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Field trip Guide to the Median Belt and subduction zone rocks, Dominican Republic

Compiled by Grenville Draper and John Lewis

with contributions by R. A. Abbott, J. Escuder-Viruete, M. Krebs, W.V. Maresch, P. Schertl, A. Perez-Estaun, and J. P. Pindell

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Compiled by Grenville Draper[1] and John Lewis[2]

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INTRODUCTION

This three day field excursion is designed to give participants at the Caribbean Conference an opportunity to examine two of the most significant structural-petrological features in the northern Caribbean. On the morning of the first day we will examine the Median Belt, a suture zone between the early oceanic units of the sea floor and the Early Cretaceous oceanic island arc terrane. Beginning in the afternoon of the first day and continuing on the second and third days we will be concerned with the high pressure metamorphic rocks of the Samana and Rio San Juan subduction complexes of the North Coast Belt. Because of the time constraints, only a limited number of stops can be made, but the road log gives a summary of the roadside geology. A summary of the main features and lithologies, that will be seen, is given for each section of the field trip. Particular features to be seen at the various stops are then given in the road logs. A general geological map of Hispaniola accompanies this field guide (see separate sheet). The route to be followed each day of the field trip is shown on Fig. A.

Most of the back ground to the descriptions in this field guide is from the review by Lewis and Draper (1990) and relevant papers in Special Paper 262 of the Geological Society of America (Mann, Draper and Lewis, 1991). The descriptions on the Cordillera Central have been updated from the work of the SYSMIN projects funded by the European Union and carried out from 1998 to the present time. The detailed results of the SYSMIN projects are contained in reports and maps available from the Direccion General de Mineria. Much of the work to date is published (in Spanish) in two volumes namely Geologica Acta Hispanica, vol. 37 (2-3) 2002, and Boletin Geologico y Minero, vol. 118 (2), 2007) and in papers referenced in the text in this field guide. Descriptions of the North Coast Belt have been updated from recent papers cited in the text. Some descriptions below are updated from previous field guides, particularly the Third Workshop of Tectonostratagraphic Correlation of the Northwest Caribbean (1993).

DAY 1 AM

Santo Domingo to Cotui

The lithologies and geological features to be examined in the morning of the first day of the field excursion are those in the northeast part of the Cordillera Central, the main mountain system through central Hispaniola (see geological map of Hispaniola)

Dominating the geology of the central Dominican Republic is the northwest trending Median Belt which includes two lithologically and structurally distinct metamorphic units of greenschist and amphibolite grade, the Amina-Maimon Formations and Duarte Complex. These two units are separated by a wide fault zone, the Hispaniola Fault Zone of Bowin (1975), within which the Loma Caribe serpentinised peridotite and associated mafic volcanic rocks are exposed (Fig.1,2,3). The main belt of rocks to the southwest of the Median Belt and south of the Duarte Complex are the volcanic and volcaniclastic rocks of the Tireo Group of Late Cretaceous age. Rocks to the northeast of Maimon Formation belt are the clastic, basaltic and rhyolitic rocks of the Los Ranchos Formation of late Aptian age. All of these lithologic units (except the Tireo Group) will be examined briefly in the field. Major faults separate all these lithologic units. Two of these structures, the Maimon Fault and Hatillo Thrust will be examined.

Loma Caribe Peridotite

The Loma Caribe Peridotite is the name given to the belt of ultramafic rocks which extends northwest through central Hispaniola and is the core of the Median Belt of Mesozoic rocks. It is one of the occurrences of ophiolite-related ultramafic rocks that crop out along the northern plate margin of the Caribbean Plate (Lewis et al. 2006). One of these occurrences is the Loma Caribe peridotite, exposed in the Cordillera Central of the Dominican Republic (Fig. 3). The peridotite body is about 4-5 km wide and extends for 95 km from La Vega to Loma Sierra Prieta north of Santo Domingo, but the southeastern part of the peridotite is exposed as thin fault slices only (Lewis & Jiménez 1991, Lewis et al. 2006). The peridotite further extends southeastward below the surface to the coast as shown by aerial magnetic surveys and drilling. Based on the mineralogy and textural features the Loma Caribe Peridotite was interpreted by Lewis & Jiménez (1991) to be serpentinized harzburgitic oceanic mantle forming part of a dismembered ophiolite complex. The occurrence of podiform chromitite pods within dunites and the exposures of pyoxenites in the northern central part of the peridotite in contact with basalts and diabases of the Peravillo Formation implies that most of the peridotite is part of a transition zone of the mantle section of the harzburgite-type of alpine peridotite complexes.

The main parent rock is harzburgite, which in a form of about 20-30 percent serpentinized rock, makes up about 50% of the outcrop. The remainder is almost entirely serpentinite-talc. Orthopyroxene generally forms 10-15% by volume of the rocks. Clinopyroxene is rarely more than 3 percent and lherzolite is found in small amounts only. Zones of dunite have also been mapped within the harzburgite, particularly in the Loma Taina and Peguera areas. Loma Peguera chromitites that are found in the dunites are rather unusual in chemical composition compared with those commonly occurring in the Moho transition zone from mantle harzburgites in ophiolites, They also display a peculiar Platinum group element (PGE) distribution and mineralogy (Proenza et al., 2007; Zaccarini et al., 2008). The genesis of the Loma Peguera chromitite is still a matter of debate, and there is no conclusive answer as to their origin. The chromitites have compositions very similar to spinel in picritic arc lavas, specifically to those from Vanuatu in the western Pacific (Eggins, 1993;Barnes, S.J. & Roeder, P.L. (2001). This is in agreement with the conclusion that the Loma Caribe peridotite and associated mafic rocks are a suprasubduction ophiolitic complex in accord with other lines of evidence (Proenza et al., 2007). Compositions of the clinopyroxene, orthopyroene and accessory chromite were summarized in Lewis et al. (2005). Compositions of accessory spinel from dunites and harzburgites resemble suprasubduction zone mantle peridotites, whereas composition of spinel in lherzolites is similar to abyssal peridotites These compositions arise from different melting histories which in turn give rise to different magma types.

Lewis et al. (2005, 2006) have interpreted Loma Caribe peridotites as a fragment of Jurassic-Cretaceous Pacific oceanic lithosphere that had been modified at a suprasubduction zone environment related to Cretaceous Greater Antilles arc, which was affected by a mantle plume (Duarte Plume). Restites for oceanic plateau basalt are peridotite that contains chromian spinel with Cr# around 0.8, similar to Loma Caribe dunites.
The ultramafic rocks strike N.W. and there are fault relationships between the ultramafics and the Peralvillo Formation and Siete Cabezas Formation to the northeast and southwest respectively. Haldeman et al, (1980; Fig. 3) considered that the structural information derived from the shear foliation attitudes within the borders of the serpentinites indicates that the body of ultramafic rock is wedge-shaped with depth; the western boundary dips eastward at 75-80° and the eastern boundary dips westward at 50-60°. A morphologically well-delineated major fault, the Guardarraya Fault, strikes 75-80° E. This fault can be traced from the Maimón River to the N.W. side of Loma Caribe. Another major fault, the Peguera Fault, is sub-parallel to the Guardarraya Fault, strikes 75–80° W. Topographic data demonstrate that both fault have an apparent vertical displacement of about 40m with the downthrown rift or graben block of Loma Larga situated between them. The bedrock in the fault zone is composed of extremely sheared, talcose serpentinite and platy, slickensided serpentinite with foliations parallel to the trend of the major faults. This lithology is in sharp contrast to that found on the upthrown blocks of Lomas Guardarraya and Taina where less serpentinized ultramafic rocks dominate. Numerous cross cutting faults are found between 45° and 90° of the strike of the Guardarraya Fault. They seem to be strike slip in nature and it is inferred from apparent offsets in the Guardarraya Fault block that they formed late in the episode of deformation.

Models as to the emplacement of the Loma Caribe peridotite are of particular interest. Recent studies on the structures within the Maimón Formation and structural relations between the Loma Caribe peridotite belt and the Maimón Formation (Draper et al, 1996) suggest the initial emplacement of the Loma Caribe peridotite took place in the late Aptian. The structural data imply northward thrust emplacement obduction of the peridotite over the arc rocks of the Maimón and probably the Los Ranchos Formations (Fig. 2a) In the late Eocene, at the time of the collision between the Greater Antilles arc with the North American Plate, some of the Aptian ductile structures were reactivated as brittle structures and the peridotite was emplaced again with northward movement over the Peralvillo Formation of probable Late Cretaceous age. Further upward movement of peridotite took place in the Late Oligocene since Oligocene rocks of the Tavera Group exposed near La Vega, are juxtaposed along faults against the peridotite in the Hispaniola Fault Zone (Bowin, 1975). The peridotite must have been exposed at the surface to weathering in the Early Miocene leading to the development of the Ni-laterite soils that are presently being mined.

Siete Cabezas and Peralvillo Formations and the Rio Verde Complex. Siete Cabeza and Peralvillo Formations are the names given to the two belts of dominantly basaltic rocks that crop out respectively to the south and north of the Loma Caribe peridotite. At its southeast end the periodotite divides into two forks which are separated by a complex area of basalts, diabases, gabbros, tuffs, breccias and cherts. Because some of these rocks between the forks are deformed and metamorphosed, Bowin (1966) classified them with the Duarte Formation (Complex). However, the rocks are lithologically and chemically different from the Duarte Complex and are now termed the Rio Verde Complex (Lewis and Draper, 1989). Each of these three units have contrasting ages and chemical compositions and were developed at different times in different environments.

Siete Cabezas Formation is the belt of basaltic and associated sedimentary rocks that underlies the high terrain (Los Sietos Picos (-900m) immediately southwest of the Loma Caribe periodotite (Fig.1,2,3). Much of the rock is unaltered or only slightly altered fine-grained or vitric basalt that presumably represent sheet flows. Less common are medium grain-size basalts, some with ophitic texture that might be the centers of flows or are sills intruded into flows. A 0.6 km wide belt of volcaniclastic sedimentary rocks and cherts separates these basaltic sheet flows from a more varied mix of basaltic lavas, vitroclastic tuffs and breccias, and cherts occupying the lower ground to the southeast (STOP 1). Siete Cabezas basalts are high Mg hy-tholeiites with a small range in composition. They show flat REE patterns and are remarkably similar in composition to oceanic plateau basalts from the Pacific (Fig.4) The Siete Cabezas Formation is Late Campanian to Maestrichtian in age based on radiolaria from tuffaceous samples (Montgomery pers. com. 1996). This agrees with the $^{40}Ar/^{39}Ar$ age of 69 Ma determined from a plagioclase separate and on fresh basalt (Sinton et al., 1998) and puts the Siete Cabezas basalts among the youngest group of plateau basalt eruptions in the Caribbean (Revillon et al., 2000).

Peralvillo Formation refers to the narrow fault bounded belt (0.5-2 km wide) of mafic and sedimentary rocks which lies immediately north of the Loma Caribe periodotite (Bowin, 1996; Jimenez and Lewis , 1989; Espaillat et al., 1991). The base north of the periodotite consists of about 200 m of basaltic flows and diabases overlain in the northwester part of the belt by 200m of fine grained mafic tuffs grading into cherty tuffaceous sedimentary rocks. This sequence is in turn overlain by volcaniclastic tuffs, breccias and amygdaloidal basalt. A bed of massive deformed limestone assocated with calcareous tuffs is exposed at Cerro de Maimon mine and in drill cores there. The contact with the Maimon Formation is a shear zone (the Maimon Fault) characterized in drill cores by a 5-10 m thick gauge zone of highly sheared chloritized mafic volcanics. Although a clear Moho transition zone between the mafic and ultramafic units, as seen in well-exposed ophiolites, has not yet been found, the occurrence of pyroxenites at the contact and microgabbros grading into flows capped by cherts and volcaniclastic sediments (Boisseau, 1987; Jimenez and Lewis, 1989) certainly is suggestive of an ophiolite or some type of mantle-oceanic crust sequence.

Peralvillo mafic volcanics at Sabana Potrero in the southeastern part of the belt consist of pillowed and massive units with minor hyaloclastites with a total thickness of between

1200-2300 m. The basalts at Sabana Potrero are a suite of fractionated hy-qz normative tholeiites (0.43-2.8% TiO_2) with chondrite-normalized REE and multi-element patterns generally similar to that of mid-oceanic ridge basalts (Fig. 5). However, this basalt chemistry differs in detail from N-type MORB in showing a distinctive arc-like depletion in HFSE, particularly in Nb and Ta and some enrichment in LILE. These are the features of the basalts of the Lau Basin in the western Pacific. In these back-arc basins the oceanic crust which directly overlies mantle peridotite is predominantly formed of basalt similar to mid-oceanic ridge basalt (MORB) but includes variants gradational to island arc tholeiites (Hawkins, 1994; 2003; Pearce, 1995; 2003). It is now widely held that the analogues of backarc systems are the dominant component of ophiolites formed over subduction zones. Hence the term subduction zone ophiolites (Pearce, 2003).

Small restricted massive sulfide bodies with associated stock work (quartz sulfide veins) and altered (bleached) rock occur within the mafic volcanics at Sabana Potrero (Espaillat et al., 1991). The oceanic volcanic association and sulfide composition indicate a Cyprus-type of association. The wide variation in composition of the basalts over a narrow thickness as seen at Sabana Potrero is thought to arise because of the eruption of successive magma batches from rapidly evolving sub-ridge magma chambers.

Rio Verde Complex is a mix of basalts, diabases, gabbros, tuffs, breccias and cherts. Along the northeastern margin, in contact with the peridotite the rocks are metamorphosed from sub-greenschist to amphibolite facies (Escuder et al. 2002). The metamorphic grade increases upward in the structural sequence from prehnite pumpellite facies (Zone1) through greenschist facies (Zone II and III) and amphibolite facies (Zone IVa) to upper amphiblite facies (Zone IVb). The metamorphic field gradient is inverse and of the low-P type. The PT paths (Fig.6.7) documented for the Rio Verde Complex are typical of sub-ophiolitic metamorphic sole rocks, characterized by a high grade assemblage, and a second event marked by a medium pressure overprint of the first stage. Chemical analyses carried out for the first SYSMIN project (Lewis et al., 2002, Fig.4) and new trace element and Nd-Sr-isotope data (Escuder and Perez-Estaun, abstract, this conference, 2008) show that these mafic rocks, like the Peralvillo basalts, also have compositions intermediate between mid-oceanic ridge basalts and island arc tholeiites. Ar/Ar plateau ages of hornblende in Fe-Ti metagabbros (118±1.3 Ma) and amphibolites with S-L fabrics (110.3±1.4 and 110.7±1.6 Ma) indicating a link with the Los Ranchos Formation, in which the basaltic rocks are of island arc tholeiitic composition. These results support the earlier interpretation of Escuder et al. (2002) that intra-oceanic thrusting took place during the closure of a back arc basin related with the Caribbean Primitive Island Arc (PIA) and the onset of subduction of arc-related units Aptian-Albian time.

The exact relations among the three basaltic units i.e. the Siete Cabezas and Peralvillo Formations and the Rio Verde Complex and, in turn, their relation to the Loma Caribe mantle periodotite are still not clear but the present data support the concept that each of the Peravillo and Rio Verde units exposed at the north and center of the peridotite, represent dismembered fragments of a complex arc/back-arc system that probably began as part of the early primitive arc. The conclusion is that that this assocation records an evolving suprasubduction zone ophiolite complex. The Siete Cabezas unit along the southern boundary, the oceanic side of the peridotite, on the other hand, reflects a much later plume event, erupted in a very different environment, not in any way related to the early primitive arc building stage. Such subjacent features (segments) are seen in the present day Pacific (ridge segments, plateaus, seamounts, back-arc basins.

As explained above the mineralogy and geochemistry of the Loma Caribe peridotite and associated massive chromitite also indicate that the peridotite is composed of different fragments of mantle material (Lewis et al., 2005 ; Lewis et al.,2006; Proenza et al., 2007) which on melting would have given rise to different magma types.

Duarte Complex Bowin (1960, 1966) was the first to describe the belt of metamorphosed mafic volcanic rocks of mainly greenschist grade in the Cordillera Central to the northwest of Santo Domingo. He named the unit the Duarte Formation, but because the unit contains a variety of lithologies that are discontinuous and lacks stratigraphic markers it is better to refer to the unit as a Complex (Lewis and Draper, 1990; Draper and Lewis, 1991). It is now known that the Duarte Complex is an extensive unit exposed in two fault bounded blocks through the north central part of the Cordillera Central of Hispaniola (see map of Hispaniola). On the 1:250,00 scale geological map of the Dominican Republic by the Bundesanstalt fur Geowissenschaften und Rostoffe (BGR) Germany (1991), rocks of the Duarte Complex and the Tireo Group were grouped together into one unit. Lewis and Jimenez (1991) disagreed with this conclusion and the recent mapping of the SYSMIN project (1:50,000 maps Direccion General de Mineria) and journal publications have confirmed that the Duarte Complex and Tireo Group are indeed two separate units. It should be realized, however, that in field mapping, it is often difficult to distinguish between the two units, particularly when the rocks are metamorphosed.

