GRANULITISATION OF FRONTAL NAPPES IN THE KABYÈ MASSIF IN NORTHERN TOGO

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Abstract

The Kabyè Massif represents one of disseminated hills which marks the suture zone of the Panafrican Dahomeyides Belt in northen Togo. Coronitic structures were described in high-grade granulites composing the frontal nappes on the south-western edge of the massif. Granulitisation is investigated through petrofabric study of the frontal nappes rocks of Kabyè Massif. Two stages of granulitisation are revealed: the first one corresponds to the formation of granulites with an Opx + Pl + Cpx + Grt ± Qtz paragenesis ; the second one has a Cpx + Pl + Grt + Qtz ± Ilm mineral assemblage. The former corresponds to metamorphic recristallization of about medium-pressure to high-temperature conditions (P = 10 to 13 kbar and T = 900 with 1000°C). The latter, which developed coronitic structures, is interpretated as formed at an ultra-high-pressure and medium- to high-temperature conditions (P = 13 to 19 kbar and T = 850 to 900°C). These coronitic petro-fabrics define an anticlockwise P-T paths trajectories corresponding to the collision and the beginning of the nappes extraction during the Panafrican tectonics.

Keywords : Granulites, suture zone, Dahomeyides, coronites, Northern Togo

Introduction

In the Dahomeyides Belt in Togo, the Kabyè Massif constitutes, with other basic to ultrabasic massifs (Dérouvarou, Kpaza, Djabatouré, Ahito, Lato, Agou, and Akuse), a narrow suture zone between an external and an internal zones. Located in the northeastern Togo, it is mainly consisting, like other massifs in the suture zone, of high-grade (amphibolite-granulite) metamorphic rocks compatible with a subduction-collision domain. The main foliation (Sn+1) and a tectono-metamorphic evolution of Kabyè Massif display several phases of deformation. The granulite facies metamorphism peak is often masked by the powerful retrograde amphibolite facies metamorphism that followed.

The well exposed Kabyè Massif shows particular interest, because (1) it is one of the most important massifs in the suture zone that is likely to provide more information than the other massifs, (2) it is composed of basic granulites whose importance in the restitution of the conditions of metamorphism at the lower crust is widely recognized nowadays.

Castaing and al, (1993), Attoh and Morgan (2004) showed that this Panafrican suture zone underwent metamorphic transformations of high grade, but these authors proposed different metamorphic peak conditions. Recent studies on the Kabyè Massif Duclaux and al, 2004, 2006; Hilairet, 2004 ; Ménot and al, 2004; Taïrou, 2006; Sabi, 2007) show that the metamorphic peak is observed in the granulite facies, followed by an increasingly retrograde evolution to the greenschist facies. But such granulitisation conditions should be well constrained. The aim of this paper is to reconstitute granulitisation process by analyzing the various deformations and petrographic markers in the frontal nappes of the Kabyè Massif characterized by rocks strongly retromorphosed.

Geological context

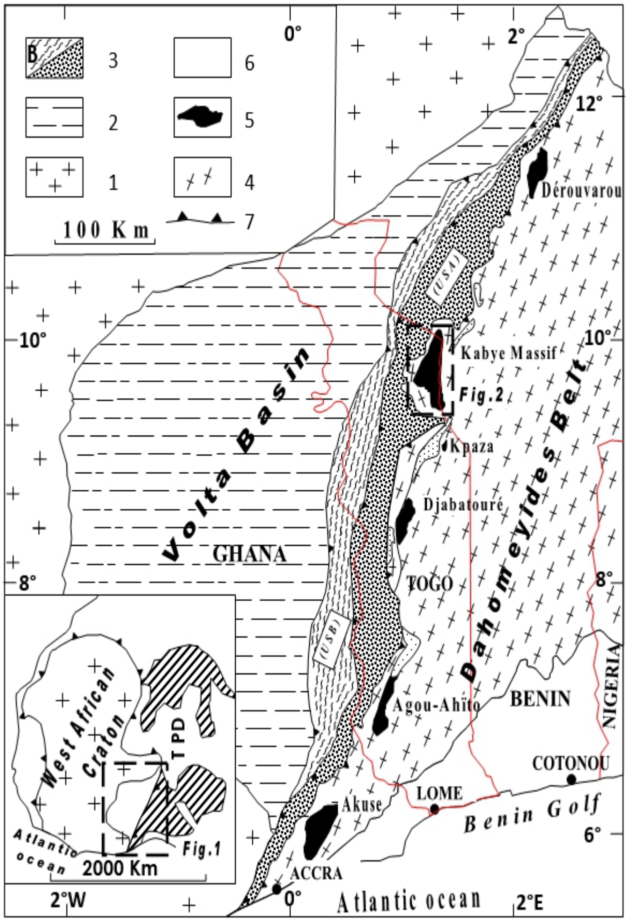
The Dahomeyides collision belt (600 ± 50 My), located at the southeastern boundary of the West African Craton, represents the SW segment of the Panafrican mobile zone (Fig.1). It forms a pile of west verging nappes and slices, grouped in several structural units and subdivided into three zones: an external zone in the West and an internal zone in the East between which a narrow suture zone is intercalated.

