite I + plagioclase → apatite + epidote + U-Th-enriched monazite II [coronas around monazite];

(vi) K-feldspar + biotite → garnet + phengite + quartz (+ rutile) [garnet corona and phengite + quartz symplectite between K-felspar and biotite].

These reactions are typical of a high-P metamorphism, which was certainly contemporaneous with the one that produced the neighbouring eclogite. However, albite is abundant and it is not clear whether these rocks ever contained jadeite. Cells of polycrystalline albite, bounded by trails of minute kyanite crystals (Grezay; Fig. 20f), likely represent pseudomorphs after plagioclase monocrystals. Such plagioclase is ordinarily replaced during eclogite-facies metamorphism by cryptocrystalline aggregates of jadeite+quartz+kyanite+zoisite (±phengite±K-feldspar), which in turn are retrograded into polycrystalline albite or oligoclase during metamorphism (e.g. Gil Ibarguchi, 1995; Tropper *et al*., 1999; Bruno *et al*., 2001). As with the Vendée coronitic gneiss, remaining rodlets of kyanite and zoisite within polycrystalline albite (Fig. 20f) strongly support the hypothesis of such a process, but jadeite relics have nowhere been observed.

The sequence of metamorphic events could be explained by an anti-clockwise P-T path from high-T (cordierite-bearing migmatitic paragneiss) to high-P (eclogite-facies coronas and pseudomorphs) conditions. However, such counter-clockwise paths are difficult to explain in terms of geodynamics. Two independent lines of evidence support the alternative hypothesis of two consecutive clockwise P-T parths (see Fig. 23):

a) Analyses of the cordierite pseudomorphs performed by scanning electron microprobe show enrichment in K_2O and loss of MgO and FeO, in comparison with ordinary cordierite compositions (Fig. 22). Moreover, the obtained compositions belong to a trend that coincides with the cordierite alteration products (i.e. "pinite") taken from the literature. This strongly suggests that cordierite was altered into "pinite" (i.e. a chlorite + sericite cryptocrystalline aggregate; T <400 °C) before being replaced by the pseudomorph, i.e. before the high-P metamorphism.

b) The phengite + quartz symplectite that partly replaced K-felspar during the eclogite-facies metamorphism grew preferentially along the perthites. This indicates that the exsolution of perthites (i.e. an early retrogression) occurred before the high-P metamorphic stage.

Therefore, the rocks would have experienced their first retrogradation between the high-T and high-P stages, and these two stages likely belong to two distinct orogenic cycles, i.e. pre-Variscan and Variscan (Fig. 23).

Other rocks

A discontinuous 10-m-wide band of manganiferous quartzite exists among the high-P gneiss, extending from Boulogne to the north of Saint-Denis-la-Chevasse (Godard, 1981; Wyns *et al*., 1987). It is mostly visible as loose blocks in vineyards near Moulin des Jarries (317.55-2211.20). This dark and banded quartzite contains microcrystalline and granoblastic quartz (> 90 vol.%) with hematite, a little epidote and spessartite-rich garnet (Moulin des

Jarries: $Spess_{63}$ Alm_{21} And_{12} Pyr_4; Fig. 24a).

Five gabbroic lenses, about 500 m in length, crop out in the Boulogne valley downstream of Rocheservière (306.18-2223.48; 306.41-2223.71; 306.89-2223.85; 305.17-2225.62; 301.66-2227.54). The rock is undeformed and displays a well-preserved ophitic structure, with laths of saussuritized plagioclase set in an amphibolitized matrix (Fig. 24b). This amphibolitized gabbro presumably represents late dykes that intruded the Les Essarts Unit after the eclogite-facies metamorphism.

