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Havana, Cuba, March 16 – 20, 2009

Post Conference Field Trip (March 21-25)

Subduction and Arc Complexes of Central Cuba

Leaders: Antonio García-Casco, Manuel Iturralde Vinent, Luis Bernal

IGCP 546 "Subduction zones of the Caribbean"
2008 INTERNATIONAL YEAR OF PLANET EARTH

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VIII Cuban Geological Congress
III Cuban Convention in Earth Sciences

Palacio de Convenciones, La Habana. March 16-20, 2009

IUGS-UNESCO IGCP PROJECT 546
"Subduction Zones of the Caribbean"
(http://www.ugr.es/~agcasco/igcp546/)

Post Conference Field Trip

"Subduction and arc complexes of central Cuba"

March 21-24, 2009

By

Antonio García-Casco
Departamento de Mineralogía y Petrología, Instituto Andaluz de Ciencias de la Tierra, Universidad de Granada-CSIC, España. agcasco@ugr.es

Manuel A. Iturralde Vinent
Museo Nacional de Historia Natural,
La Habana, Cuba. iturralde@mnhnc.inf.cu

Luis R. Bernal
Instituto de Geología y Paleontología, MINBAS,
La Habana, Cuba. bernal@igp.gms.minbas.cu

Granada, March 02, 2009

Support

INTRODUCTION

IGCP-546 "Subduction Zones of the Caribbean" and the Cuban Geological Society organized the workshop "Subduction Zones of the Caribbean" and the associated field trip "Subduction and arc complexes of central Cuba" as part of the activities offered by the VIII Cuban Geological Congress and the III Cuban Convention in Earth Sciences, held in Havana, Cuba, during March 16th-20th, 2009.

IGCP 546 project seeks to unravel the complex geologic evolution of the Caribbean region, with focus on deep earth processes taking place at convergent plate margins. The main aim of the project is the systematic characterization and comparison of subduction products, both mechanical and thermal, such as high-pressure belts, tectonic mélanges, accretionary wedges, accreted terranes, volcanic arcs, and fracture zones all along the Caribbean realm, northern South America and Nuclear Central America. Because Cuba records the tectonic interactions of the Caribbean and North American plates since the Early Cretaceous until the late Eocene, the study of these processes and materials in Cuba is one of the major targets of IGCP 546. To be noted is that the workshop "Subduction Zones of the Caribbean" is dedicated to the memory of Professor Wayne Jolly, who passed away on February 9, 2008, and who greatly contributed to the Geology and Petrology of volcanic arc rocks of the northeast Antilles.

The associated field trip "Subduction and arc complexes of central Cuba" was planned to serve as the basis for the description of the geologic architecture of the Cretaceous plate margin and the latest-Cretaceous to Tertiary orogenic belt and associated basins in the region, with special focus on high pressure complexes (tectonic blocks of serpentinite mélanges of the "northern ophiolite belt", Escambray complex), obducted ophiolitic bodies ("northern ophiolite belt"), and the deep metamorphic roots of the Cretaceous volcanic arc (Mabujina amphibolite complex). Problems with access to particular locations in the region precluded the visit to the Escambray, as originally planned.

THE GEOLOGY OF CENTRAL CUBA

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The Cuban orogenic belt formed as a result of convergence between the North American and Caribbean plates in Mesozoic to Tertiary times. The process involved subduction and accretion of large amount of oceanic material, including ophiolites and intra-oceanic volcanic arc rocks, that appear as complexly imbricated tectonic slices for the most part of the Cuban orogenic belt.

The Cuban Foldbelt of central Cuba can be subdivided into the following elements (Fig. 1):

- The northern sedimentary belts (Bahamas margin, slope and deep ocean –Protocaribbean- basin).
- The northern ophiolites and associated subduction mélanges.
- The Volcanic arc.
- The Mabujina complex.
- The Escambray complex.

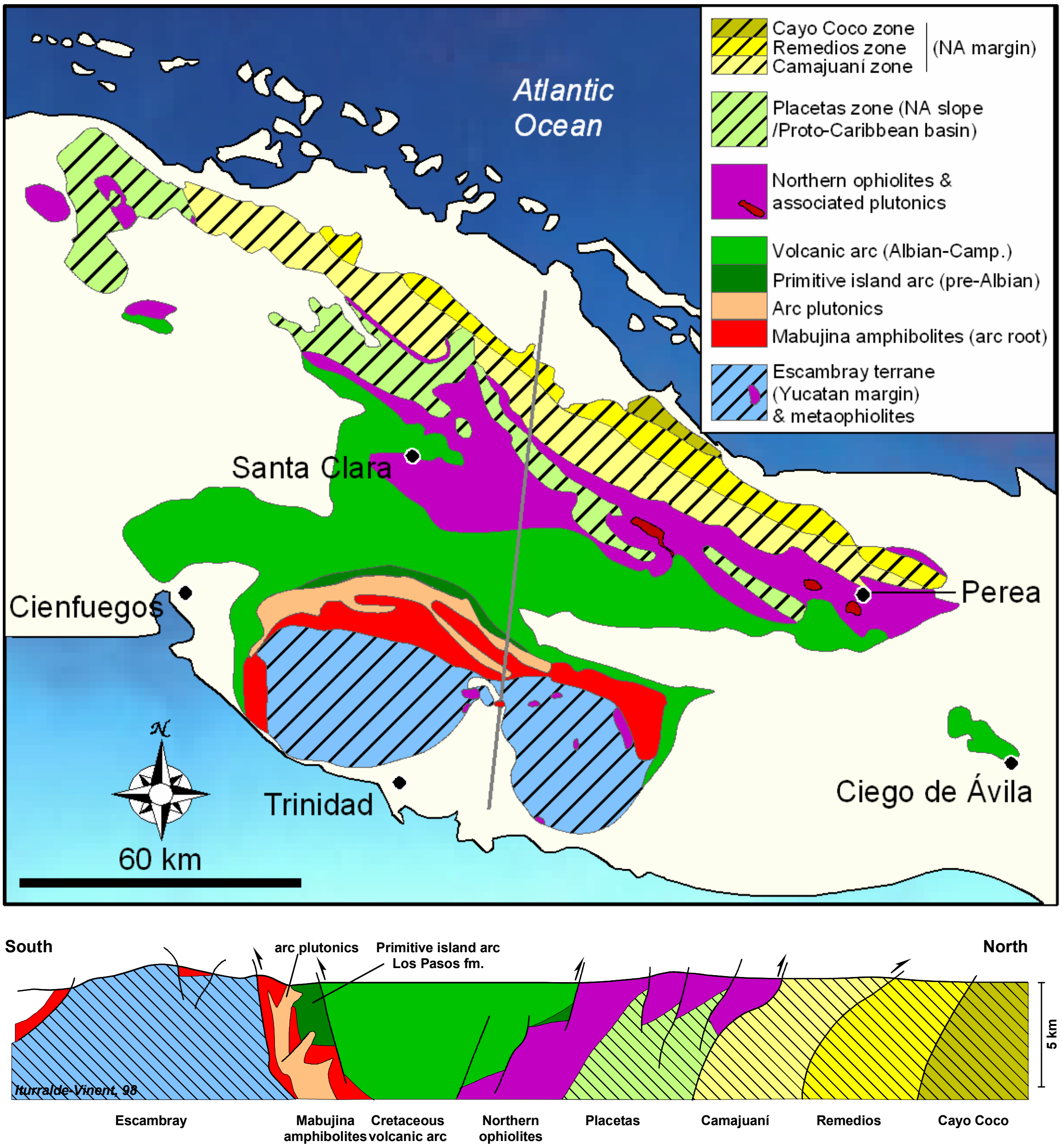


Figure 1.- Geologic sketch map and cross-section of Central Cuba. After Iturralde-Vinent (1998).

The northern sedimentary belts

The *Northern Sedimentary Belts* embrace Triassic-Jurassic through Eocene rocks deposited in various paleotectonic and paleogeographic scenarios of the North American plate. These belts are from northeast to southwest, Canal Viejo de Bahamas, Cayo Coco, Remedios, Camajuaní and Placetas. Within these belts can be distinguished the Mesozoic passive margin – oceanic basin sections, and the early Paleogene foreland deposits. The Cayo Coco belt of northern Cuba represents one of the intraplatform channels while the Remedios Belt represents an elongated carbonate platform. The Camajuaní and Placetas belts, on the other hand, represent the Late Jurassic to Late Cretaceous continental slope and oceanic basin. The oldest rocks of Canal Viejo Belt are Triassic resting upon a continental crust, while the oldest rocks known southeastward in the Placetas Belt (Camaján hills) are Early Tithonian basalts probably resting on oceanic crust. From Paleocene to early Upper Eocene developed a foreland basin and forebulge in the Protocaribbean and Bahamas margin. Defomations in the Northern Sedimentary Belts increase from northeast to southwest, from a slightly deformed section with local development of isolated linear folds in the Canal Viejo Belt, up to very tight folds and thrust faults in the Placetas Belt. These deformations are Paleocene to early Upper Eocene and reflect the syn-accresionary process of steady state SW to NE collision of the leading edge of the Caribbean plate with the North America margin.

Of the different northern sedimentary belts, only the **Placetas Belt** will be visited during the field-trip. This belt embraces a series of NW-SE elongated roughly lenticular strongly deformed and partially foliated thrust and fold bodies intercalated within serpentinite melanges, which outcrop from Matanzas to Holguín in Northern Cuba. Along strike from NW to SE the Placetas tectonic lenses became increasingly detached from each other. These tectonic slivers are built by a stack of thin nappe units, which present some stratigraphic singularities. The Placetas section in NW Santa Clara overlies a late Proterozoic Grenvillan basement intruded by Middle Jurassic granites (Somin and Millán 1981; Renne et al. 1989) and covered by arkoses (Pszczolkowski and Myczyñski, 2003). This basement underlies Oxfordian?-Late Berriasian marine arkosic and polymictic sandstones with siltstones, conglomerates and limestones interbeds (Constancia Fm) which is not recorded southeastward along the strike of the Belt. In Camaján hills, NE of Camaguey, the Placetas´s oldest unit is Lower Tithonian basalts with thin interbeds of hyaloclastites, laminated limestones and tuffites (Nueva María Fm). The Late Tithonian-Turonian sections of the Placetas Belt yield more similarities and is represented by well bedded pelagic limestones with intercalated beds of cherts, shales, sandstones and calcarenites. Within these strata occur the thick Aptian-Cenomanian well bedded cherts and silicified sandstones unit (Santa Teresa Fm). Above the Coniacian-Campanian hiatus occur calcirudites to calcarenites (Amaro and Camaján Fms), which may be either late Maastrichtian or K/T in age (Pszczolkowski, 1986; Tada et al., 2003). In Central Cuba the foreland deposits associated to the Placetas Belt are Paleocene-Lower Eocene olistostromes (Vega Fm) which yield clastic elements derived from the ophiolites, the Cretaceous volcanics and, in minor amounts, carbonate and chert fragments derived from the forebulge (Iturralde-Vinent, 1998).

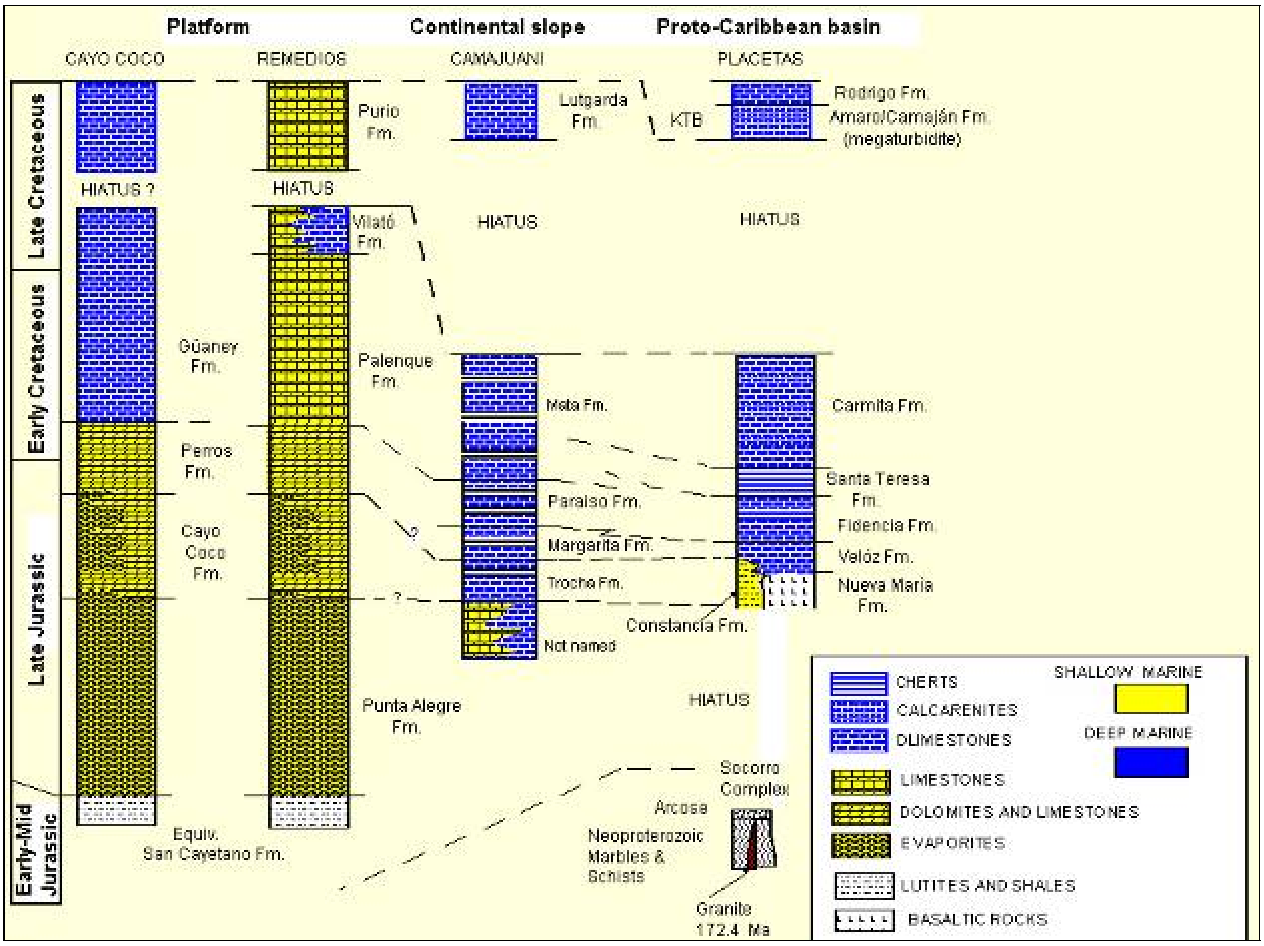


Fig. 2.- Schematic stratigraphic sections of the Northern Sedimentary Belts of Cuba.

The northern ophiolites and associated subduction mélanges.

(this text is extracted from García-Casco et al., 2006. High pressure metamorphism of ophiolites in Cuba. Geologica Acta 4, 63-88; see this paper for references).

In Cuba, ophiolitic material metamorphosed to high-pressure is found as blocks within serpentinite-matrix mélanges in a number of geological settings (Somin and Millán, 1981; Millán, 1996a). The most important ophiolitic assembly is the "northern ophiolite belt" (Iturralde-Vinent, 1989; 1996a and b; 1998), a discontinuous belt of more than 1000 km in length composed of discrete, variously sized bodies exposed in the north of the island, from W to E, Cajálbana, Mariel-La Habana-Matanzas, Las Villas, Camagüey, Holguín, Mayarí, Moa-Baracoa. All these bodies have been widely considered to represent a single geologic element formed within the same paleogeographic/paleotectonic setting during the Mesozoic, although more recently Iturralde-Vinent et al. (2006) argued that eastern Cuba bodies should not be included as part of this belt.

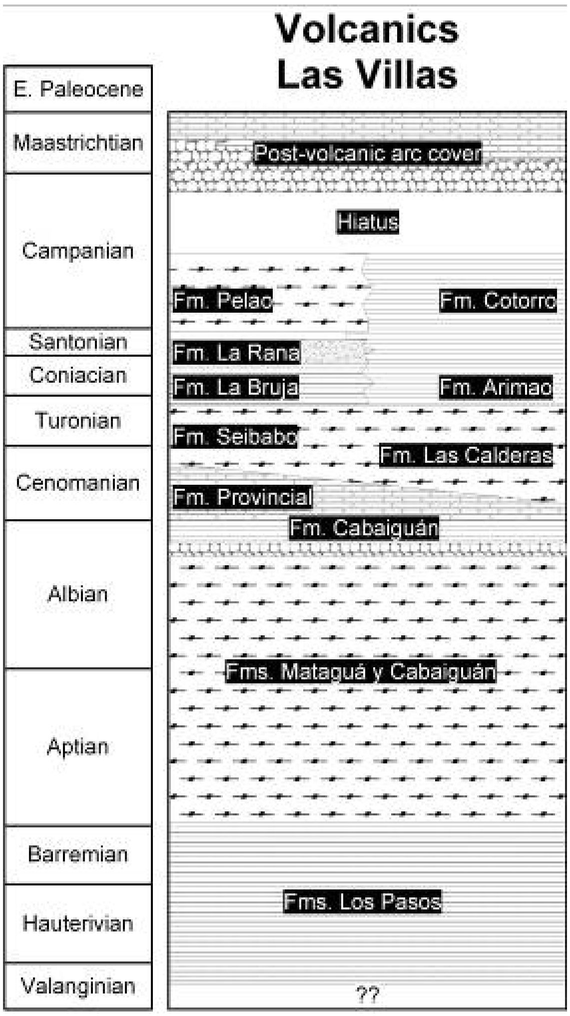
The ophiolitic bodies are composed mostly of chrysotile-lizardite serpentinites, which are the metamorphic products of harzburgite, dunite and, less abundantly, pyroxenite, wehrlite and lherzolite, though they also contain fragments of the crustal sections of ophiolite, including layered and isotropic gabbros and associated cumulate rocks, chromite ores, diabase, basalt and pelagic sediments (see Iturralde-Vinent, 1996b for review; additionally, see Khudoley, 1967; Khudoley and Meyerhoff, 1971; Pardo, 1975; Somin and Millán, 1981; Fonseca et al., 1985; Iturralde-Vinent, 1989; Millán, 1996a; Kerr et al., 1999; Proenza et al., 1999). These bodies of serpentinite have been the subject of controversy concerning the origin of Alpine-type ultramafic rocks since the 1950's, when H.H. Hess proposed a primary hydrated ultramafic magma but N.L Bowen disputed this hypothesis and interpreted the bodies as solid intrusions of serpentinized peridotite (see Young, 1998, p. 201-209). In the 1970's the bodies were recognized as oceanic fragments accreted to the Yucatan/North American margin during late Upper Cretaceous to Paleogene collision of this margin with the Upper Cretaceous volcanic arc of Cuba. Oceanic transformations resulted in serpentinization and low-pressure metamorphism (Somin and Millán, 1981; Millán, 1996a; Auzende et al., 2002; Proenza et al., 2003, García-Casco et al., 2003). During accretion, the bodies were strongly sliced off, fractured and brecciated. In fact, most of them can be considered as tectonic serpentinite-matrix mélanges that contain, in addition to co-genetic igneous and sedimentary materials, exotic blocks incorporated from adjacent sedimentary sections, volcanic-arc and subduction complexes. Other ophiolitic assemblies appear as tectonic slices within olistostromes and along faults in continental terranes that probably represent fragments of the Mesozoic platform of the Maya block or of the Caribeana paleogeographic domain (i.e., Escambray and Guaniguanico terranes of central and western Cuba, respectively; Iturralde-Vinent, 1989, 1996a; Pszczólkowski, 1999; García-Casco et al., 2008). These ophiolitic slices are composed of chrysotile-lizardite serpentinite-matrix mélanges in the Guaniguanico terrane, while in the Escambray massif they are made of a) massive garnet amphibolites (Yayabo amphibolites, sensu Millan, 1997b) and b) antigorite-bearing serpentinite-matrix mélanges containing high-pressure rocks (Somin and Millán, 1981; Millán, 1996a, 1997b; Auzende et al., 2002; Schneider et al., 2004).

