

## UPRAISED CARIBBEAN SEA FLOOR BELOW ACOUSTIC REFLECTOR B' AT THE SOUTHERN PENINSULA OF HAITI<sup>1,2</sup>

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### ABSTRACT

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The Dumisseau Formation is described as a complex of intercalated mafic and pelagic rocks of Cretaceous age exposed at the Southern Peninsula of Haiti. This formation includes a lower member of possibly Early Cretaceous age, and the St. Dominique Member of Late Cretaceous age. Their thickness exceeds 1.5 km, and the igneous rocks show geochemical affinities for abyssal and island arc tholeiites, which accumulated in a deep eupelagic environment.

The formation is here equated to an ophiolite complex described earlier by Miyashiro, and to crustal layers (2A and 2B) described by Houtz & Ewing. Correlations between the Dumisseau Formation and geophysical data concerning the crustal structure and composition of both the Caribbean crust and oceanic crust provide corroborative evidence to suggest that the complex is the land analog of crustal materials below acoustic reflector B'. The Dumisseau Formation thus represents a portion of the Caribbean crust uplifted through block faulting tectonism much similar to the adjacent Beata Ridge.

### INTRODUCTION

Until recently very little attention has been given to potential upraised Caribbean Sea floor where the crustal materials could be studied on land. MATTSON & PESSAGNO (1971) suggested that volcanic rocks cropping out in Puerto Rico and the Dominican Republic may represent layer A' interbedded with coarser volcanic debris and preserved near early Tertiary volcanic centers. Complex ultramafic rocks exposed in Cuba, Puerto Rico and the Dominican Republic have also been interpreted as uplifted parts of the Caribbean crust or

dislocated Benioff zones (MATTSON, 1971; NAGLE, 1974; BOITEAU, 1976).

MAURRASSE (1975) and MAURRASSE ET AL. (1975) made the first attempts to identify Horizon B' in sediments and igneous rocks exposed in the Southern Peninsula of Haiti. In this paper we provide further detailed palaeontologic and lithostratigraphic study of the rock sequences composed of igneous and sedimentary units exposed at the eastern portion of the Southern Peninsula of Haiti (Fig. 1). These heterogeneous rock sequences are here related to the upper part of the Caribbean crust at and below Horizon B'. Although these rocks had been mentioned in early works by WOODRING ET AL. (1924) and BUTTERLIN (1954), until the present work no further details were given and they have been since indiscriminately mapped as 'basalt'.

The relationship between the rocks in this region of Haiti and their potential deep-sea analogs in the submerged part of the Caribbean crust became meaningful mainly after the results of Caribbean Leg 15 (EDGAR ET AL., 1973). It was found, indeed, that Horizon B' corresponds to tholeiitic basalts and doleritic sills intercalated with and overlain by sediments of Coniacian to Campanian ages. Similar lithologic relationship also occurs in the Southern Peninsula of Haiti (MAURRASSE, 1975), where deep erosion in the sequences allows further

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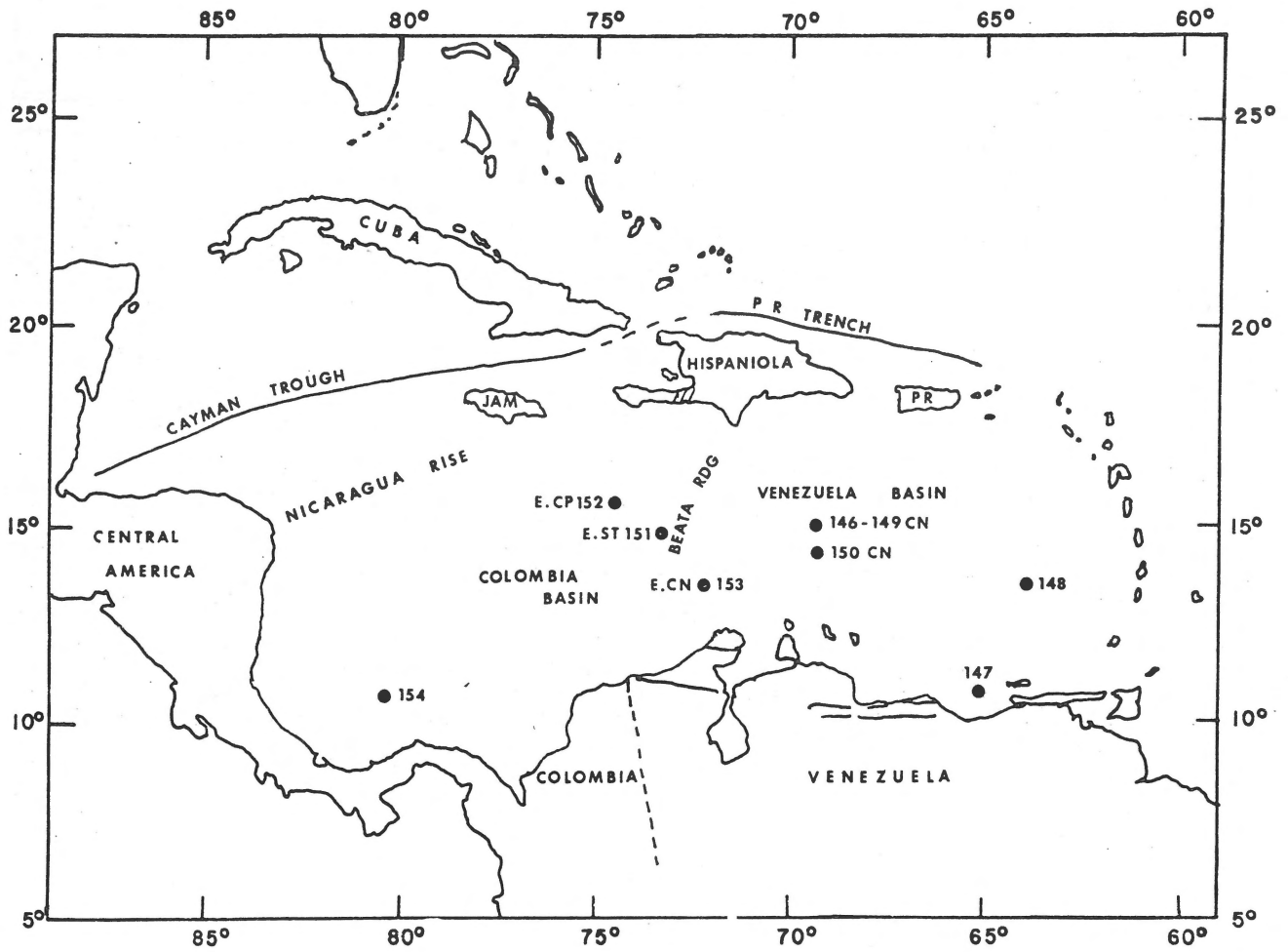


Fig. 1  
Map of Caribbean region showing location of DSDP Leg 15 sites relative to the study area. Letters near DSDP sites indicate estimated age of igneous rocks at termination of hole (from Bolli & Premoli-Silva, 1973; Edgar et al., 1973). CP = Campanian; ST = Santonian; CN = Coniacian.

observation of units below B'' down to an equivalent thickness of 1500 m or so. Thus, this region provided us an excellent opportunity to study possible sub-B'' materials that have been generally suggested to be composed of intercalated igneous and sedimentary rocks (EDGAR ET AL., 1975; HOPKINS, 1973; LUDWIG ET AL., 1975; CASE, 1975; MATTHEWS & HOLCOMBE, 1976; LADD & WATKINS, 1977), although their true lithologic make-up was not known with certainty and thus remained somewhat hypothetical.

