GEOLOGY AND GEOCHEMICAL EVOLUTION OF THE OPHIOLITIC BELTS IN GUATEMALA

FIELD GUIDE TO NICKEL BEARING LATERITES

Ricardo A. Valls, P. Geo., M. Sc.

Valls Geoconsultant

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Field Guide to Nickel Bearing Laterites

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Cover: Satellite image of Central Guatemala showing the Motagua Suture Zone (MSZ)- the environment of the ophiolitic belts in Central Guatemala related to the contact of the Caribbean Plate with the Maya Block to the north, with the location of Nichromet Extraction Inc. licenses in Guatemala. The Skye Resources - CNG's Exmibal licenses (Fenix Project) is shown for comparison purposes only.

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This publication is the result of over three years of field exploration and it represents the most current knowledge about the regional geology, petrology, and geochemistry of the ophiolitic belts in Guatemala which are located within the Motagua Suture Zone in Central Guatemala.

While my main objective was to study the Ni-bearing laterites in the area, I also wanted to study the geological evolution of the ophiolitic belts that host these laterite deposits.

This publication incorporates information previously disclosed in other field guides written by me. It also includes a more complete stratigraphic section and updated geological information. All field names of the units have been changed to proper petrographically-identified terminology, and I also included new description points for the field guide. As always, I would like to acknowledge the influence that this publication had from the field trip guidebook prepared by G. Giunta *et al.* (2002), as well as from The Preliminary Stratigraphic Lexicon for North and Central Guatemala compiled by S. A. Millan (1985). I combined information from these milestone works with my personal experiences in the mapping of the area and that of Oscar Pinzón, Julio Roberto Pérez, and other geologists from the Guatemalan Ministry of Energy and Mines. This publication has also benefit from discussions with several geologists and consultants that have visited the area over the last three years, like Velasquez Spring, Gorden Glenn, Michael Hitch, Jim Steel, Rob Callander, John Redstone, Lineu Saboia, Petronila Ronze, and Cesar Ferreiro, just to mention a few.

The Caribbean Plate (Fig. 1) is the result of the Mesozoic-Present interaction of the Nazca, Cocos, North, and South American plates. The margins of these plates are large deformed belts resulting from several compressional episodes that started in the Cretaceous and had been followed by tensional and strike-slip tectonics.

The present day north-western margin of the Caribbean Plate crops out in Guatemala along the Motagua Suture Zone (MSZ). This zone links the Meso-American trench with the Cayman Islands extensional system as shown in Fig. 2.

The MSZ represents a sinistral shear-zone between the Maya Continental Block (MCB) to the north and the Chortis Continental Block (ChCB) to the south. The MSZ includes the fault systems of Polochic, Motagua, Cabañas, and Jocotán. All these are E-W and ENE-WSW strike-slip faults. Some of them are still seismically active.

The MSZ also includes E-W uplift structures (Sierra de Chuacús, Sierra de Las Minas, and Montañas del Mico), and pull-apart basins like the one responsible for the formation of the Lake Izabal, and N-S oriented grabens (Chiquimula, Guatemala, etc.).

Figure 1. Structural sketch map of the Caribbean area (from Giunta et al., 2002).

Figure 2. Bathymetric representation of the Caribbean Plate and its relationship with the neighboring plates and structures.

The NW corner of the Caribbean Plate is complicated by the presence of a continental type block, the Chortis Block, within a mostly oceanic plate and a combination of a slip-strike boundary to the north running from the Belize-Guatemala border with a subduction zone to the west where the Cocos Plate is subducted beneath the Caribbean Plate, and an extinguished subduction zones to the north and south, were the Caribbean Plate was temporarily subducted beneath the Maya and Chortis Block.

We believe that the migration of the Chortis block in an S-SW and then N direction was one of the mechanisms responsible for the changes observed among the ophiolitic complexes in Guatemala. We are introducing the idea of the pre-existence of a trench associated with the Motagua-Jalomáx slip-strike fault system near the north border of Honduras, currently filled up and destroyed by the northward migration of the Chortis Block. Also we introduce the idea of an orogenic event - The Chuacús Orogeny - probably the same age as the Laramide Orogeny in North America. We postulate that the Chuacús Orogeny pushed younger ophiolites complexes in Guatemala to the surface and is responsible for the metamorphic basin of Central Guatemala - The Chuacús Series. The obduction of the oldest ophiolites on the western end of the belts may have being caused by the passing by of the Jamaica block on its way to its present position south of Cuba.