The earliest age of formation of the ophiolite belts in Cuba is constrained to be Upper Jurassic by Tithonian through Albian-Cenomanian oceanic sediments that locally cover the igneous rocks in different parts of the belt (Iturralde-Vinent and Morales, 1988; Iturralde-Vinent, 1994, 1996b; Llanes et al., 1998). Isotopic (mostly K-Ar) ages of igneous rocks span an interval of 160-50 Ma (see review by Iturralde-Vinent et al., 1996). Of these data, only the Upper Jurassic to Lower Cretaceous dates are commonly considered to represent formation of oceanic lithosphere, while Upper Cretaceous to Paleogene K-Ar dates are thought to represent subsequent arc-related magmatism or isotopic resetting due to post-formation alteration and deformation events. Middle-Upper Jurassic is the time of break-off of Pangea in the region and the onset of formation of an oceanic basin connected with the Atlantic, the Proto-Caribbean (sensu Pindell, 1985, 1994; see also Mann, 1999 and references therein), which opened as the Americas drifted away since that time until the Maastrichtian. According to most workers, the northern and eastern ophiolite belts of Cuba formed in the inter-Americas gap (e.g. Somin and Millán, 1981; Iturralde-Vinent, 1996a; Kerr et al., 1999), a conclusion that is strengthened by the scarcity of associated plateau basalts (or B" material; Burke et al., 1984; Kerr et al., 1999) which are typical of the Caribbean crust. However, increasing geochemical evidence accumulated recently from Early and Late Cretaceous basaltic rocks associated with these ophiolitic complexes favors supra-subduction environments (including back-arc, fore-arc and arc settings) instead of mid-ocean ridges as the locus of basalt generation. García-Casco et al. (2003) indicated IAT signatures of basaltic rocks from the Cajálbana ophiolite body metamorphosed in an Early Cretaceous (130 Ma) volcanic arc environment. Fonseca et al. (1989) and Kerr et al. (1999) described boninitic rocks in the northern ophiolite belt (Havana region) of unknown age, but the latter authors suggested that they may represent an Early Cretaceous (Aptian-Albian or older) boninite volcanic arc. In this same belt the Margot Formation (Matanzas region) consists in back arc basalts (Kerr et al., 1999) dated as Cenomanian-Turonian (Pszczólkowski, 2002). García-Casco et al. (2003) indicated probable calc-alkaline signatures in basaltic rocks from the Iguará-Perea region (northern ophiolite belt, Las Villas) metamorphosed in a Turonian-Coniacian (88 Ma) volcanic arc environment. Andó et al. (1996) indicated calc-alkaline trend in magmatic rocks of suggested Upper Cretaceous age in the Holguín ophiolite body. Cenomanian-Turonian island arc tholeiitic basalts are recorded in eastern Cuba ophiolites (Proenza et al., 1998, 1999, 2006, Iturralde-Vinent et al., 2006). Thus, volcanic material in the northern and eastern ophiolite belts document suprasubduction environments during the Early and Late Cretaceous and, possibly, a number of intra-oceanic subduction events.

Mélanges containing m- to dm-sized blocks of eclogite, garnet amphibolite, amphibolitite, blueschist, greenschist, quartzite, metapelite and antigoritite occur within the northern ophiolite belt. Available K-Ar ages from samples of high-pressure (HP) blocks in the region range from 130 to 60 Ma, but data cluster about 110±10 Ma (Somin and Millán, 1981; Somin et al., 1992; Iturralde-Vinent et al. 1996) suggesting an Early Cretaceous age for the subduction zone; younger ages are inferred to represent reworking during Upper Cretaceous-Paleogene tectonism associated with collision.

The Volcanic arc

(this text is extracted from García-Casco et al., 2006. High pressure metamorphism of ophiolites in Cuba. Geologica Acta 4, 63-88; see this paper for references).



A belt of tectonic units consisting of volcanic, volcanic-sedimentary and plutonic arc rocks of basic through acid composition all along the island (Fig. 1B) documents an Early Cretaceous (Late Neocomian-mid Albian age) island arc of tholeiitic (IAT) affinity (Los Pasos Fm) that developed into a voluminous calc-alkaline (CA) and high-alkaline arc (Albian-Campanian; Iturralde-Vinent, 1996c and d; Díaz de Villalvilla, 1997; Kerr et al., 1999, Iturralde-Vinent et al., 2006). This sequence of Cretaceous arc volcanism in Cuba is similar to that identified all along the Caribbean region (Donnelly and Rogers, 1978; Burke, 1988; Donnelly et al., 1990; Lebron and Perfit, 1993, 1994; Jolly et al., 2001). Burke (1988) named this arc the Great Arc of the Caribbean, which would have evolved as a response to Cretaceous subduction in the region, but the relationship between this volcanic-arc terrane and the various types of suprasubduction magmatic events recorded in northern and eastern ophiolite belts is uncertain. Island arc tholeiitic volcanic rocks of Paleocene to Middle Eocene age developed only in eastern Cuba (Sierra Maestra Mountains)

Fig. 3.- Schematic stratigraphic section of the Cretaceous Volcanic Arc of central Cuba.

The Mabujina complex

(this text is extracted from García-Casco et al., 2006. High pressure metamorphism of ophiolites in Cuba. Geologica Acta 4, 63-88; see this paper for references).

The volcanic-arc units overlie the Mabujina Complex, composed of the Porvenir Fm. and the Mabujina lithothem, that should be considered two distinct tectonic units. The former is probably equivalent to the Los Pasos Fm. It consists of bimodal acid-basic volcanic sequence metamorphosed in the greenschist facies. The age of the formation is Berriasian-Barremian, based on correlation with Los Pasos Fm. The Mabujina lithothem is the lower unit of the Mabujina complex. It consists of intense to moderately deformed low-intermediate pressure amphibolites, metaporphyritic amphibolites, schistose and banded amphibolites, metagrabbroic amphibolites, metapyroxenites (hornblendites), intercalated metagranodioritic and granitic gneisses, discordant veins and bodies of tonalitic-trondhjemitic-granitic bodies and veins and locally metasilicites. Both the Porvenir Fm. and Mabujina Lith. are arc-derived (Somin and Millán, 1981; Millán, 1996b; Grafe et al., 2001; Blein et al., 2003). This complex is interpreted as the metamorphosed roots of the island arc and its oceanic sole (Somin and Millán, 1981; Millán, 1996b) or as a separate arc system (Blein et al., 2003).

The Escambray complex

(this text is extracted from García-Casco et al., 2006. High pressure metamorphism of ophiolites in Cuba. Geologica Acta 4, 63-88; see this paper for references).

Escambray complex crops out in a tectonic window below the metamorphosed arc-related Mabujina complex (Fig 1 and 4). It is composed of an ensemble of strongly deformed tectonic slices that comprise continental margin metasediments and metaophiolites (Somin and Millán, 1981; Millán and Somin, 1985; Millán, 1997b). Millán (1997b) subdivided the massif into four major tectonic units (I to IV, numbered from bottom to top in the pile; Fig. 4), each of which comprises a number of smaller tectonic units. The lithological sequences consist of metacarbonatic and metapsammopelitic rocks, with local metabasite intercalations. These rocks have been correlated with non-metamorphosed Jurassic-Cretaceous continental margin sequences in the Guaniguanico terrane of western Cuba, which formed part of the borderland of the Maya block (Millán, 1997a and b; see also Iturralde-Vinent, 1994, 1996a, Pszczólkowski, 1999). However, other reconstructions locate the terrane farther southwest in the borderland of the Chortis block (Pindell and Kennan, 2001). Recently, García-Casco et al. (2008) have considered it as a fragment of the so-called Caribeana terrane, a platform-like terrane projecting off the Maya block and located within the Protocaribbean ocean.

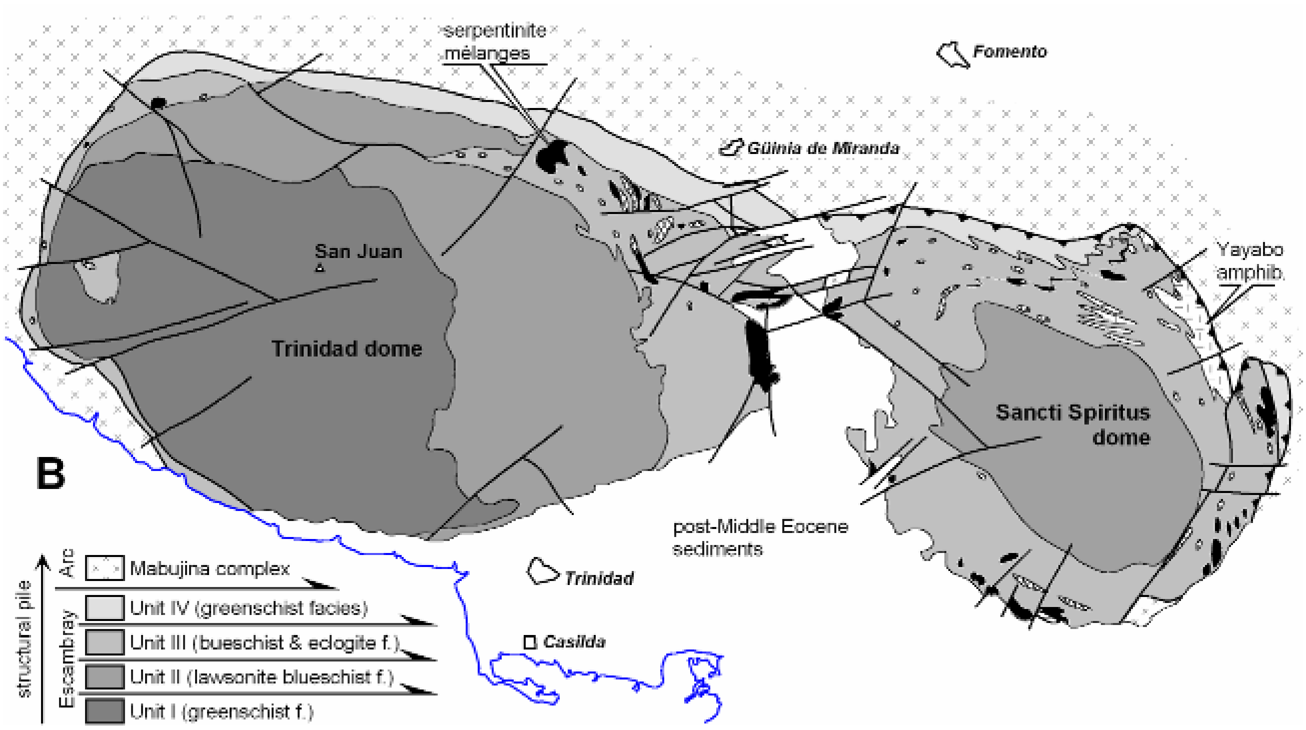


Fig. 4.- Geologic map of the Escambray (after G. Millán, 1997) with indication of major tectonic units, serpentinite mélanges and amphibolite and eclogite bodies (only shown for unit III).

P-T conditions during metamorphism in the Escambray were variable (Millán, 1997b), ranging from low grade at intermediate-P (greenschist facies) and high-P (blueschist facies) to medium grade at high-P (eclogite facies). The internal deformation is intense and complex, with numerous tectonic-metamorphic inversions. The massif has an inverted metamorphic zoning, with greenschist facies at the base in unit I, greenschist and lawsonite blueschist facies in unit II, and epidote-blueschist and eclogite facies at the top in unit III. The uppermost unit IV in contact with the overlying Mabujina complex diverges from this pattern (greenschist-blueschist facies). High pressure conditions indicate subduction of the associated continental margin-like terrane. Subduction of oceanic lithosphere is also documented by serpentinite-matrix mélanges bearing high-pressure exotic blocks. Available age data range from Upper Jurassic (U-Pb age of zircon in eclogite, Maresch et al., 2003) through mid-Cretaceous (U-Pb: 106-100 Ma; Hatten et al., 1988, 1989) to Upper Cretaceous (K-Ar: 85-68 Ma; $^{40}Ar/^{39}Ar$: 71-68 Ma; Rb/Sr: 65-69 Ma; Somin and Millán, 1981; Hatten et al., 1988; Somin et al., 1992; Iturralde et al., 1996; Schneider et al., 2004). Age data for a block of eclogite of unit III provided by Schneider et al. (2004) are $^{40}Ar/^{39}Ar$ (phengite): 69.3±0.6, $^{40}Ar/^{39}Ar$ (barroisite): 69.1±1.3 and Rb/Sr (whole-rock-phengite-barroisite): 66.0±1.7 Ma, and were interpreted as cooling ages close to thermal peak. Except for the Upper Jurassic age, these ages are consistent with subduction in the course of the Upper Cretaceous and exhumation during the late Upper Cretaceous. This suggests that the associated subduction system may be independent of the Lower Cretaceous subduction system recorded in the HP blocks of mélanges from the northern ophiolite belt in western and central Cuba. Petrologic evidence presented below also support this view.

Millán (1997b) reported that eclogite facies rocks of tectonic unit III underwent blueschist facies retrogression, and related this overprinting to the low-grade high-pressure metamorphism of unit II. This type of blueschist retrogression is not common in the HP exotic blocks of the northern ophiolite belt from western-central Cuba, a fact that may relate to tectonic processes exclusive of the Upper Cretaceous subduction system where the Escambray complex impinged. Millán (1997b) and Schneider et al. (2004) identified blueschist retrogression as a result of syn-subduction exhumation during the late Upper Cretaceous. These authors also noted that the prograde metamorphic evolution of coherent eclogite samples present in the metasedimentary formations is more complex than that of the eclogite blocks of the tectonically intercalated strips of serpentinite-mélanges, but that their peak eclogite conditions and retrograde evolutions are similar, the latter characterized by substantial cooling upon exhumation.

Tectonic events

The thrust-and-fold belt was complexly assembled during late Upper Cretaceous-Middle Eocene times, when syn-tectonic sedimentary-olistostromic formations of Paleogene age were deposited above the northern ophiolite belt and the continental margin sections (Iturralde-Vinent, 1998).

Intense collisional tectonics, ophiolite obduction and olistostrome formation of latest Cretaceous through Paleocene-Middle Eocene age relate to the collision of the oceanic volcanic arc terranes with the ophiolites and the continental margins of the Maya and Bahamas blocks (Pszczólkowski and Flores, 1986; Iturralde-Vinent, 1994, 1996a, 1998; Bralower and Iturralde-Vinent, 1997; Gordon et al., 1997). The Campanian termination of the volcanic arc and the Upper Cretaceous isotopic ages of continental metamorphic terranes (Escambray, Isle of Pines) and of the oceanic roots of the volcanic arc (Mabujina complex) (Iturralde-Vinent et al., 1996; García-Casco et al., 2001; Grafe et al., 2001; Schneider et al., 2004) indicates onset of arc-continent collision in the Cuban segment of the Caribbean orogenic belt in Upper Cretaceous times. However, Kerr et al. (1999) suggested that the earliest collision event in Cuba is of Aptian-Albian age and of intra-oceanic nature, unrelated to the Upper Cretaceous-Paleogene arc-continent collision event. This intra-oceanic event was identified by García-Casco et al. (2002) in mélanges of the northern ophiolite belt of central Cuba.

During the formation of the Cuban segment of the Antillean orogen several regional tectonic events played an outstanding role during the Cretaceous and Early Paleogene. These events, bearing on the structure and accretionary history of the orogen, encompassed oceanic-continental interactions. They took place in latest Campanian-early Maastrichtian, latest Maastrichtian-early Danian, and Middle to early Upper Eocene. As the Caribbean plate drifted eastward relative to the Americas, the leading edge of this plated collided with terrane Caribeana (García-Casco et al., 2008) during the latest Cretaceous, forming the metamorphic complexes of the Caribbean, including the Escambray complex. Latter, during the Paleocene - late Middle to early Upper Eocene, the accretionary prism collided with the Bahamas platform. As a result of the latest collision, the Cuban segment of the Antillean orogen was erected.