The interpretation of the rocks from the area studied herein brings further corroborative evidence to the geophysical data at sea concerning the lithologic identity of the sub-B'' reflectors. The sequences of rocks studied in the Southern Peninsula of Haiti are those at or near Dumisseau, hence the name of Dumisseau Formation applied to the complex in the present work (Fig. 2: star immediately southeast of Kencsoff).

#### PHYSIOGRAPHIC AND STRUCTURAL SETTING

Physiographically the study area is located in the central rugged reliefs of the Massif de la Selle, immediately south of Port-au-Prince (Fig. 2). It also lies entirely within the region previously mapped as 'Cretaceous basalts' (WOODRING ET AL., 1924; BUTTERLIN, 1954) which is characterized by lower but much rougher topography (max. elevation approximately 1500 m) than the surrounding Tertiary limestone ranges whose highest summit is the 'Pic de la Selle' (max. elevation 2674 m). While the surface features of the Tertiary limestone terranes are predominantly karstic, the Cretaceous terranes give rise to smoother but much steeper reliefs with some dip-slopes often greater than 60° angle. Sheer vertical drops are also common along the river valleys which are frequently controlled by the major or minor fault systems transecting



broad east-west striking anticlinal-like structure. Vertical displacement between blocks as determined from the height of the Tertiary limestones is estimated to be in the order of 200 to 600 meters or more, although there is considerable variability due to antithetic and subsidiary faulting.

## THE DUMISSEAU FORMATION

### *Location and boundaries*

The Dumisseau Formation as established here includes two members. The upper member, or St. Dominique Member as it will be designated hereafter, is best exposed along the hillslope east and west of St. Dominique Church in Dumisseau at Haiti meter grid 792,500 m E; 2,038,500 m N, and 791,300 m E; 2,039,300 m N to 2,038,700 m N, respectively.

The lower boundary of the St. Dominique Member is characterized by a gradual decrease in importance of the limestone beds found intercalated with the igneous rocks (Fig. 3).

The lower member is unnamed here. It is typically exposed along the ridge that runs northwest-southeast from the St. Dominique Church (Haiti meter grid 791,800 m E; 2,038,950 m N) to Grande Riviere (Haiti meter grid 793,450 m E; 2,037,000 m N), and along the valley of Ravine Nan Roseau between the following coordinates: Haiti meter grid 794,000 m E; 2,039,000 m N; and 795,000 m E; 2,037,350 m N. The equivalent of a hypostratotype to this member occurs south of Grande Riviere along the valley of Riviere Macom (Fig. 2, GR and NR south of Kenscoff).

The upper boundary of the formation is unconformably overlain by upper Eocene limestone, which is typically a shallow-water algal foraminiferal biocalcirudite. In most instances the upper boundary of the formation is concealed under slope and fault breccias previously mapped as 'basal conglomerate' in this area (BUTTERLIN, 1954, 1956). The slope breccias include mostly Eocene limestones and to a lesser extent may also incorporate fragments of the adjacent underlying rocks, regardless of their age and origin. Fragments of the Eocene limestones are predominant in this region, but in many cases fragments of the underlying Cretaceous rocks occur at the contact zones. Although upper Eocene biocalcirudite appears to be the only sediment to have developed directly above the unconformity in the type area (NS-ACSN, 1976), older types of contacts between the upper Cretaceous rocks and the Tertiary System may be expected elsewhere. In fact, well preserved lower Eocene radiolarian assemblages of the *Buryella clinata* zone/*Globorotalia formosa formosa* zone (MAURRASSE, in prep.) occurs in Kenscoff (Fig. 2) not far from the type area. Furthermore, farther west from this area or northeast of Jacmel a thick sequence of pelagic foraminiferal limestone yielded *Globigerina eugubina*, indicating the presence of early Danian in certain areas (MAURRASSE, 1975, 1976, and in prep.).

The lower boundary of the Dumisseau Formation should coincide with primordial basement rocks which are not yet identified in the type area.

### *Previous works*

Two lithostratigraphic formations have been previously named by BUTTERLIN (1954) from the Cretaceous rocks of Hispaniola. The Trois Riviere Formation is described to include 'argillite, argillaceous schists, brown and gray shales, thick bedded varicolored limestones with calcitic veins, and red or dark colored radiolarites'. The limestones become predominant particularly toward the top of the series. This formation which crops out essentially in the northern areas of Haiti has an estimated thickness of about 500 meters and ranges in age from late Early Cretaceous to Late Cretaceous.

The Macaya Formation named after Pic Macaya has its type area in the Massif de la Hotte which forms the western portion of the Southern Peninsula of Haiti. According to BUTTERLIN (1954, 1956), this formation comprises a sequence of massive varicolored and sparsely silicified limestones with abundant calcite veins. Thin argillaceous layers are also occasionally intercalated with the limestones, and increase in frequency toward the base of the sequence. Radiolarites are also reported in the formation. Butterlin estimated its thickness to be 'no less than 2000 meters'. It ranges in age from late Campanian to possibly Maastrichtian (AYALA-CASTAÑARES, 1959). Although BUTTERLIN (1954, 1956) indicated that thick underwater basaltic flows occurred prior to and after the accumulation of the Macaya Formation, none of the igneous rocks were considered to be included in it.

WOODRING ET AL. (1924) were the first to point out the presence of sedimentary layers (limestones and cherts) intercalated in the basaltic rocks of the Massif de la Selle, but they did not undertake any detailed lithologic study of the sequence.

In the present work we discuss new data concerning the lithostratigraphy, age and significance of this complex sequence of sedimentary and igneous rocks exposed at the eastern portion of the Southern Peninsula of Haiti. These rocks here referred to as the Dumisseau Formation have an estimated combined total thickness of at least 1500 meters and crop out in the type locality from about the altitudes of 1300 meters to 592 meters in the Valley of Grande Riviere (Fig. 2).