The Caribbean Plate (Fig. 1) is the result of the Mesozoic-Present interaction of the Nazca, Cocos, North, and South American plates. The margins of these plates are large deformed belts resulting from several compressional episodes that started in the Cretaceous and had been followed by tensional and strike-slip tectonics.

Any final model of the geological evolution of an area must comply with the facts. Regrettably, almost all “facts” are the direct result of man-made observations, which in many cases can be bias (intentionally or not). Also, it is common the lack of enough data to control the validity of the model in certain areas. Finally, there are also cases when the same “fact” can be interpreted in different, self-excluding ways. If this is all true, why then bother trying to create “the final model”? Because models, final, intermediates or working ones like the one that will be introduced here, are the tool to guide the work of the geologists to gather the necessary information to prove or disprove their ideas. A model can also “predict” the

existence of certain data or suggest the incorrectness of certain observation. Finally, a model could be an excellent exploration tool.

We are still far from being ready to present the final model for the Caribbean Plate, and that there are several intermediate models that deserve further data collection. Since most of the current collection of data is concentrated along the north, east and south limits of the Caribbean Plate, I would like to add to this database my working model of the northwest corner of the Plate, especially from the area of Central Guatemala.

The main difference of this sixth edition from all previous one then is the introduction of a dynamic understanding of the interaction of the NW corner of the Caribbean Plate with the Maya and the Chorits Blocks.

Guatemala is physiographically divided into four main units: (1) narrow Pacific Coastal Plain on the south; (2) Northwest Trending Volcanic Province; (3) East-west Trending Central Cordillera which includes at its centre the MSZ; and (4) the Petén Lowland (Fig. 3).

Figure 3. Physiographic map of Guatemala (Modified from Clemens et al., 1974).

Pacific Coastal Plain, which is about 50km wide along the southern coast, consists of narrow alluvial deposits derived from the Volcanic Province. Therefore, the composition of the alluvial is mainly of andesitic and basaltic pebbles and conglomerates. This area can be considered the fore-arc basin related to the subduction of the Pacific oceanic crust beneath Central America.

Volcanic Province is represented by a Quaternary chain of active volcanoes to the south and Tertiary igneous rocks to the north. Magmatic activity can be referred either to the subduction of the Cocos Plate beneath the Caribbean plate and to the collision of the Caribbean and North American plates or to some crustal adjustments. It is interesting to note that volcanism, as well as plutonic activity, has shifted to the south. The composition of volcanic materials has become more basic with time and Cretaceous granites have been dated northwards while Tertiary granites have been located to the south (Fig. 4).

Figure 4. Tertiary intrusion of a granodiorite along the RN 19 to Mataquesclintas.

Quaternary volcanoes reach up to 4,200m high, and at least seven have been active or in the fumarole stage during the present century. A few calderas such as the 80,000 years Atitlán Lake (Fig. 5) and Ayarza Lake are present.

Figure 5. This collapsed caldera surrounded by volcanic cones hosts the Lake Atitlán.

Central Cordillera, with the oldest rocks in Guatemala, is composed mainly by Paleozoic schists (Fig. 6), pegmatites (Fig. 7), Cretaceous carbonates (Fig 8), and Pre-Cretaceous to Tertiary Ophiolitic Belts (Fig. 9). The area is transected by the Motagua – Polochic fault system that is considered to be the continuation of the Cayman trench. It has a shape of an arc open towards the north.

Figure 6. Ferruginous schists from the Chuacús Series of the Central Cordillera physiographical unit.

Figure 7. Pegmatite mine Noelia located within Sierra de Chuacús, Central Guatemala.

Figure 8. Silicified limestones from La Virgen Formation.

Figure 9. Southern contact of the North Motagua ophiolitic complex, dated at 126 M.Y. by Harlow, G.E. et al. (2004).

Petén Lowlands can be considered the foreland of the Paleozoic and Mesozoic orogenies. This area is characterized by upper Cretaceous to recent carbonates, evaporites, clastics, and alluvial deposits, becoming younger and less deformed towards the north. Karst topography is developed in the carbonates.

