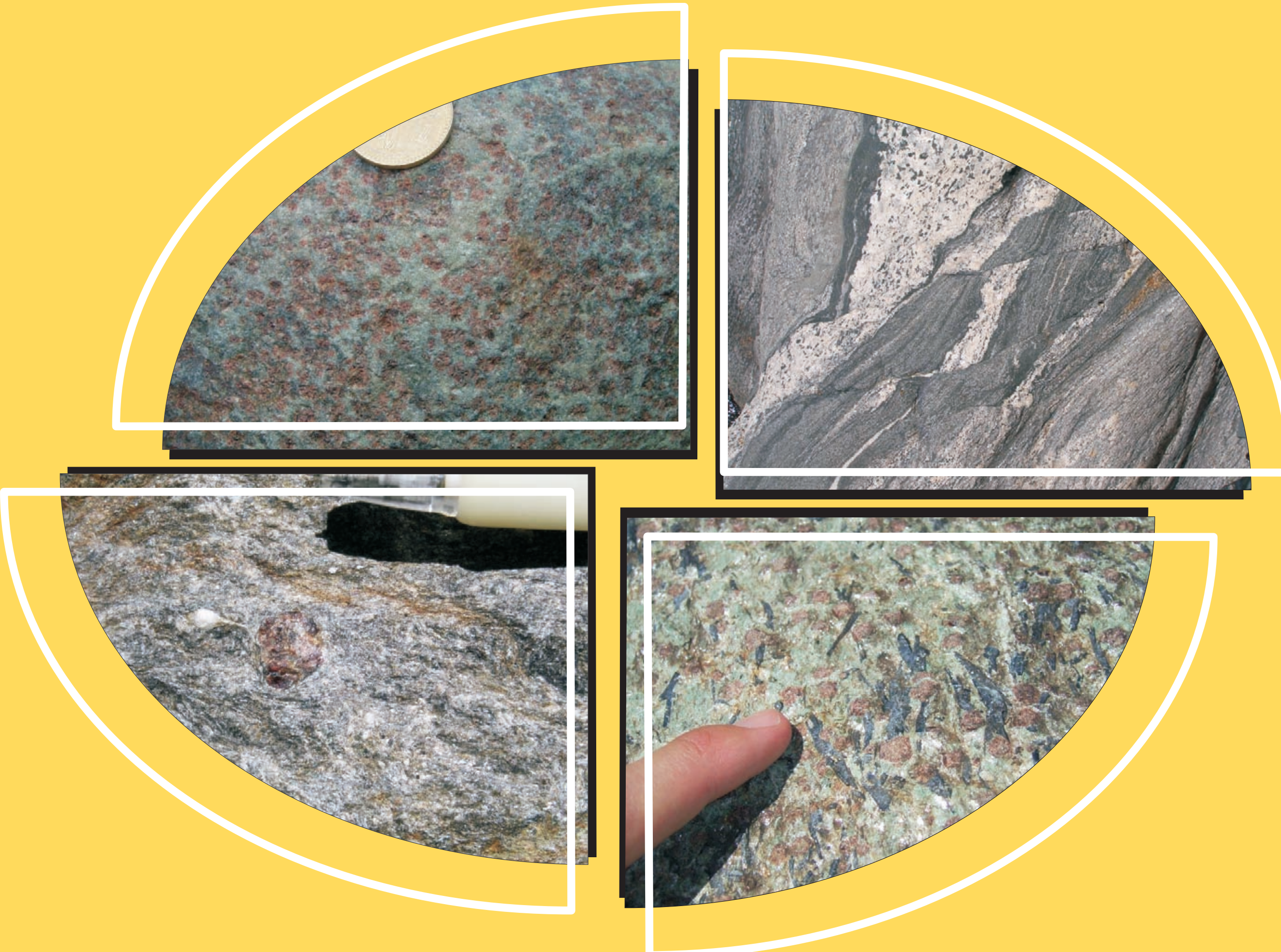
FIELD TRIP GUIDE

2007 FIELD WORKSHOP OF IGCP 546
"SUBDUCTION ZONES OF THE CARIBBEAN"



HIGH-PRESSURE BELTS OF CENTRAL GUATEMALA: THE MOTAGUA SUTURE AND THE CHUACÚS COMPLEX

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Photographs of Front Page
Upper Left: Eclogite, Belejeyá River, Sierra de Chuacús.
Upper Right: Gneiss of Chuacús Complex, Sierra de Chuacús.
Lower Left: Garnet two-mica schist, Las Ovejas Complex, south of Huité.
Lower Right: Eclogite, Carrizal Grande, Jalapa.

Courtesy Tatsuki Tsujimori and Uwe Martens

Field Trip Guide
1st Field Workshop of IGCP 546
“Subduction Zones of the Caribbean”

High-Pressure Belts of Central Guatemala:
The Motagua Suture and the Chuacús Complex

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2007

Introduction

The International Geoscience Program called for proposals in 2007 defining “The Deep Earth” among five areas of special interest. Prof. Antonio García-Casco from Universidad de Granada and PhD candidate Uwe Martens from Stanford University submitted the proposal “Subudction Zones of the Caribbean”, a project aiming to continue efforts from previous IGCP projects to unravel the complex geologic evolution of the Caribbean area, but focusing particularly on deep earth processes and materials, from both ancient suture zones and active convergent margins. The proposal was awarded support as IGCP project 546 for the years 2007-2011. Colleagues from a number of countries and institutions worldwide enthusiastically gave support to the project.

Our project endorses the program “Earth Sciences for Society - an International Year of Planet Earth”. Earth’s systems greatly impinge on our daily lives. Interpreting the history of the Earth, and using that knowledge as a basis for forecasting likely future events is a matter of global concern. Therefore, one of IGCP 546 main goals is to establishing links between ancient and current subduction zones of the Caribbean, inasmuch as this is critical for a well founded understanding of the tectonic evolution of the associated convergent plate-margins, which will hopefully enable a better understanding of the geodynamics of such a populated and geologically hazardous region.

The project will have a duration of 5 years (2007-2011). Our cooperative plan is to organize a series of workshops and field trips throughout the Caribbean that will enable a systematic comparison of high-pressure belts, help unravel the history of subduction in the region, and contribute scientific knowledge to better predict and mitigate hazards created by subduction in the Caribbean. Our major fieldwork targets will be:

* Guatemala. Motagua suture (Motagua valley and adjacent mountain ranges), sierra de las Minas, sierra de Chuacús.

* Dominican Republic. Río San Juan-Puerto Plata area and, Samaná Peninsula.

* Cuba. Central Cuba (Villa Clara and Escambray) and eastern Cuba (Sierra de Cristal, Sierra del Convento, Sierra del Purial).

* Venezuela. Villa de Cura and Cordillera de la Costa belts, and Margarita Island.

* Nicaragua. Siuna area and Nueva Segovia district.

One of the greatest examples of an ancient subduction zones in the Caribbean is the Motagua suture of Central Guatemala. This was selected as the first locality for IGCP project 546, and is the topic of the following field guide. We will conduct a series of scientific and educational activities in Guatemala between the 28th of November and the 9th of December of 2007. The activities include an international field trip to the Motagua suture zone of Guatemala open to researchers, students and interested people throughout the world, an international conference on Caribbean subduction zones, and a shortcourse on tectonics and geologic hazards for undergraduate students at Guatemala’s National San Carlos University.

In arranging this educational and scientific activities, we have worked along with Dr. Alfredo Galvez from Guatemala’s Ministry of Mining and Energy, who co-organized the event. He facilitated the organization through logisitic support, and arranging partial funding through the Guatemalan Government and mining companies. We also would like to thank our colleagues of the Geology Department of San Carlos University in CUNOR (particularly Luis Chiquín and Axel Gutiérrez), and colleagues of the Geological Society of Guatemala (especially Byron Mota) for helping to organize and promote these educational and scientific events.

Geologic Overview of High-Pressure Belts Along the Northwestern Border of the North America-Caribbean Plate Boundary

Sutures that were subduction zones and collisional belts occur throughout the perimeter of the Caribbean plate in Ecuador, Colombia, Venezuela, Trinidad-Tobago, Dominican Republic, Nicaragua, Cuba, Jamaica and Guatemala (Fig.1). These Caribbean sutures include crustal materials metamorphosed at mantle depths (~35 km- ~100 km). Investigating high-pressure rocks from Caribbean sutures is not only critical to reconstruct the complex geologic history of this region, but essential to our understanding of the subduction factory, which ultimately controls major sources of seismicity and volcanism.

Several well-known Caribbean sutures are located along the North America-Caribbean plate boundary, which is a left-lateral transform system that extends from western Guatemala to the Antillean arc (Fig. 1). This complex transform zone includes a small spreading ridge oriented perpendicular to the plate boundary, which has produced ~950-1000km of oceanic crust perpendicular to the ridge axis from the Bay Islands of Honduras to Jamaica at the Cayman trough (Fig.1; Rosencrantz and Sclater, 1986). When initial extension during rifting is added, a total opening of ~1100 km along the trough constrains the minimum displacement between the Caribbean and North American plates.

The western portion of the transform runs along continental Guatemala, where displacement is mainly accommodated through the Motagua Fault Zone (MFZ), which includes three left-lateral, arcuate, subparallel strike-slip fault systems: Polochic–Chixoy, Motagua (Cabañas–San Agustín), and Jocotán–Chamelecón (Fig.2). The MFZ juxtaposes the continental Maya and Chortis blocks (Dengo, 1969; Fig.3 and Fig. 4), possibly along the Cabañas fault (e.g., Donelly et al., 1990), which is the active fault that runs on the southern side of the Motagua valley that produced the tragic 1976 Guatemala earthquake. Recently Ortega-Obregón et al. (in press) suggested that, instead, the limit between the above blocks is the Baja Verapaz Shear Zone, located north of Guatemala City. The Maya and Chortís blocks have contrasting lithologic character, suggesting simple juxtaposition of differing terranes, and/or considerable displacement along the Motagua Fault, as suggested by the opening of the Cayman trough (Francis, 2005).

Geologic units in the Maya Block include the high-grade Chuacús Complex (McBirney, 1963; van den Boom, 1972; Ortega-Gutiérrez et al., 2004), Carboniferous-Permian sediments of the Santa Rosa Group, and deformed granitic rocks such as the Rabinal Granite. This granite has Ordovician white mica K-Ar ages, and intrudes low-grade metasediments of the lower Paleozoic or Precambrian San Gabriel sequence (Ortega-Obregón et al., in press). The Chuacús Complex includes relics of eclogitic rocks (Ortega-Gutiérrez et al., 2004), and is bounded on the north by the Baja Verapaz shear zone, recently recognized as a reverse fault with a small left-lateral component, and on the south by the San Agustín fault. These features may suggest that the Chuacús complex is a terrane, and that the southern boundary of the Maya block is the Baja Verapaz shear zone (Ortega-Gutiérrez et al., 2007). This interpretation is controversial. The Chortís block south of the fault contains the greenschist-facies San Diego phyllite, the amphibolite-facies Las Ovejas complex with felsic and mafic intrusives, and large relatively undeformed granitoids of uncertain age. There are several granitic intrusions in the Chortís block ranging from Grenvillian though Triassic, Cretaceous, and Early Tertiary age (Donnelly et al., 1990; Manton, 1996; Martens et al., 2007). It also contains the El Tambor "ophiolite complex," recently dated on the basis of radiolaria to be of Late Jurassic age (Chiari et al., 2006). Both blocks are mantled with modern arc volcanics to the south and west, further complicating interpretation of their geologic history.