Some orthogneiss seems to have escaped the high-P metamorphism, although it apparently belongs to the same unit as the eclogite. These rocks are visible, among other localities, near Corcoué-sur-Logne (e.g. 304.85-2223.80) and in the Boulogne valley near Rocheservière (e.g. 307.4-2221.9). They are made up of quartz + oligoclase + microcline + biotite + muscovite ± garnet, which, unlike the above coronitic orthogneiss, do not show garnet+phengite coronas at the biotite-plagioclase interface. Large K-feldspar augen a few centimetres in length and displaying the Carlsbad twin system are common. Although the relationships between the gneiss and the eclogite-facies rocks are not visible, the foliation and lineation seem oriented similarly to those in the high-P rocks. La Roche-aux-Lutins (307.42-2221.90), on the right bank of the Boulogne to the south-east of Rocheservière, offers the best exposure of the rock (Fig. 25). At this outcrop, two undeformed mafic dykes cut across the gneiss in a direction that is slightly oblique to its foliation (Fig. 25a). The cryptocrystalline mineral association in the dykes indicates a weak incipient eclogitization (P < 10 kbar). It is composed of Cpx [Jd_9] partly replaced by amphibole [ferroan pargasitic hornblende], plagioclase [Ab_{83-97}], garnet [Alm_{52} $Gross_{27}$ Pyr_{20}], and accessory quartz, biotite and ilmenite (Fig. 25c). The host gneiss yields an age of 483 ± 4 Ma (U-Pb method on zircon: C. Guerrot, unpub. data), which is older than the 440 Ma age attributed to the eclogite metamorphism by Peucat *et al*. (1982a).

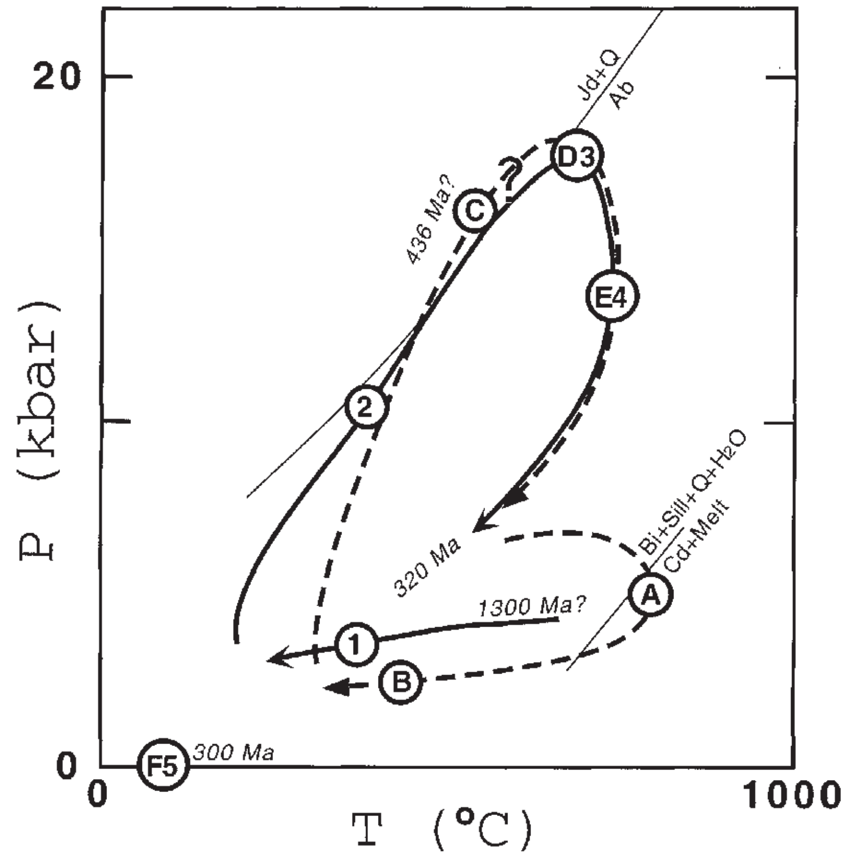


Fig. 23.- Semi-quantitative pressure-temperature paths for the eclogite and surrounding gneiss.
Dotted line: P-T path for the gneiss. A: migmatization and cordierite formation in the gneiss (Fig. 21); B: cordierite pinitization (Fig. 22) and perthite exsolution (see text); C: high-P metamorphism (Fig. 20), possibly jadeite-bearing (Fig. 20f); D: main plastic deformation event; E: incipient migmatization; F: some of the gneiss reaches the surface (pebbles in Stephanian conglomerate of the Vendée coal belt).
Solid line: P-T path for the eclogite. 1: amphibolitization and saussuritization of the pre-eclogite gabbro (Fig. 13); 2: eclogite formation (Fig. 15); 3: main plastic deformation event (Fig. 16); 4: retrograde metamorphism and amphibolitization (Fig. 17); 5: some of the eclogite reaches the surface (pebbles in Stephanian conglomerate of the Vendée coal belt).