A model of the geological evolution of Guatemala is presented in Fig. 10 and the regional geology of Guatemala is presented in Fig. 11. The oldest rocks in the region are Paleozoic. They are mainly composed by schists and other metamorphic rocks of the Pre-Permian Chuacús Series, accompanied by granitic and dioritic batholiths (Fig. 10A). Around 300 million years ago, during the Carboniferous, a deposition of marine sediments and conglomerates near the beach was followed by sandstones and shales at greater depths (Santa Rosa Group) as shown in Fig. 10B.

During the Early Permian (Fig. 10C), deposition of limestones and other carbonate rocks occurred (Chochal Formation). It was interrupted by a hiatus of nearly 51 million years during the Triassic Period, when the sea retreated and no significant deposition occurred. Around this time the Huehuetenango ophiolitic belt obducted.

Exposure of these rocks to oxidizing conditions in a tropical environment may account for the formation of the Late Jurassic red beds (Todos Santos Fm) following another hiatus at the end of this Period. Here, we also have the deposition of volcanic rocks from the San Lucas Fm.

The Late Cretaceous to Early Tertiary Periods were very active (Fig. 10D), with the deposition of more carbonate sediments (Cobán Fm., Ixcoy Fm., Petén Fm, Campur Fm. and others) and the intrusion of granitic and dioritic bodies corresponding to the Zacapa Island Arc event, followed by the deposition of marine clastic sediments (Verapaz Group) and the obduction of the North and South Motagua ophiolitic belts, followed by the obduction of the Juan de Paz – Los Mariscos ophiolitic belt. They were later on covered by the red beds of the Subinal Fm. The presence of these red beds suggests another period of sea-regression. This hiatus characterizes the entire Caribbean region (Leslie F. Moleiro León, pers. com., 2003).

The Paleocene witnessed the deposition of more marine sediments, mainly conglomerates, near the shores and sandstones and shales at greater depths, with the obduction of the Sierra de Santa Cruz and the Baja Verapaz ophiolitic belts (Fig. 10E).

Some marls and gypsum from the Icaiche Fm. were formed during the Eocene, while the end of the Tertiary Period was marked by the deposition of tuffs, lavas and other volcanic rocks accompanied by the intrusion of smaller granitoid bodies.

Finally, the Quaternary formations are represented by alluvial and deluvial material as well as by lavas and tuffs from active volcanoes (Guastatoya Fm., Toledo Fm., Desempeño Fm., Río Dulce Fm, and others). Some of the ultramafic layered intrusives that had undergone serpentinization before were oxidized, resulting in the formation of Ni lateritic zones (Fig. 10F).

Figure 10. Model of the geological evolution of Central Guatemala.

Figure 11. Regional geology of Guatemala.

STRATIGRAPHY

The stratigraphy as described by Vinson (1962) and the stratigraphic lexicon of southeast-central Guatemala are referred to in this publication (Fig. 12). The brief introductions of stratigraphy of Guatemala in the view-point of geochronology of the rock formations are shown in Figures 17, 18, and 25 with my own modifications based on field observations.

Figure 12. Type localities of Paleozoic, Mesozoic, and Tertiary formations of Guatemala and Honduras (Map from Vinson, 1962).

Chuacús Series (Early Paleozoic): McBirney (1963) suggested the name of Chuacús Series for the metamorphic rock series distributed in the Central Cordillera unit, between the Mayan and Chortís Continental Blocks. Within the studied area, we have identified the El Tambor Formation (Fig. 13) and La Virgen Formation (Fig. 14). Rocks in this series include schist, gneiss, amphibolites and marbles. The U-Pb age dating of zircon on biotite-albite gneiss and biotite-albite-epidote gneiss by Gomberg et al. (1968) show $1,075 \pm 25$ Ma of Proterozoic age. It is speculated that the sediments of the Chuacús Series were deposited during Devonian as lower Paleozoic rocks derived from a Pre-Cambrian landmass. Previous work has identified three metamorphic zones. The chlorite-sericite zone which consists of sericite schists, meta-graywackes, meta-arkose, granitoids, quartzites, and crystalline limestone is located around the city of Salamá. The biotite zone composed of biotite-muscovite-hornblende-epidote schist is found in the area of El Chol as a unit named El Chol Schist. The garnet zone is found around the town of Palibatz as a unit named the Palibatz Schist. Its typical mineral assemblage is garnet-kyanite-muscovite-hornblende.

