Ofioliti, 2002, 27 (1), 47-72

THE MOTAGUA SUTURE ZONE IN GUATEMALA

Field-trip guidebook of the I.G.C.P.-433 Workshop and 2nd Italian-Latin American Geological Meeting "In memory of Gabriel Dengo" January 2002

Giuseppe Giunta[*], **Luigi Beccaluva**[**], **Massimo Coltorti**[**], **Daniela Cutrupia**[*], **Carlos Dengo**[***], **George E. Harlow**[****], **Byron Mota**[♣], **Elisa Padoa**[♣♣], **Joshua Rosenfeld**[♣♣♣] and **Franca Siena**[**]

* *Dipartimento di Geologia, Università di Palermo, Italy (e-mail: giuntape@unipa.it)*
** *Dipartimento di Scienze della Terra, Università di Ferrara, Italy (e-mail: bcc@unife.it)*
*** *EXXON, Houston, TX, U.S.A. (e-mail: carlos.a.dengo@exxon.sprint.com)*
**** *Dept. Earth Plan. Science, Am. Mus. Nat. Hystory, New York, NY, U.S.A. (e-mail: gharlow@amnh.org)*
♣ *Cementos Progreso S.A. and Societad Geologica de Guatemala, Guatemala (e-mail: bmota@cempro.com)*
♣♣ *Dipartimento di Scienze della Terra, Università di Firenze, Italy (e-mail: padoa@geo.unifi.it)*
♣♣♣ *Ravenswood Road, Granbury 7302, Texas, U.S.A. (e-mail: balam@yahoo.com)*

INTRODUCTION

The Caribbean Plate (Fig. 1) consists of a poorly deformed central portion (Colombia and Venezuela Basins) delimited by two pairs of active systems. It results from the Mesozoic to Present interactions with the adjacent Nazca, Cocos, and Americas Plates.

The margins of the Caribbean Plate are represented by extensive deformed belts resulting from several compressional episodes beginning in the Cretaceous, subsequently affected by tensional and/or strike-slip tectonics.

These deformations have affected large portions of the Caribbean and adjoining plates. The Caribbean lithosphere has been deformed and tectonically emplaced over the Pacific and Atlantic oceanic crusts producing the western and eastern arc systems of the Central American Isthmus and Lesser Antilles. It has also been squeezed against the North and South American continental crusts thereby originating suture zones in the Cordillera of Guatemala, the Greater Antilles and Venezuela. The more internal Caribbean marginal areas were subsequently deformed and are involved in several accretionary prisms in Venezuela, Colombia, Panama, Hispaniola, etc. (Stephan et al., 1986).

Various "flower structures" with opposing vergences are identified along the northern and southern Caribbean margins where preferential shortening directions were controlled by diachronous oblique, movements. The northern and southern Plate margins consist mainly of transpressive or strike-slip shear zones, whereas the western and eastern margins are represented by convergent systems and related magmatic arcs. The Caribbean Plate margins include Jurassic-Cretaceous ophiolitic complexes exposed along suture zones and as accreted terranes on the northern, southern and western sectors of the plate.

The present-day borders of the Caribbean Plate follow these deformed belts. Sinistral and dextral strike-slip shears

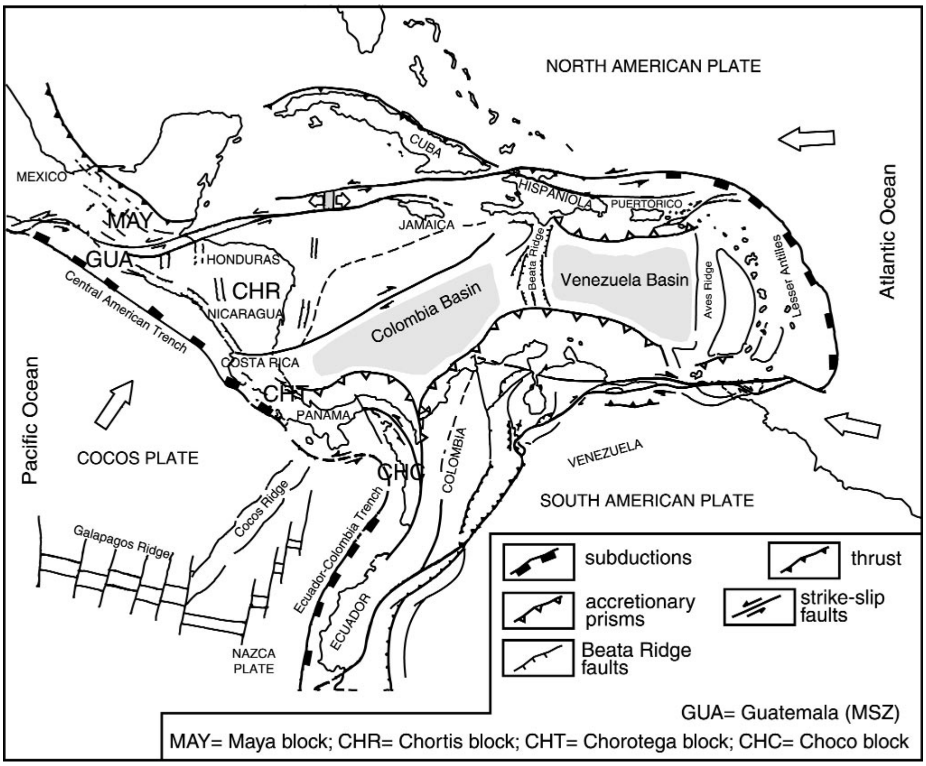

Fig. 1 - Structural sketch map of the Caribbean area (modified from Beccaluva et al., 1995).

occur respectively on the northern and southern margins. Therefore, certain portions of the deformed Caribbean lithosphere are now included in the crust of the adjacent plate margins, and should no longer be included in the Caribbean domain (s.s).

Systematic investigations carried out in recent years on the most important peri-Caribbean ophiolites allow reconstruction of the regional geometry, magmatic affinity and original tectonic setting of these oceanic units. The main results of investigations by the Italian-Caribbean Tectonics Group were presented at the International Geological Congress of Brazil 2000. The aim of the present field-trip is to provide an overview of the Motagua Suture Zone architecture in Guatemala, and to contribute to the debate on the origin and evolution of the Caribbean Plate in the framework of the I.G.C.P.-Project 433.

The workshop and field-trip have been held "In memory of Gabriel Dengo".

The field-trip was organized by the Italian Caribbean Working Group, under the aegis of IGCP, Project 433; the Sociedad Geologica de Guatemala; GLOM, the Italian Working Group on Mediterranean Ophiolites; CESEM, the Centro de Estudios Superiores de Energia y Minas - Facultad de Ingenieria, USAC Guatemala; CNR, the Italian National Council of Researches; the Direccion General de Mineria - Ministerio de Energia y Minas de Guatemala; Cementos Progreso S.A. Guatemala; and the Italian Institute of Culture in Guatemala.

Financial support was provided by the MIUR, Ministero Istruzione, Università e Ricerca Scientifica (Project Cofin 2000); the CNR, Consiglio Nazionale delle Ricerche; the IGCP/UNESCO, International Geological Correlation Project 433.

The following co-authors have collaborated in the discussion of specific topics:

- C. Dengo - the Motagua Fault System and peridotites;
- G. Harlow - the jadeitites-albitites of the North Motagua Unit;
- J. Rosenfeld - the Sierra Santa Cruz Unit;

THE MOTAGUA SUTURE ZONE (MSZ)

The present-day north-western margin of the Caribbean Plate in Guatemala is exposed along the Motagua Suture Zone (MSZ) (Figs. 2, 5) that links the Middle American trench with the Cayman Islands extensional system (Finch and Dengo, 1990; Beccaluva et al., 1995). The MSZ represents a sinistral shear-zone between the Maya and Chortis continental Blocks, and includes the Motagua Fault System (MFS) comprising the E-W and ENE-WSW strike-slip faults (in places still seismically active) of the Polochic, Motagua, Cabañas, and Jocotàn subsystems. The Motagua Fault System is remarkably complex and includes E-W trending uplifts (Sierra de Chuacus, Sierra de Las Minas, Montañas del Mico) and pull-apart basins (Lago Izabal, Bananera, etc.), as well as N-S directed grabens (Guatemala, Chiquimila, etc.) that result from interaction of the Motagua zone and the subduction of Pacific crust.

Three sectors can be distinguished on the basis of the

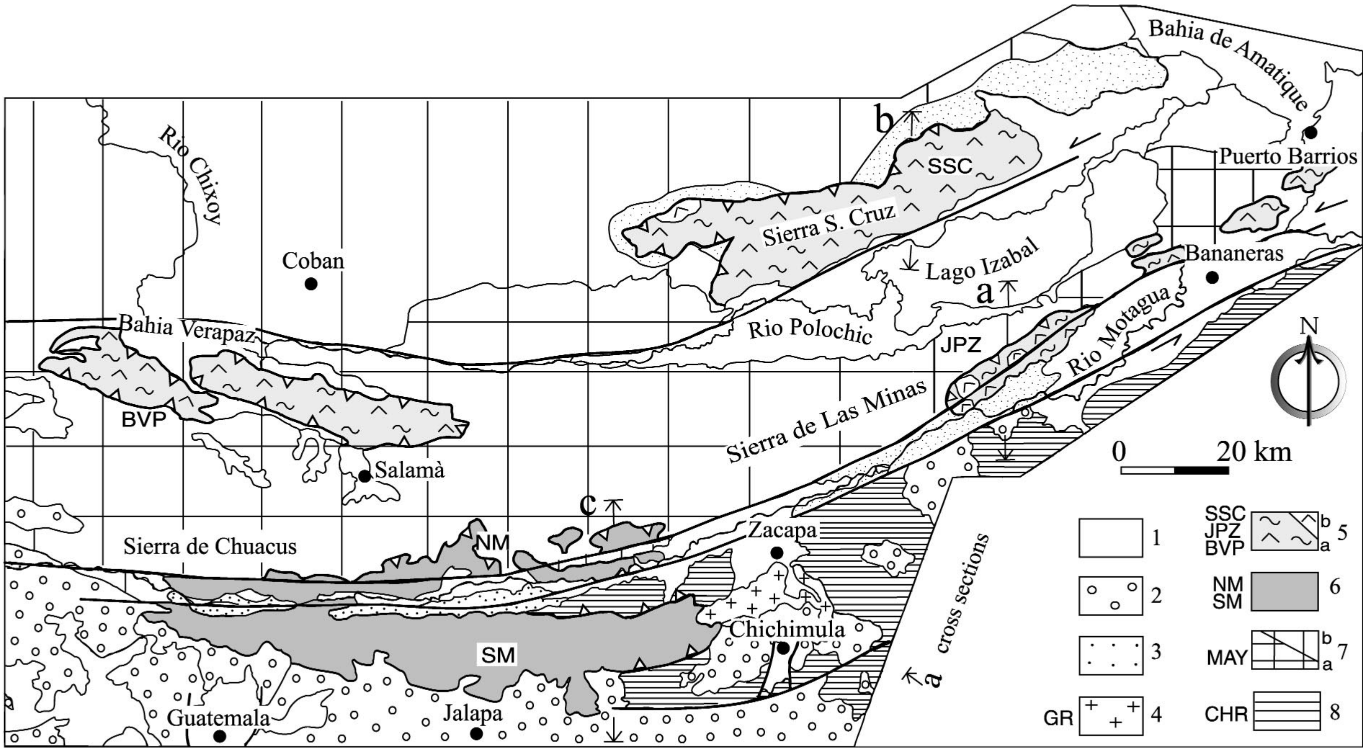

Fig. 2 - Tectonic sketch map of the Motagua Suture Zone in Guatemala (modified from Beccaluva et al., 1995). a, b, c = cross sections of Fig. 5.
Main Units: MAY= Maya cont. Block; BVP= Baja Verapaz U.; SSC= Sierra Santa Cruz U.; JPZ= Juan de Paz U.; NM= North Motagua U.; SM= South Motagua U.; GR= Zacapa granitoids; CHR= Chortis cont. Block.
Legend: 1=recent deposits; 2=Tertiary-Quaternary volcanics; 3=flysch and molassic deposits (Late Cretaceous-Eocene); 4= Arc tonalitic magmatism (granitoids,GR) (Late Cretaceous-Eocene); 5= Volcano-plutonic supra-subduction sequences (peridotites, gabbros and basalts, andesites, showing IAT (5a) and IAC (5b) affinities) with carbonatic-terrigenous sediments (Cretaceous); 6= MORB ophiolites (mantle peridotites, gabbros and basalts) with radiolarites to carbonatic-terrigenous sequences (Late Jurassic-Early Cretaceous); 7=continental basement (7a) and sedimentary covers (7b) of the Maya Block; 8=continental basement of the Chortis Block.

morpho-tectonic regional setting (Fig. 3):

a) the northern sector of the MSZ is characterized by north and north-east verging folds and by widespread, carbonate-terrigenous deposits overlying crystalline basement that is exposed in several tectonic windows. This area corresponds to the Maya Block (MAY), in turn belonging to the North American Plate (NOAM). According to Finch and Dengo (1990) and Burkart (1994), the Maya Block corresponds geographically to the area east of the Isthmus of Tehuantepec that includes almost all the Mexican states of Tabasco and Chiapas, plus the Yucatan Peninsula, Belize, and Guatemala north of the Motagua valley. This area has also been called the Yucatan Block.

Seismic data and gravity anomalies suggest that the Maya Block is underlain by continental crust ranging in thickness from 20-25 km in the Yucatan Peninsula to 30-40 km in the southern portion of the block. The Maya Block consists of a crystalline basement unconformably overlain by Late Paleozoic sedimentary rocks deposited in a basin occupying parts of Chiapas and Guatemala. Northward, the stratigraphic sequence continues as a widespread and very thick Mesozoic section comprising continental clastic sediments overlain by evaporites and carbonates.

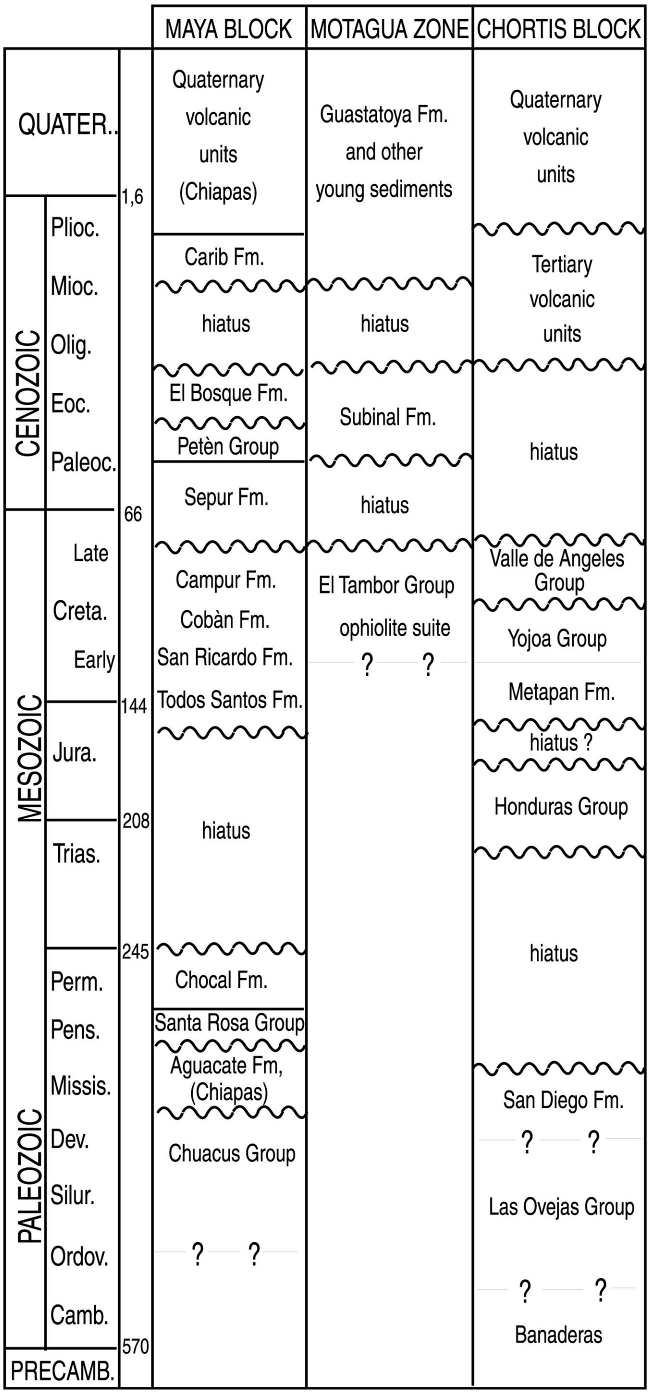

Fig. 3 - Stratigraphic relationships between the Maya block, MSZ and Chortis block (modified from Finch and Dengo, 1990).

In the Central Cordillera of Guatemala, bounded on the south by the Motagua Fault Zone, meta-sedimentary rocks of the Chuacus group predominate, although granitic intrusions are also present. The basal part of the Mesozoic sequence consists of redbeds of the Todos Santos Fm. (Late Jurassic - Early Cretaceous). The lower Lower Cretaceous sequence consists of limestones and dolostones intercalated with well-developed layers of salt and anhydrites, in turn overlain by thick mid-Cretaceous limestones and dolostones). This sequence is conformably overlain by fossiliferous Late Cretaceous limestones. Turbidites were mainly deposited from the Late Cretaceous through the beginning of the Eocene (e.g., Sepur group).

b) the Motagua zone is characterized by narrow valleys elongated along the main strike-slip faults (MFS), wide plains corresponding to pull-apart basins filled with thick Neogene through recent sediments, and localized relief in restraining zones along the fault, consisting of Paleozoic basement and basic or acidic intrusives (Sierra de Chuacus, Sierra de Las Minas, Montañas del Mico). Additionally, several allochthonous Mesozoic ophiolitic bodies, which are the main object of the field-trip, occur along these belts, and as large *boudins* along the faults.

c) South of the MSZ extending into Honduras, there is a widespread Tertiary to Present volcanic plateau (with active centers) on the Chortis Block (CHR) overlying continental basement that has progressively been incorporated into the Caribbean Plate (CARIB) since the Late Cretaceous. According to Finch and Dengo (1990) and Burkart (1994) the Chortis Block includes the southern part of the Motagua Valley in Guatemala, plus the countries of El Salvador, Honduras and almost all of Nicaragua. It also extends beneath the Caribbean Sea as the promontory of the so-called Nicaraguan Rise (Avé Lallemant and Gordon, 1999). The thickness of this continental crust has been estimated by seismic data to be in the range of 25-40 km.