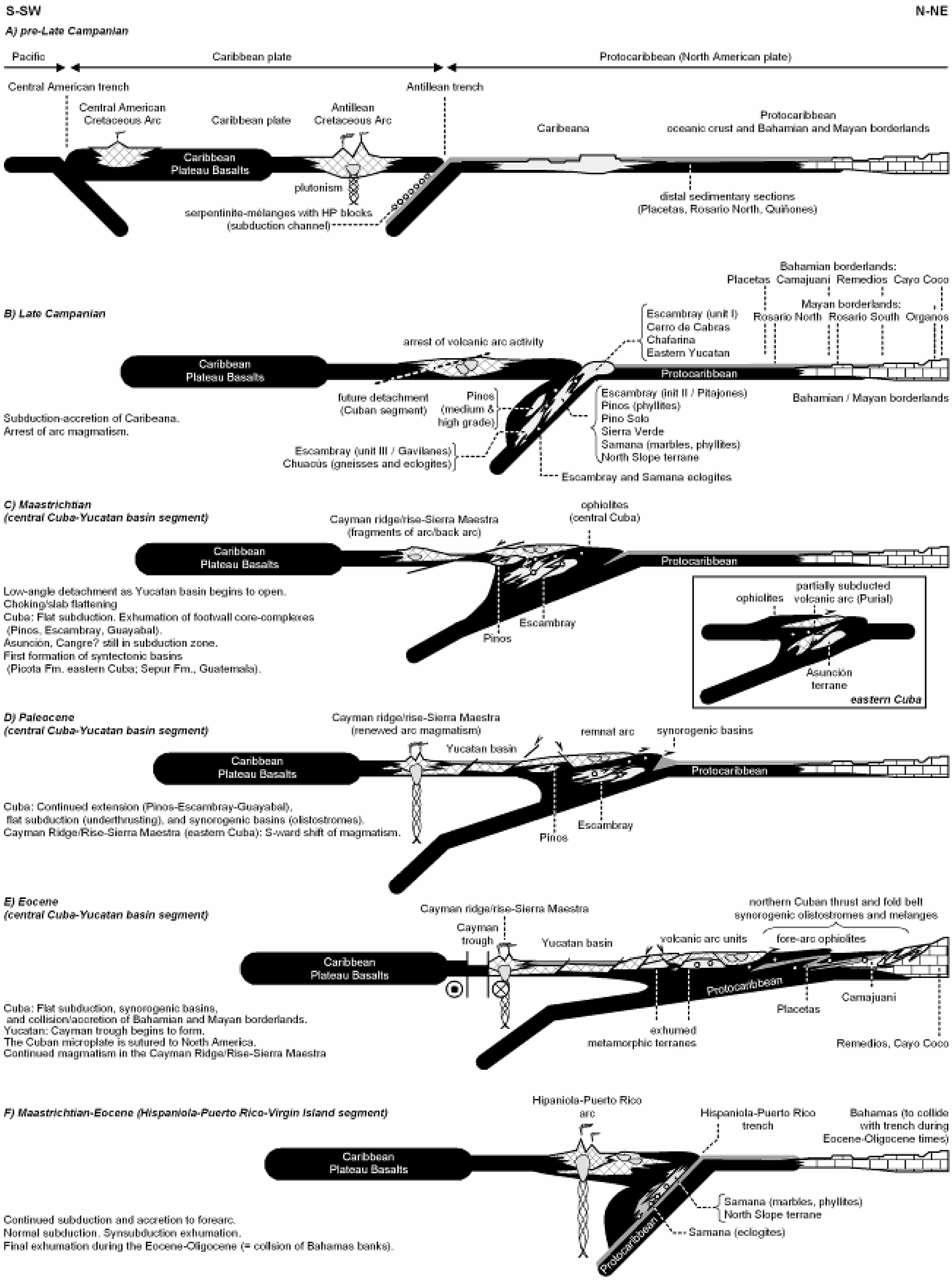
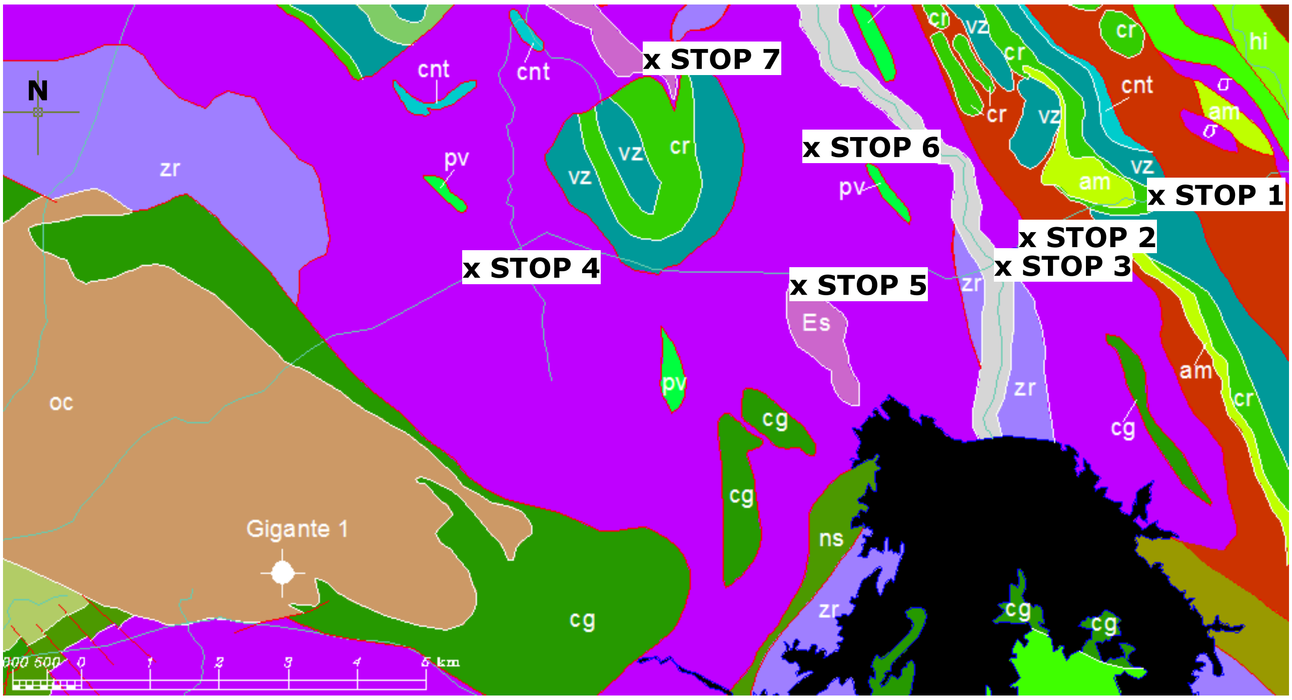


Fig.5. Tectonic sketch cross-sections showing the proposed evolution of the northern margin of the Caribbean plate, metamorphic terranes and Mayan/Bahamian borderlands. Model for Yucatan intra-arc Basin adapted from Pindell et al. (2005).[From García-Casco et al., 2008].

FIELD TRIP

March 21



*Location of stops 1-3. Key: **Bahamian borderlands**: **vga (in deep red)**: Vega Alta Fm. Olistostrome with poorly sorted blocks and fragments of limestones, silicites, serpentinites, volcanic rocks, breccias, and (rare) metamorphic rocks within an argillitic and flyschoid matrix. Intercalations of polimictic conglomerates and, sandstones, limolites and conglomerate flysch. Paleocene-lower Eocene. **am**: Amaro Fm. Calcareous breccias and sandstones with badly sorted assorted debrie of various sources. K-T boundary. **cr**: Carmita Fm: Carmita Fm: Alternate layers of limestones and sherts, with occasional fine intercalations of limolites, calcareous sandstones, marls, and argillites. Cenomanian-Turonian. **vz**: Veloz Fm. Micritic limestones (thin to medium beds), slightly argillaceous, with thin intercalated shales. Tithonian-Berriasian. **cnt**: Constancia Fm. Arcosic conglomerates and sandstones which grade into sandstones and shales. Tithonian-Berriasian. **Northern ohiolite belt:** σ (purple): Serpentinized ultramafic rocks and strongly foliated serpentinites. **es**: Blocks of "chloritic schists", amphibolites, eclogites. **zr**: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous. **ns**: Gabbros, banded gabbros, (leuco)gabbronorite, olivine gabbro, troctolite, quartz diorite, tonalite, plagiogranite-diorite. **Volcanic Arc: oc:** Ochoa Fm. Argillites, marls, limolitic marls, limolites, fine and coarse grained sandstones, conglomerates with small sized clasts, calcareous sandstones, detritic limestones and nodular limestones. upper Lower Eocene – lower Middle Eocene. **pv**: Provincial Fm. Limestones, marls, conglomerates, sandstones and rare tuffs. Upper Albian-Cenomanian. **cg**: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

Stop 1. Bahamian borderland. Carmita Fm.

Santa Clara-Camajaní road. Lomas de Santa Fe (N 22º 27' 41.5" - W 079º 46' 32.4").

Deep seated Cretaceous sediments of the Carmita Fm of the Placetas belt of the Bahamian borderland (deep oceanic basin). 40 min.

The Carmita Fm (upper Cenomanian) rests conformably on top of the Santa Teresa Fm (Albian-lower Cenomanian). Its upper limit is defined by an unconformity followed by the (mega)turbiditic Amaro Fm (upper Maastrichtian), indicating a large Campanian-lower Maastrichtian hiatus. The lithology is composed of limestones (mostly micritic) characteristically siliceous, thin siliceous (radiolaritic) beds, marls, argillites, and calcareous sandstones. The lithology indicates deep seated sedimentation.

Outcrop of the Carmita Fm., showing thin alternation of deep-seated silicic carbonate beds

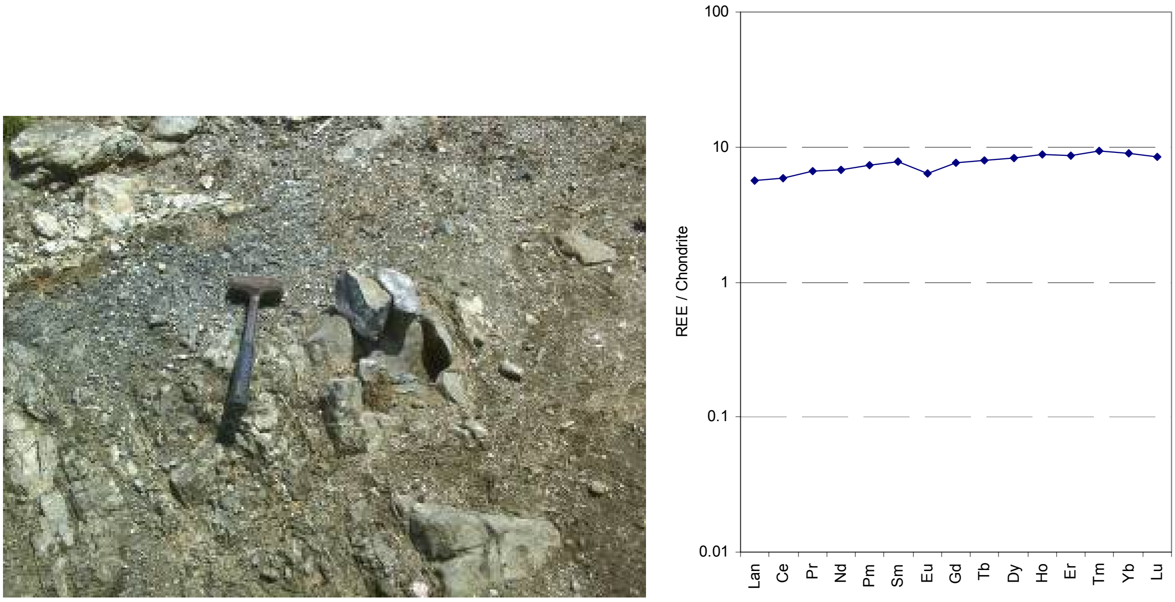
Stop 2. Ophiolitic mélange. Diabase and HP blocks.

Santa Clara-Camajaní road. Crucero Carmita (N 22º 27′ 15.7″ - W 079º 47′ 35.7″).

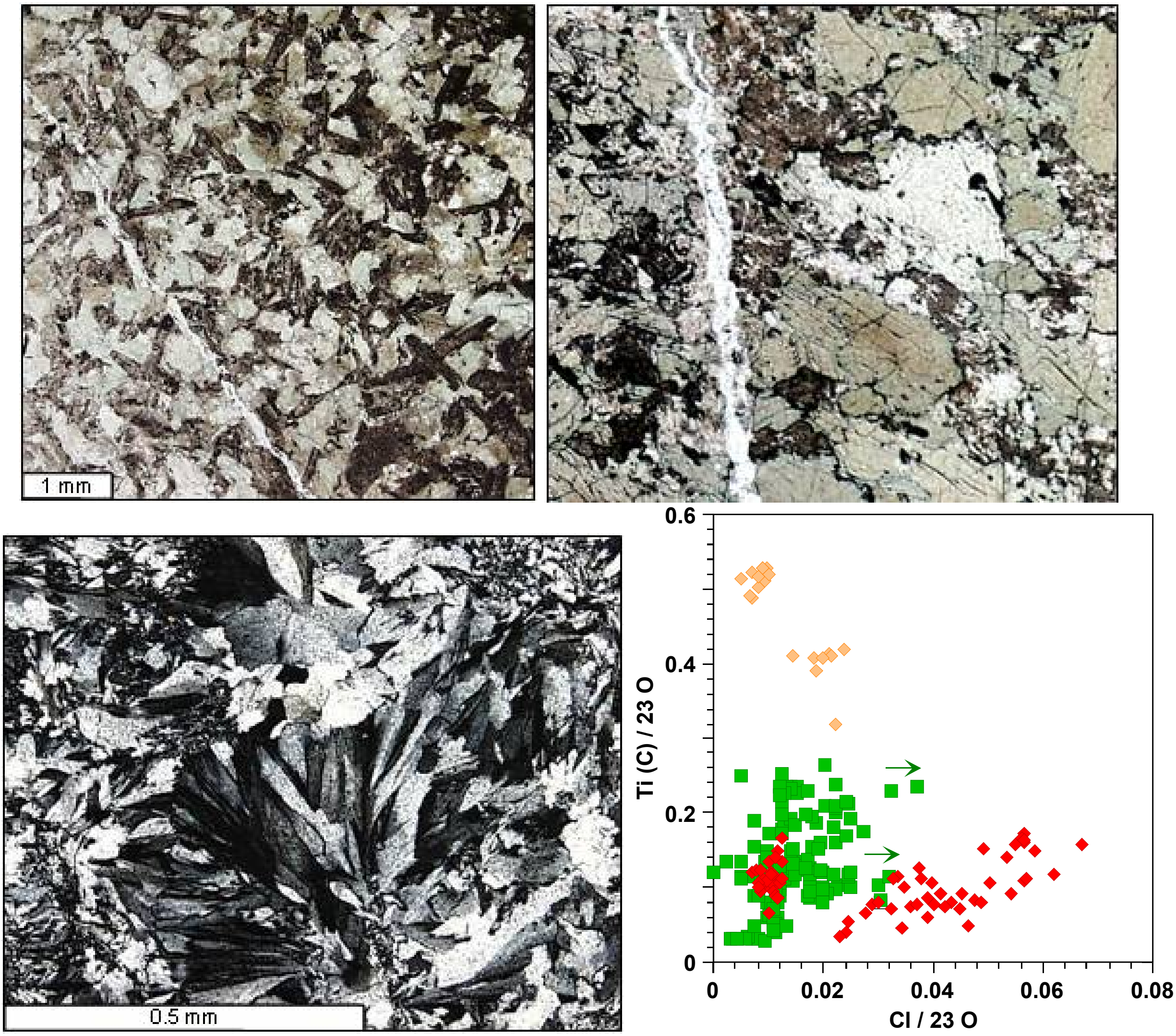
Ophiolitic mélange of central Cuba. Blocks low-pressure ophiolitic diabase and of eclogite and high-pressure mafic schists within serpentinite. 40 min.

Location. Image of Crucero Carmita. In front, serpentinitic harzburgites.

The blocks of diabase appear in a serpentinized peridotite matrix. They are small sized (20-30 cm in length) and are formed by plagioclase (laths) and augite relicts replaced by albite, epidote, hornblende (brown-green) and chorite indicating low-pressure metamorphism after emplacement. Prehnite and pumpellyite occur in late veins and voids. The chemistry of the diabase blocks indicate low-K tholeiitic character with MORB signature. The chemistry of the amphiboles indicate interaction with Cl-bearing fluids, suggesting oceanic metamorphism. Calculated metamorphic conditions are < 2 kbar.



Aspect of cm-sized blocks of low-pressure meta-diabase and REE / chondrite pattern.



Typical images of metadiabase with metamorphic amphibole+plagioclase and veins and voids or prehnite and amphibole composition. Evidence for ocean-floor type metamorphism in low-P amphibolitized diabase rocks.

The blocks of high-pressure rocks do not outcrop, but have been extracted, in addition to serpentinite, from the walls of a well located a few meters away from the location of diabase blocks, demonstrating the caotic nature of the serpentinite mélange. The extracted rocks are of well foliated (retrogressed) eclogite, garnet amphibolite and mafic schists with phengite. Garnet amphibolite is made of garnet, calcic to sodic-calcic amphibole and epidote. Late porphyroblasts of albite that bear inclusions all matrix minerals and foliation, and late stilpnomelane and chlorite replacements, document a late-stage overprint in the greenschist facies.

Aspect of cm-sized debris of high-pressure mafic schist extracted from a well in Crucero Carmita.

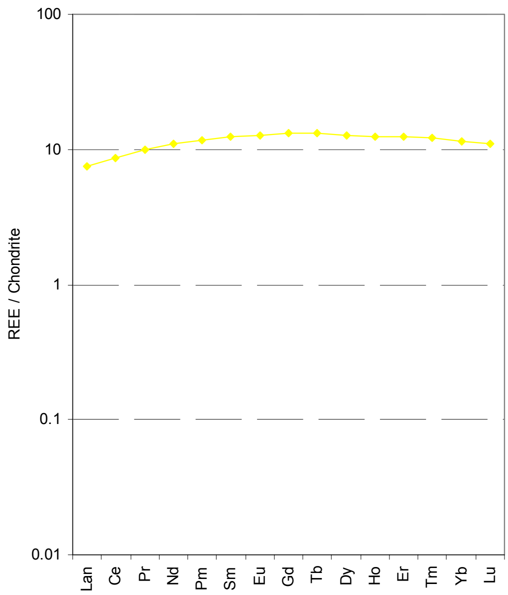
Stop 3. Ophiolitic mélange. Diabase and microgabbro blocks.

Santa Clara-Camajaní road. Sagua la Chica river (N 22º 27' 16.9" - W 079º 47' 44.2").

Large block (tens of m in size) of massive diabase, microgabbro (and basalt?) of the Zurrapandilla Fm. (Tithonian-Lower Cretaceous) within serpentinite. 40 min.