The external zone consists of two metasedimentary structural units (Buem structural unit and Atacora structural unit) and one unit corresponding to the Eburnean rocks highly rejuvenated during the Panafrican orogeny (Kara-Niamtougou structural Unit, Amlamé-Kpalimé structural Unit). The external zone overlaps the West African Craton and its sedimentary cover (Fig.1).

The internal zone corresponding to the large benino-Nigerian peneplain is made of granitoid gneiss, migmatite assemblages and méta-volcanosedimentary complexes as well as several Panafrican granitoid intrusions (Caen-Vachette, 1975; Affaton and al, 1991).. It overlaps, either the suture zone, or the external zone.

The suture zone forms a succession of small isolated basic to ultrabasic bodies (Akuse, Agou, Ahito, Djabatouré, Kabyè and Dérouvarou). It is marked by striking positive gravity and magnetic anomalies (Tidjani and al, 1977) and includes high-grade basic rocks of granulite and eclogite type. These metamorphic rocks are associated with metasediments (kyanite bearing quartzites and gneiss), large lenticular pyroxenite bodies (pyroxenolitic metacumulates or fine-grained pyroxenites), carbonatites and retromorphic equivalents of the different rocks (amphibolites, serpentinites, talcschists).

Figure 1: Simplified regional geological map showing the tectonic foreland of the Dahomeyides belt, the main structural units and the suture zone (Affaton, 1990) slightly modified.
1: Paleoproterozoïc basement of the West African Craton; 2: Neoproterozoïc sedimentary sequences of the Volta basin ; 3: Buem structural unit *(USB)* and Atacora structural unit *(USA)* representing the Western part of the external zone of the Dahomeyides belt; 4: Panafrican complex of the Dahomeyides including the Eastern part of the external zone, the suture zone and the internal units; 5: Principal granulitic massifs of the suture zone; 6: Paleozoic to Quaternary sediments; 7: Overlap TPD: "Trans-Saharan Panafrican Domain"; The hatched surfaces represent the grounds affected by the Panafrican orogenesis. The Northern part of the TPD represents the Hoggar mountains



These high-grade rocks represent the dismembered roots of an arc type crust exhumed by Panafrican tangential tectonics, (Caby and al, 1991; Duclaux, 2003; Attoh and Morgan, 2004; Hilairet, 2004). In Togo, the Kabyè Massif, consisting of basic and ultrabasic granulites, represents the northernmost segment of this suture zone.

Lithological characteristics

Two geomorphological units corresponding to three lithostructural sets are distinguished in the Kabyè Massif. The mountainous part of the massif, representing the western geomorphological unit, corresponds to the nappes and slices of the garnet bearing granulites (GLS, GYB). In the East, a lateritic hardpan covered plain with rare residual reliefs extends with outcrops of garnet free dark gray granulites with gabbroic composition (GKS). The contact between these two geomorphological units is marked by the Panalo-Tapoulitchata mylonitic zone ((ZMP), Fig.2).

