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Petrostructural and Geochemical Characteristics of the Metamagmatites in the External Zone of the Dahomeyides Belt: Case of the Kantè Serpentinites (Northern Togo)

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Abstract

Thanks to detailed field investigations, microstructural and geochemical analysis and relationship with enclosing rocks, microfabrics, magmatic typology and metamorphic evolution of the Kantè sepentinites have been specified for the first time. The Kantè serpentinites in northern Togo constitute a mega-lens of ultrabasic rocks tectonically intercalated in the sericite chlorite schists of the Atacora structural unit. The brecciated, schitotose or massive rock facies are strongly marked by an S1 schistocity plane superimposed by a flat C shear plane linked to a west vergence thrusting movement. The parageneses that compose the metamagmatites are essentially serpentinous, containing plagioclase, opaque minerals (magnetite, chromite, spinel) and pyroxene porphyroblasts. These microfabrics represent relics of a probable gabbroic protolith. In fact, the geochemical characteristics of the Kantè serpentinites suggest that their magmatic typology is that of komatiites or tholeiitic basalts with oceanic arc affinities. They would have been emplaced in an active margin environment. The retromorphic evolution of the protolith corresponds to the phase of involvement in a major tangential contact during the panafrican tectogenesis.

Keywords

Tectogenesis, Microfabrics, Serpentinites, Panafrican, Northern Togo

1. Introduction

Rocks of magmatic origin occur in the metasedimentary units in the external zone of the Dahomeyides belt. These greenstones are defined as metabasalts, serpentinites and prasinites associated with talcschists and chromitites [1] [2] [3]. They correspond to thrust outliers of intrusive volcanic bodies of voltaian ocean floor imbricated in the metasediments during the panafrican tectogenesis (600 ± 50 My).

Although reported on geological maps, the metamagmatites have been little studied except those of the Buem structural unit in the north of Benin [4] and the southeast of Ghana [5]. In the particular case of the Kantè serpentinites, the investigations of the Togolese Bureau of Mines and Geology [6] were carried out in the framework of search for the probable associated metal bearing indications. Recently, some data on chromiferous spinels were obtained by [7].

The purpose of this work is to characterize structural markers in the Kantè serpentinite outcrops, clarify their magmatic affinities and propose a geodynamic context of their emplacement. For this purpose, detailed field investigations to collect petro-structural data, thin sections for microfabric study and chemical analysis of thirteen (13) samples for major element content have been done.

2. Geological Setting

2.1. Regional Geological Context

The geological setting of the Kantè serpentinites (Northern Togo) corresponds to the external units of the panafrican Dahomeyides belt (**Figure 1**) The Dahomeyides orogen represents the southern segment of the trans-saharian mobile zone. It is considered as the ultimate result of the collision between the oriental shield of the Benino-Nigerian metacraton and the margin of the West African Craton (WAC) [8] [9] [10]. It is a nappe pile with west vergence, thrust on the neoproterozoic cover of the Volta basin.

The lithostructural sets occurring in the Panafrican Dahomeyides belt are repartitioned, from west to east, in the external, suture, and internal zones [9].

The external zone consists of two types of nappes:

- Sediments and anchi- to epizonal metasediment nappes occur in the Buem and Atacora structural units, and correspond to tectono-metamorphic equivalents of the lower and middle megasequences of the Volta basin [11] [12];
- Orthogneissic nappes constituting the Kara-Niamtougou, Mo, Amlame-Kpalime or Ho units, and defined as eburnean plutono-metamorphic suites, highly remobilized by panafrican thermo-tectonics ([13] [14] [15]).

The external nappe pile is overthrust by the granulitic or eclogitic sets found in the submeridian string of hills (Derouvarou massif, in the north-west Benin, Kabye, Kpaza, Djabatoure-Anie, Agou-Ahito massifs, in Togo, Akuse or Shai massif, in the south-east Ghana) materializing the suture zone [16] [17] [18]. These highly metamorphosed basic and ultrabasic rock suites underline the thrust front of the benino-nigerian metacraton on the occidental nappe piles. They are outliers of an important crustal thickening related to the building of the Dahomeyides orogen [13] [19].