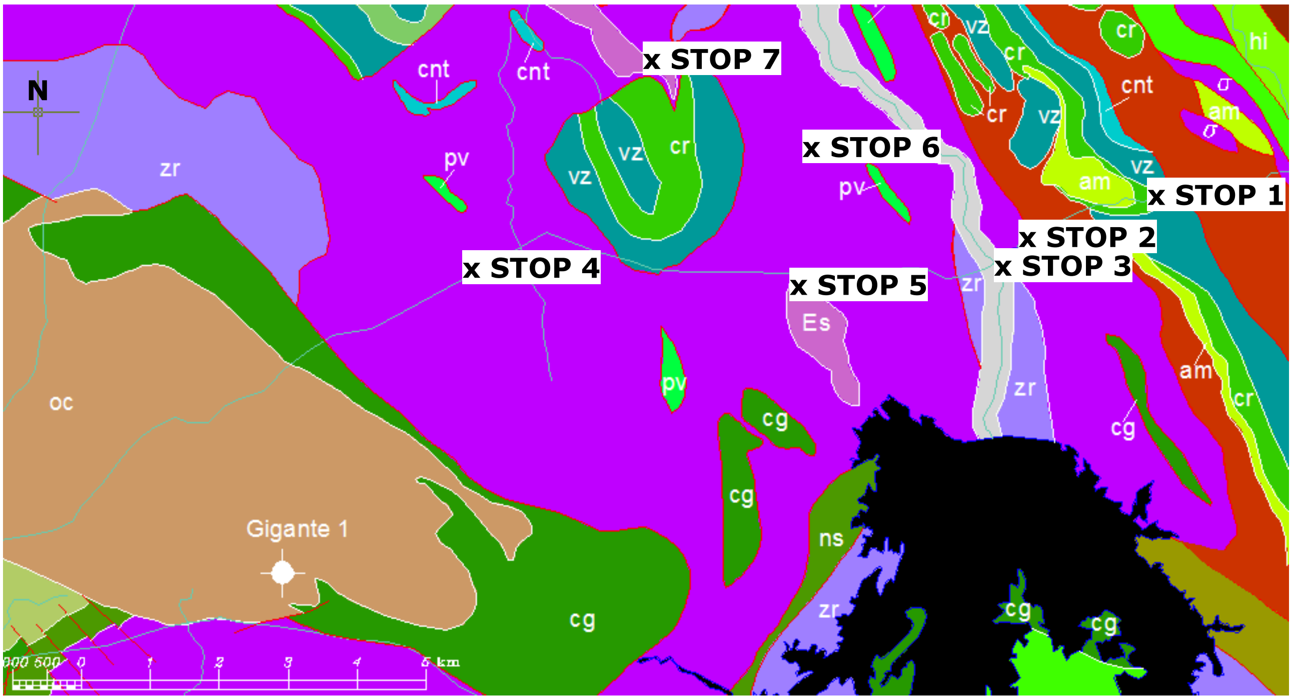
The occurrence of large blocks of massive diabase, microgabbro and diabase dikes is termed Zurranpandilla Fm. Their lithological and textural features are similar to diabase blocks occurring in Crucero Carmita and other localities. In general, a late stage of low-P metamorphism is indicated by amphibole (±chlorite, epidote, …) growth after the magmatic assemblage. The chemistry of the rocks indicates low-K tholeiitic MORB signature. However, in other locations, the chemistry suggest island arc tholeiitic signature (see stop 11).

Aspect of large blocks of diabase and microgabros in Sagua La Chicha river. Plagioclase-rich seggegations denote low-pressure metamorphic overprint.



REE / chondrite pattern of MOR microgabbro of the Zurrapandilla Fm., Sagua La Chica river.

March 22



Location of stops 4-6. Key: ***Bahamian borderlands****:* ***vga (in deep red)****: Vega Alta Fm. Olistostrome with poorly sorted blocks and fragments of limestones, silicites, serpentinites, volcanic rocks, breccias, and (rare) metamorphic rocks within an argillitic and flyschoid matrix. Intercalations of polimictic conglomerates and, sandstones, limolites and conglomerate flysch. Paleocene-lower Eocene.* ***am****: Amaro Fm. Calcareous breccias and sandstones with badly sorted assorted debrie of various sources. K-T boundary.* ***cr****: Carmita Fm: Carmita Fm: Alternate layers of limestones and cherts, with occasional fine intercalations of limolites, calcareous sandstones, marls, and argillites. Cenomanian-Turonian.* ***vz****: Veloz Fm. Micritic limestones (thin to medium beds), slightly argillaceous, with thin intercalated shales. Tithonian-Berriasian.* ***cnt****: Constancia Fm. Arcosic conglomerates and sandstones which grade into sandstones and shales. Tithonian-Berriasian.* ***Northern ohiolite belt:*** *σ (purple): Serpentinized ultramafic rocks and strongly foliated serpentinites.* ***es****: Blocks of "chloritic schists", amphibolites, eclogites.* ***zr****: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous.* ***ns****: Gabbros, banded gabbros, (leuco)gabbronorite, olivine gabbro, troctolite, quartz diorite, tonalite, plagiogranite-diorite.* ***Volcanic Arc: oc:*** *Ochoa Fm. Argillites, marls, limolitic marls, limolites, fine and coarse grained sandstones, conglomerates with small sized clasts, calcareous sandstones, detritic limestones and nodular limestones. upper Lower Eocene – lower Middle Eocene.* ***pv****: Provincial Fm. Limestones, marls, conglomerates, sandstones and rare tuffs. Upper Albian-Cenomanian.* ***cg****: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

Stop 4. Ophiolitic mélange. Serpentinite matrix.

Santa Clara-Camajaní road (N 22º 27′ 09.6″ - W 079º 52′ 22.2″).

Matrix of the ophiolitic mélange of central Cuba. Brecciated serpentinite. 30 min.

In this location it can be appreciated the typical aspect of brecciated serpentinite forming the matrix of the mélange. Relicts of harzburgitic olivine and pyroxenes are common, though near total replacement is common. Serpentinization is considered to have formed at low pressure as a result of hydration of the forearc mantle wedge prior and during to mélange formation in the Tertiary.

Aspect of brecciated serpentinite, Santa Clara-Camajaní road.

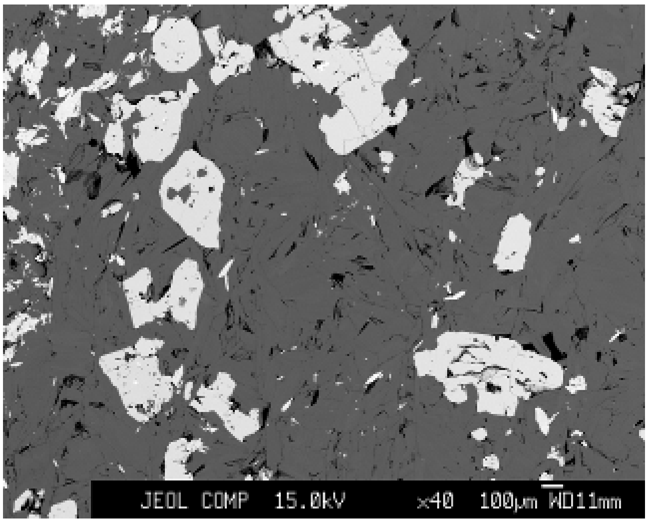
Stop 5. Ophiolitic mélange. HP blocks of amphibolitized eclogite.

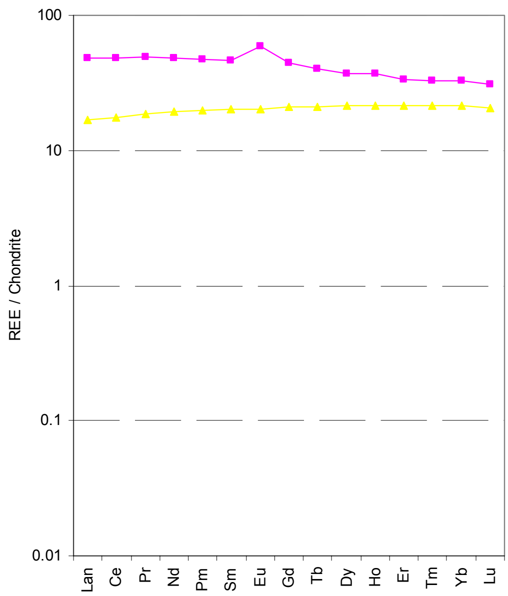
Santa Clara-Camajaní road. Sabanas Nuevas (N 22º 27′ 09.1″ - W 079º 49′ 33.5″).

Tectonic mélange of central Cuba. Blocks of eclogite, retrogressed eclogite ("amphibolite"), and (rinds of) mafic-ultramafic schists within serpentinite. 40 min.

Eclogite is made of garnet, omphacite, sodic-calcic amphibole, epidote and rutile, generally with phengite. Retrogressed areas of eclogite appear towards the external areas of the blocks, and are made of relictic garnet (with no or little omphacite) in a matrix of calcic/sodic-calcic amphibole, epidote, albite, chlorite and titanite. Some samples are very rich in sodic-calcic (Mg-katophorite) amphibole. The rims of the block, in contact with the enclosing serpentiniteare made of a chlorite±antigorite rocks with abundant apatite and titanite. Eclogites and (slightly) retrogressed eclogites are tholeiitic and of MOR basaltic composition. The ultramafic rinds of chlorite±antigorite are metasomatic rocks that show the influence of subduction-derived fluids in their chemical composition (e.g., they are rich in Ba, Rb,…).

Aspect of block of retrogressed (amphibolitized) eclogite and external zone (rind) of metasomatic ultramafic rock. Sabanas Nuevas, Santa Clara-Camajaní road.





BSE image of metasomatic rind (chlorite-apatite-titanite) and REE / chondrite patterns of MOR basaltic eclogite and metasomatic rind, Sabanas Nuevas.

Stop 6. Ophiolitic mélange. LP blocks of micrograbbro-diabase.

Santa Clara airport-Minerva road (N 22º 28′ 02.9″ - W 079º 49′ 28.5″).

Tectonic mélange of central Cuba. Blocks of ophiolitic microgabbro-diabase within serpentinite. 30 min.

The association of these rocks, when occurring as massive outcrops, is included in the Zurrapandilla Fm. In this outcrop it can be appreciated that the microgabbro-diabase a) intrudes the ultramafic rocks, and b) are in fact blocks within serpentinite. Hence, the key point to show is that these rocks (i.e., Zurrapandilla Fm.) cannot be considered as the "diabase" layer of typical ophiolites. They developed later than formation of oceanic lithosphere.

The rocks are essentially made of (altered) igneous plagioclase, brown-green amphibole of probable metamorphic origin and opaque minerals. Relicts of magmatic clinopyroxene replaced by amphibole are common. Plagioclase is replaced by epidote and albite. Chlorite, prehnite, and pumpellyite are late minerals, the latter typically located in voids and fractures. No foliation is apparent, in spite of the existence of foliation in the enclosing serpentinite. P-T paths are only retrograde (i.e., do not have prograde sections). Phase relations indicate low-P metamorphism in an oceanic context, but not necessarily an oceanic ridge.

Aspect of block of microgabbro-diabase of the Zurrapandilla Fm. metamorphosed under low-P conditions (amphibolitized) enclosed within serpentinite. Santa Clara airport-Minerva road.

Location of stops 7-9. Key: ***Bahamian bordernlands****:* ***cr****: Carmita Fm: Carmita Fm: Alternate layers of limestones and cherts, with occasional fine intercalations of limolites, calcareous sandstones, marls, and argillites. Cenomanian-Turonian.* ***st****: Santa Teresa Fm. Green-brown silicites and radiolarites, rare silicified lutites, limestones intercalations. Upper Albian-Cenomanian.* ***vz****: Veloz Fm. Micritic limestones (thin to medium beds), slightly argillaceous, with thin intercalated shales. Tithonian-Berriasian.* ***cnt****: Constancia Fm. Arcosic conglomerates and sandstones which grade into sandstones and shales. Tithonian-Berriasian.* ***Northern ohiolite belt:*** *σ: Serpentinized ultramafic rocks and strongly foliated serpentinites.* ***es****: Blocks of "chloritic schists", amphibolites, eclogites.* ***zr****: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous.* ***Volcanic Arc: cg****: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

Stop 7. Ophiolitic mélange. HP block of amphibolitized eclogite.

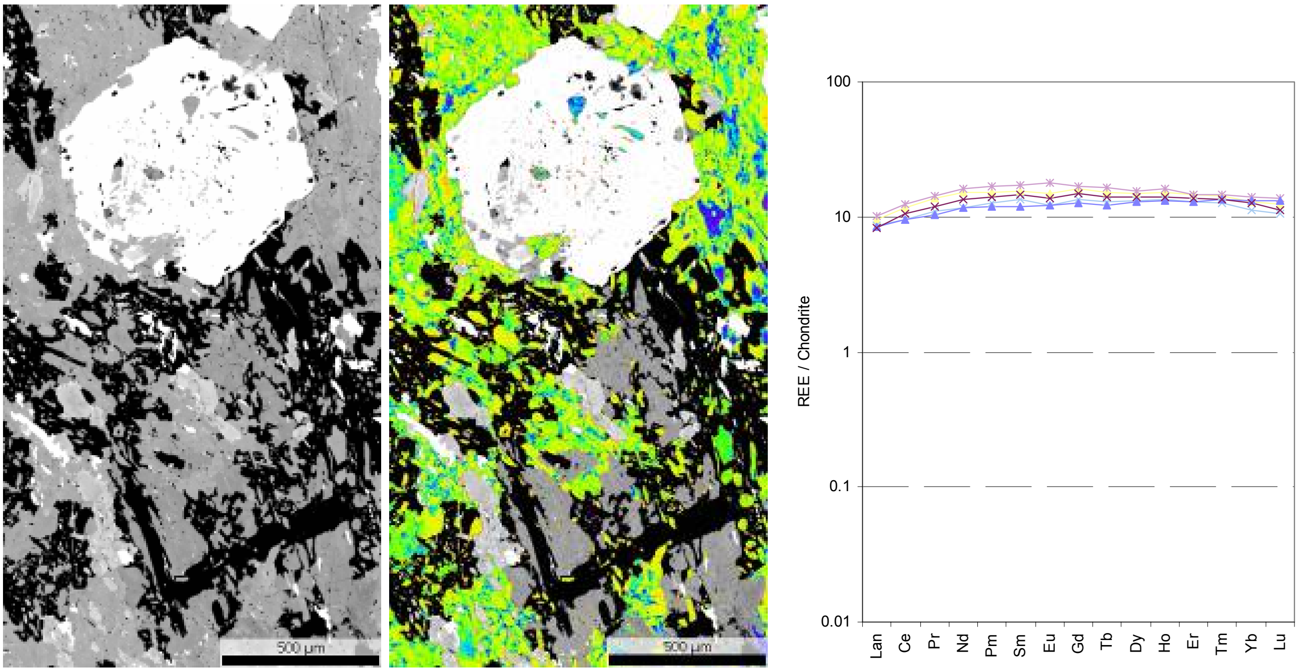
Santa Clara airport-Minerva road (N 22º 28′ 46.8″ - W 079º 50′ 46.1″).

Tectonic mélange of central Cuba. Blocks of veined retrogressed eclogite. 40 min.

The eclogitic mineral assemblage consists of garnet, scarce omphacite, barroisite, epidote paragonite, phengite and rutile overprinted by magnesiohornblende, albite, K-feldspar, epidote, chlorite and titanite. When garnet porhoyroblasts are well preserved, they develop a nice growth zoning. Omphacite is essentially located within garnet porphyroblasts. Late epidote is coarse grained and is concentrated in thin veins that crosscut earlier structures and indicate infiltration of fluids. The phase relations suggest decompression and cooling during fluid infiltration.

The chemical composition of the rocks indicates MOR basaltic composition. Fluid infiltration and associated amphibolitization and vein formation did not affect significantly the concentration of REE and most trace elements, except occasionally Ba.

Aspect of block of retrogressed eclogite with veins of epidote formed during to fluid infiltration and amphibolitization. Santa Clara airport-Minerva road.



BSE and XR Al-Kα images of retrogressed eclogite (omphacite is preserved within garnet porphyroblast) with abundant albite and amphibole and epidote forming the matrix, and REE / chondrite patterns of MOR basaltic retrogressed eclogites. The XR Al-Kα image shows the distribution of Al in amphibole on top of the BSE image.

Stop 8. Ophiolitic mélange. Bahamian borderland.

Santa Clara airport-Minerva road (N 22º 29′ 56.4″ - W 079º 52′ 45.7″).

Sediments of the Bahamian borderland. Relative autochtonous of the tectonic mélange of central Cuba. 20 min.

Though this outcrop nominally corresponds to the Santa Teresa Fm. depicted in the geological map of Cuba (1:100000), it really corresponds to the Veloz Fm. (Tithonian-Berriasian). This formation is made of a sequence of well stratified micritic limestones, locally slightly argillaceous. This formation documents platform sedimentation during the Jurassic-Early Cretaceous prior to deepening of the Placetas basin during the Upper Cretaceous.

Aspect of the Veloz Fm. of the Bahamian borderland. Santa Clara airport-Minerva road.

Stop 9. Ophiolitic mélange. Eclogite block.

Santa Clara-Encrucijada road. Las Delicias (N 22º 32′ 20.3″ - W 079º 54′ 19.3″).

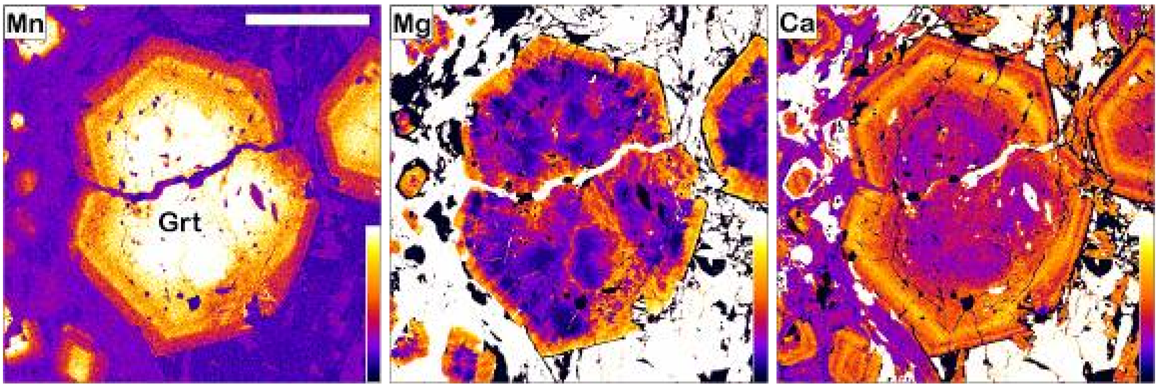
Tectonic mélange of central Cuba. Blocks of eclogite, retrogressed eclogite, and veined retrogressed eclogite. 50 min.

The eclogites are made of garnet, omphacite, sodic-calcic amphibole (barroisite), epidote, rutile and (locally abundant) phengite. The sodic-calcic amphibole retains prograde growth zoning, with cores of actinolite-magnesiohornblende. Garnet displays prograde and oscillatory zoning. The retrogressed areas contain relicts of the eclogitic assemblages (but typically little or no omphacite) overprinted by sodic-calcic and calcic amphibole, albite, epidote, chlorite, and titanite. P-T paths indicate prograde burial in a normal subduction zone and strong decompression with minor cooling during amphibolitization.

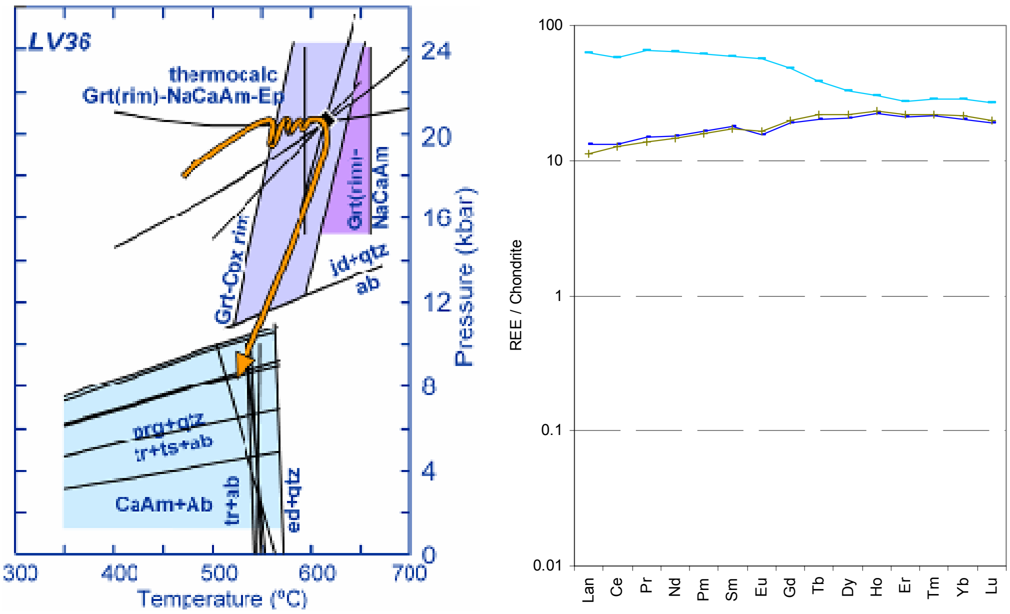
The composition of eclogite and retrogressed eclogite indicates MOR basaltic composition. Retrogression did not affect significantly the trace element composition of eclogite except in LILE (Ba and Rb) elements.