### *Lithostratigraphy*

The Dumisseau Formation as a whole is essentially characterized by a sequence of interbedded pillowed and nonpillowed basalts, dolerites, pelagic limestones, intrabasinal volcanogenic and biogenic turbidites, varicolored cherts and siliceous siltstones (Fig. 3). Although fossils such as caprinids and ammonites (REESIDE, 1947) have been reported from localities north of Jacmel (Fig. 2) no shallow-water

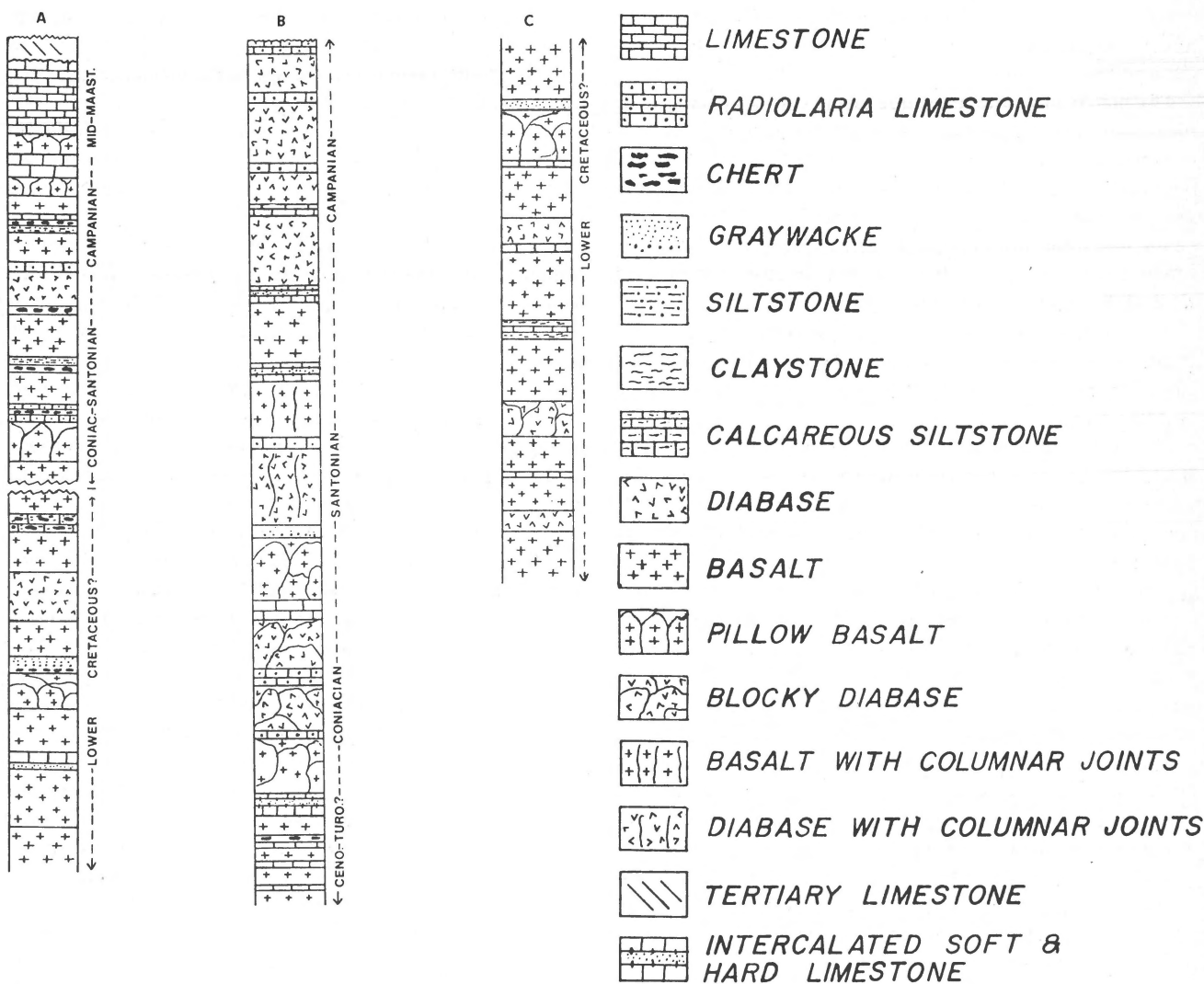


Fig. 3

Schematic lithologic representation (not to scale) of sequences at A: St. Dominique ridge; discontinuity in the column does not correspond to an unconformity but rather stresses the composite character of the sequence described at this ridge. B: hill east of St. Dominique; C: the section of the lower member exposed at Ravine Nan Roseau (RN of Fig. 2).

faunal remains have been found in the Dumisseau Formation in the type area.

### Sedimentary rocks

The sedimentary rocks of the St Dominique member consist predominantly of greyish orange (10YR7/4) to yellowish grey (547/2) limestones and chalks, varying to medium grey (N5) and medium olive grey (5Y5/1). The weathered surface of these rocks often shows a rusty color which is limited only to the altered zones. Burrow mottling occurs extensively in all the limestones, which may also display an intricate net of microfissures filled in with calcite or silica. Silicification pervades all the calcareous beds although true chert stringers are quite rare in the uppermost 30 m or so of the exposed sequence at Dumisseau. Dispersive silicification selectively af-

fects the fillings of burrows and foraminifera, and the radiolarians. Most of these calcareous layers can be described microscopically as sparse fossiliferous micrites, but occasional beds are truly packed foraminiferal-radiolarian micrite. These grain-supported layers usually display a sandy texture and slight graded-bedding much similar to such layers described from the pelagic Cretaceous limestone sequence of DSDP leg 15 sites 146 and 153 (Fig. 1) in the Caribbean Sea (MAURRASSE, 1973; SCHNEIDERMAN, 1973). In these layers, planktonic foraminifera and radiolaria predominate in the fractions coarser than 40 microns. Benthic foraminifera are always scarce, represented mostly by taxa of the lagenid and gyrogonid groups. Foraminifera and radiolaria are always better preserved in the argillaceous layers although their cavities are there also filled with microspar, spar and silica. Despite evidence of extensive fracturation of the beds, ob-

vious signs of fossil deformation such as flattening seldom affect heterohelicids and globotruncanids of the most sheared faulted zones.

The matrix in all the limestone layers consists primarily of microspar, and interlocking spar, and micrite in the less consolidated beds. Usually there are no distinguishable nanofossil remains, although some fine micritic components may be parts of dislocated coccolithophorids. The argillaceous limestone layers contain microcrystalline clay matrix often showing a very finely laminated structure accentuated by dark brown to opaque ferruginous oxides.

