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La Désirade island (Guadeloupe, French West Indies): a key target for deciphering the role of reactivated tectonic structures in Lesser Antilles arc building

JEAN-MARC LARDEAUX[1], PHILIPPE MÜNCH[2,3], MICHEL CORSINI[1], JEAN-JACQUES CORNÉE[2], CHRYSTÈLE VERATI[1], JEAN-FRÉDÉRIC LEBRUN[4], FRÉDÉRIC QUILLÉVÉRÉ[5], MIHAELA MELINTE-DOBRINESCU[6], JEAN-LEN LÉTICÉE[4], JAN FIETZKE[7], YVES MAZABRAUD[4], FABRICE CORDEY[5] and AURAN RANDRIANASOLO[4]

Key-words. – La Désirade island, Lesser Antilles arc, Reactivated tectonic structures, Lower Cretaceous compression, Pliocene to early Pleistocene extension, Active deformation, Vertical displacements.

Abstract. – In this paper we present and discuss new investigations performed on both the magmatic basement and the sedimentary formations of La Désirade. We report structural and sedimentary evidences for several episodes of deformation and displacement occurring prior to the present day tectonics. The main faults, respectively N130 ± 10º, N040 ± 10º and N090 ± 10º, previously considered as marker of the current tectonic regime corresponds to reactivated tectonic structures developed first during late Cretaceous compression and second during Pliocene to early Pleistocene extension. We demonstrate also the importance of late Pliocene-early Pleistocene and middle-late Pleistocene vertical movements in this part of the Lesser Antilles fore-arc as well as the role of compressive tectonics in the over thickened character of the arc basement in the Guadeloupe archipelago.

L'île de la Désirade (Guadeloupe, Antilles françaises) : Une clef pour comprendre le rôle de la réactivation tectonique dans l'édification de l'arc des Petites Antilles

Mots-clés. – Ile de La Désirade, Arc des Petites Antilles, Réactivation des structures tectoniques, Compression Crétacé inférieur, Extension Pliocène et Pléistocène précoce, Déformation active, Déplacements verticaux.

Résumé. – Dans cette publication nous présentons et discutons de nouvelles observations et analyses effectuées à la fois dans le soubassement magmatique et les couvertures sédimentaires de l'île de la Désirade. Des arguments structuraux et sédimentaires démontrent l'existence de plusieurs épisodes de déformation et de déplacements antérieurs au champ de déformation actuel. Les principaux systèmes de failles, respectivement orientés N130 ± 10º, N040 ± 10º et N090 ± 10, préalablement considérées comme des structures tectoniques actives récentes et post-Pléistocène, correspondent à la réactivation tectonique d'une part de structures compressives d'âge crétacé inférieur et d'autre part de structures extensives d'âge pliocène à pléistocène précoce. Nous démontrons en outre l'importance des mouvements verticaux d'âge pliocène supérieur et pléistocène dans cette partie de l'avant arc des petites Antilles. Enfin nos travaux suggèrent que l'épaississement crustal qui caractérise le soubassement de l'arc des petites Antilles est en partie le résultat de la tectonique compressive crétacée reconnue à La Désirade.

INTRODUCTION

The Lesser Antilles, located at the eastern boundary of the Caribbean plate, is the site where the Atlantic oceanic crust, related to the North-American plate, subducts beneath the Caribbean plate. The rate of convergence is low compared to other subduction zones and is known from GPS surveys to be about 2 cm/yr [Dixon *et al.*, 1998; De Mets *et al.*, 2000]. Intra-oceanic subduction drives:

– the building and the evolution of an 800 kilometres long magmatic arc, with a curvature radius of about 450 km, which stretches from the South American continental margin to the Anegada passage at the boundary with the Greater Antilles;

– the development of fore and back arc sedimentary basins with contrasting volcanogenic sedimentation;

– the generation of current strain partitioning leading, in the North-East corner of the lesser Antilles arc, to trench parallel extension accommodating the oblique convergence between the North American and Caribbean plates [Feuillet *et al.*, 2001, 2002], while further south, data obtained from

1. Université Nice Sophia-Antipolis, UMR 7329 Geoazur, Parc Valrose, 06108, Nice cedex 2, France
2. Université Montpellier 2, UMR 5243 Géosciences Montpellier, place E. Bataillon, 34095 Montpellier cedex 05, France
3. Université de Provence, 3 place Victor Hugo, 13331 Marseille cedex 3, France
4. Université des Antilles et de la Guyane, EA 4098 LaRGE, 97159 Pointe-à-Pitre, Guadeloupe, FWI
5. UMR 5276, Laboratoire de Géologie de Lyon: Terre, Planètes, Environnement, Université Lyon 1, Boulevard du 11 Novembre 1918, 69622 Villeurbanne cedex, France
6. GeoEcoMar, Str. Dimitri Onciul, nr 23-25, RO-024053, Bucarest, Romania
7. IFM-GEOMAR, Dienstgebäude Ostufer, Wischhofstr. 1-3, 24148 Kiel, Germany
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Tobago and Grenada basins show that major normal faults are arc parallel [Aitken *et al.*, 2011].

Subduction related magmatism occurred since the Middle Cretaceous in the Caribbean and, in the Lesser Antilles area, the Aves Ridge arc started its activity at the beginning of the Late Cretaceous and ceased in the Early Paleocene [Pindell and Barrett, 1990]. The Lesser Antilles arc volcanism initiated at around 40 Ma [Martin-Kaye, 1969; Briden *et al.*, 1979; Bouysse and Westercamp, 1990]. Starting northward from Martinique, the arc is divided into two groups of islands [Martin-Kaye, 1969; Westercamp, 1979]. An inner arc consists of volcanic rocks younger than 20 Ma and includes all the active volcanoes [Bouysse and Westercamp, 1990] while an outer, older and extinct arc is composed of thick carbonate platforms covering a magmatic basement.

Located east of Guadeloupe (fig. 1), the island of La Désirade exhibits the oldest rocks of the Lesser Antilles arc and the eastern Caribbean plate and represents the exhumed base of the active Lesser Antilles volcanic arc on which only indirect information is available. Moreover, recent investigations have clearly shown the importance of lower Cretaceous thrust tectonics as well as Pliocene extensional tectonics in the structural evolution of this island [Léticée, 2008; Cordey and Cornée, 2009; Corsini *et al.*, 2011; Münch *et al.*, 2013]. The latter represents therefore a key target for understanding the role of inherited structures for the development of current tectonic setting of the Lesser Antilles arc. The aim of this paper is to revisit the geology of La Désirade Island in the light first of these new discoveries and second of new geological mapping and finally to evaluate the importance of reactivation processes for arc building. After a recall of recently discovered tectono-metamorphic evolution of the old magmatic basement, we present and discuss a new geological map, we describe and re-interpret carbonate platforms resting upon this basement and we revise the previous interpretations of erosional terraces as well as the recent vertical movements of the island.

GEODYNAMIC CONTEXT

In the light of recent and detailed paleontological, geochemical and geochronological investigations [Gauchat, 2004; Mattinson *et al.*, 2008; Cordey and Cornée, 2009; Neill *et al.*, 2010; Corsini *et al.*, 2011] it is now widely accepted that the magmatic basement of La Désirade island was generated during Late Jurassic. In the framework of

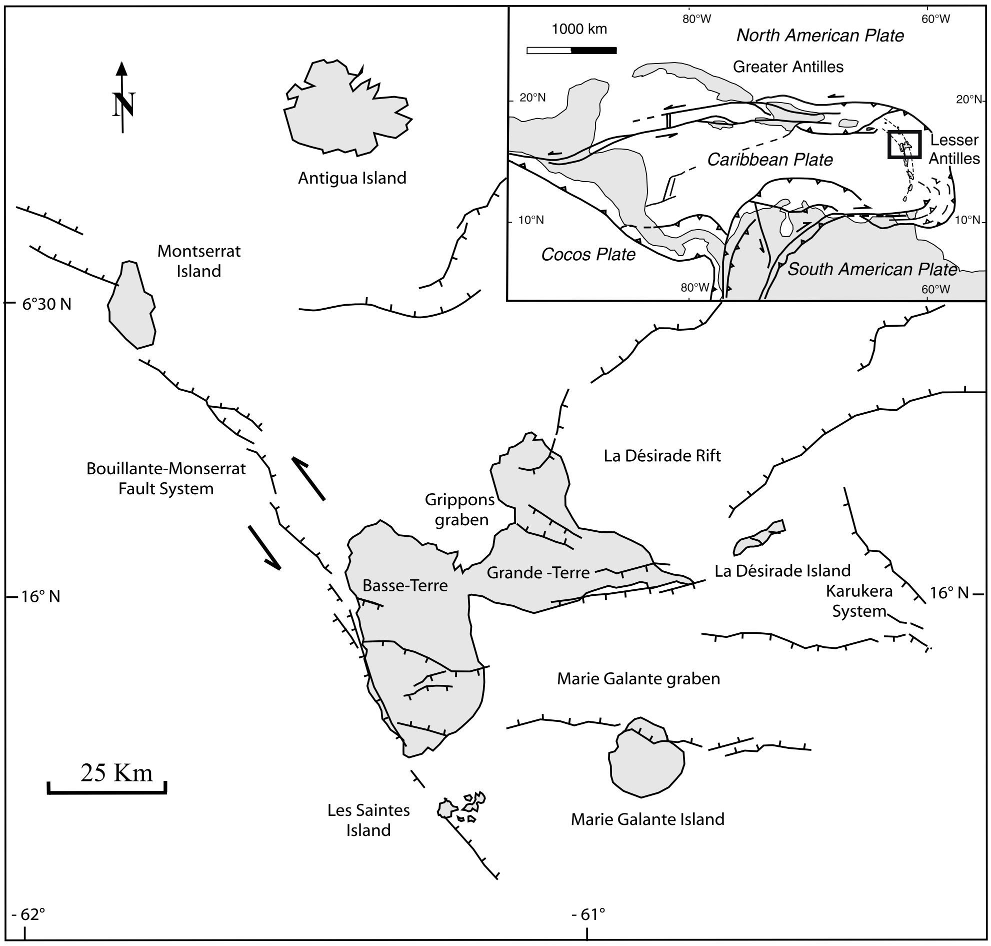

FIG. 1. – Location of La Désirade into the tectonic sketch map of the Guadeloupe archipelago [modified after Feuillet *et al.*, 2002 and Thinon *et al.*, 2010]. The main fault systems are reported and inset shows the geodynamic setting of the Caribbean plate with location Guadeloupe in the Lesser Antilles arc.

Caribbean geodynamics [Kerr *et al.*, 1999, 2003; Schneider *et al.*, 2004; Pindell and Kennan, 2009], this basement was formed in the proto-Caribbean realm east of the Andean/Cordilleran east-dipping subduction zone (fig. 2). As recently proposed by Corsini *et al.* [2011], Albian, syn-metamorphic, thrust tectonics developed in La Désirade in response to the collision of the early Caribbean-Colombian Oceanic Plateau [CCOP, Kerr *et al.*, 1997, 1998, 2003; Blein *et al.*, 2003] against the island arc located at the proto-Caribbean-Pacific boundary during Lower Cretaceous. The initiation of southwest-dipping subduction, required for the separation of the Caribbean plate from the Farallon plate, occurred to the east of La Désirade. After this subduction polarity reversal, and as a consequence of the progressive eastward displacement of the Caribbean plate, La Désirade basement moved as a passive marker to reach its present-day position (fig. 2C).