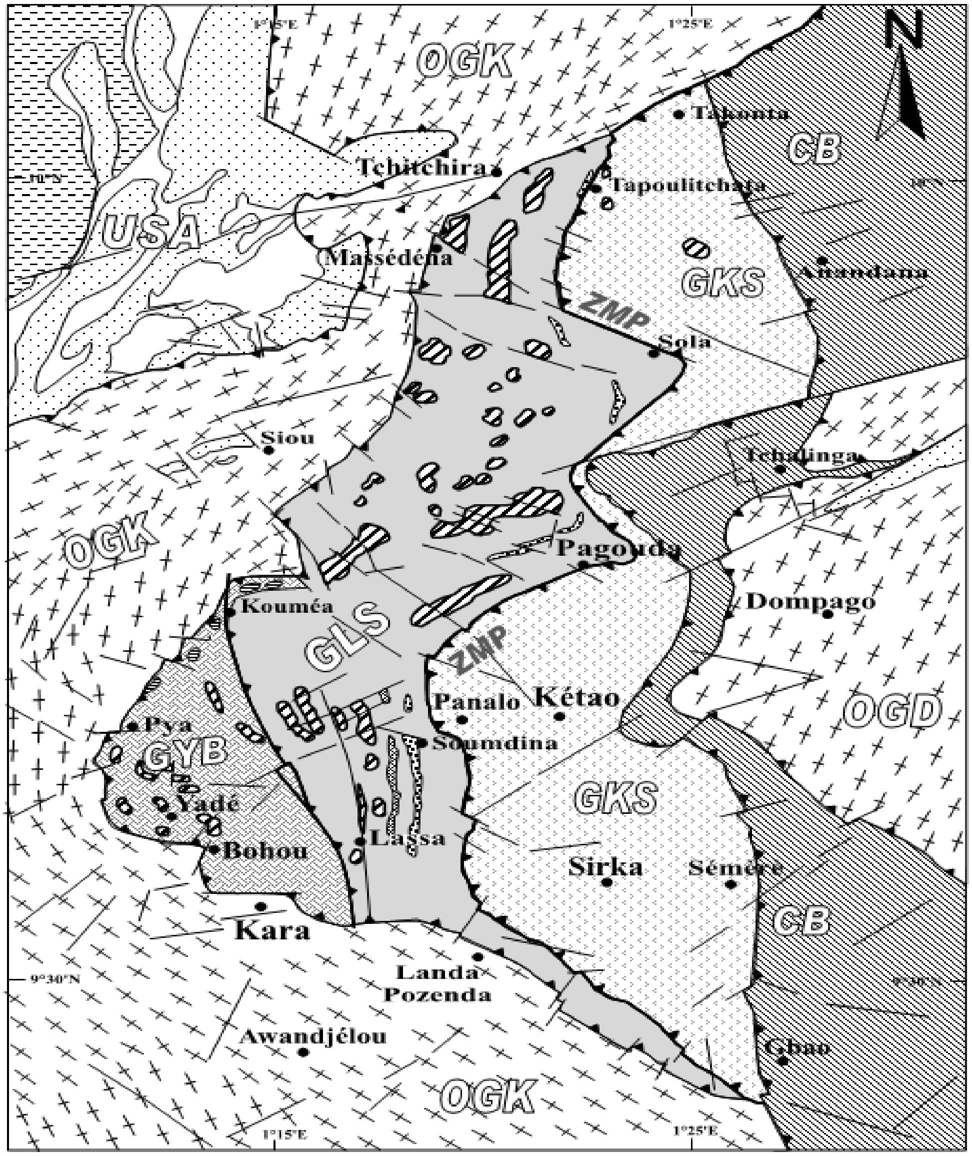
Granulites of the Kabyè Massif are enclosed in orthogneisses of granitic composition representing units of the reworked eburnean basement. The Kara-Niamtougou orthogneisses (OGK) in the West represent the eastern unit of the external zone of the Dahomeyides Belt. The Dompago orthogneisses (OGD) and their western margin represented by the volcanogenic rocks and paragneisses of the Binah complex (CB) constitute units of the internal zone which overlies upon granulites. The later are thrust over the Kara-Niamtougou orthogneisses (Fig.2).