The fabric in most layers is random, but there is a distinct preferential orientation of the microfossils in the sandy-textured layers where their long axis is always parallel to the bedding plane.

In addition to feldspars, clino- and orthopyroxenes and magnetite grains, other clasts which may also occur in the calcareous layers of the upper member comprise very rare sponge spicules, echinoid spines and occasional subhedral to euhedral spinels.

The sedimentary layers of the lower member are mainly greywacke with graded bedding and cross-lamination, shales, siltstones and occasional claystone, all apparently of intrabasinal volcanogenic origin. Calcareous layers are very scarce; they occur mostly toward the uppermost part of the lower member which grades into the St. Dominique Member. Clasts consist essentially of grains of basaltic origin in an argillaceous matrix. Some of these rocks are rich in radiolarian molds, and very well preserved specimens occur occasionally in layers showing little effect of diagenetic recrystallization. Foraminifera are generally very rare or absent in the volcanogenic turbidites; when they occur in some of the calcareous layers they belong essentially in the planktonic groups.

Chert stringers usually show gradation from dispersive and selective silicification of allochems to pervasive silicification of the matrix in the calcareous layers. Chertification is thus a progressive replacement of the calcareous constituents by microcrystalline quartz. In the upper member the cherts are predominantly brown, reddish brown and of various shades of grey to black, much reminiscent of the cherts recovered in the Cretaceous limestones from various DSDP Caribbean-Sea sites (Fig. 1) and particularly those of sites 146, 152 and 153 (EDGAR ET AL., 1973; MAURRASSE, 1973). Cherts associated with shales and siltstones of the lower member are usually green or black when directly intercalated in the igneous rocks. Either one of these cherts may show remnants of radiolarian shells although their degree of preservation varies greatly within the cherts as they often have lost their details through epigenization by chalcidony.

#### *Micropalaeontology and age*

Planktonic foraminifera comprise most of the calcareous microfossils still preserved in the carbonate layers. Although

heterohelicids and globigerine-shaped taxa are predominant, the globotruncanids and the radiolaria have been the most reliable groups upon which the age of the formation has been established. As pointed out earlier, benthic foraminifera are always very scarce at all levels, making up only an insignificant part of the biogenic components. They include mostly deep-water lagenids, gyrogonidids and scarcer agglutinated forms.

Samples from the uppermost part of the St. Dominique Member above the last occurrences of basaltic layers yielded well diversified assemblages including *Globotruncana fornicata*, *G. stuartiformis*, *G. gagnebini*, *G. ventricosa*, *G. cf. gansseri*, *G. lapparenti*, *G. linneiana*, *G. tricarinata*, *Planomalina cf. messinae*, *Hedbergella* aff. *delrioensis*, *Clavibergella* aff. *moremani*, *Rotalipora* spp., *Whiteinella* spp. and *Globigerinelloides* sp. The radiolarian fauna is quite corroded at this upper level which includes *Dictyomitra* aff. *torquata*, *D. cf. costata*, *Crucella* aff. *cachensis* (PESSAGNO, 1976), *Theocampe salilum*, *Pseudoaulophacus* aff. *pargueraensis*, *P. aff. florensensis*, and other unidentified spumellarians and spongodiscids (*Stylotrochus* spp., *Xiphospira* spp., *Spongodiscus* spp.). Although some older taxa of both foraminifera and radiolaria suggest some degree of reworking in these layers, the presence of *Globotruncana gansseri* in these assemblages indicates an early middle Maastrichtian age (BOLLI & PREMOLI-SILVA, 1973) for the youngest exposed part of the sequence.

The youngest basalt occurs some 25 meters below the youngest limestones. The foraminiferal assemblage at this level includes, among other taxa, abundant heterohelicids, *Globotruncana fornicata*, *G. gagnebini*, *G. lapparenti*, *G. rosetta*, *G. stuartiformis*, *G. ventricosa* and *G. calcarata* indicating a latest Campanian age, *Globotruncana calcarata* zone (BOLLI & PREMOLI-SILVA, 1973; MAURRASSE, 1975) for the last magmatic flow that affected this region during late Cretaceous times. SAYEED ET AL. (1978) reported a whole-rock K-Ar age of  $75.0 \pm 1.6$  Ma (early Campanian to latest Santonian) for a coarse dolerite intruded in the upper part of the sequence. This age is in agreement with the age range recorded in the fossil record. This intrusion among others shows that intermittent extrusions and intrusions were the predominant process in the formation of this upper part of the Caribbean crust, as will be discussed later.

Foraminiferal assemblages similar to the latter are also found in the calcareous layers of the hill east of St. Dominique Church which was given previously as Haiti meter grid 792,500 m E.; 2,038,500 m N. Radiolaria there are also badly corroded and include species belonging in the genera *Crucella*, *Dictyomitra* and molds of unidentified spongodiscids.

Radiolarian assemblages indicative of latest Santonian or earliest Campanian age occur at both the St. Dominique outcrop and the above mentioned hill east of it. Well preserved radiolarian specimens occur essentially in the sandy textured layers that have produced abundant spongodiscids of the *Stylotrochus* and *Xiphospira* genus-groups, and the fol-

lowing species *Alievium gallowayi*, *A. aff. murphyi*, *Archaeospongoprimum salumi*, *Arch. andersoni*, *Cavaspongia cf. antelopensis*\*, *C. cf. californiense*\*, *Clathropyrgus titthium*, *Crucella cf. espartoensis*, *Dictyomitra multicostata*, *Lithocampe aff. perampla*\*, *Orbiculiforma aff. cachensis*\*, *O. monticelloensis*, *Pseudoaulophacus cf. venadoensis*, *Patulibrachium taliaferroi*, *Theocampe salilum*. Some of the taxa in this assemblage (\*) also indicate reworking from older levels of possibly earlier Cretaceous deposits (PESSAGNO, 1976; RIEDEL & SANFILIPPO, 1974).

At the lowest portion of the St. Dominique outcrop of the upper member, or about 200 meters below the youngest layers, sandy textured layers intercalated in basalts include *Alievium cf. praegallowayi*, *A. aff. superbum*, *Cavaspongia cf. californiense*, *Crucella cf. cachensis*\*, *C. aff. plana*, *C. sp.\** (affinity *Crucella* sp.; FOREMAN, 1973, Pl. 13, Figs. 18 & 19), *Haliodyctya aff. hojnosi*\*, *Orbiculiforma aff. cachensis*, *O. aff. monticelloensis*, *O. aff. quadrata*, and *Paronaella aff. venadoensis*. Except for the species marked with an asterisk, which could indicate ages ranging from early Cretaceous to Turonian (PESSAGNO, 1976; FOREMAN, 1974; RIEDEL & SANFILIPPO, 1974), all the other taxa suggest a Coniacian age for that level.