Tectonic slices of serpentinite mélange containing high-pressure rocks occur both north (Maya block of Dengo, 1969) and south (Chortís block) of the Cabañas fault. North of the Motagua mélange the high-grade Chuacús complex contains mafic boudins with relics of eclogite-facies assemblages. This juxtaposition of three high-pressure belts of oceanic and continental origin is one of the most intriguing features of the Caribbean region (Harlow et al., 2004; Ortega–Gutiérrez et al., 2004). Metamorphic conditions and geochronology of the eclogitic belts indicates a disparate geologic evolution. South of the fault high-pressure rocks include lawsonite eclogite, blueschist, and jadeitite in serpentinite matrix, recording P-T conditions that require among the coldest and

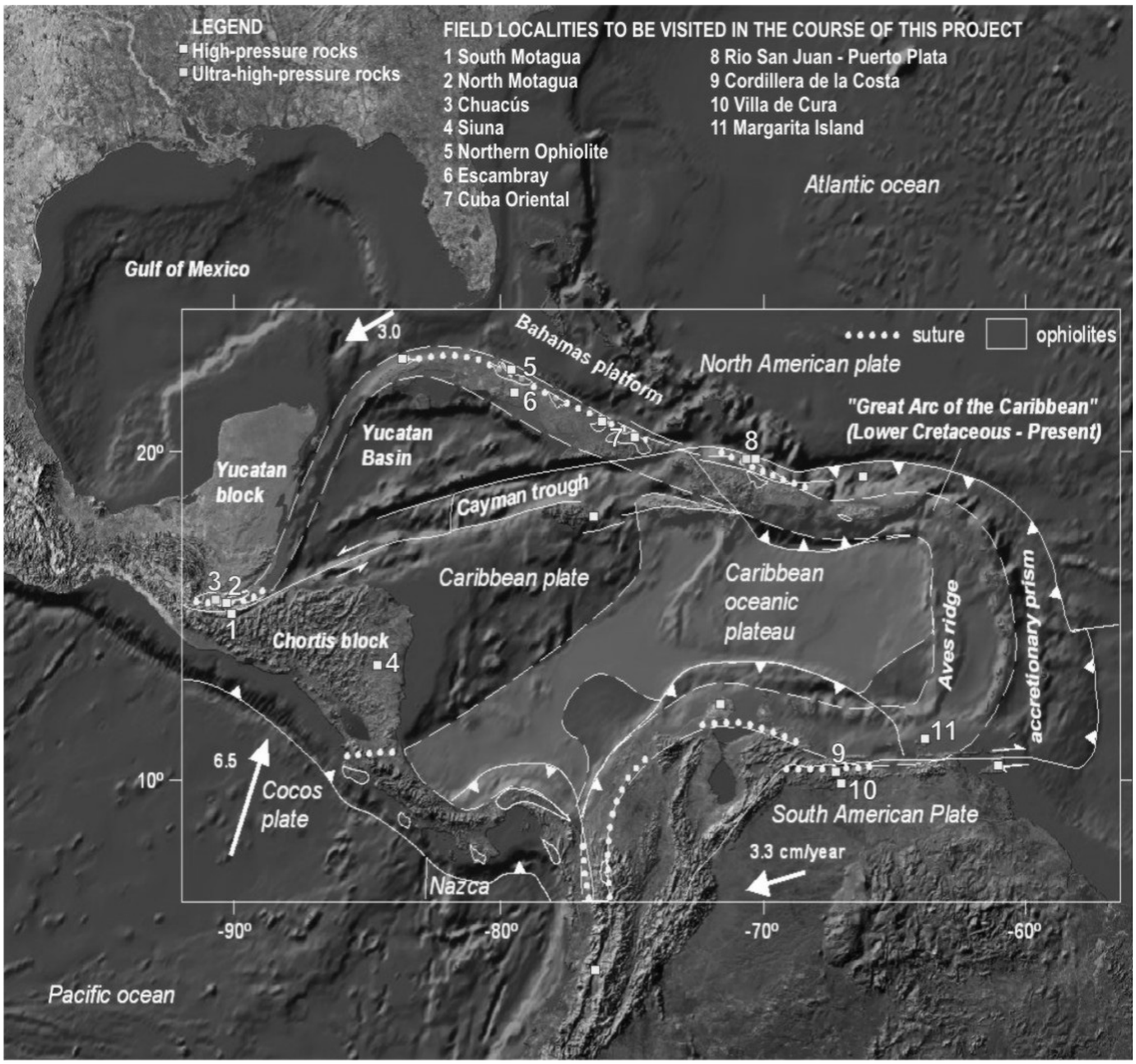

Figure 1. Tectonic map of the Caribbean, showing suture zones, ophiolites , current convergent and transform margins, and localities of high-pressure rocks. Numbers refer to localities to be visited in the course of IGCP 546 "Subduction Zones of the Caribbean".

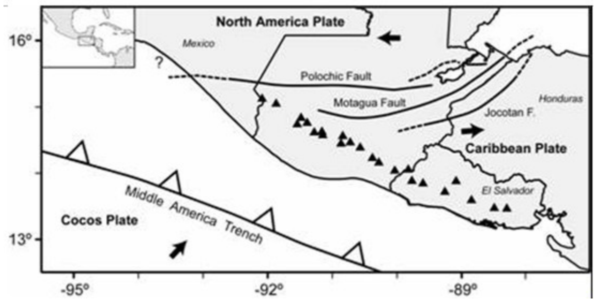

Figure 2. Main faults that accomodate relative displacement between the Caribbean and North American plates in Central Guatemala.

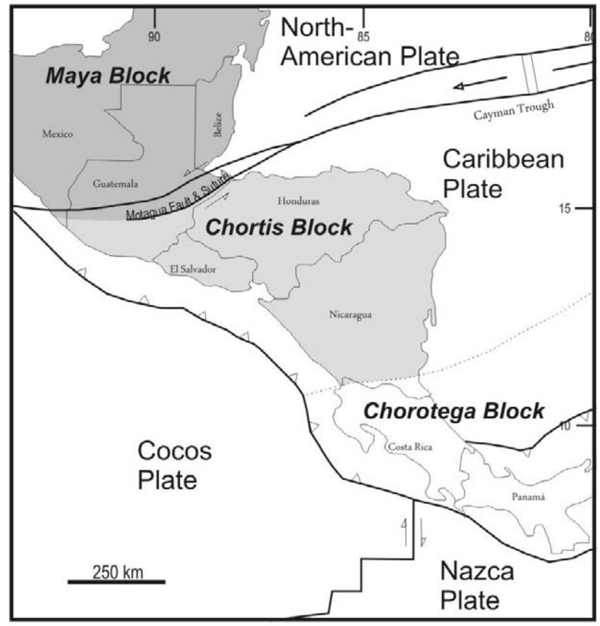

Figure 3. Tectonic blocks in Central America. The limit between the Maya and Chortís blocks is disputed, but most authors regard the Motagua fault as the boundary.

wettest deep subduction trajectories on Earth, to ~2.5 GPa and only 470 ºC, near forbidden zone conditions (Tsujimori et al. 2006a,b). In contrast, north of the Motagua fault, serpentinite mélange hosts garnet amphibolite, omphacite-taramite metabasite, jadeitite, albitite, and, more recently reported, altered clinozoisite-amphibole-eclogite in the western reaches of the serpentinite mélange (Tsujimori et al., 2004; Brueckner et al., 2005). These rocks span a wide range of conditions, from greenschist-blueschist at lower P (200-400 °C at $\leq$1 GPa) to moderate LT eclogite facies of 500-600 °C at ~ 2 GPa. Gneisses of the continental Chuacús complex contain mafic layers and boudins with relics of eclogite-facies mineral parageneses. Peak metamorphic conditions for Chuacús eclogites have been estimated at ~700°C and ~24 kbar, near UHP conditions (Martens et al., 2005).

Compounding the differences, Harlow et al. (2004) reported disparate ^{40}Ar/^{39}Ar ages on the mica and amphibole from serpentinite-hosted HP-LT rocks: north of the Cabañas fault, rocks yield ages between 65 and 77 Ma, whereas rocks south of the fault yield ages of 116-125 Ma. Ages from the northern jadeitites and albitites record their formation time, and ages in the southern eclogites record the time of late fluid infiltration. Therefore the two age clusters probably reflect the time of blueschist metamorphism in each area. This result is in sharp contrast with Nd/Sm geochronologic analyses that yield an average age of eclogitization of ~130 Ma for all serpentinite-hosted eclogites (Brueckner et al., 2005). The age of Chuacús continental eclogites has not been established precisely, but geologic relations imply a post-Triassic age (Martens et al., 2007). The oldest K/Ar and 40Ar/39Ar ages of the Chuacús are ~70 Ma, which reflect cooling after late-stage epidote-amphibolite metamorphism (e.g., Sutter 1979; Ortega Gutiérrez et al., 2004).

How ~1100 km of relative displacement between the North America and Caribbean plates has been partitioned in the MFZ, how the Chortís and Maya blocks migrated over time, how high-pressure belts in central Guatemala became juxtaposed, and whether they formed in one or several subduction zones remain key unresolved problems of Caribbean geology (e.g., Brueckner et al., 2005). The occurrence of jadeitite, lawsonite eclogite, clinozoisite eclogite, continental eclogite, and a tectonic-timing conundrum represent only some of the aspects of Guatemala's fascinating geology.

Tuesday, December 4th, 2007

Lawsonite Eclogites and Associated Rocks of the South Motagua Mélange

A fault-bounded eclogite-bearing serpentinite mélange unit occurs in Carrizal Grande, ~12 km south of the MFZ. A large number of loose blocks (< 10 m) including eclogite and related high-pressure rocks occur along the gorge of Quebrada El Silencio, Quebrada del Mico and Quebrada Seca. These streams feed into Río Jalapa, also known as Río El Tambor further downstream. The unit containing eclogitic blocks occur between antigorite-serpentinite and phyllite. The exposures can be traced over an area ~4 km long and ~0.5 km wide. The loose blocks comprise mainly eclogitic rocks, minor jadeitite, and phengite schist. Some eclogites occur intercalated with graphite-bearing quartz-micaschist suggesting that the protolith was a mixture of mafic rocks with some semi-pelagic sedimentary rocks. Serpentinite associated with eclogitic blocks consist of schistose, friable antigorite serpentinite. The eclogitic blocks show rounded shapes. Rare tremolite- or glaucophane-rich rinds have been observed. Four types of eclogitic rocks have been recognized according to their lithologic features: jadeite-bearing lawsonite-eclogite, two types of lawsonite-eclogite, and garnet-bearing lawsonite-blueschist (Tsujimori et al., 2006). Jadeite-bearing lawsonite-eclogite is a weakly-foliated light-green rock. Based on the size of garnet porphyroblasts this rock type can be subdivided into fine-grained and coarse-grained varieties. In particular, coarse-grained jadeite-bearing lawsonite-eclogite is characterized by the occurrence of large garnet porphyroblasts up to 1.5–2.5 cm in diameter (Tsujimori et al., 2005). Type I lawsonite-eclogite, dominant in the Quebrada del Mico, is a green massive eclogite containing medium- to coarse-grained garnet (0.5–1 cm). The weakly foliated fine-grained matrix is massive, while the population distribution of garnet porphyroblasts is variable; some parts rich in omphacite show gem-grade greenish transparency. In some Type I lawsonite-eclogite, irregular-shaped retrograde glaucophane-rich hydrous veins (1–15 cm wide) crosscut massive matrix. Type II lawsonite-eclogite is the dominant rock type in the Quebrada Seca. It is a well-foliated glaucophane-bearing eclogite. Most Type II lawsonite-eclogite blocks have compositional banding of mm to cm scale, defined by the alternation of omphacite-rich layers and glaucophane-bearing layers. Garnet-bearing lawsonite-blueschist is a well-foliated glaucophane-rich eclogitic schist. Garnet and omphacite are less abundant than in other rock-types.

Carrizal Grande is also a major source of jade. Jadeitites near Carrizal Grande coexist with lawsonite eclogites and blueschists and generally are found as cobbles and blocks dismembered from the hosting serpentinite mélange along nearly vertical lineaments interpreted as internal faults in the mélange. Colors of jadeitite vary from medium to dark green with veins of dark-green and/or blue omphacite and translucency surpasses most northern jade. Blue omphacite contains relatively high TiO2 contents (>0.5 to 1.8 wt%) in combination with FeOT > 1.3 to 3.5 wt%, but origin of color is still not understood (Harlow et al. 2003a, 2004b). Phengitic muscovite is common, followed by titanite, lawsonite, omphacite, minor quartz, garnet (~Alm80Gr9Sps8Py3), zircon and rare analcime. Quartz is common as very small (≤10 μm) inclusions in the cores of jadeite grains, along with small omphacite grains and fluid inclusions. Jadeite grain size is medium to fine (sub-millimeter), and alteration is minor. The combination of a large jadeite-omphacite compositional gap and the phase assemblage indicate formation at 12-20 kb, 300-400°C.

We will visit the Quebrada del Mico and Quebrada Seca area. Presenters: Tatsuki Tsujimori, George Harlow, John Cleary.