The garnet-bearing granulites (Fig.3a) are subdivided into two sets, the Yadé-Bohou group, mainly built of dark gray garnet-bearing granulites (GYB) in the western part of the massif and the Lassa-Soumdina group, with light gray garnet-bearing granulites (GLS), constituting the eastern part of the mountainous zone. The Kétao-Sirka group (GKS) is entirely made of dark gray garnet-free granulites of metagabbros type (Fig.3b).

The garnet-bearing granulites are dark or light gray colour, fined to medium graineds, and display augen structure showing large pyroxene and garnet clasts in an oriented granoblastic groundmass. These rocks are organized in decimetric to metric banks with distinct foliation made of dark layers of amphibole and pyroxene alternating with light feldspathic layers.

The foliated dark gray Yadé-Bohou granulites are organized in decametric to metric banks, with structure made of an alternation of discontinuous dark amphibole-pyroxene layers and light feldspathic layers. The GYB contains some coronitic granulite panels relatively well preserved in an environment that is strongly structured by an amphibolitic retrograde metamorphism.

Figure 2: Schematic geological map of the Kabyè Massif.
USA = Schists and quarzites of the Atacora structural unit ; OGK = Kara-Niamtougou orthogneiss ; GYB = Yadé-Bohou garnet bearing dark gray granulites ; GLS = Lassa-Soumdina garnet bearing light gray granulites ; GKS = Kétao-Sirka garnet free dark gray granulites (metagabbros); CB = Binah volcanogenic rocks and paragneiss complex ; OGD = Dompago orthogneisses and migmatites ; ZMP = Panalo-Tapoulitchata mylonitic zone



Outcrops of the Kétao-Sirka metagabbros are generally indicated by a thick lateritic cover. They are generally dark gray rocks, with metric cleavage. These rocks display a porphyroclastic texture with large pyroxene and plagioclase clasts in a granoblastic groundmass.

The granulite nappes of the Kabyè Massif show retrograde metamorphic evolution, from the granulite to the greenschist facies. The tectonic contacts within these nappes are characterized by mylonitic amphibolites. Several phases of recrystallization, in relation to the Panafrican tectonics, are highlighted here.

Panafrican deformation in the Kabyè Massif

The tectono-metamorphic history of the Kabyè Massif is marked by at least five folding phases (Affaton, 1987; Affaton and al, 1991a, 1991b, Taïrou, 1995, 2006; Sabi, 2007). The former deformation phase Dn, observed in this sector, is characterized by a Sn foliation relatively well preserved at the western edge of the Kabyè Massif (GYB) or in many enclaves and porphyroclasts disseminated overall the massif (Fig3c). It is followed by a powerful tangential folding phase Dn+1 which affects both basic granulites and the enclosing basement. The Dn+1 deformation, associated with a retrograde metamorphism in amphibolite facies conditions, develops the main Sn+1 schistosity which reorientates, completely sometimes, all the previous imprints (Fig.3d). Thus the granulitic parageneses of the Dn phase are transposed into the new foliation and the principal cleavage of the rocks becomes parallel to the Sn+1 schistosity plane. This phase also develops, on the parting plane, a persistent mineral or stretching lineation Ln+1. The principal thrust contacts are initiated during the Dn+1 phase, thus allowing nappe stacking.

The Sn+1 foliation planes are also affected by isoclinal folds Pn+2 (Fig.3e) well expressed in the thrust zones and especially on the western edge of the Yadé-Bohou granulitic complex, between Pya and Kouméa. The prominent expression of the Dn+2 phase in the zones mentioned above can be explained by the resumption of the thrust contacts initiated during the Dn+1 phase and by the superposition of a dextral shearing. This shearing also appears on a reduced scale in Cn+2 micro-planes which displace the layers of the Sn+1 schistosity (Fig.3f).

The last episodes (Dn+3 and Dn+4) of the Panafrican compression appear as folds with large radius of curvature Pn+3 or Pn+4 and by virgations (Affaton, 1990; Taïrou, 1995; Taïrou, 2006) indiscriminately affecting all the units of the Dahomeyides Belt. The Panafrican tectonics is also expressed by an intense fracturing organized in conjugate systems (Taïrou and al, 2009).