THE GEOLOGY OF LA DESIRADE REVISITED

La Désirade island is the easternmost island of the Lesser Antilles fore-arc, located at 50 km West from the subduction front between the subducting Atlantic plate and the Caribbean plate. The island is 11.5 km long, 2 km large and reaches 276 m in elevation above sea level. Because of important uplift, La Désirade Island is the only area of the Lesser Antilles arc where the basement of Caribbean plate extensively outcrops, overlain by Pliocene carbonate deposits.

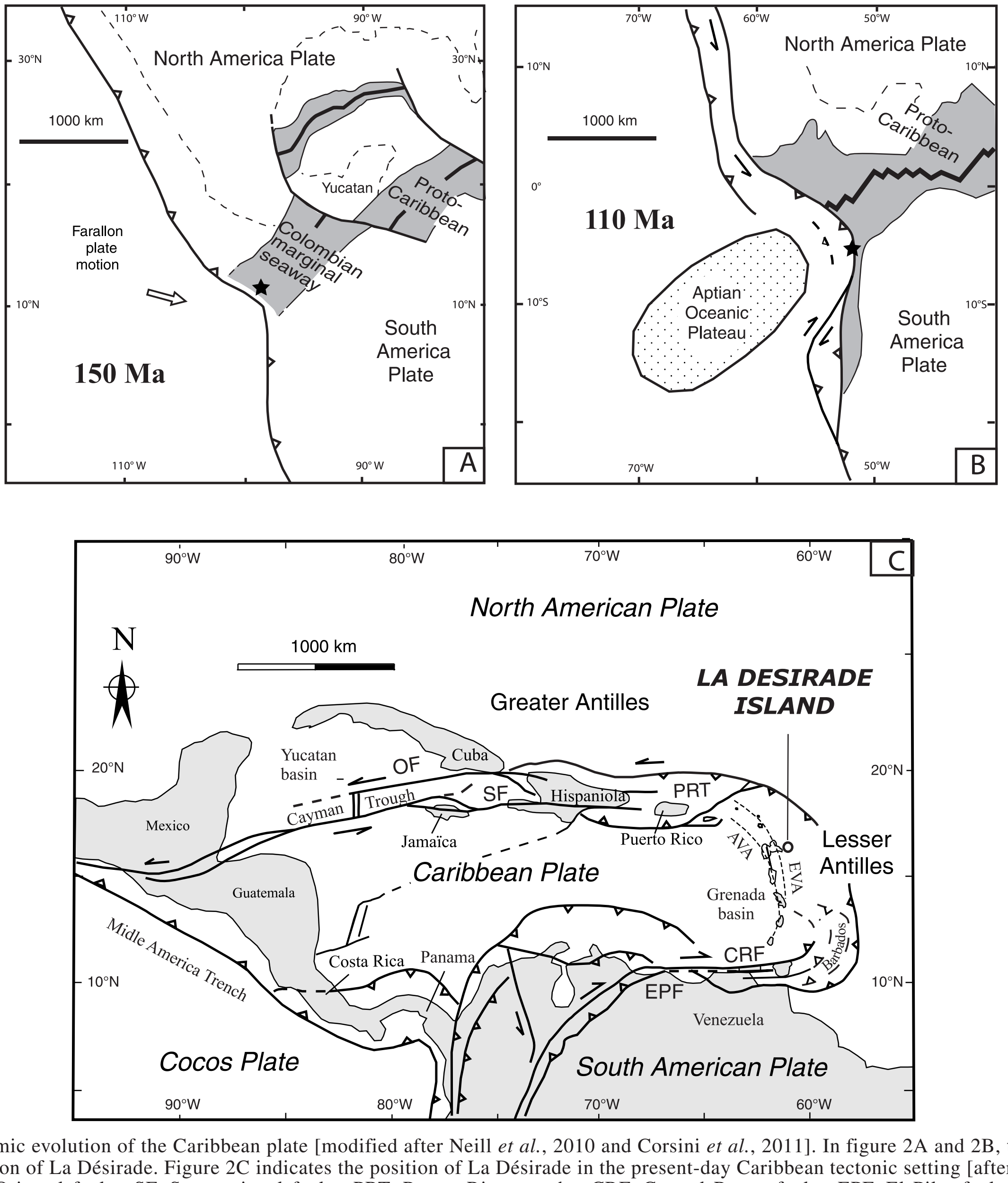

FIG. 2. – Geodynamic evolution of the Caribbean plate [modified after Neill *et al.*, 2010 and Corsini *et al.*, 2011]. In figure 2A and 2B, the star represents the probable position of La Désirade. Figure 2C indicates the position of La Désirade in the present-day Caribbean tectonic setting [after Pindell and Kennan, 2009] : OF, Oriental fault ; SF, Septentrional fault ; PRT, Puerto Rico trench ; CRF, Central Range fault ; EPF, El Pilar fault.

Our recent investigations allow a new geological map to be presented (fig. 3).

Magmatic basement

La Désirade magmatic basement is composed of three main units [Fink, 1970; Westercamp, 1980; Bouysse *et al.*, 1983; Mattinson *et al.*, 1980, 2008]:

– an ophiolitic complex located in the northeastern part of the island and characterized by the occurrence of pillow basalts, and minor micro-gabbros, with interbedded radiolarian cherts. Even if the origin of La Désirade ophiolitic complex was strongly debated [Mattinson *et al.*, 2008, with references therein], recent geochemical investigations [see discussion in Neill *et al.*, 2010] support a back-arc tectonic setting for the origin of this ophiolite. According to the paleontological investigations of Mattinson *et al.* [2008] and Cordey and Cornée [2009], the radiolarites are Late Jurassic;

– an acid magmatic complex composed of trondhjemite (i.e. quartz-diorite) and numerous rhyolitic/dacitic lavas flows. The formation of this igneous complex is contemporaneous with the radiolarian cherts deposition, as Late Jurassic radiometric crystallization ages (145-143 Ma) have been obtained on zircons from trondhjemites [Mattinson *et al.*, 1973, 1980, 2008];

– an andesitic to microdioritic dyke complex (i.e. upper meta-andesitic group of Westercamp [1980]).

Our investigations on La Désirade basement evidenced polyphased ductile to ductile/brittle deformation that occurred prior to the well-known ongoing extensional tectonics [see also Corsini *et al.*, 2011]. Indeed, two superposed finite strain patterns have been recognized (fig. 3):

– D1 deformation event is the result of the thrusting of the acid igneous complex with rhyolitic lavas onto the ophiolitic unit. Regional scale folding, with P1 N030° ± 10° oriented fold axes as well as S1 schistosity planes (fig. 4A) are related to the thrust development. Near Anse Galets (fig. 3), the NE-SW striking Grand Abaque thrust is characterized by a few meter thick greenschist facies mylonite mainly formed at the expense of rhyolites and basalts. The thrusting zone is also characterized by the abundance of deformed quartz and epidote-veins attesting for very strong fluid circulations that produced a complete transformation of the volcanic rocks. Direction of transport in the shear zone is underlined by a gently north-dipping stretching lineation with a N340° ± 20° trending. The most evident kinematic indicators are shear-band cleavages, asymmetric folds and sigmoid boudins. All the kinematic indicators show a top to the southeast sense of shear (fig. 4B);

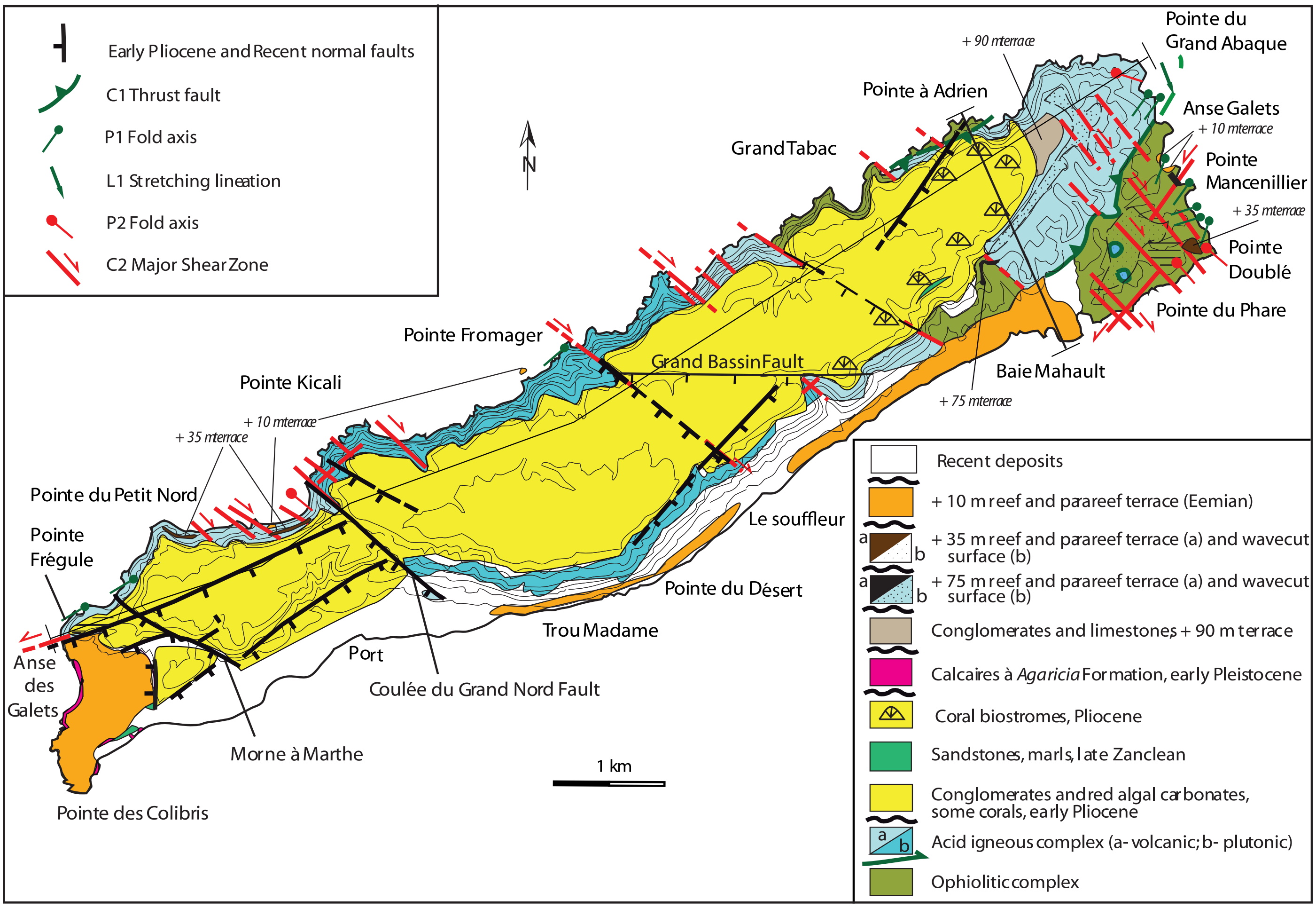

FIG. 3. – New geological map of La Désirade.