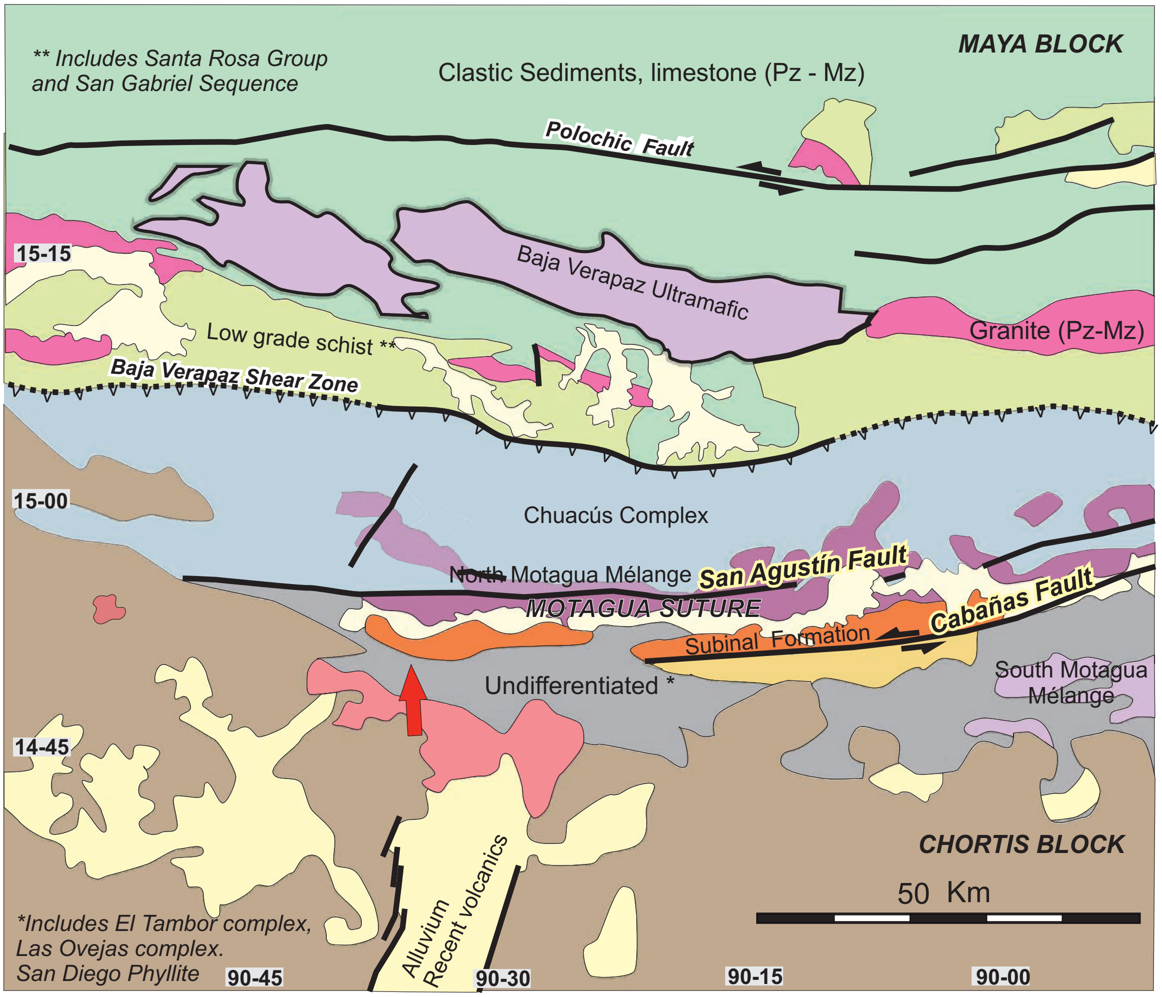

Figure 4. Geologic Map of Central Guatemala. Notice the South Motagua Mélange, the North Motagua Mélange, and the Chuacús Complex, the three juxtaposed units that contain high-pressure rocks

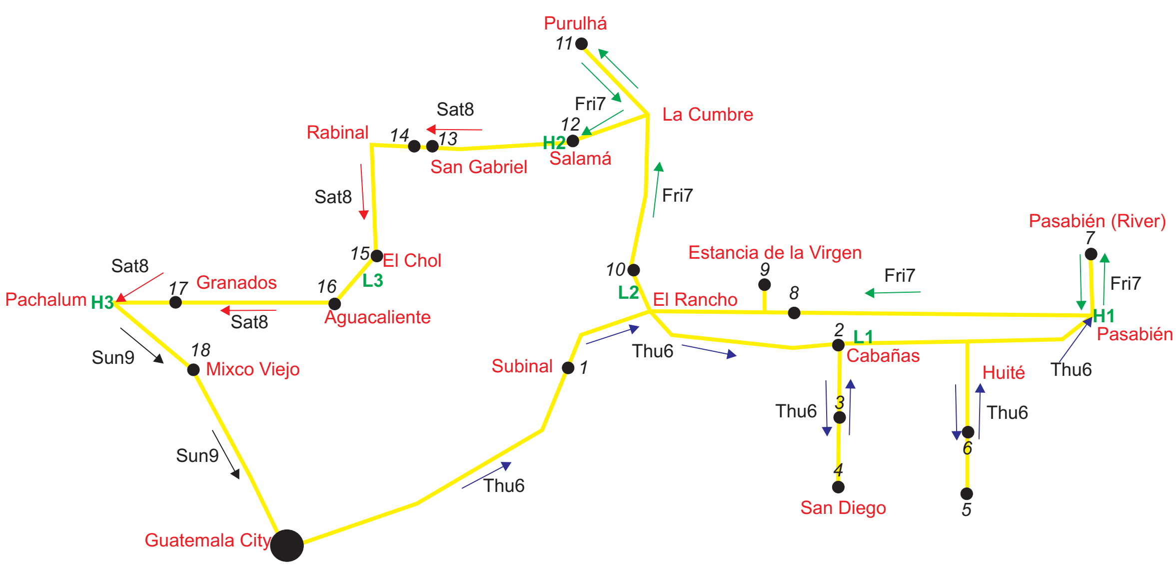

Figure 5. Topologic representation of field trip, including location of stops, hotels (H), main towns, and places for lunch breaks. See Table 1 for presenters of outcrops.

Table 1. Dates, number, locations and presenters of stops.

GEOLOGIC UNIT		LOCATION	PRESENTER
TUESDAY December 4			
South Motagua mélange, lawsonite-eclogite		Carrizal G., Quebrada del Mico	Tatsuki Tsujimori, George Harlow, John Cleary
THURSDAY December 6			
1	Subinal Formation	Ca9, km76.5	Uwe Martens
2	Motagua fault near Cabañas	Cabañas	Juan Pablo Ligorría, Uwe Martens
3, 4	Cabañas-San Diego road	Ovejas-Melange contact Blueschist locality	Jinny Sisson & George Harlow
Lunch break, Cabañas			
5,6	Ovejas complex south of Huité	Río Huité, dirt road south Huité	Rafael Torres de León & Luigi Solari
Hotel Pasabien in Santa Cruz, Río Hondo			
FRIDAY December 7			
7	Chuacús complex gneiss and mylonite	Pasabién River	Uwe Martens & Jinny Sisson
8	North Motagua jade	Pica Pica	George Harlow & group
9	North Motagua Melange	Estancia de al Virgen	George Harlow & group
Lunch break, Morazán area			
10	North Motagua Serpentinite	CA-14	George Harlow & group
11	Baja Verapaz ultramafic	Quarry Purulhá	Giuseppe Giunta
Hotel in Salamá			
SATURDAY December 8			
12	Sacapulas Formation	Salamá	Luigi Solari
13	San Gabriel Sequence & Rabinal Granite	Cumbre de San Gabriel	Luigi Solari
14	San Gabriel Sequence & Rabinal Granite	Cumbre de Rabinal	Luigi Solari
15	Chuacús complex in El Chol	El Chol	Uwe Martens & Luigi Solari
Lunch break, El Chol.			
16	Chuacús complex in Agua Caliente	Bridge Agua Caliente	Fernando Ortega-Gutiérrez & Uwe Martens
17	Eclogites and blueschist Belejeyá	Río Belejeyá	George Harlow, Hannes Bruckner, Tatsuki Tsujimori,
Hotel Pachalum			
SUNDAY December 9			
18	Mixco Viejo Archaeological Site		Juan Luis Velásquez

Thursday, December 6th, 2007

Subinal Formation

The Subinal Formation (Fig. 6) is a succession of continental red beds, including conglomerate, sandstone and minor siltstone and shale. It outcrops in the Motagua valley region, north of the Cabañas fault and south of the San Agustín fault, extending from south of Granados in Baja Verapaz, to Los Amates in Izabal. The best outcrops of the Subinal Formation occur along highway CA9, between km 76 and 80, between Guastatoya and El Rancho. There lens-shaped beds of sandstone and conlgomerat represent former channel of an alluvial system. Red beds in southeastern Guatemala, in the Chiquimula, Jocotán, Esquipulas areas, were ascribed to the Subinal Formation (IGN, 1970). However, Gutiérrez (2008) regarded red beds in southeastern Guatemala as part of the Valle de Angeles group. The thickness of the Subinal Formation has been estimated at ~750 m south of Granados, ~1000m along highway CA9 in El Progreso (Gutiérrez, 2008), and 754m in Subinal and Monte Verde in El Progreso (Hirschmann, 1963).

Conglomerates contain abundant serpentinite cobbles derived from the Motagua suture (Hirschmann, 1963). South of Granados conglomerates include cobbles of serpentinite, quartz-white-mica schist, micaceous gneiss, amphibolites, and eclogite. Sandstones are immature and contain abundant white mica and tremolite. Other detrital minerals include biotite, chlorite, tremolite, chromite, rutile, and zircon. Along CA9 (including location 2 of this fieldtrip) conglomerates contain cobbles of Cretaceous limestones, sandstones, shale, volcanic rocks, granite, quartz, chert, marble, chlorite schist. Minor quartzofeldspathic gneiss and serpentinite has been found, and fossilized wood is common. Sandstones are rich in detrital white mica, which may have been derived from the Chuacús complex.

This detrital material suggest provenance from

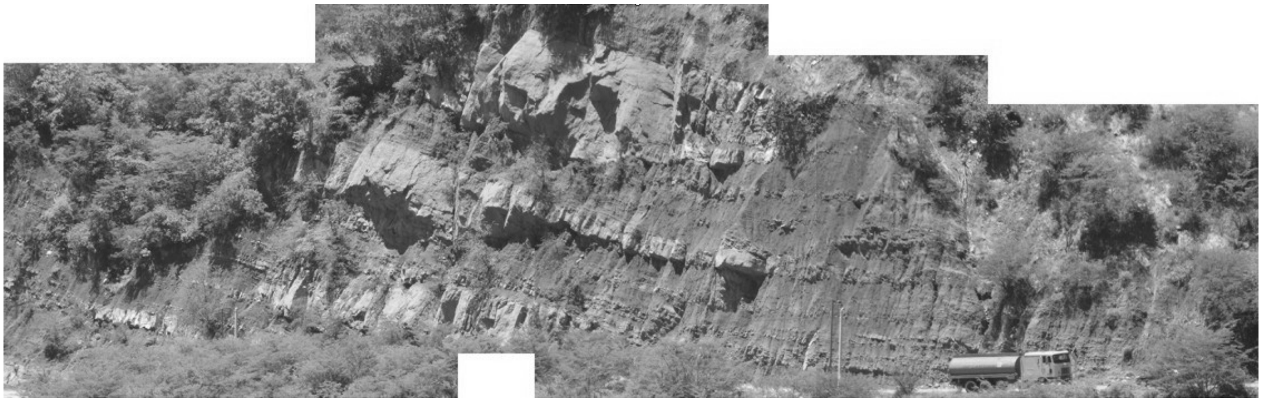

Figure 6. Outcrop of Subinal Formation along highway CA9.

rocks exposed to the north in the Sierra de Chuacús, including the Chuacús complex, and the North Motagua Mélange. Limestone cobbles within Subinal conglomerates in the El Progreso area contains fossils that are analogous to those found in Maastrichtian beds of Palo Amontonado. The presence of serpentinite, amphibolite, and eclogite constrains the time of exhumation to the surface of high-pressure rocks in Central Guatemala.

The age of the Subinal Formation is not known precisely. Volcaniclastic rocks of the Guastatoya Formation and the Grupo Padre Miguel cover Subinal red beds. In the San Agustín Acasaguastlán quadrangle, west of Estancia de la Virgen, an isolated unit of calcareous conglomerate and red limestone were assigned by Bosc (1971) to the Subinal Formation. These rocks contain upper Campanian to Maastrichtian foraminifera. Gutiérrez (2008) observed that the Late Cretaceous fossils are analogous to those found in Palo Amontonado beds, and concluded that calcareous rocks near Estancia de la Virgen are part of this latter formation, and are not useful to constrain the age of the Subinal Formation. Preliminary palinologic work shows that Subinal beds in the eastern portion of the Motagua valley were deposited in the Oligocene or Miocene (pers. comm. Enrique Martinez, UNAM).

The Subinal Formation has been regarded as a molasse (Hirschmann), possibly formed after the collision that generated the Motagua suture (Giunta et al., 2002). On the other hand, the geographic distribution of the Subinal Formation, its association with the Motagua fault, and the preliminary Oligocene-Miocene age of fossil polen suggest that the Subinal Formation was formed in pull-apart basins formed by strike-slip tectonics.

Stop 1 (30 minutes) Subinal Formation Highway CA-9. Presenters: Uwe Martens, Axel Gutiérrez. (Stops are depicted in Fig. 5)

The section is composed of up-fining bedsets ranging from conglomerate to fine sandstone. The section is tilted ~30° to the southeast, and it has been cut by normal faults.
Sedimentary structures are not common, but some sandstones show lamination. Volcanic and sedimentary clasts are the most common in the conglomerates. Serpentinite, granite and pumice are minor. Fossilized wood and trace fossils have been described in the area.

The Motagua Fault Zone

In terms of active structural geology, two main W-E striking fault strands have been identified in the Motagua valley: the San Agustín fault, which runs along the northern border of the valley, and the Cabañas fault, which runs along the southern part of the valley. The Cabañas fault separates geologic units of contrasting character (e.g., IGN, 1970; IGN, 1979), and its current activity was demonstrated by the devastating Guatemala 1976 earthquake (Espinosa, 1976), which claimed more than 23,000 lives, with damage reaching almost USD 2 billion (i.e. 18% GNP of Guatemala). The recorded surface rupture was 230 km and left-lateral, horizontal displacement across the fault averaged ~1.1m (Bucknam et al., 1978).