The principal rocks forming the Duarte Complex are metabasalts, greenstones, greenschists and amphibolites relatively enriched in Mg, Cr and Ni. Those rocks with abundant clinopyroxene are metaankaramites; those with abundant olivine are meta-picrites.. Breccias are a common lithology and cherts occur in some areas. Based on the lithologies and chemistry Lewis and Draper (1987), Donnelly et al., 1990: Draper and Lewis (1991) and Lewis and Jimenez (1991) suggested that the protolith was part of an oceanic plateau or seamount (Fig.8).

Many similar features are seen in both blocks of the Duarte but on the other hand each of the blocks has particular features not seen in the other. The descriptions in ths field guide will focus on the features in the area between Santo Domingo and Piedra Blanca. For information on the northwestern area of the Duarte the reader is referred to the Field Guide to the Jarabacoa Field trip (Escuder, 2008), Escuder et al. (2006), Escuder et al. (2007), Bowin (1966), Palmer (1979) and Lewis and Jimenez (1991),

Based on radiolaria in ribbon cherts at El Aguacate in the western block Montgomery et al. (1994) established an Upper Jurassic (Oxfordian-Tithonian) age for the Duarte Complex. Lapierre et al., 1998 obtained $^{40}Ar/^{39}Ar$ ages of 86.1 ±1.3 Ma and 86.7 ±1.6

Ma on hornblende from a picrite and an amphibolite from the eastern Duarte block suggesting that the Duarte Complex was formed during the main extrusion phase (88-89 Ma) established for much of the Caribbean plateau. These ages were disputed by Lewis et al., (1999) arguing that the hornblende ages had been reset as a result of large intrusions of tonalite one of which has been dated at 89 Ma by U/Pb on zircon. Whole rock Sm/Nd dating (Escuder et al., 2007) gave an age of 115-119 Ma for the Duarte complex.

The Duarte Complex in the area to the east of Villa Altagracia can be divided into three metamorphiczones(Fig.1, Escuder et al., 2002). The foliation and metamorphic zones not only follow the distribution of the foliated tonalities which intrude the mafic rocks of the complex but the overall distribution of the zones suggest there is a temperature increase westward and downward in the structural sequence from the upper greenschist facies (A) through the epidote-amphibolite facies (B) to upper ampibolite, transitional to granulite facies (C) formed in the margins to the Jautia layered gabbro-norite intrusion. The Grt + Opx–bearing granulites formed in a ductile shear zone. The metamorphic gradient is normal and of the mid-P type (Fig.9 25-30°C/km). The U/Pb age of 89 Ma for the foliated tonalite does not only give a crystallization age for the tonalite intrusion but also establishes a Late Cretaceous age for the main ductile shearing deformation in the rocks of the Duarte Complex. The post-thermal peak PT paths (Fig. 9) for each of the metamorphic zones, calculated from the mineral analyses, suggest that the cooling and unloading of the complex, during continuous retrograde development of deformation and non-coaxial Sp fabrics. The Ar-Ar of 84.6 ± 0.5 Ma cooling age of syn-Sp muscovite from the tonalite is considered to record the age of unloading.

The petrology and petrogenesis of the Duarte Complex has been the subject of a number of studies (see references under Lewis, Draper, Lappiere and Escuder) and
In a recent detailed study of the Duarte metabasaltic rocks in the area southeast of Moncion Escuder et al. (2007) found the Nd isotope and incompatible trace element patterns consistent with mantle sources related to a heterogeneous plume. Mantle melt modeling showed the plume mantle sources were more enriched and deeper through time.

Tireo Group
Tireo group rocks of Late Cretaceous age occupy a 290 km-long belt along the Cordillera Central in the Dominican Republic and the Massif du Nord in Haiti (Lewis et al., 1991). The rocks are intruded by granitoid (mainly tonalite) plutons. Results of the mapping and detailed chemistry and age dating through the SYSMIN project. have been published by Escuder et al. (2007). Two main units are recognized.

> **1.Lower Tireo Group (Basic Rocks)**. The oldest and most extensive rocks are a sequence(4,000m) of massive, green vitric-lithic tuffs with intercalated mudstones, shales, siltstones, graywackes and limestones found in the Cordillera Central and Massif du Nord (Haiti). In the Constanza-Rio Blanco area important lithologies are intercalated cherts (El Convento Member) and limestones (Constanza and Valle Nuevo Members) and metabasalts at the base of the unit. Microfossil age determinations indicate a Turonian (possibly late Cenomanian) to

early Senonian age for the main volcanism, but sedimentation may have continued until the early Masstrichtian in the northeast. These rocks pass without apparent discordance into the Upper Tireo Group.

2.Upper Tireo Group (Acid Rocks). This group consists of lavas, pyroclastic rocks and reworked tuffs and shallow intrusives of mainly dacite and rhyolite composition. The acid volcanism is concentrated in centers along the southern margin of the belt. The acid volcanism probably did not begin before the late Santonian and ended in the early-middle Campanian.

Lower Tireo Group rocks correlate with the *Terrier Rouge Series* in the Massif du Nord, Haiti, consisting of andesites, andesitic tuffs, tuffites, agglomerates, mudstones, and basalts. Upper Tireo Group correlates with the *La Mine Series* in Haiti, consisting of dacite flows and stocks, crystal-lithic tuffs, unsorted pyroclastic rocks, and volcaniclastic rocks. The Tireo Group and equivalent units in Haiti are overlain comfortably in the south-central part of the belt by sedimentary rocks of middle Campanian-Maastrichtian age and younger of the Trois Rivieres-Peralta Belt (Lewis et al., 1991; Boisson, 1987).
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The vitroclastic tuffs and vitric-lithic lapilli tuffs contain at least four types if clastic particle: (1) glass (palagonite) shards, (2) cryptocrystalline lithic fragments (probably devitrified glass), (3) vesicular scoria fragments, (4) fragments of accretionary lapilli. Fewer crystals are present.

The overall nature of the Tireo vitric lithic tuff deposits suggests they were mainly submarine pyroclastic flow deposits produced by phreatic and phreatomagmatic explosion eruptions.

Maimon Formation.

The Maimon Formation is a northwest trending belt, about 73 km long by 9 km wide, comprised of metamorphosed volcaniclastic and volcanic rocks of Lower Cretaceous (?) age, that outcrops within the Median Belt of central Hispaniola (Fig. 1, 2, 3). It is of economic importance, in that it contains four, and probably more, deposits of volcanogenic massive sulfides (VMS), one of which, the Cerro de Maimon deposit, is presently being developed for mining. Bowin (1966) gave a general description of the Maimon Formation but in the twenty-three years that followed the completion of Bowin's mapping, little work was done on the Maimon Formation. In 1983, Rosario Dominicana obtained the concession rights to explore all the Maimon Formation. This work, which included geological surveys, defined several exploration targets and resulted in a geological map at 1:25,000 scale and report (Rosario Dominicana, 1985). A summary of this work was published by Kesler et al.(1991). Falconbridge Dominicana (Falcondo) took over the Maimon Concession. in 1990 and in 1991. The Concession is presently held by Corporacion Minera Dominicana who are also developing the Cerro de Maimon mine.

Through the mineral exploration over past twenty years four volcanic-hosted massive sulfide deposits and have been located within the Maimon Formation. As part of the Falcondo exploration program, Lewis and Draper along with graduate students, undertook more detailed studies of the structure, petrography, whole rock geochemistry, and isotope geochemistry of the Maimon Formation and ore minerals. The results of this work are contained in the following theses and publications: Kesler et al. (1991); Horan. (1995); Astacio, (1999); Lewis et al. (2000).

The following description is an outline of the main features of the lithologies and strucures in the Maimon Formation. For more details on the Cerro de Maimon deposit and geology please see the the Field Guide to the Cerro de Maimon copper-gold deposit (Espaillat , this conference) .See also the Field Guidebook - Mineral Deposits of the Dominican Republic (G. Feiss , Editor, 1998)..

Tectonic Setting The Maimon Formation along with the Amina schists to the west, are part of a belt of contemporaneous, early arc bimodal volcanism of Early Cretacous (pre-Albian) age that extends the full length of the present day Greater Antilles arc (Lewis and Draper, 1991). This early Cretaceous belt preserves the early fore-arc and arc volcanism. In the Dominican Republic, the fore-arc and island arc components of this early volcanism are preserved as the Maimon-Amina Formation (fore-arc area) and the Los Ranchos Formation (island arc area).

The Maimon volcaniclastic rocks of the fore-arc basin host several exhalitive massive sulfide deposits whereas the extensive mineralization through the Los Ranchos Formation is of the epithermal type. Many features of the structure and lithologies of the Maimon protolith are analogous with those found in the Eocene basement of the Izu-Bonin-Mariana fore arc. The field evidence implies that extensional factors governed the onset of magmatism in the Maimon belt. A regional unconformity recognized on all the main islands of the Greater Antillies and marked by rudist-bearing limestone of Middle Albian age separates the early Cretaceous arc tholeiite bimodal volcanism from the extensive calc-alkaline volcanism that took place through the Late Cretaceous.

Maimon Formation rocks constitutes a bimodal spilite-keratophyre suite. Much of the volcanic pile consists of bedded submarine volcaniclastic units with lesser amounts of intercalated volcanic flows and shallow intrusives. The volcaniclastic rocks are mainly tuffs but horizons of breccias and conglomerates can be recognized in the less deformed rocks. A belt of well-laminated rocks of obvious sedimentary origin, occur through much of the central part of the Maimon Formation outcrop area. These are mainly fine-grained laminated meta-tuffs but cherts, dark carbonaceous shales, and limestones are also present. These meta-sedimentary rocks appear to be totally conformable with the more typical Maimon Formation meta-volcaniclastic rocks. Layers of manganese oxide, hematite iron concentrations and cherty layers that are interbedded with the volcaniclastic units must have resulted from exhalitive activity.

The age of Maimon Formation is not well established. The general structural/tectonic relations suggest the Maimon Formation is Early Cretaceous in age. Model ages calculated from lead isotope data (Horan, 1995) suggest an early Cretaceous age similar to the model ages calculated from the lead isotope data for the Los Ranchos Formation (Cumming and Kesler, 1987). Fragments of echnoid spines found in a meta-limestone interbedded with tuffs in the central part of the Maimon Formation are similar to those hemicidarids from the Early Cretaceous of Mexico and Jamaica (S.K Donovan, unpublished data, 1994).

The Maimon Formation is divided into two structural metamorphic provinces parallel to the northest-southwest structural trend of the belt (Draper et al., 1996). The Ozama shear zone in the south west of the Maimon belt is a high-strain greenschist facies ductile shear zone consisting of interlayered mafic phylonites and felsic mylonites. The extreme deformation in the zones has obliterated most of the original textures. The Altar zone in the northeast part of the Maimon belt is composed of much less deformed rocks which can be recognized as interlayered mafic and felsic tuffs, breccias and flows. These show variable degrees of schistosity and exhibit both pure shear and simple shear fabrics. The deformation and metamorphism in the Maimon Formation has been studied by Draper and Lewis, (1991); Draper et al. (1996); Draper and Gutierrez-Alonso (1997) and Escuder et al.(2002). Although the Maimon belt is formed of a single unit, it is divided into two elongate and structural-metamorphic provinces: (a) the Ozama shear zone which is a high strain, greenschist facies ductile shear zone consisting of felsic mylonites and mafic phyllonites, and (b) the Altar zone, which is less deformed, consisting of interlayered felsic and mafic tuffs, with varying degrees of schistosity, but which exhibits pure-shear and simple-shear fabrics. Rocks in the Ozama Shear Zone are L-S tectonites with stretching lineations defined by aligned actinolite, elongate quartz and/or epidote aggregates. The extreme deformation due to the shearing in the Ozama Shear zone has obliterated most of the original textures. The PT path is similar to that of the Rio Verde Complex (Fig.6,7)

These structural data suggest that the deformation features in the Maimon Formation, and in particular those in the Ozama shear zone, resulted from northward thrust emplacement obduction of the periodotites over the arc rocks of the Maimon Formation. Most of the deformation and metamorphism of the Maimon Formation rocks, particularly in the Ozama mylonite zone resulted from the obduction of the Loma Caribe peridotite on the early Antillean arc in the mind Cretaceous (Draper et al. 1996). This obduction event was followed by the deposition of limestone over early arc rocks and was accompanied by a polarity reversal so that subduction changed from northeast-dipping to southwest-dipping. The new volcanism beginning in the early Cenomanian was of the calc-alkaline type and continued to Eocene time.

In the middle to late Eocene, Hispaniola underwent notheast-southweast contraction (Mann et al., 1991). Many of the mid-Cretaceous thrust structures were reactivated at this time, including the Hatillo thrust (Bowin, 1966), which juxtaposed the Maimon belt against lower Eocene and upper Cretaceous rocks. Reactivated thrusts emplaced the periodotites in a northeast direction over the Peralvillo Formation. Horizontal axis rotation accompanying contraction steepened earlier faults and foliations. The Eocene reactivation probably faulted out high-grade metamorphic rocks, which are expected to have formed adjacent to the sole thrust of the ophiolite as well as tectonically thickening of the Maimon belt.

Geochemistry Rocks of the Maimon Formation have similar composition for both major and trace elements to those of the Izu-Bonin-Mariana arc systems (Lewis et al., 2000; 2002). The basaltic members of the Maimon Formation have a low but variable TiO2 content and low concentrations of HFSE and REE, characteristic of oceanic istand-arc tholeiites, the "primitive" island arc (PIA) series of Donnelly and Rogers (1978). The mafic rocks range from low Ti02-high MgO basalts with depleted (N-type MORB) concentrations of HFSE´s and boninitic affinities, to those with slightly higher Ti02 and lower MgO, more typical of oceanic arc tholeiites. A short interval of basalts in the Loma Pesada section show elevated TiO2 and high Fe/Mg ratios reflecting a more evolved series.

The felsic rocks, dominantly plagiorhyolites (quartz-keratophyres) with phenocrysts of quartz and plagioclase only, and like the basalts, are depleted in TiO2, HFSE's, and REE's compared with other arc rhyolites. Like the basalts, the keratophyres have a clear subduction signature with enrichments in LILE's, depletion in Nb, REE's and HFSE's with respect to N-type MORB.

Both mafic and felsic rocks of the Maimon Formation have low Pb and 208Pb/ 204Pb ratios (Horan, 1995) and fall in the Pacific MORB field (Fig.10). The chemically similar Water Island suite from the Virgin Islands has similar "primitive" Pb-isotope ratios whereas the other PIA suites (e.g., Los Ranchos Formation) which are more evolved chemically, have slightly more enriched Pb-isotope arrays (Fig. 10). The Pb data indicates a similar MORB source for all the initial bimodal volcanism in the Greater Antilles.

The isotopic and trace element data indicate the basalts and plagiorhyolites (spilites and keratophyres) have a common parent. It is difficult to derive the by direct melting of a mantle source because of their abundance and the low compatible element concentrations. Two possibilities are that the keratophyres were derived from a more mafic magma by fractional crystallization or that they are dehydration melts of arc crust (eg. Bear and Lofgren, 1991).

Los Ranchos Formation

The Los Ranchos Formation crops out mainly in the central part of the island north of the Maimon Formation and Hatillo Thrust and extends for about 100 km east to the Yabon Fault. The western area, originally mapped by Bowin (1966), has been the subject of extensive investigations by Stephen Kesler, his colleagues and students, along with geologists from Rosario Dominicana since the early 1970's. A recent paper (Kesler et al., 2005) gives an up-to-date review of the western area and contains a listing of references to their work on the Los Ranchos Formation. Earlier studies in the eastern area were made by Bourdon (1985), the Direccion General de Mineria and by mining companies for mineral exploration in the early 1980's. A two year thematic mapping study of the Cordillera Oriental, that includes the eastern extension of the Los Ranchos, was carried out by the SYSMIN project funded by the European Union (2002-2004). Maps and reports are available at the Direccion General de Mineria**.** For an account of the regional and petrological aspects of this work see Escuder et al. (2006).

The importance of the Los Ranchos Formation is that it is one several bimodal volcanic piles that make up the base of the Greater Antilles arc (Donnelly and Rogers, 1980; Kesler, 2005). In addition, the Los Ranchos Formation hosts the Pueblo Viejo gold-silver deposit, one of the largest high-sulfidation epithermal deposits of its kind in the world. Hydrothermal alteration is found throughout the Los Ranchos Formation and exploration activity for metals has been considerable. The most extensively explored area other than Pueblo Viejo is the Bayaguana district.some 60 km east of Pueblo Viejo. The general geological features and lithologies resemble those in the Pueblo Viejo area. A summary of the metallic mineral occurrences in relation to the geology was given by Espaillat (2005).