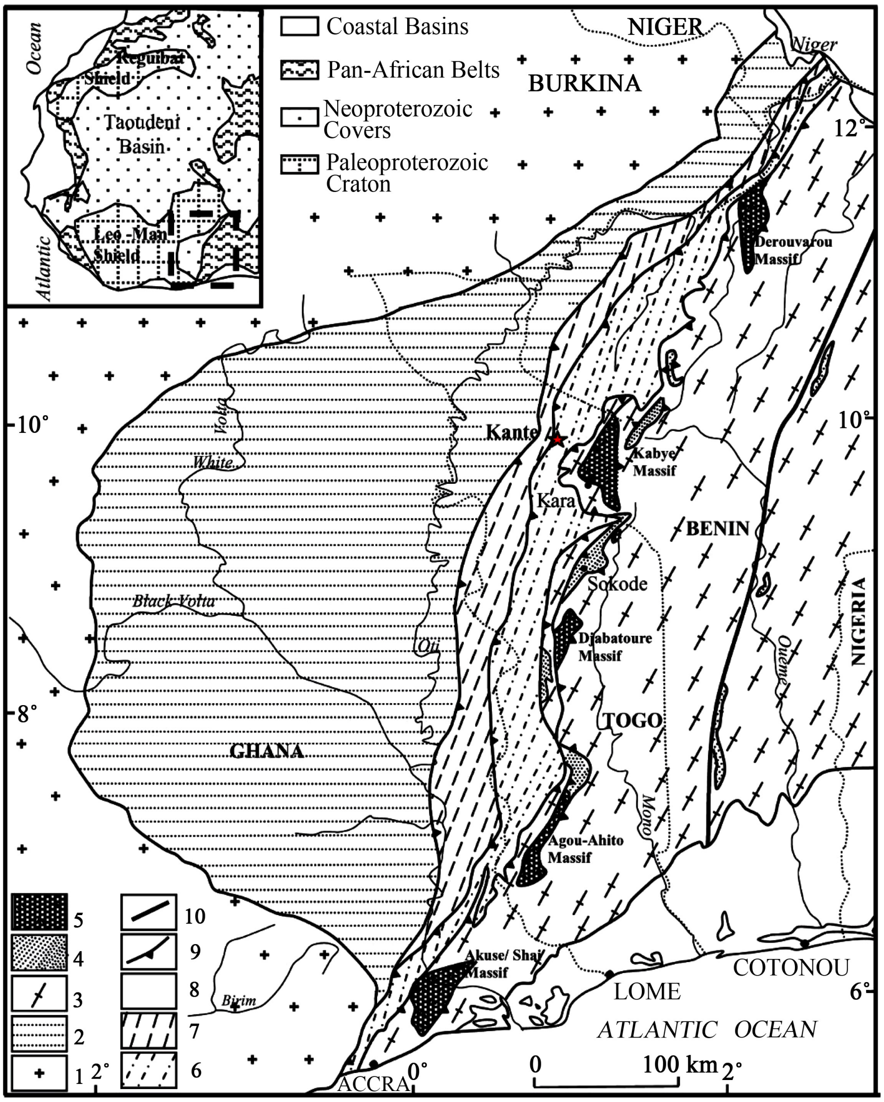

Figure 1. Schematic geological map of the Volta basin and the frontal part of the Dahomeyides belt with the location of the Kantè serpentinites (red star); 1 = Eburnean substratum of the WAC; 2 = Neoproterozoic to Paleozoic cover of the Volta basin; 3 = Internal and external gneiss-migmatitic units; 4 = Micaceous kyanite bearing quartzites; 5 = Basic to ultrabasic massifs of the suture zone; 6 = Atacora structural unit; 7 = Buem structural unit; 8 = Meso-cenozoic basin of the Guinea Gulf; 9 = Thrust contact; 10 = Kandi fault mylonitic zone.

The internal units occurring in the benino-nigerian metacraton are described as gneisso-migmatitic and granitic complexes associated with meta-volcanosedimentary belts [9] [20] [21] [22]. These lithostructural sets result from involvement of a wide eburnean or paleoproterozoic domain during panafrican remobilization.

Structural markers in the Dahomeyides belt indicate five deformation phases designated Dn and Dn+1 to Dn+4 [2] [23]. The Dn phase is contemporaneous with the collision between the southeastern margin of the WAC and the benino-nigerian metacraton, 612.5 ± 0.8 My ago [24]. It is associated with a granulite facies metamorphic peak defined by parageneses stressing Sn foliation that is generally obliterated by subsequent planar structures [18] [22]. The Dn+1 phase corresponds to nappe emplacement with west vergence. It is expressed by an amphibolite or greenschist facies retromorphosis and corresponds to the main or regional Sn+1 foliation. The last three phases (Dn+2 to Dn+4) represent post-nappe folding and fracturing phases related to the last tightening episodes [3].

2.2. Local Geological Context of the Kantè Serpentinites

In a limited context (**Figure 2**), the Kantè serpentinites occur in schists belonging to the occidental Atacora sub-unit ("Kama sub-unit" of [25] or "Atacora schists" of [2]. This sub-unit overthrusts the Buem structural unit and is in turn overlapped by the quartzitic Atacora sub-unit ("Atacora Quartzites" of [2]). The "Atacora Quartzites" tectonically carry the orthogneissic nappes of the Kara-Niamtougou unit on which the granulitic nappes of the Kabye Massif are thrusted [18] [26].

