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Tectonic implications of paleontologic dating of Cretaceous-Danian sections of Eastern Cuba

M.A. ITURRALDE-VINENT [1]   **C. DÍAZ-OTERO** [2]   **A. RODRÍGUEZ-VEGA** [3] and **R. DÍAZ-MARTÍNEZ** [3]

[1] **Museo Nacional de Historia Natural**
Obispo no. 61, Plaza de Armas, La Habana, Cuba. E-mail: iturralde@mnhnc.inf.cu

[2] **Instituto de Geología y Paleontología**
Vía Blanca y Carretera Central, San Miguel del Padrón, La Habana, Cuba.

[3] **Instituto Superior Minero-Metalúrgico**
Departamento de Geología, Las Coloradas de Moa, Holguín, Cuba.

───┤ **ABSTRACT** ├───

The sedimentary rocks intercalated in volcanic and metavolcanic sections of Mayarí-Baracoa and Sierra del Purial Mountains (Eastern Cuba), yielded Cretaceous through Danian microfossils. In the Mayarí Mountains the Téneme Fm consists of basalts and hyaloclastites with minor intercalations of well-bedded foliated limestone and shaly limestone that in the type area contain a Turonian or early Coniacian planktonic foraminifera assemblage. In the Morel area (Moa-Baracoa massif), back-arc pillow basalts with ribbon cherts include a late Turonian or Coniacian limestone bed intercalated with interbedded organic-rich calcareous shales near the top. The upper part of the Coniacian (?)-Campanian Santo Domingo Fm crops out west of Moa and it consists of fine-grained well-bedded volcaniclastic rocks with two intercalated lenses of coarse-grained impure biocalcirudites to biocalcarenites. These rocks yielded a mixed penecontemporaneous planktonic and benthonic microfossil assemblage attributed to the lower part of the late Campanian (*Globotruncanita calcarata* Zone*)*. At Sierra del Purial, crystalline limestones embedded within the metavulcano-sedimentary Río Baracoa section (Purial metamorphic complex) yielded Campanian microfossils. The Maastrichtian Yaguaneque (=Cañas) limestones crop out extensively in both Mayarí-Baracoa and Purial Mountains. All the formations previously mentioned unconformably overlie and tectonically intermingle with the late Maastrichtian-early Danian clastic rocks of the Mícara and La Picota Fms. Our new dates demonstrate that in the Greater Antilles the PIA (Primitive Island Arc—tholeiite) recorded by the Téneme Fm would be Late Cretaceous in age in opposition to the Lower Cretaceous age proposed for the PIA basalts. The protolith of the Purial metamorphic complex is probably Maastrichtian-early Danian, but certainly Campanian and older in age. This fact suggests that the metamorphism that affected the Purial rocks took place probably in the late Maastrichtian and was coeval with the detachment, exhumation and emplacement of mafic-ultramafic thrust-sheet bodies. This event recorded in Eastern Cuba/Western Hispaniola and Guatemala might have been related to the insertion of thick oceanic ridges into the subduction zone.

INTRODUCTION

The age of the Cretaceous-Paleocene volcanic, sedimentary and metamorphic rocks in Eastern Cuba has been an elusive and controversial problem for many years, due to the lack of paleontologic dating of key fossiliferous strata. The sections referred to the Téneme, Quibiján and Santo Domingo Fms, which are well represented within the Mayarí-Baracoa Mountains, and metavolcanic rocks within Sierra del Purial, were previously dated according to their stratigraphic position, on the base of scarce, inconclusive paleontologic data, or by correlation with similar rocks elsewhere in Cuba or the Dominican Republic (Somin and Millán, 1981; Millán and Somin, 1985; Millán, 1996; Quintas, 1987, 1988a; Kerr et al., 1999). The stratigraphy of the Cretaceous and Paleocene sedimentary, volcano-sedimentary and metamorphic rocks of Eastern Cuba is here revisited, in the light of our new field observations, new paleontologic dating, and laboratory research. Additional research on the petrology, geochemistry and geochronology of igneous and metamorphic rocks in the region are currently in progress (García Casco et al., this volume; Proenza et al., this volume).

As the dating of the above mentioned sections is crucial to understand the tectonic evolution of Cuba, and that they have strong bearing on the plate tectonic interpretation of the Caribbean, the studied samples were collected in good exposures, where geochemical and petrological studies have been carried out recently (Gyarmati et al., 1997; Kerr et al., 1999; García Casco et al., this volume; Proenza et al. this volume). Samples for micropaleontological dating were taken from sedimentary rocks exposed in Los Plátanos, La Yua, Centeno, Morel, and Río Baracoa (Fig. 1). Previously, the senior author conducted two other sampling expeditions to many localities of the Mícara and La Picota Fms. Several samples were taken from each locality and a minimum of 3-4 distinctly oriented thin sections or chemical separation prepared from every sample. Despite careful search no macrofossils were observed in the outcrops but most of the sampled rocks yielded microfossils. The Appendix 1, included in the electronic version of this paper, contains photomicrographs illustrating some microfossils and rock microfacies of the investigated units.

In the following section we briefly describe the main lithology of the investigated formations, their stratigraphic and/or tectonic position, the fossil content and their age. The plate tectonic implications of the age of these rocks are discussed.

GEOLOGIC SETTING

In Eastern Cuba several tectonic units have been described (Cobiella et al., 1977, 1984; Iturralde-Vinent, 1994a, 1998; Kerr et al. 1999). This region includes several tectonic units that consist of ophiolitic, volcanic-arc and sedimentary rocks (Fig. 1). The stratigraphic units considered in this paper are located within the Mayarí-Baracoa Mountains, the Sierra del Purial Mountains, and surrounding areas (Fig. 1). The Mayarí-Baracoa Mountains yield mafic-ultramafic rocks, metamorphosed mafic-ultramafic rocks (La Corea and Bernardo complexes), and metamorphosed and non-metamorphosed Cretaceous (Campanian and older) arc-related volcanic and sedimentary rocks (Téneme, Quibiján, and Santo Domingo Fms), as well as early Late Maastrichtian limestone (Yaguaneque=Cañas Fm). In these mountains, the Cretaceous and older rocks are allochthonous and overthrust (and intermingle within) the syntectonic late Maastrichtian-early Danian sedimentary sequences (Mícara and La Picota Fms). All of these units are at least partially metamorphosed from very low to low grade conditions (Boiteau et al., 1972; Millán, 1996; Gyarmati et al., 1997). They are unconformably overlain by the post-tectonic, less deformed late Danian and younger rocks (Nagy et al., 1983; Cobiella et al., 1977, 1984; Pushcharovski (ed.), 1988; Iturralde-Vinent, 1976, 1977, 1997a, 1998; Fig. 1).

Cretaceous arc-related volcano-sedimentary and plutonic rocks included in the Purial metamorphic Complex make up most of the outcrops in the Sierra del Purial Mountains. In some sections these rocks are only slightly recrystalized, but generally they are metamorphosed from greenschist to blueschists facies (Somin and Millán, 1981; Millán and Somin, 1985). Mafic-ultramafic mélange with metamorphosed mafic-ultramafic rock (Güira de Jauco and Sierra del Convento amphibolitic complexes) thrusted these rocks. Maastrichtian Yaguaneque (=Cañas) limestones also crop out in the area. Late Danian and younger slightly deformed sedimentary rocks overlie the Cretaceous rocks (Somin and Millán, 1981; Millán and Somin, 1985; Nagy et al., 1983; Cobiella et al., 1977, 1984; Pushcharovski (ed.), 1988; Figs. 1 and 2). The mafic-ultramafic bodies of easternmost Cuba and their metamorphic counterparts were described as part of the so called "Cuban Northern Ophiolites". Nevertheless, their composition, structural position and emplacement differ from those cropping out westward from Holguín (Iturralde-Vinent, 1994). Therefore, they can probably be considered distinct lithological assemblages ("Eastern Cuba ophiolites").

In the easternmost end of the region, the so called Asunción Terrane, Jurassic-Cretaceous marble and shale outcrops are generally considered to be part of the Bahamian continental margin. Iturralde-Vinent (1994, 1998) proposed that the Purial Complex and the metamorphosed mafic-ultramafic rocks (Güira de Jauco complex) overthrust the Asunción Terrane. However, other

authors (Cobiella et al., 1984; Quintas, 1987, 1988a; Pushcharovski (ed.), 1988; Fig. 1) suggest that the Asunción Terrane rocks overthrust the Purial Complex and the metamorphosed mafic-ultramafic rocks (Güira de Jauco complex). Whether the latter was the case, this would be the only place in Cuba were Bahamian continental margin rocks (Asunción Terrane) might be emplaced onto oceanic-derived complexes.

STRATIGRAPHY

Dating sedimentary rocks by means of fossils is sometimes ambiguous. For instance, if the fossil assemblage provides an Albian to Turonian age, this means that the taxa identified ranged this time interval. But under no circumstances does the fossiliferous rock sample encompass such a long period of time, since the fossiliferous layer from which the sample was obtained often would record no more than a few tens or hundred of years, depending upon the depositional processes. Therefore, it would be incorrect to date the sample, and consequently the whole formation, as Albian to Turonian. Unfortunately, this has been the usual rather than the exceptional procedure in many stratigraphic works previously carried out in the Greater Antilles. In this paper, a rock containing Albian to Turonian fossils is described as being of either Albian, Cenomanian, or Turonian in age. The age of such a formation must be evaluated also according to its stratigraphic relationships to other units, and may be finally established, just as Cenomanian. Thus, only when a fossil assemblage yields an accurate date, will this date be fully adopted for that part of the formation that contains the fossiliferous sample. The previous discussion may be considered obvious and unnecessary, but our experience demonstrates the opposite.