Age determinations in a sample of eclogite (Ar/Ar in amphibole: 103.4 ± 1.4 Ma; Ar/Ar in phengite: 115.0 ± 1.1 Ma, Rb/Sr Ms-Omp-WR: 118.2 ± 0.6 Ma) indicates Aptian subduction-related peak metamorphism and Albian exhumation and mélange formation.

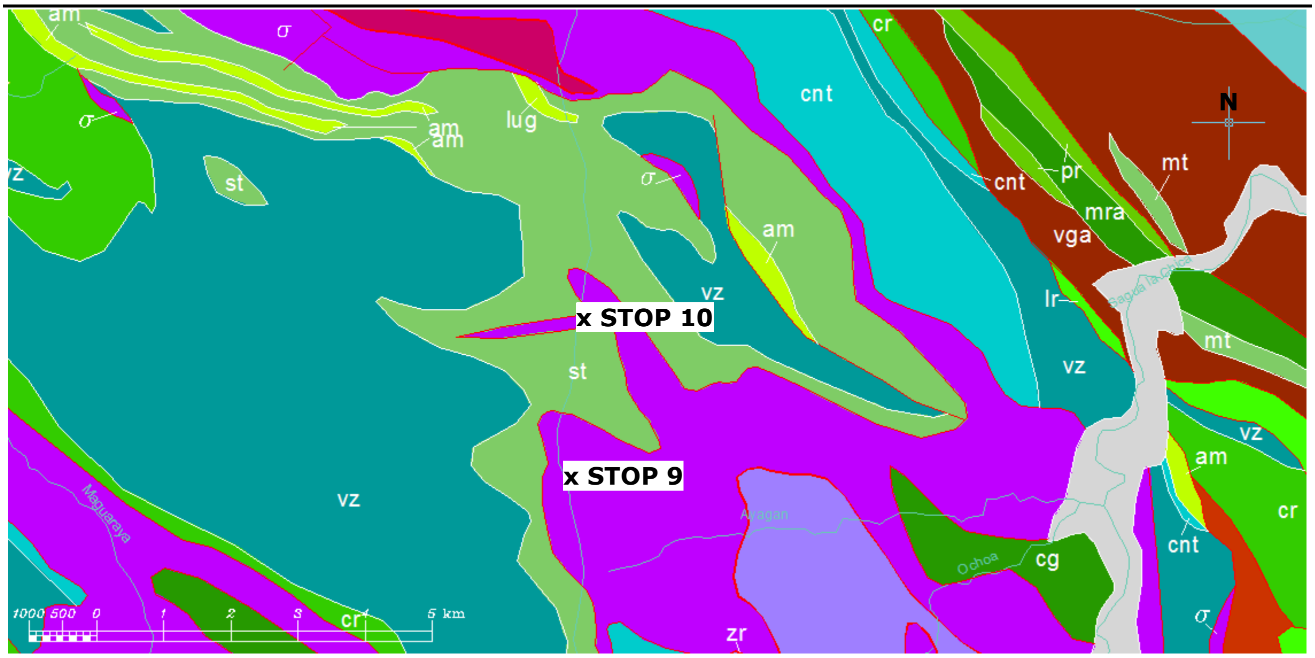
Aspect of block of eclogite, locally strongly amphibolitized and with patches of phengite. Las Delicias, Santa Clara-Encrucijada road.



XR images of Mn, Mg, and Ca (Kα) in sample of eclogite showing oscillatory zoning in garnet. Las Delicias, Santa Clara-Encrucijada road.



P-T path of eclogite and REE / chondrite patterns of eclogites, retrogressed eclogite, and Grt-rich retrogressed eclogitic material. Las Delicias, Santa Clara-Encrucijada road.



Location of stop 10. Key: ***Bahamian bordernlands****:* ***Bahamian borderlands****:* ***vga****: Vega Alta Fm. Olistostrome with poorly sorted blocks and fragments of limestones, silicites, serpentinites, volcanic rocks, breccias, and (rare) metamorphic rocks within an argillitic and flyschoid matrix. Intercalations of polimictic conglomerates and, sandstones, limolites and conglomerate flysch. Paleocene-lower Eocene.* ***am****: Amaro Fm. Calcareous breccias and sandstones with* *badly sorted assorted debrie of various sources. K-T boundary.* ***lug*** *:Lutgarda Fm. Limestones, silicites, argillites. Occasionally, the limestones are dolomitized. Upper Maastrichtian.* ***cr****: Carmita Fm: Alternate layers of limestones and cherts, with occasional fine intercalations of limolites, calcareous sandstones, marls, and argillites. Cenomanian-Turonian..* ***st****: Santa Teresa Fm. Green-brown silicites and radiolarites, rare silicified lutites, limestones intercalations. Upper Albian-Cenomanian.* ***pr****: Paraiso Fm. Limestones of varied color, microgranular, slightly argillaceous, massive or well stratified. They contain black chert. Hauterivian-Upper Barremian.* ***vz****: Veloz Fm. Micritic limestones (thin to medium beds), slightly argillaceous, with thin intercalated shales. Tithonian-Berriasian.* ***cnt****: Constancia Fm. Arcosic conglomerates and sandstones which grade into sandstones and shales. Tithonian-Berriasian.* ***Northern ohiolite belt:*** *σ : Serpentinized ultramafic rocks and strongly foliated serpentinites.* ***zr****: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous.* ***Volcanic Arc: cg****: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

Stop 10. Amphibolitized eclogite and radiolarites of the Santa Teresa Fm.

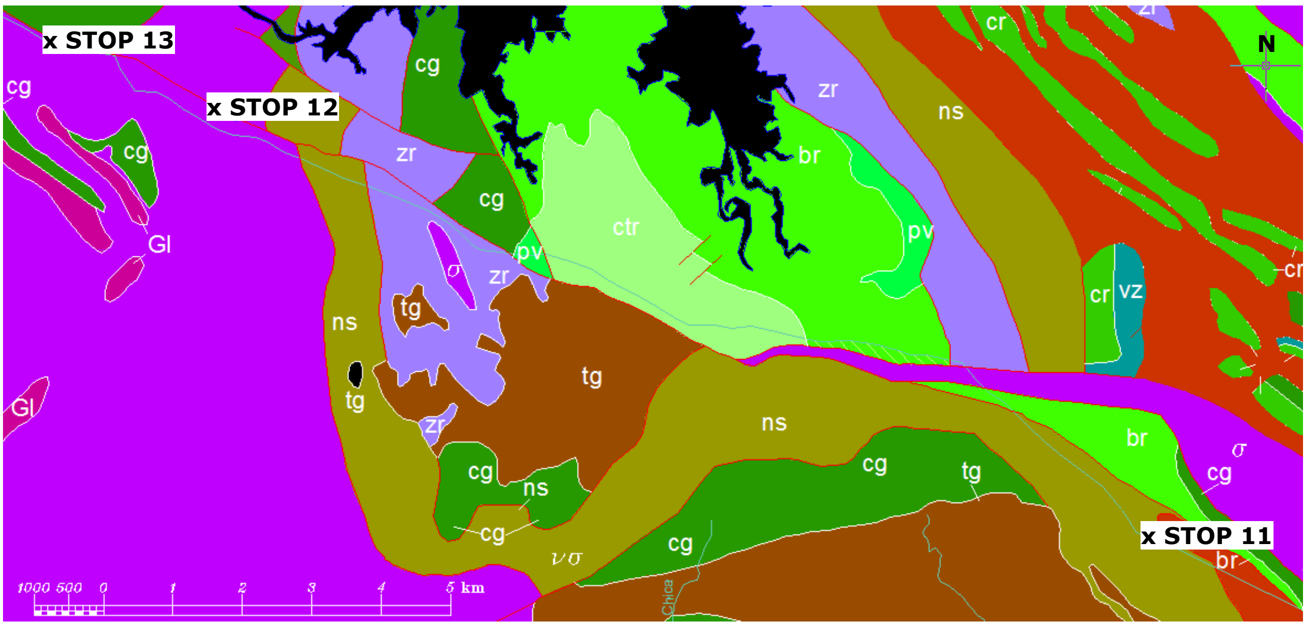
Santa Clara-Encrucijada road. Crucero San Francisco (N 22º 33' 9.76" - W 079º 54' 19.6").

Tectonic mélange of central Cuba. Blocks of retrogressed eclogite and actinolitite, and radiolarites of the Santa Teresa Fm. 50 min.

Brown silicites and radiolarites with lutite and limestone intercalations (Santa Teresa Fm. Upper Albian-Cenomanian). This formation attests for a strong deepening of the Placetas basin during the Upper Cretaceous.

Aspect of block of amphibolitized eclogite and sequence of radiolarites of the Santa Teresa Fm. Crucero San Francisco, Santa Clara-Encrucijada road.

March 23



Location of stops 11-13. Key: ***Bahamian bordernlands****:* ***vga (in deep red)****: Vega Alta Fm. Olistostrome with poorly sorted blocks and fragments of limestones, silicites, serpentinites, volcanic rocks, breccias, and (rare) metamorphic* *rocks within an argillitic and flyschoid matrix. Intercalations of polimictic conglomerates and, sandstones, limolites and conglomerate flysch. Paleocene-lower Eocene.* ***cr****: Carmita Fm: Carmita Fm: Alternate layers of limestones and cherts, with occasional fine intercalations of limolites, calcareous sandstones, marls, and argillites. Cenomanian-Turonian.* ***vz****: Veloz Fm. Micritic limestones (thin to medium beds), slightly argillaceous, with thin intercalated shales. Tithonian-Berriasian.* ***Northern ohiolite belt:*** *σ: Serpentinized ultramafic rocks and strongly foliated serpentinites.* ***Gl****: Blocks of glaucophane schists.* ***zr****: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous.* ***ns****: Gabbros, banded gabbros, (leuco)gabbronorite, olivine gabbro, troctolite, quartz diorite, tonalite, plagiogranite-diorite.* ***Paleogene basin: tg****: Taguasco Fm. Olistostrome with matrix of polymictic conglomerates and breccias. Upper Paleocene-lower Lower Eocene.* ***Volcanic Arc: ctr****: Cotorro Fm. Tuffs, sandstones, detritic limestones, micritic limestones, reef limestones, marls. Upper Campanian-Lower Maastrichtian.* ***br****: La Bruja Fm. Pyroxenic andesites, perlitic andesites, dacites, rhyodacites, tuffs, (zeolitic) vitroclastic tuffs, sandstones, limolites, marls. Coniacian-Santonian.* ***pv****: Provincial Fm. Limestones, marls, conglomerates, sandstones and rare tuffs. Upper Albian-Cenomanian.* ***cg****: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

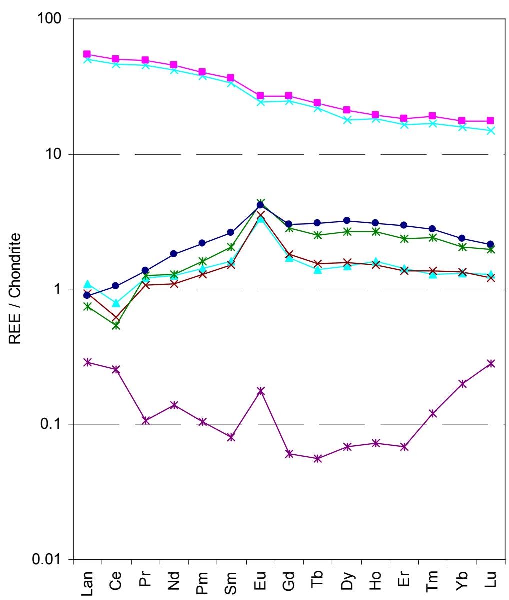
Stop 11. Ophiolite mélange. Banded gabbros.

Santa Clara-Placetas road. Sitio Potrero, outcrop in the railway close to the road (N 22º 19' 44.2" - W 079º 42' 53.1").

Tectonic mélange of central Cuba. Ophiolitic banded gabbros and related rocks. 60 min.

The banded gabbros are made of a variety of rocks including gabbronorite, olivine gabbro, troctolite, quartz diorite, tonalite, plagiogranite-diorite. In this outcrop, a common lithology is (leuco)gabbronorite made of coarse grained un zoned plagioclase and clinopyroxene with typical cumulate texture. The rocks are amphibolitized, with tremolitic amphibole, chlorite, serpentine, magnetite, prehnite, pumpellyite, and calcite as typical alteration products. Some rocks are ultramafic, but appear strongly overprinted by serpentine, calcite, and opaque minerals. Diabase – microgabbro dykes and bodies crosscut the banded structure. In these rocks magmatic plagioclase and clinopyroxene are overprinted by brown-green hornblende (brown hornblende probably late magmatic), chlorite, prehnite, pumpellyite, clinozoisite, opaque minerals, and calcite.

Aspect of banded gabbros and associated altered ultramafic rock. Sitio Potrero, Santa Clara-Placetas road.



The chondrite-normalized REE patterns of the gabbro-gabbronorites are characterized by LREE-depleted and relatively flat HREE segments, and positive Eu anomalies. These patterns indicate that these rocks are cumulates from variably fractionated N-MORB melts. The intrusive diabase-micrograbbro rocks significantly differ from those of layered cumulate rocks. They display REE patterns characterized by LREE-enriched and HREE-depleted segments, typical of arc lavas. A slight negative Eu anomaly as a result of plagioclase fractionation is present, representative of the evolved lavas with the high REE contents. The REE patterns are similar to those of the Caribbean Early Cretaceous IAT and CA series.

REE/chondrite patterns of banded gabbros, associated altered ultramafic rock, and intrusive diabase-microgabbros. Sitio Potrero

Stop 12. Ophiolite mélange. Serpentinite matrix.

Santa Clara-Placetas road (N 22º 23′ 06.7″ - W 079º 50′ 41.7″).

Brecciated serpentinite. Typical matrix of the tectonic mélange of central Cuba. 15 min.

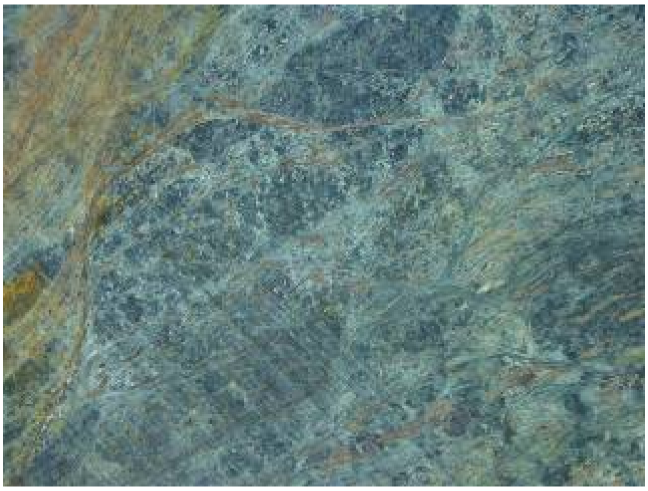
Aspect of brecciated serpentinite, Santa Clara-Camajaní road.

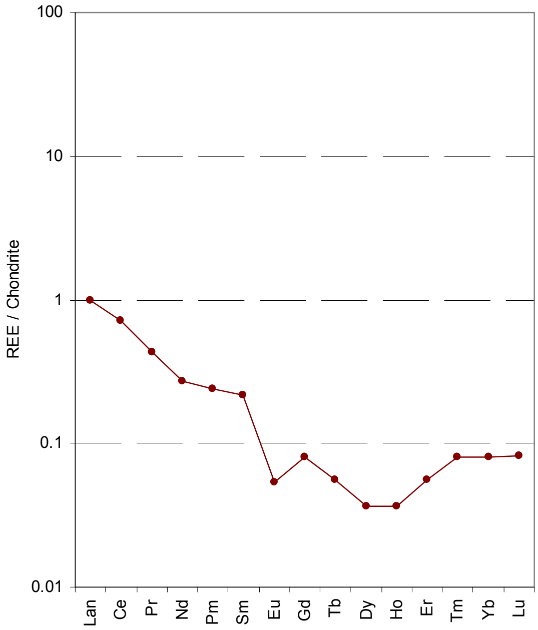
Stop 13. Ophiolite mélange. Megablock of HP antigoritite.

Santa Clara-Placetas road. Pelo Malo quarry (N 22º 23′ 42.5″ - W 079º 52′ 02.8″).

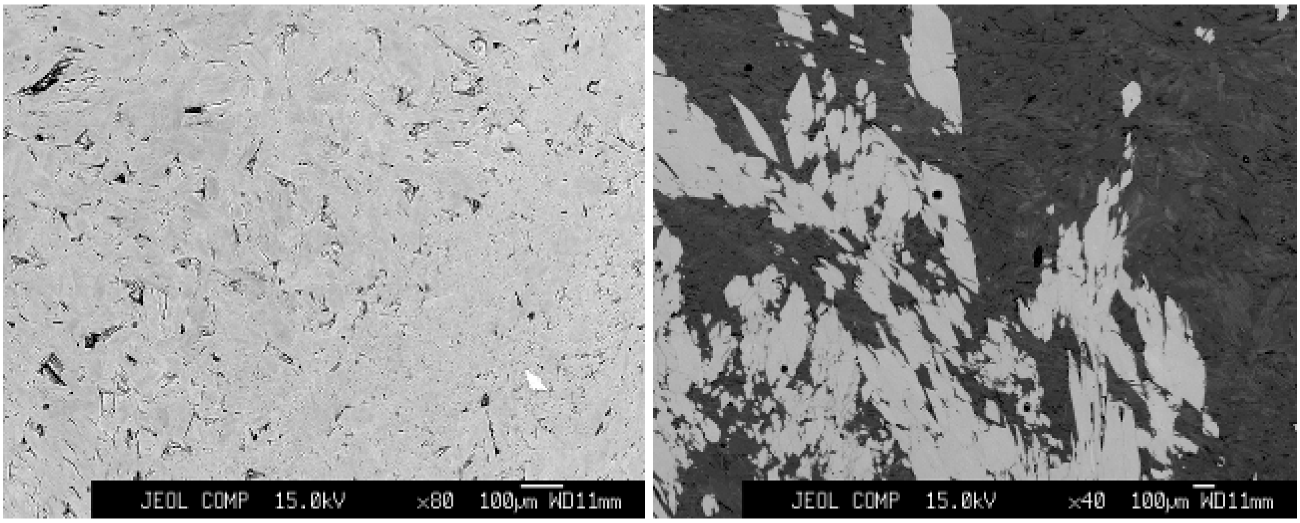
Tectonic mélange of central Cuba. Megablock of antigoritite. 40 min.