It is probable that the oldest age that may be expected for the lower part of the St. Dominique Member lies within the Cenomanian or even latest Early Cretaceous, as suggest the foraminiferal and radiolarian assemblages found at the base of the component stratotype east of the St. Dominique outcrop. The fauna includes taxa with affinities for *Hedbergella planispira*, *H. amabilis*, *Praeglobotruncana* spp., *Ticinella roberti*, and radiolaria of the *Stichomitra asymbatos* group (RIEDEL & SANFILIPPO, 1974).

The sedimentary layers of the lower member are predominantly clastics, and the fossils they contain are usually obliterated beyond recognition because of recrystallization and silicification. Despite this constraint, it can be postulated that part, if not most of the lower member of the Dumisseau Formation should lie in the Early Cretaceous. The scarce fauna that has been identified in thin shale layers in the upper part of the lower member includes probable heterohelids, and species of the families Planomaliniidae (*Globigerinelloides*) and Rotaliporidae (*Hedbergella*, *Rotalipora*).

#### Igneous rocks

The igneous rocks intercalated with the sedimentary rocks in the Dumisseau Formation are essentially basaltic. They range in grain size from microcrystalline to doleritic in dikes and sills that transect or are concordant with the sequence. Occasional gabbroic intrusions occur interspersed in the formation, while lherzolite may occur in limited expanse toward the base of the lower member.

Although olivine-rich diabase, and dunite pebbles have been found in river valleys, in situ outcrops have not yet been discovered at the type locality. It is thought probable that

these rocks are xenoclasts in inclusions in the basalts and dolerites as parts of deep-seated cumulates. Both pillowed and nonpillowed basalts may show vesicles of various sizes, and some porphyritic diabases and basalts may display abundant dark dots due to the alteration of olivine. Some of the lower member basalts also show occasionally disseminated pyrite.

The basalts are generally holocrystalline, aphanitic to phaneritic, and occasionally hypocrySTALLINE chiefly at the chilled contact zones. In thin section most of the basalts exhibit porphyritic, glomeroporphyritic textures. The vesicular basalts display ophitic texture near the vesicles, and become

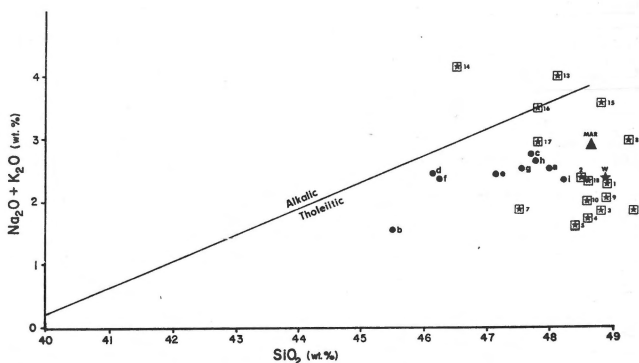


Fig. 4

Alkali/silica plot of some of the Dumisseau igneous rocks compared with average mid-Atlantic ridge (MAR) basalts (from Coleman, 1977) and DSDP Leg 15 basalts and dolerites (from Donnelly et al., 1973). Number 1 to 7 = Site 146; 8 to 10 = Site 150; 13, 14 = Site 151; 15, 16 = Site 152; 17, 18 = Site 153. See Tables I and II for sample numbers corresponding to the Haitian rocks.

#### LEGEND FOR FIGURES 4-7

- HAITI SAMPLES
- ▲ MAR MID-ATLANTIC RIDGE BASALT
- ★ W WOODRING ET AL., 1924
- ⊙ AVERAGE METAMORPHIC HARZBURGITE
- ☆ AVERAGE METAMORPHIC DUNITE
- MAFIC CUMULATES
- ◻ PYROXENE GABBRO FROM THE HIDAKA METAMORPHIC BELT
- ☆ AVERAGE HAITI SAMPLE
- + TWO EXTREME VALUES FOR ABYSSAL THOLEIITES
- ◻ DSDP LEG 15 SITES

subophitic farther away from them, in the interior portions of the flows.

The mineralogy of the basalts is dominated by plagioclase ( $An_{54-65}$ ), clinopyroxene, olivine and opaques. Although most of the samples selected were relatively fresh, many were slightly affected by different degrees of secondary alteration: siliceous veinlets which occur in samples showing the effects of cataclasis and shear, and amygdale fillings which consist of chlorite, chalcedony or zeolites.

The dolerites, like the basalts exhibit glomeroporphyritic, ophitic and intergranular textures. Groundmass in these rocks is composed essentially of clinopyroxenes, olivine and opaques. Olivine phenocrysts may occur corroded, rimmed with iddingsite, magnetite and hematite. Some dolerites also display characteristic variolitic texture in which the plagioclase phenocrysts are radially arranged, diverging from a common center, all immersed in the groundmass of mafic minerals. It may happen that a same given diabasic unit shows variolitic texture near the contact zone with the adjacent unit, while its interior portions have intergranular and intersertal textures. In the altered samples plagioclases may be saussuritized, and original pyroxenes partially replaced by chlorite. Ilmenite also occurs as an accessory mineral. The coarser diabbases have a subophitic texture with large augite crystals enclosing the plagioclases.

The gabbros and lherzolite show primary magmatic cumulate textures with cumulates of olivine and clinopyroxene and intercumulus plagioclase (MAURRASSE ET AL., 1977). Clinopyroxene and ilmenite occur as intergrowth or exsolution structure. Olivine may be altered to serpentine or iddingsite along fractures in the gabbros.

### Petrochemistry

Detailed chemical analyses of mafic rocks from the Dumisseau Formation are given in SAYEED ET AL. (1978) and results of a Sr and Nd isotope study are discussed by WAGGONER (1978). Only the geochemical data pertinent to the characterization of these rocks relative to ocean-floor basalts will be discussed in the present paper, as it is intended to deal more fully with this aspect in a later publication.