The Cabañas fault is actively disrupting the Motagua suture and altering the original positions of the Maya and Chortis blocks (Plafker, 1976; Schwartz, 1979; Rosencrantz et al., 1986; Keppie and Morán-Zenteno, 2005; Lyon-Caen et al., 2006). Superposition of high-pressure belts in Guatemala may have been the result of terrane dispersal by the Motagua fault system (e.g., Harlow et al., 2004). A key to understanding eclogitic belt superposition is to evaluate the accumulated strike-slip displacement between the North America and Caribbean tectonic plates, and how this displacement was partitioned.

The understanding of the dynamics of the transform system between the Chortís and Maya blocks is a subject of scientific discussion. Detachment, translation and rotation of these lithospheric blocks may have been active since the late Jurasic (Mann et al., 2006). The total displacement due to strike-slip tectonics between the North American and Caribbean plates is constrained by ocean crust spreading at the Cayman trough. The trough has had episodic periods of activity with a peak during the Oligocene (~30 MA), and a posterior decrease in spreading rate around Miocene time (~26-20 MA). To calculate the total opening at the Cayman trough, initial extension during rifting needs to be accounted for. Rosencrantz & Scatler (1986) assigned an ad hoc stretching factor of two, and calculated a total opening along the trough of ~1100km. Surveys of ocean floor topography have allowed identifying strike-slip faults both north and south of the spreading center (Rosencrantz & Mann, 1991). This implies the existence of a small microplate between the Caribbean and North America plates, and more importantly, that adding ocean opening and extension in the Cayman trough only gives a minimum value for the relative displacement between the Caribbean and North American plates along the northern strike-slip boundary.

Adding generated oceanic crust and initial extension during rifting implies that the relative displacement between the Caribbean and North American plates is at least 1100km. How this relative displacement has been accomodated in Central Guatemala, and if this displacement accounts for the juxtaposition of the Chortis and Maya blocks is a matter of debate (e.g. Keppie and Moran-Centeno, 2005).

Stop 2 (30 minutes) Cabañas fault at Rio El Tambor. Presenters: Juan Pablo Ligorría, Uwe Martens.

The active character of the Cabañas fault is clearly shown in the series of displaced alluvial terraces on the western bank of El Tambor River at stop 2, near the town of Cabañas. Measured slip ranges between ~24m on the youngest recognizable terrace up to ~58m on the oldest of them (Schwartz et al., 1979; Fig. 7). Geologic relations imply an age between 10,000 and 40,000 ka for the oldest terraces, which implies an average slipe rate of ~0.45-1.8 cm/year. Based on this rate, and assuming that strike-slip started in the late Eocene and slip rate was more or less constant, Schwartz et al. (1979) hypothesized that accumulated displacement is of the order of 170-685km.

South Motagua Mélange and Serpentinite

Most serpentinite is sheared and recrystallized antigorite schist but competent antigorite serpentinite is quarried for building stone. Lizardite is much less common than antigorite, and

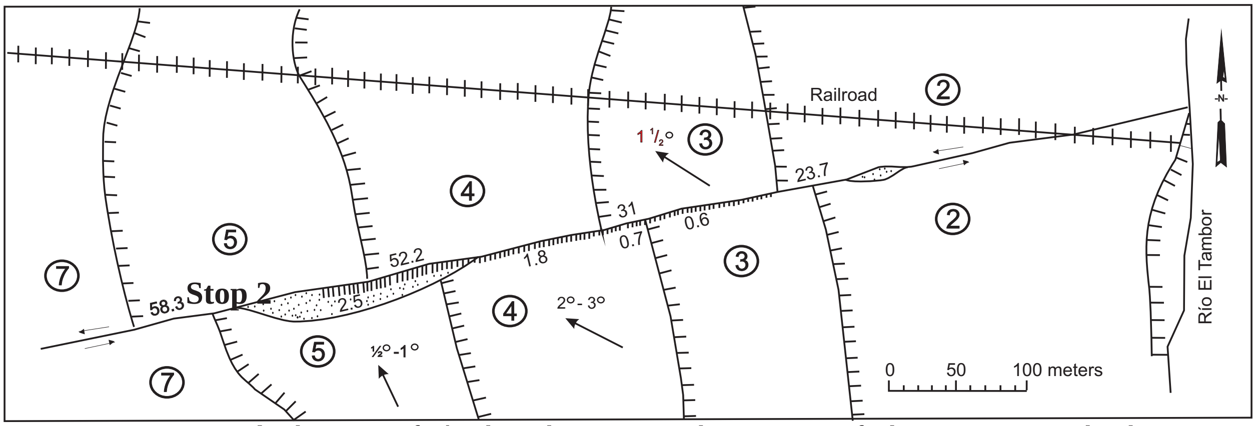

Figure 7. Progressive displacement of Río El Tambor terraces along Motagua fault. Terrace scarps level sequence is indicated by rounded numbers. Fault scarp shown by hachures on down thrown side with vertical slip in meters. Arrows show slope of terrace surfaces. Modified after Schwartz et al., 1979.

chrysotile has not been observed. Although Mn-ilmenite, talc, and chlorite are found, olivine, brucite and andradite are rare. Carbonates include both magnesite and dolomite; calcite and silica are secondary. Magnetite is common; chromite less so. In addition to pentlandite, a variety of low temperature Ni-sulfides can be found as minor phases. Some serpentinite samples contain relict or pseudomorphed orthopyroxene and, less commonly, clinopyroxene. Largely unserpentinized cobbles of spinel lherzolite and dunite have been found only in the Río Las Ovejas south of the MF. Most serpentinites formed from harzburgite and less commonly lherzolite and dunite protoliths (see also Bertrand and Vuagnat 1976, 1980). The clinopyroxenes, with up to ~8 wt% Al2O3, indicate high-T equilibration and/or formation of these protoliths (Harlow et al., 2006a). Trace and major element geochemistry and Sr and Nd isotopic patterns indicate the peridotite protoliths originated at a mid-ocean ridge (Simons et al., 2008), although the mélange interpretation suggests these peridotites were stored in the mantle wedge adjacent to the subduction channel. The greater carbonate content north of the MFZ suggests higher levels of CO2 in the serpentinizing fluids and may represent the distinct ~70 Ma metamorphic event. The greater abundance of lizardite south of the Motagua fault zone is consistent with the colder, and perhaps even wetter, conditions that produced lawsonite eclogites during the ~120 Ma event. Vein systems within the serpentinites include talc-magnesite replacements, cross-vein edenitic hornblende, diopside + magnesio-axinite, and, most commonly, pale yellow to orange rodingite, typically boudinaged.

Las Ovejas Complex

Las Ovejas Complex (Bosc, 1971; Lawrence, 1975; Schwartz, 1976) is a high-grade metamorphic terrane traditionally considered as the basement of the Chortís Block. It crops out in the central and eastern Guatemala. It is bounded to the north by the Cabañas Fault, which is part of the Motagua Fault System (Cabañas-Jubuco-Cuyamel are the major faults). To the south it is in tectonic contact with the low-grade metamorphic San Diego Phyllite (Lawrence, 1975). It occupies the northern side of Sierra del Merendón in Guatemala and it extends toward the northeast in Sierra del Espíritu Santo in Honduras.

The Las Ovejas complex is formed by a group of metasedimentary and metaigneous units. The metasedimentary part consists mainly of schists and gneisses, a smaller proportion of marbles, amphibolites, and quartzites, which are associated with the schists. These rocks were metamorphosed to middle-high amphibolite facies. The metaigneous part consists of orthogneisses (in some areas associated with metasedimentary gneisses) and metavolcanic rocks. Small intrusive bodies and dikes, which show various degrees of deformation, cut the former units.

The structural penetrative fabric elements characteristic of all lithological units are a ductile foliation and/or a mineral lineation. Both structures are mainly expressed by mica (biotite and/or muscovite). The superimposed structures include folds (with very varied geometry, style and size) and several episodes of brittle failure mainly associated with the Motagua Fault System displacement.

In the eastern part of Las Ovejas Complex in the Gualán area (approximately 40 km to the northeast of Huité) the dominant units are paragneisses and orthogneisses, the latter being more abundant. Both lithological varieties include biotite, quartz and feldspar as main constituents. In the paragneisses muscovite is also abundant. Paragneisses and orthogneisses can be distinguished by diverse fabric elements, e.g. grain size, grain shape, banding thickness, etc.

In the western portion of the Las Ovejas Complex (region of Huité) mica schists (biotite and muscovite in varied proportion) with scarce feldspar and quartz are predominant. Staurolite and garnet have also been observed. Schwartz (1976) also reported sillimanite. These schists are associated with quartzite layers whose thickness is up to 10 cm. The metaintrusive suite contains many penetratively deformed bodies, including metatonalite, metadiorite and metagranodiorite, which are the most common rock types.

The absence of geologic and geochronologic data have complicated the correlation of Las Ovejas Complex with other metamorphic belts existent in other parts of Central America or México. U-Pb analyses of zircons in two samples of orthogneisses from the eastern portion of Las Ovejas Complex, yielded an age of 170 Ma for both samples. K-Ar analysis made in two samples, one of biotite in gneisses, and another of white mica in schist yielded ≈30 Ma in both samples.

In the Espíritu Santo and Omoa mountain ranges of northwestern Honduras basement units similar to the Las Ovejas Complex outcrop. In those rocks, Precambrian ages have been reported in gneisses and deformed intrusives (Horne et al., 1976; Manton 1996).

The Xolapa Complex, southern México, has similar ages to those reported here for the Las Ovejas Complex (Guerrero-García, 1975; Guerrero et al., 1978; Morán-Zenteno, 1992; Herrmann et al., 1994; Ducea et al., 2004). In principle these data suggest a correlation between both complexes, which supports the correlation between the Chortís Block and southern México (Malfait and Dinkelman, 1972; Pindell et al., 1988; Ross y Scotese, 1988; Meschede y Frisch, 1998).

Stop 3 (30 minutes) Contact Ovejas-South Motagua Melange. Presenters: Jinny Sisson, George Harlow.

At stop 3 we will observed the tectonic contact between a granite, possibly from the Las Ovejas complex, and low-grade metasediments of the El Tambor. The granite is thrust faulted over the metasediments, the latter being strongly tectonized. The outcrop exposes a series of interesting duplex structures. Formation of the duplex may be the result of transcontraction associated with strike slip tectonics of the MFS. Alluvium of the El Tambor River covers granite and metasediments in the upper part of the outcrop.

Stop 4 (60 minutes) Blueschist and other blocks in South Motagua Melange. Presenters: Jinny Sisson, George Harlow.

The section of road at stop 4 exposes an excellent section of serpentinite mélange south of the Cabañas fault. Serpentinite is strongly sheared and structures are mostly chaotic. Exotic blocks at the section include blueschist, gabbro, and rondigites.

Stop 5 (30 minutes) Ovejas Complex South of Huité, road to El Jute, San Miguel. Presenters: Rafael Torres de León, Luigi Solari.

Outcrop along a stream that drains to Huité River. Throughout this section a metasedimentary sequence is exposed. It consists of two-mica schists and quartzites that are intruded by deformed dikes of granitic composition.

The schists are characterized by abundant white mica, biotite, quartz, plagioclase, and sporadic occurrence of garnet and staurolite. The foliation is defined by biotite and muscovite flakes, the quartz and feldspar are porphyroclasts while the staurolite and garnet are sin-tectonic or late sin-tectonic porphyroblasts. A clear mineral lineation formed by mica flakes is also observed in these rocks.

Some deformed and leucocratic granite sills that intrude the metasedimentary sequence are also present (Fig. 8). The sills reach up to 30 cm of thickness. These granites have a penetrative ductile foliation and an incipient mineral lineation, both structures defined by muscovite. The foliation in these granites is parallel to the foliation of the schists.

Stop 6 (40 minutes) Ovejas Complex South of Huité. Río Huité. Presenters Rafael Torres de León, Luigi Solari.

At this stop metavolcanic rocks of the Las Ovejas Complex are intruded by deformed pegmatitic dikes. The metavolcanic rocks contain anhedral to subhedral plagioclase porphyroclasts, with 1 to 5 mm in size, within a matrix formed by very fine grains of biotite, chlorite and quartz. These rocks present an incipient foliation. Pegmatitic dikes are mainly composed of feldspars, quartz and muscovite. In thin section the general

Figure 8. Faulted boudin of granite in two-mica schist of the Las Ovejas complex

mineral association of these rocks is feldspar+quartz+muscovite+garnet+opaque±zircon. These dikes have variable grain size and deformation intensity. Both units, metavolcanic rocks and pegmatitic dikes are strongly folded. The closed and isoclinal folds are predominant but sheath folds are also observed. Brittle faults superimposed to ductile structures are also abundant.

Friday, December 7th, 2007

Chuacús Complex in the Sierra de las Minas

The Chuacús complex builds up a large portion of the Sierra de Las Minas (Roper, 1978; Bosc, 1971; Newcomb, 1975). In the San Agustín Acasaguastlán–Río Hondo area the arrangement of rocks and structures is complex; rocks regarded as part of the Chuacús complex consist of garnet–mica schists, marbles, mylonitized augen gneiss, migmatites and amphibolites, which are tectonically interleaved with allochthonous mafic and ultramafic rocks. The main units that build up the Chuacús complex in eastern Guatemala are the mylonitized San Agustín orthogneiss, the Jones formation and the San Lorenzo marble. No particular name has been given to a series of granofels, banded gneiss and phengite gneiss within the Chuacús complex in the El Progreso area.