The oldest known rocks of the Chortis Block are represented by Paleozoic (or older) meta-sedimentary and meta-igneous complexes including schists, gneiss and marbles of the Las Ovejas Group. The most extensive metasedimentary rocks in the Chortis Block are the phyllites of the San Diego Fm. and its correlative units in Honduras, that are considered to be younger than the Las Ovejas Group.

A thick Mesozoic sedimentary sequence that overlies the metamorphic basement differs significantly from the stratigraphic sequence of the Maya Block. This consists of sandstones, lutites, and marine shales with ammonites. This sequence is overlain by redbeds similar to the Todos Santos Fm. (Early Cretaceous). A very widely exposed Aptian-Albian carbonate sequence reaches a great thickness in southern Guatemala. Upper Cretaceous rocks again consist of redbeds.

The MSZ is a typical transpressional "flower structure", characterized by northward and southward vergences. The following main ophiolitic units have been recognized in the MSZ (Beccaluva et al., 1995):

i. the Sierra de Santa Cruz (SSC) and Baja Verapaz (BVP) Units clearly overthrust the Maya Block; the former onto the Upper Cretaceous-Paleocene carbonate-terrigenous sequences of the Sepur Fm., the latter onto the Paleozoic metamorphites of the Chuacus group or the Mesozoic evaporitic-terrigenous-carbonate deposits of the Todos Santos, Coban and Campur Fms.;
ii. the Juan de Paz Unit (JPZ) is thrust over the Paleozoic metamorphic basement of the Sierra de Las Minas and the Montañas del Mico (Maya Block);
iii. the South Motagua (SM) and North Motagua (NM) Units, with the latter outcropping as a narrow belt along the Motagua valley, is overthrust onto both the Paleozoic continental basement (Las Ovejas group and San Diego Fm.) of the Chortis Block (SM) and the Paleozoic metamorphic terranes of the Sierras de Chuacus and Las Minas of the Maya Block (NM). These Eocene units are imbricate with out-of-sequence basement slices and variably dipping fault surfaces.

Lithologically, the SSC, BVP and JPZ units consist generally serpentinized mantle harzburgites, layered gabbros, dolerites, basalts and rare andesites. These have been interpreted as island-arc magmatic sequences associated with sub-arc mantle rocks (Beccaluva et al., 1995). The SSC Unit is locally covered by small outcrops of terrigenous and volcaniclastic sequences, including andesitic and dacitic fragments (Cretaceous Tzumuy Fm., Rosenfeld, 1981), whereas the JPZ Unit is covered by basic and andesitic volcaniclastic breccias, passing upward to carbonate breccias and calcarenites, with sandstone and microconglomerates containing acid volcanic fragments (Upper Cretaceous Cerro Tipon Fm., Muller, 1980).

The SM and NM, on the other hand, consist of the so-called El Tambor group, mainly comprising serpentinized mantle peridotites and foliated gabbros, followed by a thick basaltic pillow lava sequence showing mid-ocean ridge affinity (Beccaluva et al., 1995), radiolarian cherts, meta-siltites and meta-arenites with intercalations of basaltic lavas. The top of the sequence is represented by marbles and dark meta-calcarenites alternating with phyllitic meta-siltites (Upper Cretaceous Cerro de La Virgen Fm.).

Along the Motagua river, the JPZ, SM and NM Units are unconformably overlain by the continental molasse of the Subinal Fm.

THE FIELD TRIP (Figs. 4, 5)

1ST DAY:
CIUDAD DE GUATEMALA - SANARATE - EL PROGRESO - SANSARE - SANARATE - EL RANCHO - RIO HONDO

Main topic: The South Motagua Unit (Sm)

Stop 1a - ***76.5 km from Ciudad de Guatemala, on C.A.9 (Carretera al Atlantico n. 9), north-east of Ciudad de Guatemala***

Panoramic view of the Motagua valley from north (Maya Block) to south (Chortis Block). The elongated uplift of the Sierra de Chuacus-Sierra de Las Minas (southern Maya Block) borders the left (north) side of the Motagua valley. The MSZ ophiolitic Units overthrust both the Maya and Chortis Blocks as a flower structure. The MSZ ophiolites are, in part, unconformably covered by terrigenous deposits of the Subinal Fm. and by recent volcanics. The left lateral Motagua Fault System (MFS) (composed of the Polochic, Motagua, Cabanas, and Jocatan- Chamelecon Faults) cross cuts the central portion of the MSZ as well as the stream sediments of the Rio Motagua.

Stop 1b - ***76.5 km of C.A.9, north-east of Ciudad de Guatemala***

Eocene terrigenous deposits of the **Subinal Fm.** (Fig. 6) consist of continental red sandstones and conglomerates with andesitic clasts. This formation represents a molassic (post-orogenic) sequence unconformably lying on MSZ. It is also crosscut by the Tertiary-Recent MFS.

Stops 2, 3, 4 (Fig. 7): **South Motagua Unit (SM)**

The **South Motagua Unit** (SM) crops out on the right (south) side of the Rio Motagua, and is limited on the north by the Cabañas Fault. This unit consists of several tectonic

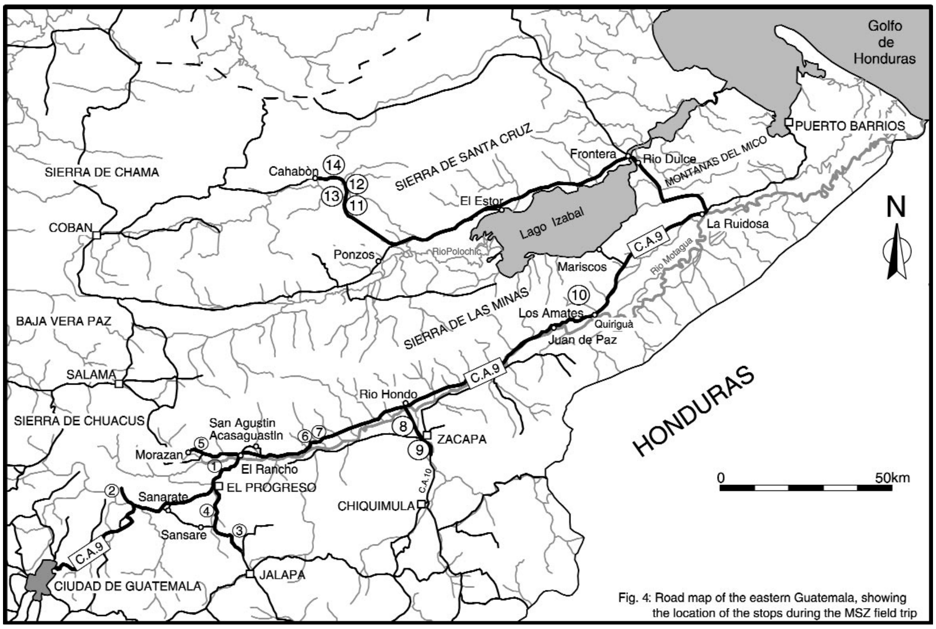

Fig. 4 - Road map of the Eastern Guatemala showing the location of the stops during the field-trip.

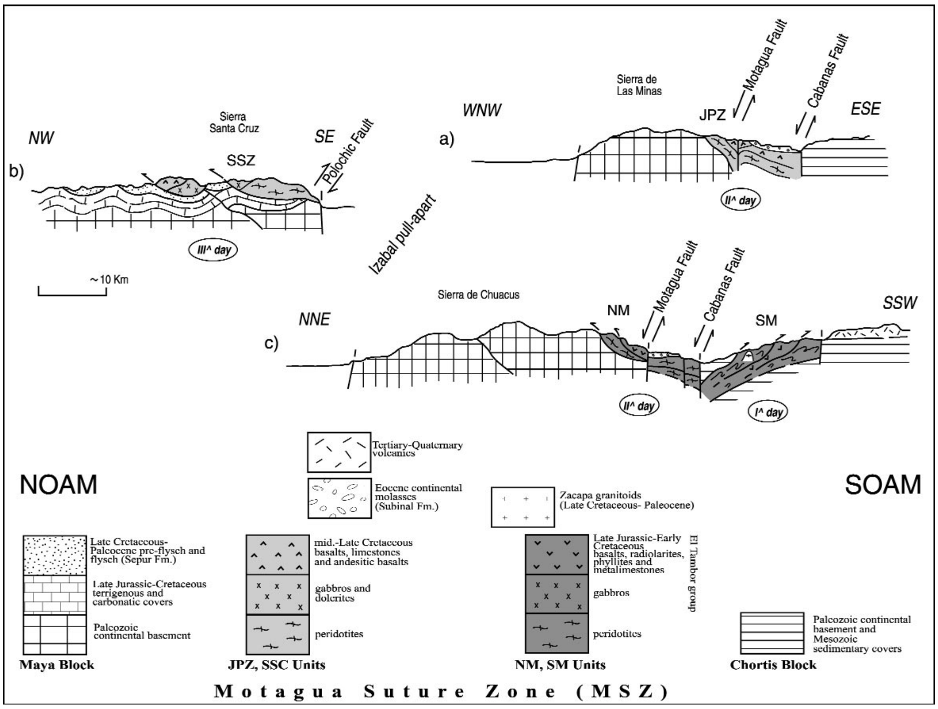

Fig. 5- Schematic cross sections of the Motagua Suture Zone (MSZ), with the field trip days.
"This cross section has been drawn by G.Dengo and G.Giunta at the Posada El Quetzal in July 1990, drinking a delicious Zacapa Centenario Ron Aniejo!"

sheets emplaced southward onto the Paleozoic continental basement of the Chortis Block represented by the Las Ovejas group and San Diego Fm. Out of sequence basement slices are also tectonically imbricate within the SM Unit. The SM tectonic stack is unconformably overlain by the Subinal Fm., as well as by calc-alkaline volcanics of the Central America Isthmus (Tertiary-Present plateau of Jalapa) and recent alluvial sediments of the Motagua valley.

The SM Unit is represented (Fig. 8) by the so-called El Tambor Group (Donnelly et al., 1990), consisting of a dismembered ophiolitic sequence, in turn, made up of (from bottom to top): serpentinized mantle peridotites (including tectonic blocks of eclogites, jadeitites, and amphibolites) and foliated gabbros; basaltic pillow lava flows (in a thick, slightly deformed, sequence); radiolarian cherts; phyllites (meta-siltites and meta-arenites) intercalated with basaltic flows. The upper part of the sequence is represented by phyllitic meta-siltites alternating with marbles and dark meta-calcarenites that pass upward to meta-limestones (Cerro de La Virgen Fm.).

The ophiolitic magmatic rocks (intrusives and lavas) are generally attributed to the Late Jurassic-Early Cretaceous, while Early-middle Cretaceous (Hauterivian-Cenomanian) ages could be assigned to the phyllitic sequence and Cerro de La Virgen limestones.

The SM Unit basalts are sometimes picritic and show clear Mid-Ocean Ridge (MOR) affinity, as is further indicated by the crystallization order of plagioclase before clinopyroxene. Chondrite normalized REE patterns of the basalts (Fig. 9 and Table1) generally show light REE depleted patterns typical of N-MORB. Nonetheless, basalts cropping out in the basal portion of the El Tambor group reveal slightly enriched REE patterns resembling T-MORB. Locally, some basalts associated with the N-MORB volcanics show ocean island (OIB) alkaline affinity (e.g., sample GUA 47, Table1) probably representing seamount activity.

The SM Unit has been locally deformed and metamorphosed under high-pressure/low temperature (HP-LT) conditions. The magmatic textures are, however, generally preserved due to the discontinuity of recrystallization imprinting and/or to the dismembering of the oceanic sequences in the subduction zone. Relicts of magmatic pyroxene, plagioclase and subordinate olivine can be observed, even though the effects of hydrothermal alteration and ocean-floor metamorphism are widespread.

Three main tectono-metamorphic phases can be locally recognized in the SM Unit. The first (D_1) is represented by relicts of HP-LT assemblages. Two principal eclogitic rock-types have been distinguished (Mc Birney et al., 1967): (a) garnet-pyroxene eclogites made of porphyroblasts of almandine-rich garnet (Sp = 1,4; Gr = 24,3; Py = 9,8; Al = 63,7; An = 0,8) in a weakly foliated groundmass consisting of omphacite (Jd = 38,6) and lesser amounts of muscovite, sphene, rutile, lawsonite; (b) amphibole-bearing eclogites consisting of contrasting blue and green centimetric layers, which result from varying proportions of glaucophane s.l. (+ actinolite, garnet, muscovite, fine-grained omphacite, sphene, and sporadic lawsonite) and omphacite (+ porphyroblastic garnet, quartz, muscovite, apatite).

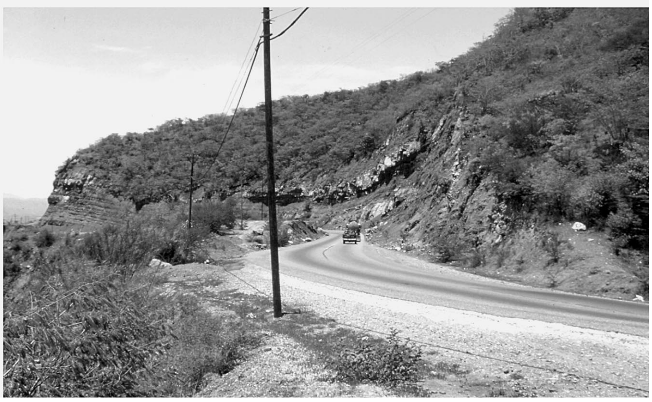

Fig. 6 - C.A. 9 East of Ciudad de Guatemala: continental molassic deposits of the Eocene Subinal Fm.

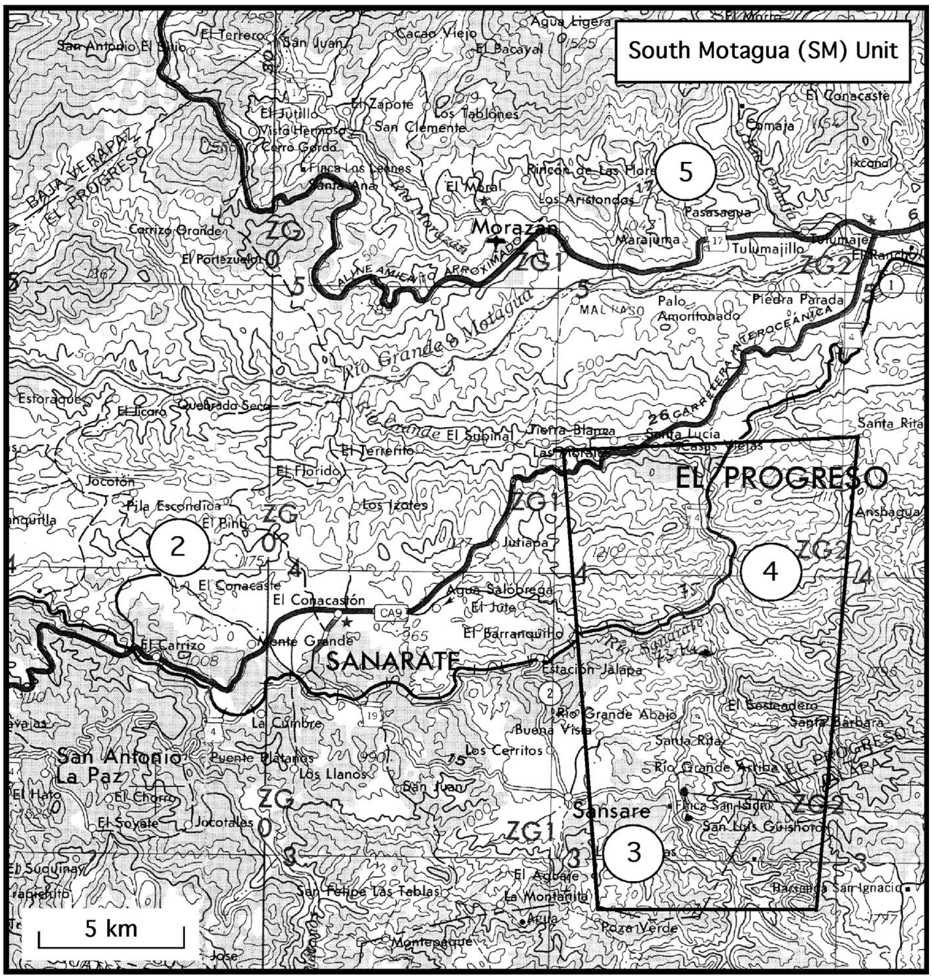

Fig. 7 - Topographic map of El Progreso area showing the stop locations on the SM Unit. The framed area is related to the geological map of Fig. 14.

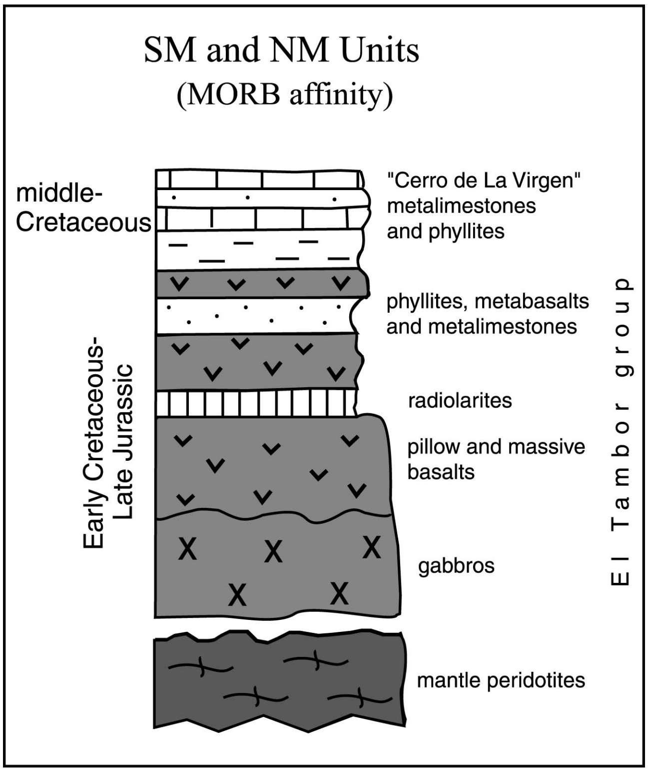

Fig. 8 - Reconstructed stratigraphic column of the South Motagua (SM) and North Motagua (NM) Units.