This interesting outcrop is made of massive antigoritite formed by fine grained antigorite. "Ghosts" of protolithic peridotite minerals are common. The rock represents subducted serpentinites of the oceanic lithosphere that were transformed into antigoritite during subduction. Fluid-rock interaction is denoted by abundant veins made of coarse grained tremolite. The wall rocks of the veins are formed by fine-grained tremolite, chlorite, and antigorite.

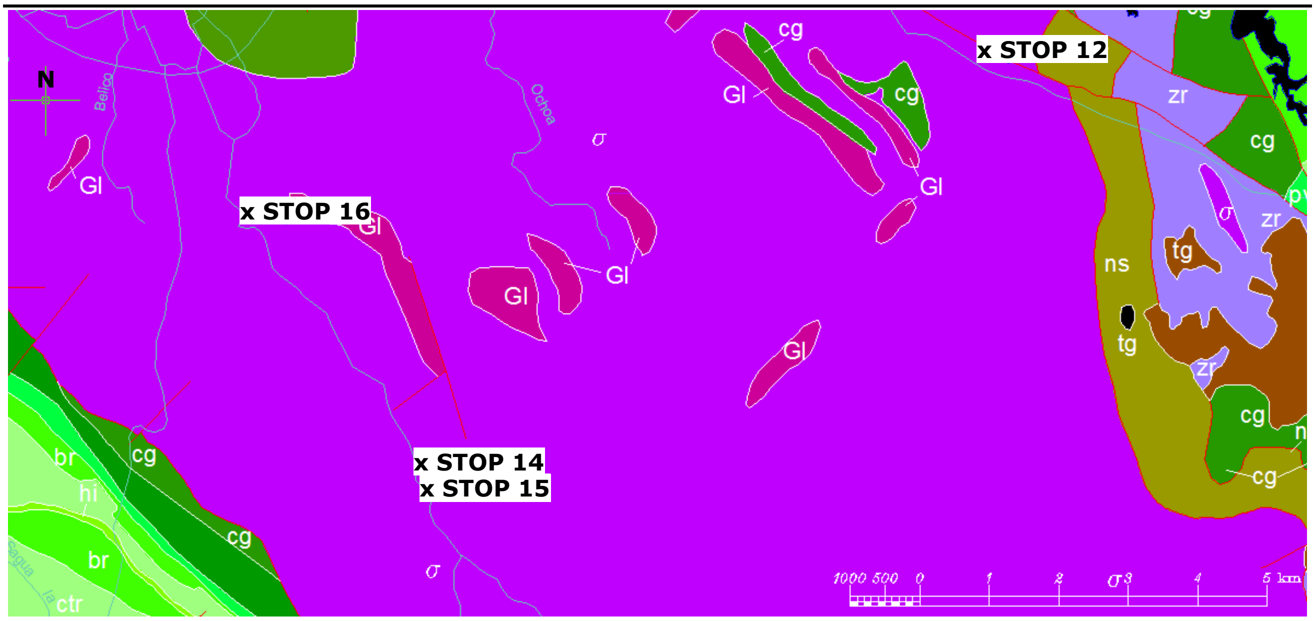




Aspect of block of antigoritite, with veins of tremolite-chlorite and REE / chondrite pattern of massive antigoritite.



BSE images of massive antigoritite and asbestoid (tremolite-chlorite-antigorite) region adjacent to tremolite vein.



Location of stops 14-16. Key: ***Northern ohiolite belt:*** *σ: Serpentinized ultramafic rocks and strongly foliated serpentinites.* ***Gl****: Blocks of glaucophane schists.* ***zr****: Zurrapandilla Fm. Diabase and basalts, rare limolites and limestones. Tithonian-Lower Cretaceous.* ***ns****: Gabbros, banded gabbros, (leuco)gabbronorite, olivine gabbro, troctolite, quartz diorite, tonalite, plagiogranite-diorite.* ***Paleogene basin: tg****: Taguasco Fm. Olistostrome with matrix of polymictic conglomerates and breccias. Upper Paleocene-lower Lower Eocene.* ***Volcanic Arc: ctr****: Cotorro Fm. Tuffs, sandstones, detritic limestones, micritic limestones, reef limestones, marls. Upper Campanian-Lower Maastrichtian.* ***hi****: Hilario Fm. Tuffs, subordinate marls, limestones, sandstones. Coniacian-Maastrichtian.* ***br****: La Bruja Fm. Pyroxenic andesites, perlitic andesites, dacites, rhyodacites, tuffs, (zeolitic) vitroclastic tuffs, sandstones, limolites, marls. Coniacian-Santonian.* ***pv****: Provincial Fm. Limestones, marls, conglomerates, sandstones and rare tuffs. Upper Albian-Cenomanian.* ***cg****: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous.*

Stop 14. Ophiolite mélange. Blocks of (trench?) metasediments.

Santa Clara-Baez road. Small quarry (N 22º 19' 55.5" - W 079º 55' 25.8").

Tectonic mélange of central Cuba. Blocks metaterrigenous material within serpentinite. 30 min.

The metaterrigenous material is not in-situ, but it represents the typical metasedimentary blocks within serpentinite of the region. The rocks are strongly foliated and folded quartzites and phyllites. However, fine lamination of probable sedimentary origin is still preserved, suggesting deep-seated "ritmites". Mineral assemblages are characterized by quartz, phengite, glaucophane and stilpnomelane, the latter grown in a late post-peak pressure stage.

We interpret these rocks as metamorphosed fragments of the fore-arc accretionary prism in the subduction environment.

Aspect of block of debris of HP metaterrigenous material within serpentinite and BSE image of glaucophane-bearing quartzitic rock within serpentinite. Small quarry in Santa Clara-Baez road.

Stop 15. Ophiolite mélange. Blocks of (trench?) metasediments.

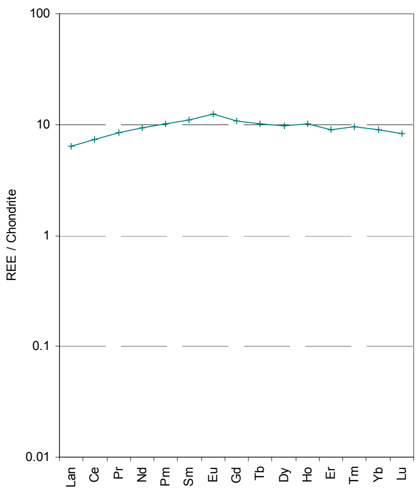
Santa Clara-Baez road (N 22º 19′ 48.0″ - W 079º 55′ 23.6″).

Tectonic mélange of central Cuba. Blocks of deep-seated metaterrigenous material within serpentinite. 30 min.

Aspect of block of HP metaterrigenous material within serpentinite. Santa Clara-Baez road.

Stop 16. Ophiolite mélange. Blocks of metabasalt.

Santa Clara-Baez road. Boquerones (N 22º 21′ 53.9″ - W 079º 56′ 45.9″).

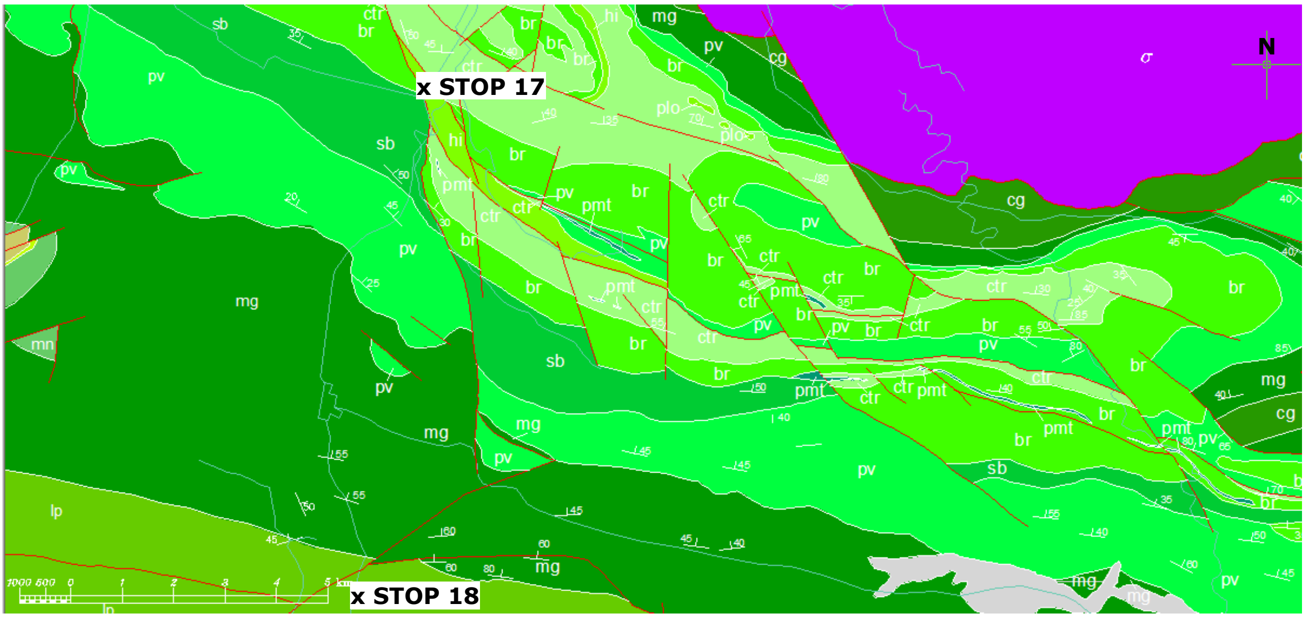


Tectonic mélange of central Cuba. Blocks of metabasalt within serpentinite. 30 min.

Aspect and REE / chondrite pattern of blocks of MOR metabasalt. Boquerones, Santa Clara-Baez road.

Slightly deformed and irregularly recrystallized blocks of MOR basaltic composition made of amphibole, chlorite, epidote, albite, and opaque minerals in a fine-grained matrix of albite-clinozoisite.

March 24



*Location of stop 17. Key: **Northern ohiolite belt:** σ (purple): Serpentinized ultramafic rocks and strongly foliated serpentinites. **Volcanic Arc: ctr**: Cotorro Fm. Tuffs, sandstones, detritic limestones, micritic limestones, reef limestones, marls. Upper Campanian-Lower Maastrichtian. **hi**: Hilario Fm. Tuffs, subordinate marls, limestones, sandstones. Coniacian-Maastrichtian. **br**: La Bruja Fm. Pyroxenic andesites, perlitic andesites, dacites, rhyodacites, tuffs, (zeolitic) vitroclastic tuffs, sandstones, limolites, marls. Coniacian-Santonian. **pv**: Provincial Fm. Limestones, marls, conglomerates, sandstones and rare tuffs. Upper Albian-Cenomanian. **cg**: Cabaiguán Fm. Crystalline and vitreous tuffs of intermediate to acid composition, sandstones, limolites, andesites and dacites. Upper Cretaceous. **mg**: Fm. Matagua: Basalts, basaltic andesites, andesites, basic and intermediate tuffs, limestones, sandstones, limolites. Aptian-Albian. **lp**: Los Pasos Fm. Rhyolites, dacites, plagiorhyolites, acid tuffs, basalts, aphyric basalts, basaltic andesites, basaltic tuffs, and subordinate andesites, andesitic tuffs, sandstones, and limolites. Berriasian-Barremian.*

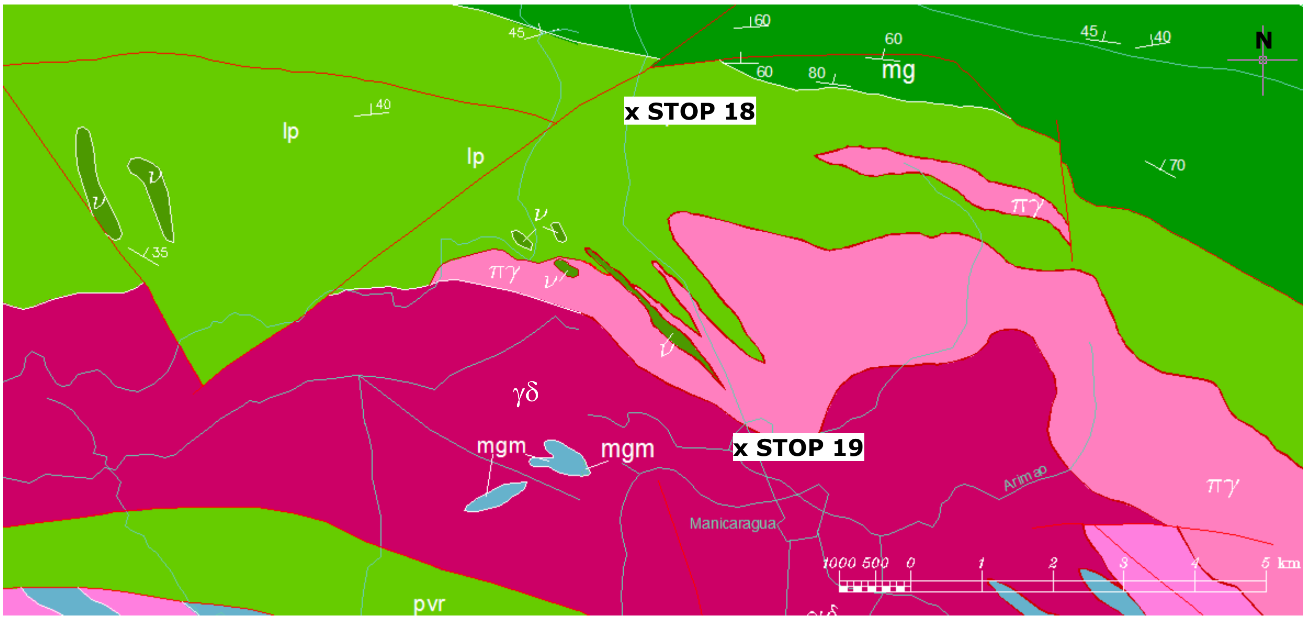
Stop 17. Cretaceous volcanic arc. Upper Cretaceous successions.

Santa Clara-Manicaragua road. Upper Cretaceous volcanic arc.

La Bruja Formation. 40 min.

Pyroxenic andesites, perlitic andesites, dacites, rhyodacites, tuffs, (zeolitic) vitroclastic tuffs, sandstones, limolites, marls (Coniacian-Santonian).

Aspect of La Bruja Fm. Santa Clara-Manicaragua road.

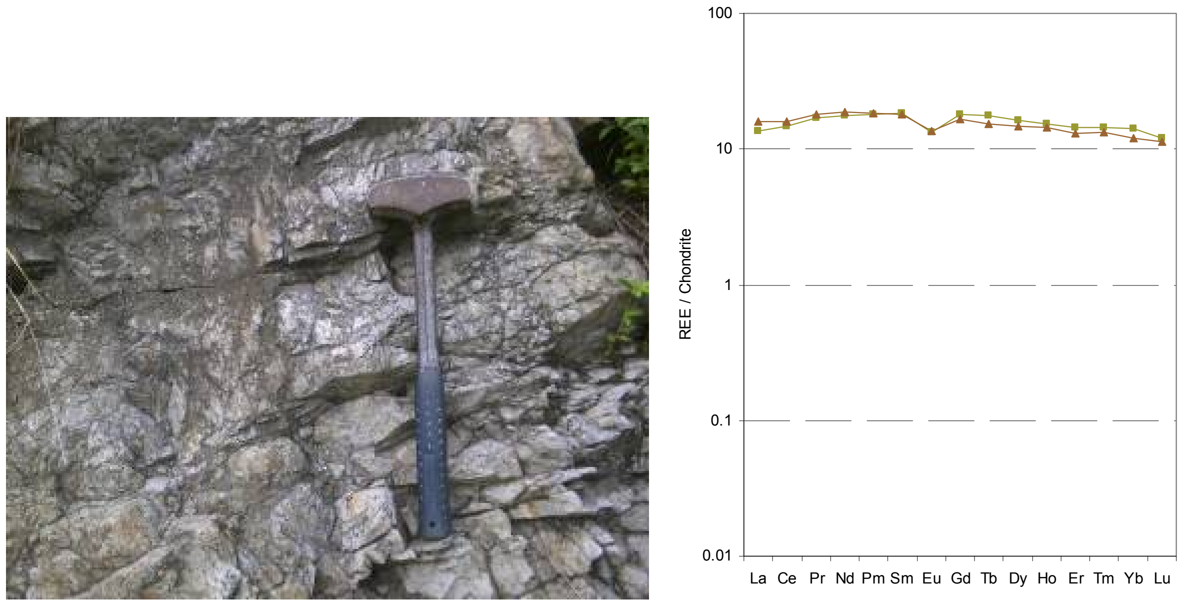


Location of stops 18-19. Key: ***Volcanic Arc: mg****: Fm. Matagua: Basalts, basaltic andesites, andesites, basic and intermediate tuffs, limestones, sandstones, limolites. Aptian-Albian.* ***lp****: Los Pasos Fm. Rhyolites, dacites, plagiorhyolites, acid tuffs, basalts, aphyric basalts, basaltic andesites, basaltic tuffs, and subordinate andesites, andesitic tuffs, sandstones, and limolites. Berriasian-Barremian.* ***Intrusive rocks:*** *ν: gabbros. πγ: plagiogranites. γδ: Granodiorites, tonalites, quartz-diorites and rare diorites.* ***Mabujina Complex****:* ***pvr****: Porvenir Fm, upper unit. Bimodal acid-basic volcanic sequence metamorphosed in the greenschist facies. Berriasian-Barremian.* ***mgm:*** *banded metagabbros.*

Stop 18. Cretaceous volcanic arc. Neocomian successions

Santa Clara-Manicaragua road. West of Loma Sambumbia (N 22º 12' 06.4" - W 079º 59' 37.2").

Los Pasos Formation. Pre-mid Albian (probably Berriasian-Barremian) primitive volcanic arc. 30 min. The outcrop is made of plagio-rhyolites.