Figure 13. Phyllites from El Tambor Formation near the Cementos Progreso Plant.

Figure 14. La Virgen Formation along the road RN-5 to Rabinal.

Chicol Formation (Late Paleozoic): The Chicol Formation is a sedimentary sequence which outcrops on the both sides of the Chitxoy-Polochic fault zone to the east and southeast of San Sebastian Huehuetenango. This formation is composed of a distinctive sequence of interbedded greenish-gray, gray and light blue-gray conglomerate and sandstone, gray-green, gray and maroon tuffs, and volcanoclastic beds and less common andesite breccia, which outcrop along the rivers Chicol and Selegua. Thickness of the formation is in the order of 1,000m. The age of the Chicol is placed within Ordovician-Permian (Fig. 15).

Sacapulas Formation (Late Paleozoic): The Sacapulas Formation (Fig. 16) outcrops along the Chitxoy-Polochic fault zone 35km to the east of San Sebastian Huehuetenango. The Sacapulas consists of 600m of conglomerates transitional into slate and sandstone with local volcanic and meta-volcanic interbeds. The Sacapulas formation is a unit of Santa Rosa Group.

Figure 15. Artificial cut on the road to Cementos Progreso Plant showing the sequence from Chiocol to the Sacapulas Formation.

Figure 16. Metamorphic conglomerates of the Sacapulas Fm.

Tactic Formation (Late Paleozoic): The index locality of Tactic Formation is in the east of the small village of Tactic, Alta Verapaz. The formation is widespread, outcropping in the Sierra de Los Cuchumantanes. It is also recognized in a band extending across the southern part of the Petén basin from Chiapae, Mexico in the west to the Caribbean Sea in the east. The formation consists of brown to black shale and mudstone with local thin quartzite bed and rare limestone and dolomite layers (Fig. 17). The Tactic Formation is 800m thick. It is contacted by the overlying Esperanza Formation with the gradually increasing contact of limestone. Fossils in the limestone beds of the upper part of the formation indicate a Permian age.

Figure 17. Outcrop of thin layered shales of the Tactic Fm. in Baja Verapaz.

Esperanza Formation (Late Paleozoic): The Esperanza Formation occurred in the Altos Cuchumatanes between the Chixoy-Polochic and Río Ocho fault zones. This unit was first mapped by Blount (1967), Boyd (1966), Davis (1966) and Anderson (1967) as the Esperanza member of the Santa Rosa Formation. Brown to black fossiliferous shale, mudstone and siltstone with limestone and dolomites interbeds characterize the Esperanza. The thickness of the Esperanza Formation in the Altos Cuchumatanes is more than 470m.

Chochal Formation (Late Paleozoic): The massive limestone and dolomites of the Chochal Formation are widespread along the southern Río Ocho and Chixoy-Polochic fault zones. The Chochal Formation outcrops eastward to the Coban-Purulha and Senahú area of Alta Verapaz and westward towards Mexican frontier.

The Chochal Formation consists of massive-bedded, cliff forming dolomite and limestone, ranging from grayish-black to brownish medium to dark gray in colour. The Chochal lithology is similar to the Esperanza Fm (Fig. 18).

Figure 18. Grayish-black, cliff forming, limestones and dolomites from the Chochal Fm.

The Chochal Formation is at least 500m thick and, locally, along the southern flank of the Cuchumatanes, may be as thick as 1,000m. It is separate from the overlying Todos Santos Formation by an angular unconformity. The Chochal Formation has been included in the Santa Rosa group.

Macal Formation (Late Paleozoic): The Macal Formation is distributed in Maya mountain of Belize and is extended into eastern Guatemala in the region. Various authors have correlated the Macal Formation with Santa Rosa group of Guatemala. Fossils in the Macal indicate an age of Upper Permian to Pennsylvanian.