The second phase (D_2) developed in retrograde P-T conditions toward the greenschist-amphibolite facies (chlorite, albite, quartz, green hornblende, tremolite-actinolite, white mica). It is mainly characterized by isoclinal folds with associated, well-developed S_2 axial plain foliation (Fig. 10). S_2 foliation mainly dips northward and represents the main structural surface observable at the mesoscale. D_2 detachment horizons generally occur between the different lithotypes along the main horizons of competence contrast. Tectonic transport direction is toward the southern sectors.

Phase D_3 is mainly represented by a superimposed crenulation cleavage developed under low and/or very-low grade conditions (prehnite-pumpelliyte facies).

Structural evidences suggest that strike-slip tectonics were already active during the D_2 phase (i.e., the beginning of the exhumation).

46.3 km of C.A. 9 - 4.7 km from intersection towards San Miguel

Stop 2 - *San Miguel, Cementos Progreso Quarry*

The **Cerro de la Virgen Fm.** (Figs. 11, 12) is composed of a thick sequence of meta-limestones and phyllites which represent the most recent portion of the SM Unit. The basal contact of this formation onto the El Tambor sequence is at present tectonic, even if an original stratigraphic contact between them is locally recognizable.

Black meta-limestones interbedded with dark gray to

Table 1 - Major and trace element analyses for the main Motagua Suture Zone (MSZ) units.

Sample	GUA4	GUA 18	GUA 38	GUA 42a	GUA 42b	GUA 44	GUA 45a	GUA 47	GUA 73	GUA 74	GUA 75	GUA 76	GUA 77	GUA 79	GUA8	GUA82	GUA83	GUA48	GUA81
Unit	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**SM**	**NM**	**NM**	**NM**	**NM**	**NM**
Lithology	Gb	Bas	Bas	Bas	Bas	Bas	Bas	Alk-Bas	Bas	Bas	Bas	Bas	Bas	Quarz	Amph	Amph	Amph	Hz	Bas
Affinity	N-MOR	N-MOR	N-MOR	N-MOR	N-MOR	N-MOR	N-MOR	OIB	N-MOR	N-MOR	N-MOR	T-MOR	T-MOR	-	N-MOR	N-MOR	N-MOR	-	N-MOR
SiO2	49,53	50,08	47,57	46,73	39,21	48,09	44,73	43,23	43,35	46,86	44,08	50,37	43,70	88,00	42,59	40,70	48,11	42,21	50,62
TiO2	1,47	1,45	1,36	0,68	1,30	1,58	0,84	2,55	0,73	1,28	0,93	2,02	1,40	0,17	1,32	2,50	1,91	0,02	1,02
Al2O3	13,01	15,79	16,10	19,23	18,67	13,08	18,42	15,26	20,38	15,89	20,66	15,53	16,96	2,12	12,93	10,67	13,35	1,54	10,56
Fe2O3	11,76	9,53	10,26	5,87	12,32	11,27	9,25	10,22	7,32	10,29	8,90	8,75	10,90	1,51	13,95	15,99	13,03	7,16	8,37
MnO	0,19	0,17	0,16	0,10	0,15	0,16	0,18	0,23	0,11	0,16	0,07	0,16	0,16	0,09	0,22	0,24	0,16	0,10	0,15
MgO	9,36	6,28	8,37	7,93	12,88	9,69	10,47	6,50	11,55	7,87	4,67	5,27	8,39	1,03	12,33	11,54	7,56	37,36	2,95
CaO	9,10	7,30	12,02	8,26	6,31	10,11	6,25	9,30	9,04	9,90	9,65	9,43	10,56	2,30	12,24	13,04	9,81	0,04	18,73
Na2O	2,49	3,65	2,17	4,72	2,29	2,58	3,40	4,88	2,70	3,45	2,74	4,55	2,99	1,16	1,88	2,39	4,54	0,00	0,00
K2O	0,10	1,65	0,08	0,09	0,42	0,20	0,02	0,08	0,19	0,26	2,40	0,42	0,09	0,17	0,33	0,69	0,42	0,00	0,02
P2O5	0,19	0,15	0,20	0,07	0,10	0,18	0,06	0,65	0,13	0,21	0,40	0,28	0,26	0,00	0,34	1,07	0,31	0,00	0,34
L.O.I.	2,79	3,94	1,73	6,33	6,35	3,06	6,38	7,1	4,51	3,83	5,50	3,21	4,60	3,43	1,87	1,17	0,81	11,59	7,25
Tot	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mg#	0,64	0,60	0,65	0,75	0,70	0,66	0,72	0,59	0,78	0,63	0,54	0,58	0,63	0,61	0,67	0,62	0,57	0,92	0,44
Ni	82	50	122	129	148	76	195	206	159	71	82	51	102	n.d.	182	164	85	1941	112
Co	38	33	40	29	54	38	49	37	45	41	28	40	48	2	57	59	31	88	27
Cr	245	108	447	265	443	246	357	271	372	375	352	71	359	19	517	569	223	2644	297
V	335	255	286	219	268	321	208	252	157	285	161	312	251	17	362	438	382	47	173
Rb	1	26	1	2	8	3	n.d.	4	2	4	39	8	n.d.	6	4	16	12	n.d.	n.d.
Sr	182	44	259	241	204	162	116	228	472	171	438	91	83	83	148	154	195	4	668
Ba	28	100	82	43	29	25	56	184	49	39	n.d.	99	n.d.	36	117	162	141	7	n.d.
U	0,04	0,23	0,03	-	-	0,07	0,07	0,53	-	-	-	0,33	0,24	-	0,03	1,03	0,20	-	-
Th	0,17	0,24	0,08	n.d.	1	0,10	0,10	1,81	-	-	-	1,11	0,69	-	0,03	2,28	0,26	n.d.	6
Hf	0,28	1,81	0,45	-	-	0,40	0,79	5,06	-	-	-	3,68	2,27	-	0,53	1,03	0,64	-	-
Ta	0,30	0,40	0,80	-	-	0,34	0,30	1,91	-	-	-	0,89	0,44	-	0,27	0,14	0,03	-	-
Nb	2	2	1	1	n.d.	4	2	44	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1	n.d.	n.d.	n.d.	n.d.
Zr	121	83	109	50	86	130	52	322	37	85	43	148	84	545	64	202	117	n.d.	66
Y	31,0	29,0	29,1	13	23	32,2	17,1	30,3	19	33	22	37,5	23,9	11	32,0	41,7	35,1	2	21
La	3,65	3,63	3,02	n.d.	6	3,07	1,21	27,2	-	-	-	12,6	7,30	-	2,05	40,7	4,17	n.d.	-
Ce	10,8	10,1	9,63	4	23	9,75	3,74	58,7	-	-	-	27,6	16,5	-	7,14	73,4	12,9	n.d.	-
Pr	1,99	1,87	1,72	-	-	1,71	0,67	7,85	-	-	-	4,05	2,44	-	1,48	11,3	2,31	-	-
Nd	11,2	10,7	9,32	-	-	9,18	4,05	33,0	-	-	-	19,3	11,7	-	8,87	45,2	13,5	-	-
Sm	3,69	4,11	3,01	-	-	3,03	1,67	7,14	-	-	-	5,51	3,40	-	3,44	10,7	4,49	-	-
Eu	1,34	1,56	1,08	-	-	1,08	0,59	2,09	-	-	-	1,90	1,23	-	1,33	3,47	1,65	-	-
Gd	4,43	4,64	3,30	-	-	3,40	1,86	6,71	-	-	-	6,92	4,28	-	4,07	10,9	6,06	-	-
Tb	0,95	1,00	0,70	-	-	0,71	0,40	1,05	-	-	-	1,27	0,78	-	0,85	1,81	1,19	-	-
Dy	6,05	6,16	4,36	-	-	4,45	2,53	6,19	-	-	-	7,74	4,89	-	5,46	9,93	7,65	-	-
Ho	1,32	1,32	0,95	-	-	0,99	0,57	1,20	-	-	-	1,65	1,03	-	1,21	2,05	1,69	-	-
Er	3,63	3,61	2,69	-	-	2,68	1,65	3,09	-	-	-	4,60	2,91	-	3,40	5,69	4,83	-	-
Tm	0,54	0,54	0,39	-	-	0,40	0,26	0,43	-	-	-	0,70	0,45	-	0,50	0,86	0,69	-	-
Yb	3,38	3,24	2,59	-	-	2,73	1,73	2,82	-	-	-	4,36	2,87	-	3,18	4,76	4,62	-	-
Lu	0,48	0,48	0,37	-	-	0,36	0,28	0,38	-	-	-	0,65	0,41	-	0,46	0,69	0,61	-	-

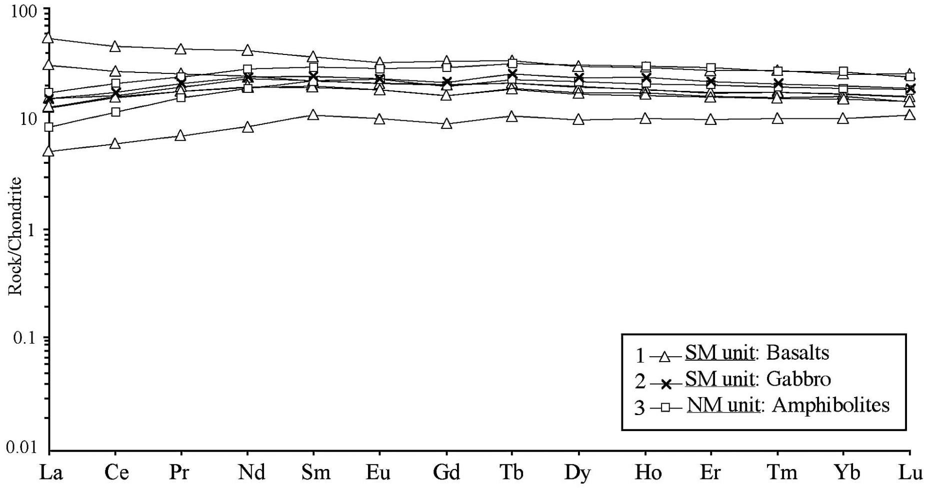

Fig. 9 –Chondrite normalized REE patterns of basic rocks showing MORB affinity from the Motagua Suture Zone of Guatemala. Normalizing factors after Sun and McDonough (1989).
1. Basalts from the South Motagua (SM) unit (samples: GUA 18, 38, 44, 45a, 76, 77);
2. Gabbro from the South Motagua (SM) unit (samples: GUA 4);
3. Amphibolites from the North Motagua (NM) unit (samples: GUA 8, 83).

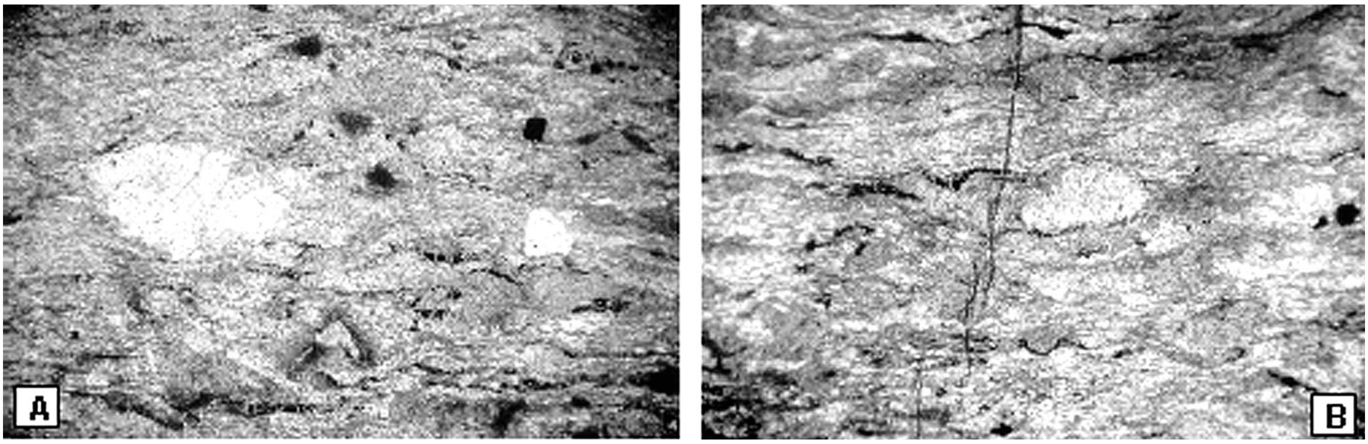

Fig. 10 - Rio El Tambor: microstructures in highly strained meta-basalts of the SM unit (sample GUA 38).

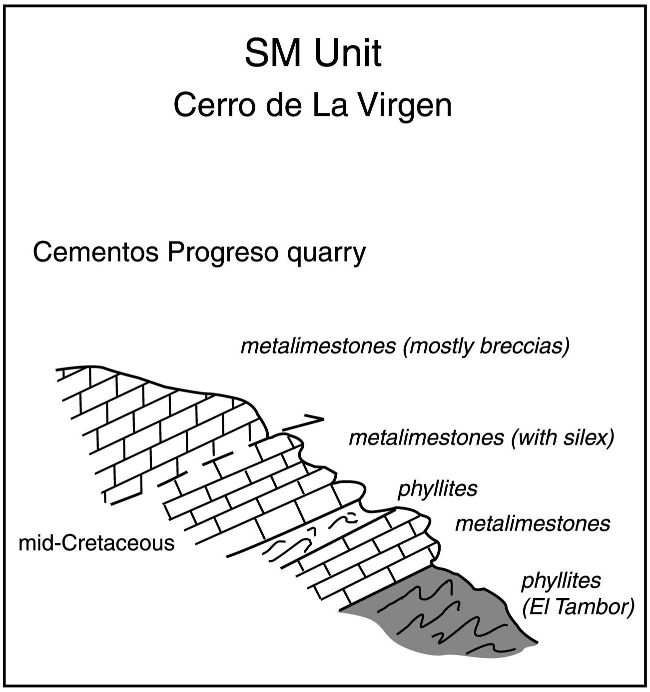

Fig. 11 - Schematic cross section of the Cerro de La Virgen Fm at the Cementos Progreso quarry.

Fig. 12 - Cementos Progreso quarry: Cerro de La Virgen limestones with silex, and phyllitic intercalations.

green slates, siltstones and graywackes are frequent. The metamorphic imprint appears to be within the greenschist facies.

In the lower portion of the sequence the meta-limestones are interbedded with phyllites of the El Tambor group. This occurrence suggests an originally continuous stratigraphic sequence.

The Cerro de La Virgen limestones contain fragments of mid-Cretaceous rudists (Wilson, 1974).

Sanarate (51.2 km of C.A. 9) - 21.25 km from intersection with Road 19, through Sansare, towards Jalapa

Along the road from Sanarate to Sansare, overlooking the Paleozoic **Las Ovejas Group** of the Chortis Block (Fig. 13).

Stop 3 - *Puente del Rio Grande transect*

The classical sequence of the **El Tambor group** outcrops in the Puente del Rio Grande transect (Figs. 14, 15). It includes, from bottom to top:

i. pillow basalts (Fig. 16) with scattered inter-pillow radiolarites and cherts, passing to massive basaltic lava flows (Fig. 17);
ii. red or light-grey meta-radiolarites and meta-cherts (Fig. 18) of Late Jurassic? - Early Cretaceous age;
iii. a thick sequence of phyllites interlayered with radiolarites, T-MORB basaltic lavas (samples GUA 76 and 77 in Tab.1) and volcaniclastics, and meta-limestones. The Early Cretaceous age of the sequence is inferred from the mid-Cretaceous age of the overlying Cerro de La Virgen Limestones.

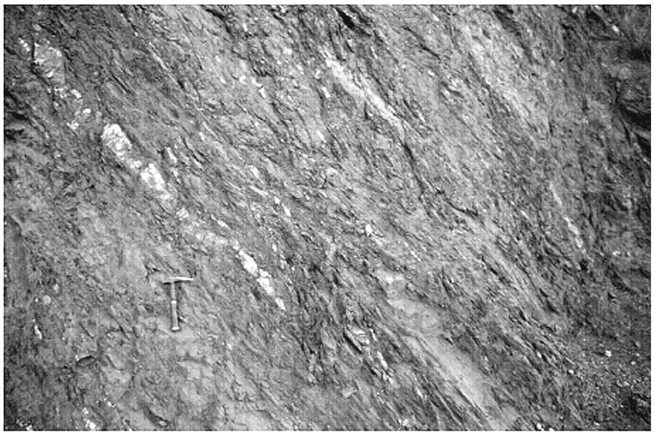

Fig. 13 - Sanarate-Sansare road: schists and microgneisses of Las Ovejas group, Paleozoic continental basement of the Chortis block.