Téneme Fm

The Téneme Fm was briefly described in the legend of the 1:250 000 geologic map of Cuba as basalts, andesite-basalts, tuffs, tuffaceous breccias and limestone (Pushcharovski (ed.), 1988). Proenza et al. (this volume) have concluded that the Téneme basalts show island arc tholeiite (IAT) signature, and have referred to them as "Primitive Island Arc (PIA)" rocks. These rocks crop out west of Moa and are overthrusted by deformed mafic-ultramafic ophiolite rocks, or unconformably overlain by the Maastrichtian-early Danian Mícara Fm (Figs. 1 to 3). The Téneme basalts are brecciated and the limestones display a faint schistosity, probably due to an early deformational event related to the imbrication of the basaltic unit with
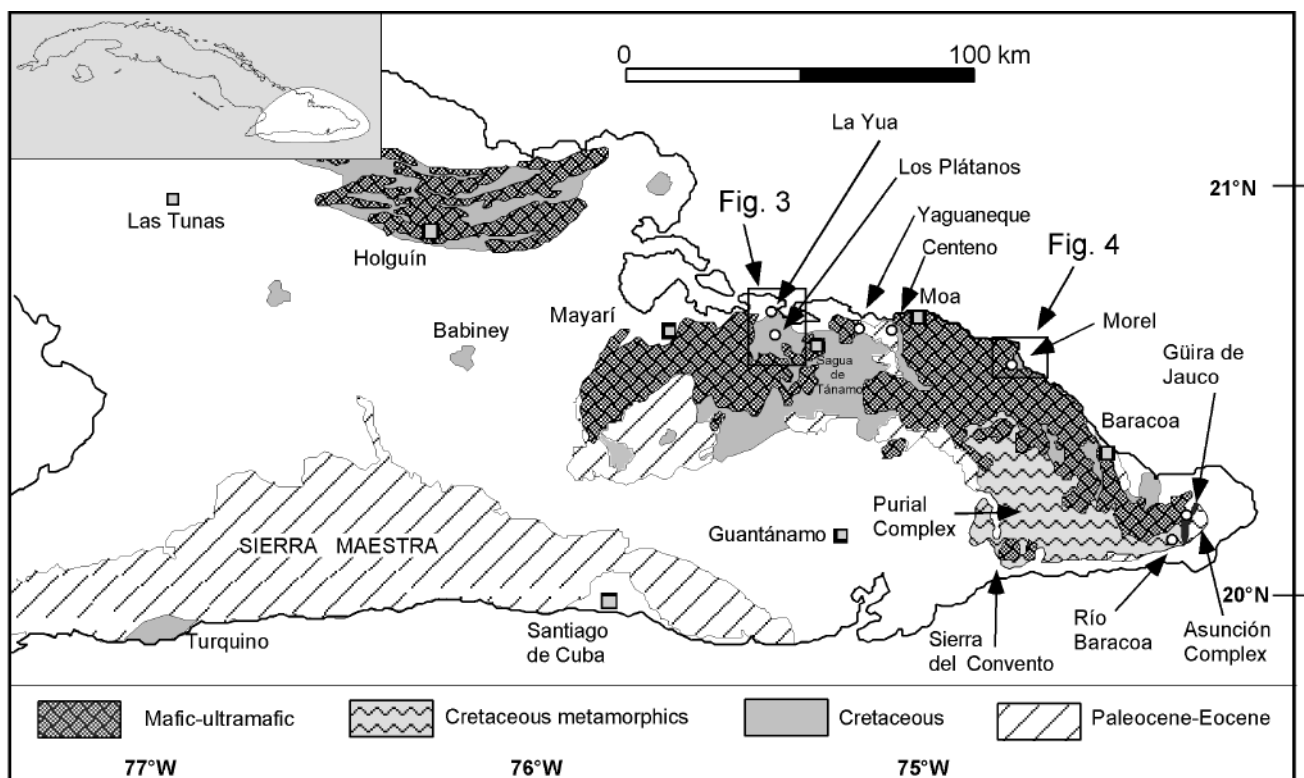

FIGURE 1 | **Map of Northeastern Cuba with location of sampling localities, reference points, and distribution of some Mesozoic rocks. Insets show the location of detailed maps in Figs. 3 and 4. Modified from Iturralde-Vinent (1998). Geographic Coordinates.**

the ophiolitic serpentinites and gabbroids. A small plug of plutonic rocks with volcanic arc affinities cut the basalts, but probably not the mafic-ultramafic bodies (Pushcharovski (ed.), 1988; Fig. 3). In the area near Los Plátanos (Fig. 3), serpentinites and gabbroids overthrust the Téneme basalts that display a strongly foliated about 5 m thick tectonite. This intense deformation observed in the basalts does not occur between the mafic-ultramafic bodies and the Mícara and La Picota Fms, suggesting that deformation took place before -or in an early stage of- the final tectonic emplacement of the mafic-ultramafic allochthonus rocks.

The Téneme Fm in the type area (Fig. 3) includes pillow basalts, hyaloclastites and a few intercalations of well-bedded foliated limestones, shaly limestones and tuffites. Previously they had been grouped with other volcanic rocks and referred to the all embracing "Tuff series" or "Bucuey Fm" (Adamovich and Chejovich, 1964; Nagy et al., 1983). On the other hand, the Barrederas Member of the "Bucuey Fm" was defined by Nagy et al. (1983) as Aptian-Turonian limestones cropping out north of Téneme (Fig. 3). Field observation and microscopic comparison of thin sections indicate that the Barrederas Member limestones at La Yua and the limestone beds within the Téneme section in Los Plátanos (Fig. 3) are similar in age, lithology and fossil content. Furthermore, the

Barrederas limestones in the type area are interbedded with basalts apparently identical to those of Téneme. Thus, since both units are not distinguishable in the field, we propose here to include the Barrederas limestones within the Téneme Fm.

At Los Plátanos area (coord. x651.6; y219.8; Fig. 3), a ~10 m thick, well bedded, pervasively foliated section crops out. This section is intercalated with the basalts of the Téneme Fm. and consists of hyaloclastites, a few black, dark-purple and gray fine-grained limestones, and shaly limestones, with abundant planktonic microfossils (foraminifera and radiolaria). These fossils are slightly deformed by the foliation, but the assemblage identified in thin sections includes unidentified Radiolaria and planktonic foraminifera (*Clavihedbergella simplex*, *Marginotruncana* aff. *M. coronata*, *Marginotruncana* aff. *M. sinuosa*, *Whiteinella* spp., *Heterohelix* sp., *Globigerinelloides* sp., *Rotalipora* cf. *R. greenhornensis,* and *Rotalipora* cf. *R. cushmani*).

Near La Yua (coord. x649.7; y225.65; Fig. 3), usually recognized as the type area of Barrederas Member, foliated limestone outcrops, which are identical to those described in the previous paragraph, are associated with weathered hyaloclastites and basalts. The limestones yield radiolaria and planktonic foraminifera (*Globigerinel-*
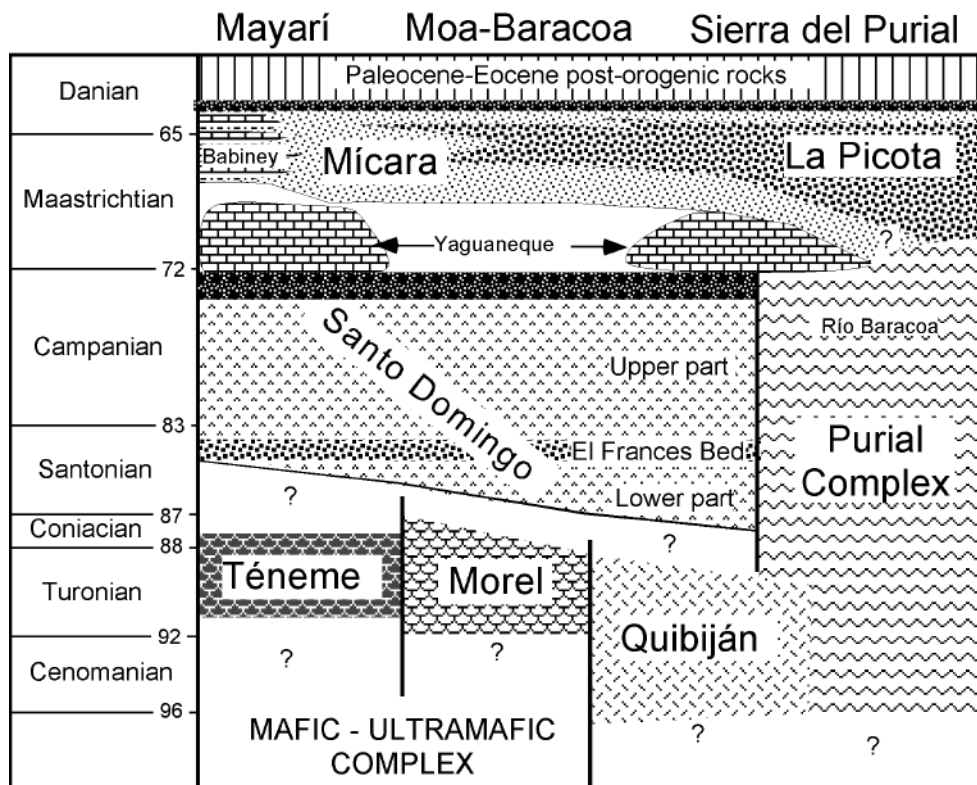

FIGURE 2 | **Stratigraphic chart of the Cretaceous-Paleocene formations in Eastern Cuba. See further explanation on lithofacies in the text.**

loides cf. *G. bolli*, *Marginotruncana aff M. marginata*, *Whiteinella* spp. Heterohelicidae, *Dicarinella? sp.* and *Rotalipora aff. R. greenhornensis).*

The occurrence of *Marginotruncana* in the described sections implies a Turonian or younger age, but *Whiteinella* spp. is reported from late Cenomanian to early Coniacian (Premoli-Silva and Sliter, 1995). Therefore, we propose a Turonian or early Coniacian age for the fossil assemblage, with redeposition of Albian-Cenomanian microfossils.