– D2 deformation event is characterized by the development of two sets of conjugated shear zones, main N130º ± 10º striking dextral strike-slip shear zones and N040º ± 10º sinistral strike-slip shear zones. This deformation pattern is compatible with an N-S shortening direction in its present day coordinates. P2 folds, with N130º oriented axes, are associated with steeply deeping S2 shistosity planes and shear zones development (fig. 4 C and D) and indicate a transpressive regime for D2 deformation event.

Typical criteria for superposed deformation can be observed at the outcrop scale (fig. 5), while superposition of two folds systems is clearly evidenced by structural mapping of the layers of radiolarian cherts interbedded with pillow basalts in the ophiolitic complex (fig. 6).

Cordey and Cornée [2009] provided new biochronological data from radiolarian assemblages extracted from several chert localities in this complex. The fauna range in age from Kimmeridgian to early late Tithonian, showing first that basalt/cherts successions are not all coeval and second that age distribution exhibits a southeast to northwest-directed polarity. Considering superposed folds pattern, the oldest outcrops of cherts (late Kimmeridgian – early Tithonian) are found in the vicinity of anticlinal axes whereas the youngest one (early-late Tithonian) are located in the vicinity of synclinal axis. At the regional scale, the length-scale of folds is therefore clearly highlighted by the spatial distribution of radiolarian assemblages of different ages.

Since pioneering investigations of Westercamp [1980] it is now widely accepted that all the previously described magmatic rocks have been metamorphosed under, regional scale, Greenschist facies metamorphic conditions. Metamorphic minerals like chlorite, albite, epidote and actinolite underline S1 or S2 schistosity planes and D2 discrete shear zones showing that Greenschist facies metamorphism are contemporaneous with D1 and D2 deformation events (fig. 7).

The P-T conditions of this metamorphism cannot be precisely calculated, however the occurrence of chlorite in all studied samples implies a temperature lower than 500ºC [Spear, 1993] and the development of the association albite+chlorite+calcite+titanite+clinozoïsite in metabasalts is limited to a maximum temperature of 400ºC. The lack of pumpellyite at the equilibrium with actinolite or chlorite is consistent with a minimal temperature of about 320ºC (fig. 8) [Maruyama *et al.*, 1986, 1996; Spear, 1993; Ernst and Liou, 2008]. For such a temperature range between 320

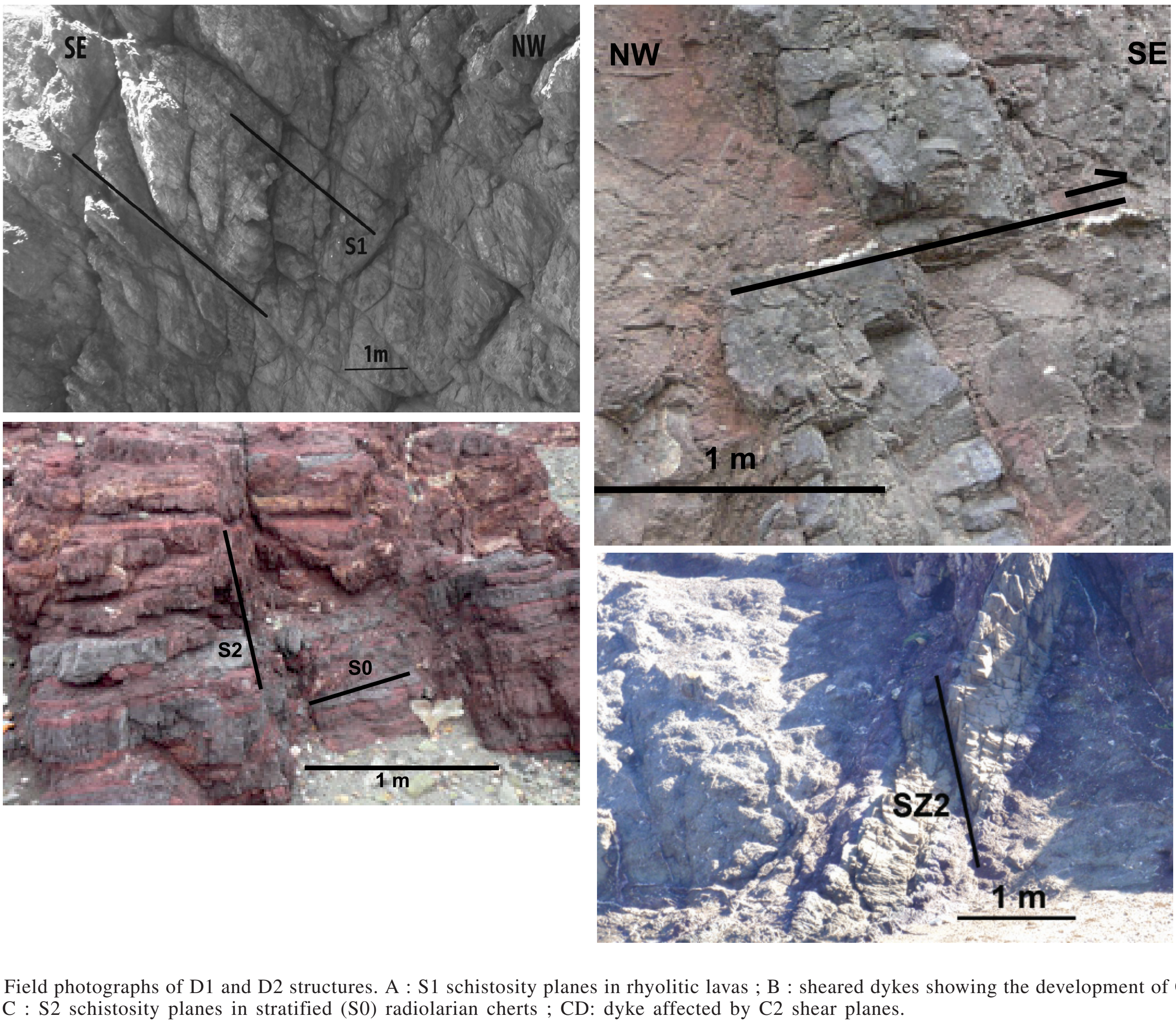

FIG. 4. – Field photographs of D1 and D2 structures. A : S1 schistosity planes in rhyolitic lavas ; B : sheared dykes showing the development of C1 shear planes ; C : S2 schistosity planes in stratified (S0) radiolarian cherts ; CD: dyke affected by C2 shear planes.

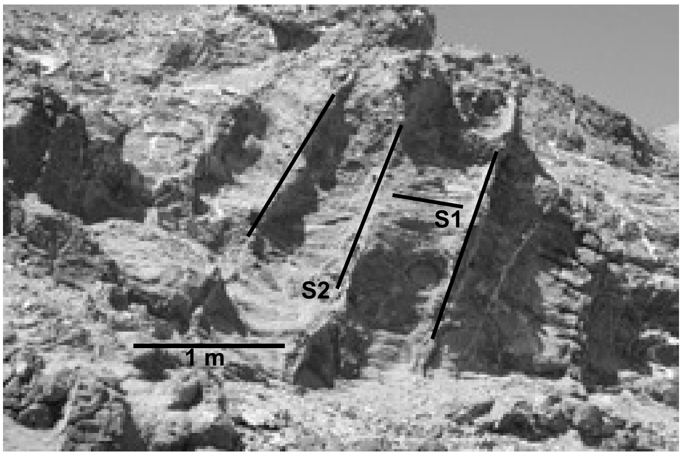

FIG. 5. – Superposed schistosity planes (S2 on S1) in Greenschist facies meta-basalts.

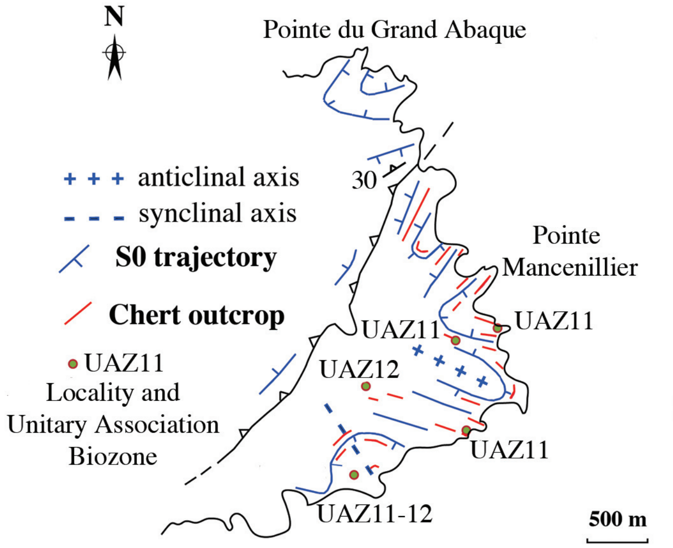

FIG. 6. – Superposed folds in the northeastern ophiolitic complex. Distribution of ages of Jurassic radiolarian assemblages after Cordey and Cornée [2009].

and 400°C, the occurrence of actinolite instead of barroisite or glaucophane and the widespread development of calcite instead of aragonite in all the studied lithologies impose a maximum pressure of 4 Kbar (fig. 8) [Maresch, 1977; Brown, 1977; Ernst, 1979; Spear, 1993; Maruyama *et al.*, 1996]. Near Pointe Mancenilliers (fig. 3), we found adularia minerals within a deformed zone oriented N30° ± 10° and related to the second deformation event (D2). $^{40}Ar/^{39}Ar$ analyses were performed on these metamorphic phases [Corsini *et al.*, 2011] yielding Albian age (106.2 ± 1.6 Ma) for D2 deformation.

Pliocene carbonate platforms

According to the last stratigraphical and sedimentological works on the Neogene formations from La Désirade [Westercamp, 1980; Bouysse and Garrabé, 1984], the island is capped by a ~100 m thick, lower Pliocene [N19 Biozone from Bolli and Premoli-Silva, 1973], para-reefal to reefal limestone table. The limestones unconformably rest upon the magmatic basement through a subaerial, smoothed surface that outcrops at the Grand Abaque, to the East. Westercamp [1980] distinguished two facies within the limestones: to the east, para-reefal to reefal limestones containing red-algae, corals, gastropods, bivalves, benthic foraminifers and rare planktonic foraminifers (the limestone table *s.s.*); to the west, loose biodetrital and muddy limestones containing abundant planktonic and benthic foraminifers. These latter should correspond to open-sea, fore-reef slope deposits and the former to the reef core [Westercamp, 1980]. During the middle Pliocene, La Désirade should have suffered a 300 m amplitude uplift that brought the

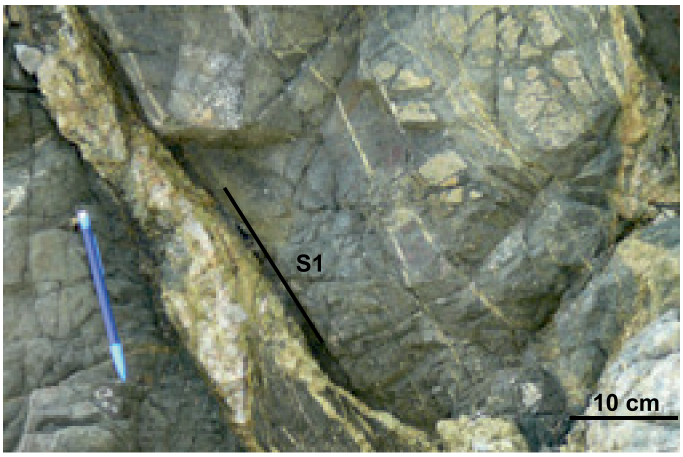

FIG. 7. – S1 schistosity planes underlined by greenschist facies minerals (albite, chlorite, epidote).