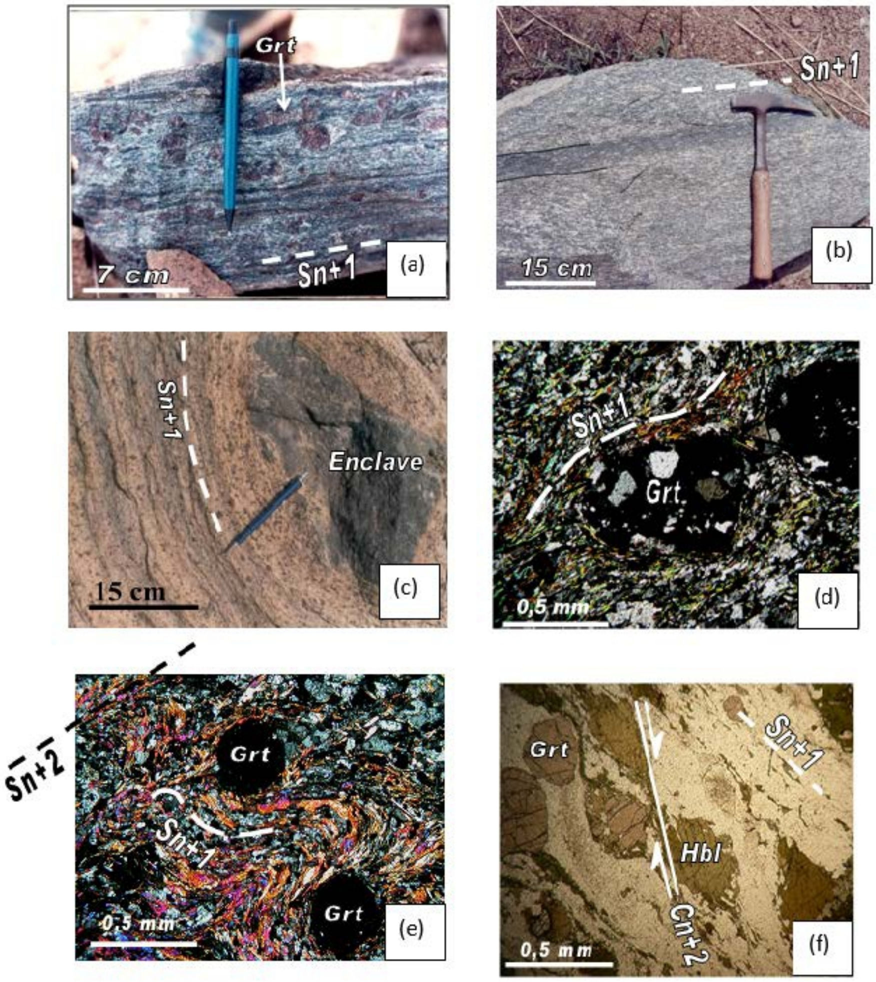


Figure. 3 Petrostructural characteristics of Kabyè Massif granulites
(a) : garnet bearing granulite showing Sn+1 foliation (schistosity) clearly expressed ; (b) : garnet free dark gray granulites with principal foliation Sn+1; (c) : wedge of older rock moulded by Sn+1 foliation; (d) : garnet clast (Grt) reorientated by Sn+1 foliation; (e) : Sn+2 schistosity by deformation of Sn+1 foliation; (f) : Cn+2 micro-shears displacing Sn+1 foliation

Tectono-metamorphic evolution of the frontal nappes of the Kabyè Massif

After their emplacement at the base of the continental crust (900 to 700 My), the basic magmatites were variously involved in a process of metamorphic recrystallization. The metamorphism peak was attained in the granulite or eclogite facies and is later retrogressed to the greenschist facies. In this paper, our investigations are just concerned the evolution of granulite facies metamorphism of these rocks.

The retromorphosed granulites in the Kabyè Massif, are characterized by a principal foliation (Sn+1) underlined by an alternation of green hornblende beds and plagioclase. These rocks show a symplectitic association of the mineral components, where one can follow the regressive evolution of the metamorphic conditions from granulite facies to the greenschist facies. The earliest granulitic foliation (Sn) was largely obliterated by the succeeding powerful retrogressive metamorphism of (Dn+1) phase. Nevertheless, an analysis of certain deformation markers allow to highlight several stages during this granulite facies recrystallization (Table1).