Morel Fm

In the area of Morel (coord: x730; y207; Figs. 1, 2 and 4), along the road between Moa and Baracoa, ribbon chert bearing pillow basalts and some hyaloclastites are widespread. These rocks underlie tuffaceous sandstones, andesite-basaltic tuffs and andesite-basalts referred to the Santo Domingo Fm (Gyarmati and O'Conor, 1990) or occur thrusting gabbroid rocks (Fig. 4). Gabbroid and serpentinite thrust sheets locally overthrust both Morel and Santo Domingo Fms. Kerr et al. (1999) incorrectly referred Morel basalts as the Quibiján Fm (misspelled Quiviján), and geochemically characterized them as back-arc island arc tholeiites. Nevertheless, this Morel section cannot be correlated with the Téneme or Quibiján Fms, since Morel basalts show distinct lithology and geochemical signature (Proenza et al., this volume). Accordingly, we consider these rocks a new unit named here Morel Fm.

A 390 m deep exploratory well drilled in the outcropping area of the Santo Domingo Fm (Figs. 4 and 5), cuts a 230 m thick section, of andesite-basaltic tuff and tuffaceous sandstones with interbedded minor andesite-basalts, here assigned to the lower part of the Santo Domingo Fm (Gyarmati and O'Conor, 1990). These rocks overlie more than 160 ms of basalts, olivine basalts and hyaloclastites, which in the upper part intercalate thin layers of organic-rich calcareous black shales and limestone, referred here to the above- mentioned Morel Fm. In the past, several samples were collected from outcrops of the ribbon cherts within the Morel basalts, but they lacked fossil remains. A sample was collected from a foliated brown to light brown limestone layer interbedded within weathered and foliated organic-rich calcareous shales. According to the exploratory well log data, these facies occur interbedded in the upper part of the Morel basalts (Fig. 5). This sample yielded planktonic microfossils of late Turonian or Coniacian age (*sensu* Premoli-Silva and Sliter, 1995), including *Dicarinella* sp., *Globigerinelloides bollii*, Globotruncanidae, *Hedbergella planispira, Hedbergella simplex, Heterohelix* cf. *H. moremani, Heterohelix* cf. *H. reussi, Marginotruncana* cf. *M. pseudolinneiana, Pithonella ovalis, Whiteinella?* sp.. Therefore, the

age of the Morel Fm is late Turonian or Coniacian and probably older, as the sample belongs to the upper part of the unit (Fig. 5).

Quibiján Fm

According to the original description by Quintas (1988b), in the type section along the Quibiján River, the Quibiján Fm consists of slightly metamorphosed, thick bedded, porphyritic and amigdaloidal basalts, basaltic breccias, lapilli-tuff and fine-grained tuffaceous rocks. This unit crops out in many localities within the Moa-Baracoa Mountains (Quintas, 1988b; Fig. 4), but not in the Morel area. Millán (1996) described the outcrops along the Quibiján river basin as part of the Purial metamorphic Complex, essentially as noted by Quintas (1988b). Geochemically they are described as calc-alkaline (Millán, 1996) or tholeiite to calc-alkaline arc-related rocks (Gyarmati et al., 1997).

In East Central Cuba, the basal part of the tholeiite to calc-alkaline island arc sections are Albian through Coniacian in age, and are made up by porphyritic basalts,
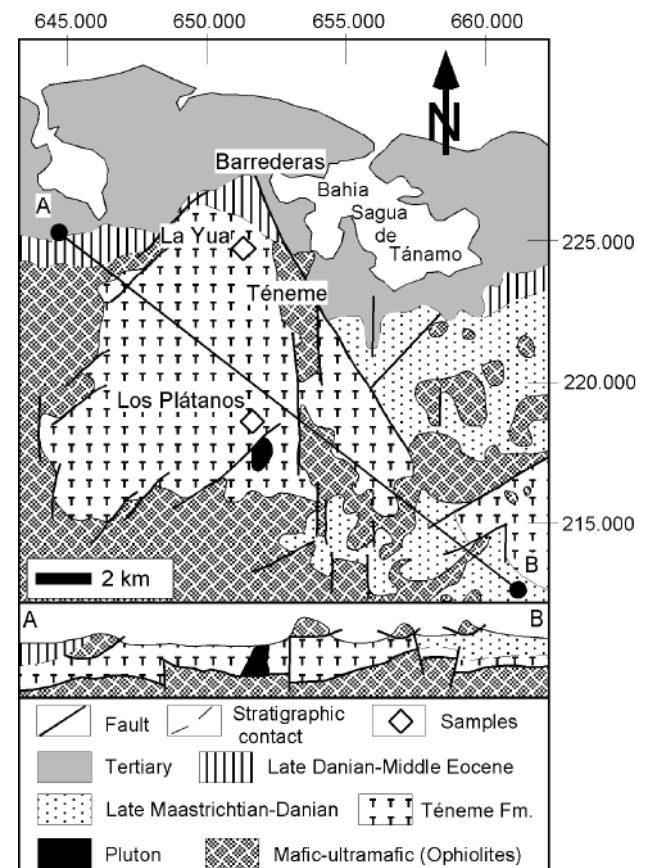

FIGURE 3 | **Geological sketch of the type area of the Téneme Fm. See location in Fig. 1. Modified from Pushcharovski (ed.) (1988). Coordinates x and y are referred to the Cuban 1:50 000 scale maps.**

andesite-basalts, and volcanic breccias that are interbedded with tuffaceous sandstones and other sedimentary rocks (Iturralde-Vinent, 1994a, 1996a, 1996b, 1998; Piñero et al., 1997). These lithologies, and especially the Guáimaro/Camujiro Fms (Piñero et al., 1997) strongly resemble those of the Quibiján Fm. As no fossils have been yielded by the Quibiján Fm, it can be tentatively assumed that the age of this unit may range from Albian to Turonian as that of the Guáimaro/Camujiro Fms in East Central Cuba (Figs. 2 and 6).

Santo Domingo Fm

This unit crops out extensively in the Mayarí-Baracoa Mountains (Iturralde-Vinent, 1976, 1977) and shows in general complex relationships with the mafic-ultramafic bodies, and the latest Cretaceous-Paleocene sedimentary section (Pushcharovki ed., 1988). According to Quintas (1987, 1988a), rock sections assigned to the Santo Domingo Fm overlie the Quibiján Fm and locally are overthrusted by metamorphic rock sheets referred to the Purial Complex. Volcaniclastic and sedimentary rocks, with a few andesite sills make up the bulk of Santo Domingo Fm. In the type section, Iturralde-Vinent (1976, 1977) split the Santo Domingo Fm into four parts: (1) A lower ~1000 m thick section that consists of well bedded, laminated, dark green, thin to very thin grain andesitic tuffs and radiolaria bearing sparse tuffites (up to 50% calcium carbonate). Andesitic sills are minor. The rocks weather to a light to dark brown color. (2) A conspicuous ~200 m thick layer named "El Frances bed", which is formed by massive, light brown, coarse grained tuffites with angular lithic fragments that are included in a matrix

FIGURE 4 | **Geological sketch of the Morel area (see location in Fig. 1). Modified from Gyarmati and O'Conor (1990). Coordinates x and y are referred to the Cuban 1:50 000 scale maps. See legend in Fig. 3.**

of very fine volcanic glass. The basal surface of this bed is erosional, with large angular fragments of the underlying unit embedded in the tuffites. This layer is widespread in the Mayarí-Baracoa Mountains and constitutes a marker horizon. It was originally interpreted as a turbidite, but more properly must be considered a megaturbidite. (3) The next part of the section overlies transitionally the previous one, and is represented by ~700 m thick, well bedded, graded upward, green, thin to very thin grain tuffaceous sandstones, tuffites and sparse andesitic tuffs. (4) The uppermost part of the Santo Domingo Fm is ~200 m thick, and consists of gray to dark green color, laminated and upward graded, coarse to middle grained sandstone and tuffites with calcite matrix. Some authors, in the course of geological mapping, have included many other lithological units within the Santo Domingo Fm, especially thick lava units (Gyarmati and O'Conor, 1990; Gyarmati et al., 1997). These thick lava units are not included in the Santo Domingo Fm as it is considered in this paper. Eventually they may belong to the underlying Quibiján Fm as defined by Quintas (1988b).

Well bedded, fine grained, light to dark brown tuffites and tuffaceous sandstones, equivalent to the upper part of the Santo Domingo Fm crop out in the village of Centeno, west of Moa (coord. x692.000; y222.500; Fig. 1). These units interbed two calcareous lenses up to 5 m thick. These calcareous rocks are composed by thick bedded, light gray, graded calcirudites to calcarenites, with calcareous and volcaniclastic grains, and abundant bioclastic material. Despite of carefully searching no macrofossils were observed. The microfossils are penecontemporaneous planktonic and benthic foraminifera, with prevalence of the planktonic ones, suggesting that these beds record turbidite deposition of intrabasinal clasts derived from calcareous shallow marine environments.

The samples collected in these beds yielded an assemblage that corresponds to the lower part of late Campanian (KS27: *Globotruncanita calcarata* zone, sensu Premoli-Silva and Sliter, 1995; Fig. 2) with planktonic forams (*Globotruncana arca, Globotruncana bulloides, Globotruncana linneiana, Globotruncanita calcarata, Globotruncanita aff. G. elevata, Globotruncanita stuartiformis, Globigerinelloides alvarezi, Globigerinelloides messinae, Pseudotextularia elegans, Rugoglobigerina rugosa, *Heterohelix aff. H. moremani, *Marginotruncana*? sp.), mixed with benthic organisms, as large forams (*Orbitoides tissoti, Rotalia* sp., *Sulcorbitoides pardoi, Sulcoperculina globosa, Sulcoperculina vermunti*), Melobesiae algae (*Ethelia alba*), echinoid spines, and rudist fragments. Some of the mentioned planktonic forams (marked with *) were redeposited from older Upper Cretaceous rocks.
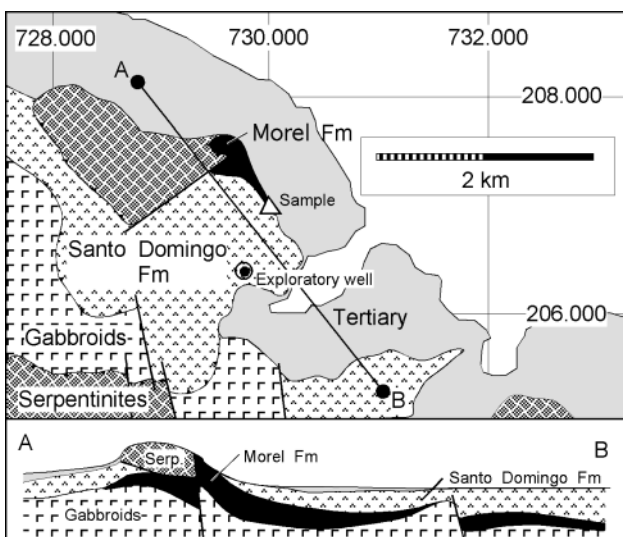
The Santo Domingo Fm is older than Maastrichtian, as it is overlain by rocks of Maastrichtian age (Quintas, 1987, 1988a). Moreover, the samples collected in Centeno at the top of the formation point to the lower part of the late Campanian. On the other hand, the age obtained from samples collected from the underlying Morel Fm (Figs. 4 and 5) suggest that the Santo Domingo Fm is younger than Coniacian or late Turonian (Fig. 2). This correlates well with the upper part of the calc-alkaline volcanoclastic sections of Central Cuba (Fig. 6), which are dated as late Coniacian to mid-Campanian (Iturralde-Vinent, 1996a, 1996b, 1997a, 1998; Piñero et al., 1997).