Fig. 23.- Trajectoires pression-température semi-quantitatives des éclogites et de leurs gneiss encaissants.
Ligne pointillée : trajectoire P-T pour les gneiss. A : migmatisation et formation de la cordiérite dans les gneiss (fig. 21) ; B: pinitisation de la cordiérite (fig. 22) et exsolution des perthites, (voir texte) ; C : métamorphisme de haute pression (fig. 20), peut-être à jadéite (fig. 20f) ; D : principal épisode de déformation plastique ; E : début de migmatisation ; F : une partie des gneiss atteignent la surface (galets dans les conglomérats stéphaniens du Sillon houiller de Vendée).
Ligne continue : trajectoire P-T pour les éclogites. 1 : amphibolitisation et saussuritisation du gabbro anté-éclogitique (fig. 13) ; 2 : éclogitisation (fig. 15) ; 3 : principal épisode de déformation plastique (fig. 16) ; 4 : rétromorphose et amphibolitisation (fig. 17) ; 5 : une partie des éclogites atteignent la surface (galets dans les conglomérats stéphaniens du Sillon houiller de Vendée).

Discussion

Possible translation from the Bas-Limousin

The Central Vendée Massif is made up of several distinct geological units whose histories, dating mainly from the Ordovician to the Devonian, can hardly be correlated between themselves. They were brought into their present position by NW-SE-directed dextral faults (Sainte-Pazanne-Mervent line, Vendée coal belt, South Armorican Shear Zone: Fig. 1) related to the Variscan compression. We can regard these terrains as pieces of a gigantic tectonic breccia.

Three of these units occur between the Vendée coal belt and Sainte-Pazanne-Mervent tectonic lineaments: (i) the Les Essarts high-pressure eclogite-bearing Unit, (ii) an Ordovician orthogneiss, and (iii) the

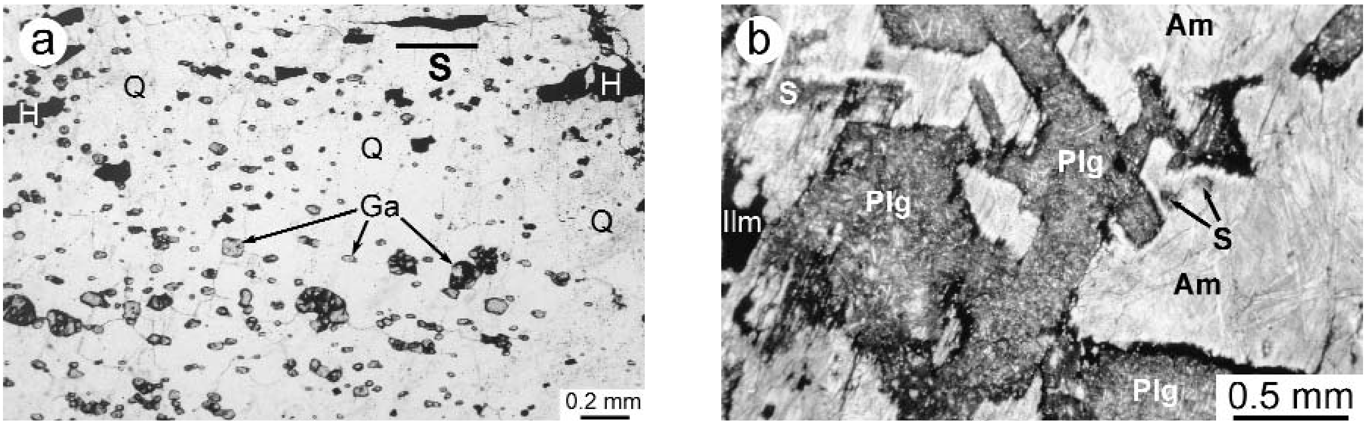


Fig. 24.- Other rocks.
a) Manganiferous quartzite. Moulin des Jarries (317.55-2211.20), near Saint-Denis-la-Chevasse; H: hematite; Ga: spessartite-rich garnet; Q: quartz; S: layering; plane-polarized light.
b) Amphibolitized gabbro displaying a well-preserved ophitic texture. 306.18-2223.48; Plg: laths of saussuritized plagioclase (cryptocrystalline zoisite + accessory albite); Am: amphibole after schillerized magmatic pyroxene; S: relics of Schiller structure; Ilm: ilmenite; plane-polarized light.