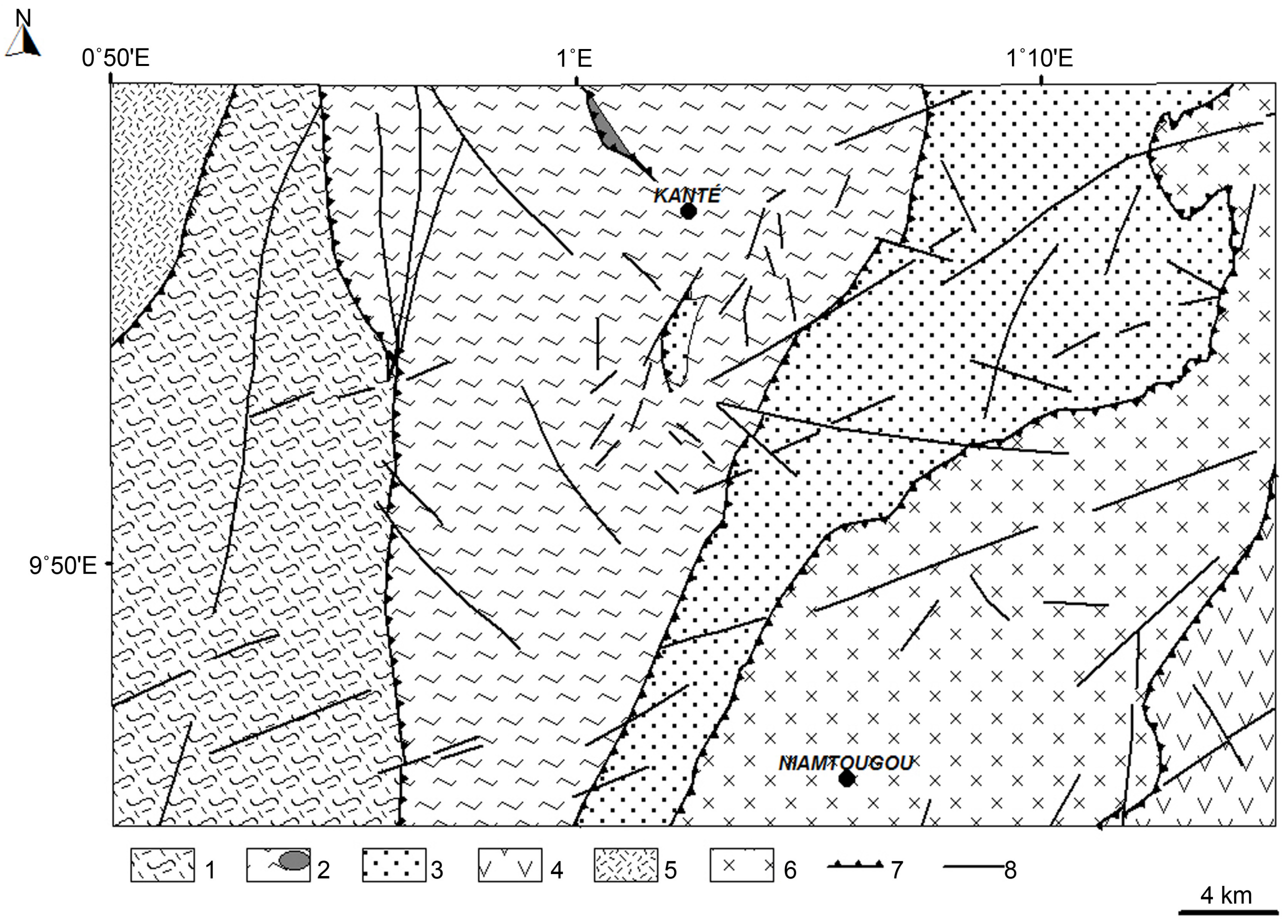

Figure 2. Specific geological context of the Kantè serpentinites (extract from 1/500,000 geological map of Togo by [1]). 1 = Buem structural unit; 2 = Occidental Atacora sub-unit ("Atacora Schists"), with the Kantè serpentinites; 3 = Oriental Atacora sub-unit ("Atacora Quartzites"); 4 = Granulitic suite of the Kabye Massif occidental thrust front (Suture Zone); 5 = Part of the eastern border of the Volta basin; 6 = Kara-Niamtougou orthogneissic unit; 7 = thrust contact; 8 = fracture.

3. Main Petrostructural Characteristics

The detailed cross-section in Figure 3 shows that the serpentinites form a big lenticular body tectonically enclosed in the schists. Contrary to the clearly outcropping serpentinites, the schistose country rock only occurs in deep gullies in an environment with wide-spreading debris of exsudation quartz. Thus, on the thrust sole or back of the serpentinites, sericite schists, or sericite chlorite schists exist in beds often associated with quartz vein boudins. Their cleavage corresponds to the N150˚ to N180˚ S1 schistocity plane with medium to high (55˚ to 80˚) east dips (Figure 3).

The serpentinite outcrops are distinguishable by their jagged aspect, their generally greenish grey colour and strong structuring (Figure 4). They are composed of three main rock facies: 1) a dark massive facies, rich in antigorite, and appearing as decimetric to metric bodins. 2) a lighter, brecciated facies with a yellowish green patina, a schisto-lenticular cleavage and rich in chrysotile fibers, and 3) a very finely schistified facies, with a purplish or ferruginous patina and belonging to the thrust sole of the entire serpentinite lens. All these facies are structured by a schistocity plane, S1, N130˚ to N160˚ with 45˚ to 55˚ NE dip, on which is superimposed a shear plane C, with low (15˚ to 35˚) NE dip (Figure 3). This flat shear plane signifies an overthrusting movement toward the west.