Puente del Rio Grande - Sansare - Sanarate - 73.0 km of C.A.9, entrance Guastatoya (El Progreso), 6 km southwards

Stop 4 - *El Progreso - Rio Guastatoya transect*

The Rio Guastatoya transect, from El-Progreso to Jalapa station, runs through the **SM Unit** (Figs.14, 15). The Rio Gaustatoya outcrops are represented, from north to south, by:

i. Tertiary-Quaternary pyroclastics;
ii. An out of sequence thrust sheet of the Las Ovejas group (Paleozoic basement of the Chortis Block);
iii. Cerro de La Virgen Fm. (middle Cretaceous) overthrust onto the El Tambor phyllites (Fig. 19);

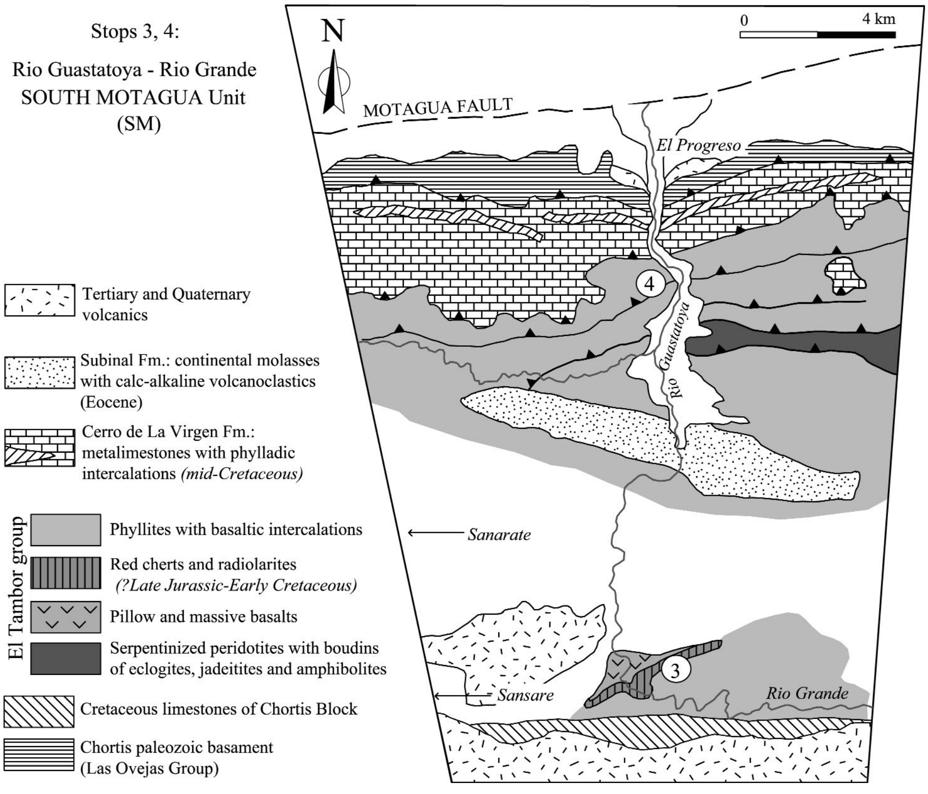

Fig. 14 - Geological sketch map of the Rio Guastatoya and Rio Grande area (SM Unit).

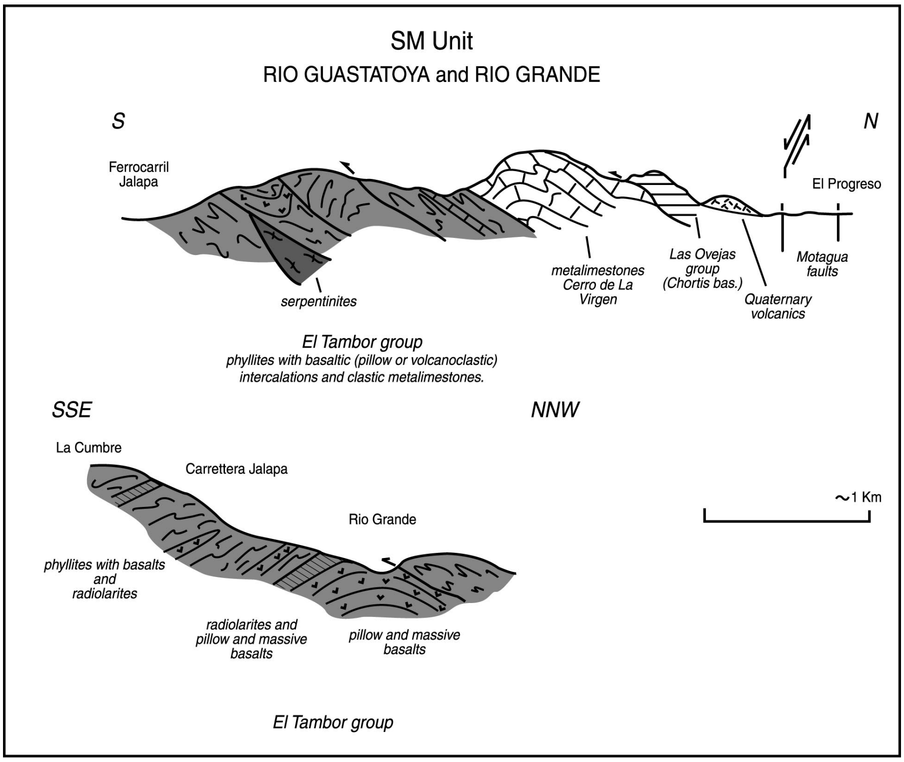

Fig. 15 - Schematic geological cross section of the SM Unit in the Rio Guastatoya and Rio Grande area.

iv. **El Tambor group** (Fig. 20), made of phyllites with interbedded N-MORB basaltic flows, volcaniclastics and meta-limestones, subdivided into several thrust sheets;
v. Serpentinized peridotites, containing mafic blocks metamorphosed in the blueschist and eclogite facies, and tectonically emplaced as *boudins* between the phyllite thrust sheets.

El Rancho (84.2 km of C.A. 9) - intersection Road 17 towards Coban - 12-8 km towards Morazan

Stop 5 - ***Morazan area***

The central portion of the MSZ, attributed to the NM Unit, outcrops along the El Rancho-Morazan road. Severe **shear zones** (Fig. 21) involving the El Tambor lithologies (phyllites, volcaniclastites and meta-limestones) are observable in this area.

The main deformations comprise at least three ductile phases, as well as both ductile-brittle and brittle geometries, where in the E-W sinistral transpressional stress-component can be recognized.

Morazan area - C.A. 9 - Rio Hondo (end of the 1st day)

2nd DAY:

RIO HONDO - SAN AGUSTIN ACASAGUASTLAN - ESTANZUELA -ZACAPA - JUAN DE PAZ - LOS AMATES - LA RUIDOSA - RIO DULCE

Main topics: The North Motagua (Nm) and Juan De Paz (Jpz) Units

Rio Hondo (137 km of C.A. 9) - Teculutan - San Agustin Acasaguastlan area

Stops 6, 7 (Fig. 22): **North Motagua Unit (NM)**

The **North Motagua Unit** (NM) crops out on the hydrographic left (north) side of the Rio Motagua; and is exposed along the C.A. 9 highway.

A series of ophiolitic bodies (sometimes present as boudins squeezed between subvertical structures) outcrop along the main faults of Motagua, in the higher part of the Motagua valley west of the Rio Hondo village. Wherever the early tectonic relationships are preserved, the ophiolitic bodies overthrust the Paleozoic metamorphic terrains of the Sierra de Chuacus and part of the Sierra de Las Minas (Maya Block).

The NM Unit generally consists of several tectonic sheets, often chaotic, that are pervasively deformed along the shear surfaces. Southward, it is unconformably overlain by the Eocenic continental molasses of the Subinal Fm., and by the Tertiary and Quaternary clastic sequences of the Motagua Valley.

The lithostratigraphic sequences of the NM and SM Units are almost the same (Fig. 8), represented by the El Tambor group. In spite of this, the NM Unit distinctively shows stronger degrees of tectono-metamorphic deformation. Highly serpentinized peridotites represent the main lithotype, and include blocks and/or *boudins* of jadeitites, albitites, meta-basites, and amphibolites. Pillow basalts and scattered radiolarites (Late Jurassic?-Early Cretaceous) are subordinate, grading in places to phyllites with interbedded basalts and scarce meta-limestones, followed by the inferred Cerro de La Virgen limestones.

The analyzed amphibolites of the NM Unit (Table 1) show clear N-MOR affinity, and geochemically are strictly comparable with the basalts from the SM Unit (Fig. 9).

The NM Unit was clearly affected by HP-LT metamorphism during the Cretaceous tectonic phases, but its tectono-metamorphic evolution is still poorly constrained. The only available data on the P-T evolution of this unit are offered by detailed studies carried out on blocks (mainly jadeitites and albitites) enclosed in tectonized serpentinites (Harlow, 1994). According to this author, pressure conditions for the petrogenesis of NM jadeitites range between 5-11 Kbar at maximum temperatures of 400°C. The subse-

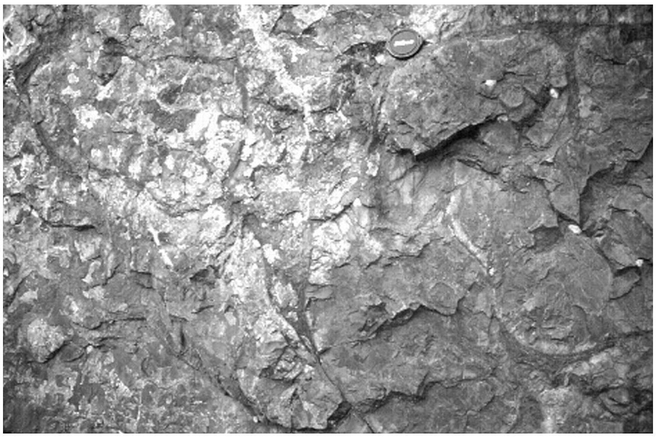

Fig. 16 - Rio Grande bridge: pillow basalts of El Tambor group (SM unit).

Fig. 19 - Panoramic view of the left side of the Rio Guastatoya, showing the tectonic contact between the Cerro de La Virgen Fm. (right) and El Tambor group phyllites (left).

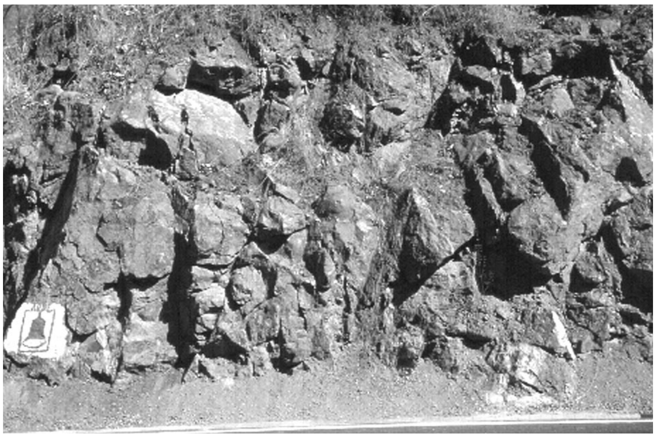

Fig. 17 - Road from the Rio Grande bridge to Jalapa: massive basalts of El Tambor group (SM unit).

Fig. 20 - Rio Guastatoya: El Tambor group phyllites with basaltic and volcanoclastic intercalations. The subvertical main foliation corresponds to S2.

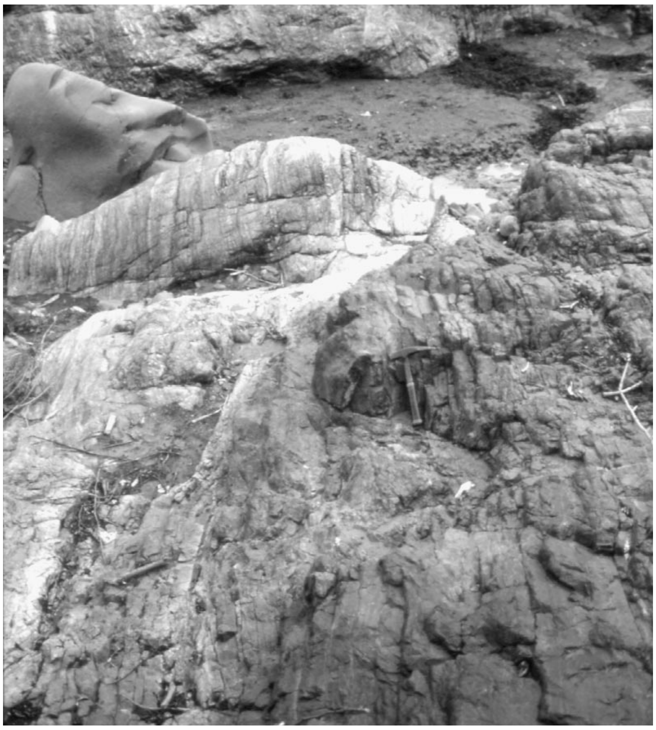

Fig. 18 - Rio Grande: radiolarites and cherts (Late Jurassic?- Early Cretaceous) of El Tambor group (SM unit).

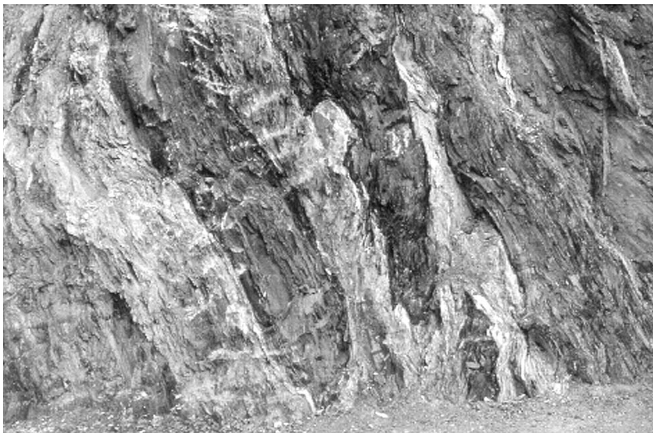

Fig. 21 - El Rancho Morazan road: El Tambor group of North Motagua (NM) unit: phyllites and volcanoclastites (dark), and metalimestones and phyllites (light). The main foliation corresponds to the S2 refolded in S3. The pseudo-alternance of light and dark bands is caused by the Motagua sinistral Shear Zone with related boudinage.

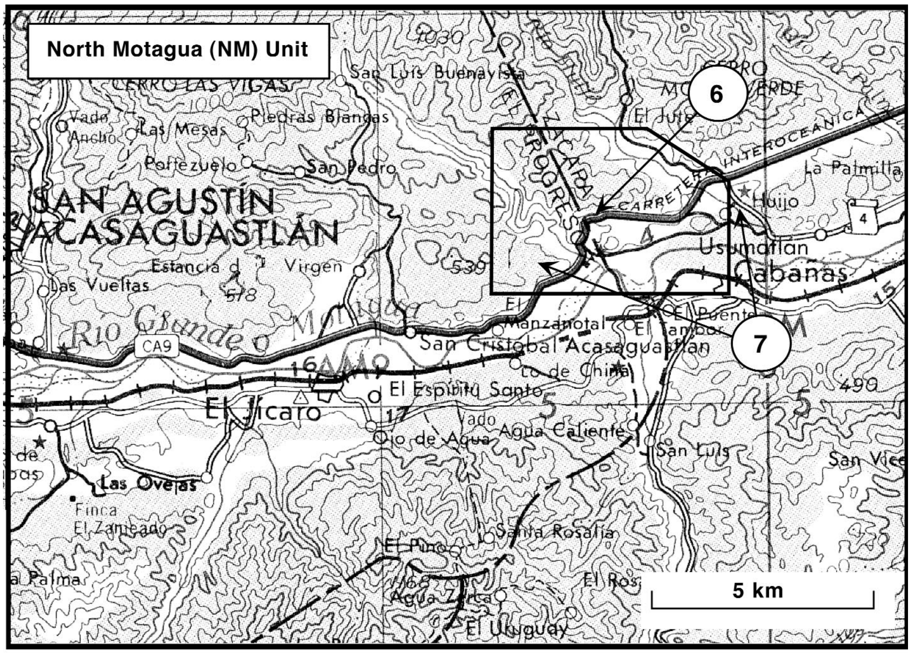

Fig. 22 - Topographic map of San Agustin Acasaguastlan area (East of Rio Hondo) with the stop locations on the NM unit. The framed area is related to the geological map of Fig. 25.

quent replacements of jadeite by analcime and/or albite suggest that pressure and temperature decreased toward values of T<300°C (up to P = 10Kbar) and P<7.5Kbar (at 400°C), respectively.

From a structural point of view, at least three ductile phases characterize the evolution of the NM Unit. The first tectono-metamorphic event (D_1) is recorded by the HP-LT assemblages and related S_1 foliation conserved in the tectonic *boudins* included in the serpentinites (Fig. 23a).

The second phase (D_2) is represented by isoclinal to sub-isoclinal folds with similar geometry. Folds are characterized by a well-developed and continuous S_2 axial plane foliation developed under metamorphic conditions ranging from greenschist to amphibolitic facies representing the main foliation observable at the mesoscale (Figs. 23b, c). The main schistosity surfaces are generally subvertical or southward-dipping. The syn-D_2 metamorphic assemblage is marked in the basic lithotypes by albite, chlorite, quartz, actinolite, green hornblende, white mica, calcite, and epidote.

Discrete crenulation cleavage represents the D_3 phase, generally related to the MFS shear zone (Fig. 23d).

C.A. 9, west of Rio Hondo

Eastward from Rio Hondo, C.A.9 runs along the west side of the Motagua River. Exposed along both sides of the road are several sheared bodies of serpentinized **peridotites**, gabbros, amphibolites, scattered eclogites and jadeitites (NM Unit) (Fig. 24). Most noticeable are the green colored belts of serpentinized peridotite. These serpentinites, representing remnants of Caribbean oceanic crust (Dengo, 1972), were emplaced onto Paleozoic metamorphic basement. Silva (1969), Dengo (1976), and Bertrand and Vaugnat (1976) describe the most common type of serpentinite along the Motagua as green to bluish-green, highly sheared and composed of chrysotile-lizardite. The original igneous textures are difficult to identify. Subordinate to this type is a blocky, massive serpentinite, which is dark green to black where the dominant mineral phase is antigorite. Igneous textures are preserved, in this case, including relict olivine and pyroxene crystals. Pyroxene is abundant and includes orthopyroxene (enstatite and bronzite). Magnetite inclusions are found in the pyroxenes. Trace amounts of other opaque minerals include chromite and picotite; limonite and goethite staining is also observed. Amphibolites occur as tectonic inclusions within the serpentinites, and are characterized by an assemblage of muscovite, actinolite, quartz, plagioclase and garnet. Locally, schists also occur in fault contact with the serpentinites. Albitite and jadeitite boulders are found scattered throughout the area. Boulders of quartz and magnesite are also found as inclusions in the serpentinite. Rodingite inclusions and dikes are observed in many outcrops for a 19 km stretch on the highway between El Rancho and Coban. Rodingites are the product of metasomatism of gabbros or equivalent igneous rocks.