Fig. 24.- Autres roches.
a) Quartzite manganifère. Moulin des Jarries (317.55-2211.20), près de Saint-Denis-la-Chevasse ; H : hématite ; Ga : grenat riche en spessartine ; Q : quartz ; S : rubanement ; lumière non analysée.
b) Gabbro amphibolitisé montrant une structure doléritique préservée. 306.18-2223.48 ; Plg : lattes de plagioclase saussuritisé (zoïsite cryptocristalline + albite) ; Am : amphibole ayant remplacé un pyroxène magmatique schillerisé ; S : relique de structure de Schiller ; Ilm : ilménite ; lumière non analysée.

Roc-Cervelle low-grade Unit (Fig. 2). They show contrasted features and metamorphic histories, but, as a whole, they have a surprising resemblance to similar terrains in Bas-Limousin (NW Massif Central), 200 km to the southwest. Three main units, stacked during eo-Variscan convergence, have been recognized in this latter region (e.g. Ledru and Autran, 1987; Ledru *et al.*, 1989, 1994):

a) The *Unité supérieure des gneiss* comprises numerous eclogite lenses boudinaged within strongly schistose gneiss. The Limousin eclogite, notably that of the Uzerche area, is similar to the Vendée eclogite, showing the same textures, parageneses and tholeiitic differentiation (e.g. Brière, 1920; Coffrant and Piboule, 1975; Santallier, 1976, 1978, 1981, 1983; Santallier and Floc'h, 1979; Cabanis *et al.*, 1983; Ezzayani, 1991).

b) The *Unité inférieure des gneiss* is primarily made up of Cambrian-Ordovician orthogneiss belts that bound the eclogite-bearing units to the east (arc de Saint-Yrieix, arc de La Dronne: e.g. Floc'h, 1977; Floc'h *et al.*, 1977). In the Vendée, the Ordovician Chantonnay-Mervent orthogneiss has a similar position. An intermediate unit with metaophiolite occurs in places in the Limousin between these first two units (e.g. Mercier *et al.*, 1985; Dubuisson *et al.*, 1987, 1989).

c) The lower *Unité micaschisteuse*, with shale, metapelite, metagreywacke and a few basic metavolcanic layers (Millevaches, Saint-Goussaud and Dronne area), is similar to the Roc-Cervelle Unit.

The similarities between the Vendée and Bas-Limousin suggest that the terrains that are bounded by the Vendée coal belt and the Sainte-Pazanne-Mervent lineament were tectonically translated from Limousin to Vendée. This took place by the combined dextral displacement of late-Variscan faults, such as the Vendée coal belt and South Armorican Shear Zone. Such a hypothesis is also supported by a positive aeromagnetic axis that extends the Les Essarts Complex to the southeast, under the Jurassic cover as far as Périgueux (Autran and Peterlongo, 1979). Some other connections between the Vendée and Limousin terrains are also plausible: the Chantonnay Synclinorium, on the one hand, and the Thiviers-Paysac (e.g. Guillot *et al.*, 1977) and the Gartempe and Mézières-sur-Issoire Units (e.g. Floc'h *et al.*, 1993), on the other hand; the Saint-Martin-des-Noyers Unit and the Vergonzac Unit; the West-Vendée *porphyroïdes* and the Genis *porphyroïdes*, etc. In Central Vendée, these units were strongly disrupted by late-Variscan tectonism, which makes it difficult to reconstruct the eo-Variscan jigsaw.

On a wider scale, the Vendée and Limousin belong to the eastern part of the Ibero-Armorican arc, which is considered as resulting from a continental collision during the eo-Variscan orogeny (e.g. Bard *et al.*, 1980; Dias and Ribeiro, 1995; Ribeiro *et al.*, 1995; Matte, 1986; see Faure *et al.*, 1997). The eclogite and glaucophanite from the Ibero-Armorican arc have various origins and belong to at least three groups (i.e. "Champtoceaux-like eclogites", "Vendée-like eclogites", "Groix-like glaucophanites": Godard, 1988; Ballèvre *et al.*, 1992). The first group, i.e. the Champtoceaux and Malpica-Tuy eclogite, does not have an oceanic origin. On the other hand, the Vendée and Limousin eclogite, which has a rather clear oceanic origin, apparently belongs to the same high-P belt as the Braganca eclogite (Portugal) and the Cabo Ortegal eclogite (Galicia: see Mendía-Aranguren, 2000).