The Los Ranchos Formation consists largely of basalt/basaltic andesite and dacite/rhyolite (or plagiorhyolite) (a bimodal suite) that have undergone extensive low grade metamorphic recrystalization. Rocks of this type in the northern Caribbean have been commonly referred to as spilite and kerotophyre respectively (Bowin 1966; Donnelly, 1966). These terms are less commonly used today (eg. Nelson, 2000 ; Jolly and Lidiak, 2005) but in this writers opinion it is useful to retain this terminology (see also Kesler et al, 2005). Current opinion is that the mineralogy and to some extent the chemical composition of these rocks results from subsolidus reaction with sea water.

The Los Ranchos Formation (Table 1, Fig.11, 12). in the western area, is divided into basal units consisting largely of (locally pillowed) spilite flows (Cotui Member), kerotophyre and quartz kerotophyres flows, minor tuffs and intrusions (Quinto Sueño Member) which are overlain by debris flows and other fragmental rocks, finer grained, water-laid sedimentary (Meladito Member), and unpillowed spilite flows (Platanal and Naviza Members). The Meladito and Platanal members are cut, and partly overlain, by volcaniclastic and carbonaceous sedimentary rocks of the Zambrana and Pueblo Viejo Members, which host the mineralization (Russell and Kesler, 1991; Kesler et al., 2005). The Pueblo Viejo Member is composed of course fragmental rocks at its base that grade upward into carbonaceous sandstones and finally into fine-grained carbonaceous mudstones. These clastic rocks fill a basin that has been interpreted as a maar-diatreme complex (Sillitoe and Bonham,1984; Russel and Kesler, 1991; Kesler 1998; 2008) which formed during a phreatomagmatic eruption during late Los Ranchos time. The carbonaaceous sediments contain abundant plant fossils, that probably had a freshwater origin. Furthermore, there is a similar sequence of sedimentary clastic sedimentary rocks grading into carbonacous

sedimentary rocks at Bayaguana 60km east of Pueblo Viejo. In order to account for their regional occurrence and for their non-marine isotopic signature (Kettler et al.,1992) suggested that the carbonaceous sediments were deposited in a marginal basin and that their deposition is related to the oceanic anoxic event (OAE1b) that occurred at this time (Kesler, et al., 2005 a,b). As an alternative suggestion for the origin of the Pueblo Viejo ore deposits Nelson (2000) considered that the ore is spatially and temporally related to a series of previously unrecognized Early Cretaceous volcanic domes mantled by coarsely fragmental breccias.

A late Early Cretaceous age was established for the Los Ranchos Formation from four independent sources. (1) Fossil determinations from intercalated limestones/cherts gave an Aptian to Middle Albian age (Bowin, 1966), (2) The plant fossils in the Platanal and Pueblo Viejo Members were assigned a Lower Cretaceous Neocomian age (Smiley, 1982; Smiley, 2002), (3) The fact that the Los Ranchos Formation underlies the Hatillo Limestone of Middle Albian age with a depositional contact (Bowin, 1966; Russel and Kesler, 1991; Miczynski and Iturralde, 2005; Fig.12), (4) Model ages determined from Pb isotope analyses of the Los Ranchos volcanic rocks support a similar Lower Cretaceous age for both the volcanism and the mineralization at Pueblo Viejo. The isotope ratios suggest the age lies in the range of between 115 to 135Ma (Cummings et al., 1982).

It is only very recently that isotopic determinations have been made that give more precise ages for the magmatism and for the mineralization (Kesler, 2005 a ,b). U-Pb zircon ages were carried out on five samples. The lower part of the Los Ranchos, the Quito Sueno quartz keratophyre crystallized at either 118.6±0.5 Ma or 113.9± 0.8 Ma depending on the interpretation of the data. A quartz porphyry from the Pueblo Viejo Fragmental Member gave an age of 110.9 ± 0.8 Ma. The data of of two further samples of quartz porphyries from the same fragmental member were combined giving an age of 111.4 ± 0.5Ma. A sample of the Cotui (Zambrana) stock crystallized at 111.8 ± 0.6 Ma. This led Kesler et al. (2005b) to conclude that the Cotui stock was the probable source of both the quartz porphyry (quartz keratophyre) magmas and the mineralizing fluids. A slightly older U/Pb zircon age of 115.5 ± 0.3 Ma was reported for a sample of the Cotui stock by Escuder (2005). However the data show a second zircon population that gives an age of 112.8 Ma. A quartz keratophyre from Bayaguana analysed by the same method gave an age of 116.0 ± 0.8 Ma. $^{40}Ar/^{39}Ar$ determinations on hornblendes from the tonalities in the eastern area give ages from 106-109 Ma (Escuder et al., 2006). These are interpreted as final cooling ages.

In summary the present age data indicate that that the Los Ranchos magmatism was relatively short lived from 118 to 111 Ma and that the mineralisation occurred at the end of this period. Kesler et al. (2005b) have argued that the presnce of the carbonacous sedimentary rocks isolated the hydrothermal system and promoted ore deposition.

Reecently, Sillitoe et al. (2006, 2007) have proposed that the high sulfidation epithermal Au-Ag ore deposit at Pueblo Viejo is a product of Late Cretaceous-Early Tertiary rather than Early Cretaceous magmatism. This reinterpretation is based on evidence that the mineralization post- rather than predated the deposition of the Hatillo Limestone. This and other questions related to the Pueblo Viejo deposit and Los Ranchos Formation will be dicussed at a workshop at the 18th Caribbean Conference, March, 2008.

Good exposures of the Los Ranchos Formation are readily accessible in the area between the Hatillo dam and Cotui, and at the Pueblo Viejo mine. Although this particular field trip will not visit the Pueblo Viejo mine it will be possible to briefly examine the characteristics of several lithologic units within the formation.

Granitoid Plutons

Granitoid plutons occur in tw belts through Hispaniola. The main belt of plutons, several of batholithic dimensions, curves in a northwest direction through the Cordillera Central and into the Massif du Nord of Haiti (see the geological map of Hispaniola). These plutons intrude the Tireo Group and Duarte Complex in the Dominican Republic and the Terrier Rouges Series in Haiti. These granitoids belong to the low normative orthoclase group and to the low and intermediate K groups on K-SiO2 diagrams with the exception of some acid and intermediate rocks (Lewis, 1980; Lidiak and Jolly, 1996). The rocks are dominantly hornblende tonalities.

The second older belt of plutons lies north of the Loma Caribe suture zone and totally within the Los Ranchos Formation (see above). A number of small stocks of dioritic composition of apparent Eocene age intrude the Maimon Formation. The three groups of intrusive rocks are of different composition and age and represent different magmatic events.

Day 1: Santo Domingo to Cotui

Kilometers	**Observations**
0	Km 9 Autopista Duarte. Leave City of Santo Domingo.
11.06	Good exposure of Siete Cabezas Fm. Mainly breccias (see STOP 1)
13.8	Enter through gate on right and drive through to the quarry.
STOP 1.1	**Quarry in Siete Cabezas basaltic rocks.** Exposed in this quarry area wide variety of interesting textural features in volcaniclastic and flow rocks of the Siete Cabezas Formation. The rocks are a variety of breccias and flows that were erupted under submarine conditions. No detailed study has yet been made of the features, but some conclusions can be made as to the eruptive style and the general environment as to where the eruption(s) took place. The rocks are variety of breccias and flows. The dominant breccias are multilithic and some of these might be epiclastic, others are monolithic, very few crystals are present. Some are true hyaloclastites in the sense of

Rittmann. In one outcrop at the west end of the quarry the breccias include types composed almost entirely of fragments of pure glass (only slightly altered to palagonite and smectite). An exposure on the east of the quarry shows a vitric lava grading into a hyloclastite. The question arises as to whether the lithic breccias resulted from a process of chill-shatter fragmentation of the magma as it cooled or are they the result of phreatomagmatic eruptions. How far from their source did the fragments travel? Were the hyaloclastic breccias and flows produced from central vents, perhaps on the sides of seamount, or from eruptions along the fissure of mid-oceanic ridge? The latter seems unlikely since mid-oceanic ridge volcanic activity produces little fragmental volcaniclastic material.

16.8 Toll gate

18.7 Uppermost level of coastal terraces.

20.4 Beginning of road cut exposure of Duarte Complex.

25.6 **STOP 1.2** Continuous exposure of Duarte metabasalts along major curve in highway. Stop is off the highway through a gate to the right. The rock is **Duarte greenschist**. Note how the rock is variably deformed.

27.8 **STOP 1.3** Madrigal. Take road down to Rio Jaina. Cross the bridge (dam) and take path for short distance to outcrop of Duarte amphibolite in riiver **Duarte amphibolite in bed of Rio Jaina at Madrigal**. Adjacent to t tonalite plutons, Duarte mafic rocks have been metamorphosed to amphibolote facies. The nearest exposure of tonalite, the Medina tonalite stock, is 0.6 km to the west from this locality and the thickness of the amphibolite aureol (at the surface) is in the order of 1.2 km in this area. Note the massive nature (lack of foliation) of the outcrop. The amphibolite is patchy in appearance, probably reflecting variation grain size and texture in the original basaltic rock. Some of the amphibolite is spotted with porphyroblastic clusters of hornblende. Trains of amygdules can be seen in some places. The metabasalt (amphibolite) is cut by a second mafic phase (gray fine-grained rock).

29.0 Good view. Valley to the left (west) is underlain by tonalite. Duarte metabasalts form the hill to the west. The high hills(Los Siete Picos, -

900m) to the right (east), are mainly the very hard basalt of the Siete Cabezas Fm.

34.0		Villa Altagracia.
40.0		Valley with pineapple fields to the west in underlain by El Puerto tonalite. Hills to left (west) are Duarte. Low hills to the right foreground are Duarte. The high hills to the right are Siete Cabezas basalts.Quarry on right. Exposure of Duarte rocks. Here the rock is a metagabbro.
54.6		Pinkish weathered exposures of foliated tonalite. Cuts made in constructing the highway showed the complexity of the Duarte.
62.2	0.0	Piedra Blanca road Junction. Turn right to Maimón and Cotui.
1.0		Exposure of Siete Cabezas Fm on right.
3.8		Exposure of Siete Cabezas Fm on right..
4.4		Contact of serpentinized peridotite with Siete Cabezas Formation.
4.5		Laterite on south side of peridotite.
5.9	**STOP 1.4**	Extensive exposure of Loma Caribe serpentinized peridotite. Peridotite is harzburgite. Bastite pseudomorphs after opx. can be seen on some surfaces
6.3		Redeposited laterite on north side of peridotite.
7.1		Mafic dykes in peridotite. Contact of peridotite with Peralvillo Fm. not seen in this area.
8.3		Peralvillo Formation. Fine-grained laminated tuff or shale.
10.2	0.0	Maimón town. Turn right on to road to Cotui.
0.6		View of Loma Taina laterite mining operation.
2.6		Fine-grained well-foliated quarz-sericite schist (Maimón Fm).
2.9	0.0	Corner. Veer left to Cotui. Straight ahead to Cerro de Maimon Mine.
		Fine-grained laminated green mafic tuffs (Maimón Fm).

	Tocoa
4.7	**STOP 1.5** Greenish (chlorite) fine-grained well-foliated mafic tuffs of the Maimon Formation.
6.3	**STOP 1.6** The Hatillo Thrust brings schits of the Maimon Formation of apparent Lower Cretaceous age over mudstones of the Las Lagunas Fm of Upper Cretaceous age. The attitude of the fault plane is 211/ 25. The effects of erosion make it clear that the schistosity in the Maimon is parallel to the fault plane and that movement seems to have effected only the Maimon rocks. Maimon rocks here have undergone intense hydrothermal alteration with silica , sericite and pyrite alteration. Partial oxidation of pyrite produced solutions of iron which on precipitation resulted in the brownish varnish color.
6.9	Las Lagunas mudstones.
8.0	Las Lagunas mudstones. The lithologies and stratigraphic features of Las Lagunas Formation as documented by Boisseau (1987) can be examined in the Arroyo Noranjo in this immediate area of the Las Lagunas locality adjacent to the main road.
8.4	Small exposure of Hatillo Limestone.
8.9	Exposure to right of fractured mudstones of Las Lagunas .
9.6	Entrance to Rosario Dominicana-Pueblo Viejo gold-silver mine. Tour of Mine (see separate field guide).
10.6	Road to Loma El Rayo to left.
11.6	View directly south behind of Loma El Rayo (570m), highest peakwithin the Maimon Formation.
12.6	Roadside cliff exposure of **Zambrana Fragmental Member.** The rocks are clearly volcaniclastic and weakly foliated and bear a general resemblance to some of the Maimon units.
15. 0	View over the Zambrana Valley. The occurrence of abundant kaolin deposits suggests that the Zambrana Valley is underlain by a felsic intrusive rock (tonalite).

20.3	Climb a small rise over a tonalite stock (Cotui stock) intrusive into the Los Ranchos Formation. It is probably an extension of the felsic intrusive underlying the Zambrana Valey. This is the western-most exposure of th narrow belt of high level tonalite stocks that intrude the volcanic rocks of the Los Ranchos Formation. The tonalite has been dated by U/Pb on zircons at ca. 111.8 ± 0.6 or 112.9 ± 0.9 Ma. depending whether 8 grains relect subtle inheritance. Kesler et al., 2005). A separate sample of the tonalite gave an age of 115.5 ± 0.3 Ma but a second zircon population gave 112.8 Ma. View to the northeast (right) over Loma La Navisa composed of basalt
28.7	**STOP 1.8** Entering Cotui town. At km 20 turn left just passed the FreeTrade Zone. Go for 50 meters past the small church. Outcrop of **spilite pillow basalt and agglomerate** (possibly flow-top breccias)consisting of balls of gray spilite in an epidote-rich matrix. This is the Cotui Member and considered to be the oldest unit in the Los Ranchos Formation.
29.7	Proceed into Cotui town. Go arond the Park (one way anticlockwise)
0.0	At the northeast corner turn left and continue west. Turn left at the Ayuntiamento Municipal de Cotui/ Policia Nacional. Turn left and continue toward the the Hatillo dam (Presa Hatillo).
4.3	**STOP 1.9** Entrance on left into large quarry. Excellent exposure of **quartz keratophyre and keratophyre of the Quita Sueño Member Los Ranchos Fm.** The quartz keratophyre form small intrusions -flow structures are absent. In thin section the quartz keratophyres consist of equal proportions of quartz and altered plagioclase phenocrysts as large as 0.5 cm in diameter in a granoblastic groundmass consisting of albite, quartz and chlorite. Plagioclase phenocrysts are euhedral quartz phenocrysts are commonly rounded.
6.9	Hatillo dam (buit over Rio Yuna. Completed in 1985 for irrigation and electric power generation (-20 mega watts).
9.2	Exposure of basal part of **Meladito Fragmented Member (Los Ranchos Formation**) rocks made up of angular to sub-rounded blocks in a matrix of fine grained rock debris. The rocks include spilite, keratophyre and quartz keratophyre, suggesting that they were derived from the underlying Quito Sueño Member. The

mixed fragment population and nature of the matrix suggests that these rocks are debris flows.

DAY 1 PM

Continue north to La Mata and on to road. Take road to La Mata and on to San Francisco de Macoris..

Leave west side of Hatillo dam and follow dirt road about 2.5 km.

Encounter surfaced road follow this a further 7km to La Mata. Turn left.

Drive another 5 km to Cruce de Angelina. Turn Right.

Drive 2.5 km, take the left fork in the road to Las Guáranas (further 4.5 km)

Drive 10 km and arrive at main San F. De Macorix-Pimentel road at Cruce de Guiza. Turn left towards San Francisco

On arriving at fork in the road at gas station take right fork of Avenida Libertad.Dive 1.5-2 km. Turn right at Calle Castillo

Pa

Proceed northeast out of San Francisco de Macoris on the Cuevas road through Las Guazumas.

At the village of Cuevas (UTM 03**75**700E, 213**83**000N) turn left onto gravel road. Proceed past two shallow-water fords to the end of the road. Park just past the primary school on right.

Day 1 PM (cont.)

Southern Rio San Juan complex: Cuaba Gneiss Terrane, Rio Cuevas

Abbott, R.N., Jr. and Draper, G.

Setting Units and Structure

The southern Rio San Juan Complex is composed of two main units: the Cuaba Gneiss and the Rio Boba Intrusive Suite (Draper and Nagle, 1991). The Rio Boba intrudes the Cuaba Gneiss along the latter's northern boundary.

The Cuaba Gneiss is the only ultra high pressure (UHP) terrane presently known in the northern part of the Americas, (although there are hints that another such terrane exists, or existed, elsewhere in the North American Cordillera, MacKenzie et al. 2005). The Cuaba terrane is unusual among globally scarce UHP rocks because it was part of an intra-oceanic island arc (Jones et al. 1979, Kesler et al. 1977), confounding mechanisms of uplift involving buoyancy. The Dominican example may be one of only three where UHP rocks were delivered to the surface at an ocean-ocean convergent plate boundary, the two other examples being in Europe (G. Medaris, pers. comm.).

The Cuaba terrane is the southernmost unit in the Rio San Juan complex (Fig. 1). On its north side, the terrane is intruded by the Rio Bobo gabbro complex (g), except toward the east end, where the terrane is nonconformably overlain by Tertiary limestone (Tl). On its south side, the terrane is faulted against Tertiary siliciclastics (Tcs).