In the San Agustín Acasaguastlán area an east–west elongated augen orthogneiss with composition that ranges between quartz–monzonite and granodiorite has mylonitic foliation, strong lineation and exhibits abundant ductile shear zones. It is associated with migmatites and strongly banded gneisses that occur in the Hondo River and Pasabien River. This unit has been called San Agustín formation (Bosc, 1971; IGN, 1978) though the name "retrograde cataclastic gneiss" was used in a study by Newcomb (1978).

In spite of the diverse structures and textures present in the rock, the mineralogy is quite homogeneous in the Pasabien area, chiefly quartz + microcline + oligoclase + biotite + chlorite, which are igneous relics, and the product of recrystallization and retrogression induced by strong shearing.

Bosc (1971) found high–grade minerals and 'nebulitic' banding in the gneisses along the Teculután River. There the mineral parageneses is microcline + quartz + biotite + muscovite + garnet ± epidote ± sillimanite, which indicate that the area reached amphibolite–facies conditions, ranging from the staurolite–almandine subfacies to the quartz–sillimanite–almandine–orthoclase subfacies. An irregular vein network crosses the gneiss, deformed dark xenoliths occur and mylonitization along shear zones are very common features. Teculután River rocks bear striking similarities with high–grade gneisses described in the Sierra de Chuacús. Nonetheless interesting differences exist, such as the existence of sillimanite, the relative abundance of K–feldspar, and the apparent absence of high–pressure phases in gneisses from the Sierra de Las Minas. It is not known what particular conditions favored the growth of sillimanite and abundant K–feldspar in the San Agustín area, nor any attempt to meticulously look for high–pressure phases has been undertaken there.

The Sierra de Las Minas also holds the complex metasedimentary Jones formation (Newcomb, 1975), which is constituted chiefly by pelitic schists and phyllites, minor quartzite, and marble. Composition of the Jones formation changes along strike. In the Río Hondo quadrangle it is characterized by dark folded phyllites associated with high–Ca marbles that grade southwestwards into mica schists in the San Agustín quadrangle. North of this town quartz + albite + white mica ± garnet schists occur along with extensive marbles that eventually reach the top of the range. Green actinolitic bands occur interbedded in the Jones formation. This rock sequence, with the addition of some micaceous gneisses, continues as far as the El Progreso (Roper, 1976) and El Chol quadrangles.

Newcomb (1975) also defined the San Lorenzo formation, which is a very pure, fine–grained marble that crops out in the central and eastern parts of the Sierra de Las Minas. Its color ranges from black to white and its mode of presentation is mainly massive, although fine banding is locally present. The marble occurs within the Jones formation and forms a good marker horizon of the Chuacús group throughout the Sierra de Las Minas range (Roper, 1976). Marbles containing minor garnet, green mica flakes and tremolite needles are found NE and NW of San Agustín and in the El Progreso quadrangle (Bosc, 1971). In the Gualán area, Johnson (1984) found dolomitic marble in the San Lorenzo formation.

Stop 7 (40 minutes) Gneisses of the Chuacús complex at Pasabien River. Presenters: Uwe Martens, Jinny Sisson

A road parallels the Pasabien River. Several staircases give access down to rock outcrops along the river. The southern part of the river exposes a sequence of banded metasedimentary rocks, chiefly crenulated white mica schist. These rocks are representative of the Jones Formation. The northern part of the section exposes mylonitic granites, which are widespread in the Sierra de las Minas. Such granites may be correlatives of orthogneisses of Teculután and San Agustín Acasguastlán. The contact between metasedimentary and metagranitic rocks is exposed along the gorge of the river.

Jadeitites and Related Rocks, North of the Motagua Fault Zone

Guatemala is second only to Myanmar (Burma) as a jadeite jade source, of which there are ~13 worldwide (and increasing slowly in number; see Harlow et al. 2007). Jadeitite (jadeite rock) in dismembered tectonic blocks occurs sporadically in the sheared serpentinite mélange fault slices that are distributed E–W along the Motagua fault. The zone of greatest concentration (and exploitation) resides between Río Hondo, Zacapa Dept., and Estancia de La Virgen, El Progreso Dept., spanning ~20 km. However, jadeitite occurrences continue in patchy distributions westward to Pachalúm (Granados Quad.), Baja Verapaz, another 100 km west and eastward perhaps as far as the Montaña del Micos south of Río Dulce, another 80 km east. Thus the probable extent in Guatemala is about 200 km in the discontinuous distribution of serpentinite bodies (new sources have been reported in Chiapas which may be part of the dismembered terrane).

Jadeitites north of the MFZ share many characteristics and are distinct from those several types found south of the MFZ. These rocks are whitish to gray-green with rare streaks of imperial (emerald) or dark green, generally coarse grained (mm to cm scale), and dominated by idioblastic jadeite, sometimes with nematoblastic overgrowths of either jadeite or omphacite. Centers of jadeite grains are commonly filled with inclusions of albite, analcime, white mica, fluid inclusions and trace phases like barite, calcite, and even galena. Around the centers are cleaner oscillatory growth zones of somewhat more diopsidic and/or aegirine-rich jadeite. Interstitial phases include albite, analcime, white-to-tan mica(s) (paragonite ± phengite, phlogopite, preiswerkite) and zoisite/clinozoisite, with-or without titanite , zircon, apatite, graphite and sulfide (usually pyrite). Most samples are partially altered by albitization with enhanced amounts of albite, analcime, taramitic amphibole and nepheline, as described by Harlow (1994). Based on the lack of quartz, spotty presence or analcime and albite, width of the jadeite-omphacite compositional gap, and zoisite or clinozoisite as the common calcium aluminosilicate, formation or equilibration conditions are interpreted as 6-11 kb and 300-400°C (Harlow, 1994; Sorensen and Harlow, 1999; Sisson et al. 2005; Harlow et al 2006b). From careful CL examination of microstructures and oscillatory zoning abundant hydrous fluid inclusions, and lithotectonic setting, Sorensen and Harlow (1999), Sorensen et al. (2006) and Harlow et al. (2007) have interpreted these jadeitites (as well as those south of the MF and most jadeitite worldwide, in general) to be the result of direct crystallization from a hydrous fluid, in most cases passing into fractures and shear zones serpentinizing peridotite, presumably of the mantle wedge a subduction channel.

Albitites are commonly associated with jadeitite (and perhaps even more abundant) ranging from sugary texture to fine-grained mylonite, white to pale green and contain albite, actinolite, diopside, titanite ± phengite, zoisite, zircon, and chlorite. Jadeite- or omphacite-free albitites may contain quartz. Mica-albite rocks are common, as well, ranging from albitite with minor phengite to rocks dominated by barian phengite and, as well, generally contain minor-to-trace chlorite, K-feldspar, hyalophane, celsian or cymrite, zoisite, titanite, and zircon (see Harlow, 1994, 1995). Structural setting and observed relationships with jadeitite indicate that albitite can be either the alteration product of jadeitite or a distinct fluid crystallization product. In the former setting it usually surrounds jadeitite as a rind intermediate with a tectonic block’s boundary to serpentinite with an intervening blackwall zone (actinolite + chlorite ± biotite, talc) Phase assemblages suggest formation conditions of T < 400 ºC at ~ 3 to 8 kbar (Sorensen and Harlow, 1999; Johnson and Harlow, 1999, Harlow, 1994, 1995).

The other lithologies commonly found with jadeitite north of the MFZ are omphacite-taramite rock and omphacitite. Omphacite-taramite rock (used as black jade when fine grained) is more common than jadeitite (and thus a good indicator of ripe mélange). It has provisionally interpreted as jadeite-flavored metabasite, but otherwise it is a curiosity (Harlow & Donnelly 1989). There does not appear to be a replacement texture. Grain size varies from multi-millimeter grains with long black blades of amphibole crisscrossing an omphacite matrix, usually without any fabric, to an aphanitic, basalt-like texture. However, experience from jade manufacturers has shown that healed fractures contain wide amphibole blades aligned with the fracture such that the rock becomes weak in that direction, making for a poor quality lapidary material.

Little attention has been paid to omphacitite, however, findings by Bröcker & Enders (2001) and Bröcker & Keasling (2006) of omphacitite surrounding jadeitite surrounding eclogite on Syros, Greece may point to it as either a late stage in the jadeitite crystallization or related to remobilization of metabasite (eclogite?) in the fluid. In Guatemala omphacite increases in abundance in late stage growth of jadeitite and occurs as veins in some jadeitite (as in the blue variety from near Carrizal Grande). In general it is a medium to dark green rock with either a granoblastic and nematoblastic texture. Mineralogy is similar to that in jadeitite from north of the MFZ but with little or no jadeite, fewer inclusions in the pyroxene cores (mainly fluid inclusions).

Stop 8 (50 minutes) Jade blocks at Pica Pica. Presenter: George Harlow.

Blocks of jadeitite up to 1.5 meters across have been found as float in this section of serpentinite mélange just off highway CA9 (Carretera al Atlántico); what we are likely to see are the decreasing remnants as collectors and “jaderos” (jade hunters) continue to remove material. Jadeitite here is whitish green with a mixture of a medium-coarse to fine textured jadeitite. Jadeite is generally equant with nematoblastic overgrowths creating grains to over 3mm, sometimes terminating in omphacite blades, with intergranular paragonite and analcime. Inclusions and interstitial grains of small (<30 μm across) ttn, rt, and zrn (the latter two sometimes as cores of ttn). Oscillatory zoning of jadeite is spectacular in jadeitite from Pica Pica. In addition to jadeitite, omphacitite, omphacite-taramite rock, and albitite can be found in the general area, as is common at most jadeitite occurrences north of the MFZ.

Stop 9 (30 minutes) Amphibolites and other exotic blocks in serpentine mélange at Estancia de la Virgen. Presenter: George Harlow, Jinny Sisson.

In the serpentinite mélange near this town are blocks of garnet-zoisite amphibolite, taramite-omphacite rock, jadeitite and albitite. At the edge of the soccer field is a large block of garnet amphibolite. Whereas the primary mineralogy consists of grt(Alm)–amph(Parg/MgHbld)–zo-czo–pheng–ttn–ab–chl, inclusions of omphacite are found in the garnet along with czo and amph; Grt-Cpx thermometry gives 540±20 ºC (error is based on compositional variations) using the Krogh-Ravna (2000) calibration and assuming a pressure of 1.5 GPa. Other local clinozoisite-rich garnet amphibolites manifest amphibole and clinozoisite inclusions in garnet but not omphacite so far. An outcrop of a mixed assemblage of omphacitite and garnet amphibolite exists at Km 92 on the Atlantic highway, and Grt-Cpx temperatures are 480±30 ºC for coexisting pairs, but no omph inclusions in grt have been documented. This outcrop in presently painted over with political signs, and there is no place nearby to pull off the highway nearby.

Stop 10 (60 minutes) North Motagua Serpentinite mélange along highway CA-14. Presenter: George Harlow, Jinny Sisson.

The outcrop at this stop is one of the largest continuous sections of serpentinites exposed in Guatemala. The lower part of the exposure is antigorite rock, with lower temperature varieties of serpentinite on the surface of blocks and cracks. Relict textures of original peridotites are visible. Rocks are strongly tectonized and show abundant fault fibers. Going upwards along the blocks allows observing exotic meter-scale blocks of mafic rocks contained in serpentinite.

Baja Verapaz Ultramafic

The Baja Verapaz ultramafic was thrust faulted over the Maya Block. It was emplaced mainly over Mesozoic evaporitic-terrigenous-carbonaceous deposits of the Todos Santos, Coban and Campur formations. Similarly the Sierra de Santa Cruz unit, which outcrops ~70 km NE of Baja Verapaz, was thrust faulted over the Late Cretaceous-Eocene carbonaceous-terrigenous sequences of the Sepur formation. Mafic and ultramafic rocks in Baja Verapaz and the Sierra de Santa Cruz of somewhat serpentinized mantle harzburgites, layered gabbros, dolerites, and andesitic basalts, with an island-arc tholeite to calc-alkaline magmatic affinity. Little petrologic and geochemical work has been done on the ultramafic rocks of Baja Verapaz. Petrographic examination reveals recrystallized olivine, large orthopyroxene crystals with minor exsolved clinopyroxene, and fresh chromitic spinel. Some samples exhibit a very low degree of serpentinization (<10%; see Fig. 9).

Stop 11 (30 minutes) Harzburgite Quarry at Purulhá. Presenter: Giuseppe Giunta.

Saturday, December 8th, 2007

Stops in the Salamá-San Miguel Chicaj-Rabinal area will focus on the intrusive relationships of the Rabinal granite suite into the San Gabriel sequence, and the unconformably overlying sheared conglomerates that possibly correlate with the Sacapulas Formation, which represent the basal unit of the Santa Rosa Group. We will also have a look to the superimposed shearing that is widespread on Rabinal and San Gabriel sequence, as well as on the conglomerates, and that we interpret as an evidence for activity of the Baja Verapaz Shear Zone.