PERIODS OF DASTROPHISM	AGE	NORTHERN GUATEMALA	CENTRAL & SOUTHEAST GUATEMALA
		VINSON 1962 WALPER 1960	McBIRNEY 1963 HIRSCHMANN 1962 CRANE 1965 BURKART 1965
L A R A M I D E	QUATERNARY		ALLUVIUM
	TERTIARY		PADRE MIGUEL GROUP
		CARIBE FORMATION	SUBINAL FORMATION
	UPPER CRETACEOUS	PETEN GROUP	
		VERAPAZ GROUP	
	LOWER CRETACEOUS	IXCOY FORMATION	IXCOY FORMATION
	PALEOZOIC	COBAN FORMATION	TODOS SANTOS FORMATION
	PALEOZOIC	TODOS SANTAS FORMATION	
	PALEOZOIC	JURASSIC	
	PALEOZOIC	PERMIAN CHOCAL-TACTIC-FORMATION	SANTA ROSA GROUP
		CARBONIF. SANTA ROSA FORMATION	
	PALEOZOIC	Metamorphic Intrusive Rocks	Metamorphic Intrusive Rocks

Figure 19. The stratigraphic unit from upper Paleozoic to Quaternary of Guatemala with modifications by the author.

Todos Santos Formation (Triassic to Jurassic): The Todos Santos Formation is lying unconformably on the Chochal and the Macal-Santa Rosa and, in some places, the basement metamorphics, which is a thick series composed dominantly of conglomerate member and siltstone-shale member. The upper part of the Todos Santos Formation is occupied by the San Ricardo Formation composed of siltstone, sandstone, and dolomite rocks. Richard (1963) divided the Todos Santos Formation into two members, lower conglomerate unit and upper silty to shaly unit.

The Todos Santos Formation ranges in thickness from a few meters to at least 1,240m near La Ventosa section. It seems to be a type section because of good exposures. Vinson (1962) and Walper (1960) divided the age of the Todos Santos as the upper Jurassic period in the northern part of Guatemala and McBirney et al. (1963) classified the formation as the middle Jurassic to middle Cretaceous in the type section of central and southeast Guatemala.

San Lucas Formation (Late Jurassic?) This unit has not been described before; however archived reports from geological companies mention this volcanic unit and in some cases identified it as the Jalomáx Formation or Unit. We have identified fragments of this formation as xenoliths within the limestones of the Ixcay Formation at San Lucas, within the Sierra de Santa Cruz ophiolitic complex (Fig. 21).

Figure 21. Xenoliths of basalts from the San Lucas Formation within the bituminous-rich limestones of the Ixcay Formation at the Sierra de Santa Cruz ophiolitic complex.

The best example of this formation is found along the road to the village of San Lucas. The formation appears to be composed by two series: a thick lower series composed dominantly of conglomerates and siltstone-shales member (Fig. 22) and an upper series composed of mafic tuffs intensively and pervasively weathered to form a reddish clay material.

Figure 22. Tectonic contact between the San Lucas Formation (in red) with the Sierra de Santa Cruz ophiolitic belt (left). The photo shows the sedimentary series of the San Lucas Formation.

Cobán Formation (Early to Middle Cretaceous): The thick series of Cretaceous limestones, dolomites, and argillaceous to arenaceous clastics represents nearly continuous deposition throughout the Cretaceous. It is unconformably overlying the Todos Santos Formation. Among the Cretaceous formations it is the lowermost. Sapper (1937) gave the name Cobán to the Cretaceous limestones occurring near Cobán, Alta Verapaz (Fig. 23). The age range of the Cobán Formation is Neocomian to Turonian. However, the evaporite part of the unit is probably restricted to the Comanchean or the lower Cretaceous.

Figure 23. Outcrop of Cobán limestones near the village of Puruláh.

Ixcoy Formation (Middle Cretaceous): The Ixcoy Formation described by Termer (1932) in the Department of Huehuetenango was thought to represent an indistinct lower part of the Cobán Formation. My own observations indicate that the bituminous cryptocrystalline Ixcoy Formation is younger than the Cobán Formation. The Ixcoy Fm. is very common and spreads to the east central part of Guatemala (Fig. 24).

Figure 24. Outcrop of Ixcoy limestones near Salamá village, Baja Verapaz.