Our recent investigations have established that there are three units in the Cuaba Gneiss (Fig. 1), from west to east: (1) hornblende schist and fine-grained gneisses (Kc1), (2) hornblende gneiss, retrograded from eclogite (Kc2), and (3) a coarse-grained garnet metadiorite (Kc3). Most of our attention has focused on the second unit as this is the one that we have shown to be retrograded eclogite containing the UHP garnet ultramafic rock. Foliation and banding in the gneiss is generally vertical and trends NNW, somewhat oblique to the trend of the terrane. Poorly defined sheath folds suggest intense shear. Rotated porphyroblasts consistently suggest a dextral sense of shear.

Another intriguing feature of the Cuaba Gneiss is that it contains pods (xenoliths) of garnet-bearing ultramafic rock with very unusual mineral assemblages (e.g., the only natural occurrence of coexisting garnet+spinel+corundum). Detailed petrological studies on the garnet ultramafic rock enabled us to recognize the Cuaba gneiss as a UHP terrane (Abbott et al. 2005, 2006b, 2007).

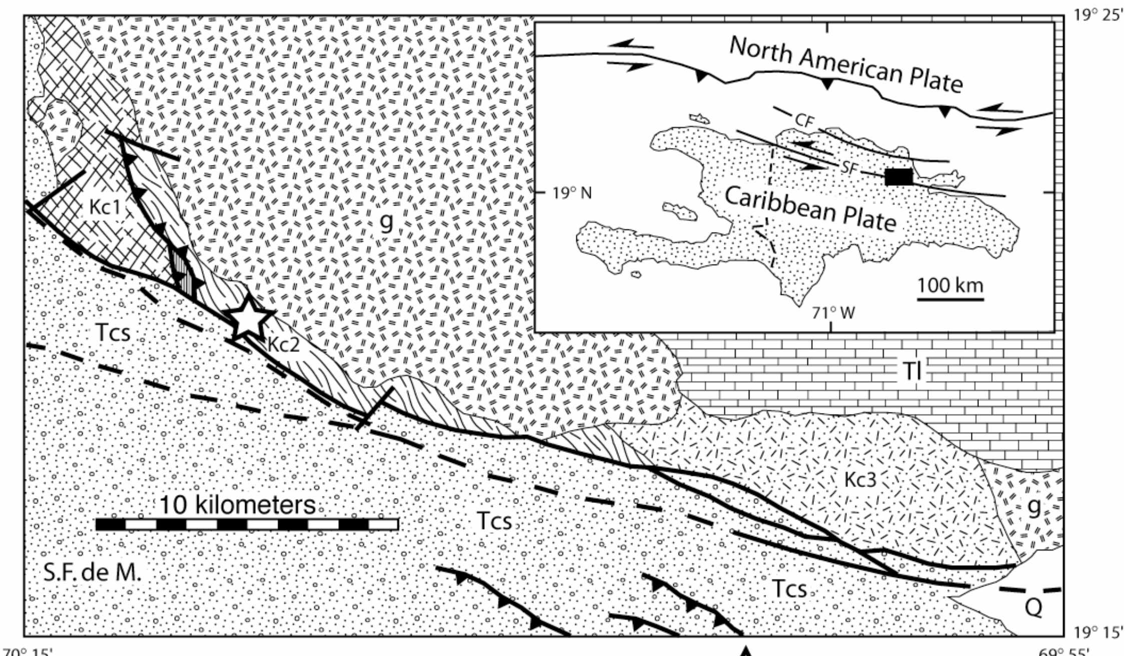


Figure 1. Geologic Map, and field trip stop, ☆.

Petrology

Abbreviations, consistent with Kretz (1983), used in text and Figure 2: Bt=biotite, Coe=coesite, Cpx=clinopyroxene, Crn=corundum, D=diamond, Ep=epidote, Gr=graphite, Grt=garnet, Hbl=hornblende, Ky=kyanite, Mag=magnetite, Ol=olivine, Omp=omphacite, Opx=orthopyroxene, Qtz=quartz, Rt=rutile, Spl=spinel, Srp=serpentine, Sym=sympletite. Mineral components (Fig. 2): ab=albite, cats=Ca-tschermak, di-diopside, grs=grossular, jd= jadeite, prp=pyrope.

The common mineral assemblage in all three units is Hbl + Pl (andesine) + Qtz + Rt +/- Grt +/- Bt +/- Ep. Draper and Nagle (1991) suggested a mafic protolith (basalt/diabase/gabbro) of oceanic crustal origin. Evidence for eclogite in Kc2 comes in the form of plagioclase-clinopyroxene symplectite + garnet, with greater or lesser amounts of hornblende depending on the extent of retrograde hydration (Abbott and Draper 2007, Abbott et al. 2006a). The retrograded eclogite occurs as mm- to dm-scale layers in otherwise symplectite-free hornblende gneiss. The UHP ultramafic rock (Abbott et al. 2005, 2006b, 2007), which includes garnet-bearing peridotite, garnet clinopyroxenite and more recently discovered olivine clinopyroxenite and clinopyroxene garnetite (Abbott et al. 2007), occurs as boulders ranging in size up to 5 m, weathered out of the gneiss. The ultramafic rock is interpreted as minor constituents of the Cuaba Gneiss. Distribution of the boulders shows that the source is in the gneiss. We have found a single locality where a very weathered ultramafic pod occurs in deeply weathered gneiss.

Eclogite. The texture is granoblastic to subtly foliated, depending on the amount of hornblende. Subhedral to euhedral porphyroblasts (1-3 mm) of garnet are enclosed by a narrow (~0.5-mm) mantle of a fine-grained intergrowth of hornblende, quartz and epidote. The garnet and its mantle are set in a matrix dominated by fine-grained (0.01-0.05 mm) vermicular Pl-Cpx symplectite (Sym). Minor minerals include Fe-Ti oxide, rutile, titanite, apatite, and pyrite. Titanite forms rims on the Fe-Ti oxide minerals. Hornblende is interpreted to be the last product of retrograde hydration. Prior to the formation of hornblende, the rock consisted of Grt + Sym + Qtz + Ep + Rt + Fe-Ti oxide. The inferred highest grade assemblage was Grt + Omp + Ky + Coe + Rt + Fe-Ti oxide (Abbott and Draper 2007).

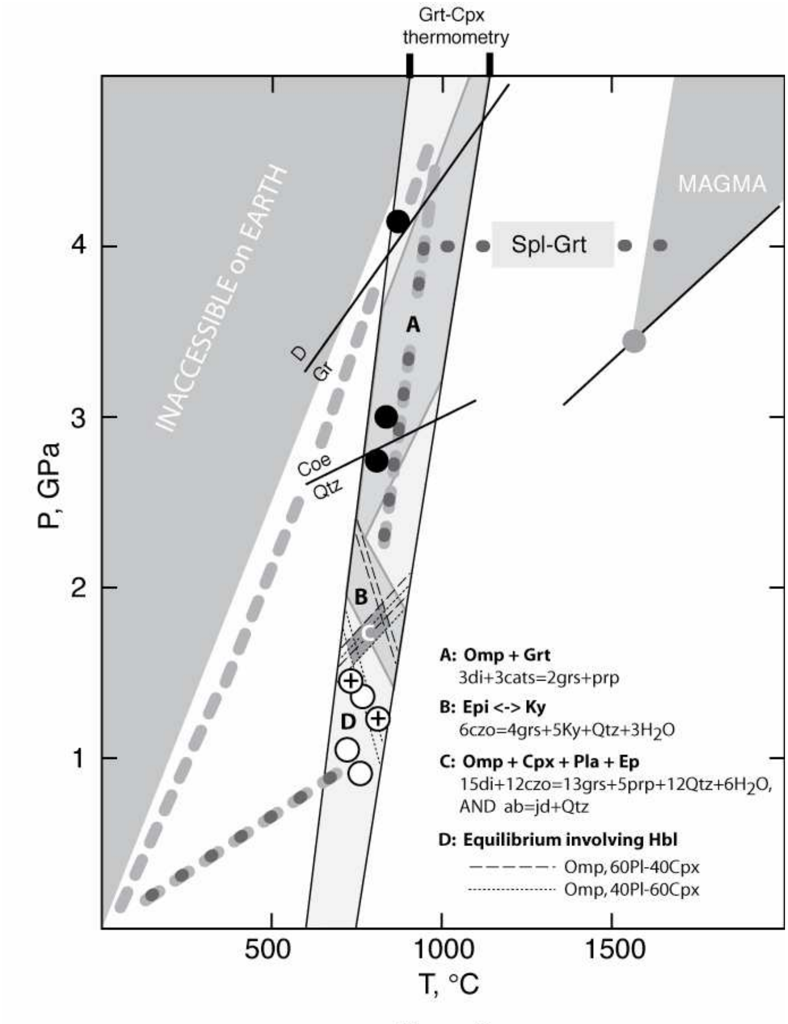


Figure 2

Estimated P-T conditions (Abbott and Draper, 2007) are shown in Figure 2. The shaded region "A" relates to the highest grade assemblage, Grt + Omp + Ky + Coe + Rt +

Fe-Ti oxide. The region "B" defines the highest pressure for epidote and lowest pressure for kyanite. Region "C" marks the conditions for the breakdown of omphacite to symplectic Pl + Cpx. Circles "D" relate to the formation of retrograde hornblende. The inferred P-T path is dashed, and corresponds to deep subduction of basalt to >120 Km (P > 4 GPa), followed by nearly adiabatic uplift to ~30 Km (~1 GPa), followed by a final stage of uplift with accelerated cooling through crustal conditions.

Garnet ultramafic rock and related olivine clinopyroxenite. The rocks are of igneous plutonic origin (dikes, cumulate texture) and document a series of mineral asssemblages related by fractional crystallization. Field relationships and theoretical considerations indicate the following products of fractional crystallization, from high temperature to low temperature:

I. Olivine clinopyroxenite: Cpx + Ol + Opx + Mag + (retrograde Cr-Spl + Hbl + Srp),

II. Garnet olivine clinopyroxenite: Cpx + Ol + Grt + (retrograde Hbl + Srp),

III. Garnet peridotite: Cpx + Ol + Grt + Spl + (retrograde Hbl + Srp),

IV. Garnet clinopyroxenite and dikes of clinopyroxenite garnetite:
Cpx + Grt + Spl + (retrograde Hbl),

V. Corundum-bearing garnet clinopyroxenite: Cpx + Grt + Spl + Crn + (retrograde Hbl).

Stability of coexisting Grt + Spl + Crn (Akermand et al. 1975) and high pressure melting experiments (Milholland and Presnall 1998) indicate that the magma could have existed only at P > 3.4 GPa and T > 1550 °C (Abbott et al. 2005, 2006b, Abbott et al. 2007). The relevant conditions are indicated in Figure 2 by the shaded region marked "MAGMA." Evidently, the magmatic system was in the deepest part of the lithosphere or within the asthenosphere. Fe-Mg exchange thermometry for Spl-Grt (Abbott et al. 2007) indicates temperatures approaching magmatic conditions. Fe-Mg exchange thermometry involving pairs of minerals from Ol, Cpx, Grt indicate subsolidus reequilibration at T = 800-1100 °C. The envisioned P-T path is dotted, and involves approximately isobaric (P ~ 4 GPa) cooling from solidus conditions (~1550 °C) down to ~850-900 °C (Abbott and Draper 2007; Abbott et al. 2006a), where the ultramafic rock was incorporated into, or otherwise mixed with, deep-subducted oceanic crust (eclogite). The xenoliths of ultramafic rock were delivered to the surface in the eclogite.

At this field trip stop, we will examine boulders of these intriguing rocks where the dominant lithology is garnet peridotite (III). Locally, where olivine is scarce or absent, corundum is possible in the residual assemblage Cpx + Grt + Spl + Crn (V).

Interpretation.

Figure 3 offers a bare bones tectonic interpretation (Abbott et al. 2006a).
The isobaric part of the P-T path for the garnet ultramafic rock took place in the mantle and involves delivery to the subduction zone in mid to upper Cretaceous time (1, Fig. 3). Garnet ultramafic rock of the mantle wedge was cooled and introduced into the deep-subducted oceanic crust in response to forced convection in the mantle wedge (corner flow) combined with erosion of the hanging wall of the subduction zone. The eclogite, with pods of the garnet ultramafic rock onboard, was transported up the subduction zone (2, Fig. 3), perhaps by reverse flow as modeled for instance by Gerya et al. (2002) and

Gerya and Yuen (2003). This stage was essentially completed prior to mid-crustal intrusion by dioritic to gabbroic rocks (Rio Boba Complex) of uncertain, but presumably Upper Cretaceous, age. The last part of the history relates to uplift through the crust to the surface (3, Fig. 3), completed by mid-Eocene, perhaps in response to initiation of transcurrent tectonics (Mann et al., 1990; Pindell et al., 2006; Draper et al., 1994, 1996; Pindell, 1994; Pindell and Barrett, 1990).

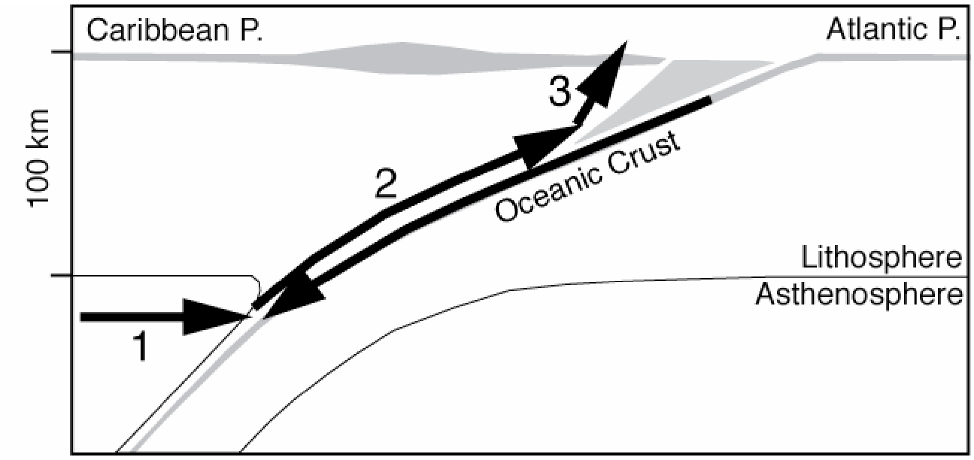


Figure 3

STOP 1.10

Proceed on foot upstream (north) by way of the trail on the east side of Rio Cuevas. The destination (~1 km) is a 2 meter-high water concrete catchment dam structure (UTM E0375.78, N2140.93). There are exposures of eclogite on the west side of the stream and boulders of garnet peridotite (among other lithologies) as we proceed back down stream. To the east is Loma de quita Espuela (985 m), the highest point in the area. To the west is Loma El Quemada (565 m).

At the dam. The freshest samples of eclogite come from the low outcrop ~25 m downstream from the water catchment, on the west side of Rio Cuevas. Rounded boulders of the eclogite can also be found in the stream bed. The eclogite has 3-5 mm subhedral porphyroblast of pink garnet in a light gray-green matrix of symplectite (plagioclase + clinopyroxene). Garnet is separated from the matrix by a thin (0.5 mm) mantle of hornblende. Quartz makes up less than 5 modal % of the rock.

Proceeding downstream. Boulders of garnet peridotite are first encountered near the mouth of a small tributary (Arroyo El Arroyaso), which enters Rio Cuevas from the east (~100 m downstream from the water catchment). Boulders of garnet peridotite can be traced up the arroyo to the east ~600 m. Further upslope the terrain is covered by landslide deposits. In the stream bed of Rio Cuevas, boulders of garnet peridotite range in size up to 3 meters. They are easy to recognize by the large (1-2 cm) phenocrysts of pink garnet. The garnets are mantled by pale gray-green clinopyroxene and late hornblende. The matrix consists of black, partially serpentinized olivine. Spinel occurs as minute (<0.5 mm) emerald green inclusions in the garnet. Locally, where olivine is scarce, the assemblage is Cpx + Grt + Spl + Crn (IV). Other ultramafic assemblages (I, II, IV) have not been recognized in this part of the drainage basin of Rio Cuevas. Boulders of the other assemblages (I, II, IV) occur mainly in the upper parts of the next two tributaries to the east (Arroyo Los Canos and Rio Los Bracitos).

Return to vehicles.

Proceed to Samana via San Francisco de Macorix, Pimentel, Nagua (about 2 hours)

DAY 2 AM SAMANA PENINSULA

Grenville Draper, Javier Escuder-Viruete and Andres Perez-Estaun

The Samana Peninsula forms another high pressure metamorphic terrane in northern Hispaniola, but is significantly different in protolith composition and character to the Rio San Juan Complex. Aspects of the geology and petrology has been described by Nagle (1974), Joyce (1991), Goncalves (20xx), and Escuder-Viruete et al.