Purial Complex

Metamorphosed Cretaceous sedimentary, volcano-sedimentary and plutonic rocks that crop out in Sierra del Purial Mountains and surrounding areas (Fig. 1) are named Purial Complex after Boiteau et al. (1972). These are deformed greenschist, blueschist and slightly recrystalized sections (Millán and Somin, 1985; Millán, 1996). Some other rock assemblages that include distinct lithostratigraphic units have been misleadingly assimilated into the Purial Complex, just because they were metamorphosed to some degree, or because they crop out within the Sierra del Purial Mountains (Nagy et al., 1983; Cobiella et al., 1977, 1984; Quintas 1987, 1988a, 1988b; Pushcharovski (ed.), 1988; Gyarmati and O'Conor 1990; Gyarmati et al., 1997). Rocks included in the Purial Complex are generally overthrusted by mafic-ultramafic rocks (Cobiella et al., 1984; Pushcharovski (ed.), 1988; Quintas, 1987, 1988a, 1988b).

Millán (1996) described several informal units in order to characterize diverse lithological assemblages cropping out in the Purial Mountains, which should be formalized in the future. A general description and comparison of the protoliths of these informal units to the lithostratigraphic units known from east-central Cuba, show many similarities (Fig. 6). Consequently the Purial Complex is generally interpreted as the record of a Cretaceous tholeiite to calc-alkaline axial volcanic arc (Millán, 1996; Iturralde-Vinent, 1998). As a consequence of the very poor biostratigraphic dating from Purial Complex, the ages of the informal units (Fig. 6) are hypothetical with the exception of the Río Baracoa section. On the other hand, the meta-siliciclastic rocks of Mal Nombre are a puzzle, because they show many similarities with the Maastrichtian-early Danian Mícara Fm (Millán, 1996). If this correlation proves to be true, it suggests that dynamic metamorphism locally embraced elements of the Maastrichtian-early Danian sections, but this statement requires further investigation.

The metamorphic recrystalization at Purial generally destroyed or concealed the fossil record in the meta-sedimentary rocks, except for two localities along Río Baracoa (Fig. 1). One locality is an isolated block found in the confluence between Río Baracoa and Arroyo Cayo. It is composed of crystalline, white, massive limestone that grade into metatuffaceous rocks. Millán and Somin (1985) reported large forams of Campanian age (*Orbitoides cf. O. tissoti*, *Pseudorbitoides* sp., *Sulcoperculina diazi*, *Sulcoperculina globosa*) identified by C. Díaz-Otero (Millán, 1996). Another locality, downstream in the Río Baracoa, is an outcrop of similar crystalline lime-
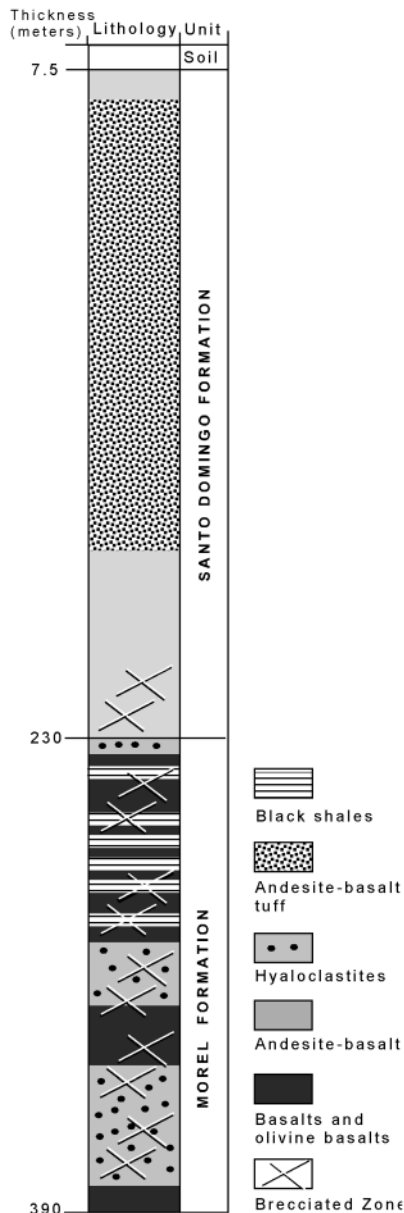

FIGURE 5 | **Lithological log of the exploratory well drilled in the Morel area (location in Fig. 4). Adapted from Gyarmati and O'Conor (1990). Stronger fracturation of the Morel Fm suggests, but do not surely imply, a tectonic contact with the overlying Santo Domingo Fm.**

stone within metatuffaceous green rocks. From one sample, Millán, (1996) identified Campanian planktonic and benthic foraminifera (*Globotruncana arca*, *Globotruncana cf. G. elevata*, *Globotruncana lapparenti*, *Globotruncana linneiana*, *Globotruncanita cf. G. calcarata*, *Globigerinelloides* sp., *Hedbergella* sp., *Pseudorbitoides* sp.). Our samples from Río Baracoa yielded Cretaceous planktonic foraminifera, but too recrystallized to be properly identified. The Campanian age of Río Baracoa section correlate well with the lithologically equivalent Piragua Fm of east-central Cuba (Fig. 6).

Yaguaneque Fm

The Maastrichtian Yaguaneque Fm (Nagy et al., 1983=Cañas Fm, Cobiella et al., 1984) consists of up to 10-50 ms thick, white, gray, light brown, sometimes pink, massive fossiliferous limestones. These rocks are shallow to basinal marine in origin and occur strongly fractured and partially recrystalized (Nagy et al., 1983). This formation occurs in different locations within the Mayarí-Baracoa and Purial Mountains, and generally crops out as blocks and boulders without a clear stratigraphic relationship with country rocks; hence some of these contacts may be tectonic (Nagy et al., 1983, Cobiella et al., 1984; Quintas 1987, 1988a). This Maastrichtian limestone overlies amphibolites near Güira de Jauco, but also occurs over mafic-ultramafic rocks, the

Purial Complex *sensu lato*, and the Santo Domingo Fm (Cobiella et al., 1984; Quintas 1988a, 1988b).

The microfossils reported by Nagy et al. (1983) from the Yaguaneque limestones in the type locality near Moa (Fig. 1), includes benthic foraminifers (*Omphalocyclus* sp., *Orbitoides* sp., *Pseudorbitoides cf. P. israelskyi*, *Sulcoperculina cf. S. globosa*, *Vaughanina* sp.), rudist fragments, radiolaria, and planktonic forams (*Contusotruncana contusa, Contusotruncana cf. C. fornicata, Globigerinelloides* sp., *Globotruncana linneiana, Globotruncanita cf. G. stuarti*). In outcrops located in the area of Güira de Jauco and close to Río Baracoa, the Yaguaneque Fm overlies amphibolites of the Güira de Jauco Complex and greenschists referred to the Purial Complex (Fig. 1). In this area, according to Cobiella et al. (1984) the limestones are neither metamorphosed, nor recrystalized and yield both benthic (*Orbitoides apiculata s.l., Orbitoides* sp., *Pseudorbitoides rutteni, Pseudorbitoides* sp., *Sulcoperculina dickensoni, Sulcoperculina globosa, Vaughanina cubensis*) and planktonic foraminifers (*Heterohelix* sp., *Pseudotextularia* sp., *Rugoglobigerina* sp.). These fossil assemblages can be dated as Maastrichtian. Nevertheless, the fact that blocks and boulders of Maastrichtian limestone and isolated rudist fragments (*Titanosarcolites* sp.) occur within La Picota Fm (Cobiella et al., 1984; Quintas, 1988a), strongly suggests that the Yaguaneque Fm is older than Mícara and La Picota, probably pre-Latest Maastrichtian (Fig. 2).
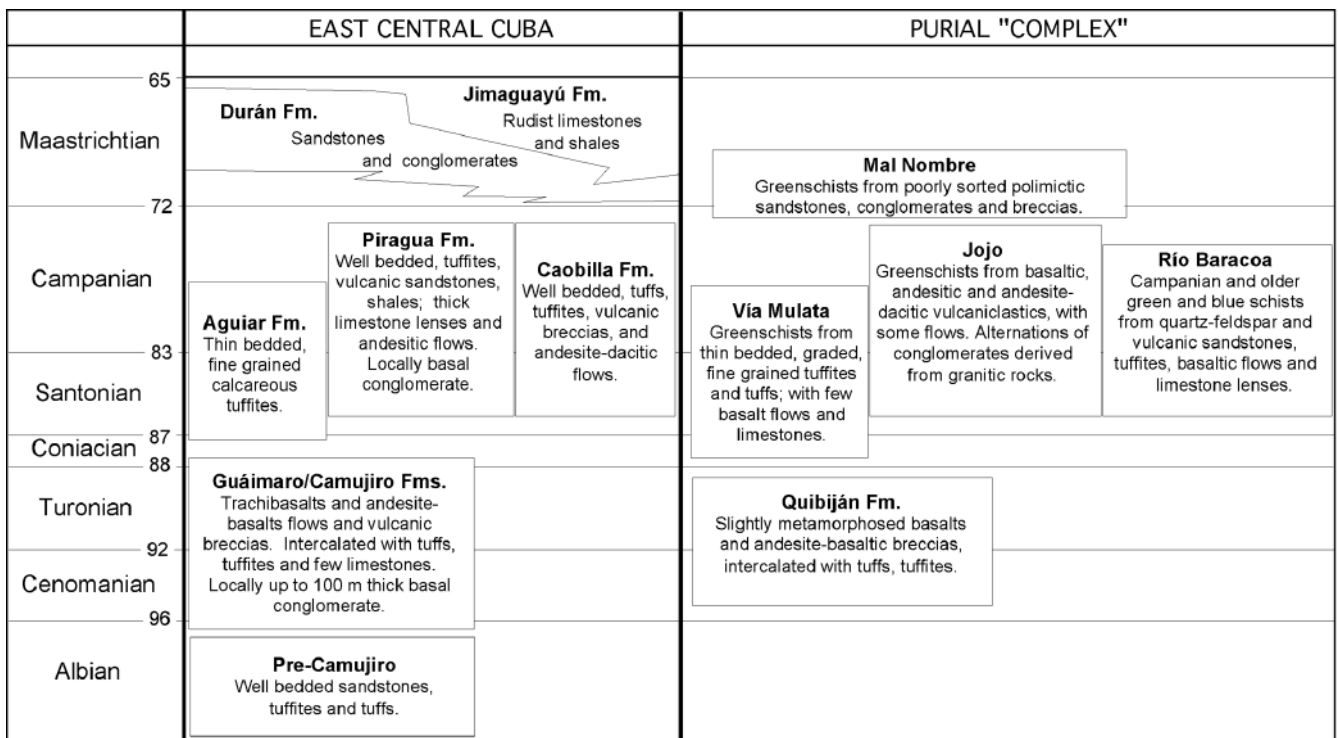