Phases		Granulite 1	Granulite 2	
Deformation		Anté-Dn	Dn	
Imprints		Unknown	Sn	-
Stages of recrystallization		Ante-Sn	Syn-Sn	Post-Sn
Hypersthene	Opx_0			
	Opx_1			
Clino-pyroxene	Cpx_1			
	Cpx_2			
Plagioclase	Pl_0			
	Pl_1			
	Pl_2			
Garnet	Grt_1			
	Grt_2			
Quartz				
Rutile				
Ilmenite				
Kyanite				

Table 1: Mineralogical evolution during the granulite facies metamorphism in the Kabyè Massif complex.

The early granulite 1 phase (ante-Dn stage)

It is represented by hypersthene porphyroclasts (Opx_0) and plagioclase (Pl_0) which constitute the oldest mineral assemblage still recognizable in these metabasites (Fig.4a and fig.4b). The absence of all previous imprints acquired by these porphyroclasts and their big size, would favour a magmatic origin since the cooling of a magma can take place under granulitic conditions. But the metamorphic origin of the orthopyroxene was clearly mentioned (Agbossoumondé, 1998), based on chemical data, in the same structural context in the South of the suture zone.

The granulite 2 phase

It is associated to Dn deformation and is broken down into two stages: 1) the syn-Sn stage and 2) the post-Sn stage.

The syn-Sn stage

A coarse foliation Sn, often dislocated by the more recent phases, is the oldest deformational imprint still preserved in the Kabyè mafic rocks. The mineralogical assemblage is : Hyp + Pl + Cpx + Ilm ± Grt ± Qtz.

$Opx_0 + Pl_0 = Cpx_1 + Pl_1 \pm Qtz \pm Opx_1$

$Opx_0 + Pl_0 = Cpx_1 + Pl_1 \pm Ilm \pm Opx_1$ (for garnet-free granulites, Fig.4C)

$Opx_0 + Pl_0 = Cpx_1 + Grt_1 + Pl_1 \pm Qtz_1$ (for garnet-bearing granulites, Fig.4d, Fig. 4f)

The hypersthene Opx_0 and Opx_1 do not present any petrographic difference and this notation simply allows to distinguish the initial mineralogical assemblies from those after transformation. Opx_1 form smaller grains in the Sn foliation. Former work (Agbossoumondé, 1998) showed, in the Agou massif case, that the two type of hypersthene have been chemically re-equilibrated during the granulite facies metamorphism (same Mg # ratio = 100*MgO/MgO+FeOt+MnO).

The post-Sn stage

It is developed in rocks of frontal slices of Kabyè Massif especially in Yadé-Bohou granulites (GYB). The rocks are characterized by high-grade corona textures. The analysis of mineral relations shows that this coronitisation succeeds the syn-Sn recrystallization. In the garnet-free granulites only one Cpx rim, associated with rare ilmenites (Ilm) and quartz (Qtz), surrounds Opx porphyroclasts (Fig.4c). Garnet-bearing granulites show a double rim around Opx porphyroclasts, an internal diopside rim and an external garnet rim (Fig 4d). Thus in Sn foliation, the old Opx blasts and Pl coexist with the new crystalline phases represented by clinopyroxene (Cpx), garnet (Grt) and rare quartz (Qtz) according to the reaction:

$Opx_1 + Pl_1 = Cpx_2 + Pl_2 \pm Ilm \pm Qtz$ (Fig.4c)

$Opx_1 + Pl_1 = Cpx_2 + Grt_2 + Pl_2 \pm Qtz_2$ (Fig 4d)