Stop 6 - *San Agustin Acasaguastlan area, 107 - 108 km of C.A. 9*

The **NM Unit** (Figs. 25, 26) overthrusts the Sierra de Chuacus Paleozoic basement (Fig. 27) of the Maya Block. It outcrops in deformed thrust sheets, made up of:

i. serpentinized peridotites;
ii. **El Tambor** phyllites with pillow and massive basaltic lavas, volcaniclastics, scattered radiolarites, and meta-limestone intercalations;
ii. Cerro de La Virgen Fm.: meta-limestones with phyllitic intercalations, probably representing an equivalent of the Cerro de La Virgen meta-limestones of the SM Unit.

Stop 7 - *Usumatlàn (111.8 km of C.A. 9) - Rio Uyús (106.0 km of C.A. 9) - Manzanal area*

7a - ***Usumatlán area*** - **Jadeitites**: Guatemala is second only to Myanmar (Burma) as a jadeite jade source, of which there are fewer than 10 worldwide. Jadeitite in dismembered tectonic blocks occurs sporadically in the sheared serpentinite body that extends E and W from Río La Palmilla to Estancia de La Virgen (~14 km). Jadeitites here are partially altered by albitization and usually con-

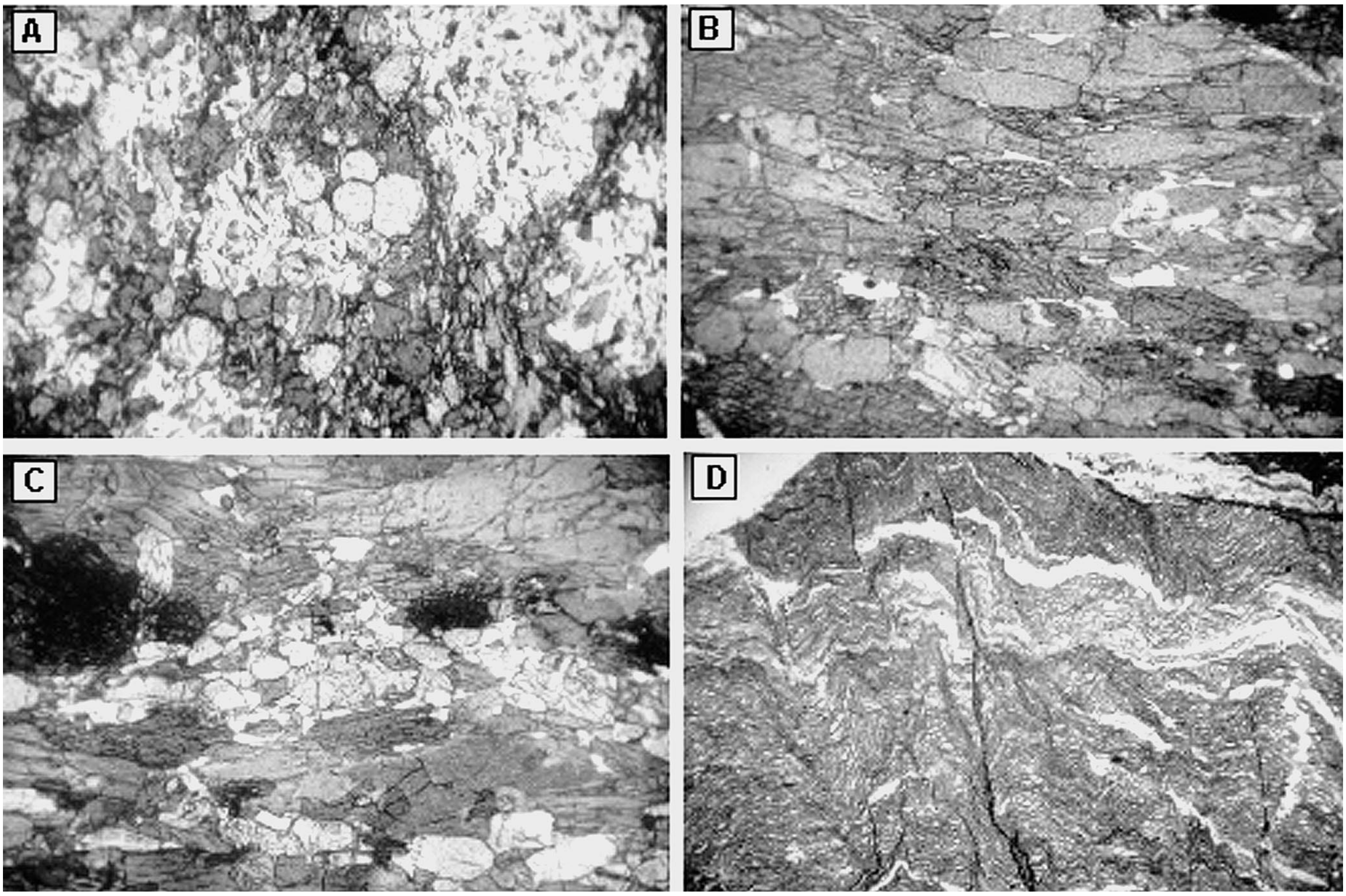

Fig. 23 - Tectonic microstructures in the NM unit: A) C.A. 9, km 107-108 (San Agustin Acasaguastlan area): boudin of garnet amphibolite in the serpentinites (sample GUA 83); B) C.A. 9, km 107-108 (San Agustin Acasaguastlan area) boudin of amphibolite in the serpentinites (sample GUA 82); C) C.A. 9, between El Rancho and Rio Hondo: boudin of epidote-bearing amphibolite in the serpentinites of the NM unit (sample GUA 8); D) C.A. 9, north-east of Ciudad de Guatemala: phyllites of El Tambor group showing the S1-2 composite foliation crenulated by the D3 phase (sample GUA 3).

Fig. 24 - C.A. 9, between El Rancho and Rio Hondo: serpentinized peridotites of the NM unit including boudins of amphibolites.

tain jadeite, albite, omphacite, paragonite, taramitic amphibole, titanite, phengite, phlogopite, preiswerkite, zoisite, zircon, apatite, and graphite. Albitites are also abundant and contain albite, actinolite, diopside, titanite, phengite, zoisite, zircon, and chlorite. Jadeitite and albitite are interpreted to form from seawater-like fluids derived from the subducting slab that entered a serpentinizing peridotite in or above a subduction zone; jadeitite crystallized at 100 < T < 400ºC; 5 < P < 11kbar with $0.0>\log_{10}a_{SiO2}{}^{\geq}0.7$. and albitite crystallized at T < 400ºC and ~ 3 to 8 kbar (Sorensen and Harlow, 1999; Johnson and Harlow, 1999; Harlow, 1994; 1995). Serpentinite slices containing jadeitite, eclogite, glaucophane eclogite, albitite and other high P/T rocks were brought up from depth either by the collision or (preferred by the above authors) coeval and subsequent left-lateral faulting.

7b - *Usumatlán area* - Jadeitites: Same rocks as the other stop, but 100 meters from the road are jadeitites decorating Ojo de las Minas. This hill has the form of a cinder cone with a central crater but is composed of serpentinite, jadeitite, and albitite detritus. Just few kilometers away is an archaeological site, so our suspicion is that this is a man-made edifice, perhaps made from jade mining/working waste by Maya or Formative culture inhabitants.

7c - *Río Uyús Bridge* - The bed of the creek contains float of serpentinite, **jadeitite**, albitite and altered garnet-amphibolites (+ qtz, zoisite, chlorite, etc.). However, the constant search for jadeitite jade by local collectors for the tourist trade in jade has left the creek depleted of jadeitite.

7d - *Manzanal Village* - The cut adjacent to the road is where McBirney et al. (1967) observed a large **jadeitite** boulder that now resides outside the Archaeological Museum in Guatemala City. The pasture North of this spot was once rich with cobbles of jadeitite, albitite, and albite-mica rock (Silva, 1967; 1970); the jadeitite is now extremely rare–the jade collectors are efficient!

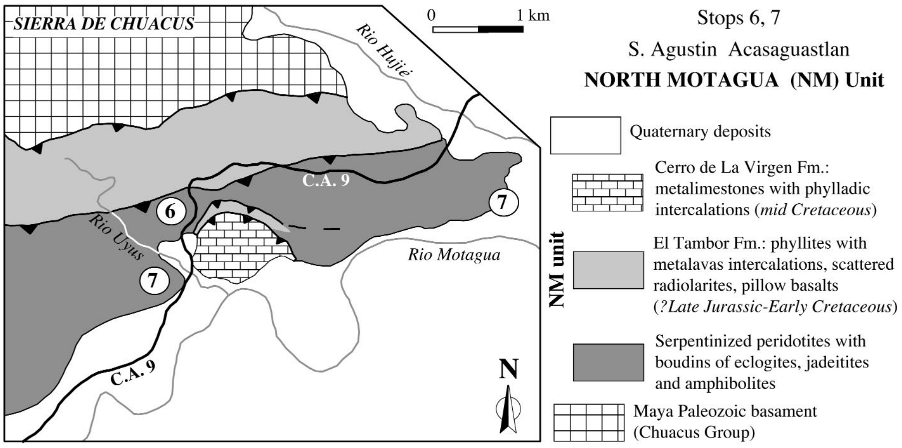

Fig. 25 - Geological sketch map of the area east of San Agustin Acasaguastlan (NM unit).

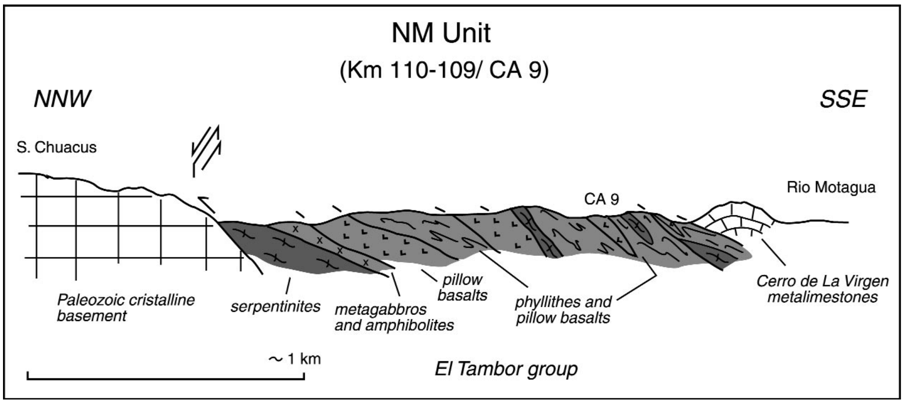

Fig. 26 - Schematic geological cross section of the NM unit in the area east of San Agustin Acasaguastlan.

San Agustin Acasaguastlan area - C.A. 9 (136 km of C.A. 10 junction - towards Estanzuela

Stop 8 - ***C.A. 10 towards Estanzuela (3.1 km from C.A. 9 intersection)***

Cabañas Fault: the discrete border between the NOAM and CARIB plates, crosscutting the stream sediments of the Motagua river, is recognizable along the road (Fig. 28).

The road crosses the Cabañas Fault in Quaternary terrace deposits. Road C.A. 10 was shifted about 60 cm by the main shock of the 7.5 magnitude earthquake that occurred on February 4, 1976. The ground breakage was continuous for nearly 230 km, with a large sinistral displacement. A series of en echelon veins in the road pavement suggest that sinistral slip still continues today (Finch and Dengo, 1990).

The Motagua and Polochic faults form a system of two major sub-parallel, left-lateral strike-slip faults that trend east-west across Guatemala and parts of Mexico, Honduras, and the Caribbean (Dengo and Bohnenberger, 1969). Their general characteristics are described in studies by Muehlberger and Ritchie (1975), Schwartz et al. (1978), Burkart (1978), Donnelly (1978), Dengo (1985), and Dengo and Dengo (1992). Total offset across the plate bounding faults is not well understood but could be as much as 1100-1400 km, as measured by the opening of the Cayman Trough, to which these fault systems are linked.

West of the town of Chimaltenango it is not possible to trace the Motagua Fault; consequently, numerous interpretations have been put forward relatively to its westward continuation. Burkart (1978), Dengo (1985), and Dengo and Dengo (1992) suggest that the Motagua Fault merges with the Polochic Fault near the town of Huehuetenango in western Guatemala. It is thus the Motagua, and not the Polochic Fault that extends westward into Mexico.

Estanzuela - Zacapa

Stop 9 - ***Zacapa (11 km from C.A. 9 /C.A.10 junction)***

Zacapa Granitoid intruding the SM Unit and the Chortis basement. A single analysis (Table 1) of this intrusion, probably Late Cretaceous in age, reveals a granodioritic composition.

The petrogenesis of the Zacapa Granitoid is uncertain due to the lack of detailed investigations; it may represent either arc-related or anatectic magmatism.

Fig. 27 - El Rancho-Coban road: metamorphic continental basement (Paleozoic Chuacus group) of the Maya block.

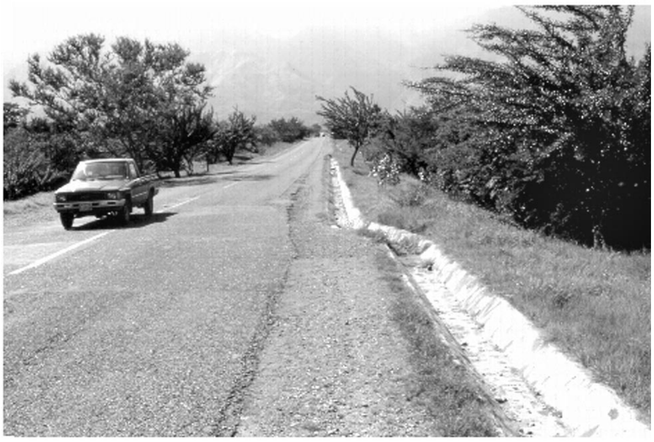

Fig. 28 - C.A. 10, toward Estanzuela: sinistral offset of the drainage crossed by the Cabañas fault, as NOAM- CARIB Plate border.

Zacapa - C.A. 10/C.A. 9 junction - Gualan - Juan de Paz - Los Amates (200 km of C.A. 9)

Stop 10 a, b (Fig. 29): **Juan de Paz Unit (JPZ)**

The **Juan de Paz Unit** (JPZ) crops out few tens of kilometres eastwards from the NM Unit in a series of ophiolitic bodies located along the main Motagua faults between the pull-apart basins of Izabal and Bananera, on the hydrographic left (north) of the lower Rio Motagua. The main outcrops are close to Juan de Paz, Los Amates and Morales villages, extending as far as the southern coast of Lake Izabal. Small outcrops are also found in the Quaternary plains near Puerto Barrios.

Wherever the early tectonic relationships are preserved, the JPZ Unit is thrust over the Maya Block Paleozoic continental basement (Chuacus Group of the Sierra de Las Minas and Montañas del Mico). It is, in turn, unconformably overlain by both the molassic deposits of the Eocene Subinal Fm. and recent sediments of the Bananera pull-apart basin.

The JPZ consists (Fig. 30) of several tectonic slices made up of serpentinized mantle harzburgites, gabbros, dolerites, scarce basalts, and scattered radiolarian cherts (El Pilar group).

Upward, and in inferred original stratigraphic contact, occur carbonate breccias and nodular calcarenites, intercalated with sandstones and microconglomerates (with acidic volcanic fragments) of the Upper Cretaceous Cerro Tipon Fm. (Muller, 1980).

The whole sequence (Table 1) shows island-arc magmatic affinity characterized by the crystallization order ol-cpx-pl. The distribution of the incompatible elements and REE (Fig. 31) show a general island-arc tholeiitic (IAT) affinity for the basal volcano-plutonic part of the sequence, whereas strongly plagioclase porphyritic basalts characterize the upper part of the sequence and indicate an island-arc calc-alkaline (IAC) character.

The JPZ Unit is extensively affected by low grade metamorphism which has generally resulted in static recrystallization of the primary igneous phases, including replacement of clinopyroxene by actinolite and/or chlorite and the local alteration of plagioclase.

Local deformations in the ophiolitic lithotypes are characterized by cleavages subparallel to the magmatic layering. Deformations are more severe in the mantle serpentinites (Fig. 32) which present boudinage and shear geometries. Shear deformation (with E-W direction) is strongly superimposed in the basal parts of the suite that are highly deformed and metamorphosed.

Near the hill of the Torre Guatel (communications tower), the uppermost JPZ formations are folded and overlain unconformably (or in fault contact) by the molasse of the Subinal Fm.

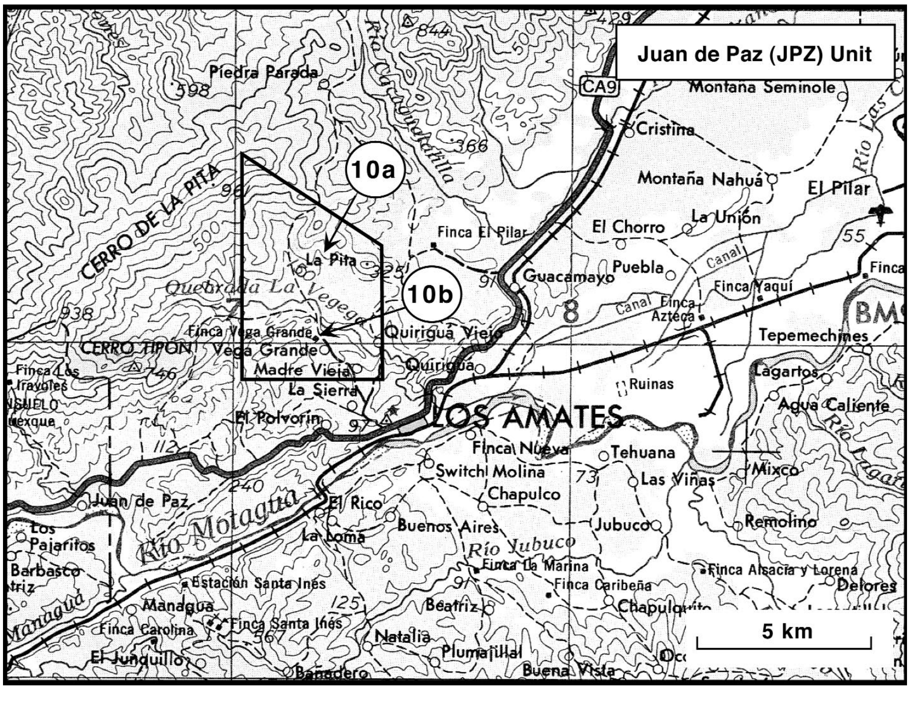

Fig. 29 - Topographic map of Los Amates area showing the location of the stops on the JPZ unit. The framed area is related to the geological map of Fig. 33.