Pre-Variscan terrains involved in the eo-Variscan convergence

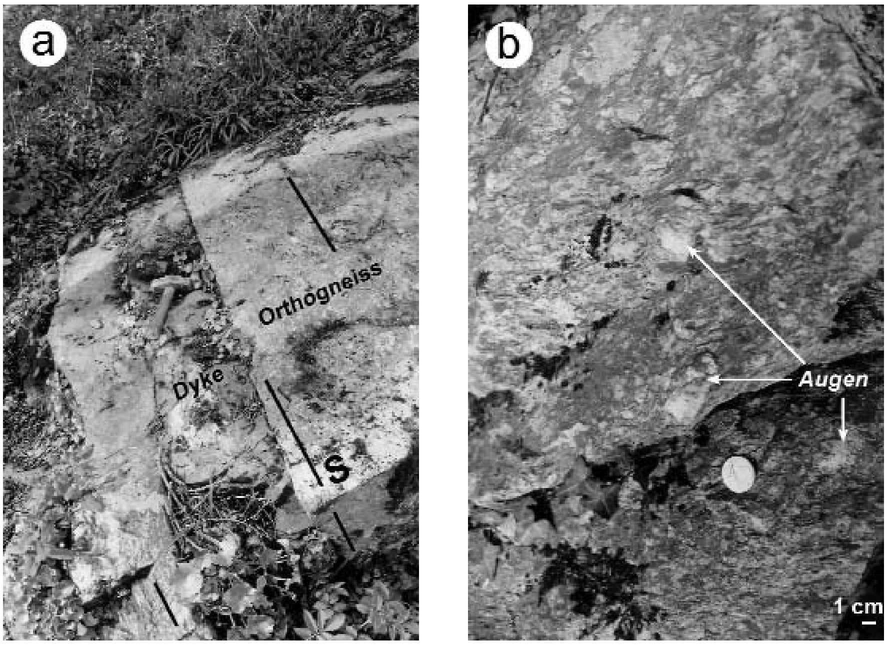
The coronitic paragneiss and orthogneiss have undergone a complex evolution: high-T metamorphism, early retrograde metamorphism, high-P eclogite-facies metamorphism and later retrograde metamorphism. The two high-T and high-P stages likely belong to two distinct orogenic cycles, possibly pre-Variscan and Variscan.

The various and abundant Cambrian-Ordovician orthogneiss, whether affected or not by the later eclogite-facies metamorphism, could represent granitic intrusions related to the end of the earlier cycle. Its age (around 480-495 Ma: Guerrot, unpubl. data) seems to have preceded the high-P metamorphism (around 436 Ma: Peucat *et al.*, 1982a) by about 50 Ma.

It is possible that the eclogite also experienced two orogenic cycles, because it derives from amphibolitized and saussuritized gabbro (Fig. 13) that could correspond to retrograde metamorphism in the earlier cycle. If we assume this hypothesis, the orthogneiss, migmatitic paragneiss and pre-eclogite amphibolitized gabbro could represent the remnants of a complex pre-Variscan continental crust that was partly subducted (i.e. eclogitized) at the beginning of the Variscan orogeny.

However, the Vendée eclogite has many of the geochemical features of oceanic rocks (see "Protoliths", p. 31). The pre-eclogite paragenesis (i.e. the amphibolitized and saussuritized gabbro) and O isotope compositions can be attributed to oceanic metamorphism and alteration (see pp. 33-35). Some paragneiss and ortho-leptynite, intimately interleaved within the eclogite (Figs. 10, 11e, 12a), might also have an oceanic origin. If we accept such an oceanic origin for the eclogite and related rocks, we must explain how these rocks came to be intimately associated with continental orthogneiss and paragneiss. This association could have resulted from a tectonic melange during high-P metamorphism, i.e. during eo-Variscan accretion (Godard, 1983).

Whatever the origin (oceanic or continental) of the Vendée eclogite, the Les Essarts Unit probably represents remnants of pre-Variscan terrains that were involved in the eo-Variscan convergence and accretion. During the Carboniferous, this unit was disrupted by late-Variscan faults, and mixed with other units (e.g. Saint-Martin-des-Noyers, Chantonnay Synclinorium) that record a complex Variscan evolution (e.g. Faure *et al.*, 1997).