The Rabinal - Salamá area lies between the Baja Verapaz and Polochic faults (Fig. 4). Geological mapping of this area (Ortega-Obregón, 2005, Fig. 10) revealed the presence of three units: (i) the San Gabriel unit (Salamá sequence of van den Boom, 1972, redefined), which is intruded by (ii) the Rabinal granite suite (Gomberg et al., 1968 calculated U-Pb discordant ages for this granite using very large zircon fractions, with intercepts of 1075 ± 25 Ma and 345 ± 20 Ma, interpreted as either inheritance and intrusion, or as crystallization of hosting gneisses and metamorphism); and (iii) the Santa Rosa Group (Sacapulas formation of van den Boom, 1972).

San Gabriel unit

The San Gabriel unit consists of low grade, interbedded sandstone, arkose, greywacke, phyllite (Fig. 11), slate, and mafic-felsic lavas and tuffs. These lithologies indicate a continental, possibly shallow marine environment of deposition. Petrographically, the metasedimentary rocks contain quartz, feldspar, muscovite, epidote, chlorite, scarce biotite, and clay minerals. The mafic volcanic rocks are made up of albite-oligoclase, green amphibole (rare hornblende and, more often, tremolite), epidote and chlorite set in a cryptocrystalline matrix, whereas felsic rocks contain feldspar and quartz. The mineral associations found in metasediments

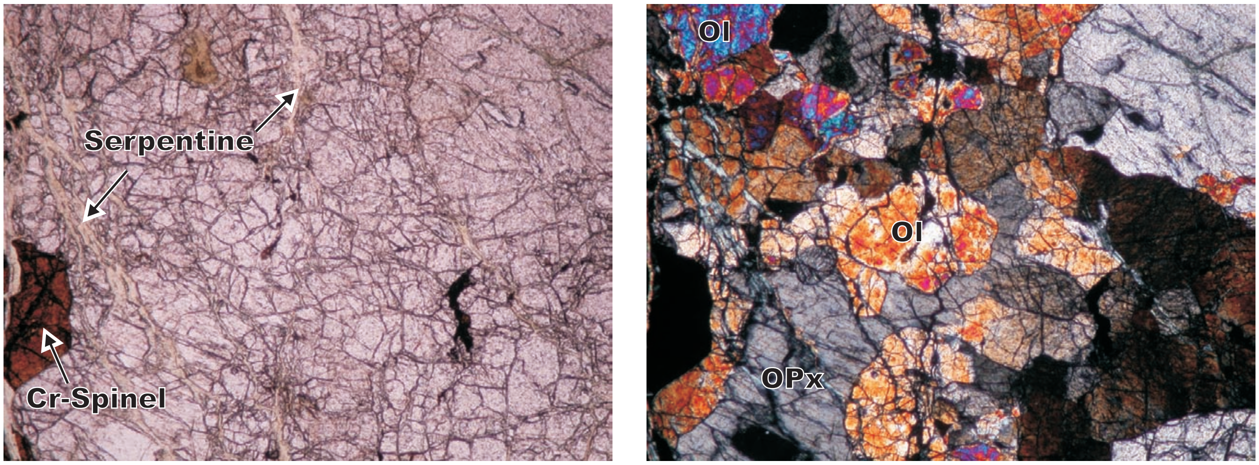

Figure 9. Photomicrographs of Baja Verapaz Spinel Harzburgite. Left photograph taken with plane-polarized light, right photograph under crossed polars. Degree of serpentinization is <10%.

and metabasites suggest that these rocks were metamorphosed under greenschist facies conditions. There are no continuous sections across the unit, and this, combined with the folding and discontinuous outcrop, makes it impossible to measure a type section. Although it is difficult to estimate the real thickness of the San Gabriel unit, we argue that it is at least 200 m thick, based on the continuous and undeformed section outcropping along the San Miguel – Rabinal paved road. The best exposures are on the road between San Miguel Chichaj and San Gabriel and Rabinal (Figs. 10a and 10b, and STOP 14).

No independent age constraints are available for this unit, however an Ordovician upper limit is provided by the Rabinal granite suite, which is intrusive into the unit. The San Gabriel unit shows striking similarities with low-grade metasediments cropping out south of Huehuetenango, in western Guatemala, where detrital zircon geochronology yielded Precambrian ages bracketed between ~ 920 and ~ 1,000 Ma (Solari et al., in press).

Rabinal granite suite

The Rabinal granite (STOPS 13 and 14) and its associated minor intrusions and pegmatites intrude the San Gabriel unit, which locally preserves sedimentary (primary) features, such as graded and/or cross stratification. It is locally weakly foliated, and composed of K-feldspar (orthoclase and rare perthite), plagioclase (oligoclase), quartz, muscovite, accessory apatite, zircon, titanite, and opaque minerals. Secondary sericite and chlorite are replacing biotite. Modal analyses show a range from granite to granodiorite. The dikes contain quartz, microcline, and biotite, and the pegmatites are made up of quartz, K-feldspar, and muscovite. The lack of contact metamorphism suggests that intrusion occurred into sediments at shallow depths with crystallization of magmatic muscovite occurring at a minimum depth of ~ 10 km (Chatterjee and Johannes, 1974; Wyllie, 1977).

Chemically the granite has a SiO_2 content of 72-76%, high-K, and calc-alkaline/peraluminous affinity. Normalized against primitive mantle, the analyzed trace elements show enrichment in high field strength elements, low Nb, P and Ti anomalies, and high K and Pb. Normalized against chondrites, the REE pattern is slightly enriched in light rare earth elements. On discriminant diagrams, they plot in the volcanic arc field, straddling in part the fields of within plate and syn-collisional granites (Fig. 12).

Three granite samples and three pegmatite samples were dated by U-Pb zircon and K-Ar geochronology. All of the zircons yielded discordant

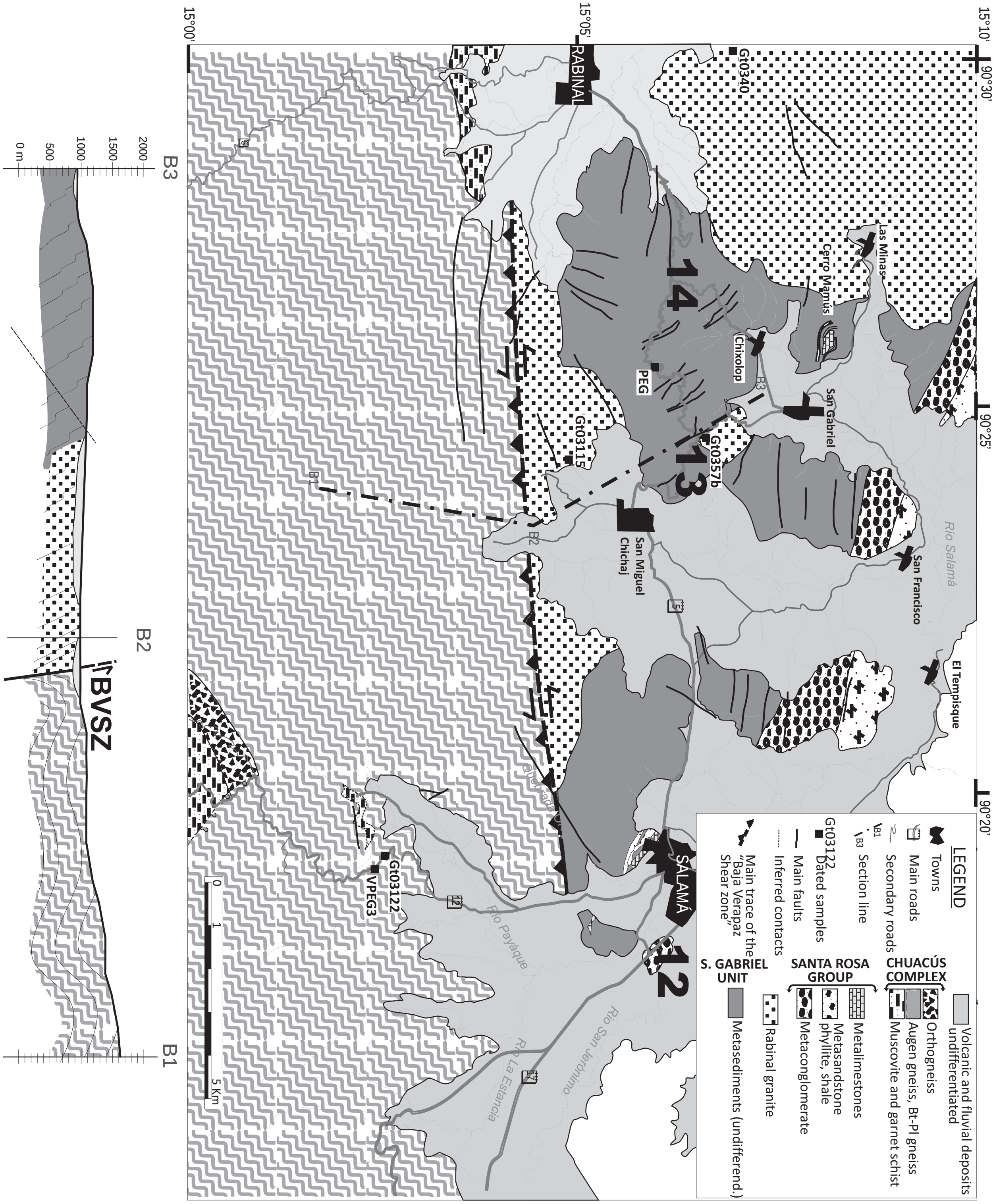

Fig 10. Simplified geologic map of the Rabinal Salamá area. Modified from Ortega-Obregón et al., 2007. Bold numbers indicate the stops.

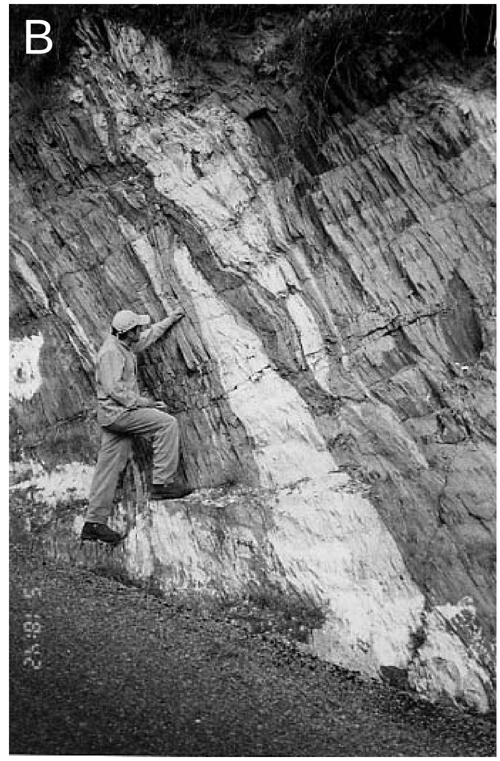

Figure 11.
A) Phyllite bands of the San Gabriel sequence embedded in the Rabinal granite. Tectonic foliation, subvertical in this picture, is refracted and primary structures can be seen in these sedimentary bands.

B)Tectonic relationships between the Rabinal granite and the San Gabriel sequence metaarkoses. Both Rabinal granite and San Gabriel sequence underwent deformation in low grade metamorphic conditions, represented by the intense shearing, dated at Late Cretaceous.

analyses, and chords through analyses from each sample yielded lower intercepts of 496 ± 26 Ma, 462 ± 11 Ma, and 417 ± 23 Ma and an upper intercept of 483 ± 7 Ma (Ortega-Obregón et al., in press). The best fit chord is through the analyses of three zircons from a pegmatite sample. One of these analyses is nearly concordant, and is regarded as most closely constraining the age of intrusion at 462 ± 11 Ma. Upper intercepts of three of four dated samples (Gt0457b, Gt03115, and PEG; see Fig. 10) range from 1312 ± 76 Ma through 1351 ± 110 Ma, to 1736 ± 190 Ma.

Muscovite from two pegmatites cutting the San Gabriel unit yielded K-Ar ages of 453 ± 4 Ma and 445 ± 5 Ma. As these pegmatites represent the last crystallization phase of the Rabinal granite, their K-Ar cooling ages provide a younger limit for the age of intrusion. Furthermore, as the granite appears to be a relatively high level intrusion (~ 10 km), the K-Ar ages probably closely post-date intrusion. Thus, together with the least discordant, U-Pb zircon age, the granite was probably intruded between ~462 and 445 Ma, i.e. Upper Ordovician. In view of this interpretation, the ~417 Ma, U-Pb, lower intercept age is probably due to lead loss. On the other hand, the Middle Proterozoic, U-Pb, upper intercept ages possibly reflect inheritance from the source terrane.