FIGURE 6 | **Lithostratigraphic correlations of the Cretaceous volcanic arc sections of East-Central Cuba (after Iturralde-Vinent, 1996a, 1996b; Iturralde-Vinent and Thieke, 1987; Piñero et al., 1997) and the informal units defined by Millán and Somin (1985) and Millán (1996) for the Purial Complex.**

Cobiella et al. (1984) and Quintas (1987, 1988a, 1988b) suggested that the Yaguaneque limestones were deposited onto the coevally emplacing thrust sheets. In this context, they assumed that the limestones were contemporaneously dismantled and incorporated into Mícara and La Picota Fms. Resedimentation of Maastrichtian and Eocene shallow water limestones (Jimaguayú and Florida Fms) into deeper water penecontemporaneous clastic deposits (El Brazo Member of the Jimaguayú Fm and calcareous breccias within the Florida Fm), have been observed within slightly deformed piggyback basins of central Cuba (Iturralde-Vinent and Thieke, 1987; Pushcharovski ed., 1988), but this is in contrast with such dynamic tectonic environment as described by Cobiella et al. (1984). Instead we propose the scenario shown in Fig. 7, where the limestones were deposited overlying the Santo Domingo Fm, and they were later incorporated into the tectonic pile during the general deformation of the area. This interpretation agrees with the fact that the Yaguaneque Fm is older than Mícara-La Picota Fms (Fig. 2).

Mícara and La Picota Fms

The Mícara (Cobiella, 1974) and La Picota (Lewis and Straczek, 1955) Fms, as redefined by Iturralde-Vinent (1976, 1977), crop out in the Mayarí-Baracoa and Purial Mountains (Cobiella et al., 1984; Quintas, 1987, 1988a; Pushcharovski ed., 1988). Rocks of the Mícara Fm are well-bedded, graded, polymictic sandstones and shales, with local intercalations of conglomerates and breccias. In some sections up to 10 m thick, well-bedded serpentinitic sandstones and gravels occur, usually near very large thrust sheets of gabbroids and serpentinites. The La Picota Fm occurs as lenticular intercalations within the Mícara Fm, and is represented by massive, chaotic layers of pebbles, blocks and boulders of gabbroids and serpen-

tinite, a few Maastrichtian limestones (Yaguaneque Fm) or isolated rudist (*Titanosarcolites* sp.), and some scattered masses of synsedimentary folded elements of the Mícara Fm. The stratigraphic sections of Mícara and La Picota are strongly intermingled with allochthonous tectonic olistoliths and olistoplates composed by mafic-ultramafic rocks, the Santo Domingo Fm, and the Purial Complex (Fig. 7; Cobiella, 1974, 1978; Iturralde-Vinent, 1976, 1977; Quintas 1987, 1988a). Mícara and La Picota Fms were generally deposited in deep marine environments, within a basin facing the thrust front. Laterally, toward the southeast, in these units are found intercalated fairly thick conglomerates (Iturralde-Vinent 1976, 1977). Deeper marine water sections occur toward the west, near Babiney (García Delgado et al., 2001).

In general, La Picota and Mícara have been dated as Maastrichtian to early Danian (Iturralde-Vinent, 1976, 1977; Cobiella et al., 1984; Pushcharovski ed., 1988). Recent sampling for paleontologic dating in many outcrops resulted in early Danian dates of well-exposed sections previously identified as Maastrichtian, and reworked Maastrichtian microfossils are common. In only one or two sections Maastrichtian fossil assemblages were identified in samples kindly studied by Timothy Bralower (nannofossils) and Mark Pucket (foraminifera and ostracoda). The Mícara and La Picota Fms often grade upward into late Danian marls, marly limestones and conglomerates with white tuffaceous intercalations (Gran Tierra and Sabaneta Fms in Cuba, Iturralde-Vinent, 1976, 1977; and upper half of Imbert Fm in Hispaniola, Iturralde-Vinent, 1997b), recording the early development of a new Paleocene-Middle Eocene volcanic island arc.

Toward the west (Babiney area in Fig. 1) isochronous Maastrichtian to Paleocene rocks consist of well-bedded
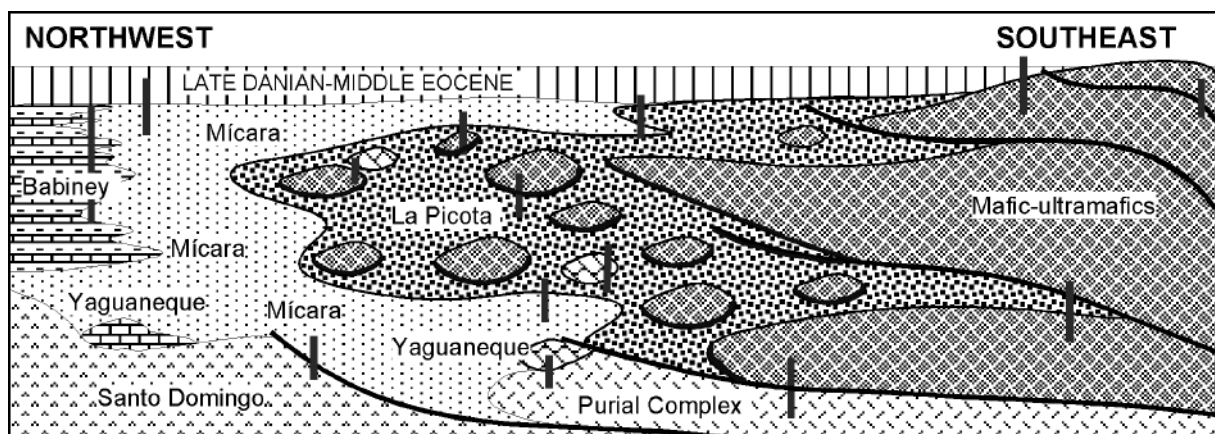

FIGURE 7 | **Diagrammatic cross section of the Mícara and La Picota late Maastrichtian-early Danian basin, depicting general relationships among the different units discussed in this paper (Fig. 2). The vertical bars are actual sections observed in the field (Iturralde-Vinent, 2003). Modified from Cobiella (1974, 1978). See stratigraphic chart in Fig. 2.**

polymictic sandstones, fine-grained calcareous sandstones, marls, siltstones and limestones, with few intercalated layers of diabase-rich breccia-conglomerate. The diabase is quite fresh, suggesting that it was not exposed to subaerial weathering or seawater alteration. The detrital material is represented also by grains and pebbles of carbonate, volcanic, metamorphic and mafic rocks. García Delgado et al. (2001) included this section in the Mícara Fm, but it is sufficiently distinctive as to be considered an independent unit, named Babiney Fm in an unpublished report by Kozary (1957).

The Mícara Fm records syntectonic turbidite sedimentation that towards the southeast includes more olistostromes derived from la Picota Fm. West of the Mayarí Mountains, the Babiney Fm represents a distal and probably deeper part of the basin (Figs. 1 and 7). This lithological zonation suggests that the source of the allochthonous debris (and probably of the allochthonous bodies) was located to the southeast of the basin (Fig. 7).

DISCUSSION: DATING MAGMATIC, METAMORPHIC AND TECTONIC EVENTS

Without an appropriate stratigraphic framework it is difficult to elaborate any scenario for the geodynamic evolution of a region as complicated as Eastern Cuba. Our present knowledge of the stratigraphy is summarized in Fig. 2. In this section the available stratigraphic data will be used to constrain the sucession and dating of the geologic events recorded in the region as expressed by the tectono-magmatic events, tectonic deformation and regional metamorphism.

Tectono-Magmatic events

Oceanic basalts and other volcanic and sedimentary rocks of different geochemical signature occur associated with the mafic-ultramafic and island arc bodies that crop out in Cuba (Kerr et al., 1999). The biostratigraphic dating from these rocks presented in this paper provides new insight into the magmatic events developed in Eastern Cuba.