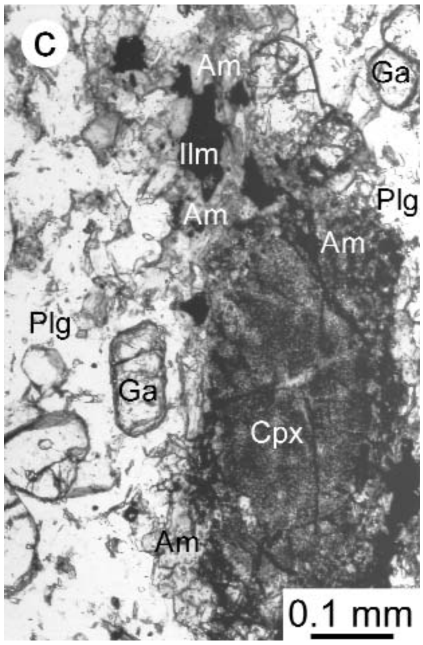


Fig. 25.- Gneissic and mafic rocks that have escaped the eclogite-facies metamorphism.
La Roche-aux-Lutins, near Rocheservière; 307.42-2221.90.
a) Undeformed mafic dyke cutting slightly obliquely across the foliation (S) in the host orthogneiss.
b) Orthogneiss displaying large K-feldspar augen.
c) Mafic dyke. Cpx: schillerized clinopyroxene [Jd_9]; Am: brown amphibole; Plg: plagioclase; Ga: garnet growing from plagioclase; plane-polarized light.

Fig. 25.- Roches gneissiques et mafiques indemnes du métamorphisme éclogitique.
La Roche-aux-Lutins, près de Rocheservière ; 307.42-2221.90.
a) Dyke mafique non déformé recoupant l'orthogneiss selon une direction légèrement oblique sur la foliation (S).
b) L'orthogneiss, montrant de larges augen de feldspath potassique.
c) Dyke mafique. Cpx : clinopyroxène schillérisé [Jd_9] ; Am : amphibole brune ; Plg : plagioclase ; Ga : grenat ayant crû aux dépens du plagioclase ; lumière non analysée.