The Samana peninsula is composed of marbles, pelitic schists and with a few minor calc-silicate lithologies garnet blueschists and eclogites. These are overlain by Neogene shallow water limestones.

Lithological Units

The metamorphic rocks are composed of four major units (after De Zoeten et al., 1991):

Majagual Marble. This unit outcrops in the southwestern Part of the peninsula and consists of both massive and schistose grey marbles. A single, and unconfirmed, report of a Campanian-Maastrichtian fossil has been reported from this unit.
Rincon Marble. The Rincon Marble unit outcrops on the northern and northeastern part of the peninsula and consists of thinly banded black marbles intercepted with bands of micaceous schist. Near Las Terrenas, original sedimentary features are preserved and the meta-terriginous schists are intercalated with dolomitic meta-calcarenites.
Santa Barbara Schist. This unit occupies the central part of the peninsula, geographically between the two carbonate units. It consists of terrigenous sedimentary rocks metamorphosed to mica schists. Locally the schists contain lawsonite indicating their high pressure meatmorphism.
Punta Balandra zone. This zone forms a narrow belt in the southeastern part of the penisinsula where both the protolith and metamorphism differ from that of the Santa Barbara Schists. In this zone, the pelitic schists are associated with talc schists, calc-slicates, garnet blueschists and eclogtes. The mafic rock have island arc geochemical affinities (Perfit and McCulloch, 1982, Perfit and others, 1982; Joyce, 1991. The age of the protolith of these rocks is unknown.
Radiometric ages from the Punta Balandra rocks indicate a minimum of 80Ma for initiation of metamorphism. Joyce (1991) suggested peak metamorphism for the Punta Balandra zone at 430-480 ^{0}C at 10-12kb. Phengite K-Ar ages ages suggest that the blocking temperature was reached at 37Ma.

Structure

The Punta Balandra zone and Majagual marbles are thrust NE over the Santa Barbara schists (Fig 2.1), which in turn are thrust northeastward over the Rincon Marbles. Both Santa Barbara schist and Rincon marble show strong internal shear structures such as NE verging asymmetrical folds, ?sheath folds and S-C facrics. The age of deformation is unknown, but seems to be synmetamorphic and so is assumed to be Late Cretaceous age.

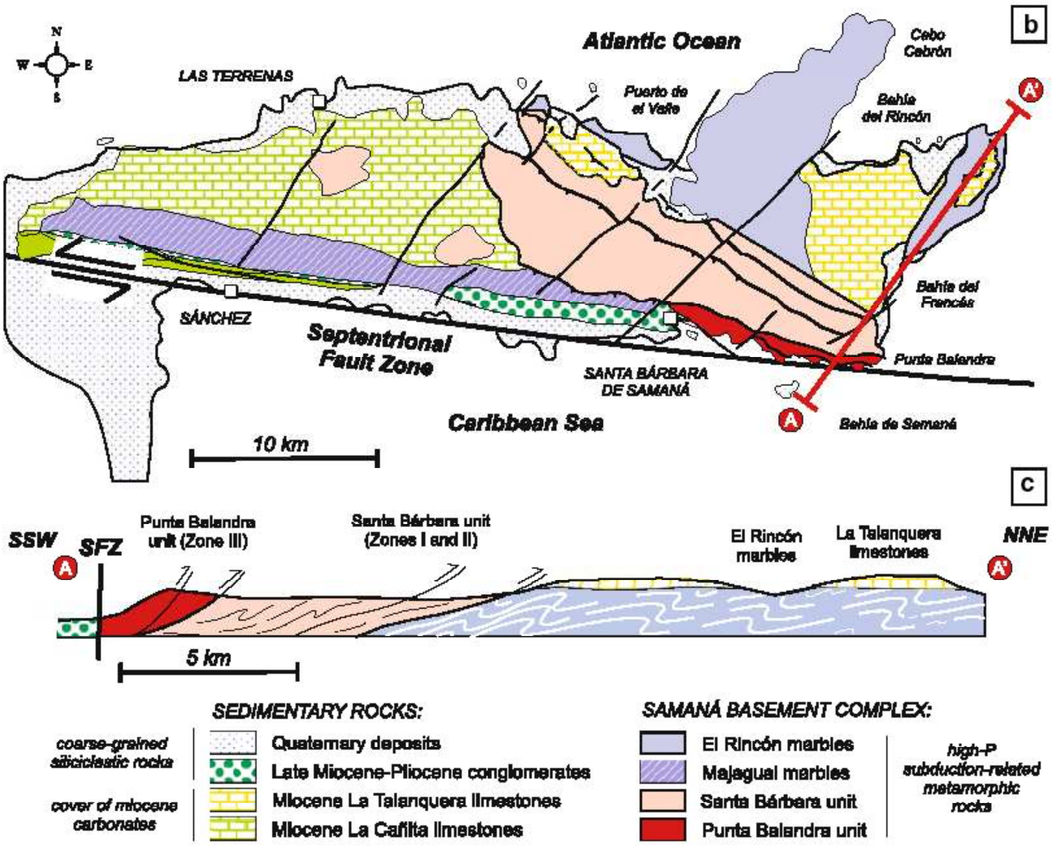


Figure 2.1. Geologic map of Samana and section across eastern Samana (from Escuder-Viruete, and Perez-Estaun, 2006).

In the Punta Balandra zone, Escuder-Viruete and Perez-Estaun describe a D1 fabric within eclogite and blueschist blocks. A D2 non-coaxial shear produced an L-S that wraps around the blocks. D3 deformation produced recumbent folds and transposes the D2 foliation. A late D4 produced 100m scale WNW-ESE trending upright folds.

Age of metamorphism

Phengites in the blueschists of the Punta Balandra zone have yielded a consistent pattern of ages of 36±0.13 Ma, 33.65±0.12 Ma(Ar-Ar), 33.68±0.47 Ma(inverse isochron), 32±2Ma(whole rock-phengite Rb-Sr isochron), 37 (K-Ar). This Late Eocene-Oligocene age corresponds to regional exhumation rathe than metamorphism. Age determinations of the metamorphism have been elusive. Perfit and McCulloch (1982) determined that metamorphism had to have been earlier than 80 Ma, Joyce and Aronson (1983) obtained an K-Ar age of 100 Ma±50Ma, and Escuder-Viruete et al. (1999) determined an Sm-Nd isochron age of 86±47Ma.

Metamorphic conditions

Nearly all of the P-T estimates of metamorphism and P-T path determinations have been from the Punta Balandra zone; comparative data is urgently needed for the Santa Barbara schist, although the latter unit's composition and weathering may preclude P-T determination.

Both Gonclaves et al. (2000) and Escuder-Viruete and Perez-Estaun(2006) developed P-T curves for the Punta Balandra zone.

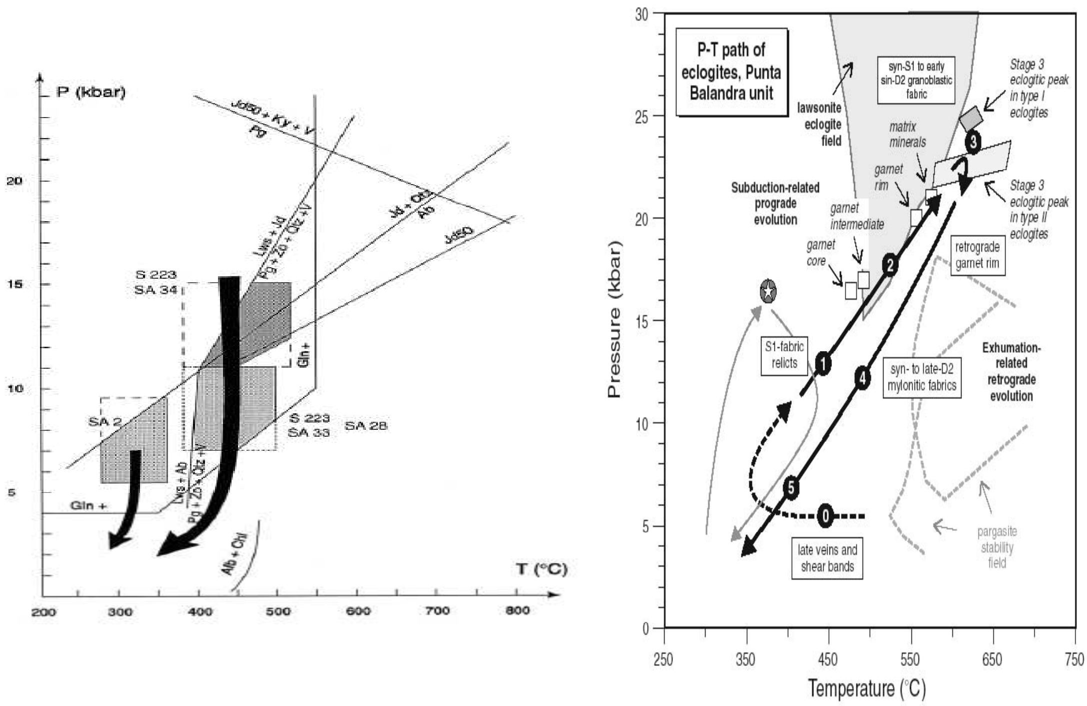


Figure 2.2 a P-T paths according to Goncalves et al (2000) and Fig 2.2 Escuder-Viruete and Perez-Estaun (2006).

Itinerary

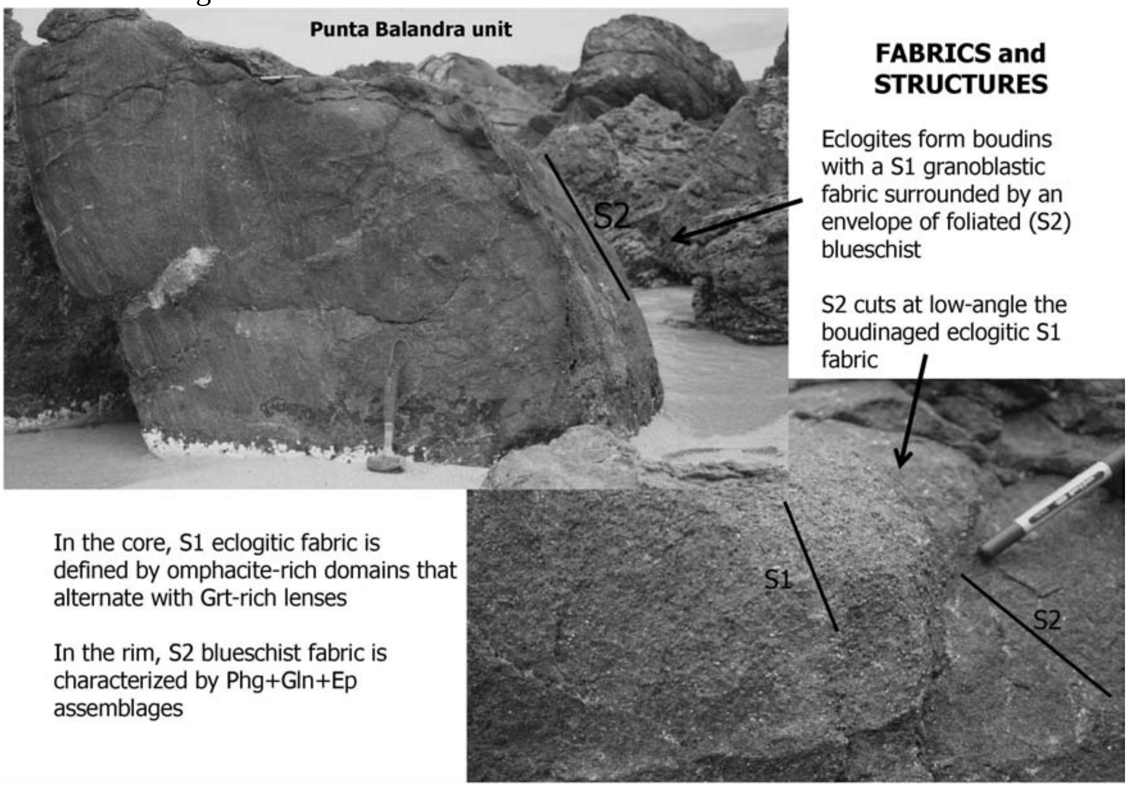
Note: localities are given according using a six figure grid reference on the UTM grids on the Dominican topographic map sheets. Easting quoted first. Set GPS readers to NAD 27 in order to get correct coordinates.

Leave eastward from Santa Barbara de Samana. 665 235 (Santa Barbara de Samana sheet)

Follow coast road to Punta Balandra (about 16 km). 761 208 (Las Galeras sheet).

STOP 2.1
4**76**100E 21**20**800N (Las Galeras sheet).

Park vehicles at 4**76**100E 21**20**800N. Descend path down to beach to see exposures of boudins of eclogite. If



If time allows, this section can be explored further east to Punto La Palometa (766 209)

Return to vehicle. Continue northward on road to Las Galeras for about 8-9 km

Turn right (eastwards) at 4**77**600E 21**26**600N (near Cuatro ojos) and continue along unsurfaced road toward Puerto El Fronton

STOP 2.2
4**82**5E 21**29**900N

Trains of large scale folds in Rincon Marble.
Descend toward sea to see highly deformed marble and cal-silicate lithologies. Some care may be needed in descending.

Return towards Santa Barbara de Samana.

At 4**66**100 21**23**900 turn right (north on road to El Valle).

Continue about 1.5 km to 660 251

STOP 2.3

Outcrops of Santa Barbara Schists for about another kilometer. Schists are fine-grained mica-schists with quartz and occasional lawsonite (not visible in hand specimen)..

Return to Santa Barbara de Samana.

Leave Santa Barbara de Samana and drive to Rio San Juan via Nagua and Cabrera on the North Coast Road (about 2 hours)

DAY 2 PM NORTHERN RIO SAN JUAN COMPLEX

Grenville Draper, Martin Krebs, Walter V. Maresch and Hans-Peter Schertl

The northern part of the Rio San Juan (RSJ) complex lieas at the eastern extension of the Camu Fault. The northernmost part of the complex is cut by many spaly faults that branch off the main Camu trend. The similarity of rock types in the southern Puerto Plata region suggests that the two regions were once contiguous. If this is so the lateral displacement on the Camu Faut is about 50 km.

The relationship of the northern part of the RSJ with the Cuaba Gneiss and Rio Boba intrusives to the southis still not clear.

Lithological Units

The units of the northern RSJ complex (see Fig. 2.3) were first identified by Eberle et al (1982) but were named and described in more detail by Draper and Nagle, 1991. Both coherent and mélange terranes are present both high-pressure, low-temperature (HP/LT).

Hicotea Schist. This unit consists of fine-grained schists and minor interbedded marble. A distinctive field feature of this marble is its highly fractured appearance. The protolith probably consisted of interbedded tuffs and minor limestones. Unpublished data indicate an arc geochemical signature. The rocks are metamorphosed to blueschist-greenschist facies.

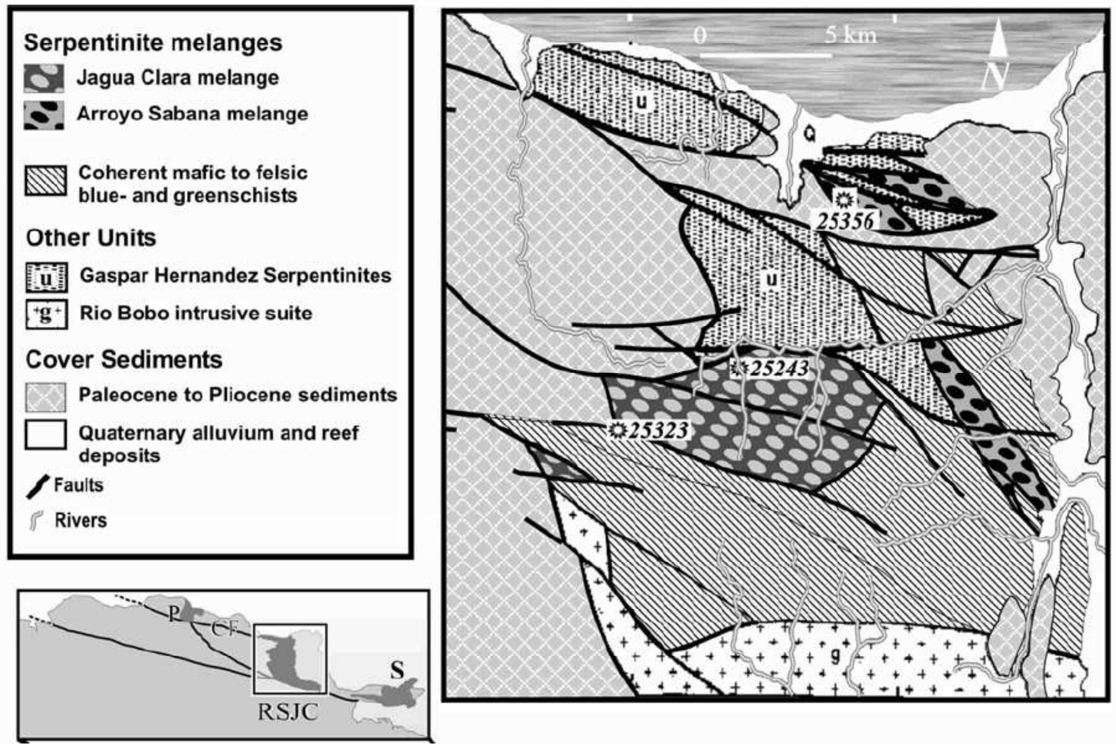


Figure 2.3 Map of the northern part of the Rio San Juan Complex (from Krebs et al. in press)

Puerca Gorda/El Guineal Schist. This unit is similar to the Hicotea Schist in compostition and metamorphic grade. They differ in that the Puerca Gorda contains no marble and that there are occasional bands of leucocratic schists. What was originally named El Guineal schist simply had a greater proportion of felsic schist. Regional geological mapping by the SYSMIN project will reveal if thee is merti in mapping these unis as separate entities.