BURBANK (1924) published the first known chemical analysis for a sample of basalt collected further west of the area studied in this work. The results of this analysis show relatively high concentration of titanium oxide and low  $Fe_2O_3$  indicating that the iron oxide is mostly as ilmenite and titaniferous augite. These results are consistent with those obtained for the rocks at the complex sequence of the Dumisseau Formation. An alkali-silica plot is given in figure 4 and clearly shows the tholeiitic affinity of the Dumisseau rocks and their geochemical relationship to the rock analyzed by BURBANK (1924) and an average value for mid-Atlantic ridge basalt (COLEMAN, 1977). A similar affinity is found with the Cayman Trench rocks (PERFIT, 1977), despite their relatively higher average alkali and silica contents. Further affinity

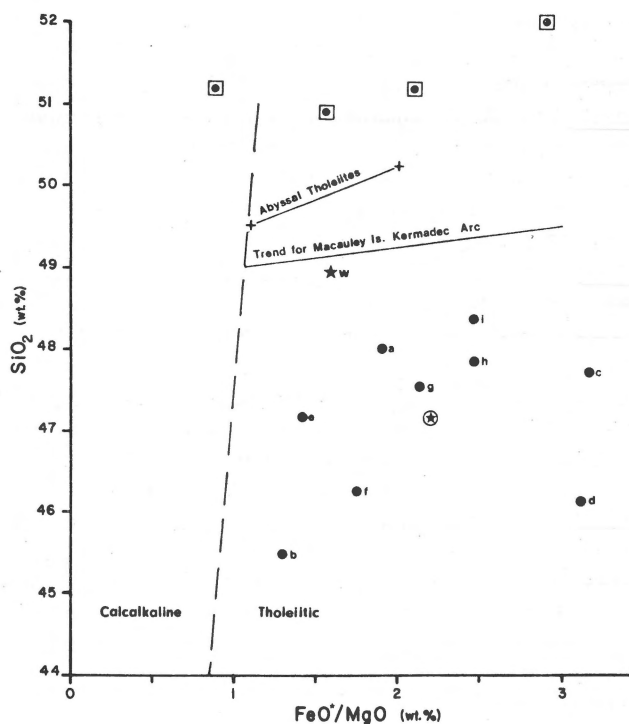


Fig. 5  
Plot of  $SiO_2$  versus  $FeO^*/MgO$  after total iron has been converted to  $FeO(FeO + 0.9 Fe_2O_3)$ . Data other than those for Haiti are from Miyashiro (1975, 1977). Circled star is an average for 9 Dumisseau rocks. W represents the values for an analysis given by Burbank (in Woodring et al., 1924) for a rock sample much farther west of the study area.

between the Dumisseau rocks and Caribbean Sea basalts and dolerites recovered in DSDP Leg 15 (DONNELLY ET AL., 1973; BENICE ET AL., 1975) may be seen in figure 4. The data clearly show that the Dumisseau rocks appear to be more closely related to the deeper sites 146, 150 and 153, than the topographically higher sites 151 and 152 (Fig. 1). For similar  $SiO_2$  concentrations the Dumisseau rocks have a lower K concentration than sites 151 and 152. The Dumisseau rocks show a relatively lower  $SiO_2$  concentration than the deeper sites.

Despite these differences, like the Caribbean Sea rocks, the Dumisseau rocks show a  $K_2O$  content ( $K_2O < 0.4$  weight %) and silica concentrations consistent with that of abyssal tholeiitic suites (ENGEL & ENGEL, 1964; ENGEL ET AL., 1965; MIYASHIRO, 1975). Their abyssal tholeiitic affinity is further demonstrated in figures 5, 6 and 7. The trends shown in these figures also indicate that the Dumisseau rocks are closely related chemically and have undergone some degree of fractionation. In the AFM  $[(K_2O + Na_2O) + FeO^* + MgO]$  ternary diagram (Fig. 7) the Dumisseau rocks evince a fractionation trend slightly oblique to the  $MgO-FeO^*$  side of the diagram, much similar, and parallel to the trend observed for Atlantic abyssal tholeiites (SHIBATA & FOX, 1975). The Haitian rock suite also overlaps with the composition field of abyssal tholeiites of MIYASHIRO ET AL. (1969) (Perfit, 1977), but shows distinct iron enrichment.

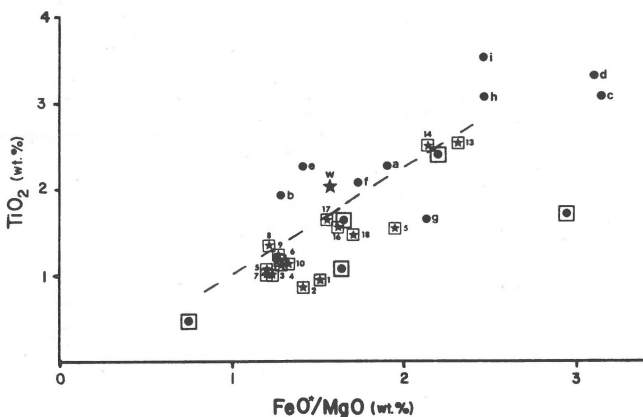


Fig. 6  
Plot of  $\text{TiO}_2$  versus  $\text{FeO}^*/\text{MgO}$  after total iron has been converted to  $\text{FeO}$ . Sources of data are same as those shown in figures 4 and 5. Dashed line represents the trend for abyssal tholeiites (after Miyashiro, 1975).

Another distinctive feature of the Dumisseau rocks is their  $\text{Al}_2\text{O}_3$  content (Tables I and II) analogous to the range attained by mid-oceanic ridge basalts, but the latter have characteristically lower  $\text{TiO}_2$  contents. In that respect the Dumisseau rocks would more closely approximate oceanic island tholeiites (ENGEL ET AL., 1965; HUBBARD, 1969; MIYASHIRO, 1975), and the rocks recovered at DSDP sites 151 and 152, but the Haitian rocks reach higher range values (Fig. 6).

Rare earth elements will be discussed in a subsequent paper when more analyses become available, but the preliminary results suggest a fractionated pattern. So far only one sample has shown a relatively flat pattern. The thorium content in the Dumisseau samples (0.35 to 1.5) approximates that of the topographically higher sites 151 and 152 (DONNELLY ET AL., 1973). However, unlike the Leg 15 sites the Dumisseau samples show no apparent relationships between high-Th values and higher-K values.

In summary, the present data on the Dumisseau rocks indicate that they conform to the geochemical characteristics of fractionated abyssal tholeiites. In this respect they are different from those discussed by DONNELLY & RODGERS (1978), which they group among the primitive island arc basalts. The Dumisseau rocks probably originated from magmas closely related or similar to those recovered at DSDP sites 146, 150 and 153. The relatively low silica values of the Haitian rocks could also be consistent with an early stage of fractional crystallization of 'normal' abyssal tholeiites.