Campur Formation (Late Cretaceous): Vinson (1962) formally proposed that name for the sequence of Senonian age rocks which conformably and gradationally overlie the Cobán Formation in the Alta Verapaz area. The type section of the Campur Formation occurs along the Cobán-Sebo road approximately 3-6 km south of Finca Campur. The Campur Formation principally consists of gray, gray-brown and dark brown limestone deposited in reef-associated environment. It has minor amounts of dolomite. It is interbedded with thin streaks of shale, siltstone, and limestone breccia or conglomerate.

Verapaz Group (Late Cretaceous): According to the clarifications of Vinson (1962), the group consists of the Chemal, Sepur, and Lacandon Formation. Its name took from the Departments of Baja and Alta Verapaz where the group is best developed. The formations are composed predominantly of clastic material including shale, sandstone, siltstone, limestone, and conglomerate.

The thickness of the Verapaz Group is approximately 600~700m. The age of the group is Campanian and Maestrichtian of upper Cretaceous, based on rich foraminifera assemblage.

- ***Chemal Formation***: The Chemal Formation is restricted to the Chemal region near the highest point of the Altos Cuchumatanes near Huehuetenango. The upper part of the formation has been eroded. Thickness is 95m.

Lithologically, the unit consists of red and reddish brown shale with minor thin beds of coarse calcarenites and conglomeratic limestones in the lower part and finer calcarenites and dense argillaceous limestone in the upper part (Fig. 25). The main lithologic characteristic which differentiates the Chemal from the Sepur is its dominant red coloration.

- ***Sepur Formation***: The Sepur Formation was named by Sapper (1899) after a place called Sepur near Lanquin Village and Finca Campur in central Alta Verapaz. The formation is composed of brown clays, shales, siltstones, sandstones and marls, interbedded with lenses of limestone. Maximum thickness is about 600m.

The formation lies unconformably on the Upper Cretaceous (Senonian) limestones of the Campur Formation. Overlying the Sepur with a contact both gradationally and locally unconformable are the clastic limestones of the Lacandon Formation.

Figure 25. Outcrop of reddish brown shale with finer calcarenites and dense argillaceous limestone in the upper part of the Chemal Fm, near Huehuetenango.

- ***Lacandon Formation***: The Lacandon Formation occurs in the Lacandon region in northwestern Petén. The Lacandon is the thick series of detrital carbonates locally with algal beds and microcrystalline limestone of light and light yellow to light cream colour. The composite section was divided into three units having thickness of 650m and 600 to 400m near Lacandon, Petén.

Subinal Formation (Paleocene): Previously described as a molasses unit, this formation is composed of a series of flischoid polymictic conglomerates (Fig. 26) overlaying in many cases the ophiolitic belts associated to the Motagua and the Río Negro-Polochic Fault.

A typical cut can be observed on km 77 of the CA-9, just after the Guastatoya village (UTM E: 816603, UTM N: 1647109, Elevation: 600 m; Zone 15). On this outcrop we can observe three flischoid sequences: a fine-grained consolidated polymictic conglomerate, a coarse-grained polymictic conglomerate, and a fine-grained unconsolidated sequence. They are geochemical very different as shown in Fig. 27.

Figure 26. The Subinal Formation is composed by a flsichoid sequence of polymictic conglomerates.

Figure 27. Chemical characteristics of the different facies of the Subinal Fm.

We recently located a possible source for the Subinal Fm. south of the Motagua Fault at UTM E: 815968, UTM N: 1636071, Elevation: 640 m (Zone: 15). It is a polymictic conglomerate, very hard and silicified, that outcrops on top of schists from the Chuacús Series and is also found in big boulders on creek beds (Fig. 28). There are reports of gold values in many of these creeks and rivers, which maybe related to the quartz fragments found on these conglomerates.

Figure 28. Boulders of a polymictic conglomerate in a red matrix that could be the source for the Subinal Fm. can be found on the beds of rivers and creeks south of the Motagua Fault.

Petén Group (Early Eocene): Vinson (1962) divided the Petén group into 5 units such as Cambio Formation, Reforma Formation, Teledo Formation, Santa Amelia Formation, and Buena Vista Formation in aspects of some tectonic and paleontologic evidences. The description of the Petén Group is based on the report compiled by Millan (1985).

Icaiche Formation (Late Eocene): This unit was described first by Millan (1985). It is composed mainly by gypsum and marls (Fig. 29).

Figure 29. Gyps from the Icaiche Fm.