Jagua Clara/Arroyo Sabana Melange. Originally Draper and Nagle thought that there were two separate mélange units in the complex based on the composition of the blocks in the bodies. Subsequent studies (Krebs et al, in press) has led to a re-evaluation of this notion and it might well be that there is really only a single mélange unit. The mélange has a serpentinite matrix containing blocks of blueschists, garnet blueschists and eclogites. The size of the blocks varies from fist-sized to tens of meters. Internal structures and in the blocks are variable. Some are granoblastic and show little fabric, others are strongly schistose and still others are strongly banded and show well developed shear zone structures such as sheath folds.

Gaspar Hernandez Serpentinite. This unit occurs between Rio San Juan and Gaspar Hernandez on the north coast. It contains inclusions of diabase and amphibolite, but HP/LT are either rare or not present. In some zones, crushed clastic sedimentary rocks of reminiscent of the Imbert Formation is present. The association of the serpentinites is a close one, although the exact relationship remains elusive. The base of the Imbert

Formation has conglomerates with high serpentinite cobble content. It could be that some of what is mapped as “serpentinite” in Puerto Plata and the RSJ complex are actually sedimentary serpentinites of the Imbert Formation.

Imbert Formation. This clastic sedimentary formation is much more extensive in the Puerto Plata area, but it occurs in the RSJ as a few small faut bounded slices. The lower part the sequence consists of coarse sandstone and conglomerates. Clasts of serpentinite are found in both and the conglomerates sometimes also contain clasts of metamorphic rocks. Further up sequence, the sandtones and conglomerated become interbedded with distinctive turquoise tuffs and the very top pf the formation is composed of thickly-bedded cream-colored porcellanous tuffs.

Metamorphic petrology and P-T-t of blocks in the melange

The blocks of metamorphic rocks encountered in the Rio San Juan serpentinite mélanges represent a variety of lithologies predominantly composed of various types of basic to intermediate magmatic protoliths. This description draws on a study of approximately 400 samples.

The blocks can be grouped into the following categories:
1) Omphacite-bearing blueschists and eclogites that can be further divided into:
- eclogite with calcic but without sodic amphibole
- eclogite with sodic amphibole
- garnet-omphacite blueschist
- omphacite blueschist without garnet

2) Blueschists without omphacite:
- garnet-bearing blueschist
- coarse-grained blueschist without garnet, jadeite, lawsonite
- fine-grained lawsonite-blueschist without jadeite
- jadeite-bearing blueschist (rare)

3) Orthogneiss (Metagranite, Metatrondhjemite)
4) Amphibolite
5) Metapelite (rare)
6) Jadeitite (rare)

Microanalytical study of 30 of these samples, with further complementary geochronological data from ten of these, has allowed pressure-temperature-time-paths to be defined (see Krebs et al., 2007). P-T trajectories are based on classical thermobarometers, multivariant mineral equilibria and pseudosection calculations. Geochronological methods include U/Pb, Lu/Hf, Rb/Sr and Ar/Ar.

Fig. 1 summarizes the petrological and geochronological data from three exemplary samples of eclogite and blueschist that allow a series of different but interrelated pressure-temperature-time paths to be delineated. Fig. 2.4 indicates all available P-T-paths for metabasic blocks from the Rio San Juan mélanges. Eclogites in general indicate a low P/T gradient during subduction and appear to record conditions in the early stages of the history of the subduction zone. Fig. 2.5 shows that for eclogites in this early, very

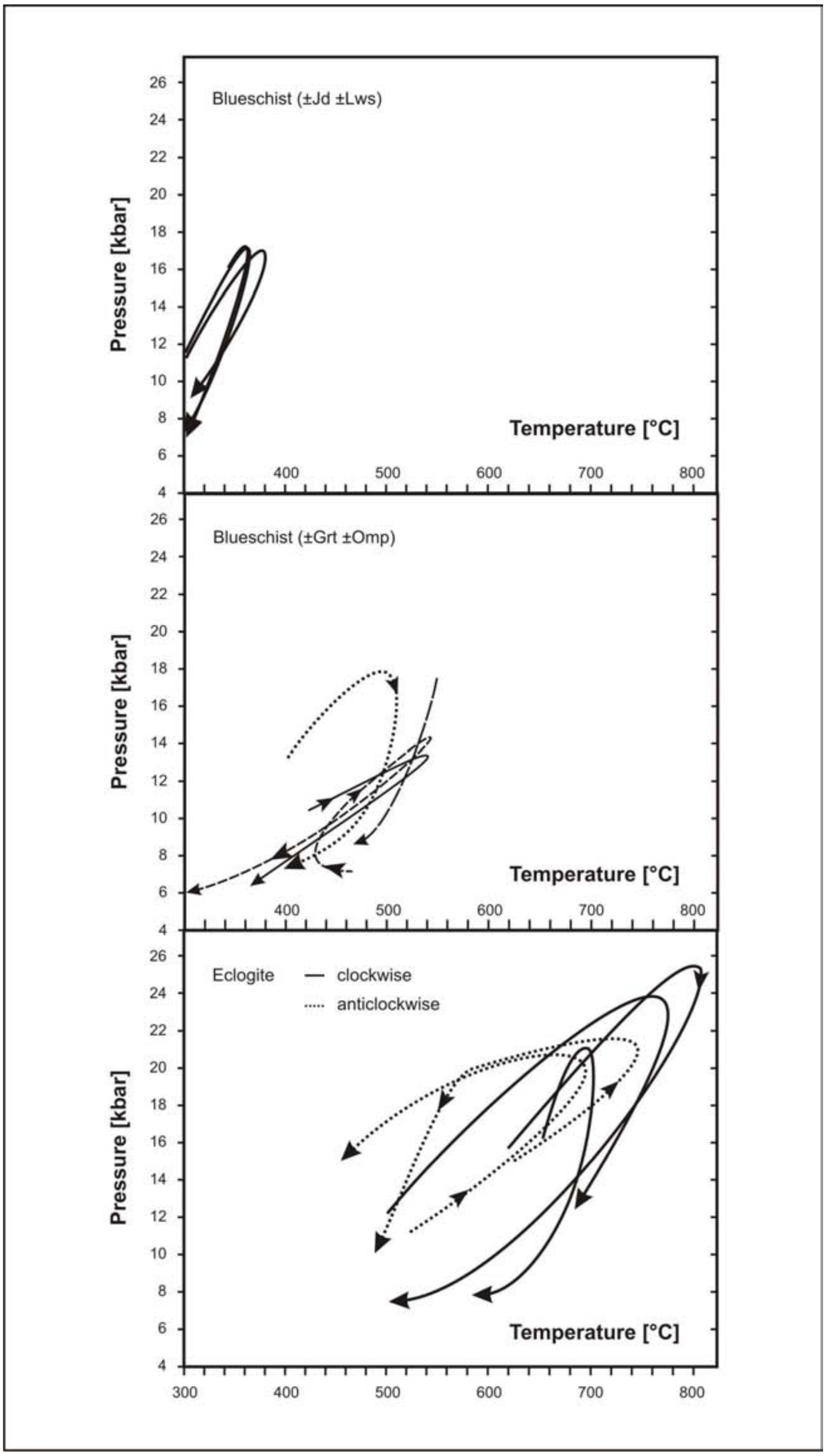


Fig. 2.4: Summary of exemplary P-T-t-paths for eclogite, omphacite-blueschist and jadeite-blueschist blocks in the Rio San Juan serpentinite mélanges (from Krebs et al., 2007).

heterogeneous stage, both clockwise and anticlockwise paths are evident, depending on how quickly the return flow was initiated.

Where age data are available, these indicate that clockwise, hair-pin, low P/T paths are typical for eclogites that were exhumed very early. Fig. 2.5 indicates an anticlockwise eclogite path where exhumation was initially arrested. For an example of this type, Lu-Hf data yield 103.9 ± 2.2 Ma for peak metamorphic conditions of 23 kbar / 750°C.

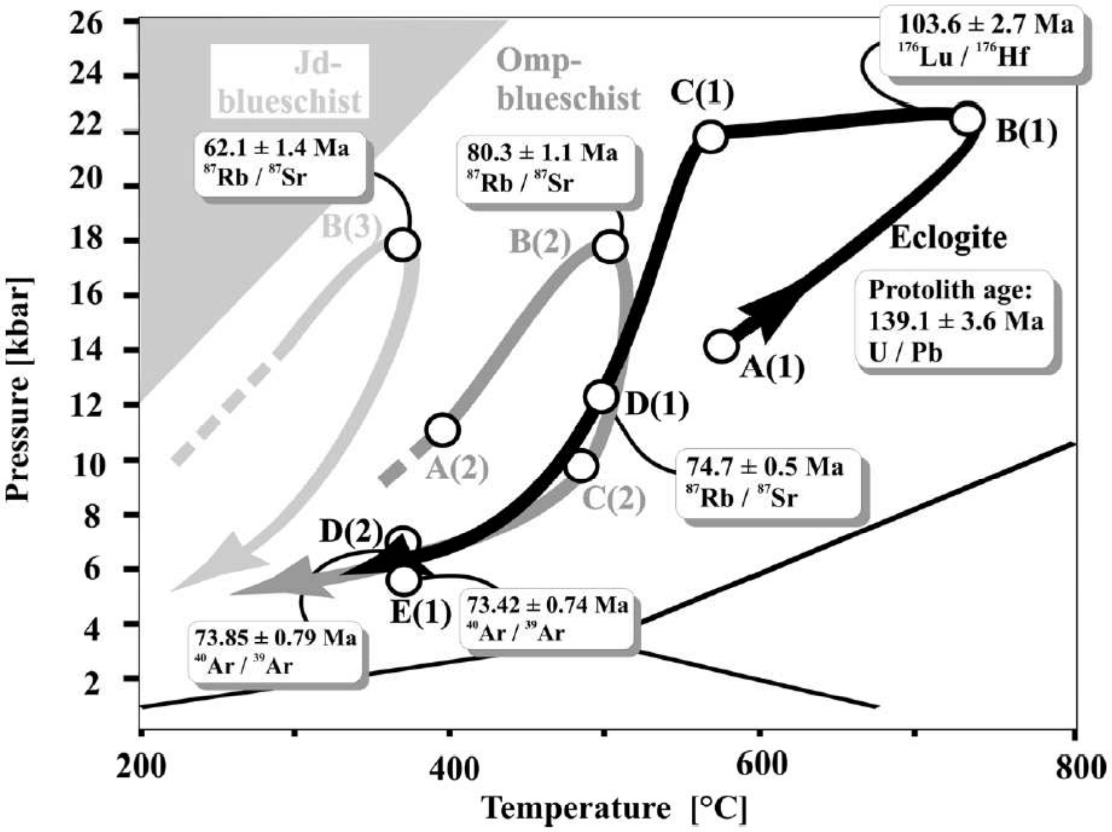


Fig. 2.5: Summary of P-T paths obtained for various metabasic blocks in the Rio San Juan serpentinite mélanges obtained from pseudosection analysis (from Krebs, 2008).

Blueschist blocks typically record the continuous cooling of the evolving subduction zone and show clockwise P-T-paths. Omphacite blueschists reach maximum P-T-conditions of 17-18 kbar / 520 °C at 80.3 ± 1.1 Ma (Rb-Sr age data). The mature subduction zone is typified by jadeite blueschists recording very high ("cold") P/T gradients. A Rb-Sr age of 62.1 ± 1.4 Ma dates peak metamorphic P-T conditions at 16-18 kbar / 340-380°C.

The array of P-T-t data allows overall cooling rates of the subduction zone at depths of c. 60 km to be constrained to c. 9 °C/Ma. Cooling rates and exhumation rates (i.e., vertical component of retrograde trajectories) of the metamorphic blocks are 9-20 °C/Ma and 5-6 mm/a, respectively. The derived P-T-t array can be compared with a 2-D numerical subduction-zone model published by Gerya et al. (2002; 45° slab dip, 40 Ma lithosphere age, convergence rates of 10 – 40 mm/a), which incorporates weakening of lithospheric mantle of the hanging wall by fluids emanating from the downgoing slab, resulting in an increasingly more funnel-shaped subduction channel system with time. The numerically derived array of simulated P-T-t paths as well as the calculated rates of exhumation and cooling agree well with the P-T-t data derived from the metamorphic blocks of the Rio San Juan serpentinite mélanges when convergence rates of 15 to 25 mm/a are chosen. This value is also in accord with available paleogeographic reconstructions calling for a long-term average of 22 mm/a (Pindell, pers. commmun., 2006; based on Pindell and Kennan, 2001). On the basis of the comparison, the onset of subduction in the Rio San Juan segment of the Caribbean Great Arc can be constrained to approximately 120 Ma. This segment was thus obviously active for more than 65 Ma. An orthogonal convergence rate of 15 - 25 mm/a requires that a minimum amount of 975 - 1625 km of oceanic crust must have been subducted.

Geochronology

As might be expected if the mélange is interpreted as a corner-flow subduction-channel terrane, there is a spectrum of ages from separate blocks.

The following ages were reported iby Krebs et al (in press). One eclogite gives zircon U-Pb ages of the protolith as 139.1±1.9 and 137.8± Ma (early Cretaceous). The same sample yields a 103.6±2.7 Ma (latest Early Cretaceous) Lu-Hf age for peak metamorphism at 23 kbar & 750^{0}C , a 74.7±0.5 Ma Rb-Sr phengite-garnet age and 73.42±0.74 Ma Ar-Ar age on phengite (late Campanian). An omphacite blueschist yielded a 80.3±1.1 Ma Rb-Sr phengite-amphibole age and 73.85±0.79 Ar-Ar on phengite. A jadeite blueschist gave a 62.1±1.4 Ma Rb-Sr phengite-amphibole age (early Cenozoic).

Itinerary

Arrive at Rio San Juan 3**87**400E 21**72**300N (Rio San Juan sheet)

Continue ~6km to La Cantera . Large Mogote of Cenozoic limestone.

Continue 3.5 km to entrance of *the Bahia Principe* resort.

Continue 3-4 km to Magante

OPTIONAL STOP 2.4
3**77**500E 21**68**700N
Melange blocks (but not matrix) of blueschists and amphibolites can be seen on hillside. If time is available and access easy, these can be viewed in more detail.

Proceed eastwards, toward Gaspar Hernandez, about 11 km to 680721

STOP 2.5
36**78**00N 21**72**100E (Gaspar Henandez sheet)

Road is very close to the sea at this point and there are outcrops of serpentinite at the south side of the road.

Serpentinite has clastic appearance and may be a sedimentary serpentinite associated with the Imbert formation.

Continue westwards to Gaspar Hernanez.

Entering Gaspar Hernandez, there is an intersection with a traffic light at 662 701
Turn left (south) at the intersection.

Continue about 11 kilometers to Joba Arriba.

On entering Joba Arriba there is an unpaved road on the left which leads to Jagua Clara where there is a fine view over the mélange terrain. Unfortunately. It is steep in parts and is best accessed by jeep or truck. Unfortunately, the road was made temporarily impassable by the rains of November and December 2007.

Continue through Joba Arriba. At the 90 degree continue straight between houses that leads to a ford across the Rio Joba at 3**66**700E 21**63**400 N. Park vehicles.

STOP 2.6
3**66**700E 21**63**400 N

Various lithologies from the mélange unit, which lies in the headwaters of the Rio Joba can be found in the river. Rock Types to be expected in the Rio Joba are:

Garnet-Omphacite-blueschist. Assemblage: sodic amphibole, epidote, garnet, omphacite, zoisite, quartz, plagioclase, ± calcic amphibole, white mica, chlorite, plagioclase (accessories: titanite, rutile, ore minerals)

These are foliated rock types with oriented chlorite, white mica, epidote, zoisite, omphacite and sodic amphibole. Symplectites of sodic amphibole + plagioclase surround omphacite. In part layered: differentiation into epidote/zoisite-rich- and sodic-amphibole/calcic-amphibole-rich layers.