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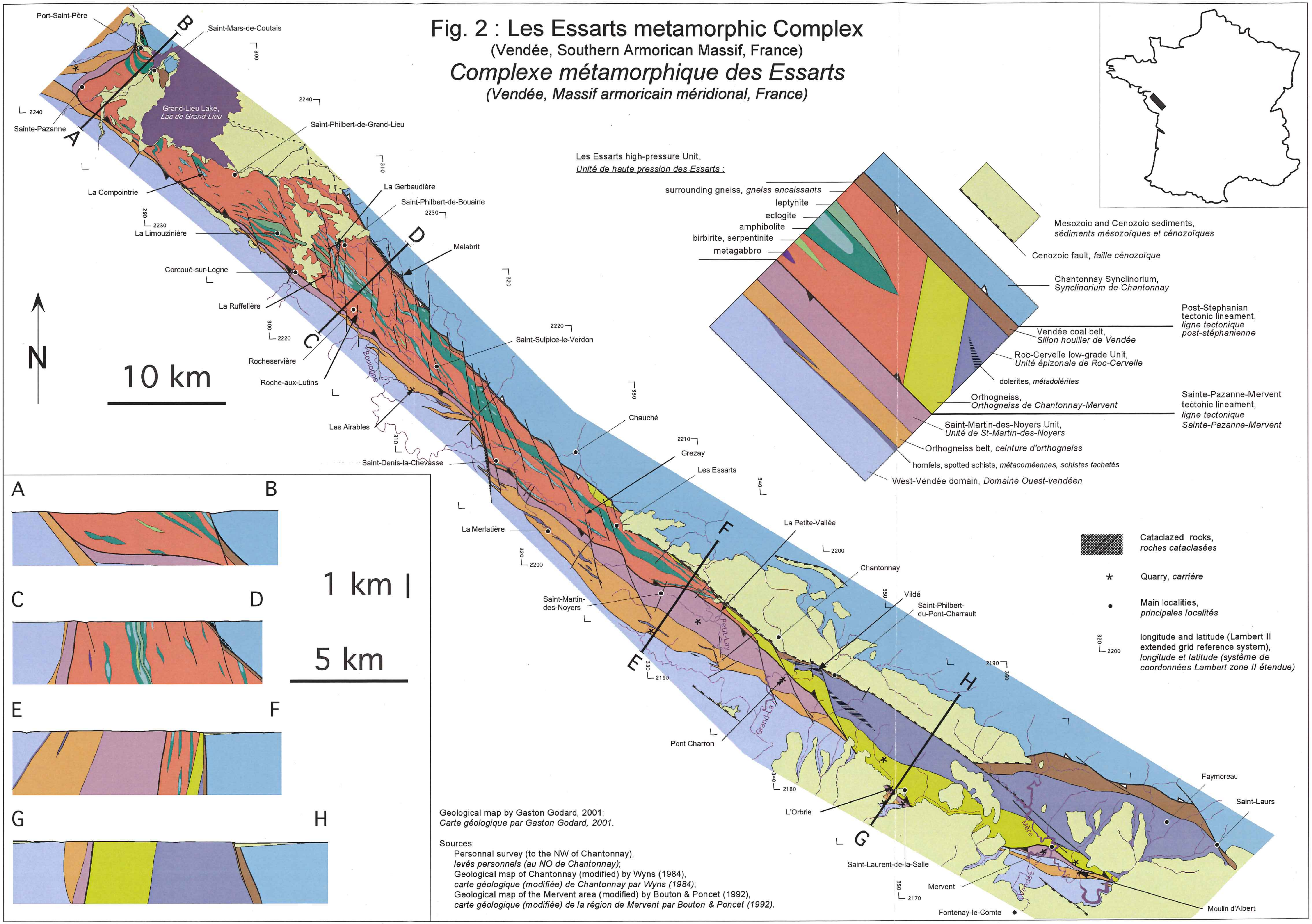
Fig. 2 : Les Essarts metamorphic Complex
(Vendée, Southern Armorican Massif, France)
Complexe métamorphique des Essarts
(Vendée, Massif armoricain méridional, France)



Geological map by Gaston Godard, 2001;
Carte géologique par Gaston Godard, 2001.

Sources:
- Personnal survey (to the NW of Chantonnay), *levés personnels (au NO de Chantonnay)*;
- Geological map of Chantonnay (modified) by Wyns (1984), *carte géologique (modifiée) de Chantonnay par Wyns (1984)*;
- Geological map of the Mervent area (modified) by Bouton & Poncet (1992), *carte géologique (modifiée) de la région de Mervent par Bouton & Poncet (1992).*