Under the microscope, all the rocks present a porphyroblastic texture, with relics of plagioclase, pyroxene and opaque minerals in an oriented groundmass with antigorite, chrysotile and talc in places (Figure 5). The plagioclasic porphyroblasts with strong deformation signs show undulatory polysynthetic twin and rolling extinction (Figure 5(a)). They appear in isolation or in clusters molded by the S1 schistocity and trapped between consecutive shear planes.

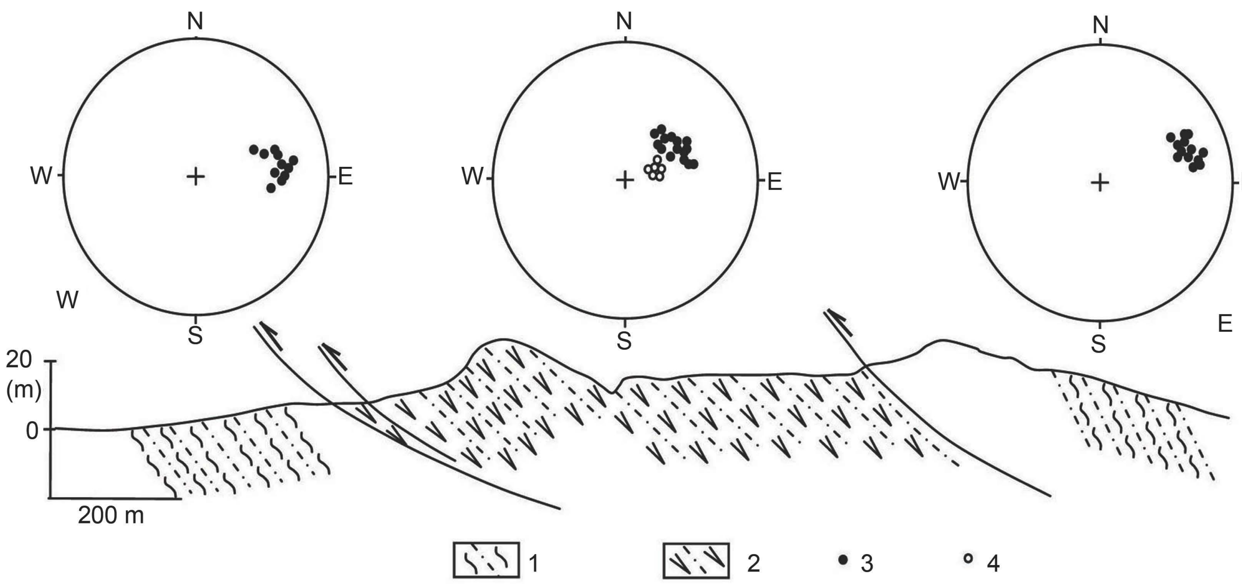

Figure 3. Scheme of detailed cross-section showing the structural relations between the serpentinites and their schistose enclosing rocks ("Atacora Schists"). 1 = sericite chlorite schists, 2 = serpentinites, 3 = pole of S1 plane, 4 = pole of C planes (the stereograms result from upper hemisphere projection).