Sodic-amphibole-bearing eclogite with large garnet porphyroblasts. Assemblage: omphacite, garnet, sodic and sodic-calcic amphibole, phengite, chlorite, epidote/zoisite, ± calcic amphibole, plagioclase, quartz, chlorite, stilpnomelane (accessories: titanite, rutile). These are foliated rock types. Garnet porphyroblasts contain near-rim inclusions of matrix minerals. Randomly oriented amphibole, epidote, chlorite, and stilpnomelane grow across the main foliation.

Eclogite without sodic amphibole. Assemblage: omphacite, garnet, calcic amphibole, epidote, chlorite, quartz, ± white mica, biotite, zoisite (accessories: rutile, titanite, plagioclase, pumpellyite, talc, carbonate, ore minerals). Both massive and foliated rock types occur. Massive types are characterized by granoblastic-polygonal garnet-omphacite assemblages. In the deformed types, the foliation is defined by fine-grained omphacite and recrystallized or newly formed calcic amphibole, white mica, chlorite, epidote, and titanite.

Orthogneiss. Assemblage: quartz, plagioclase, ± K-feldspar, white mica, epidote, zoisite, allanite, calcic amphibole, chlorite, lawsonite, pumpellyite, garnet (accessories: apatite, zircon, titanite, rutile, carbonate, ore minerals). Two main types occur: one is largely undeformed with magmatic texture preserved; newly crystallized lawsonite, epidote/zoisite is observed. The second type is intensely deformed with segregation into chlorite-white mica-pumpellyite-epidote/zoisite- and quarz-plagioclase-rich layers.

Return to Gaspar Hernandez. Turn westward at intersection of Joba Arriba road with coast road. Proceed to Cabarete

DAY 3

PUERTO PLATA AREA

Grenville Draper and James Pindell

The Puerto Plata area occurs north of the Camu Fault zone and is composed of Early Cretaceous (possibly Jurassic) ophiolitic rocks. Paleogene and Neogene clastic and carbonate sedimentary rocks.
There has been some controversy about the stratigraphy of the Puerto Plata since Nagle's original work on the area (see Fig 3.1). Most of the controversy concerns the interpretation of the enigmatic San Marcos Formation.

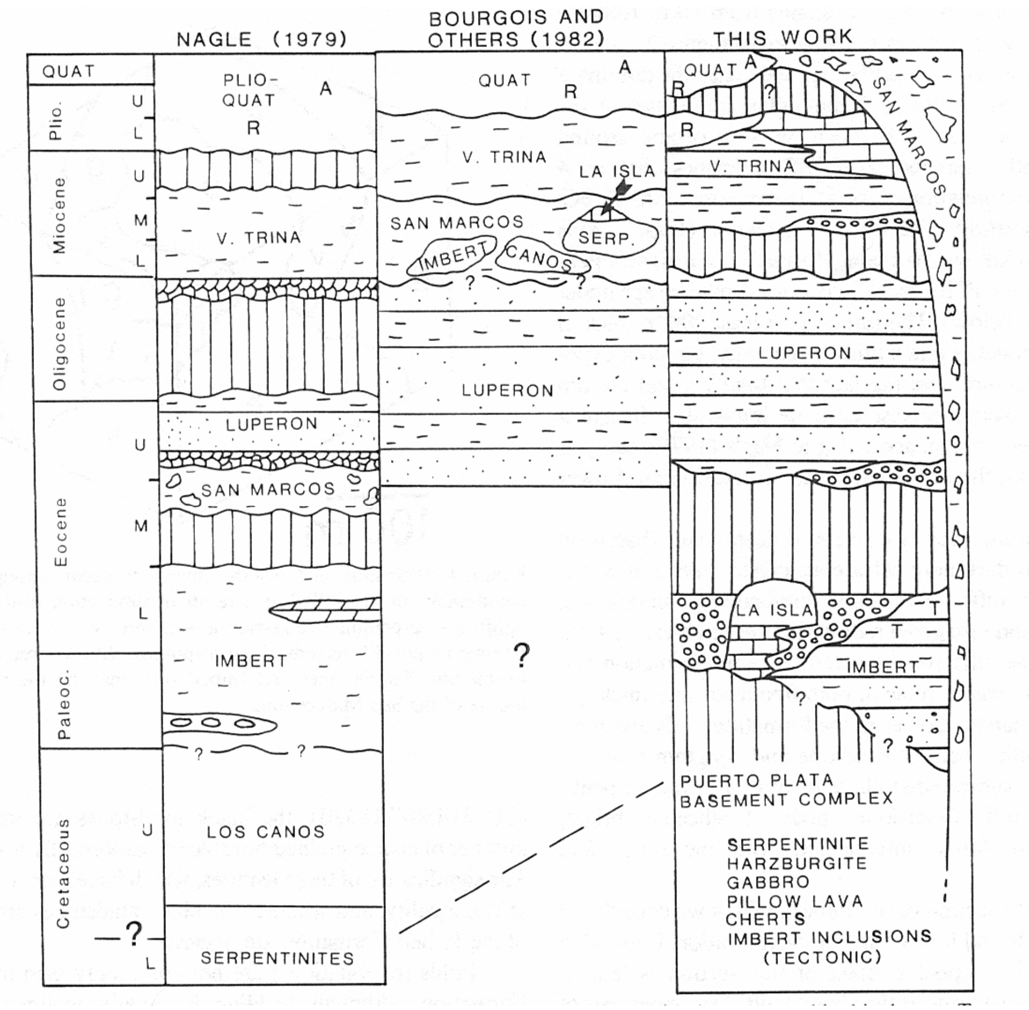


Fig 3.1 Comparison of different interpretations of the stratigraphy of the Puerto Plata area (from Pindell and Draper, 1991

Lithostratigraphy

Puerto Plata Basement Complex. The Puerto Plata basement complex is defined by Pindell and Draper (1991) and replaces the Los Caños and Serpentinites of Nagle (1966). It is the oldest unit in the Puerto Plata area and consists of serpentinite (with diabase and microdiorite indusions) leucogabbros, and pillow lavas. The individual components of tile complex do not appear to have any stratigraphic order and occur as fault bounded blocks 10 to 1000m in size. Finds of radiolaria from chert in the pillow lavas suggest an Early Cretaceous age (H. Montgomery. pers. comm.).

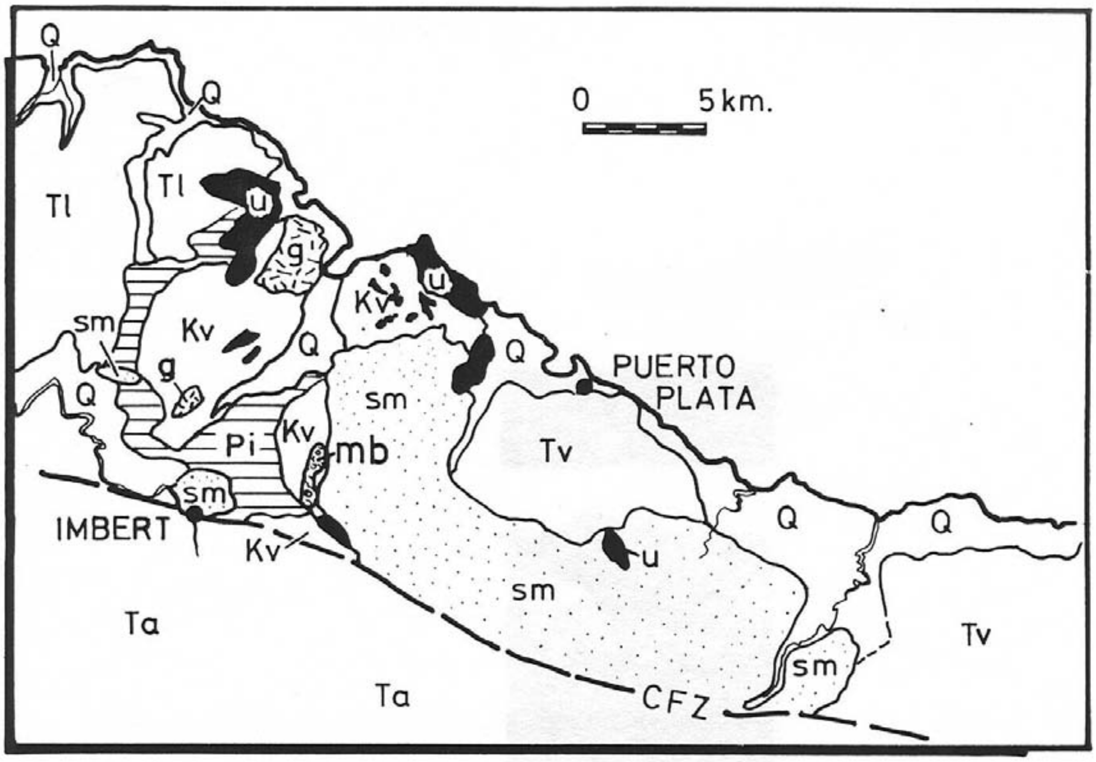


Fig 3.2 Geology of the Puerto Plata region (after Nagle 1966). Kv, g, and u = the volcanics, gabbros and serpentinites of the Puerto Plata basement complex; Pi = Imbert Formation; Tl = Luperon Formation; Ta = Altamira Formation; sm = Sam Marcos Formation; Tv = Villa Trina Fm./Isabela la Torres Fm; Q = Quaternary alluvium. CFZ = Camu Fault Zone

Imbert Formation. The unbent Formation consists of hlrbictitlc sandstones and debris flow conglomerates interbedded with distinctive, fine-grained, white tuffs. Black siltstone and mudstones are also present in the lower part of the sequence. The conglomerates and sands have fasts composed of serpentinite and schists. Some of the conglomerates are composed entirely of serpentinite debris. The thickness of the pale tuff beds to increases in the upper part of the sequence. Fossils found by Nag1e (1966) indicate a Paleocene age for the Imbert Formation.

La Isla Formation . The La Isla Formation (previously La Isla limestone) is a white, recrystallised, shallow water algal limestone that occurs as distinctive *mogotes* in the area to the west of Puerto Plata. Serpentinite conglomerates occur in isolation with the limestone and may form the base of the formation. The relationship to the underlying insert Formation, and especially its serpentinite conglomerates, is not clear. Nagle (1966), without any paleotological control, suggested a Miocene age for the limestone. Pindell and Draper (1991) suggest the La Lsla to be younger that the Imbert Formation, but older than the Luperon Formation (U. Eocene). La Isla Formation is, therefore, probably late Paleocene to early Eocene in age.

Luperon Formation. The Luperon Formation consists of thinly bedded sandstones and siltstones easily distinguished from the other formations of the Mamey Group by the presence of detrital mica and their pale buff color. Gypsum beds occur at the base of the formation. Nagle (1966) and Bourgois and others (1982) both assigned a late Eocene to late Oligocene age to the formation.

Villa Trina Formation/Pico Isabel de Torres series. The Villa Trina Formation consists of middle Miocene (? to Pliocene) clastic and reefal limestones thàt cover large areas of the Cordillera Septentrional south of the Camu Fault. In the Puerto Plata area the rocks composing the isolated Pico Isabel deTorres are of the same age and similar in composition. The basal part consists of conglomerates containing clasps of the older rocks of the area.including metamorphic rocks. Most of the formation, however consists of soft, white to cream colored marts and calcarenites. The uppermost part of the formation consists of hard reefal limestones that have developed a typical mogote tropical karst landforms.

San Marcos Formation. The San Marcos Formation (=San Marcos Olistostrome of Nag1e, 1966) is the focus of some stratigraphic controversy. The unit consists of decimeter to 100m sized blocks in a gray, argillite matrix. Blocks derived from a11 of the other units in the Puerto Plata area can be found in the melange including serpentinite, pillow lavas, and metamorphic rocks (marbles, arrlpltibolites and bluesddsts). The most common lithology, however, is the ?Luperon sandstone, which is often found with large tension gashes filled with selenite. Nagle (1966), based on some fossil finds thought the San Marcos to be Eocene in age and to be positioned stratigrallltically between the Impart and Luperon Formations. Bourgois and others (1982) found younger fossils in carbonate blocks and thought the Sat: Marcos to be Miocene. More recently, Pindell and Draper (1992) concluded from field relations that the San Marcos was post middle Miocene - the youngest unit in the region (apart from Quaternary fluvial and coastal deposits). Pindell and Draper (1992) suggested that the San Marcos is a mud diaper that breached the surface near the Camu fault and then flowed northwards.

Itinerary

Leave Cabarete and travel eastward to Sosua

Sosua

Entrance to La Union International Airport 33**63**00E 21**84**300N

Entrance to touristic road to Santiago

STOP 3.1
3**29**500E 21**82**500N (Puerto Plata sheet)

Panoramic view of the San Marcos Formation.
The San Marcos Formation presents a low relief area with occasional knobs, which are usually large blocks within the Formation. As can be seen from Fig. 3.2, the formation underlies a large part of the Puerto Plata. Region.

Pass Playa Dorada Resort complex on N side of road.

Traffic circle and baseball stadium at entrance to Puerto Plata.

By- pass road Puerto Plata. Views of Pico Isabel de Torres to south.

Mogotes of La Isla Formation close to road.

STOP 3.2 - CAUTION ! HEAVY TRUCK TRAFFIC FROM PORT OF PUERTO PLATA
3**17**000E 2193000N (approximate; Puerto Plata Sheet)

Serpentinite at Cofresi.
The serpentinite at Cofresi has a phacoidal fabric. No exotic blocks have been reported at this site, but a site further west on this same road has a block of microdiorite (now overgrown). At the western end of the outcrop there are rodingite dikes. The proximity to leucogabbros to the west of this outcrop and pillow lavas on the coasts begs the question if these units represent a fragment(s) of metasomatized oceanic crust.

Quarry in leucogabbro on north side of the road.

STOP 3.3 - CAUTION ! HEAVY TRUCK TRAFFIC FROM PORT OF PUERTO PLATA
2**16**100E 21**93**200N (Imbert Sheet)

San Marcos Formation near the monument at Barba Rucia
Exotic blocks of various lithologies (concentrated as lag deposits) in an argillite matrix. One of the most prominent lithologies here is a sandstone with veins of transparent

selenite. At this outcrop, a fist-sized piece of garnet blueschist by Brian Redmeond and Fred Nagle (Nagle, pers. comm. 1979). Nagle found large (1-2 meter) blocks of micaceous blueschists in the NE of Imbert. We have observed these, and other blocks in stream beds NW of Imbert. In our opinion, these blocks are simply lag deposits of blocks within the San Marcos Formation. Other blocks composed of metamorphic lithologies such as black marble and amphibolite have also been observed.

Large mogote of La Isla on north side of road.

STOP 3.4 OPTIONAL
2**08**500E 21**88**500N (Imbert sheet)

Quarry in white tuffs of the upper part of the Imbert Formation on south side of road.

Cross Camu fault at Rio Bajabonico. Continue 14 km to El Tunel. Pass bu outcrops of clastic rocks of the Upper Eocene to Lower Miocene Mamey Group.

SOUTHERN CORDILLERA SEPTENTIONAL

Rocks of the Southern Cordillera Septentrional (here defined as south of the Camu Fault zone and west of the Rio San Juan Complex) are imposed of (1) Cretaceous to early Paleogene igneous and carbonate rocks (2) late Paleocene to early Neogene deep marine mastic sentimental rocks and (3) late Neogene carbonate rocks.

Cretaceous to lower Paleogene rocks

Pedro Garcia Complex. The Pedro Garda Complex consists of massive basaltic rocks intruded by a small granodiorite plug. These rocks form the basement of the terrane east of tile Rio grande Fault zone. Nagle (1980) gave a preliminary K-Ar age of 7N7 Ma for a basalt.

Los Hidalgos and Palma Picada Formations. The Los Hidalgos Formation consists of thinly-bedded, micritic, pelagic limestones of upper Paleocene to lower Eocene age. These rocks are intruded by dikes and sills, and overlain by andesitic flows of the Palma Picada Formation.

Late Paleogene to lower Neogene: El Mamey Group. TheEl Mamey Group consists of four formations of deep marine mastic rocks that are distinguished on the basis age and/or composition and fades (Dolan and others, 1991)

Luperon Formation. This is the only formation of the E1 Mamey Group that occurs north of the Camu Fault zone and was first described by Nagle (1960. It consists of thinly bedded turbidity sandstones and siltstone easily distinguished from the other formations in the Mamey Group by the presence of detrital mica and by its pale buff color (see below).

Altamira Formation. This formation is late Eocene to Oligocene in age and ttrtconfornubly overlies the older Ternary rocks (Los hidalgos and Palma Picada Formations), south of the Camu fault zone and west of the Rio Grande Fault Zone, in the Altamira block of De Zoeten and Mann (1991). The formation consists of grey (but brown weathering), thinly-bedded turbidity sandstones and mudstones with subordinate pebble-conglomerates and thickly-bedded sandstones.

Las Lavas Formation. The Las Lavas formation is late Oligocene to early Miocene in age and occurs west of the Rio Grande Fault Zone. It is a 1600 m thick sequence of siliciclastic and clastic carbonate rocks that overlies tmcordbrzzlably the Altamira Formation in the Altamira Block. The Las Lavas Formation is distinguished lpm the Altamira Formation by the presence of carbonate conglomerates and calcarenite beds, and a greater abundance, in conglomerates of igneous fasts and grains of shallow water carbonates.