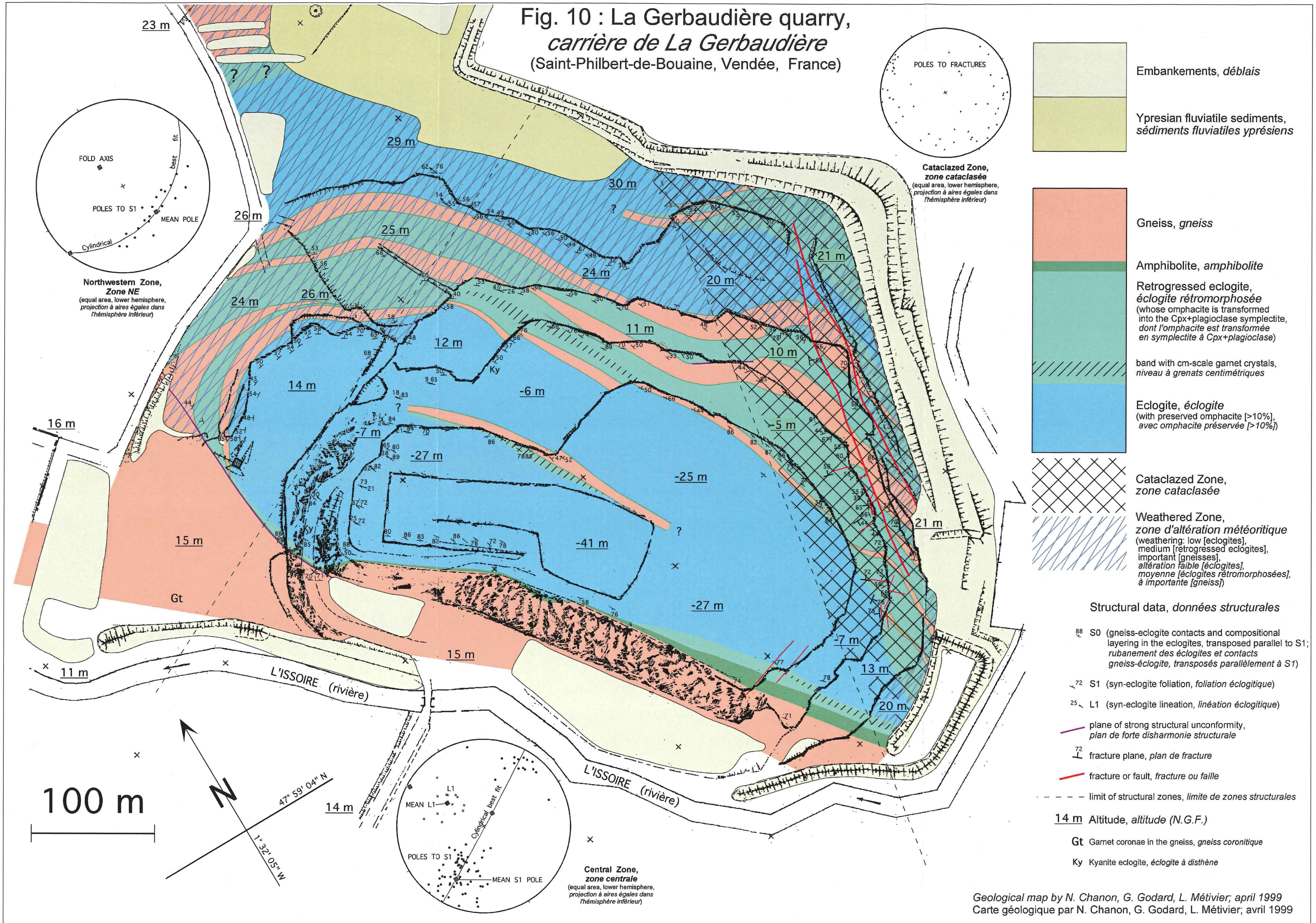


Fig. 10 : La Gerbaudière quarry, *carrière de La Gerbaudière*
(Saint-Philbert-de-Bouaine, Vendée, France)

VOLCANISMES, SÉDIMENTATIONS
ET TECTONIQUES CÉNOZOÏQUES PÉRIALPINS

par

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Document du BRGM n° 291

Les dernières années ont vu des avancées majeures dans la compréhension des relations spatiales, temporelles et de causalité entre le volcanisme, les grandes déformations lithosphériques associées et les pièges sédimentaires induits à l'avant de l'arc alpin. Ces avancées ont permis d'éclairer d'un jour nouveau notre connaissance du sol et du sous-sol du Massif central : synthèse du stratovolcan du Cantal, cartographie par tomographie sismique du sous-sol ou compréhension des processus globaux et de leur répercussion topographique, ne sont que quelques volets de ces progrès.

Ces travaux ont fait l'objet d'une réunion scientifique, co-organisée par le Bureau de Recherches Géologiques et Minières et la Société Géologique de France, à Aurillac du 6 au 10 septembre 1999.

Cet ouvrage regroupe les résumés des contributions scientifiques présentées lors de ces journées ainsi que les guides de deux excursions, la première sur le stratovolcan du Cantal, l'un des plus grands volcans européens et caractérisé par de gigantesques avalanches de débris, et la seconde sur le rift du Massif central.

The last years have seen major scientific advances in our understanding of the spatial, temporal and causal relationships between the alkaline volcanism, associated major lithospheric deformations and resultant sedimentary traps at the front of the Alpine arc.

The major scientific advances on these topics were presented and discussed at a special meeting co-organized by the Bureau de Recherches Géologiques et Minières (BRGM) and the Société Géologique de France (SGF) at Aurillac from 6 to 10 September 1999.

This volume contains (i) the abstracts of the papers presented during the meeting, and (ii) the field guides of the two associated excursions: the first to the Cantal volcano, one of Europe's largest stratovolcanoes that is characterized by gigantic debris avalanches, and the second to the Massif Central Rift.