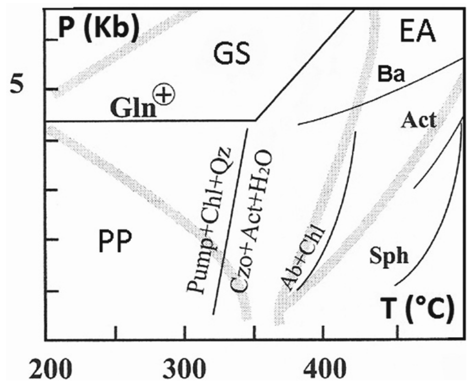

FIG. 8. – Pressure-temperature diagram after Maruyama *et al.* [1996] showing the stability fields of metamorphic facies for mafic rocks. Key mineral equilibria after Maresch [1977]; Ernst [1979]; Maruyama *et al.* [1986]; Spear [1993]. Mineral abbreviations after Kretz [1983]. Abbreviations for the various facies are as follows: PP = prehnite-pumpellyite; GS = greenschist; EA = epidote amphibolite.

limestone table at its present-day elevation [Bouysse and Garrabé, 1984]. Contemporarily with the uplift, or soon after, the island has been divided into three compartments by two normal faults (the N130°-striking Coulée du Grand Nord fault and the N090°-striking Grand Bassin fault; fig. 3) and it has been also tilted toward the northeast [Bouysse and Garrabé, 1984]. According to Feuillet *et al.* [2002, 2004] the two major normal faults should be related to a post 330 ka, N-S extensional strain.

Our investigations along the northern cliffs revealed that the thickness of the platform is highly variable, i.e. between 20 m in the central part of the island (Grand Bassin) and 120 m at maximum near the Pointe à Adrien to the east (fig. 9 and 10a). In the central part of the island, between the Grand Bassin and the Coulée du Grand Nord scarp, the thickness of the platform is ~50 m and does not vary significantly (fig. 9). In the westernmost part of the island, down of the Coulée du Grand Nord scarp, the thickness of the platform reaches 110 m and appears uniform (fig. 9). The same geometry can also be observed along the southern cliffs, with the minimum thickness of the platform near the locality of Le Souffleur (fig. 3). These variations in thickness are related to an irregular initial palaeotopography of the magmatic basement with two basement highs. The highest one is located in the central part of the island (Grande Montagne area) and the other one in the easternmost part (Grand Abaque area). The highs separate two main depressions, one to the west of the Coulée du Grand Nord fault and another near Pointe à Adrien, to the east. At a shorter scale, the morphology of the basal surface of the platform is also irregular with palaeovalleys in the magmatic basement (e.g. near Pointe Frégule; fig. 10b) and marine abrasion surfaces (e.g. Pointe Grand tabac; fig. 10c). In the palaeotopographic lows, the lowermost deposits of the platform are coarse breccias composed of up to meter-scale blocks of the magmatic basement within an orange colored, dolomitized red algal limestone matrix (1-5 m thick). Above these breccias, four lithological units can be recognized in the limestone table, from bottom to top: 1) 10 to 55 m thick, orange to ochre colored, red algal thin-bedded limestones with rare isolated coral colonies and with some rounded pebbles from the magmatic basement near the base of the unit. These limestones are dolomitized in their lowermost part; 2) 40 m thick red algal, thick-bedded limestones that contain abundant benthic foraminifers (*Amphisteginids*); 3) up to 10 m thick sandstones with basement-derived millimeter sized clasts and planktonic foraminifers; 4) the top of the platform is a 10 to 20 m thick reef unit mainly observable in the easternmost part of the island.

Within the third unit, just below the base of the reefal unit, planktonic foraminifers (table I) yielded a late Zanclean-early Piacenzian age as indicated by the co-occurrence of *Sphaeroidinellopsis seminulina* and *Truncorotalia crassaformis* [Pl2-Pl3 foraminiferal zones of Berggren *et al.*, 1995; 4.31-3.13 Ma; calibrated ages from Lourens *et al.*, 2004]. This result agrees with that of Westercamp [1980] and clearly suggests that the island emerged during the late Pliocene. At the scale of the island, the two lowest units display significant changes in thickness whilst the two uppermost ones remain constant. Indeed, the deposits have an overall onlapping and aggradational geometry on an inherited and irregular palaeotopography. The lowest units infilled narrow palaeovalleys or were deposited onto palaeo-wavecut erosive surfaces and the uppermost ones burried the basement highs (fig. 9). As a consequence, the basal conglomerates of the limestone table, indicated on the map of La Désirade at the Pointe à Adrien at 75 m and 90 m elevations [Westercamp, 1980] are actually 30 to 40 m

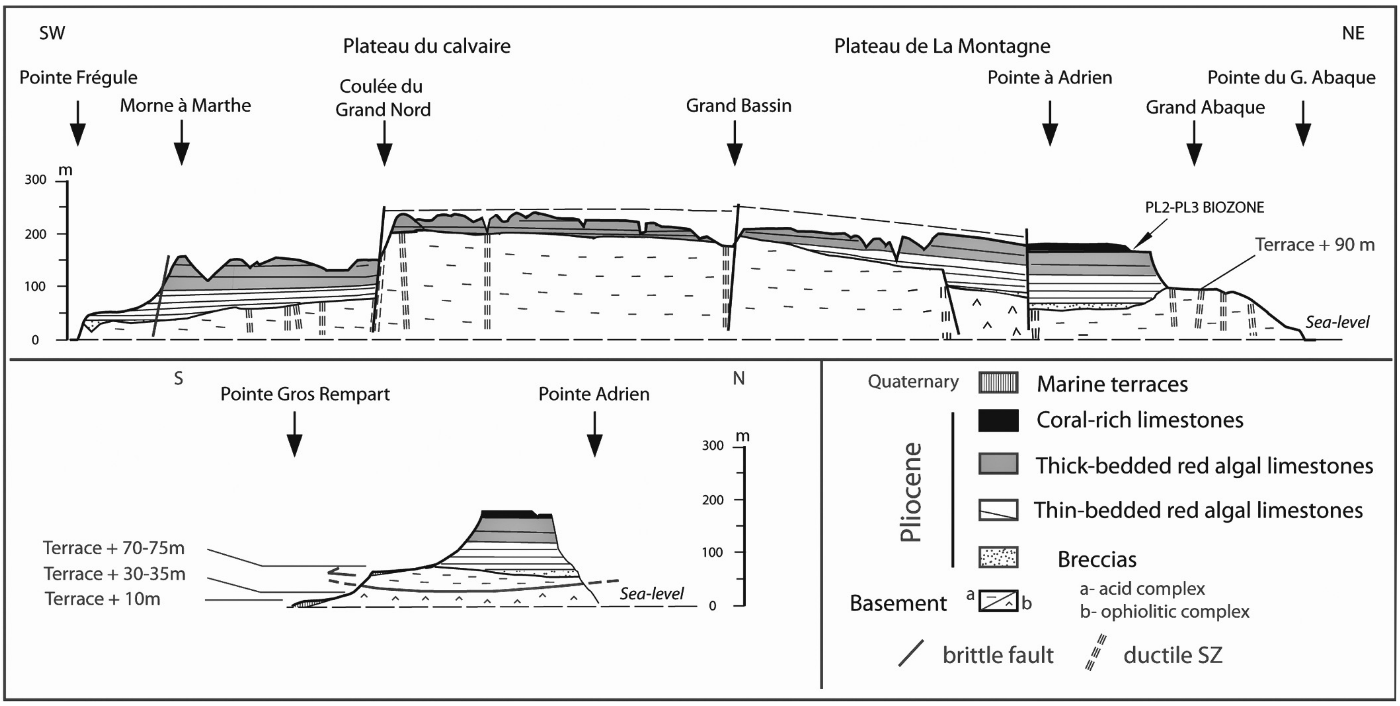

FIG. 9. – SW-NE and S-N cross-sections showing the onlap of the carbonate platform on the previously faulted basement (location on figure 3).

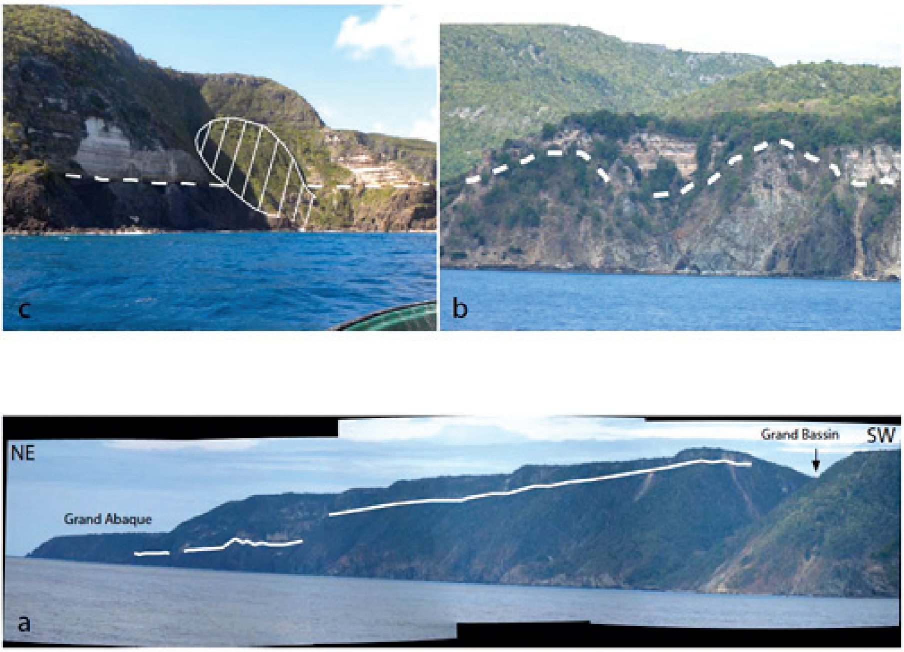

FIG. 10. – A. Field of view to the southwest of the northern cliffs of La Désirade from Pointe Fromager to Grand Abaque exhibiting the northeastward thickening of the carbonate platform together with the retrograding geometry. B. Base of the Pliocene carbonate platform exhibiting palaeovalleys within the magmatic basement infilled by Pliocene limestones near Pointe Petit Nord. The field of view is to the East. C. Marine planation surface at the base of the Pliocene carbonate platform. The field of view is to the east at the Pointe Grand Tabac.

above the base of the Pliocene platform. In accordance with Lasserre [1961] and de Reynal [1966], we consider that these "basal conglomerates" are uplifted Pleistocene marine terraces.