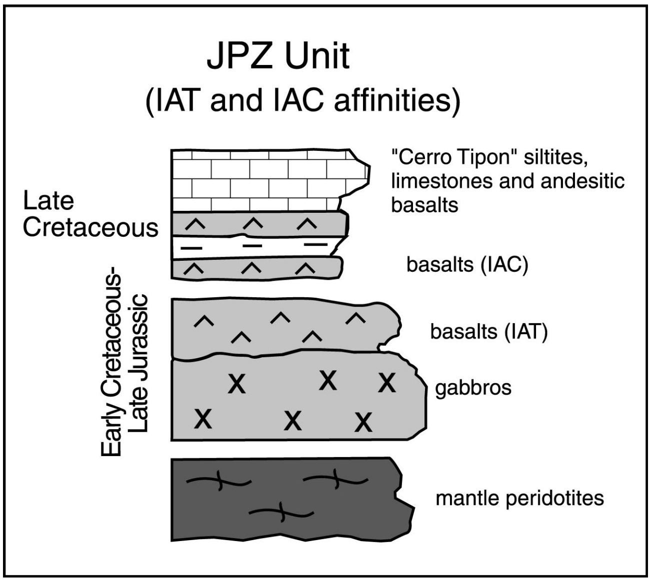

Fig. 30 - Reconstructed stratigraphic column of the Juan de Paz (JPZ) unit.

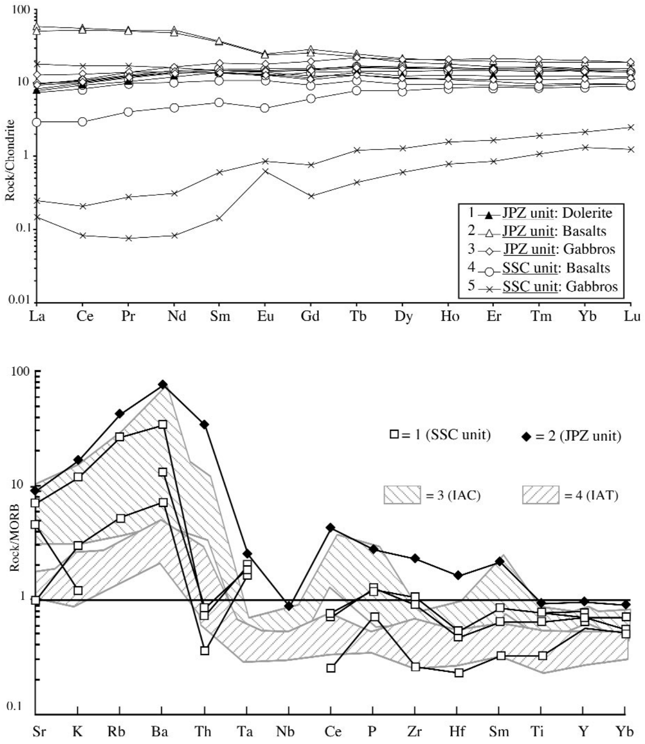

Fig. 31 - A) Chondrite normalized REE patterns of basic rocks showing IAT and IAC affinities from the Motagua Suture Zone of Guatemala. Normalizing factors after Sun and McDonough (1989).
1) Dolerite from the Juan de Paz (JPZ) unit (sample: GUA 51); 2) Basalts from the Juan de Paz (JPZ) unit (samples: GUA 52, 69); 3) Gabbros from the Juan de Paz (JPZ) unit (samples: GUA 36, 68, 64, 66); 4) Basalts from the Sierra Santa Cruz (SSC) unit (samples: GUA 20, 32, 61, 63); 5) Gabbros from the Sierra Santa Cruz (SSC) unit (samples: GUA 25, 60).
B) MORB-normalized incompatible element patterns of basic rocks showing IAT and IAC affinities from the Motagua Suture Zone of Guatemala. Normalizing factors and IAC (3) and IAT (4) basalts field after Pearce (1983). 1) Basalts and dolerites from the SSC unit; 2) Basalts from the JPZ unit.

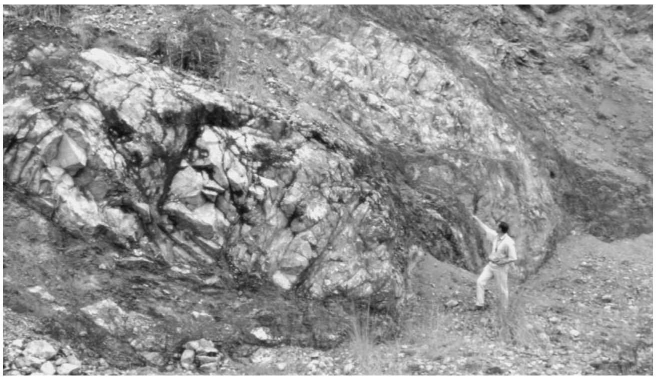

Fig. 32 - West of Los Amates: serpentinized peridotites (JPZ unit), strongly boudinated along the Motagua sinistral Shear Zone.

Los Amates - intersection to Vega Grande (5 km) - La Pita (2.5 km)

Stop 10 a *La Pita*

Outcrops of the **JPZ Unit** are observable along the La Pita transect (Figs. 33, 34). The JPZ Unit overthrusts the Sierra de Las Minas Paleozoic basement and is subdivided into several thrust sheets. Along the transect, the JPZ sequence is exposed although the original stratigraphic contacts are often obliterated. The main lithotypes are observable at:

La Pita creek: serpentinized **peridotites**, **gabbros**, **dolerites**, and basalts with IAT affinity;

Cerrito La Pita: **basalts** with IAC affinity, and scattered radiolarites.

Stop 10 b - *Finca Vega Grande*

The **Cerro Tipon Fm.** (Fig. 35) represents the youngest portion of the JPZ Unit composed of Upper Cretaceous reefal limestones with volcaniclastic, andesitic basalt intercalations, and calcareous breccias including volcanic elements.

Los Amates - C.A. 9 - La Ruidosa (244.5 km of C.A. 9) - Rio Dulce (34 km from La Ruidosa) (end of the II^ day)

3rd DAY:
RIO DULCE - LAGO IZABAL - EL ESTOR - SOLEDAD - SIERRA DE SANTA CRUZ - EL ESTOR - RIO DULCE

Main topic: The Sierra De Santa Cruz Unit (SSC)

Rio Dulce - Lago Izabal- El Estor (45 km) - Soledad (36 km)

Polochic fault. The new road along the northern side of Lake Izabal is more or less parallel to the Northern border of the Motagua Fault System (MFS) represented by the Polochic sinistral strike-slip fault (Fig. 36). This fault has induced the formation of the Izabal pull-apart basin that is filled by a thick (5 km maximum) Mio-Pliocene sedimentary section. The lake itself is 30 km wide and 75 km long with a maximum depth of 30 m.

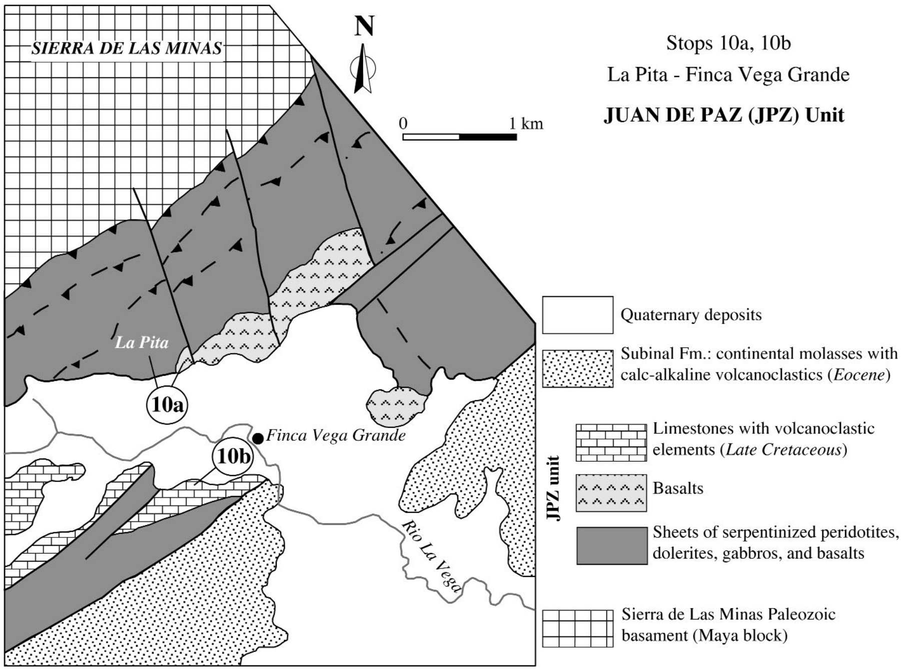

Fig. 33 - Geological sketch map of the La Pita and Finca Vega Grande area (JPZ unit).

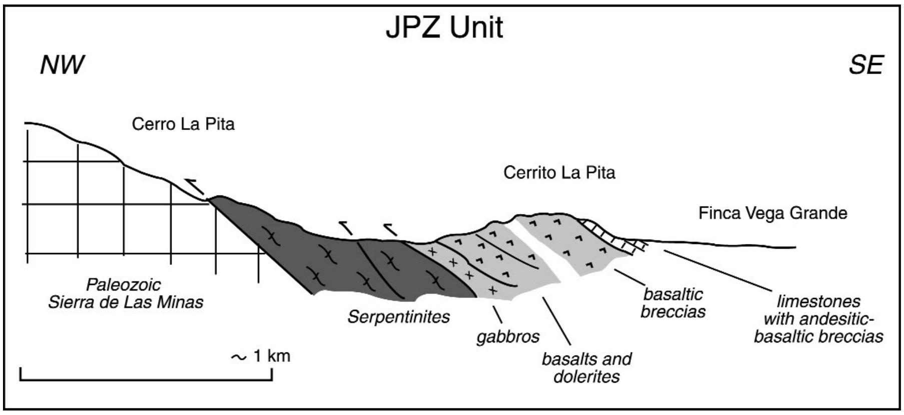

Fig. 34 - Schematic geological cross section of the JPZ unit in the area of La Pita, northwest of Los Amates.

Fig. 35 - Panoramic view of the Cerro Tipon from Finca Vega Grande. The highest parts of the picture correspond to Cerro Tipon Fm. (Late Cretaceous), mostly folded.

Fig. 36 -Aerial view (looking westward) of the Polochic sinistral strike-slip fault, west of the Lago Izabal and Rio Polochic delta.

Soledad - Buena Vista - Finca Chulac - Rio Cahabón - Oxec mine - Cahabón

Stops 11, 12, 13 (Figs. 37, 38). **Sierra de Santa Cruz Unit (SSC)**

The **Sierra de Santa Cruz Unit** (SSC) represents the northernmost ophiolitic unit of the MSZ; it outcrops to the north of the Polochic fault and clearly thrusts over the carbonate-terrigenous sequences of the Maya Block, mainly onto the Upper Cretaceous - Eocene foredeep deposits of the Sepur Fm. (Wilson, 1974).

The SSC Unit is mainly made up of (Fig. 39): serpentinized mantle harzburgites, layered gabbros, leucogabbros, dolerites, and pillow basalts, sometimes olivine-clinopyroxene porphyritic. Amphibolitic lenses have been also observed. Rare cherts and limestones interbedded with the basalts have yielded Cretaceous radiolarian and foraminiferal faunas, passing upward to scaly argillites (Jolomax Fm., Rosenfeld 1981).

An overlying volcano-sedimentary cover (Cretaceous Tzumuy Fm., Rosenfeld, 1981) is locally present in small outcrops and consists of terrigenous and volcaniclastic se-

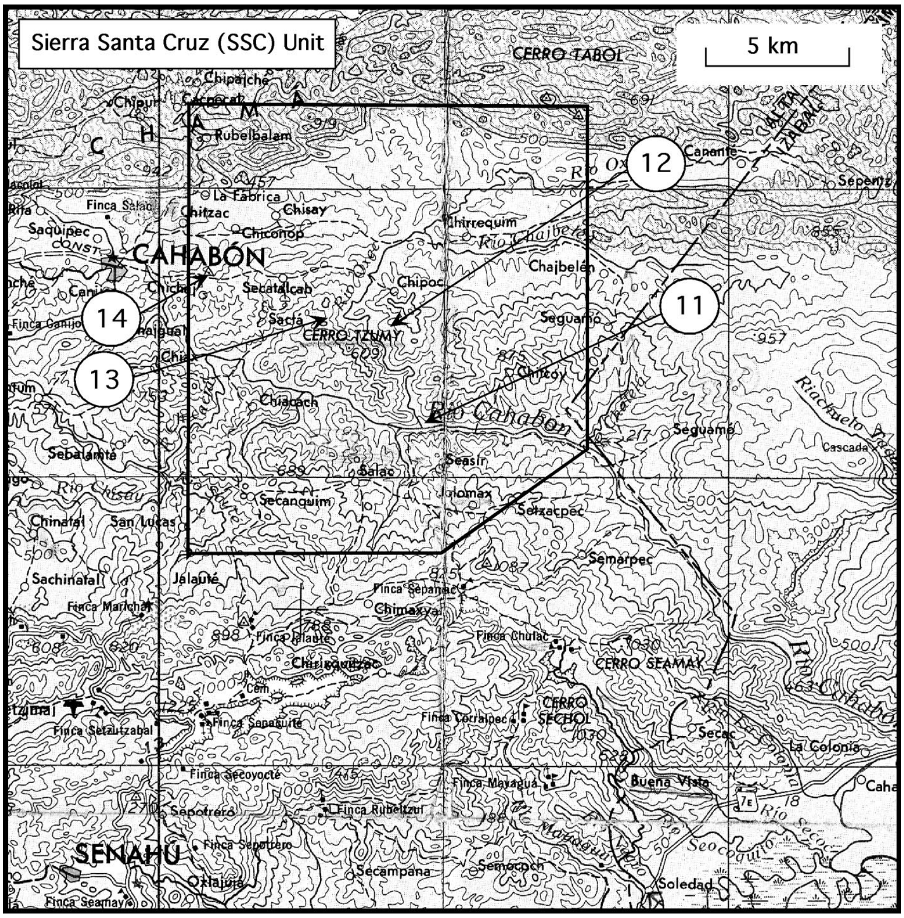

Fig. 37 - Topographic map of Cahabón area with the stop locations on the SSC unit. The framed area is related to the geological map of Fig. 38.

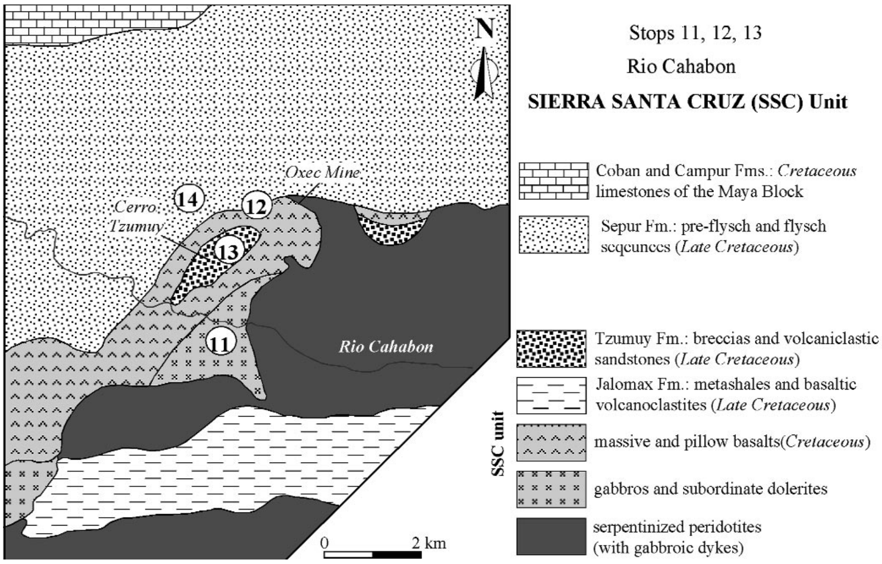

Fig. 38 - Geological sketch map of the Rio Cahabón- Cerro Tzumuy area (SSC unit).

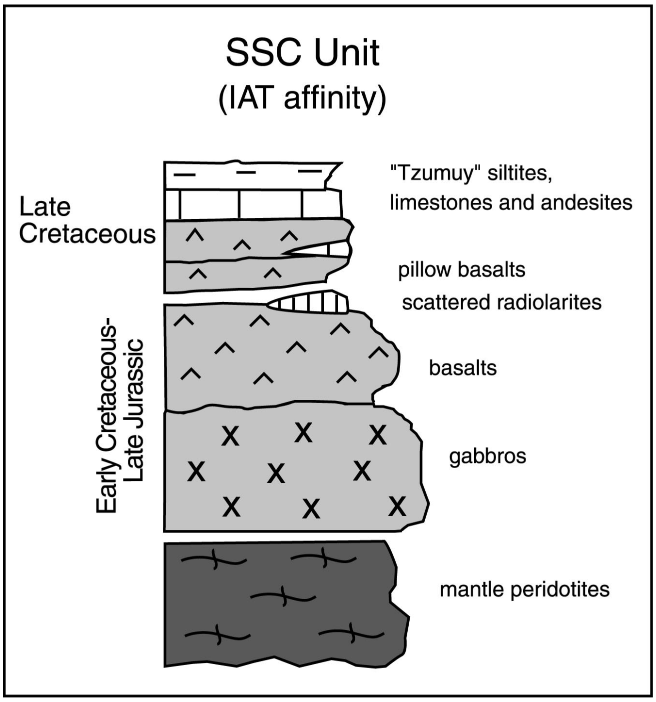

Fig. 39 - Reconstructed stratigraphic column of the Sierra Santa Cruz (SSC) unit.

quences including andesitic basalts and dacitic fragments.