A note of caution, however, since there may be in fact more than one conceivable explanation regarding their geochemical characteristics (MACGREGOR, 1965; NISBET & PEARCE, 1973; MIYASHIRO, 1975; PEARCE, 1975). Further geochemical study will concentrate on  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, as HAWKESWORTH ET AL. (1977) demonstrated that the only clear distinction between abyssal tholeiites and island-arc tholeiites which is supported without qualification by their data

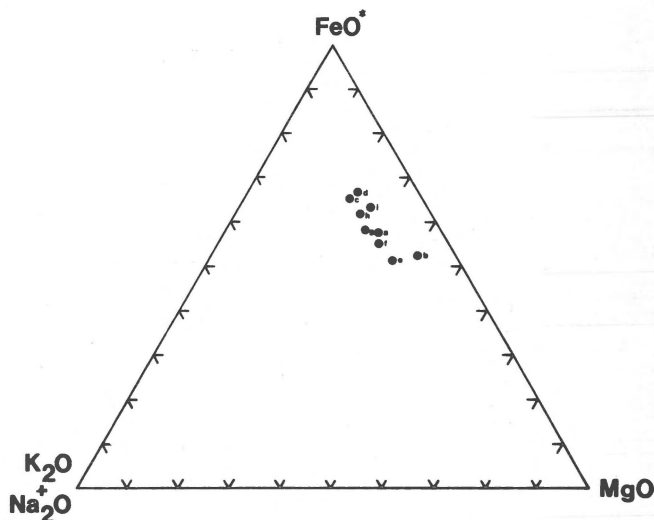


Fig. 7  
AFM diagram showing fractionation trends of tholeiitic basalts and dolerites from the Dumisseau Formation.  $\text{FeO}^*$  is total iron.

from the Scotia Sea is unquestionably higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the latter.

## DISCUSSION

It has been postulated (EDGAR ET AL., 1973) that basalts and dolerites associated with sediments of Late Cretaceous age (Fig. 1) represent the last phase of igneous activity within the deep basins of the Caribbean Sea, and that the crust was probably formed in the early Mesozoic. The study of the Dumisseau Formation, which may be considered the emerged analog of the Caribbean crust, seems to corroborate this assumption, although it does not concur with the idea of a 'flood basalt event' (DONNELLY ET AL., 1973; LUDWIG ET AL., 1975). In fact, the Dumisseau complex shows that extensive magmatic outpouring appears to have occurred intermittently at least throughout the Late Cretaceous, and possibly throughout the Early Cretaceous as well. These voluminous basaltic flows and intrusions are here inferred to have also contributed to the thickening of the Caribbean crust (OFFICER ET AL., 1959; EWING ET AL., 1965; EDGAR ET AL., 1971, 1973) and led to its layered structure underneath acoustic reflector B'' (EDGAR ET AL., 1973; HOPKINS, 1973; LUDWIG ET AL., 1975; LADD & WATKINS, 1977). It also may be questioned whether the age-distribution pattern of the terminal depths found at the various Leg 15 sites (Fig. 1) which are aligned with decreasing age in a northwest-southeast trend, does not truly represent a time-transgressive build up of the Caribbean crust possibly in a pull-apart process. The gradual increase of the calcareous units toward the upper part of the Dumisseau Formation does suggest that the sequence was either progressively accumulating away from the main center of magmatic activity, or that igneous processes diminished

Table I  
X-ray fluorescence analyses by John G. Malpas, Memorial University of New Foundland, Canada.

SAMPLE	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	L.O.I	SUM
a HA76-120	48.0	14.6	3.44	8.92	6.29	10.76	2.27	0.24	2.29	0.18	0.10	1.70	98.79
b HA76-127	45.5	11.6	6.05	6.41	9.11	12.00	1.49	0.06	1.93	0.22	0.11	4.55	99.03

Table II  
Analyses by John Husler, University of New Mexico, Albuquerque.  
\*Reacts with H<sup>+</sup>.

Approximate relative positions of samples stratigraphically are from top to bottom: H; G; (D, C); A; I; (E, B); F.

SAMPLE	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	H <sub>2</sub> O <sup>+</sup> (+CO <sub>2</sub> )	H <sub>2</sub> O <sup>-</sup>	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	MnO	SrO	BaO	S	SUM
c HA76-118	47.70	15.58	6.08	7.20	3.98	10.88	2.56	0.20	1.33	1.18	3.05	0.24	0.199	0.029	<0.02	<0.1	100.13
d HA76-119	46.11	15.38	6.45	8.05	4.44	10.68	2.33	0.08	1.48	1.30	3.30	0.28	0.246	0.029	<0.02	<0.1	100.16
e HA76-123	47.16	15.40	4.56	6.15	7.20	11.20	2.16	0.27	1.57	1.66	2.27	0.20	0.185	0.022	<0.02	<0.1	100.01
f HA76-125	46.23	14.41	2.80	7.27	5.60	14.00	2.04	0.33	3.60*	1.36	2.07	0.22	0.213	0.025	<0.02	<0.1	100.17
g HA76-153	47.56	17.44	8.22	2.88	4.77	9.92	2.34	0.17	1.73	2.62	1.65	0.15	0.143	0.015	<0.02	<0.1	99.61
h HA76-165	47.87	15.23	4.97	7.55	4.84	10.37	2.37	0.25	1.24	1.35	3.06	0.25	0.165	0.027	<0.02	<0.1	99.54
i HA76-173	48.35	13.06	4.60	10.26	5.80	10.25	2.18	0.17	1.00	0.66	3.50	0.31	0.222	0.028	<0.02	<0.1	100.39

and ceased there toward the latest Cretaceous (MAURRASSE ET AL., 1977). Although many recent attempts which invoke spreading processes in the formation of the Caribbean crust (DONNELLY, 1973; CHRISTOFFERSON, 1973, 1976; WATKINS & CAVANAUGH, 1976) appear to remain inconclusive, such processes may not be totally ruled out as the Caribbean plate has been complicated by multiple faulting (CASE, 1975; CASE & HOLCOMBE, 1975; MATTHEWS & HOLCOMBE, 1976). Further complication of the palaeomagnetic record may have also resulted from secondary spreading centers between rotating blocks or along major transcurrent faults that developed during the major shifts that took place between the Americas (LADD, 1976). In any case, the lithologic sequence at Dumisseau demonstrates that submarine magmatic eruptions and intrusions occurred as more than a single major event. These activities may have spanned at least 40 million years within the Cretaceous.