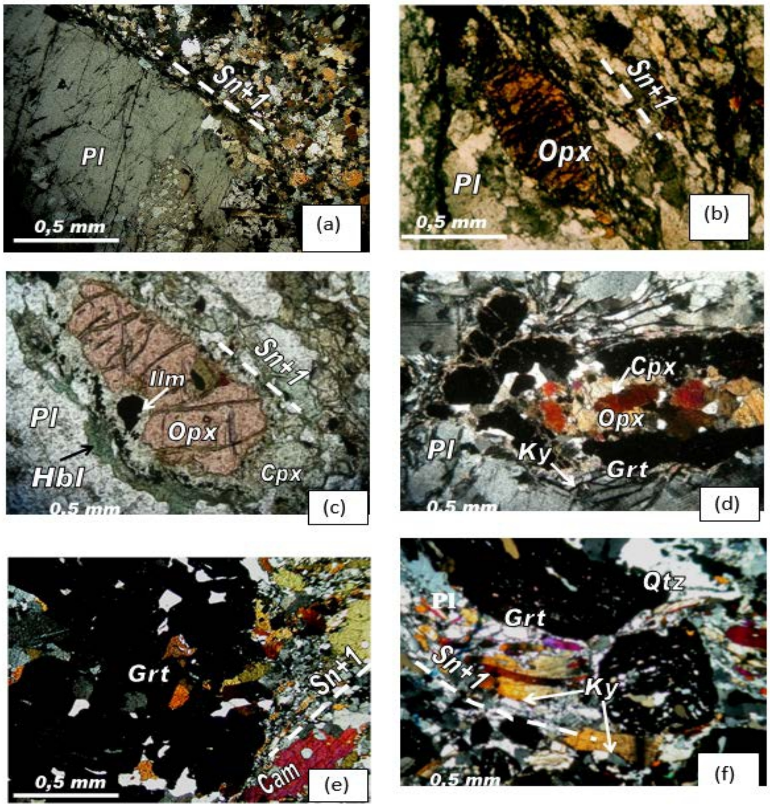


Figure 4 Microscopic imprints of ante-Dn, syn-Dn, and post-Dn deformations in garnet-bearing granulites (A) : plagioclase porphyroclasts (Pl) ante-Dn by principal Sn+1 foliation ; (b) : porphyroclasts of orthopyroxene (Opx) transposed Sn+1 foliation ; (c) : reaction rim around hypersthene (Opx) ; (d) : double corona rim around Opx claste ; (e) : post-Sn poecilitic garnet surrounded by Sn+1 schitosity ; (f) : Ante-Sn+1 kyanite (Ky) in kyanite-bearing gneisses associated with garnet-bearing granulites

Studies of coronitic Cpx_2 of the Agou and Akuse massifs (southern part of the suture zone) show their enrichment in Al and Na compared to Cpx_1 related to high contents of jadeite in Cpx_2 (Agbossoumondé, 1998 ; Attoh, 1998) representing an increase in pressure during coronitisation.

These corona textures thus constitute rebalancing reactions between hypersthene (Opx) and plagioclase (Pl) subjected to compression. The increase in pressure during the post-Sn stage is also confirmed by the crystallization of kyanite (Ky) in plagioclase (fig. 4d).

3 An = 1 Grossularite + 1 Qtz + 2 Ky (Bucher and Frey, 1995)

An + Grt_1 + Qtz_1 = Cpx_2 + Ky (Bucher and Frey, 1995)

The apparition of kyanite in the acid gneisses during the post-Sn stage, preceeding the Dn+1 deformation, confirms this overpressure (fig. 4f).

This increase in pressure was also observed in the internal nappes of the Dahomeyides Belt where it was rather attributed to the transpressional movements along the Kandi fault (Castaing and al, 1993) probably contemporaneous with collision.

Discussion

Metamorphism in the Kabyè Massif is polyphase and increasingly retrogressed from the peak of the granulite facies. The various granulitic assemblages (Opx, Cpx, Grt, Pl) recristallize under amphibolite facies conditions (Cam, Czo) and finally to greenschist facies conditions (Sabi, 2007).

The peak metamorphic conditions in the Kabyè Massif, dated at 612±0,8 My (Affaton and al, 2000), are associated with the Panafrican collision (Dn phase) which shows several stages and allowed the individualization of nappes and slices. Whereas certain scales are gradually exhumed, others are found more and more deeply burried because of crustal thickening thus inducing additional constraints and overpressure allowing the formation of the coronites.

In the Kabyè Massif, the conditions of an eclogite facies metamorphism were apparently not attained as in other segments of the suture zone (Ménot and Seddoh, 1985; Agbossoumondé and al, 2001 Attoh, 1990, 1998; Guillot and al, 2004). The peak of metamorphism associated with the Dn phase is increasing generally from East to West in the Dahomeyides suture zone.