In addition, lateritic nickel and Cyprus-type copper deposits on the SSC massif have been mined close to Lake Izabal.

The basalts of the SSC Unit show a clear IAT affinity (Fig. 31 and Table 1) as testified to by the crystallization order of clinopyroxene before plagioclase in both the volcanic and plutonic sections and by the consistently flat REE pattern and the characteristic distribution of incompatible elements. The generally cumulitic nature of the layered gabbroic sequence is evidenced by remarkably low level of REE in the analyzed samples (i.e., GUA 25, and GUA 60).

The SSC Unit is subdivided into several tectonic slices cut by high-angle faults. Overturned north-verging faults can be observed in the frontal area, and several exposure of the SSC basal thrust fault can be examined.

Ophiolitic rocks of the SSC Unit have experienced variable extents of metamorphism under greenschist and amphibolitic facies conditions. The hydrothermal alteration results in the serpentinization of mantle harzburgites, and in the substitution of magmatic pyroxenes of gabbros and basalts by tremolitic-actinolitic amphiboles and sporadic green horneblende. Nonetheless, igneous textures and large relicts of the original olivine, clinopyroxene and plagioclase are generally preserved in the basic rocks.

The slightly metamorphosed (under prehnite-pumpellyite facies conditions) and highly deformed Jolomax Fm. has been interpreted by Rosenfeld (1981) as subduction related trench fill, tectonically included in the obducted slab. This unit is difficult to observe in the field since the road cuts are very deeply weathered. Somewhat better outcrops occur along streams.

Stop 11 - ***Puente Rio Cahabón (47 km from Soledad)***

The contact between the Jolomax Fm. scaly argillites (with minor amphibolite inclusions) and the **serpentinite matrix mélange** (including large blocks of coarse-grained gabbro cumulates intruded by pyroxenite and dolerite parallel dikes) is observable along the road. Most of the ophiolitic lithologies are well represented in cobble and boulder sized alluvium at the bridge. Layered cumulitic **meta-gabbros** with dikes of dolerites outcrop under the bridge (Fig. 40),

The stratigraphic superposition of melange/gabbro/dolerite/basalt can be observed by walking 2-3 km to the west along the south bank of the river.

Stop 12 - ***Mina de Oxec (6 km from Rio Cahabón bridge)***

Two lithotypes of the SSC Unit crop out around the Oxec mine:

i. serpentinized **peridotites** with dikes of microgabbros (Fig. 41);
ii. pillow **basalts** (Fig. 42) with IAT affinity.

The Oxec copper deposit is a Cyprus-type subseafloor hydrothermal stockwork deposit (Rosenfeld, 1981, and quoted references). Some 2 million tons of copper ore were extracted and processed at the mine in the 1970's. The host rock for the ore is chloritized and sheared basalt within a framework of tectonically dismembered dolerite dikes. The mineralization consists of pyrite/chalcopyrite/pyrrhotite/quartz in veins that are thickest and more copper enriched along the edges of the dolerite dikes. Most of the workings are underground, although an open-cut exists that at one time allowed the observation of lithologic and structural relations within the ore body. If the open face of the mine can be safely examined (although unfortunately the old bridge for the mine was destroyed by Hurricane Mitch), an interesting partially serpentinized peridotite dike may be seen among the dolerites. There are excellent exposures of pillow basalt in the river bed southwest of the mine.

Stop 13 - ***Cerro Tzumuy***

Cerro Tzumuy Fm. represents the youngest portion of the SSC suite, it is composed of breccias and volcaniclastic wackes of Late Cretaceous age. The structural setting of the western end of the SSC can be appreciated in the panoramic vistas provided by Cerro Tzumuy.

Mina de Oxec - towards Cahabón village

After crossing the thrust front of the SSC Unit at Cerro Tzumuy, the road to Cahabón continues across a large ex-

Fig. 40 - Panoramic view of the Rio Cahabón crossed by the road from Soledad to Oxec Mine. Under the bridge, on the left side of the river, gabbro cumulates outcrop.

Fig. 41 - Oxec Mine: serpentinized periditites crossed by gabbroic dikes (SSC unit).

Fig. 42 - Road from Oxec Mine to Cahabón: pillow basalts (SSC unit).

panse of the **Sepur Fm.** (Maya Block) foredeep sequence, comprising Upper Cretaceous pre-flysch (Fig. 43) with occasional debris flow (wildflysch) deposits. The dominant lithologies are alternating siltstones and sandstones in truncated Bouma sequences. The coarser grained sandstones often have channelized bases. Sandstone clasts are calcareous, volcaniclastic and ophiolitic. The best exposed debris flow is at the bridge just east of Cahabón where the rock has been dynamited. Pebble to cobble sized debris flow clasts consist of volcanic and plutonic igneous rocks, limestone and reworked fine grained clastics. The Sepur Fm. is as young as Eocene north of the SSC (Rosenfeld, 1981, and references therein). The Sepur Fm. is very deeply weathered along most of the road cuts and the freshest and most complete section is found along the Río Cahabón.

Stop 14 - *6 km from Mina de Oxec towards Cahabón village and Road to Secante*

The **Sepur Fm.** represents Upper Cretaceous (Maastrichtian, Fourcade et al., 1994)-Eocene carbonate-siliciclastic pre-flysch and flysch sedimentation, deposited on the Maya Block (i. e. foredeep sediments). It consists of an upward coarsening sequence of silicic siltites, as well as lithic sandstones and conglomerates. In contrast with sandstones and clast-supported carbonate matrix granule conglomerates of the Sepur Fm., the matrix supported wildflysch conglomerates are devoid of ophiolitic detritus, suggesting that their provenance is different from that of the finer grained components of the Sepur Fm.

The Sepur Fm. is generally deformed by tight asymmetrical folds showing northward vergences (Fig. 44), in accordance with the whole Peten regional tectonics.

Cahabón village - Mina de Oxec - Rio Cahabón - Soledad - El Estor - Rio Dulce (end of the 3rd day and of the field-trip)

Fig. 43 - East of Cahabón village: calcareous mudstones with alternances of siltstones and volcanoclastics (Late Cretaceous pre-flysch deposits of the Sepur foredeep basin).

Fig. 44 - Main road north of Frontera. Sepur Fm.: layered siltstones (Late Cretaceous- Eocene), folded with a northward vergence.

DISCUSSION

Five main ophiolitic units have been identified in the Motagua Suture Zone (MSZ) on the basis of both their tectono-magmatic significance and their positions with respect to the main tectonic alignments (Fig. 45).

Among these units, three groups can be further distinguished considering their relationships with the continental blocks: **i**- the SSC and BVP Units overthrust onto the continental Paleozoic-Mesozoic sequences of the Maya Block (NOAM plate) with a northward vergence; **ii**- the JPZ and NM Units either northward-overthrust or are deformed against the continental belt of the Sierras de Chuacus and de Las Minas, related to the Maya Block; **iii**- the SM Unit is imbricate and overthrust onto the continental Chortis Block (CARIB plate), showing southwards vergences.

The SM and NM Units show a clear MORB magmatic affinity. One alkaline basalt found within these oceanic sequences may represent the remnant of a seamount lying on the oceanic crust.

Magmatic affinities of the JPZ and SSC indicate the influence of the subduction zone; i.e, basaltic rocks show island-arc affinity and belong to the tholeiitic (IAT) or, more rarely, to the calc-alkaline (IAC) series. The predominant occurrence of mantle harzburgites in the BVP Unit suggests that this unit probably represents a sub-arc mantle body comparable to those of the SSC and JPZ Units.

The MSZ ophiolitic Units have been variably metamorphosed and deformed by ductile deformative phases, related to either subduction (in an intra-oceanic environment) and exhumation, or to the obduction.

A reconstruction of the kinematic role played by the MSZ ophiolitic Units in the geodynamic evolution of the Caribbean Plate’s northwestern margin (Figs. 46, 47) is attempted below (see also Giunta, 1993; Giunta et al., 1998; 2001, for details).

The spatial-temporal definition of the main evolutionary stages of the MSZ is based on the tentative paleogeographic restoration of some recognised kinematic elements, which are: a) the continental margins of NOAM and SOAM, and of the minor blocks of Maya and Chortis; b) the oceanic crust, showing MORB, and subordinately OIB affinities; c) the intra-oceanic subduction complexes and related volcanic arcs with IAT and IAC affinities.

A tentative paleogeographic reconstruction (Figs. 46, 47)

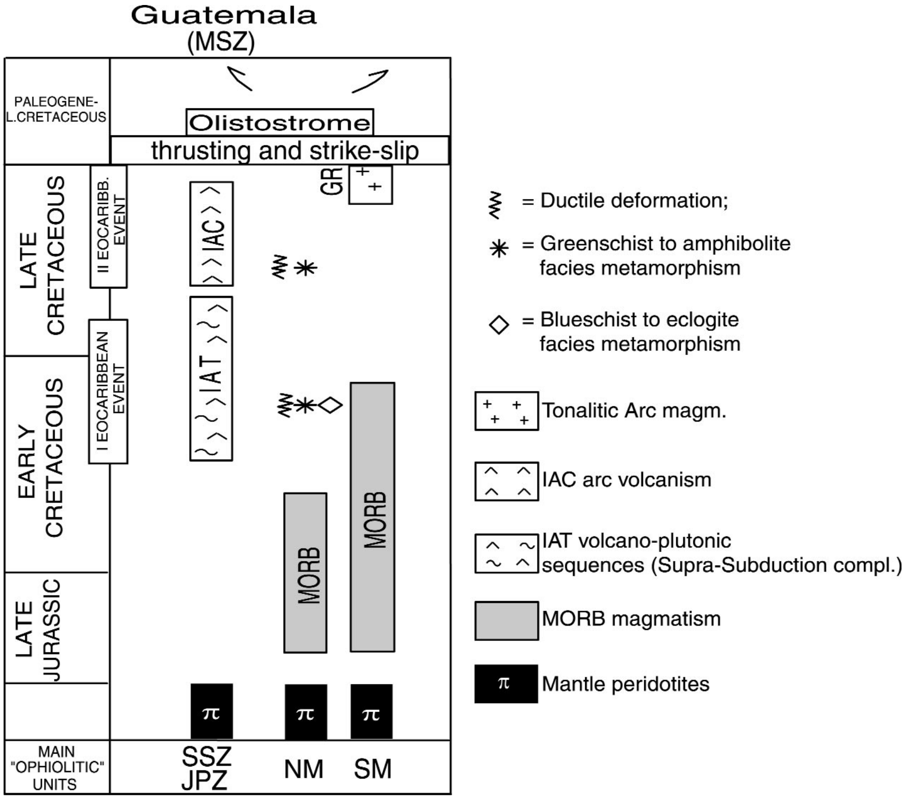

Fig. 45 - Sketch showing the main tectonic, magmatic, and metamorphic events of the Motagua Suture Zone unit (modified from Giunta et al., 2001).

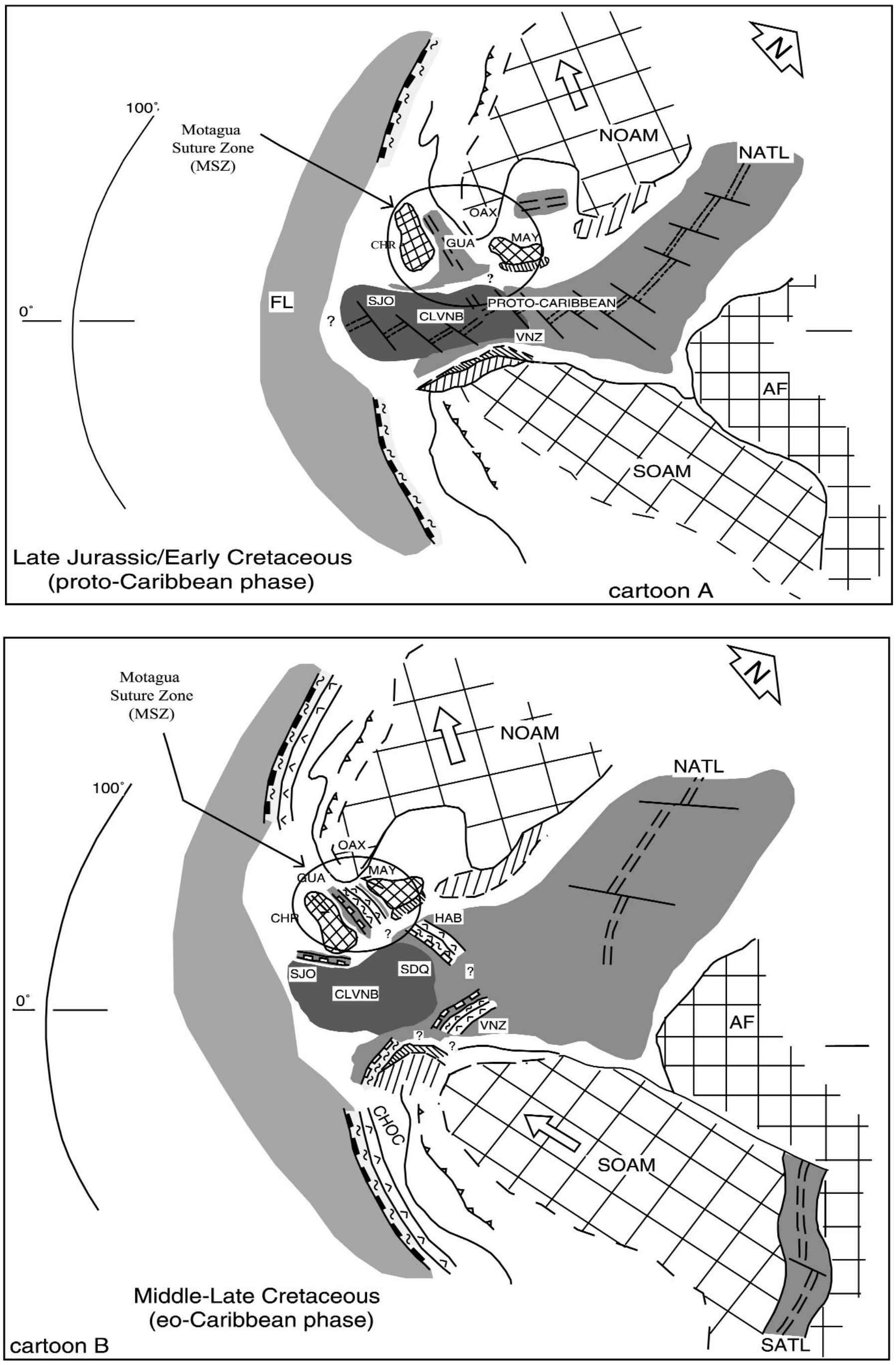

Fig. 46

should start by restoring the flower structure represented by the Upper Cretaceous-Lower Tertiary MSZ, primarily considering the sinistral strike-slip movements of the Motagua Fault System (MFS). The ophiolitic units were thus probably located northwestward in a poorly defined area trending “en echelon” between the contemporaneous Maya and Chortis continental blocks; while the latter are considered to be restored to their hypothetical original position.

Oceanization was preceded and accompanied by rifting tectonics affecting both the Maya and Chortis Blocks, as testified to by the Upper Jurassic terrigenous sedimentary sequences of the Todos Santos Fm. on the Maya Block and the Metapan Fm. on the Chortis Block.

Remnants of the lithosphere of the Jurassic-Lower Cretaceous Motagua oceanic area are only found in the NM and SM Units, although their relationship with the main proto-Caribbean Sea are still difficult to define (seaway ?). The sedimentary cover of the SM and NM Units includes Upper Jurassic-Lower Cretaceous radiolarian cherts, clastic-terrigenous sediments, and finally mid-Cretaceous limestones and suggests proximity to continental margins.

During the middle Cretaceous, an intra-oceanic subduction system developed, marking the beginning of the eo-Caribbean convergent phase. This occurrence is recorded by the relict HP-LT metamorphism in the MORB Units (NM and SM), as well as by island-arc magmatism and sub-arc mantle structures of the supra-subduction units (SSC, JPZ, and BVP). In particular, arc magmatism is mainly characterized by IAT affinity associated with IAC basalts during the final stages.