La Toca Formation. This formation, about 1200 m thick, is approximately contemporaneous with the Las Lavas Formation, but was deposited east of the Rio Grande fault zone where it "basement" rocks (Pedro' Garcia and Rio ban Juan overlies the Cretaceous complexes). It is distiguished computationally from the the Altamira and Las Lavas Formations by the presence of metamorphic and serpentinite coasts in the conglomerate beds. 'This formation is the host to the well-known amber deposits of the Dominican Republic.

STOP 3.5 El Tunel
Sto on south end of tunnel at 3**07**600E 21**72**200N (La Esperanza sheet)

Clastic sedimentary rocks of the Mamey Group.
Here. There are exposures of moderately-bedded gray (brown-weathering) sandstones and siltstones, with occasional limestone blocks that slumped into the basin. Syn-sedimentary faulting is present.

Return to Santo Domingo via Santiago, La Vega, Bonao

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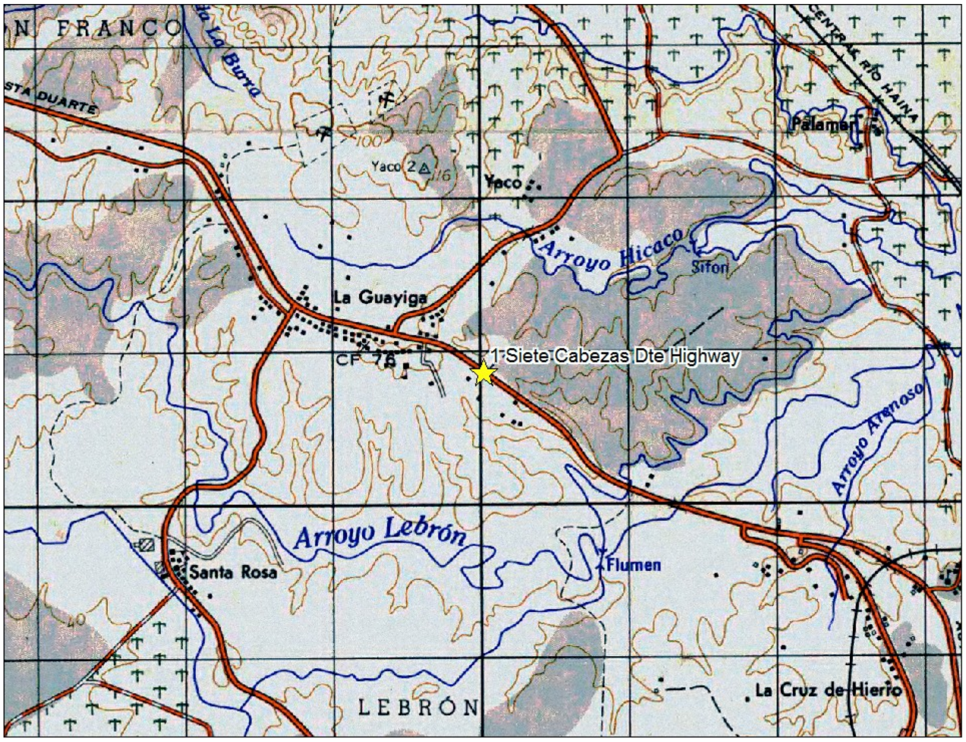
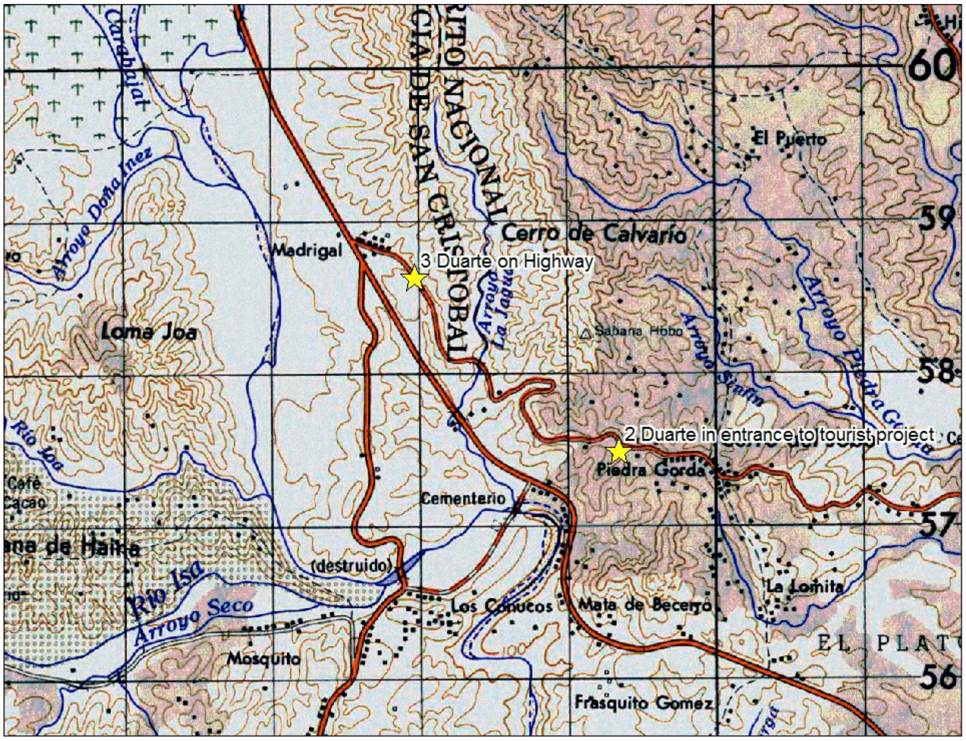
Field Trip 4 Stops day 1 am



Stop #1: On Duarte highway before the toll gates. Exposure of Siete Cabezas volcanics (coords 390,030 mE – 2,050,880 mN. I recommend this one as oposed to the one on km 22.

Stop #1: Siete Cabezas on Duarte highway.

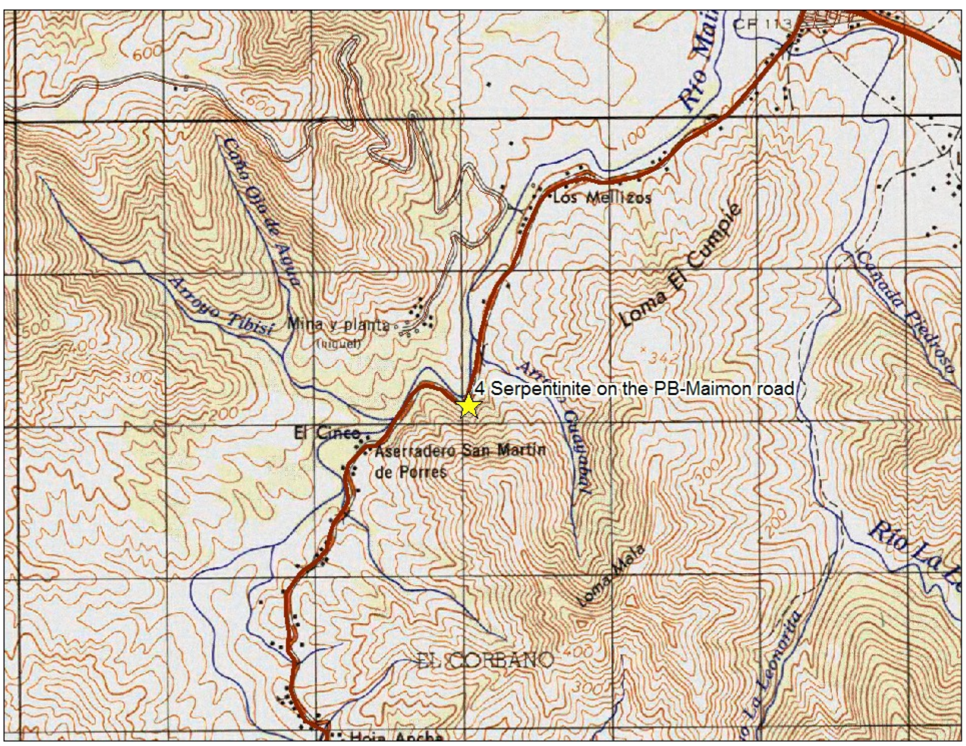
Stop #2: Duarte Schists on highway. Locality of Cerro del Jobo (coords. 379350 mE – 2,057,500 mN). Note: new highway not shown on map.



Stop #2: Duarte Schists on highway.

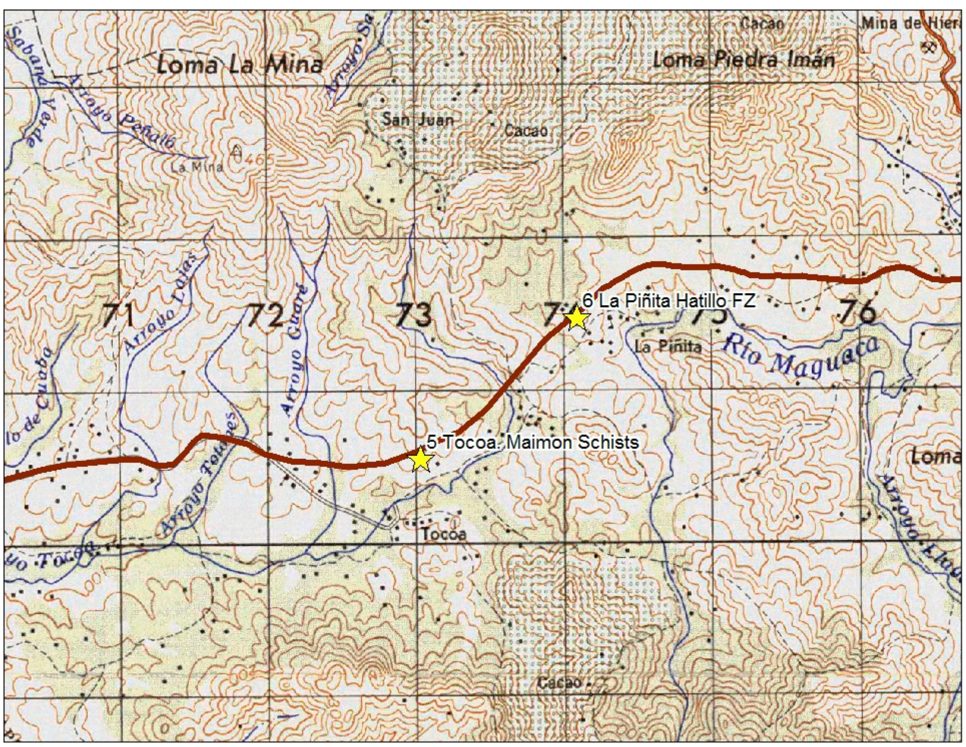
Stop #3: On Duarte highway. Outcrop of Duarte schists at Madrigal (377,973 mE – 2,058,646 mN).

Stop #4: Loma Caribe serpentinite on Piedra Blanca – Maimon road (mE - mN)



Stop #4: Loma Caribe serpentinite on Piedra Blanca – Maimon road (363,050 mE - 2,088,140 mN)

Stop #5: Tocoa. Maimon schists. (373,045 mE - 2,090,562 mN).



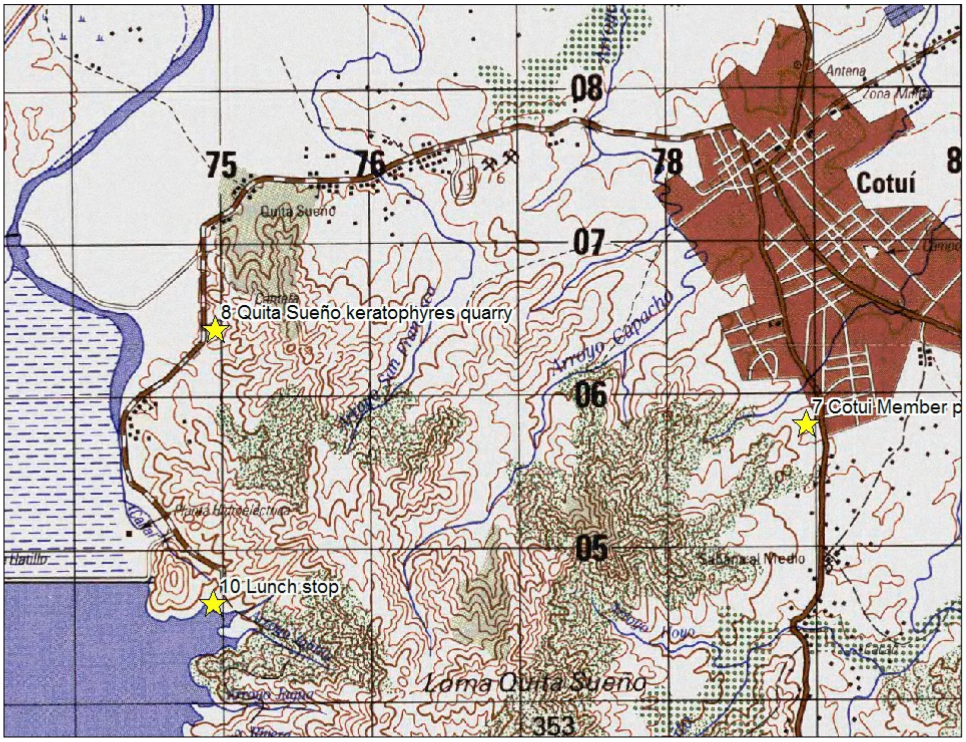
Stop #6: La Piñita. Maimon Schists and Hatillo Thrust fault (374,109 mE – 2,091,480 mN).

Stop #5: Tocoa. Maimon schists.

Stop #6: La Piñita. Altered Maimon Schist, Hatillo Thrust and Las Lagunas sediments.

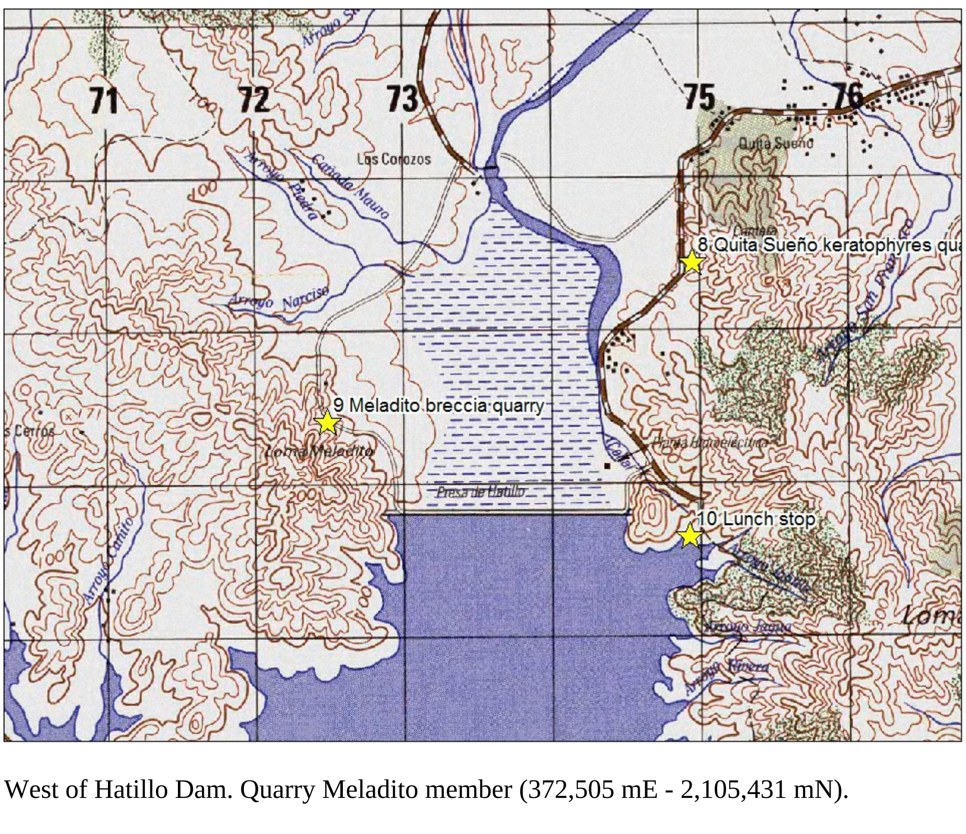
Stop #7: Cotui. Cotui Member of Los Ranchos, spilite basalts and pillows (378,956 mE - 2,105,820 mN).

Stop #8: Quita Sueño. Quarry of Quita Sueño keratophyre Los Ranchos member (374,972 mE - 2,106,464 mN)



Stop #7: Cotui member pillows near Cotui.

Stop #8: Quita Sueño member quarry on road to Hatillo dam.



Stop #9: West of Hatillo Dam. Quarry Meladito member (372,505 mE - 2,105,431 mN).

Stop #9: Quarry of Meladito lahar breccia member. West of Hatillo dam.