The Téneme Fm has been geochemically characterized as primitive island arc tholeiites (PIA), similar to other Cretaceous PIA sections in the Greater Antilles (Proenza et al., this volume). Since earlier contributions by Donnelly and Rogers (1980), evidence has been provided to show that all PIA rocks in the Greater Antilles are of Lower Cretaceous Aptian-Neocomian age (Díaz de Villalvilla and Dilla, 1985; Lebrón and Perfit, 1994; Iturralde-Vinent, 1997b; Kerr et al. 1999). However, in the light of the new paleontologic dating of the Téneme Fm, contributed in this paper, a younger

PIA unit of Late Cretaceous Turonian or early Coniacian age is recognized.

The switch from primitive island arc (island arc tholeiites) into calc-alkaline geochemical signature in the Lower Cretaceous, is currently interpreted as a consequence of a polarity flip in the arc subduction zone (Lebrón and Perfit, 1994). However this interpretation has been criticized by Iturralde-Vinent (1994a, 1998), Jolly et al. (1998) and Kerr et al. (1999). The fact that primitive island arc rocks can also be found in the Late Cretaceous, may be a complication for the polarity flip interpretation, because two flips in a single arc are unusual and not predicted by any published plate-tectonic reconstruction. Maybe, a more appropriate approach to explain the variety of igneous rocks in space and time within an arc system is to accept that distinct geochemical signatures are the result of magmatic processes, which, in turn, are not necessarily tied to a particular time range. For instance, two samples taken, just a few m apart from arc-related basalts of the same stratigraphic unit and age, were found to have different geochemical signatures (Kerr et al., 1999). These samples from Encrucijada Fm in Western Cuba differ markedly, ENC2 being much more primitive than ENC1. Thus, Kerr et al. (1999) concluded that they belong to different parental magmas. Similarly, two samples from the Colombia basalt of East-Central Cuba, represent island arc-tholeiite (COL1), and calc-alkaline rock (COL2). Therefore, flipping might not be the only explanation for geochemical variations in extrusive rocks.

The identification of subduction polarity of the Cretaceous arc (or arcs) in Eastern Cuba is another problem yet to be solved. In the Mayarí massif, the partially isochronous island arc tholeiites (Téneme Fm; Proenza et al., this volume) were developed northwestward of the back-arc rocks, represented in the Moa-Baracoa massif by the Santo Domingo and Morel Fms (Iturralde-Vinent, 1994a, 1996a, 1996b, Kerr et al., 1999; Proenza et al., this volume). Furthermore, the tholeiitic to calc-alkaline volcanic and plutonic arc-related protolith of the so-called Purial Complex is located to the southeastward, and has been interpreted as a basin located within the axial part of an arc (Iturralde-Vinent 1994a, 1996a, 1996b). Therefore, from northwest to southeast, today three partially isochronous belts occur (Fig. 8): an island arc tholeiite belt (Mayarí), a back-arc tholeiite belt (Moa-Baracoa), and an axial-arc tholeiitic to calc-alkaline belt (Purial). Nevertheless, since this relative position may have been determined by the tectonic emplacement of these bodies, one cannot directly identify the present scenario as the original relative position of the arc (or arcs) elements. Additional structural research is needed, including appropriate palinspastic reconstruction of the tectonic pile, before the original position of the arc belts, and the arc polarity may be properly identified.

Tectonic deformation and metamorphism

Early Maastrichtian and older rocks that crop out in Eastern Cuba are allochthonous (Nagy et al., 1983; Pushcharovski (ed.), 1988; Quintas, 1987, 1988a, 1988b; Cobiella, 1974, 1978; Cobiella et al., 1977, 1984; Iturralde-Vinent, 1976, 1977, 1996a, 1996b, 1998; Fig. 1). The early Maastrichtian (?) and certainly Campanian and older rocks of the Purial Complex display some degree of recrystalization and are unconformably overlain by non-metamorphosed late Danian-Early Eocene and younger rocks (Pushcharovski, ed., 1988; Cobiella et al., 1984; Millán, 1996; Figs. 2 and 6). This suggests that the metamorphism of the Purial Complex took place during the late Maastrichtian.

The thrust sheet emplacements took place within the late Maastrichtian in the Mícara-La Picota marine basin, where syntectonic clastic and clastic-gravitational sedimentation (olistostrome) took place simultaneously (Cobiella, 1974, 1978; Iturralde-Vinent, 1976, 1977). The hypothetical structure of the basin is diagrammatically presented in Fig. 7, taking into account field observations of actual sections. The Mícara Fm displays drag folds with axes oriented NE-SW and recumbent folds downturned to the NW (Quintas, 1987, 1988a), suggesting that the tectonic transport took place from SE to NW. This emplacement direction is reflected in the sedimentary facies as olistostromes of La Picota Fm are more widespread to the southeast (Cobiella et al., 1984; Quintas, 1987, 1988a), while isochronous sandstones and marls dominate to the west (Babiney Fm). The same age and direction of tectonic transport was postulated by means of structural measurements in the Purial Complex and in the mafic-ultramafic rocks (Núñez Cambra, 2003). No major deformations are recorded in Eastern Cuba after the early Danian and before Oligocene (Iturralde-Vinent, 1976, 1977; 1994a; Cobiella et al., 1977, 1984; Pushcharovski ed., 1988). This means that Eastern Cuba was not strongly affected by the latest Paleocene to early Late Eocene deformations recorded elsewhere (Mattson, 1984; Pszczolkowski and Flores, 1986).

In other areas of Cuba, there are no stratigraphic sections of the same age, similar to the La Picota and Mícara Fms. Mafic-ultramafic rock clasts occur only as fine detritic materials in the Late Cretaceous deposits, and abundant boulders and olistoliths of serpentinites and gabbroids occur only in the late Paleocene and Eocene foredeep deposits (Iturralde-Vinent, 1997a, 1998; García Delgado and Torres, 1997).

In Hispaniola, the lower half of the Imbert Fm includes Maastrichtian-early Danian conglomerates and breccias similar to La Picota Fm, which underline late Danian-

Eocene white tuffaceous sections as in Cuba (Iturralde-Vinent, 1994b; Iturralde-Vinent and MacPhee, 1999).

In Guatemala, the Sepur Group is associated with a major change from stable platform to mobile belt, and has been described as latest Cretaceous (Campanian)-Paleocene in age, containing "abundant ophiolitic debris ranging from serpentine grains to ophiolitic slide masses many km wide, which record tectonic emplacement of ophiolitic rocks..." "It is dominantly a shale-sandstone flysch unit of turbidites that represent a submarine fan complex. It can be divided into a lower and upper unit; the Santa Cruz ophiolite allochthon occurs at the boundary between the two" (Donnelly et al. 1990). Rosenfeld (1981) described the lower unit as dominantly shales and shaly flysch and minor interbedded polymictic conglomerates, some of which contain blocks of limestone and calc-alkaline volcanic and plutonic clasts. The upper part carries abundant ophiolitic debris. The similarities between the lower Sepur Group and the Mícara Fm, and the upper Sepur Group with the La Picota Fm are remarkable, suggesting a common cause both in time and tectonic mechanism. In this region, as in Eastern Cuba, the emplacement of thrust sheets encompassed Cretaceous arc and mafic-ultramafic rocks, as well as their metamorphic equivalents and limestone boulders (Rosenfeld, 1981; Donnelly et al., 1990). Not any similar section (in age and lithology) occurs in other place in the Caribbean. These sections are apparently restricted to only two localities along the Caribbean plate boundaries, in Guatemala and Eastern Cuba/Western Hispaniola.
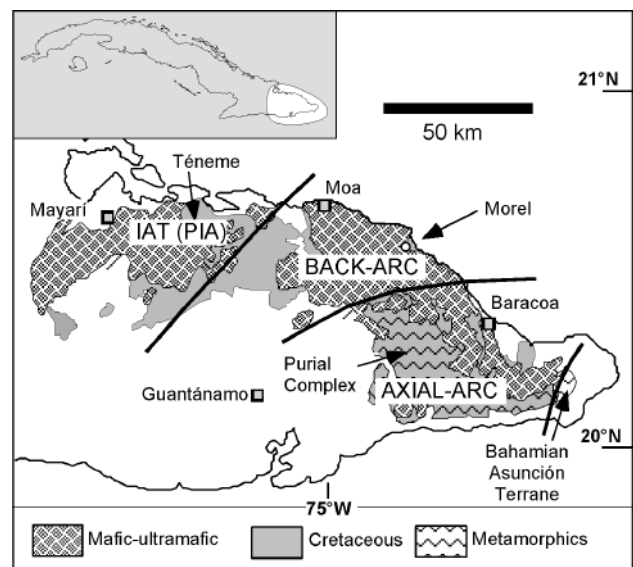

FIGURE 8 | **Schematic geologic map of Easternmost Cuba, illustrating the present position of the primitive arc, back-arc and axial arc belts. This scenario resulted from its tectonic emplacement, so may not represent the original relative position of these belts. Geographic Coordinates.**

The succession of tectonic events that took place in about 5 Ma (during the late Maastrichtian) in Eastern Cuba can be summarized as: (1) deep seated metamorphism, (2) crustal uplift and exhumation, (3) subhorizontal gravity emplacement of thin tectonic sheets within a marine basin, and (4) shallow dynamic metamorphism associated with the thrusting. The main question is what triggered these events. One possibility is that they resulted from the collision between the Caribbean Plate with the North and South American Plates (Pindell, 1994). But the collision is not an answer in itself, because it does not account for the local character of these events, which did not extend all along the plate boundary. On the other hand, it is possible to correlate the late Maastrichtian tectonic event with a worldwide orogeny linked to a major change in the rate and direction of plate movements (Schwan, 1980; Iturralde-Vinent, 1994a, 1998). Nevertheless, again the restricted location of the events in Guatemala and Eastern Cuba/Western Hispaniola remains unexplained. Another speculative possibility is to postulate that these local events were triggered by the insertion of thick intraplate ridges into the subduction zone, as described for the interaction between the South American plate and the Pacific crust today (Ramos and Aleman, 2000) but the acceptation of this mechanism would require further investigation in the Caribbean.