In the western part of the island, we evidence early Pliocene extensive tectonics. The loose bioclastic limestones of Westercamp [1980] provided planktonic foraminifers and calcareous nannofossils (table I). The co-occurrence of *S. seminulina* and *Menardella miocenica* indicates the Zanclean-lower Piacenzian (Pl2-Pl3 foraminiferal zones; 3.77-3.16 Ma). The co-occurrence of *Pseudoemiliania lacunosa* and *Sphenolithus abies* points to the same interval [CN12a-c nannofossils zone of Okada and Bukry, 1980; 3.82-3.54 Ma]. The loose limestones were deposited at the hangingwall of a N-S trending fault that transected the thick-bedded red algal limestones. Moreover, we consider that the outcropping area of the loose bioclastic limestones (labeled Mx) is much more reduced than indicated on the map of Westercamp [1980]. They have been largely confused with the Pliocene red algal limestones and with middle-late Pleistocene marine terraces uplifted at 35 m and 10 m elevations.

Reefal carbonate platforms can be observed at the western and eastern tips of the plateau, near the Anse des Galets and the Pointe à Adrien (fig. 3). They onlap unconformably upon the Pliocene platform and it is composed of up to 10 m thick reefal to para-reefal limestones. The coral assemblage is quite different from the one observed in the uppermost unit of the limestone table. This second carbonate platform is a fringing reef with abundant *Agaricia* sp. and the occurrence of *Diploria labyrinthiformis* indicates a Pleistocene age [Léticée, 2008]. These reef limestones are similar to the early Pleistocene reefal formations of Grande-Terre [Léticée *et al.*, 2005; Léticée, 2008; Cornée *et al.*, 2012; Münch *et al.*, 2013]. As a consequence, La Désirade must have emerged during Gelasian.

Middle-late Pleistocene marine terraces

A late Quaternary, i.e. Eemian, marine terrace has been previously identified upon a marine erosional surface transecting the magmatic basement [Lasserre, 1961; de Reynal, 1966; Westercamp, 1980; Battistini *et al.*, 1986; Feuillet *et al.*, 1984]. The terrace is composed of marine conglomerates and of fringing reefs. In the western part of the island, the corals yielded U/Th ages of 119 ± 9 ka [Battistini *et al.*, 1986] and 141 ± 7 ka [Feuillet *et al.*, 2004] and were uplifted to + 3.5 m and + 5 m, respectively. Battistini *et al.* [1986] proposed that the elevation of this terrace is + 5 m at the western tip of the island and increases towards the East up to + 10 m.

In both the southwestern (near Anse des Galets) and eastern (from the Baie-Mahault village to the vicinity of the Pointe Mancenillier) parts of the island, our investigations revealed that from the top of the uplifted reef terraces located near the present shore line, a low dipping surface rises slowly up to an altitude of *ca* 10 m and is locally overlain by loose pebbles or by conglomeratic limestone with isolated massive corals colonies or by beach sands. Near Anse des Galets, we found this conglomeratic limestone unconformably resting upon Pliocene and Pleistocene carbonate platforms (fig. 3). We performed, at the IFM-Geomar Institute, an U/Th dating on a coral colony at an altitude of 8 m

TABLE. I. – Planktonic foraminifera assemblages and calcareous nannofossil associations in samples from the Pliocene marly limestones of La Désirade. Location of samples is indicated on figure 3.

Samples from the limestone table, in the eastern part of la Désirade island (location on figure 3)	
DS-10-06	*PF : Orbulina universa, Sphaeroidinellopsis seminulina, Sphaeroidinellopsis kochi, Globigerinella siphonifera, Globigerinoides quadrilobatus, Globigerinoides sacculifer, Globigerinoides ruber, Globigerinoides extremus, Globigerinoides obliquus, Globigerinoides conglobatus, Dentoglobigerina altispira, Globoquadrina* baroemoenensis, Neogloboquadrina acostaensis, Neogloboquadrina humerosa, Pulleniatina praecursor, *Globorotalia margaritae, Globorotalia tumida, Globorotalia crassaformis, Menardella menardii, Menardella multicamerata, Menardella exilis.*
DS-10-07	*PF : O. universa, S. seminulina, S. kochi, G. siphonifera, G. quadrilobatus, G. sacculifer, G. extremus, G. obliquus, G. conglobatus, D. altispira, G. baroemoenensis, N. humerosa, G. margaritae, G. tumida, G. crassaformis, M. menardii, Menardella limbata, M. exilis.*
DS-10-08	*PF : O. universa, S. seminulina, G. siphonifera, G. quadrilobatus, G. sacculifer, G. extremus, G. obliquus, G. conglobatus, D. altispira, N. humerosa, N. acostaensis, Pulleniatina primalis, G. margaritae, G. tumida, G. crassaformis, M. limbata.*
DS-08-19	*PF : O. universa, S. seminulina, Sphaeroidinella dehicens, S. kochi, G. siphonifera, G. quadrilobatus, G. sacculifer, G. extremus, G. obliquus, G. ruber, G. conglobatus, D. altispira, N. acostaensis, N. humerosa, Globoconella puncticulata, Truncorotalia crassaformis, G. tumida, M. menardii, M. limbata, M. exilis* *CN : Discoaster pentaradiatus, Discoaster brouweri, Discoaster tamalis, Sphenolithus abies, Pseudoemiliania lacunosa, Calcidiscus leptoporus, Calcidiscus macintyrei, Helicosphaera sellii, Helicosphaera carteri, Coccolithus pelagicus, Scyphosphaera sp., Reticulofenestra haqii, R. minuta, R. minutula* *Probably Pliocene taxa reworked: Reticuolofenestra pseudoumbilicus, Amaurolithus primus, Triquetrorhabdulus rugosus.* *Lower-Middle Miocene taxa reworked: Sphenolithus heteromorphus, Triquetrorhandulus carinatus, Helicosphaera ampliaperta.*
DS-08-20	*PF : O. universa, S. seminulina, G. quadrilobatus, G. sacculifer, G. ruber, G. extremus, G. conglobatus, G. obliquus, N. altispira,G. baroemoensis, N. acostaensis, N. humerosa, G. tumida, Menardella miocenica, M. menardii, M. exilis* *CN : Reticulofenestra pseudoumbilicus, Sphenolithus abies, Pseudoemiliania lacunosa, Thoracosphaera sp., Braarudosphaera bigelowii, Coccolithus pelagicus, Calcidiscus leptoporus, Calcidiscus macintyrei.*
Samples from the loose bioclastic limestones, in the western part of La désirade island (location on fig. 3)	
DS-10-13	*PF : Orbulina universa, Sphaeroidinellopsis seminulina, Globigerinoides quadrilobatus, Globigerinoides sacculifer, Globigerinoides ruber, Globigerinoides extremus, Globigerinoides obliquus, Globigerinoides conglobatus, Dentoglobigerina altispira, Neogloboquadrina humerosa, Globorotalia scitula, Globorotalia tumida, Globorotalia crassaformis, Menardella limbata, Menardella exilis, Menardella miocenica*
DS-10-14	*PF : O. universa, S. seminulina, G. quadrilobatus, G. sacculifer, G. conglobatus, D. altispira, N. humerosa, G. tumida, G. scitula, G. crassaformis, M. exilis*
DS-10-15	*PF : S. seminulina, G. quadrilobatus, G. sacculifer, G. extremus, G. obliquus, D. altispira, N. humerosa, Neogloboquadrina acostaensis, G. tumida, G. scitula, G. crassaformis, M. exilis, Menardella multicamerata* *CN : S. abies, Discoaster pentaradiatus, D. tamalis, D. brouweri, P. lacunosa, C. leptoporus, C. macintyrei, H. sellii, H. carteri, Pontosphaera japonica, R. haqii, Thoracosphaera sp.*
DS-10-16	*PF : S. seminulina, Globigerinella siphonifera, G. quadrilobatus, G. sacculifer, G. extremus, G. quadrilobatus, G. conglobatus, D. altispira, N. humerosa, G. tumida, M. multicamerata*
DS-10-17	*PF : S. seminulina, G. quadrilobatus, G. sacculifer, Globigerinoides ruber, G. obliquus, G. conglobatus, D. altispira, N. humerosa, N. acostaensis, G. tumida*
DS-10-18	*PF : S. seminulina, G. quadrilobatus, G. sacculifer, G. extremus, G. obliquus, G. conglobatus, D. altispira, N. humerosa, G. tumida, M. exilis, M. miocenica*
DS-10-19	*PF : O. universa, S. seminulina, G. quadrilobatus, G. sacculifer, D. altispira, N. humerosa, G. tumida, G. crassaformis, Menardella limbata, M. exilis, M. miocenica* *CN : S. abies, D. brouweri, D. tamalis, C. leptoporus, C. macintyrei, H. sellii, H. carteri, P. lacunosa, Florisphaera profunda, Thoracosphaera sp., B. bigelowii.*

that yielded an age of 118 ± 4 ka. This age is concordant with the previous ones realized on corals at lower altitudes from the same part of the island [Battistini *et al.*, 1986; Feuillet *et al.*, 2004]. These deposits represent the Eemian palaeo-sea level highstand and were uplifted at 10 m on La Désirade, thus twice than that previously considered for this part of the island [Battistini *et al.*, 1986; Feuillet *et al.*, 2004]. As a consequence, the maximum present-day altitude (10 m) of the Eemian marine terrace is rather constant all around the island and does not rise towards the east. This is also supported by the occurrence of some marine conglomerates, uplifted at 10-12 m, in the northern central part of the island (near Pointe Fromager; fig. 3 and de Reynal [1966]).

Lasserre [1961] and Battistini *et al.* [1986] mentioned three other wavecut erosive surfaces in the eastern part of the island at + 35, + 75 and + 90 m elevations. In this part of the island, some marine deposits have also been reported at the weather station at an altitude of 35 m (fig. 3) [de Reynal, 1966; Westercamp, 1980] and have been associated with the + 35 m wavecut surface [Battistini *et al.*, 1986].

We have also identified and mapped three conglomeratic and reefal depositional marine terraces around the island (fig. 3 and 11). They can be correlated with the three wavecut surfaces previously recognized which develop at the top of the terraces and extend onto the basement. On the geological map of Westercamp [1980], these terraces had been erroneously considered as either as Pliocene bioclastic loose limestones or as basal conglomerates of the Pliocene limestone table. They unconformably rest upon either the magmatic basement or the Pliocene and Pleistocene carbonate platforms. The + 35 m depositional/erosive marine terrace is now identified all around the island at constant elevation (fig. 3). The + 75 m and the + 90 m marine terraces have only been recognized in the eastern part of the island (fig. 3). All these terraces have been deposited at the foot of palaeo-cliffs composed of Pliocene carbonates or Mesozoic rocks of the basement. The + 35, + 75 and + 90 m terraces still remain undated because of the meteoric diagenesis that lead to the more or less intense recrystallization of the corals aragonite into calcite. These terraces developed after the early Pleistocene Calcaires à *Agaricia* Formation and before Eemian. Consequently they have middle to late Pleistocene age.