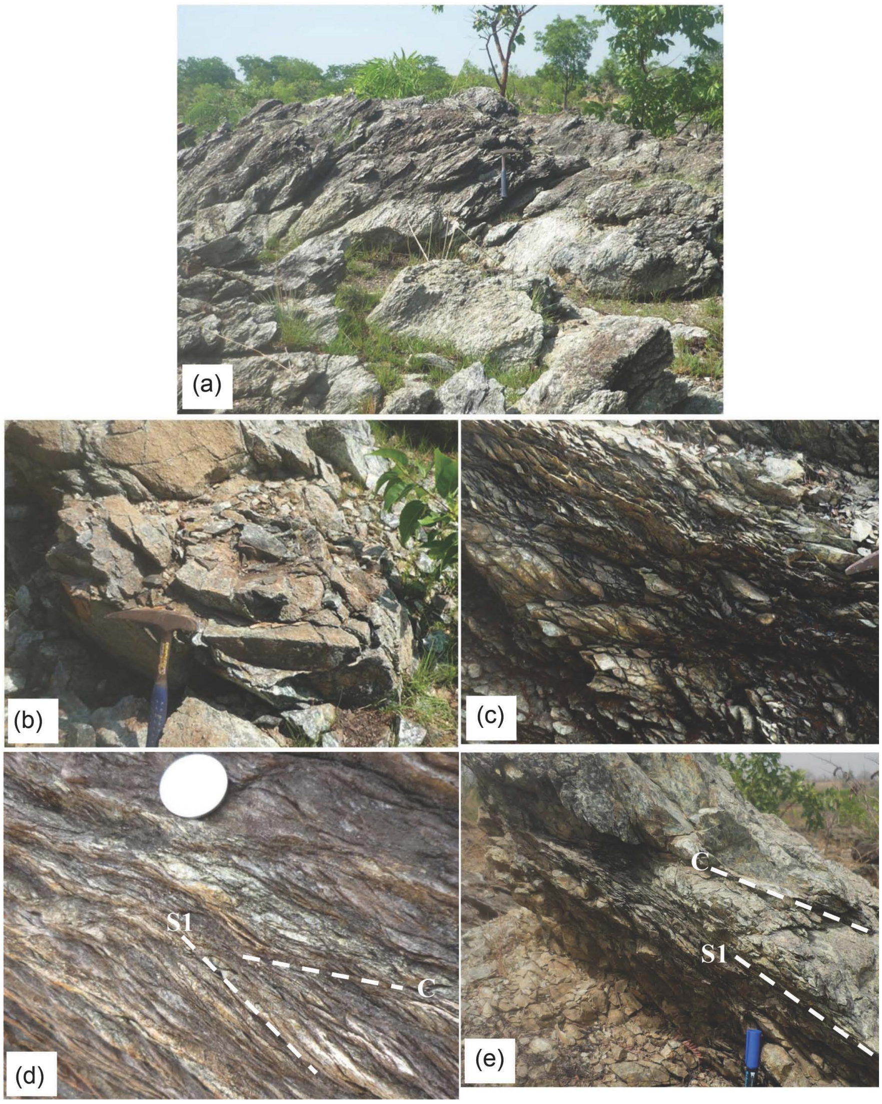

Figure 4. Main petro-structural characteristics of the Kantè serpentinites outcrops. (a); the generally jagged aspect of outcrops, (b); facies of massive rock constituting a fractured boudin, (c); brecciated rock facies, (d); schistose rock facies with S1 and C planes (flat shear plane related to overthrusting) which appears roughly on the other facies (e).

Small, rare ovoid relics of pyroxene occur in a state of advanced retromorphosis forming talc and serpentine (**Figure 5(b)**). Opaque clusters (magnetite, chromite and spinel, according to [7] are also molded by the S1 schistosity. Thus, all these relics are witness of the protolith involved in the panafrican tectogenesis to which should be associated the S1 and C plane development.

4. Geochemistry of the Kantè Serpentinites

The serpentinites results (**Table 1**) show a very high loss on ignition (3.36 to 15.09 wt%). This high value of the loss on ignition indicates a very extensive alteration of the samples harvested. To reduce the effect of this alteration, the oxide contents of the major elements were recalculated relative to the sum of

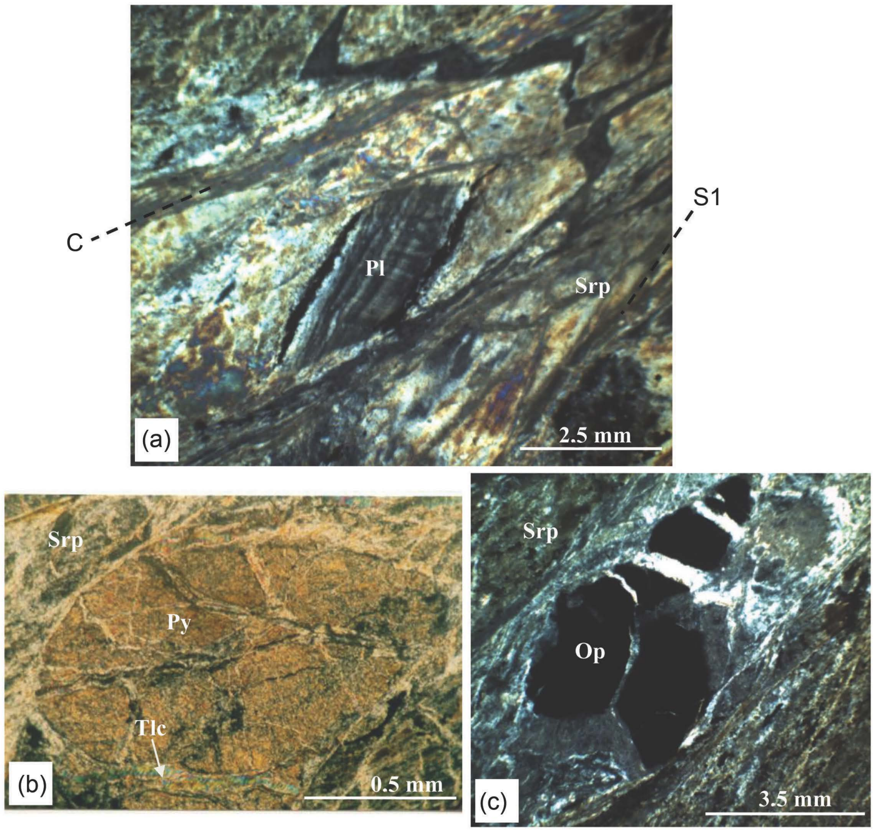

Figure 5. Microphotographs of Kantè serpentinites showing S1 and C planes structuring intimately the rocks (a) and microfabrics of the ante-tectonic relics of plagioclase (a), pyroxene (b), and opaque minerals (c). Op = opaque minerals, Pl = Plagioclase, Py = pyroxene, Srp = serpentine minerals (antigorite and chrysotile), Tlc = talc.