Santa Rosa Group

Sheared conglomerate and sandy conglomerate containing cobbles of metasandstone, phyllite, and granite similar to the Rabinal granite suite crop out in the Salamá area (e.g., STOP 12). In the Cerro Mumús (Fig. 10), these rocks are accompanied with shale and limestone containing crinoids and the conodont Siphonella sp. (Ed Landing, written communication, 2005), which dates the base of the unit as Tournaisian (Lower Mississippian). The limited outcrop and structural complexities make it impossible to provide a measured type section. The lithologies indicate a continental to shallow marine environment of deposition. They correlate with the Santa Rosa Group in the Maya block (cf. Bohnenberger, 1966; Anderson et al., 1973). The lowest conglomerate beds in the Rabinal-Salamá area

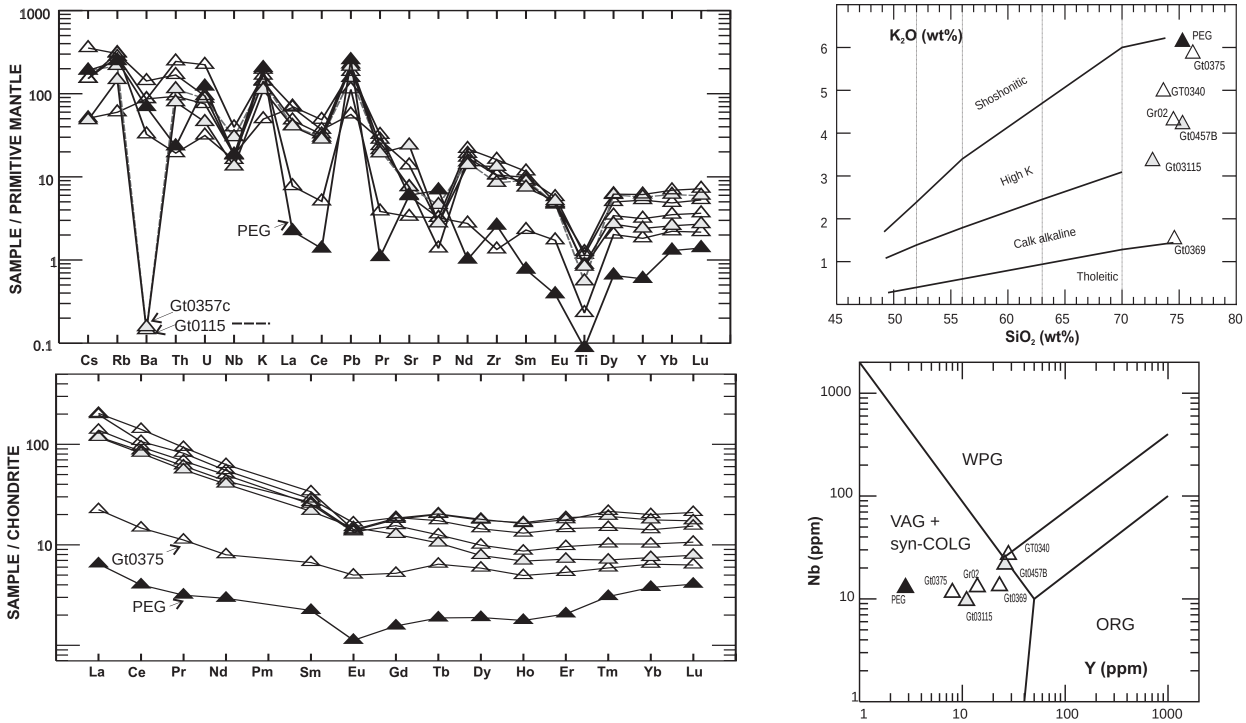

Fig 12. Geochemical characteristics of the Rabinal granite. Modified from Ortega-Obregón et al., in press.

(named the Sacapulas formation, Forth, 1971), are in fault contact with the San Gabriel unit and Rabinal granite suite (Ortega-Obregón et al., in press).

Implications

Taken altogether the geological, geochemical and geochronological data of the Rabinal-Salamá area suggest that:

1. The (actual) southern Maya block margin is made up of pre-Ordovician sediments, here named San Gabriel sequence, affected by a very low metamorphic grade. It is intruded by Mid-Ordovician granites, which geochemistry suggest they produced by crustal melting (i.e., they are S-type granites).

2. On top of such sequence it rests a sedimentary sequence that goes from conglomerated to sandstone, pelites and carbonates. The latter has been dated at the Tournasian (345 Ma). His sequence can be tentatively associated to the Santa Rosa Group.

3. Both San Gabriel and Rabinal granites, as well as the basal conglomerates of the Santa Rosa Group, show a low grade, top-to –the NNE shearing, with a reverse kinematics. The age of this shearing is restricted to the Late Cretaceous, and tectonically associated with the collision of the southern Maya block with either the Greater Antillan arc or the Chortís block, the obduction of El Tambor Group and the Baja Verapaz, Sierra de Santa Cruz and San Juán de Paz ophiolites and ultramafics. Such age also coincide with the exhumation and accretion of the Sierra de Chuacús metamorphic rocks.

4. Current data suggest that difference in metamorphic grade, lithotectonic associations, presence versus absence of the overlying Santa Rosa sediments, as well as ages, constitute major arguments against the inclusion of the Sierra de Chuacús metamorphic rocks into the Maya block. We propose that the Baja Verapaz Shear Zone should be considered as the southern tectonic limit of the Maya block and, in general, the north America plate.

Stop 12 (20 minutes) Sacapulas Formation of the Santa Rosa Group in Salamá. Presenter:

Luigi Solari.

Conglomerates of the Sacapulas Fm. Road El Rancho – Salamá, approaching Salamá (Fig. 10). Deformed conglomerates, metamorphosed under greenschist facies conditions, are exposed at this locality. They constitute the base of the Santa Rosa Group in the studied area, and are correlated with the Sacapulas Fm. of Forth (1971). Main foliation is gently to moderately SW dipping, NW to WNW-trending, whereas a moderately SW-plunging stretching lineation is sometimes visible on foliation planes. Kinematic indicators are generally well observed, as rotated clasts (mainly granites to quartzites), as well as S-C foliation in the sheared matrix. Both kinematic indicators suggest a top-to the NE sense of shearing, indicative of the BVSZ activity in the outcrop.

Stop 13 (30 minutes) San Gabriel Sequence and Rabinal Granite, Cumbre de San Gabriel. Presenter: Luigi Solari.

Rabinal granite. Quarry at the intersection between San Miguel Chicaj – Rabinal and S. Gabriel roads. In this outcrop it is possible to observe the mineralogy and tectonic relationships of one of the granites we included in the Rabinal granite suite. Particularly, the sample we dated at 417 ± 23 Ma (lower intercept) belongs to this outcrop. Intrusive relationships are evident just few tens of meters before the intersection, along the main road. Locally the granite is weakly foliated, and kinematic indicators, indicating a top-to-the NE sense of shearing, are visible in the quarry outcrops.

Stop 14. (30 minutes). San Gabriel sequence, and intrusive Rabinal granite, Cumbre de Rabinal. Presenter: Luigi Solari.

Contact relationships between the sheared metasediments of the San Gabriel sequence, and intruding dikes of the Rabinal granite, are exposed in this outcrop. S to SW moderately dipping foliation is clearly visible in the outcrop, and affecting both metasediments and interlayered granites. Although shearing is in part transposing the primary contacts between the two units, some metasedimentary bands inside the granite indicate the original intrusive nature of the latter. Quartz stretching lineation is generally SW-NE trending, gently to moderately SW plunging.

Gneiss-hosted Eclogites in the Sierra de Chuacús

The Chuacús Complex (Ortega-Gutiérrez et al., 2004) is an elongated metamorphic belt that stretches throughout central and eastern Guatemala for a length of ~ 220 km (McBirney 1963; Kesler et al. 1970; van den Boom 1972; Anderson et al. 1973; Roper 1978; Donnelly et al. 1990; Giunta et al. 2002; Ortega-Gutiérrez et al. 2004) (Fig. 4). To the north, the Chuacús terrane is bounded by low-grade greenschist-facies schists along the south-dipping high-angle Baja Verapaz shear zone. The MFZ puts the Chuacús Complex in contact with serpentinite mélange of Motagua Valley. Most gneissose rocks show compositional banding and contain both mafic amphibolite and quartzofeldspathic gneiss. Ortega-Gutiérrez et al. (2004) first described relict eclogite preserved in mafic epidote-amphibolite of the banded quartzofeldspathic gneiss in the El Chol area of the central Sierra de Chuacús. The retrograded eclogite is characterized by a relict eclogitic assemblage garnet + omphacite + rutile + quartz and overprinted by an epidote-amphibolitic assemblage of hornblende + epidote + albite + titanite; omphacite contains up to 45 mol.% jadeite component. Garnet grains exhibiting radial fractures around quartz inclusions were recognized and eclogite-facies conditions were estimated at 2.2-2.4 GPa and 730-750 °C (Ortega-Gutiérrez et al. 2004; Martens et al.. 2007).

Field relations suggest that the protolith of orthogneiss was intruded by mafic dikes, subsequently subjected to eclogite-facies conditions, and finally strongly overprinted at epidote-amphibolite conditions. Cathodoluminescence images, Th/U, U/Pb and REE patterns of Agua Caliente gneiss zircon cores indicate magmatic crystallization between 217 – 229 Ma of at least part of the orthogneisses. Refolding and conventional U-Pb geochronology of zircons from banded gneiss at El Chol yields early Paleozoic upper intercept ages and Carboniferous lower intercept ages, indicating that some of the units of the Chuacús Complex are older than Mesozoic. Bright CL metamorphic zircon rims from both samples contain low U (<60 ppm), and yield a weighted mean U238/Pb206 age of 75 ± 3 Ma (n = 7). Ages between 215 and 80 Ma are compatible with partial recrystallization of magmatic zircon or mixed analyses. Zircon rims of orthogneiss show less steep heavy REE patterns suggestive of growth in equilibrium with garnet, and are enriched in light REE. Eu anomalies in REE patterns indicate that cores and rims grew stable with plagioclase, and that neither represents the eclogite-facies event. This implies the ca. 75 Ma metamorphic age represents the epidote-amphibolite overprint, and constrains the high-pressure event to have occurred after the Triassic and before the Late Cretaceous.

Stop 15 (40 minutes) Banded gneisses and eclogite relics at El Chol. Presenters: Uwe Martens, Luigi Solari.

Lithology at Rio Agua Caliente

Outcrops of the Chuacús Complex in the Agua Caliente river were first visited in January, 2002 during a traverse of the Chuacus and Las Minas sierras in central Guatemala after the field excursion on the geology of the Motagua Valley organized by the working group of IGCP project. The rocks taken on that occasion, in spite of their garnetiferous nature, were not known to be or have been in the eclogite facies until examined in thin section with the polarizing microscope. In fact eclogite facies rocks had no been formally mentioned before in the Chuacús Complex, although garnet, barroisite and rutile were reported as forming part of the metamorphic rocks mapped by McBirney (1963) south of Rabinal.

The Agua Caliente bridge outcrop consists (Ortega-Gutiérrez et al., 2004) of a sequence of finely to coarsely banded (1-100 cm) gneisses composed of mafic (garnet amphibolite), felsic (quartzo-feldspathic) and mixed lithologies in which red garnet concentrates mainly in the mafic bands in quantities that may exceed 50 % of the rock, but is also present in the quartzo-feldspathic layers. Banding may be sharp to gradual. Leucosomatic anatectic veins may be identified because they slightly cut across the layered structure or developed a coarser texture grading to meter-sized pegmatite pods rich in white mica and albite (Fig. 13a).

Locally, the abundance and transgressive structure of leucosomatic bodies impart to the rock a migmatitic, stromatic appearance. The main minerals visible in outcrop are quartz, feldspar, garnet, amphibole, and abundant white mica. Clinopyroxene or rutile, on the other hand, are no apparent, although in thin section omphacite and rutile are rather common.

The occasional presence of layers very rich in quartz and the dominant gradational contacts between bands with different composition suggest that the sequence originally consisted of psammitic and pelitic sedimentary rocks, although some of the sharply bounded mafic bands within the quartzo-feldspathic gneisses upstream could have been diabase dikes or sills (Fig.13b and c).