THE ROLE OF INHERITED STRUCTURES IN THE CURRENT TECTONIC SETTING OF THE LESSER ANTILLES ARC

Thickening of the arc: tectonics versus magmatism

Following the first observations of Edgar *et al.* [1971], Case *et al.* [1990] and Mauffret and Leroy [1997], the thickened nature (~8-20 km) of the oceanic crust of the Caribbean plate is well established. Moreover, recent tomographic imaging [Kopp *et al.*, 2011] reveals a thick crust of the overriding plate with the Moho interface being at 24-30 km depth below the sea floor. These values are compatible with crustal investigations along the southern extent of the Lesser Antilles Island arc, which resolved a ~24 km thick crust underneath the island arc [Christeson *et al.*, 2003]. On the other hand, Westbrook and McCann [1986] placed the crustal thickness of the island arc North of Guadeloupe, on a section that passes close to Montserrat, also at ~27 km, based on gravity modeling with sparse seismic control. Recently the estimate of crustal thickness for the Montserrat region based on receiver function analysis ranges from 26 to 34 km [Sevilla *et al.*, 2010].

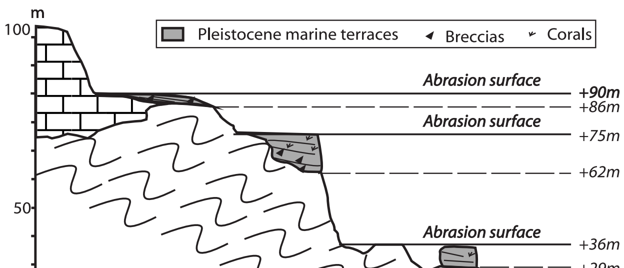

FIG. 11. – Synthetic sketch of the organization of the middle to late Pleistocene marine terraces and associated wave cut surfaces in the northeastern part of La désirade.

Considering the geodynamic evolution of the Caribbean plate, the following points are now widely accepted [Kerr *et al.*, 2003; Pindell and Kennan, 2009]:

– the Pacific origin of the Caribbean lithosphere;

– the formation of the Caribbean-Colombian Oceanic Plateau [CCOP, Kerr *et al.*, 1997, 1998], on the Farallon plate (i.e. in the Pacific), in different stages: an Aptian [124-112 Ma] phase, a 91-83 Ma phase (the most voluminous) and a 78-72 Ma phase [Lapierre *et al.*, 2000; Blein *et al.*, 2003; Kerr *et al.*, 2003];

– the lower Cretaceous collision of the CCOP with the proto-Caribbean arc as a consequence of the eastward movement of the Farallon plate.

In this geodynamic framework, the Caribbean oceanic crust is in a large part the remnant of the progressive insertion of the CCOP between the two Americas and therefore the anomalous crustal thickness of the Caribbean ocean floor is the result of the magmatic activity of the oceanic plateau. However, both North and South Caribbean plate boundaries are transpressive orogenic fold and thrust belts in which abundant Cretaceous to Eocene high-pressure and low-temperature metamorphic rocks are the record of significant thickening of the Caribbean crust in relation to subduction/collision processes [Maresch, 1975; Stöckhert *et al.*, 1995; Draper, 1986; Mann and Gordon, 1996; Avé Lallemant, 1997; Kerr *et al.*, 1999; Goncalves *et al.*, 2000; Schneider *et al.*, 2004; Tsujimori *et al.*, 2006; Kroehler *et al.*, 2011]. Albian tectonics we recognized on La Désirade island is characterized by folds, thrust and strike-slip development (fig. 3). It is thus another piece of evidence for thickening related to tectonic processes in the Caribbean domain. The maximum pressure contemporaneous with Albian tectonics is 4 Kbar; therefore a maximum of 10 to 12 km of tectonics-related thickening must be envisaged. Because the magmatic basement of La Désirade corresponds to the exhumed base of the present-day active Lesser Antilles volcanic arc, we suggest that Albian compressive tectonics may have played a significant role in the thickening of the Caribbean plate in addition to magmatic processes.

Reactivation of inherited structures

Following previous works, the island of La Désirade underwent extensional tectonics only after the end of deposition of the limestone table, either in Pliocene times [Westercamp, 1980; Bouysse and Garrabé, 1984] or in late Pleistocene [Feuillet *et al.*, 2002]. The main structures may correspond to rectilinear steeply dipping brittle normal faults crosscutting the limestone table and the magmatic basement. Two main sets of faults, oriented WNW-ESE and E-W, should be responsible for the division of the island into three compartments. A third set, oriented NE-SW, was also recognized and notably exemplified in the magmatic basement by the Grand Savane normal fault (Feuillet *et al.* [2002] and figure 3).

However, it appears first that the extensional tectonic activity started much earlier on La Désirade than previously considered. The geometry of the Pliocene limestones reveals that they settled on an initial irregular paleotopography with up-to 70 m relieves. This initial topography was mainly controlled by inherited N130°E-striking D2 shear-zones recognized within the magmatic basement, from West to

East: the Coulée du Grand Nord, the Grand Bassin and the Grand Abaque shear-zones. The comparison of Albian and Recent finite strain patterns (fig. 3) clearly emphasizes the role of structural inheritance. The main scarps were associated with west-facing scarps and may have been formed in relation to a NE-SW trending extension that pre-dated the deposition of the Pliocene carbonate platform and that re-activated Mesozoic shear zones (figs 3 and 9). Consequently, the major WNW-ESE oriented normal fault (ca. the Coulée du Grand Nord fault), previously considered as recently formed, is in fact inherited from Albian tectonics and represent susceptible structures to be reactivated in the present-day tectonic regime.

During and after the deposition of the Pliocene carbonate platform, i.e. in the late Pliocene-early Pleistocene interval, multidirectional extensional tectonics was active on La Désirade:

– the major active faults are still the WNW-ESE oriented normal faults, and particularly the Coulée du Grand Nord fault, that have been reactivated (fig. 9);

– main NE-SW oriented normal faults with south-facing scarps are also identified (fig. 3). They are, at least in part, reactivated D2 NE-SW shear zones from the Albian conjugated strike-slip system. However, we found no structural evidence for the so-called Grand Savane and Baie Mahault NE-SW oriented normal faults, proposed by Feuillet *et al.* [2002], located between Pointe du Grand Abaque and Baie Mahault and between Baie Mahault and Grand Bassin fault respectively (fig. 3). In the first place, the present-day NE-SW oriented scarp appears related to an Albian thrust zone instead of a recent, even active, normal fault (see discussion in Corsini *et al.* [2011]). In the second place, the lack of structural markers leads to consider the southern cliffs as erosional features, not as active tectonic structures;

– minor N090-100°E-striking normal faults with south-facing scarps and a N-S normal fault with west-facing scarps have also been recognized. These are the only fault systems that developed during Pleistocene to Recent times without reactivation of inherited structures.

Finally, the main faults pattern previously considered as marker of the current tectonic regime corresponds to re-activated tectonic structures developed first during the late Cretaceous compression and second during the Pliocene to early Pleistocene extension. The three major fault directions, respectively N130 ± 10°, N40 ± 10° and N90 ± 10°, recognized in La Désirade, agree with the main fault directions identified at the scale of the Guadeloupe archipelago (see fig. 1) [Westercamp, 1980; Bonneton and Scheidegger, 1981; Bouysse, 1988; Julien and Bonneton, 1989; Bouysse *et al.*, 1993; Feuillet *et al.*, 2002; Thinon *et al.*, 2010]. The N130 ± 10° system is represented by the Plaine des Grippons graben in Grande-Terre, the Bouillante/ Montserrat fault system or on the Karukera spur. Our results indicate that this system is inherited from late Cretaceous tectonics. The N040 ± 10° trending system corresponds to the direction of the La Désirade valley that is a ~5000 m deep escarpment North of La Désirade. This system is inherited from late Cretaceous and/or Pliocene tectonics. The N090 ± 10° oriented system is linked to the Marie-Galante graben. It is clearly the youngest one, inherited from Pleistocene to Recent tectonics.

Pliocene tectonics and vertical displacements of the present-day fore-arc

The Pliocene-Quaternary shallow-water carbonate systems are very useful to unravel and to quantify the vertical motion of the fore-arc since around 5 Ma.

According to our structural observations, the Pliocene carbonate platform was deposited on an initial irregular topography resulting from a NE-SW trending extension (fig. 9). For example, west of Coulée du Grand Nord fault, the platform is almost complete, with a total thickness of 120 m. East of this fault, only the youngest units of the platform have been deposited, with a total thickness of 50 m. This clearly indicates that an initial relief pre-existed. As littoral deposits onlap the basement in the lower part of the Pliocene table, the topography of the basement was made under aerial conditions. By comparison with Marie-Galante, this emersion surface was probably created during the latest Miocene to early Zanclean time-span [Münch *et al.*, 2013]. Then, La Désirade suffered a drowning during the Zanclean. The early Zanclean eustatic rise is generally accepted as + 80 m above the present-day sea-level at maximum [Lugowsky *et al.*, 2011]. As palaeoenvironments remained rather constant through the ~120 m thick carbonate platform, La Désirade necessarily underwent subsidence during the deposition of the Pliocene carbonate platform, as in Grande-Terre [Münch *et al.*, 2013]. Extensional tectonics has been evidenced during the red algal limestones deposition in the western compartment of the island (see above). It was coeval with a local deepening of the depositional environments at the hanging wall of west-facing scarps normal fault and with the erosion and the resedimentation of older red algal deposits of the footwall. Despite the early Pliocene sea level rise [Lugowsky *et al.*, 2011], the subsidence of the carbonate platform was also controlled by extensional tectonics. As a consequence, some of the present-day fault scarps are not fully related to the recent extensive tectonics.

As previously discussed, late Pliocene-early Pleistocene extensional tectonics was recognized on La Désirade. This extension was coeval with the uplift of the island that led to the emergence and erosion of the Pliocene platform. The carbonate platforms resumed in early Calabrian times on both sides of a central horst that may have remained emerged until present days. At this time, the apparent vertical fault throw of the Coulée du Grand Nord fault is estimated at around 30 m at maximum. As the deposition of carbonate platforms went on in Grande-Terre, Petite-terre and Marie-Galante islands until middle Pleistocene [Münch *et al.*, 2013], the late Pliocene-early Pleistocene uplift of La Désirade does not correspond to a regional uplift of the whole fore-arc but was limited to its easternmost part.