CONCLUSSIONS

The main magmatic and tectonic events that took place in Eastern Cuba from pre-Maastrichtian to Danian time can be summarized as follows:

1. Pre-Maastrichtian (>72 Ma): Development of the Cretaceous arc systems.

2. Late Campanian (75-72 Ma): Extinction of the arc's magmatic activity. Probably beginning of deep crustal detachment and regional metamorphism.

3. Early Maastrichtian (72-68 Ma): Partial shallowing of the marine basin within the extinct arc and deposition of shallow water limestone, probably directly overlying the Santo Domingo Fm.

4. Late Maastrichtian (68-65 Ma): Crustal uplift and exhumation of the deep-seated metamorphic rocks and exposure of the thrust front. Rapid subsidence of the marine basin and syntectonic deposition and deformation of clastic sequences (Mícara and La Picota Fms) during the gravitational emplacement of allochthonous thrust sheets.

5. Danian and younger (< 65 Ma): Partial uplift and deposition of post-orogenic volcaniclastic and sedimentary rocks that overly almost every older rock in the basin.

ACKNOWLEDGEMENTS

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APPENDIX

Paleontologic Dating of Cretaceous-Danian Sections of Eastern Cuba.

Geodynamic Implications

M.A. ITURRALDE-VINENT, C. DÍAZ-OTERO, A. RODRÍGUEZ-VEGA and R. DÍAZ-MARTÍNEZ

The following figures illustrate the microfacies representative of the investigated sedimentary units and some index fossils.
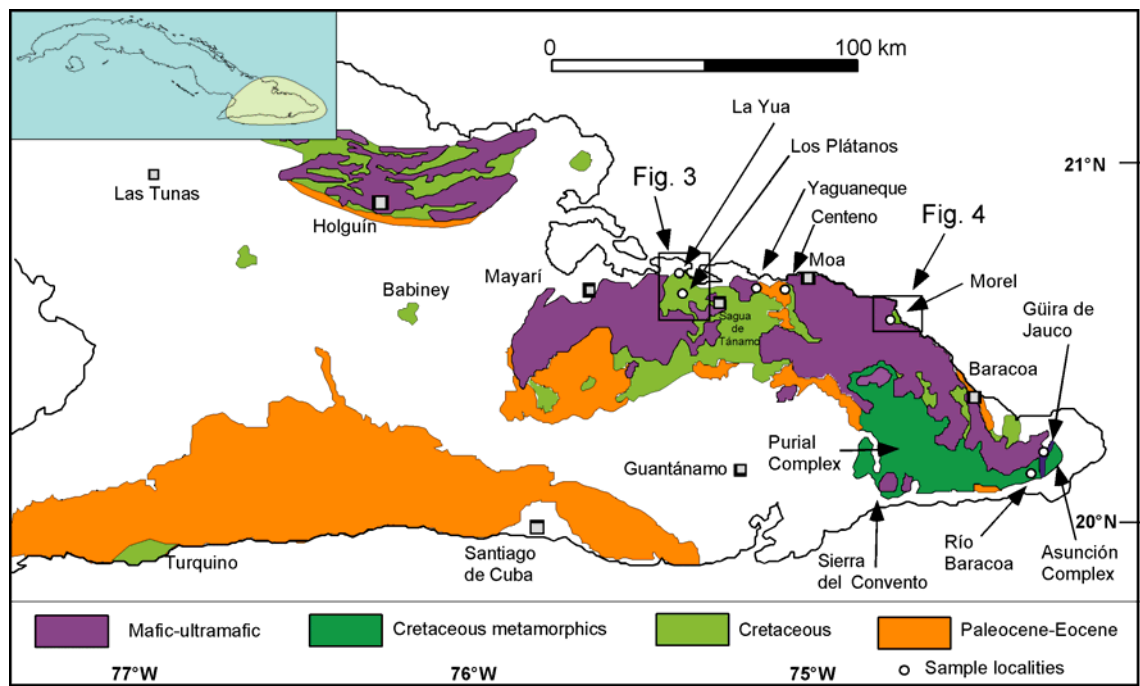