The peak metamorphic pressures in the Kabyè Massif were estimated at 18±3 kbar, and temperatures up to 850°C in the western assemblage of the GYB against only 10.4 to 13.2 kbar and 780°C to 940°C in the GLS and GKS (Duclaux and al, 2004 Hilairet, 2004). These lower metamorphic conditions in the eastern assemblage (GLS and GKS) are in conformity with those described somewhere else (Agbossoumondé, 1998 ; Ménot and al, 2004). The stability field of the orthopyroxene (Opx) in the metabasites is generally defined for temperatures higher than 800°C and pressures lower than 12 kbar (Pattison, 2003). The increase in pressure during metamorphism leads hypersthenes (Opx) and plagioclases (Pl) to react with each other to form a reaction rim around Opx. Thus the syn-Sn stage described above would correspond to conditions of pressure lower than 12 kbar (before coronitisation) and the post-Sn stage, associated with coronitisation, at pressures bordering on 18 kbar. The absence of corona textures in the eastern assemblage of the Kabyè Massif could be partly explained by the weak conditions of pressure but also by the intensification of deformation which could have dislocated these structures there.

Of the two types of corona textures described in the Kabyè Massif, some ones are anhydrous rims (Opx + Pl = Cpx_2 + Grt_2,) therefore of high-grade (HP-HT) others hydrated rims within which clino-amphibole (Cam) is formed (Cpx_2 + Pl = Hbl). If the development of the anhydrous coronites testifies to an overpressure associated with the collision, those hydrated could be associated with a cooling following the extraction of the nappes.

The corona textures led to understand the process of mass transfer and to deduce, when possible, pressure and temperature conditions favorable for these reactions.

After the peak was reached in the Dn phase, metamorphism decreases everywhere, during exhurmation of granulite facies rocks and nappe stacking (Fig. 5).

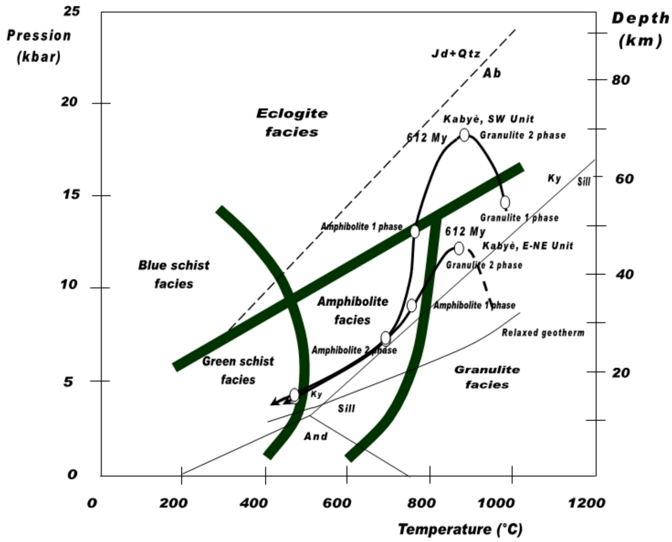


Figure 5: P-T path evolution of the basic and ultrabasic lithostructural units of the Kabyè massif. According to Hilairet, (2004), modified (Field of the metamorphic facies according to Spear, 1995; fields for aluminosilicates according to Holdaway, 1971, Jd+Qtz=Ab according to Holland, 1983; relaxed geotherme according to Duchêne and al, 1977).

Conclusion

In the Kabyè Massif, the imprints of the collision and postcollisionnal phases are relatively well represented and allow us to constrain the tectono-metamorphic history of the massif (Taïrou, 2006 ; Sabi, 2007). All the rock groups underwent the different stages of panafrican deformation but few rock enclaves were only partially affected. The isolation of large coronitic granulite panels preserved at the western front of the massif shows that they were also better preserved with respect to the vigorous tangential phases Dn+1 and Dn+2 which deeply affected all parts of the massif and the Dahomeyides Belt. The absence of corona textures in the eastern part (GLS, GKS) can be explained by the peak metamorphic conditions and the degree of the implication of these rocks in the different phases of nappes and crustal slices formation and their stacking.

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