The occurrence of marine terraces up to + 90 m elevation indicates that the uplifted and emerged Pliocene carbonate platform was once again uplifted during middle-late Pleistocene. The occurrence of the two highest marine terraces only in the eastern part of the island suggests that either only this part of the island could have been uplifted first, may be in relation with footwall uplifts on the Coulée du Grand Nord fault, or that they have not been preserved in the western part of the island. The occurrence of the two lowest marine terraces all around the island indicates that the whole island has then been recently uplifted. Moreover, their constant altitude indicates that there was no trench perpendicular tilt of La Désirade and no differential uplift at the scale of the island. As a consequence, the Coulée du Grand Nord fault was not active since their deposition and its middle-late Pleistocene apparent vertical fault throw cannot exceed 70 m. Taking into account that the Eemian sea level was around + 6 m above the present day sea level, La Désirade island should have suffered a general uplift of around 4 m since ~120 ka. This yields an average uplift rate of 0.04 mm/yr since that time. This rate is half of the proposal of Feuillet *et al.* [2004] but consistent with the estimate of Battistini *et al.* [1986].

CONCLUSIONS

The present-day strain pattern described in La Désirade island, as well as in the Guadeloupe region of the Lesser Antilles arc, is interpreted as mainly North-South, arc-parallel, extension. In this study we report evidence for several episodes of deformation that occurred prior to that current tectonic activity:

– la Désirade magmatic basement underwent Albian, syn-metamorphic, superimposed deformation. This first event is characterized by pervasive folding associated with thrust development, while the second one is responsible for upright folding coeval with two sets of conjugated steeply dipping strike-slip shear zones, respectively dextral N120/130° and sinistral N030/040° striking;

– following this late-Cretaceous compression, a NE-SW trending extension, involving the tectonic reactivation of the NW-SE shear zones, is responsible for the development of an irregular topography that pre-dated the deposition of the Pliocene platform;

– Late Pliocene to early Pleistocene extensional tectonics affects La Désirade island, leading to the reactivation of the N130 ± 10° oriented shear zones and the development of N040 ± 10°E-striking (possibly reactivated N40 ± 10° Albian shear zones). More recent tectonics leads to minor N90 ± 10° E-striking normal faults in relation with arc-parallel extension;

Because these three structural directions are considered to be still tectonically active, our study underlines the importance of inherited structures in localizing the current deformation in the studied area.

This study emphasizes also the importance of both late Pliocene-early Pleistocene and middle-late Pleistocene vertical movements in La Désirade and therefore in the present-day Lesser Antilles fore-arc. However, there is no evidence for present-day trench perpendicular tilt or differential uplift of La Désirade. An average uplift rate of 0.04 mm/yr can be estimated since ~120 ka.

Finally, our investigations on the basement of the Guadeloupe volcanic arc (i.e. La Désirade magmatic complex) suggest that the over thickened character of the Caribbean crust beneath in the Lesser Antilles may be partly inherited from late-Cretaceous shortening/thickening tectonics.

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References

AITKEN T., MANN P., ESCALONA A. & CHRISTESON G.L. (2011). – Evolution of the Grenada and Tobago basins and implications for arc migration. – *Mar. Petrol. Geol.,* **28**, 1, 235-258.

AVE LALLEMANT H.G. (1997). – Transpression, displacement partitioning and exhumation in the eastern Caribbean / South American plate boundary zone. – *Tectonics*, **16**, 2, 272-289.

BATTISTINI R., HINSCHBERGER F., HOANG C.T. & PETIT M. (1986). – La basse terrasse corallienne pleistocène (Eémien) de la Guadeloupe: Morphologie, datations $^{230}Th/^{234}U$, néotectonique. – *Rev. Géomorph. Dyn.*, **35**, 1-10.

BERGGREN W. A., KENT D. V., SWISHER III C. C. & AUBRY M.P. (1995). – A revised Cenozoic geochronology and chronostratigraphy. *In*: W.A. BERGGREN, D.V. KENT, M.P. AUBRY & J. HANDERBOL, Eds., Geochronology time scale and global stratigraphic correlation. – *SEPM Spec. Publ.,* **54**, 212.

BLEIN O., GUILLOT S., LAPIERRE H., MERCIER DE LEPINAY B., LARDEAUX J.M., MILLAN TRUJILLO G., CAMPOS M. & GARCIA A. (2003). – Geochemistry of the Mabujina complex, central Cuba: implications on the Cuban Cretaceous arc rocks. – *J. Geol.*, **111**, 89-110.

BOLLI H.M. & PREMOLI-SILVA I. (1973). – Oligocene to Recent planktonic foraminifera and stratigraphy of the Leg 15 sites in the Carribean Sea. – *Init. Rep. DSDP*, **XV**, 475-498.

BONNETON J.R. & SCHEIDEGGER A.E. (1981). – Relations between fracture patterns, seismicity and plate motions in the Lesser Antilles. – *J. Struct. Geol.,* **3**, 4, 359-369.

BOUYSSE P. (1988). – Opening of the Grenada back-arc basin and evolution of the Caribbean plate during the Mesozoic and early Paleogene. – *Tectonophysics,* **149**, 121-143.

BOUYSSE P., SCHMIDT-EFFING R. & WESTERCAMP D. (1983). – La Desirade island (Lesser Antilles) revisited: Lower Cretaceous radiolarian cherts and arguments against an ophiolitic origin for the basal complex. – *Geology*, **11**, 244-247.

BOUYSSE P., GARRABE F. & MAUBOUSSIN T. (1993). – Carte géologique de la France (1/50 000), Feuille Marie-Galante et îlets de la Petite-Terre (Guadeloupe). Service géologique national. – BRGM, Orléans, France.

BOUYSSE P. & GARRABE F. (1984). – Evolution tectonique néogène des îles calcaires de l'archipel de la Guadeloupe. – *C. R. Acad. Sci., Paris*, IIA, **298**, 763-766.

BOUYSSE P. & WESTERCAMP D. (1990). – Subduction of Atlantic aseismic ridges and Late Cenozoic evolution of the Lesser Antilles island arc. – *Tectonophysics*, **175**, 349-380.

BRIDEN J., REX D.C., FALLER A.M. & TOMBLIN J.F. (1979). – K-Ar geochronology and paleomagnetism of volcanic rocks in the Lesser-Antilles island arc. – *Phil. Trans. Royal Soc. London*, A, **291**, 485-528.

BROWN E.H. (1977). – The crossite content of Ca-amphibole as a guide to pressure of metamorphism. – *J. Petrol.,* **18**, 53-72.

CASE J.E., MAC DONALD W.D. & FOX P.J. (1990). – Caribbean crustal provinces; Seismic and gravity evidence. *In*: G. DENGO AND J.E. CASE, Eds, The geology of North America, (H), The Caribbean region. – Geological Society of America, Boulder, Colorado, 15-36.

CHRISTESON G.L., BANGS N.L. & SHIPLEY T.H. (2003). – Deep structure of an island arc backstop, Lesser Antilles subduction zone. – *J. Geophys. Res.*, **108**, 2327.

CORDEY F. & CORNÉE J.-J. (2009). – Late Jurassic radiolarians from La Desirade basement complex (Guadeloupe, Lesser Antilles arc) and tectonic implications. – *Bull. Soc. géol. Fr.*, **180**, 399-409.

CORNÉE J.-J., LÉTICÉE J.-L., MÜNCH P., QUILLÉVÉRÉ F., LEBRUN J.-F., MOISSETTE P., BRAGA J.-C., MELINTE-DOBRINESCU M., DE MIN L., OUDET J. & RANDRIANASOLO A. (2012). – Sedimentology, palaeoenvironments and biostratigraphy of the Pliocene-Pleistocene carbonate platform of Grande-Terre (Guadeloupe, Lesser Antilles forearc). – *Sedimentology*, **59**, 1426-1451.

CORSINI M., LARDEAUX J.-M., VERATI C., VOITUS E. & BALAGNE M. (2011). – Discovery of Lower Cretaceous synmetamorphic thrust tectonics in French Lesser Antilles (La Désirade Island, Guadeloupe): Implications for Caribbean geodynamics. – *Tectonics*, **30**, TC4005, doi: 10.1029/2011TC002875.

DE METS C., JANSMA P.E., MATTIOLI G.S., DIXON T.H., FARINA F., BILHAM R., CALAIS E. & MANN P. (2000). – GPS geodetic constraints on Caribbean-North America plate motion. – *Geophys. Res. Lett.*, **27**, 437-440.

DE REYNAL A. (1966). – Carte géologique de Marie-Galante et de la Désirade à 1/50 000. – Service de la Carte géologique de la France, Paris.

DIXON T.H., FARINA F., DE METS C., JANSMA P.E., MANN P. & CALAIS E. (1998). – Relative motion between the Caribbean and North American plates and related boundary zone deformation from a decade of GPS observations. – *J. Geophys. Res*, **103**, 15157-15182.

DRAPER G. (1986). – Blueschists and associated rocks in eastern Jamaica and their significance for Cretaceous plate margin development in the northern Caribbean. – *Geol. Soc. Amer. Bull.*, **87**, 48-60.

EDGAR N.T., EWING J.I. & HENNION J. (1971). – Seismic refraction and reflection in the Caribbean Sea. – *AAPG*, **55**, 833-870.

ERNST W.G. (1979). – Coexisting sodic and calcic amphiboles from high-pressure metamorphic belts and the stability of barroisitic amphibole. – *Mineral. Mag.*, **43**, 269-278.

ERNST W.G. & LIOU J.G. (2008). – High and ultrahigh pressure metamorphism: Past results and future prospects. – *Amer. Min.*, **93**, 1771-1786.

FEUILLET N., MANIGHETTI I. & TAPPONNIER P. (2001). – Active extension perpendicular to subduction in the Lesser Antilles island arc; Guadeloupe, French Antilles. – *C. R. Acad. Sci.,* Paris, II, **333**, (9), 583-590.

FEUILLET N., MANIGHETTI I. & TAPPONNIER P. (2002). – Arc parallel extension and localization of volcanic complexes in Guadeloupe, Lesser Antilles. – *J. Geophys. Res.*, **107**, B12, 2331.

FEUILLET N., TAPPONNIER P., MANIGHETTI I., VILLEMANT B. & KING G.C.P. (2004). – Differential uplift and tilt of pleistocene reef platforms and quaternary slip rate on the Morne-Piton normal fault (Guadeloupe, French West Indies). – *J. Geophys. Res.*, **109**, BO2404.

FINK L.K. (1970). – Field guide to the island of La Desirade with notes on the regional history and development of the Lesser Antilles island arc. *In:* International field guidebook to the Caribbean island arc system. – American geological Institute and National Science Foundation, 17 p.

GAUCHAT K. (2004). – Geochemistry of Desirade Islands rocks (Guadeloupe, French Antilles). – Unpublished diploma Thesis, University of Lausanne, Switzerland, 80 p.

GONCALVES P., GUILLOT S., LARDEAUX J.-M., NICOLLET C. & MERCIER DE LEPINAY B. (2000). – Thrusting and sinistral wrenching in a pre-Eocene HP-LT Caribbean accretionary wedge (Samana peninsula, Dominican Republic). – *Geodin. Acta*, **13**, 119-132.

JULIEN P. & BONNETON J.R. (1989). – Regional stress field in the Lesser Antilles between Guadeloupe and Barbuda islands. – *Geophys. Res. Lett.*, **16**, 11, 1313-1316.