Table 1. Chemical composition of the Kantè serpentinite samples (the oxide contents of the major elements were recalculated relative to the sum of these contents reduced to 100% without the loss on ignition for each sample).

	W17	W32	W33	W34	W35	W36	W37	W38	W39	W40	W41	W42	W43
SiO_2	43.48	46.84	45.60	45.58	46.74	48.89	49.37	46.53	48.82	49.37	48.44	48.69	47.18
TiO_2	0.36	0.02	0.05	0.03	0.02	0.04	0.02	0.03	0.04	0.03	0.03	0.03	0.03
Al_2O_3	6.59	1.22	1.81	1.06	0.92	1.92	1.06	1.49	1.04	1.08	0.98	1.06	1.11
Fe_2O_3	46.48	6.47	7.65	9.02	7.40	8.35	6.16	7.43	7.33	6.45	6.61	6.80	6.86
FeO	1.01	1.01	1.01	1.03	1.02	1.02	0.99	1.03	1.02	1.00	0.99	1.01	1.01
MnO	0.20	0.10	0.10	0.07	0.08	0.10	0.11	0.12	0.10	0.09	0.08	0.10	0.07
MgO	0.37	44.17	43.64	43.07	43.68	39.51	42.14	43.19	41.50	41.83	42.71	42.14	43.55
CaO	0.09	0.04	0.03	0.02	0.02	0.06	0.03	0.05	0.04	0.04	0.05	0.05	0.06
Na_2O	0.03							0.01	0.01			0.01	
K_2O	1.15												
P_2O_5	0.10	0.01		0.01			0.01	0.01					0.01
	100	100	100	100	100	100	100	100	100	100	100	100	100
FeOT	47.49	7.48	8.66	10.05	8.42	9.37	7.15	8.45	8.35	7.45	7.60	7.81	7.87
FeOT/MgO	127.087	0.169	0.198	0.233	0.193	0.237	0.170	0.196	0.201	0.178	0.178	0.185	0.181

these contents reduced to 100% without the loss on ignition for each sample. The alkalis (Na_2O and K_2O) appear completely leached. Despite the ultrabasic character (SiO_2: 45 - 58 wt%) of the analyzed samples, the CaO content remains low (0.02 - 0.06 wt%). The W17 sample with poor SiO_2 (43 wt%) content has a particular behavior compared to the rest of the samples. It is very poor in MgO (0.37 wt%) and is on the other hand very rich in Al_2O_3 (6.9 wt%), $Fe_2O_3^t$ (47.49 wt%) with Mg/(Mg + Fe) = 0.4, in corundum (51.91 wt%) and magnetite (291.05 wt%) normative. The other samples have slightly varying oxide contents: Al_2O_3 (0.92 - 1.92 wt%), $Fe_2O_3^t$ (7.15 - 10.05 wt%), MgO (39.51 - 44.17 wt%), TiO_2 (0.018 - 0.04 wt%). The ratio Mg/(Mg + Fe) is constant (0.99).

5. Magmatic Typology and Geodynamic Implication

A positive linear correlation is well expressed in the $Fe_2O_3^t = f(Fe_2O_3^t/MgO)$ diagram and suggests that the analyzed samples are indeed comagmatic (**Figure 6(a)**). Their Al_2O_3 content compared to the Al_2O_3/CaO ratio remains almost constant despite some disturbances probably related to the alteration (**Figure 6(b)**).

In the triangular classification diagram of Al-(Fe^t + Ti)-Mg volcanic rocks in cationic percentages of [27], the analyzed samples predominantly occupy the