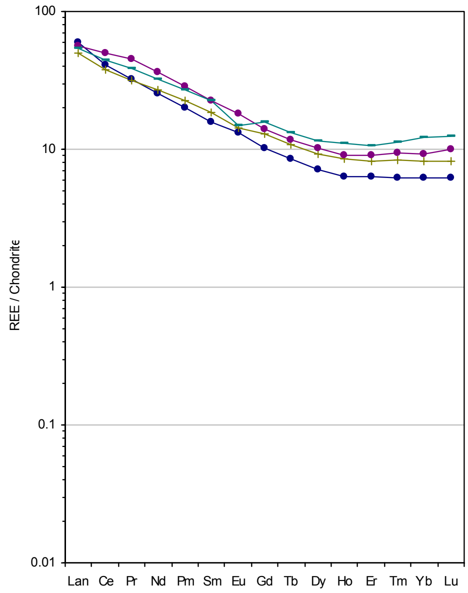
Aspect and REE / chondrite pattern of plagio-rhyolites of Los Pasos Fm. West of Loma Sambumbia, Santa Clara-Manicaragua road.

Stop 19. Cretaceous volcanic arc. Manicaragua batholith.

Below bridge in Manicaragua (N 22º 09' 32.3" - W 079º 58' 44.4").

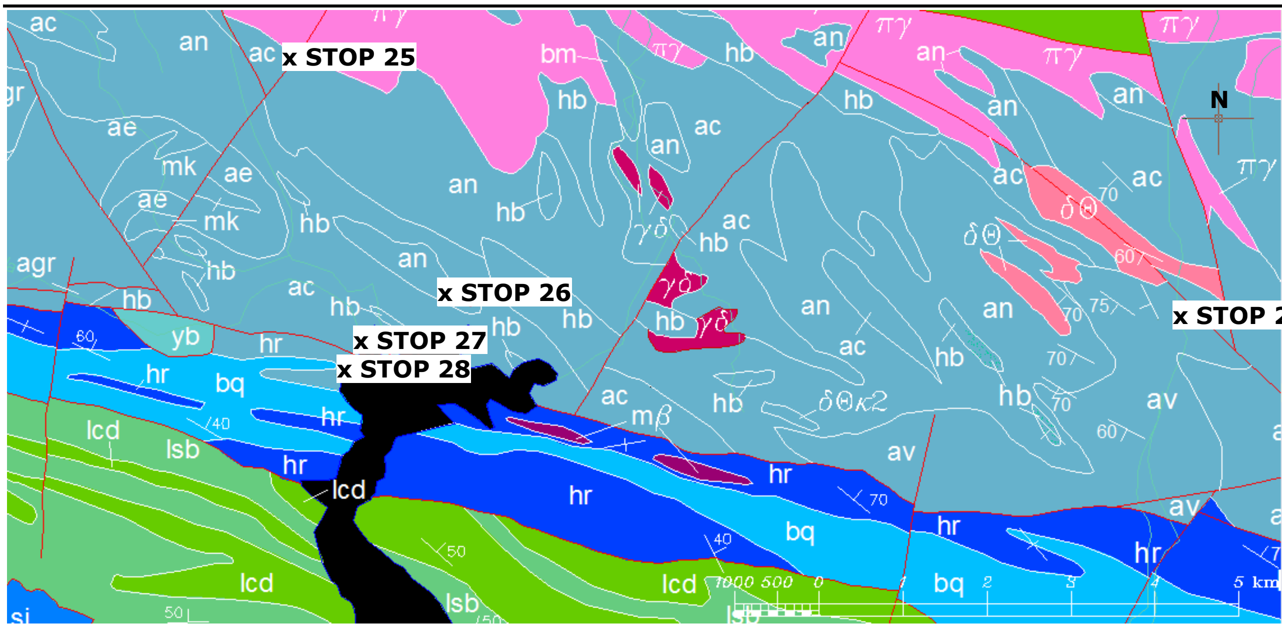
Granodiorites of the Upper Cretaceous Manicaragua batholith. 40 min.

The granodiorites are made of quartz, plagioclase with oscillatory zoning, K-feldspar, hornblende, biotite, and magnetite, with apatite and zircon as main accessory minerals. The feldspars are typically altered, and biotite is commonly replaced by chorite. The enclaves have tonalitic-quartzdioritic-dioritic composition and are made of the same minerals as the granodiorites, though with more abundant plagioclase and hornblende. They are fine grained and commonly show porphyritic texture. The rounded shape of the enclaves, their local accumulation in regions with little interstitial granodiorite, and structures suggest magma mingling, though the porphyritic varieties may also represent earlier intrusions or wall rocks included in the granodioritic magma. The trace element composition of the granodiorite and enclaves is similar, suggesting a common origin, and the REE patters are typical of cordilleran calc-alkaline magmas.



Aspect and REE / chondrite patterns of Manicaragua granodiorite with enclaves. Manicaragua city, below bridge.

SHRIMP dating of zircons (Y. Rojas-Agramonte, unpublished data) indicate minimum age of intrusion of the Manicaragua batholith of 88 Ma (Coniacian).



Location of stop 20. Key: ***Intrusive rocks:*** *πγ: plagiogranites. γδ: Granodiorites, tonalites, quartz-diorites and rare diorites. δ(Θ): Diorites, quartz-diorites, tonalites and plagiogranites.* ***Mabujina Complex****:* ***ac****: Banded Bt-amphibolites.* ***ae****: Schistose, Bt-bearing, fine grained amphibolites.* ***agr****: Coarse grained amphibolites (after banded gabbros).* ***an****: Amphibolites, locally banded.* ***av****: Banded ("well stratified") Bt-amphibolites.* ***bm****: Magmatic breccia formed by blocks of* *metagabbros.* ***Hb****: ("metapiroxenitic") Horblendites.* ***mgm:*** *banded metagabbros.* ***mk****: Fine grained, hornblende gneiss.* ***Escambray Complex. lcd****: Los Cedros Lithothem. Foliated marbles, well stratified and fine banding, grey color, fine-medium grained, with white mica, locally dark-grey or black. Lower Cretaceous.* ***lsb****: La Sabina Fm. Metaquartzites with intercalations of schists, local metasandstones rich in plagioclase, and marbles. Lower Cretaceous.* ***bq****: Boquerones Lithothem. Schistose marbles and calcitic schists rich in graphite and white mica, with fragments of metadolomitic limestones. Upper Jurassic.* ***hr****: Herradura Lithothem. Graphite-bearing quartz-schists and phyllites. Upper Jurassic.* ***sj****: San Juan Group: Well stratified generally graphitic black-grey marbles. Upper Jurassic.* ***yb****: Yayabo Lithothem. Garnet amphibolites with occasional muscovite, and rare intercalations of metasilicites.* ***mβ****: Metabasalts, occasional metagabbros and metadiabases.*

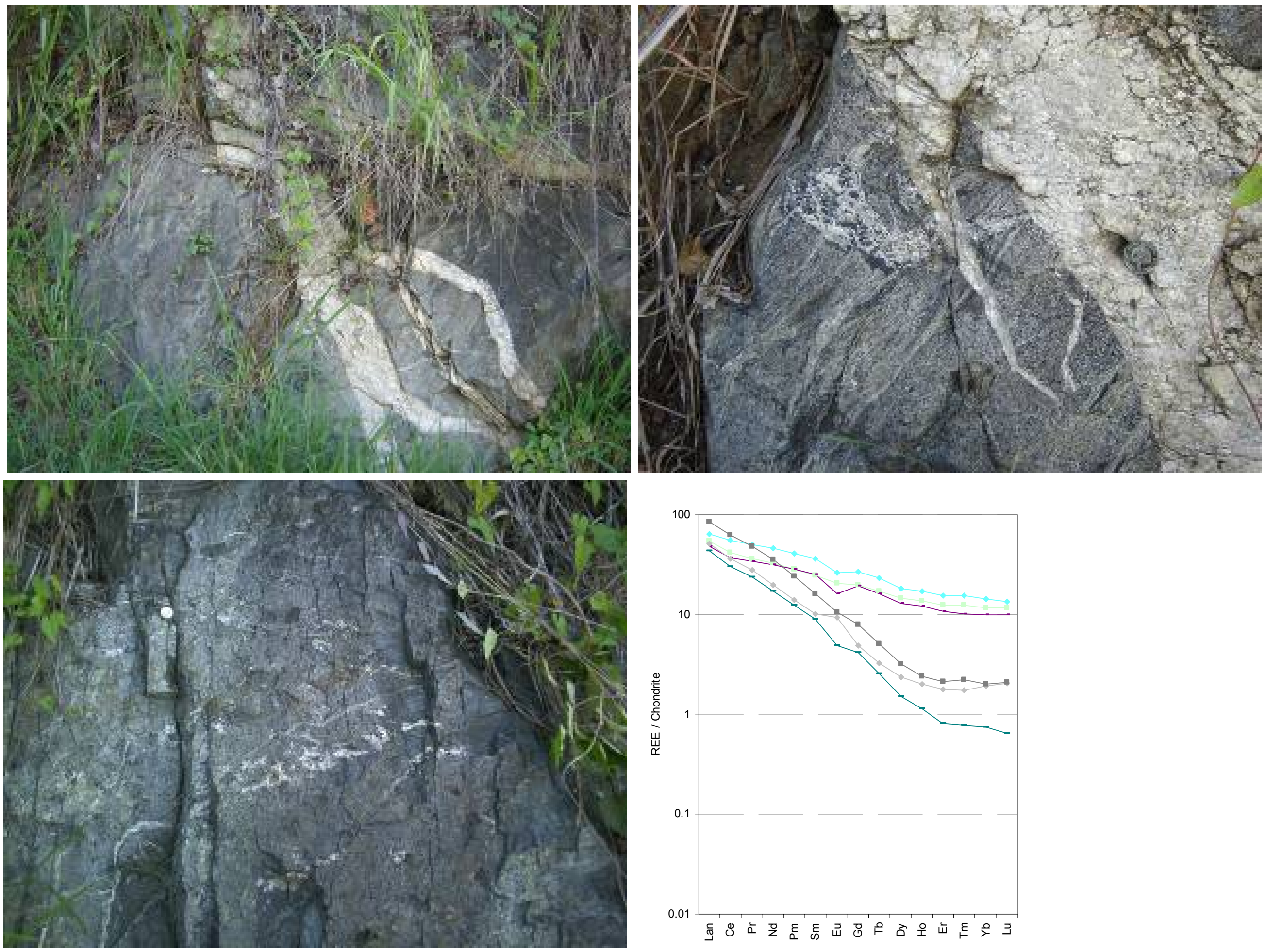
Stop 20. Mabujina Complex.

Manicaragua-Jibacoa road. Loma Sijú (N 22º 05' 35.8" - W 079º 58' 40.8").

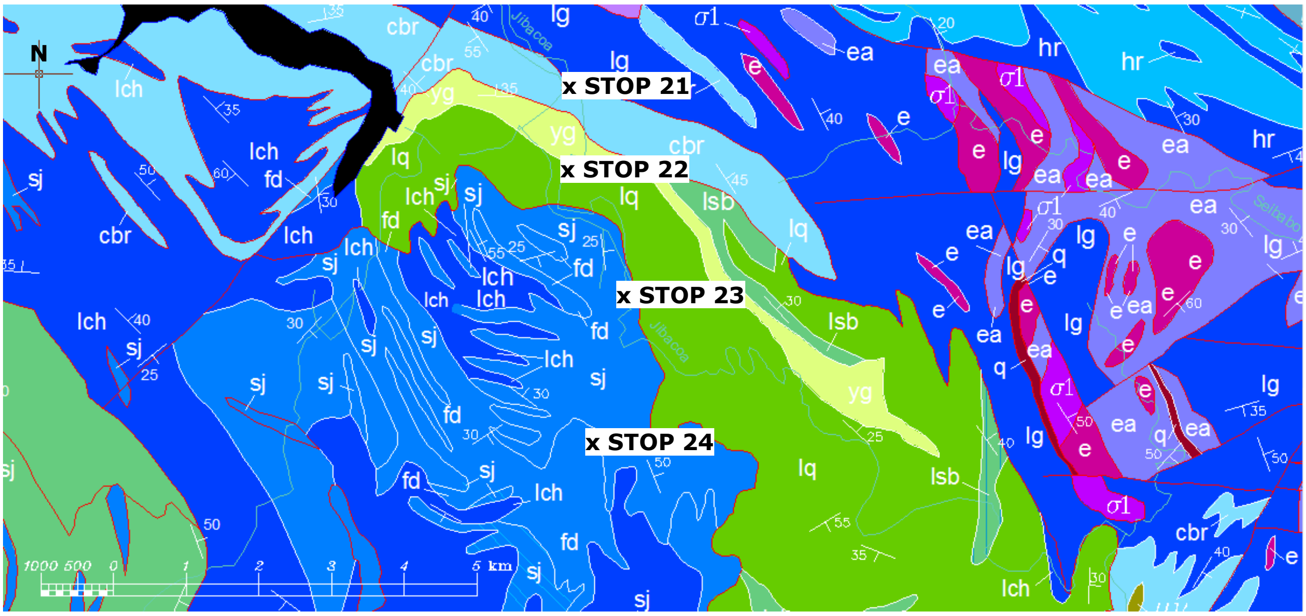
Low-intermediate P amphibolite and granitic rocks of the Mabujina complex. 40 min.

The outcrop is made of amphibolites and veins and concordant layers of granitic composition. The amphibolies are made of hornblende (edenite-hastingsite), intermediate plagioclase ± epidote and (minor) diopsidic clinopyroxene. Concordant layers of leucocratic gneisses are mylonitic and have garnet (rich in spessartine) and minor biotite. The amphibolites are intruded by leucocratic granitic veins that crosscut the main foliation, suggesting intrusion of arc-related granitic melts. However, the amphibolites locally show small-scale leucocratic segregations that crosscut the foliation and concordant layers of tonalitic-trondhjemitic composition. These structures suggest partial of the amphibolites. Typically, "hornblendite" (made of coarse grained hornblende) develops adjacent to the leucocratic segregations. Rather than restitic material left after partial melting, we interpret these rocks as the result of interaction between amphibolite and fluids released by the hydrous crystallizing melts.

The chemical composition of amphibolites indicate island-arc tholeiitic signature. The chemical composition of the leucocratic material indicates calc-alkaline signature, though they are poor in HREE as compared to typical calc-alkaline magmas of the region.



Field aspect and REE / chondrite patterns of amphibolite, discordant leucocratic veins, discordant-concordant leucocratic segregations and associated hornblendite. Loma Sijú, Manicaragua-Jibacoa road.



Location of stops 21-24. Key: Location. ***Escambray Complex. lq****: Loma Quivicán Lithothem. Light colored marbles, with layers of intraformational breccias and calcitic metasandstones. Lower Cretaceous.* ***lcd****: Los Cedros Lithothem. Foliated marbles, well stratified and fine banding, grey color, fine-medium grained, with white mica, locally dark-grey or black. Lower Cretaceous.* ***yg****: Yaguanabo Lithothem. Greenschist facies metabasites (metavulcanites), with local intercalations of marbles and quartzites. Cretaceous.* ***lsb****: La Sabina Lithothem. Metaquartzites with intercalations of schists, local metasandstones rich in plagioclase, and marbles. Lower Cretaceous.* ***bq****: Boquerones Lithothem. Schistose marbles and calcitic schists rich in graphite and white mica, with fragments of metadolomitic limestones. Upper Jurassic.* ***cbr****: Cobrito Lithothem. Marbles, black schists, graphitic muscovite-bearing calc-schists. Upper Jurassic.* ***sj****: San Juan Group: Well stratified, generally graphitic, black-grey marbles. Upper Jurassic.* ***fd****: Felicidad Lithothem Member. Greenschsitst with lawsonite and intercalations of black-grey marbles, metaterrigenus schists, quartzites, and metasilicites. Upper Jurassic.* ***hr****: Herradura Lithothem. Graphite-bearing quartz-schists and phyllites. Jurassic.* ***lg****: Loma La Gloria Lithothem. Metaterrigenous schists, occasionally graphitic, with intercalations of marbles and calcareous schists, quartzites, and eclogite layers. Jurassic.* ***lch****: La Chispa Lithothem. Metaterrigenous schists with abundant intercalations of metasilicites, bands of metavolcanic greenschists with lawsonite, and bands of marbles. Jurassic.* ***ea****: El Algarrobo Lithothem. Crystallyne schists, generally strongly carbonated. These rocks commonly appear intercalated within Loma La Gloria Lithothem. Jurassic.* ***yb****: Yayabo Lithothem. Garnet amphibolites with occasional muscovite, and rare intercalations of metasilicites.* ***mβ****: Metabasalts, occasional metagabbros and metadiabases.* ***σ1****: Serpentinites, locally with talc-actinolite-chlorite schists.* ***e****: Eclogites, commonly retrograded within the greenschist facies.* ***q****: Quartzites.*

Stop 21. Escambray Complex.

Manicaragua-Jibacoa road (N 22º 01' 27.4" - W 079º 59' 11.7").

Graphitic muscovite-bearing calc-schists of the Cobrito Lithothem (Upper Jurassic). 40 min.

The mineral assemblage is made of quartz, white mica, calcite, albite, chlorite, and opaque minerals. Three phases of deformation can be distinguished. The main phase (D2) developed a penetrative foliation that was crenulated by phase D3 folds. D1 is relictic and not well developed. The location pertains to Unit II of G. Millán. Following this author, the unit was metamorphosed in the blueschist facies.

Aspect of folded and faulted graphitic muscovite-bearing calc-schists of the Cobrito Lithothem. with deformed veins of calcite.

Stop 22. Escambray Complex.

Jibacoa-Tope de Collantes road (N 22º 00' 50.1" - W 079º 59' 11.7").

Strongly folded marbles and impure marbles of the Loma Quivicán Lithothem (Lower Cretaceous). 20 min.

The location pertains to Unit II of G. Millán. Following this author, the unit was metamorphosed in the blueschist facies.

Aspect of strongly folded marbles and impure marbles of the Loma Quivicán Lithothem. Jibacoa-Tope de Collantes road.

Stop 23. Escambray Complex.

Jibacoa-Tope de Collantes road. NW of Loma del Soldado (N 21º 59′ 52.8″ - W 079º 58′ 46.0″).

Slaty black-grey graphitic muscovite-bearing calc-schists of the San Juan Group (Upper Jurassic). 15 min.

The mineral assemblage is made of calcite, white mica, quartz, chlorite and graphite. The main foliation (S2) transposes an earlier foliation (S1). The location pertains to Unit II of G. Millán. Following this author, the unit was metamorphosed in the blueschist facies.

Aspect of the slaty black-grey graphitic calc-schists of the San Juan Group. Jibacoa-Tope de Collantes road, NW of Loma del Soldado.