KERR A.C., MARRINER G.F., TARNEY J., NIVIA A., SAUNDERS A.D., THIRLWALL M.F. & SINTON C.W. (1997). – Cretaceous basaltic terranes in western Colombia: elemental, chronological and Sr–Nd isotopic constraints on petrogenesis. – *J. Petrol.*, **38**, 677-702.

KERR A. C., TARNEY J., NIVIA A., MARRINER G. F. & SAUNDERS A. D. (1998). – The internal structure of oceanic plateaus: inferences from obducted Cretaceous terranes in western Colombia and the Caribbean. – *Tectonophysics*, **292**, 173-188.

KERR A.C., ITURRALDE-VINENT M.A., SAUNDERS A.D., BABBS T.L. & TARNEY J. (1999). – A new plate tectonic model of the Caribbean: Implications from a geochemical reconnaissance of Cuban Mesozoic volcanic rocks. – *Geol. Soc. Amer. Bull.*, **111**, 1581-1599.

KERR A. C., WHITE R. V., THOMPSON P. M. E., TARNEY J. & SAUNDERS A. D. (2003). – No oceanic plateau-No Caribbean plate? The seminal role of an oceanic plateau in Caribbean plate evolution. *In*: C. BARTOLINI, R.T. BUFFLER and J.F. BLICKWEDE, Eds, The circum-Gulf of Mexico and the Caribbean; hydrocarbon habitats, basin formation, and plate tectonics. – *AAPG Mem.,* **79**, 126-168.

KOPP H., WEINZIERL W., BECEL A., CHARVIS P., EVAIN M., FLUEH E.R., GAILLER A., GALVE A., HIRNA., KANDILAROV A., KLAESCHEN D., LAIGLE M., PAPENBERG C., PLANERT L., ROUX E. & Trail and Thales teams (2011). – Deep structure of the Lesser Antilles island arc: relevance for the formation of continental crust. – *Earth Planet. Sci. Lett.*, **304**, 121-134.

KRETZ R. (1983). – Symbols for rock-forming minerals. – *Am. Mineral.,* **68**, 277-279.

KROEHLER M.E., MANN P., ESCALONA A. & CHRISTESON G.L. (2011). – Late Cretaceous-Miocene diachronous onset of back thrusting along the South Caribbean deformed belt and its importance for understanding processes of arc collision and crustal growth. – *Tectonics*, **30**, TC6003, doi: 10.1029/2011TC002918.

LAPIERRE H., BOSCH D., DUPUIS V., POLVE M., MAURY R.C., HERNANDEZ J., MONIÉ P., YEGHICHEYAN D., JAILLARD E., TARDY M., MERCIER DE LEPINAY B., MAMBERTI, M., DESMET M., KELLER A. & SENEBIER F. (2000). – Multiple plume events in the genesis of the peri-Caribbean Cretaceous oceanic plateau. – *J. Geophys. Res.*, **105**, 8403– 8421.

LASSERRE G. (1961). – La Guadeloupe. – Unpublished Thesis, Bordeaux I University, Talence, France.

LÉTICÉE J.-L. (2008). – Architecture d'une plate-forme carbonatée insulaire plio-pléistocène en domaine de marge active (avant-arc des Petites Antilles): chronostratigraphie, sédimentologie et paléoenvironnements. – Unpublished PhD Thesis, University Antilles-Guyane, France, 229 pp.

LÉTICÉE J.-L., RANDRIANASOLO A., CORNÉE J.-J., MÜNCH, P., LEBRUN, J.-F., SAINT-MARTIN J.-P. & VILLENEUVE M. (2005). – Mise en évidence d'une discontinuité émersive majeure au sein de la plate-forme récifale Plio-Pléistocène l'avant-arc des Petites Antilles). – *C. R. Acad. Sci.,* Paris, IIA, **337**, 617-624.

LOURENS L.J., HILGEN F.J., LASKAR J., SHACKLETON N.J. & WILSON D.S. (2004). – The Neogene period. *In*: F.M. GRADSTEIN, J.G. OGG AND A.G. SMITH, Eds, A geologic time scale 2004. – Cambridge University Press, Cambridge, 409-440.

LUGOWSKY A., OGG J., GRADSTEIN F.M. & AULT A. (2011). – Time Scale Creator 4.2.5 software. Available at: http://www.tscreator.org.

MANN P. & GORDON M.B. (1996). – Tectonic uplift and exhumation of blueschist belts along transpressional strike-slip fault zones. In: G.E. BEBOUT, D.W. SCHOLL, S.H. KIRBY and J.P. PLATT, Eds, Subduction top to bottom. – *Geophys. Monogr. Ser.*, **96**, AGU, Washington D.C., 143-154.

MARESCH W.V. (1975). – The geology of northeastern Margarita island, Venezuela: A contribution to the study of Caribbean plate margins. – *Geol. Rundsch.*, **64**, 846-883.

MARESCH W.V. (1977). – Experimental studies on glaucophane. An analysis of present kwowledge. – *Tectonophysics*, **43**, 109-125.

MARTIN-KAYE P.H.A. (1969). – A summary of the geology of the Lesser Antilles. – *Overseas Geol. Miner. Ressources.*, **10**(2), 171-206.

MARUYAMA S., CHO M. & LIOU J.G. (1986). – Experimental investigations of blueschist – greenschist transition equilibria: pressure dependence of Al_2O_3 contents in sodic amphiboles – a new geo-barometer. *In*: B.W. EVANS and B.W. BROWN, Eds, Blueschists and eclogites. – *Geol. Soc. Amer. Mem.*, **164**, Boulder, 1-16.

MARUYAMA S., LIOU J.G. & TERABAYASHI M. (1996). – Blueschists and eclogites of the world and their exhumation. – *Int. Geol. Rev.,* **38**, 485-594.

MATTINSON J.M., FINK L.K. JR. & HOPSON C.A. (1973). – Age and origin of ophiolitic rocks on La Desirade Island, Lesser Antilles Island arc. – *Year Book Carnegie Inst. Washington*, **72**, 616-623.

MATTINSON J.M., FINK L.K. JR. & HOPSON C.A. (1980). – Geochronologic and isotopic study of the La Desirade Island basement complex. Jurassic oceanic crust in the Lesser Antilles. – *Contrib. Mineral. Petrol.*, **71**, 237-245.

MATTINSON J.M., PESSAGNO E.A. JR., MONTGOMERY H. & HOPSON C.A. (2008). – Late Jurassic age of oceanic basement at La Désirade Island, Lesser Antilles arc. *In*: J. WRIGHT and J. SHERVAIS, Eds, Ophiolites, arcs, and batholiths: a tribute to Cliff Hopson. – *GSA Spec. Paper*, **438**, 175-190.

MAUFFRET A. & LEROY S. (1997). – Seismic stratigraphy and structure of the Caribbean igneous province. – *Tectonophysics*, **283**, 61-104.

MÜNCH P., LEBRUN J.-F., CORNEE J.-J., THINON I., GUENNOC P., MARCAILLOU B. & RANDRIANASOLO A. (2013). – Pliocene to Pleistocene carbonate systems of the Guadeloupe archipelago, French Lesser Antilles: a land and sea study. *In*: J.F. LEBRUN and B. MARCAILLOU, Eds, Carribean geosciences. – *Bull. Soc. géol. Fr.,* **184**, 1, 99-110.

NEILL I., GIBBS J.A., HASTIE A.R. & KERR A.C. (2010). – Origin of the volcanic complexes of La Désirade, Lesser Antilles: Implications for tectonic reconstruction of the Late Jurassic to Cretaceous Pacific-proto Caribbean margin. – *Lithos*, **120**, 407-420.

OKADA H. & BUKRY D. (1980). – Supplementary modification and introduction of code numbers to the Low Latitude Coccolith Biostratigraphy Zonation (Bukry, 1973, 1975). – *Mar. Micropal.*, **51**, 321-325.

PINDELL J.L. & BARRETT S.F. (1990). – Geological evolution of the Caribbean region: a plate tectonic perspective. *In*: G. DENGO and J.E. CASE, Eds, The Caribbean region, the geology of North America. – Geol. Soc. Amer., Boulder, CO, 405-432.

PINDELL J.L. & KENNAN L. (2009). – Tectonic evolution of the Gulf of Mexico, Caribbean and northern South America in the mantle reference frame: an update. *In*: K.H. JAMES, M.A. LORENTE and J.L. PINDELL, Eds, The origin and evolution of the Caribbean plate. – *Geol. Soc., London, Spec. Pub.*, **328**, 1-55.

SCHNEIDER J., BOSCH D., MONIE P., GUILLOT S., GARCIA-CASCO A., LARDEAUX J.M., LUIS TORRES-ROLDAN R. & MILLAN TRUJILLO G. (2004). – Origin and evolution of the Escambray massif (Central Cuba): an example of HP/LT rocks exhumed during intraoceanic subduction. – *J. Metamorph. Geol.*, **22**, 227–247.

SEVILLA W.I., AMMON C.J., VOIGHT B. & DE ANGELIS S. (2010). – Crustal structure beneath the Montserrat region of the Lesser Antilles island arc. – *Geochem. Geophys. Geosyst.,* **11**, doi: 10.1029/2010GC003048.

SPEAR F.S. (1993). – Metamorphic phase equilibria and pressure-temperature-time paths. – Mineralogical Society of America, Washington, D.C., 799 p.

STÖCKHERT B., MARESCH W.V., BRIX M., KAISER C., TOETZ A., KLUGE R. & KRUCKHANS-LUEDER G. (1995). – Crustal history of Margarita island (Venezuela) in detail: Constraint on the Caribbean plate-tectonic scenario. – *Geology*, **23**, 787-790.

THINON I., GUENNOC P., BITRI A. & TRUFFERT C. (2010). – Study of the Bouillante bay (West Basse-Terre island shelf): contribution of geophysical surveys to the understanding of the structural context of Guadeloupe (French West Indies-Lesser Antilles). – *Bull. Soc. géol. Fr.,* **181**, 1, 51-65.

TSUJIMORI T., SISSON V.B., LIOU J.G., HARLOW G.E. & SORENSEN S.S. (2006). – Petrologic characterization of Guatemalan lawsonite eclogite: Eclogitization of subducted oceanic crust in a cold subduction zone. *In*: B.R. HACKER, W.C. MCCLELLAND and J.G. LIOU, Eds, Ultrahigh-pressure metamorphism. Deep continental subduction. – *Geol. Soc. Amer., Sp. Pap.*, **403**, 147-168.

WESTBROOK G.K. & MCCANN W.R. (1986). – Subduction of Atlantic lithosphere beneath the Caribbean. *In*: P.R. VOIGHT and B. TUCHOLKE, Eds, The geology of North America, vol. M – The western North Atlantic region. – Geol. Soc. Amer., Boulder, 341-350.

WESTERCAMP D. (1979). – Diversité, contrôle structural et origines du volcanisme récent dans l'arc insulaire des Petites Antilles. – *Bull. BRGM*, Sect. IV, **3-4**, 211-226.

WESTERCAMP D. (1980). – La Désirade, carte géologique à 1: 25 000 et notice explicative. Service géologique national. – *BRGM,* Orléans, France.