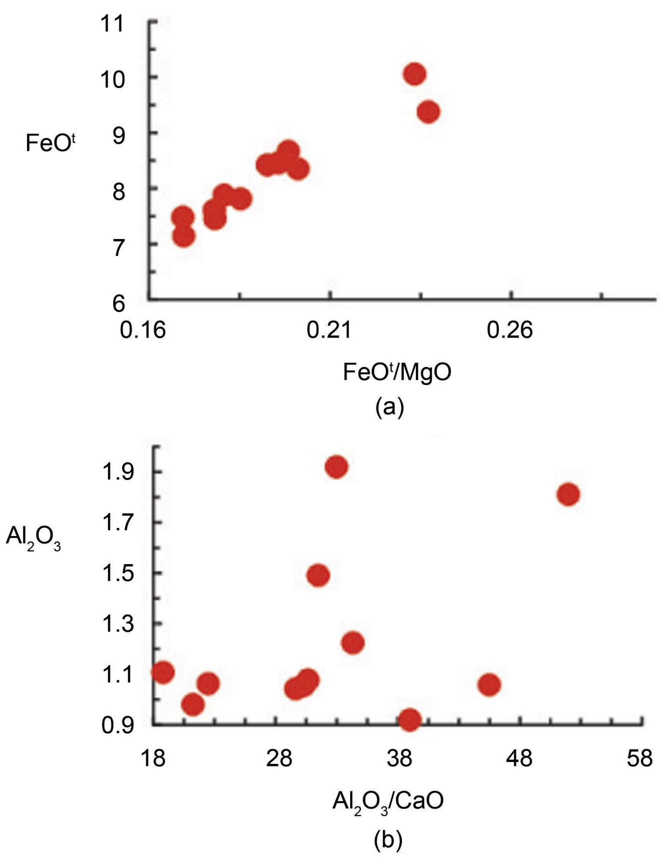

Figure 6. $Fe_2O_3^t = f(Fe_2O_3^t/MgO)$ (a) and Al_2O_3 $f(Al_2O_3/CaO)$ diagramms (b) of the Kantè serpentinites.

field of komatiites with the exception of the W17 sample which occupies the field of tholeiitic rhyolites (**Figure 7**). Their low P_2O_5 content (0.1 wt%) compared to their Zr content (1130 - 3170 ppm) classifies them as tholeiitic basalts [28] (**Figure 8**). Moreover, the Zr-Ti diagram of [29] indicates that these rocks have the affinity of tholeiites of island arc which is confirmed in the Zr-Zr/Y diagram of [30], where samples are in the field of oceanic arc basalts (**Figure 9**). The geodynamic context of emplacement of these rocks would be an active margin as suggested by the Zr/Y-Ti/Y diagram [31] (**Figure 10**).

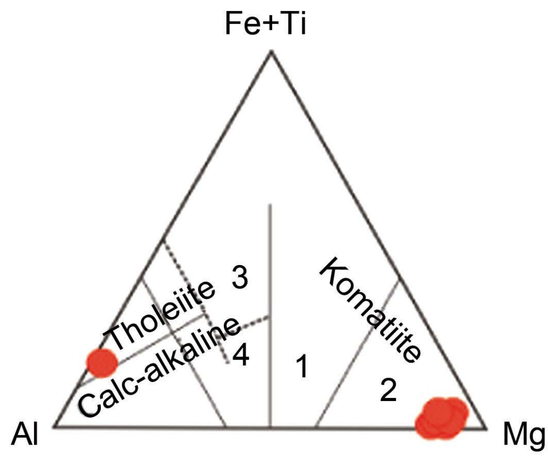

Figure 7. Position of the Kantè serpentinites in the (Al-(Fet + Ti)-Mg) classification diagramm of [27]. 1, komatiitic basalt, 2, komatiite, 3, high-Fe tholeiite basalt, 4, high-Mg tholeiite basalt.

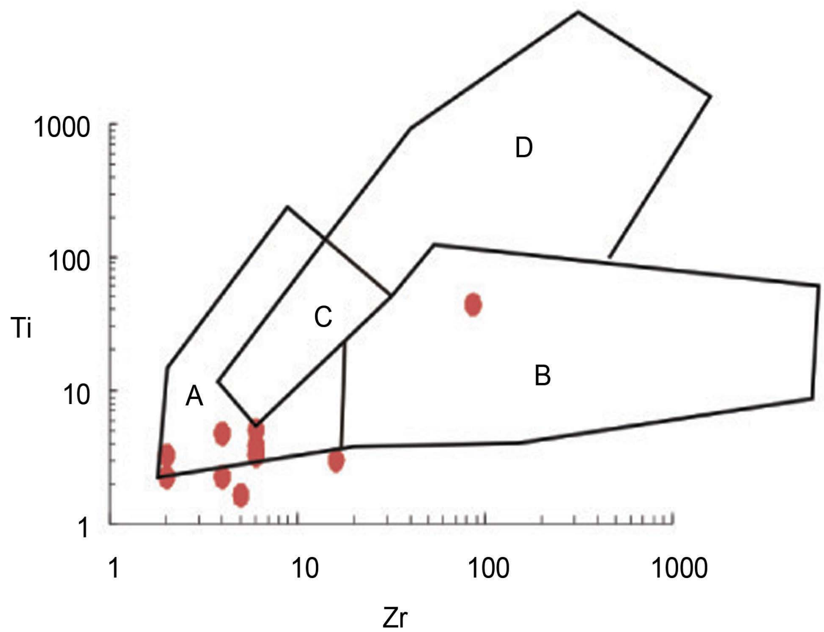

Figure 8. Position of the Kantè serpentinites in the Zr-Ti diagramm of [29]: A, Island-arc tholeiites, C, calc-alkali basalts, D, MORB, B contains all three types.