Further correlation between the rock sequence at Dumisseau and published geophysical data concerning the crustal structure of the Caribbean crust (OFFICER ET AL., 1959; EWING ET AL., 1965; EDGAR ET AL., 1971, 1973; HOPKINS, 1973; WATKINS & CAVANAUGH, 1976; LADD & WATKINS, 1977), lend further support to the widespread occurrence of these magmatic activities and their role in the formation of this crust. Lithologic similarities between the Dumisseau Formation and models proposed for the oceanic crust derived from geophysical data for different parts of the world (SCHREIBER & FOX, 1976; HYNDMAN & DRURY, 1976; KENNETT & ORCUTT, 1976) lead us to further suggest that the St. Dominique Member is analog to crustal layer 2A (HOUTZ & EWING, 1976) and the

lower member to crustal layer 2B (HOUTZ & EWING, 1976). Since the ages of the youngest igneous rocks in the Dumisseau Formation are also in agreement with those recorded at the various Leg 15 sites (BOLLI & PREMOLI-SILVA, 1973; EDGAR ET AL., 1973) we consider the topmost part of the Dumisseau Formation to be correlative with seismic reflector B" (MAURRASSE, 1975). Nonetheless, it is still questionable whether the smooth acoustic basement B" is truly igneous, or is rather due to the abundant opaque and semi-opaque chert layers that overlie the igneous basement. Such layers are indeed known to create false impressions of a smoothed basement at different parts of the world oceans. The apparent heterochronous character of Horizon B" (Fig. 1) suggests that such a case may not be totally ruled out in the Caribbean. Although our data may not allow a reconstruction of the 'primordial' Caribbean crust under the Southern Peninsula they are most consistent with expected materials below B".

The Dumisseau Formation is here inferred to have been produced by intermittent submarine flows and intrusions whose resulting accumulation may be compared to an ophiolite complex (MIYASHIRO, 1975, 1977). The geochemical affinities of the sequence described in the preceding paragraphs indicate that the igneous activities could have taken place either in an immature island arc or at an oceanic-ridge like environment. Both types of tectonic settings are known to produce characteristic abyssal tholeiitic suites. Their formation in a back-arc basin along tensional fractures in a pull-apart zone of a marginal sea is also a possibility that cannot be ruled out. Assuming that the geochemical results are primary features controlled by crystallization differentiation,

absence of both calc-alkalic series and late differentiate is inconsistent with their being formed by magmatism in a mature arc or close to a well defined subduction zone. Some of the rocks approximate oceanic island tholeiites and olivine tholeiite suites (Figs. 4, 5, 6) with very low potassium values. The high  $\text{TiO}_2$  content may also suggest formation at an incipient ridge (MAURRASSE, 1975), probably associated with early dislocation of the primordial crust. The relatively high  $\text{TiO}_2$  content ( $>2.5\%$ ) of some of the rocks may also indicate early differentiates and/or crystallization differentiation as indicates their cumulative nature (WAGER ET AL., 1960; WAGER & BROWN, 1967; MAURRASSE ET AL., 1977). Their  $\text{TiO}_2$  contents (Fig. 6) show that the Dumisseau Formation rocks fall between the abyssal tholeiites ( $\text{TiO}_2$ : 0.7-2.3) and oceanic island tholeiite series ( $\text{TiO}_2$ : 0.2-5.0) (MIYASHIRO, 1975). In all, these rocks tend to fall in some intermediate category between the ordinary abyssal tholeiites (MORB types) and the island arc tholeiites. The data thus clearly indicate that the Dumisseau complex is part of an oceanic-related series of magmas which have been variously modified by crystallization differentiation and its like.

Magmatic effusions must have occurred above the carbonate compensation depth of that time as planktonic foraminifera are generally well preserved at all the levels. The vesicular nature of some of the flows further suggests depths probably less than 4000 m, since vesiculation usually occurs in submarine flows in water shallower than that depth (MOORE, 1965). The sedimentary rocks in the Dumisseau area are essentially of deep-eupelagic facies, although shallow-water faunas are reported in rocks of similar age farther west (Woodring in REESIDE, 1947). Since shallow-water facies of Cretaceous age seem to be rare in the Southern Peninsula, they may have developed over isolated peaks, probably submarine volcanoes, while most of the Peninsula remained under deep-water sedimentary regime until the late Eocene. Even though some of these submarine peaks might have developed from early block faulting we should emphasize that the various tectonic activities that affected the Southern Peninsula since the Cretaceous seem to have never been either synchronous or of the same intensity. Furthermore, the Laramide orogeny did not seem to have affected this part of the peninsula to any great extent either as most of it appears to have remained pelagic or neritic-pelagic until the Oligocene (MAURRASSE, 1976 and in prep.). In fact, although the Dumisseau area does show shallow-water calcarenite and calcirudite overlying the Cretaceous complex, lower Eocene to lower Middle Eocene limestones that crop out near Kenscoff (Fig. 2) are of eupelagic character, and may contain abundant radiolaria (MAURRASSE, in prep.). Also, lowermost Palaeocene pelagic limestones are known to occur farther west, northeast of Jacmel (MAURRASSE, 1975, 1976). The only evidence for unstable crustal conditions in the Cretaceous of this region is produced by the intermittent intrabasinal turbidites that occurred throughout most of the sequence, and mainly during middle Late Cretaceous time. Like the early turbidites

at the DSDP leg 15 sites (EDGAR ET AL., 1973), the older turbidites in the Dumisseau Formation are essentially volcanoclastic, containing very few faunal remains. The younger turbidites in both cases (EDGAR ET AL., 1973; MAURRASSE, 1973, 1976-b) are predominantly biogenic, often mainly composed of radiolaria. Most of these turbidite activities diminished or ceased toward the end of the Cretaceous and the early Tertiary. The early subaqueous turbidity flows may be interpreted to be associated with earlier faulting and doming effects of the crust prior to major subsequent block faulting tectonics. Differential uplift affected the various parts of the peninsula which seems to have risen along major normal faults at different stages (MAURRASSE, 1976-a) in the Tertiary. The most important tectonic activities that affected the area are late Oligocene or younger, when most of the Dumisseau Formation and its younger Tertiary cover were uplifted through extensive block faulting, tilting and associated gravity folding. Strike-slip displacements appear to have remained minimal. The final dislocations which occurred toward the end of the Miocene or in the early Pliocene were associated with both compressional and tensional fracturing; they gave rise to the step-like structure that controls the present-day relief and physiography.

Thus, from the data discussed herein, we may conclude that the lithologic and geochemical characteristics of the Dumisseau rocks concur with geophysical and petrochemical data from both the Caribbean and elsewhere which justify their being equated with an upraised portion of the Caribbean crust below B". Published seismic reflection profiles near the Southern Peninsula are still scanty; those available (EDGAR ET AL., 1971; MATTHEWS & HOLCOMBE, 1976) show rather sharp transitions from the Venezuela Basin toward the island's margins. Both A" and B" are depressed before disappearing suddenly toward the Southern Peninsula. Our study lends further credence to the idea (MAURRASSE 1975; MAURRASSE ET AL., 1977) that these horizons have been uplifted through block faulting and differential vertical movements in a way much similar to those affecting the adjacent Beata Ridge complex (ROEMER ET AL., 1976). We presume that at least parts of the Southern Peninsula thus have the same tectonic significance and origin as the Beata Ridge system. The peninsula underwent greater uplift than the ridge because of its position relative to the edge of the northern boundary of the Caribbean plate.

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