The occurrence of intra-oceanic subduction, characterized by a slab dipping toward the Maya Block, is demonstrated by: a) the SM and NM Units were partially metamorphosed under HP-LT conditions and then involved in the

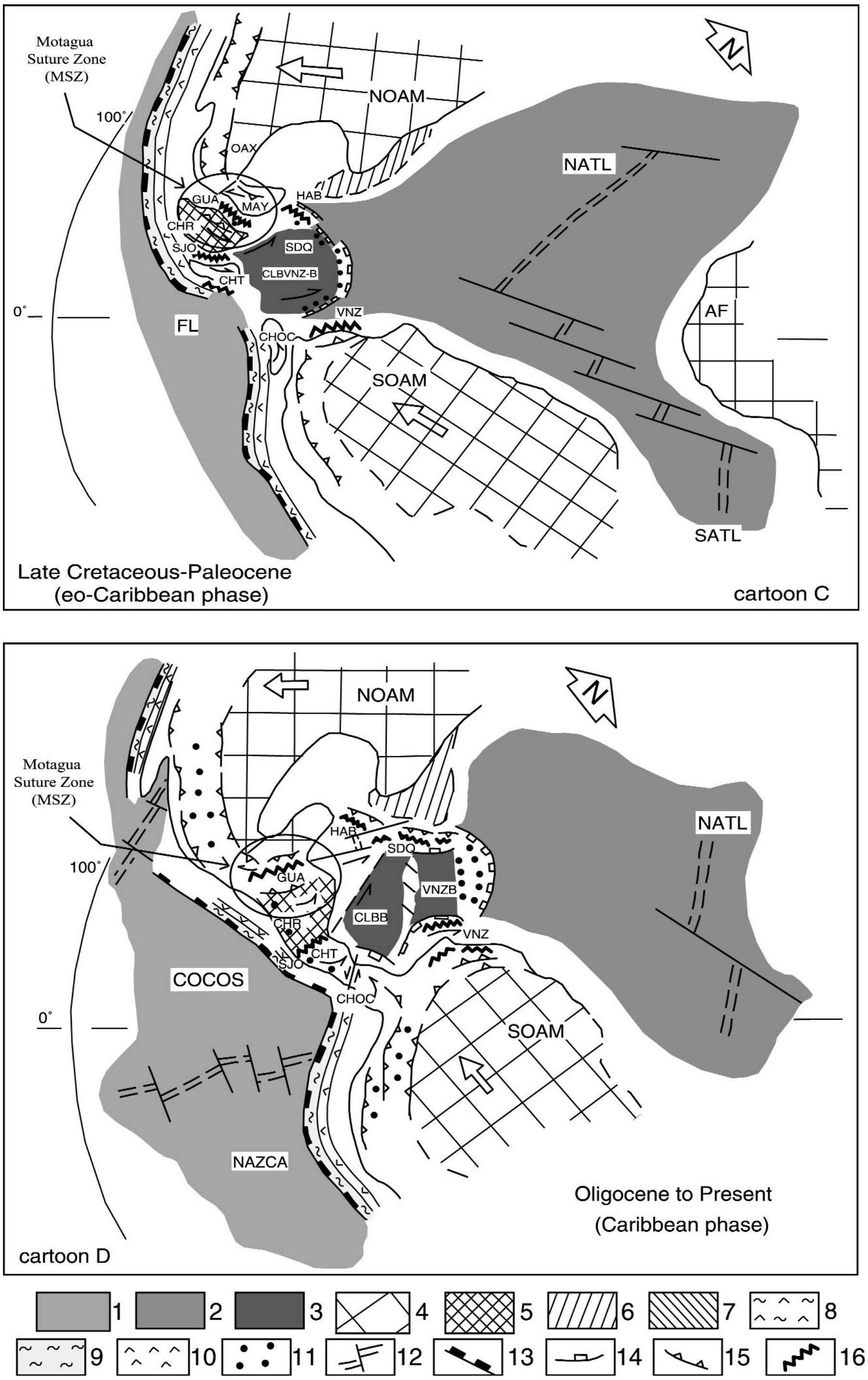

Fig. 46 - Cartoons showing the kinematics of the Motagua Suture Zone in the framework of the Caribbean Plate evolution, from Late Jurassic to Tertiary (modified from Giunta et al., 2001).
Legend: 1= Oceanic crust of the Farallon Plate; 2= Proto-Caribbean and Atlantic oceanic crusts (NM and SM in Guatemala); 3= Proto-Caribbean oceanic area undergoing crustal thickening; 4= Major continental plates (NOAM, SOAM, AF); 5= Minor continental blocks (MAY, CHR); 6= Continental margins; 7= Rifted continental margins, with Within Plate Tholeiitic magmatism; 8= Metamorphosed volcano-plutonic arc sequences with IAT and IAC affinities; 9= melanges including ophiolitic blocks with MORB affinity; 10= Arc volcanism with IAT and IAC affinities (SSC and JPZ in Guatemala); 11= Tonalitic arc magmatism (GR in Guatemala?); 12= Oceanic spreading centers; 13= Subductions of the Farallon-Pacific oceanic lithosphere; 14= Intraoceanic and sub-continental subductions in the Caribbean area; 15= Main overthrust fronts; 16= Deformed thrust belts, including suture zones, accretionary prisms, and olistostromes.
Abbreviations: FL= Farallon; NOAM= North America; SOAM= South America; AF= Africa; NATL= North Atlantic; SATL= South Atlantic; OAX= Oaxaca; MAY= Maya; CHR= Chortis; CHT= Chorotega; CHOC= Choco; SJO= Costa Rica; GUA= Guatemala; SDQ= Hispaniola; HAB= Cuba; VNZ= Venezuela; CLVNB= Colombia-Venezuela Basins; CLBB= Colombia Basin; VNZB= Venezuela Basin.

oblique subduction, as well as being included in the accretionary prism; b) the supra-subduction zone and related arc magmatism (SSC, BVP, JPZ) Units were obducted onto the Maya Block, whereas the MORB (NM and SM) Units either overthrust the Chortis Block or are juxtaposed to the Maya Block; c) the terrigenous-carbonate and volcaniclastic sedimentary cover (Tzumuy and Cerro Tipon Fms.) of the northern ophiolitic units which, at least in part, can be correlated to the Upper Cretaceous Sepur Fm. of the Maya Block cover.

Progressive collision took place along a transpressive sinistral system between the Chortis and Maya Blocks, probably starting before Laramide tectogenesis (Late Cretaceous-Paleocene). This may have induced delamination of the already deformed oceanic areas, their progressive exhumation, and their emplacement onto both opposing continental margins, thereby giving rise to the MSZ flower structure. In this framework, two possible kinematics of the deformative northern front (e.g. in the SSC Unit) can be considered to have occurred during the Late Cretaceous-Paleocene: (a) progressive deformation of a northward prograding foredeep-like basin, extending northward onto the continental margin of the Maya Block (Sepur Fm.) and southward onto the Cretaceous volcanic arc (Cerro Tipon and Tzumuy Fms.); (b) a gradual approach toward the Maya margin of the yoked foredeep (e.g. lower Sepur Fm.) + deformative front, which carried piggy-back type basins (e.g., Tzumuy, Cerro Tipon, and upper Sepur Fms.). According to

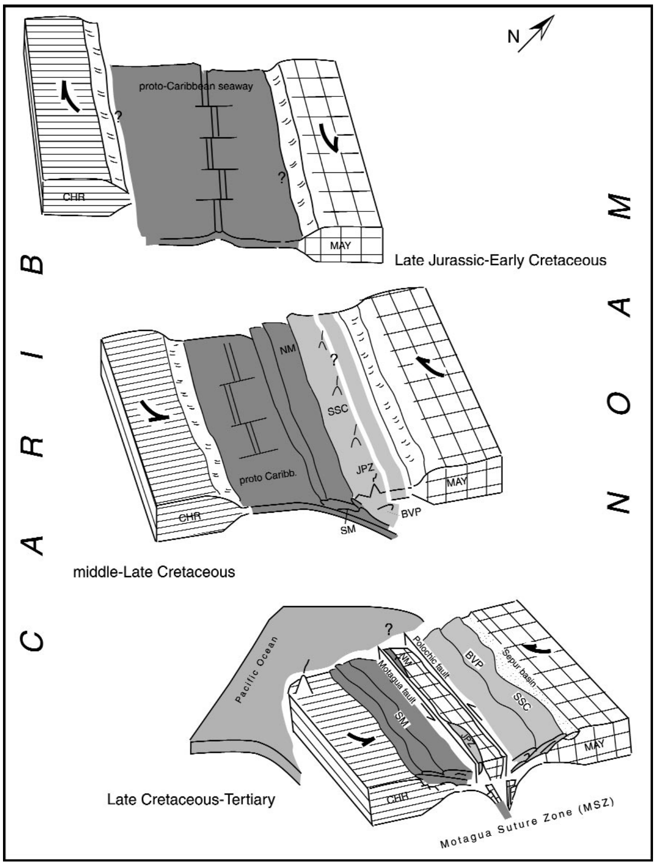

Fig. 47 - Block diagrams showing the kinematic evolution of the Motagua Suture Zone.

the latter hypothesis the basal age of the piggy-back formations should be diachronous.

The MSZ formed during the Cretaceous-Paleocene after the collision between the Chortis and Maya Blocks, which then induced complete closure of the narrow oceanic area and progressively increasing deformation of the continental margins towards the respective forelands. This collision was probably also responsible for granitoid magmatism, represented by variably sized intrusive bodies (e.g. Zacapa Granitoids).

The end of the eo-Caribbean phase corresponds to the Upper Cretaceous-Paleogene obduction or the tectonic emplacement of the proto- and eo-Caribbean ophiolitic units onto or against the continental blocks, as a suture zone, with flake and wedge geometries.

The tectonic evolution of the MSZ also appears to be closely related to the kinematics of the Maya, Chortis, Chorotega and Choco Blocks, which today constitute the Meso-American Isthmus. From the Late Cretaceous, the Chortis continental Block moved eastward in an anticlockwise rotation with respect to the Maya Block, giving rise to the MSZ of Guatemala (Gordon and Muehlberger, 1994). This movement, in turn, induced Pacific intraoceanic convergence to the west against the southern part of the Chortis Block, forming the Chorotega Block. The latter block (corresponding to present-day Costa Rica) started as a pile of oceanic thrust sheets, and was progressively inserted between the Maya-Chortis and Choco-South America continental Blocks. The subsequent convergence of the North and South America Plates during their general westward drift caused a counterclockwise rotation of both the Chorotega and Choco Blocks with respect to the Chortis Block, and progressively juxtaposed all the blocks in an accommodation mosaic along the Mid-American Trench. As a consequence, the inner, undeformed portions of the Caribbean Plate (i.e., the Colombian and Venezuelan Basins) were trapped by the intervening Central American subduction system.

During the Eocene, the molassic Subinal Fm. was deposited over the already formed structures and tectonic contacts of the MSZ.

The Motagua Fault System can be identified starting in the Miocene, , and is represented by strike-slip faults (Polochic, Motagua-Cabañas, and Jocotan) which dislocated the suture zone with a sinistral component giving rise along restraining zones to the uplift of the elongated Sierras de Chuacus and Las Minas, producing the present-day configuration.

In order to stimulate scientific debate, some first-order problems should be discussed in the kinematic evolution of the MSZ: (a) - the paleogeography and the original location of the Motagua oceanic seaway, - its relationships with the proto-Caribbean, - the paleogeography of the MAY and CHR continental margins; (b) the possible development of intra-oceanic subduction, as well as the HP-LT metamorphism, in a transpressional stress-field; (c) the mechanisms for the exhumation of the deepest units; (d) the relationships to the main portions of the northern Caribbean Plate margin (Greater Antilles).

Aknowledgments

We thank the meeting participants for their effort expended to the success of the event.

We are especially grateful to Juan Carlos Amado, Hans Avé-Lallemant, Otto Bohnemberger, Sam Bonis, Percy Denyer, Antonio Garcia Casco, Mark Gordon, Manuel Iturralde-Vinent, Uwe Martenz, Napoleon Rodriguez, for constructive discussions and suggestions during the field-trip, that led to the improvement of this guide-book.

We extend our sincere appreciation to Luz Helena Hernandez for the collaboration in organizing the secretary’s office of the workshop.

We are particularly indebted to Michele Marroni and Luca Pandolfi (“Ofioliti” Int. Journal) for their invaluable assistance in editing and publication of this guide-book.

REFERENCES

Avé Lallemant H.G. and Gordon M.B., 1999. Deformation history of Roatan Island: implications for the origin of the Tela Basin (Honduras). Caribbean basins, sedimentary basins of the Word. Elsevier Sci. B.V., Amsterdam, p. 197-218.

Beccaluva L., Bellia S., Coltorti M., Dengo G., Giunta G., Mendez J., Romero J., Rotolo S. and Siena F., 1995. The northwestern border of the Caribbean Plate in Guatemala: new geological and petrological data on the Motagua ophiolitic belt. Ofioliti, 20 (1): 1-15.

Bertrand J., Vaugnat M., 1976. Étude petrographique de diverses ultrabasites ophiolitiques du Guatemala et de leurs inclusions. Extr. Bull. Suisse Min. Petr., 56 (3): 527-540.

Burkart B., 1978. Offset across the Polochic Fault of Guatemala and Chiapas, Mexico. Geology, 6: 328-332.

Burkart B., 1994. North Central America. In: S. Donovan and T. Jackson (Eds.), Caribbean geology: an introduction. Kingston, Jamaica, West Indies University, p. 193-207.

Dengo G., 1972. Review of Caribbean serpentinites and their tectonic implications. Geol. Soc. Am. Mem., 132: 303-312.

Dengo C.A., 1976. A petrologic study of the serpentinized peridotites from the El Progreso Quadrangle, Guatemala, Central America. Syracuse Univ. B.S. Thesis, 34 pp.

Dengo G., 1985. Mid-America: tectonic setting for the Pacific margin from southern Mexico to north western Colombia. In: Nairn A. E. M., Stehli F. G., Uyeda S. (Eds.), The ocean basin and margins, 7: 15-37.

Dengo G. and Bohnenberger O., 1969. Structural development of northern Central America. A.A.P.G. Mem., 11: 203-220.

Dengo C.A., and Dengo G, 1992. A possible convergence zone between the Polochic and Motagua fault systems in western Guatemala, Central America. 13th Annual Conf. GCSSEPM, p. 17.

Donnelly T. W., 1978. Geological history of the Motagua Valley and the Motagua fault system. Proc. Inter. Symp" Feb 4, 1976 Guatemalan earthquake and the reconstruction process", 1, not paginated.

Donnelly T.W., Horne G.S., Finch R.C. and Lopez-Ramos E., 1990. Northern Central America; The Maya and Chortis bloks. In: Dengo G., Case J. E. (Eds.), The Caribbean Region. Geol. Soc. Am., The Geology of North America, Vol. H: 37-76.

Finch R.C. and Dengo G., 1990. NOAM-CARIB Plate boundary in Guatemala: A Cretaceous suture zone reactivated as a Neogene Trasform Fault. G.A.S. Annual Meeting.

Fourcade E., Mendez J., Azema J., Bellier J.P., Cros P., Michaud F., Carballo M. and Villagran, 1994. Age de l'installation, de l'effondrement de la plateforme carbonatée et de la mise en place des ophiolites du Bloc Maya au Mesozoique (Guatemala).

Giunta G., 1993. Los margenes mesozoicos de la Placa Caribe: Problematicas sobre nucleacion y evolucion. Mem. Congr. Colomb. Geol., 6th, Medellin, Soc. Geol. Colomb., 3 (8): 1-14.

Giunta G., Beccaluva L., Coltorti M. and Siena F., 1998. Tectonomagmatic significance of the peri-Caribbean ophiolitic units and geodynamic implications. In Proceed. 15th Caribbean Geol. Conf. Kingston, Jamaica, West Indies Univ., p. 1-21.

Giunta G., Beccaluva L., Coltorti M., Siena F., Mortellaro D. and Cutrupia D., 2001. The peri-Caribbean ophiolites: structure, tectono-magmatic significance and geodynamic implications. Carib. J.. Earth Sci., in press.

Gordon M.B. and Muehlberger, 1994. Rotation of the Chortis Block causes dextral slip on the Guayape Fault. Tectonics, 13: 858-872.

Harlow G.E., 1994. Jadeitites, albitites and related rocks from the Motagua Fault Zone, Guatemala. J. Met. Geol., 12: 49-68.

Harlow G.E., 1995. Crystal chemistry of barian (barium??) enrichment in micas from metasomatized inclusions in serpentinite, Motagua Valley, Guatemala. Europ. J. Min., 7: 775-789.

Johnson C.A. and Harlow G.E., 1999. Guatemala jadeitites and albitites were formed by deuterium-rich serpentinizing fluids deep within a subduction-channel. Geology, 27: 629-632.

McBirney A.R., Aoki K.-I. and Bass M., 1967. Eclogites and jadeite from the Motagua fault zone, Guatemala. Am. Min. 52: 908-918.

Muehlberger W.R. and Ritchie A.W., 1975. Caribbean - Americas plate boundary in Guatemala and southern Mexico as seen on Skylab IV orbital photography. Geology, 3: 232-235.

Muller P.D. 1980. Geology of the Los Amates quadrangle and vicinity, Guatemala, Central America. Unpublished Ph.D. N.Y. State Univ., 326 pp.

Pearce J.A., 1983. Role of sub-continental lithosphere in magma genesis at active continental margins. In: Hawkesworth C.J., Norry M.J. (Eds.), Continental basalts and mantle xenoliths. 231-249.

Rosenfeld L. 1981. Geology of the western Sierra de Santa Cruz, Guatemala. Unpublished Ph.D., N.Y. State Univ., 313 pp.

Schwartz D.P., Cluff L.W., and Donnelly T.W., 1978. Quaternary faulting along the Caribbean-North American plate boundary in Central America. Proceed. Intern. Symp. "Feb 4, 1976 Guatemalan earthquake and the reconstruction process", 1, not paginated.

Silva Z.C.G., 1967. Studies on jadeites and albites from Guatemala. M.A. Thesis, Rice Univ.

Silva Z. C. G., 1969. Estudio sobre jadeitas y albititas de Guatemala. Inst. Geogr. Nac., Guatemala, 22 pp.

Silva Z.C.G., 1970. Origin of albitites from eastern Guatemala. Bol. Serv. Geol. Min. (Brazil), 22: 23-32.

Sorensen S.S. and Harlow G.E., 1999. The geochemical evolution of jadeitite-depositing fluids. G.S.A. Ann. Meeting, Abstr. Progr., 31: A-101.

Stephan J.F., Blanchet R. and Mercier de Lepinay B., 1986. Northern and Southern Caribbean Festoons (Panama, Colombia, Venezuela, Hispaniola, Puerto Rico) interpreted as subductions induced by the East West shortening of the peri-Caribbean continental frame. In: F.C. Wezel (Ed.), The origin of arcs., Development in geotectonics, Elsevier, 21: 35-51.

Sun S-S. and McDonought W.F., 1989. Chemical and isotopic systematics of oceanic basalts. Implications for mantle composition and processes. In: A.D Saunders., J. Norry (Eds.), Magmatism in the ocean basins. Spec Publ. Geol. Soc London, 42: 313-346.

Wilson H.H. 1974. Cretaceous sedimentation and orogeny in nuclear Central America. Am. Ass. Petrol. Geol., 58: 1348-1396.

Received, November 15, 2001
Accepted, May 3, 2002