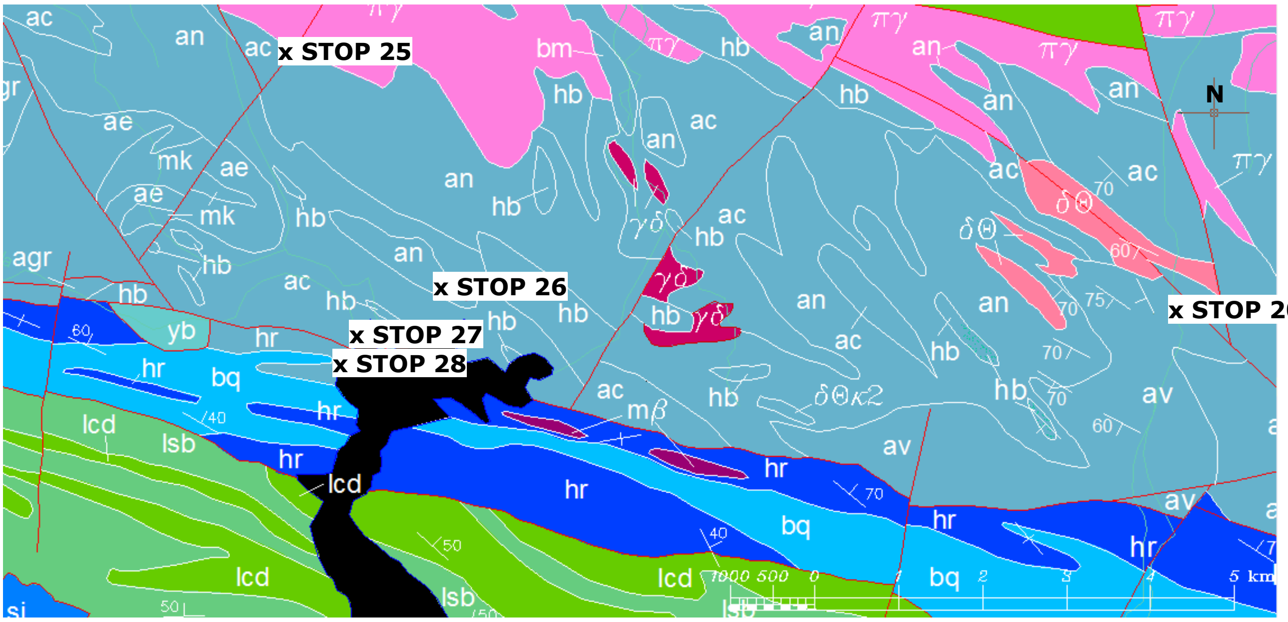
Stop 24. Escambray Complex.

Jibacoa-Tope de Collantes road. SW of Sumidero de Jibacoa valley (N 21º 58′ 48.0″ - W 079º 59′ 00.2″).

Metaterrigenous material of the Felicidad Member (Upper Jurassic). 15 min.

Mineral assemblages are made of albite, quartz, white mica, stilpnomelane, epidote, actinolite and opaque minerals. The main foliation (S2) transposes an earlier foliation (S1). The location pertains to Unit II of G. Millán. Following this author, the unit was metamorphosed in the blueschist facies.

Aspect of the metaterrigenous schists and quartzites of the Felicidad Member. Jibacoa-Tope de Collantes road, SW of Sumidero de Jibacoa valley.



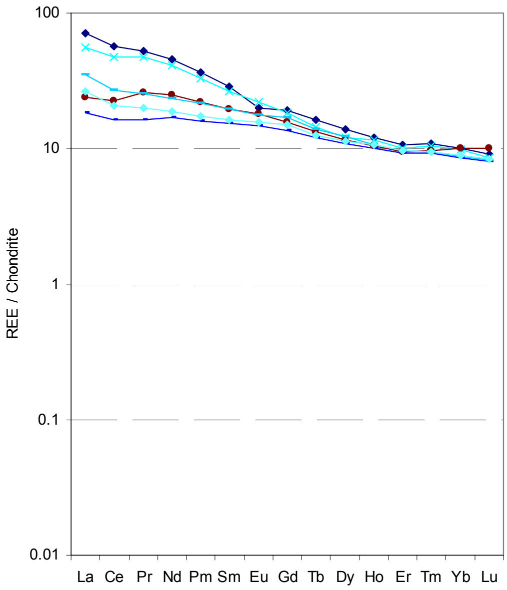
Location of stops 25-28. Key: ***Intrusive rocks:*** *$\pi\gamma$: plagiogranites. $\gamma\delta$: Granodiorites, tonalites, quartz-diorites and rare diorites. $\delta(\Theta)$: Diorites, quartz-diorites, tonalites and plagiogranites.* ***Mabujina Complex****:* ***ac****: Banded Bt-amphibolites.* ***ae****: Schistose, Bt-bearing, fine grained amphibolites.* ***agr****: Coarse grained amphibolites (after banded gabbros).* ***an****: Amphibolites, locally banded.* ***av****: Banded ("well stratified") Bt-amphibolites.* ***bm****: Magmatic breccia formed by blocks of metagabbros.* ***Hb****: ("metapiroxenitic") Horblendites.* ***mgm:*** *banded metagabbros.* ***mk****: Fine grained, hornblende gneiss.* ***Escambray Complex. lcd****: Los Cedros Lithothem. Foliated marbles, well stratified and fine banding, grey color, fine-medium grained, with white mica, locally dark-grey or black. Lower Cretaceous.* ***lsb****: La Sabina Lithothem. Metaquartzites with intercalations of schists, local metasandstones rich in plagioclase, and marbles. Lower Cretaceous.* ***bq****: Boquerones Lithothem. Schistose marbles and calcitic schists rich in graphite and white mica, with fragments of metadolomitic limestones. Upper Jurassic.* ***hr****: Herradura Lithothem. Graphite-bearing quartz-schists and phyllites. Upper Jurassic.* ***sj****: San Juan Group: Well stratified generally graphitic black-grey marbles. Upper Jurassic.* ***yb****: Yayabo Lithothem. Garnet amphibolites with occasional muscovite, and rare intercalations of metasilicites.* ***m****β: Metabasalts, occasional metagabbros and metadiabases.*

Stop 25. Mabujina Complex.

Manicaragua-Hotel Hanabanilla road. Loma del Muerto (22º 07' 18.3'' - 080º 04' 43.0'').

Low-P amphibolites and granitic rocks of the Mabujina complex. 30 min.

The amphibolite is made of amphibole (magnesiohornblende-tschermakite), plagioclase (X_{an} = 0.32-0.15), quartz, epidote, titanite, magnetite and ilmenite. The foliation of the amphibolites is near vertical and are crosscut by thick layers and veins of biotite (-hornblende) granitic rock that contains enclaves of deformed amphibolite. The intrusion is locally subhorizontal, and deformation is brittle. The crosscutting relations and the chemical composition of the granitic rocks suggest that the latter are late intrusions related to the emplacement of the Manicaragua batholith. The 1:100000 Geological Map of Cuba depicts a large "plagiogranite" body adjacent to the location.



Field aspect and REE / chondrite patterns of Magujina amphibolite and discordant biotite granitic rocks. Loma del Muerto, Manicaragua-Hotel Hanabanilla road.

Stop 26. Mabujina Complex.

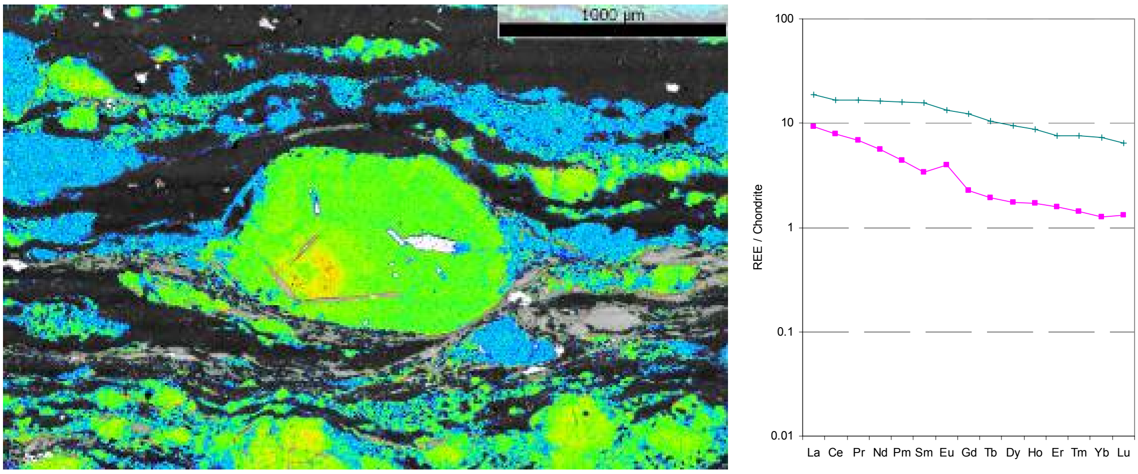
Manicaragua-Hotel Hanabanilla road. Hanabanilla Damp (22º 05' 45.1'' - 080º 03' 39.5'').

Low-P amphibolite and concordant gneisses of the Mabujina complex. 20 min.

The amphibolite is made of amphibole (magnesiohornblende-edenite-hastingsite), oligoclase, epidote, titanite, and apatite (plus retrograde chlorite and hematite). The gneissic rock is made of quartz, plagioclase (X_{an} = 0.41), K-feldspar, epidote, muscovite and very scarce biotite. It shows a mylonitic fabric, with grain size reduction of quartz and feldpars. Its fabric and mineral and chemical composition contrast with those of undeformed granitic veins and intrusions in the Mabujina Complex, resembling those of leucocratic concordant and discordant segregations (e.g., Loma Sijú, stop 20).

SHRIMP dating of zircons from the gneissic rock (Y. Rojas-Agramonte, unpublished data) yielded 92.0±2.2 Ma (Turonian).

Field aspect of amphibolite and deformed concordant granitic rocks of the Mabujina Complex. Hanabanilla Damp, Manicaragua-Hotel Hanabanilla road.



XR Al-Kα image of deformed concordant gneiss and REE / chondrite patterns of amphibolite (green) and deformed concordant gneiss (purple) of the Mabujina Complex. The XR Al-Kα image shows the distribution of Al in feldspars (green-red: plagioclase; blue: K-feldspar) on top of the BSE image (dark grey: quartz; grey: muscovite; note inclusions of biotite –white- and muscovite –grey-within plagioclase porphyroclast). Hanabanilla Damp, Manicaragua-Hotel Hanabanilla road.

Stop 27. Mabujina Complex.

Manicaragua-Hotel Hanabanilla road. Hanabanilla Damp (N 22º 05′ 25.6″ - W 080º 04′ 12.0″).

Low-P amphibolite of the Mabujina complex. 20 min.

Strongly foliated amphibolites and nice view of the Hanabanilla Damp.

Hanabanilla damp and aspect of strongly layered amphibolite Hanabanilla Damp, Manicaragua-Hotel Hanabanilla road.

Stop 28. Escambray Complex.

Hotel Hanabanilla (N 22º 05′ 16.3″ - W 080º 04′ 21.7″).

Graphite-bearing quartz-schists and phyllites of the Herradura Lithothem (Upper Jurassic). 20 min.

Three phases of deformation can be distinguished. The main phase (D2) developed a penetrative foliation that was crenulated by phase D3 folds. The location pertains to Unit IV of G. Millán, the upper structural unit of the Escambray. Following this author, the unit was metamorphosed in the greenschist facies.

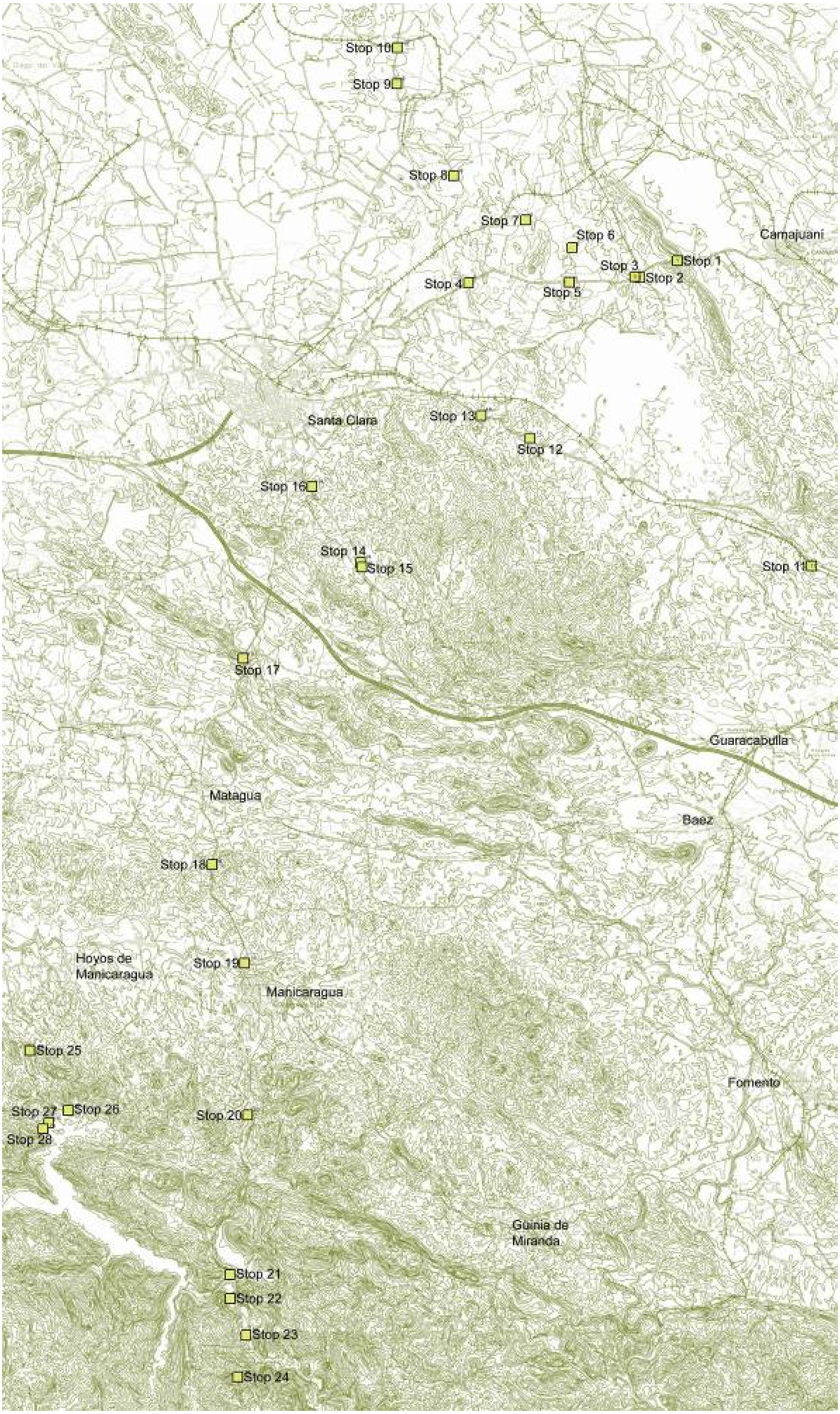
Aspect of graphitic phyllites of La Herradura Lithothem. Hotel Hanabanilla.

FAREWELL

Wish you have enjoyed the trip, the beauty of the rocks, the Geology of Cuba, the Country and its People, and perhaps also our unpretentious descriptions. See you soon in another trip!!

Antonio, Manuel, and Bernal.

The authors doing their job (hanging around) in Santa Clara region, Cuba, August 2009, shortly before "*el ciclón Gustavo*" badly smashed Cuba.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Guaracabulla
Matagua
Baez
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Hoyos de
Manicaragua
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Guinia de
Miranda
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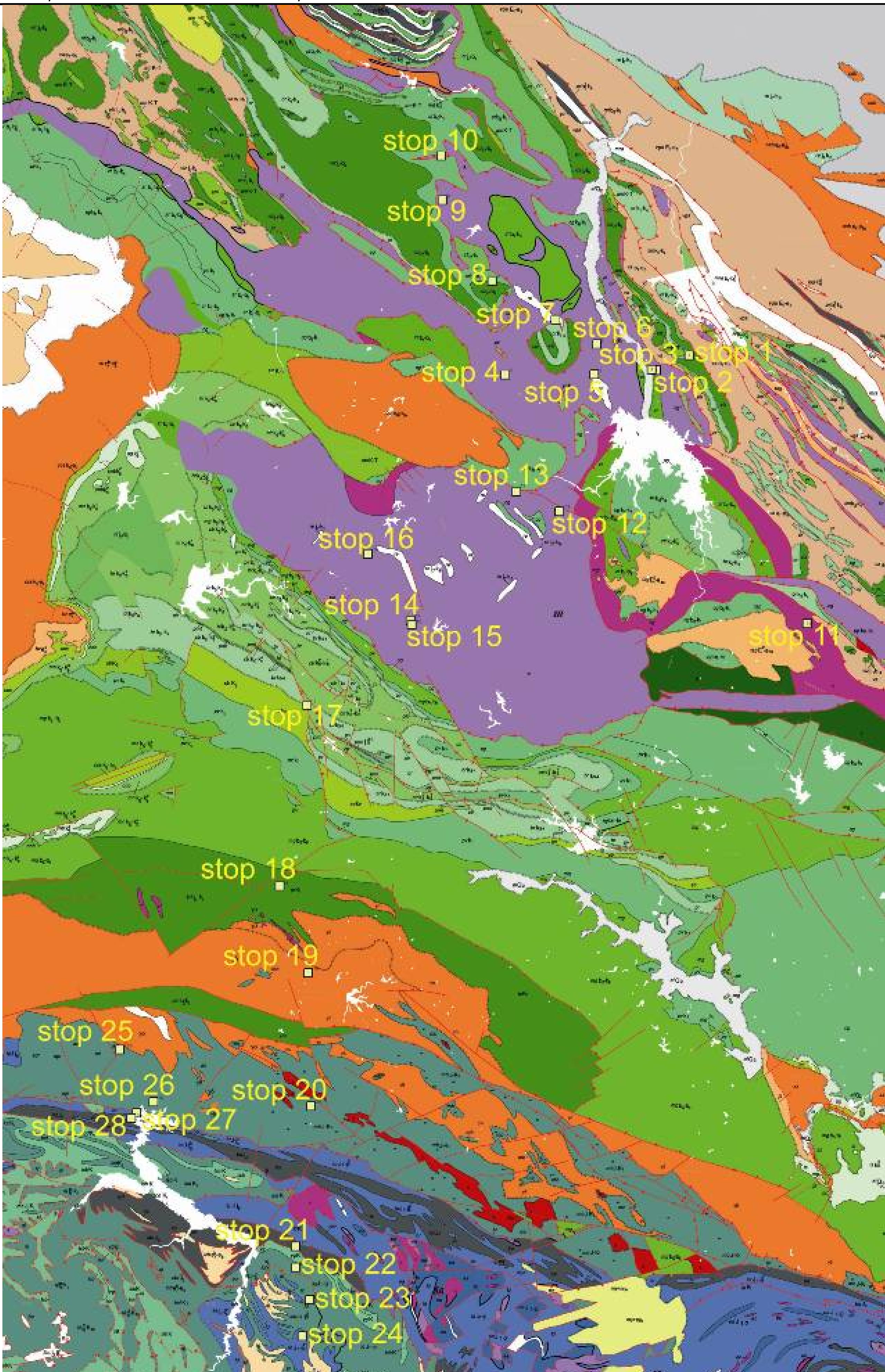
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