The vertical to subvertical, banded structure is often folded by a second ductile event that produced asymmetric tight to open microfolds, and some boudinage of the felsic layers (Fig.13d).Eclogitic amphibolites consist in thin section of over a dozen phases corresponding to relict and retrograde assemblages. Primary omphacite shows a marked grass green color and is in textural equilibrium with albite, garnet

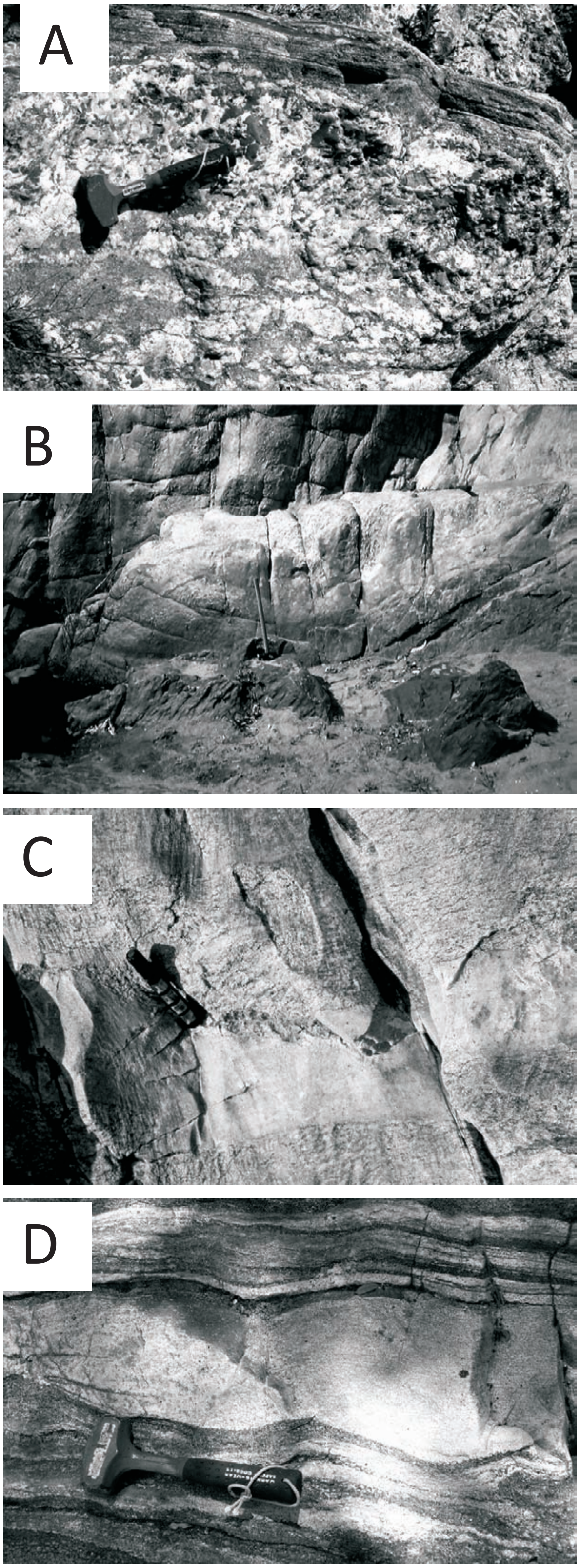

Figure 13. Photographs of Chuacús Complex rocks at Río Agua Caliente.

and rutile. Garnet is weakly colored in reddish tints commonly showing stronger shades in the cores. It is of small size and distinguished by the abundance an diversity of inclusions, specifically rutile, quartz, and epidote. Not uncommonly radial cracks around quartz inclusions developed due to volume changes associated with a SiO2 phase transition. Amphibole is apparently of retrograde origin because with albite it often forms symplectitic rims and pseudomorphs after clinopyroxene. However, its intense bluish pleochroism and fresh rutile and garnet inclusions require that some amphibole grew in equilibrium with high pressure phases. Titanite, on the other hand, is always rimming rutile indicating its late crystallization under lower pressures. Albite is almost pure sodium plagioclase and is in perfect textural equilibrium with the rest of the phases except omphacite. Quartz, besides its presence as inclusions in garnet or amphibole, it coexists with albite. White mica is present in many of the metaeclogitic amphibolites and it has been determined (Ortega-Gutierrez et al., 2004) as a high-silica phengite. Amphibole is strongly colored in greenish shades varying from brownish to grayish and bluish. Albite forms large poiquiloblasts with literally hundreds of inclusions of high pressure phases such as garnet, rutile and clinopyroxene, together with hydrous, probably retrograde amphibole, titanite and rarely biotite and primary carbonates. Other minor but important phases found in equilibrium with the high pressure mineralogy are zoisite, apatite, and tourmaline.

These textural relationships indicate sequential crystallization from the truly eclogitic assemblage omphacite-garnet-rutile-phengite, towards the retrograde amphibole-albite-titanite dominant assemblage, while garnet and phengite remained stable, probably changing their composition. An important petrogenetic aspect that should be considered further in these rocks deals with the possibility that some of the assemblages at Barranca Agua Caliente are the product of high-pressure partial melting of mafic rocks, yielding a trondhjemitic magma represented by the assemblage albite-quartz-garnet-rutile.

Stop 16 (70 minutes) Orthogneisses and amphibolitized eclogites at Agua Caliente. Presenters: Fernando Ortega-Gutiérrez, Uwe Martens.

Sm-Nd Mineral Isochron Ages from Eclogites of the Motagua Fault Zone

Eclogites that equilibrate at low temperatures, as is the case with the eclogites from the Motagua Fault (MF), tend have zoned and inclusion rich garnets and therefore are difficult to date by the Sm-Nd mineral isochron technique. Nevertheless, samples that had large garnets with relatively clean rims or cores from both sides of the Motagua Fault were selected for analyses. The following samples were analyzed: Southern Eclogites: Eclogites from south of the MF were collected on the path below Carrizal Grande (MVE02-6-3), and from two steeply plunging valleys downhill from the village: (MVE02-14-6, TT03-01, TT03-17). Northern Eclogites: Eclogites north of the MF were collected along a dry creek bed called Quebrada de Los Pescaditos (MVE04-44-6, MVE04 44-7) about 5 km south of the town of San Buenaventura on the Río Motagua (El Chol Quad.) and from Río Belejeyá immediately west of highway 5, about 5 km west of the town of Granados (Granados Quadrangle).

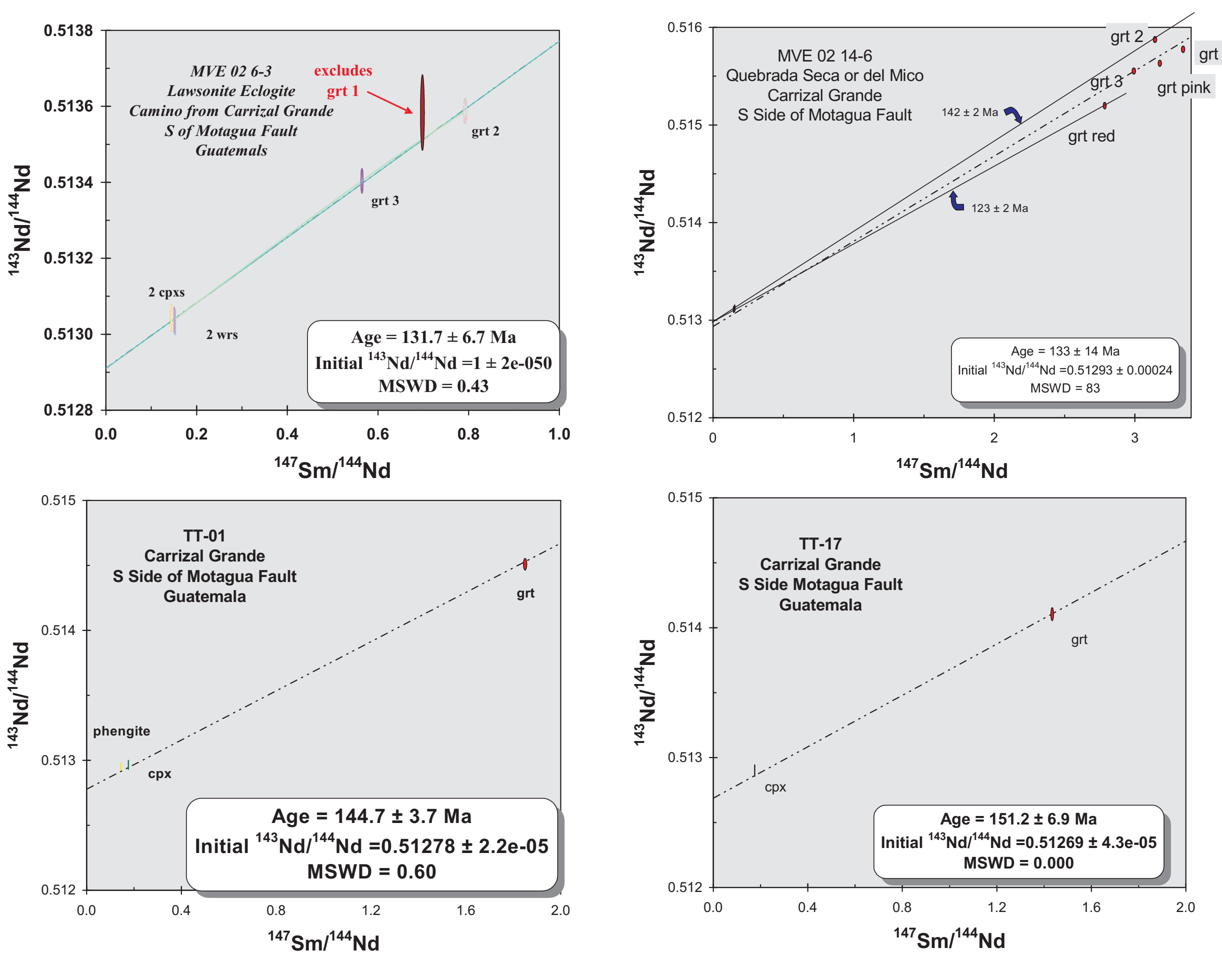

Figure 14. Sm-Nd mineral isochron plots of eclogites from the area of Carrizal Grande, southern Mayan Block, Central Guatemala

Sm-Nd data are plotted on Fig. 14 and 15 (southern eclogites) and (northern eclogites). The Sm-Nd ages considered reliable are the 131.7 ± 6.7 Ma (2sigma, MSWD = 0.43) age from MVE 02 6-3, the 140.6 ± 3.4 Ma (MSWD = 0.54) from TT-17, the 130.7 ± 6.3 Ma (MSWD = 0.79) Ma from MVE 04 44-7 and the 125.0 ± 7.8 Ma (MSWD = 1.3) age from MVE 06 5-3. The first two ages are from south of the Motagua Fault from a single fault sliver containing eclogite; the latter two are from north of the fault in separate slices of serpentinite mélange. The ages are essentially Early Cretaceous (Neocomian) and give an average of 132 Ma and a weighted average of 136 ± 11 Ma. The scatter from the other analyses, particularly from sample MVE 02 14-6 (Fig. 15), and the fact that most garnets are zoned suggests that all ages “average” a period of eclogite-facies recrystallization that, based on the large age span for garnets from MVE 02 14-6, may have lasted roughly 20 million years or more.

These ages create an interesting tectonic problem of how they could remain so close to each other on opposite sides of a fault system that underwent strike-slip motion of more than 1,000 km.

Stop 17 (30 minutes) Eclogites and Blueschist, Belejeyá River

At Rio Belejeya will be see blocks of eclogite and blueschist that have been partially eroded and transported a short distance from serpentinite melange located a few km north of the Cabañas fault. An eclogite from this locality was dated by Sm-Nd yielding an isochronic age of 125+/- 7.8Ma (Fig. 15).

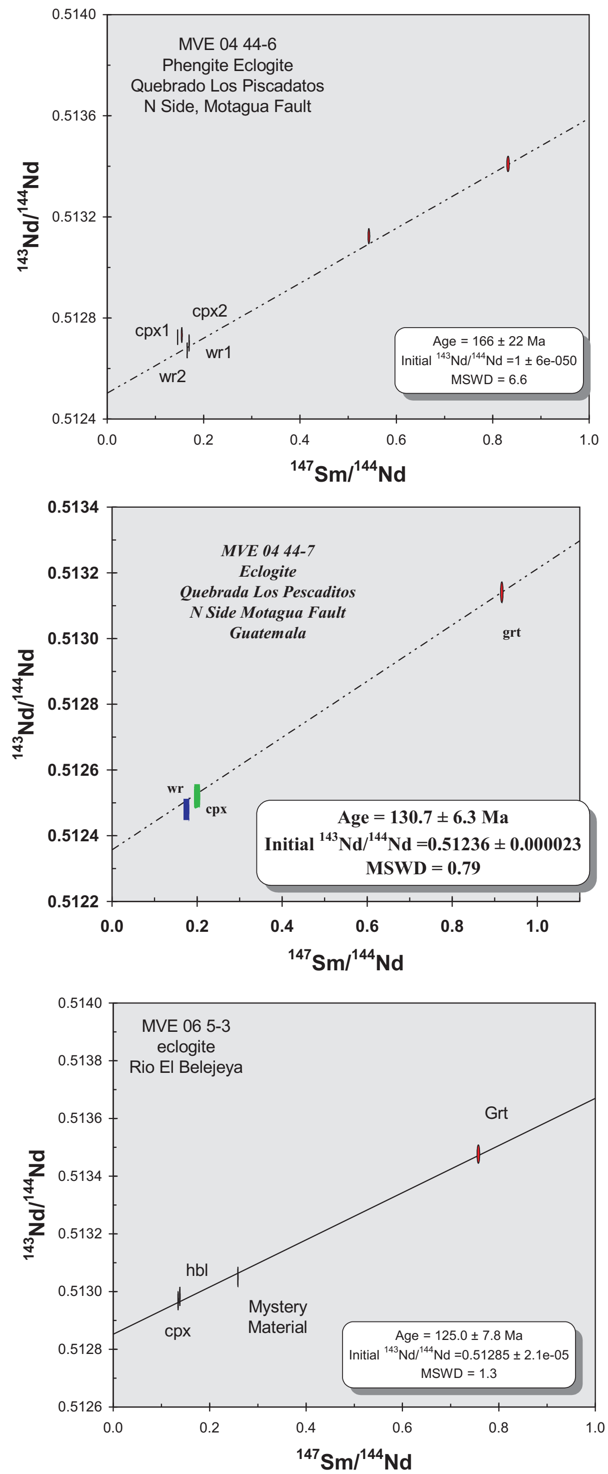

Figure 15. Sm-Nd mineral isochcron diagrams from eclogites from Quebrada los Pescaditos and Rio del Belejeya.

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