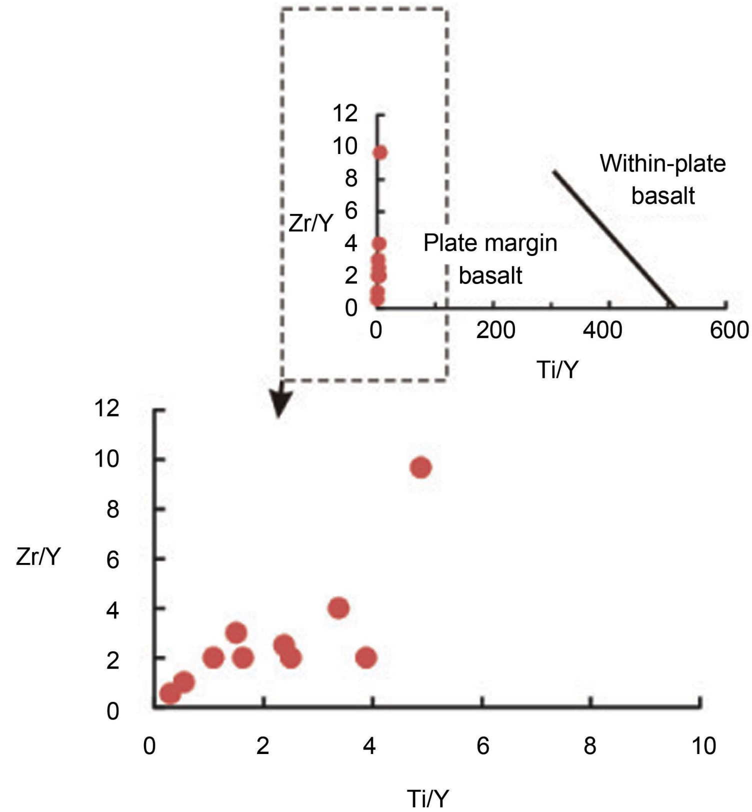

Figure 9. Zr-Zr/Y diagramm of [30].

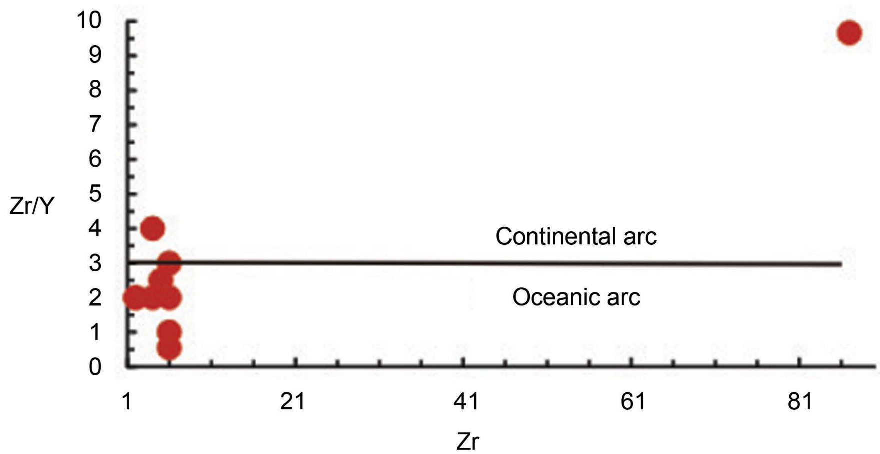

Figure 10. Geodynamic context of the Kantè serpentinites emplacement, according to the Zr/Y-Ti/Y diagramm of [31].

6. Conclusions

The Kantè serpentinous body is tectonically enclosed in schists of the occidental Atacora sub-unit. It includes rock facies with massive, brecciated, or schistose structure. From outcrop to microscopic examination, these rocks are distinguished by a strong deformational imprint materialized by an S1 schistocity plane and a flat C shear plane. The latter indicates a west vergence tangential movement involving the serpentinites.

Mineralogically, the rocks consist of an abundant serpentinous groundmass containing rare porphyroblasts of plagioclase, pyroxene and opaque clusters (magnetite, chromite and spinel). These porphyroblasts represent relics of a probable gabbroic to peridotitic protolith. In fact, by their chemical composition, the Kantè serpentinites are defined as ultrabasic rocks [7]. Their magmatic typology is that of komatites or tholeiithic basalts with ocean arc affinity, probably belonging to an active margin geodynamic context.

The geochemical characteristics of the Kante serpentinites reveal their particularities. In fact, these rocks are not comparable to the Tiélé volcanites that are assimilated to the MORB which belongs to a passive margin tectonic context [4]. They are also far from varied volcanites (pillows, and agglomerates associated with hawaiites, trachytes and phonolitic trachytes) represented in the Buem in southeast Ghana. According to [5], the latter were the products of a wide volcanic structure in the context of an oceanic rift zone. Moreover, the Kantè serpentinites differentiate themselves from their equivalents in the suture zone (particularly those of Monts Ahito-Meliendo, in the southwest of Togo) that are related to continental intraplate tholeiites derived from primitive mantellic magma [32].

For [7], the Kantè serpentinites could correspond to peridotitic cumulates comparable to stratiform complexes emplaced in an arc context. During the panafrican tectogenesis, such complexes were found in association with epizonal metasediments by "exhumation" related to reverse fault contacts or deep overthrusting.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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