FIGURE I   Generalized geologic and locality map of eastern Cuba, showing the location of the investigated samples.
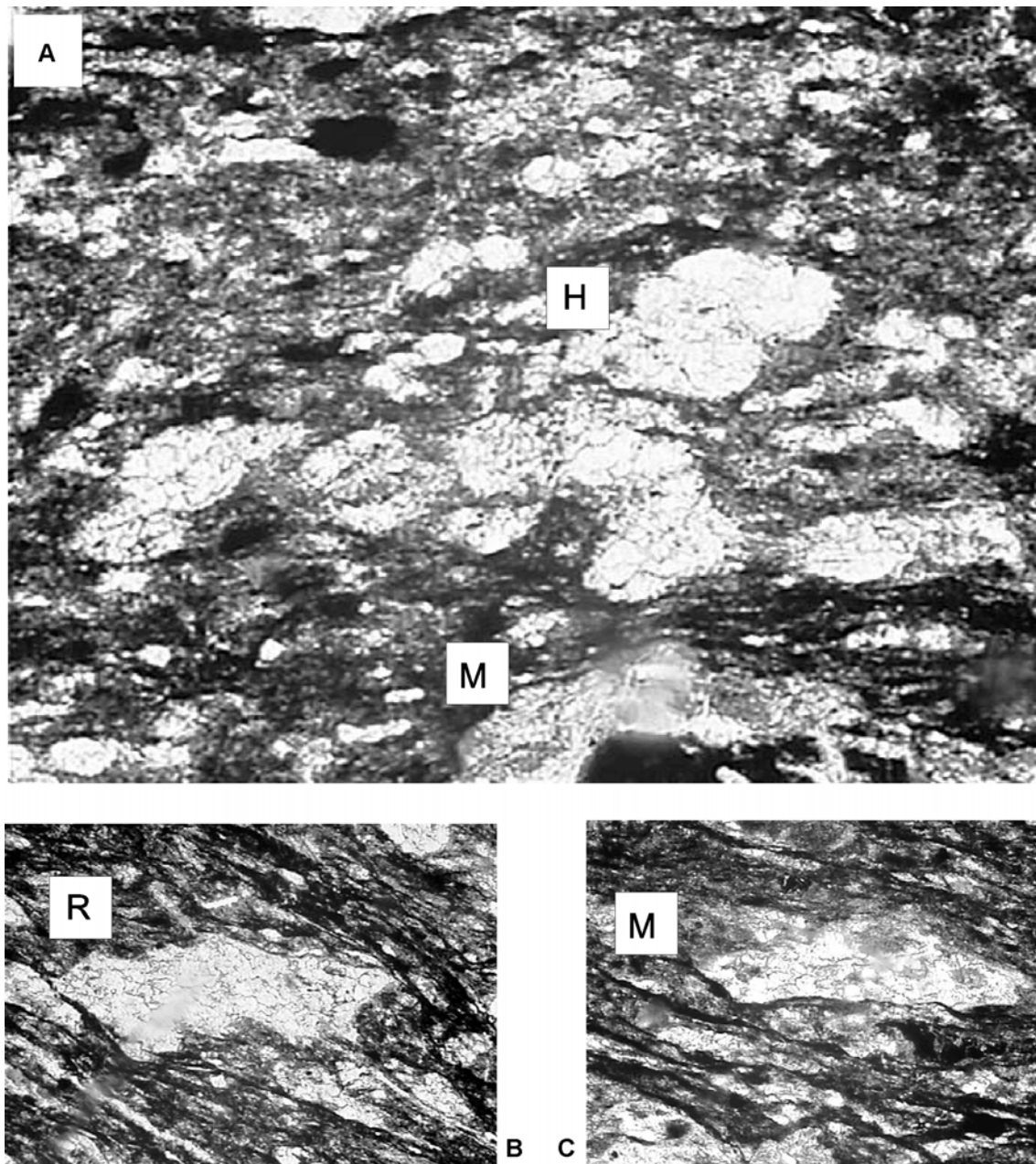
FIGURE II   Téneme Fm, Locality Los Plátanos. See location in Fig. I and further details in Fig. 3 in the printed version.   Photomicrographs of foliated shaly hemipelagic limestone with planktonic microfossils. A. Microfacies with *Marginotruncana* sp. (M) and Hedbergellidae (H). Width of the field 1642 microns; B. *Rotalipora cf. R. cushmani* (R) Maximun length 600 microns; C. *Marginotruncana coronata* (M) Maximun length 605 microns.
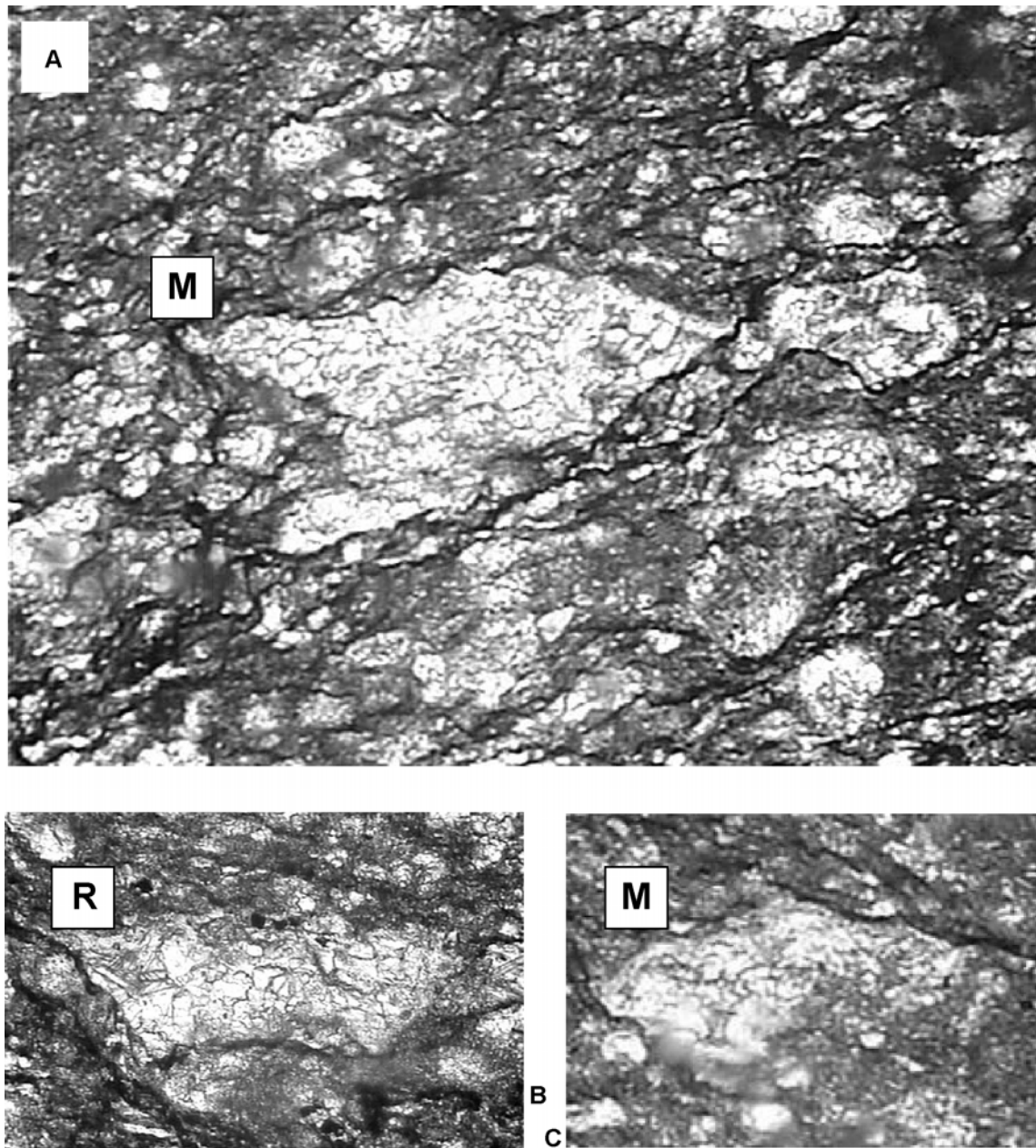
FIGURE III   Photomicrographs of foliated shaly hemipelagic limestone with planktonic microfossils. Téneme Fm, Locality La Yua. See location in Fig. I and further details in Fig. 3 in the printed version. A. Microfacies with *Marginotruncana sigali* (M) Width of the field 1010 microns; B. *Rotalipora cf. R. brotzeni* (R) Maximun length 400 microns; C. *Marginotruncana sinuosa* (M) Maximun length 510 microns.
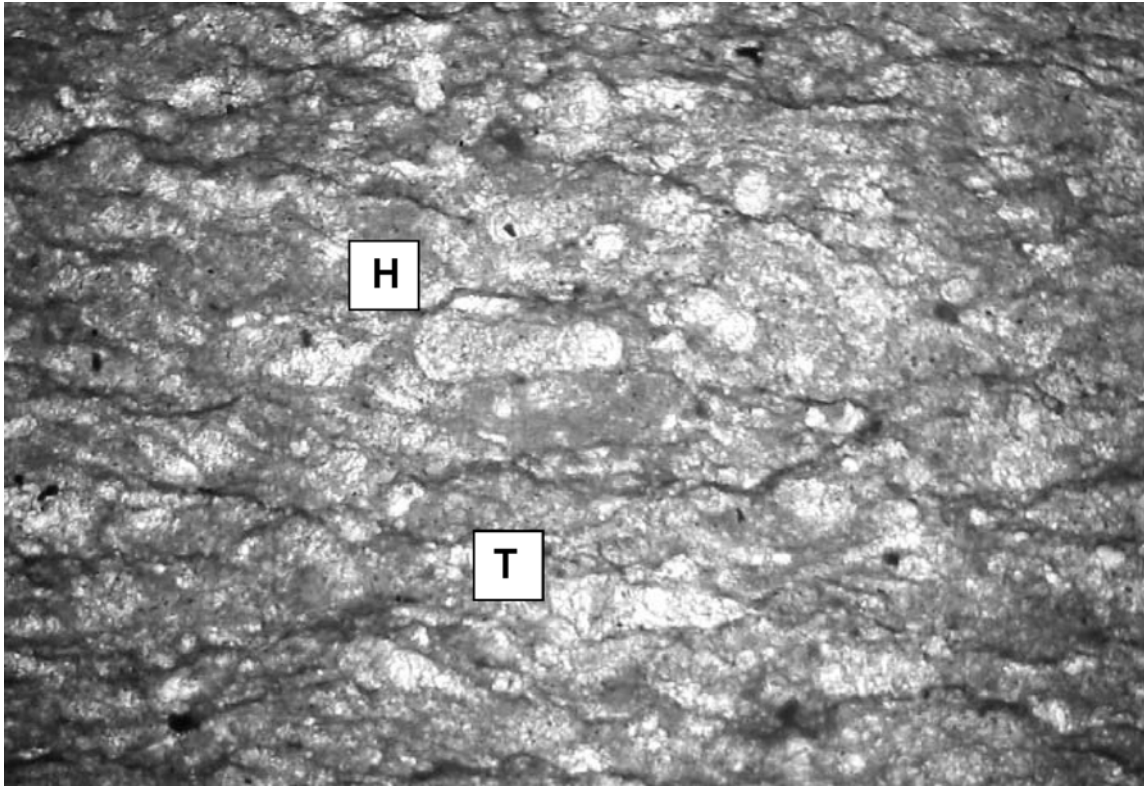
FIGURE IV   Photomicrographs of foliated and recrystalized hemipelagic limestone with planktonic microfossils. Morel Formarion, Locality Morel. See location in Fig. I and further details in Fig. 4 in the printed version. Microfacies with *Hedbergella simplex* (H) and Heterohelicidae (T). Width of the field 1410 microns
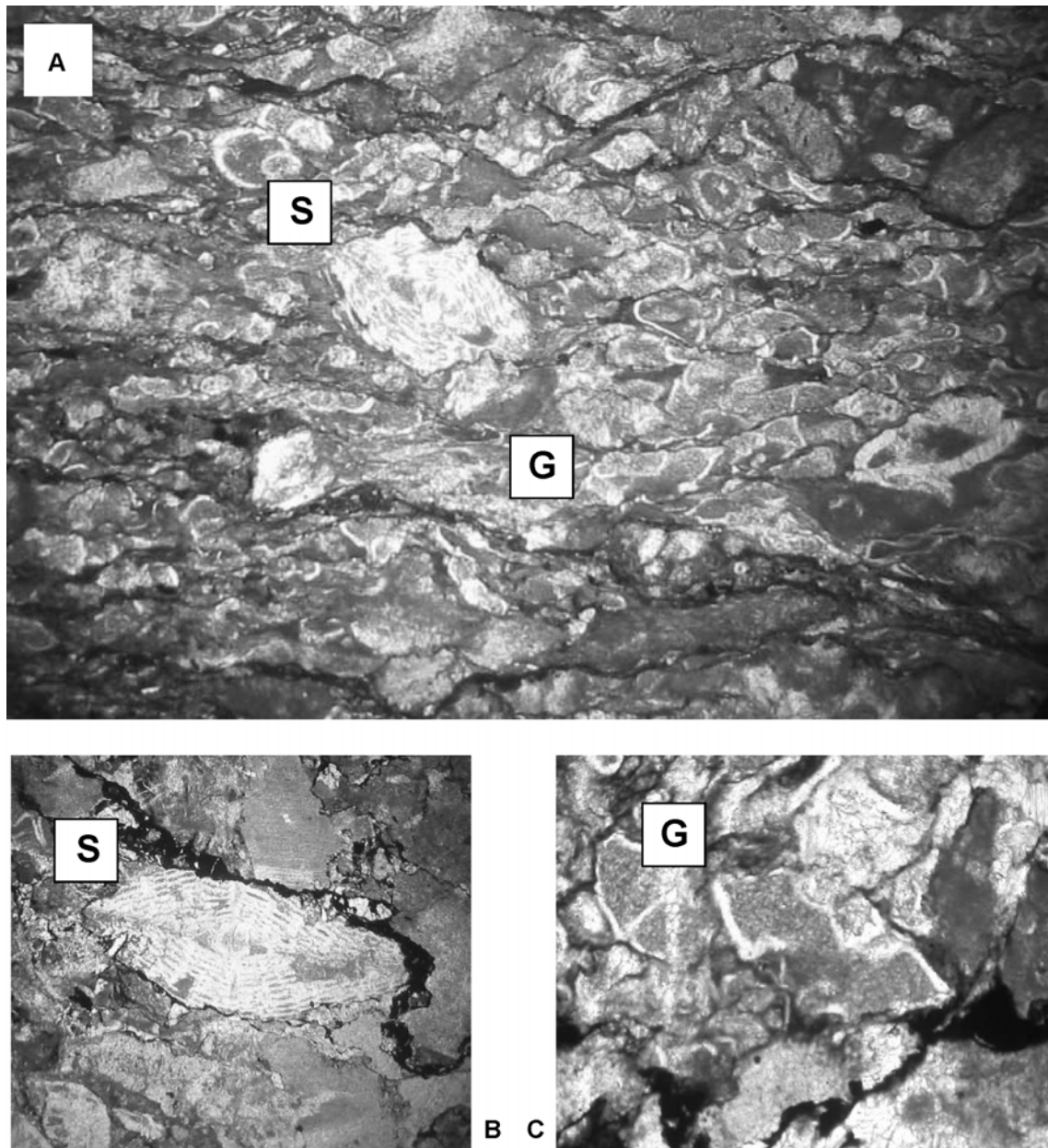
FIGURE V   Photomicrographs of biodetritic calcarenite with planktonic and benthic microfossils. Santo Domingo Formarion, Locality Centeno (Fig. I).   A. Microfacies with *Sulcorbitoides* sp. (S) and *Globotruncanita calcarata* (G). Width of the field 3900 microns;   B. *Sulcorbitoides pardoi* (S) Maximun length 990 microns; C. *Globotruncanita calcarata* (G) Maximun length 480 microns.