Desempeño Conglomerate Formation (Upper Oligocene): This formation consists predominantly of variable size channel type conglomerates containing quartzitic and siliceous pebbles ranging up to ten centimeters in diameter. It occurs as a wedge shaped mass in a low-lying erosional pocket on the south flank of La Libertad arch. The formation attains a maximum thickness of 200 meters in the type area. These terrigenous conglomerates are massive and hard and have an over-all gray coloration weathering black. The pebbles are very similar to those found in the Caribe and Lacantun Formations and may indicate a comparable source.

Lacantun Formation (Upper Oligocene): The predominantly red bed formation overlying the Petén Group is the Lacantun Formation named after the type locality near the mouth of Río Lacantun.. It has a variable thickness ranging up to 500 meters distributed in the lower Río Saldas, lower Río Pasión, upper Río Usumasinta, and lower Río Lacantun region of south-western Petén and eastern Chiapas, The Lacantun Formation consists of red and brown arkosic and ferruginous sandstones and siltstone, quartz-rich conglomerate, red and brown ferruginous and nodular claystone, and mottled hard to soft nodular shales.

Caribe Formation (Upper Oligocene-Lower Pliocene): The Caribe Formation is exposed in the Río Salina just south of El Caribe, Petén, where it's most complete section is found. The formation is also found in adjoining regions of Alta Verapaz and El Quiché.

Vinson (1962) suggested the Caribe Formation is a probable time equivalent to the Río Dulce Formation of eastern Guatemala. The total formation thickness in the type section is in excess of 800 meters. The formation consists of variegated clays, clay shales, grits, sandstones, siltstones, sandy limestones and quartz-rich conglomerates.

Río Dulce Formation (Lower Miocene): This formation is known to occur only in the Amatique embayment area of eastern Guatemala. It is characterized by light buff, tan, and cream-coloured limestone unconformably deposited on Permian, Cretaceous, and Eocene rocks. The Río Dulce Formation is overlain by the Herrería Formation of Pliocene (?) age. Its upper contact infers a low angle unconformity. The type locality of the formation is just above sea-level along Río Dulce, upstream from the Town of Livingston, Izabal.

Herrería Formation (Pliocene): The Herrería Formation with a long, narrow, gentle-dipping north-south strip of clastics is overlying the early Miocene Río Dulce limestone east of Río Dulce gorge (Fig. 30). The description on the Herrería Formation is presented in this publication on bases of the lexicon compiled by Millan (1985). This formation was named by J. P. Gallagher in a private oil company report cited by Vinson (1962). The type section extends from Punta Herrería southwest to the contact with the Río Dulce Formation, a distance of about one mile. The thickness of the Herrería Formation is 240 meters. Herrería Formation is composed of poorly consolidated claystones, siltstones, marls and sandstones, which are characteristically conglomeratic.

Figure 30. Herrería Formation within Río Dulce, Izabal.

Armas Formation: The Armas Formation composed of the Red Bed and associated deltaic sediments occur in Motagua River valley in Izabal. The formation is a thick series of young or fresh-appearing strata which overlie with a marked unconformity older basement metamorphics and Cretaceous limestones. The unit is divided into two sub units (upper and lower) that consist of the sedimentary rocks derived from the volcanic, metamorphic and sedimentary rocks. The formation consists of Red Beds with claystone, siltstone and sandstones. The total estimated thickness is 2,500~3,000 meters.

Finally, we present a “work-in-progress” stratigraphic column for the area, compiled from Millan (1985) and my own mapping efforts and interpretations (Fig. 31).

PERIOD	EPOCH	COLUMN	UNIT	SYMBOL	
Quaternary	Pleistocene & Holocene		Pumice	Q _p	Thick pumice fills and mantles of diverse origin.
		Undivided volcanic rocks	Q _{uv}	Lava flows, laharic deposits, tuffs, cones and domes.
Tertiary	Miocene-Pliocene		Herrera Fm.	PH _{ms}	Conglomerates of claystones, siltstones, marls and sandstones.
		Río Dulce Fm.	MRD _{carb}	Light buff, tan, and cream-coloured limestones.
	Oligocene		Caribe Fm.	OC _{ms}	Variegated clays, clay shales, grits, sandstones, siltstones, sandy limestones and quartz-rich conglomerates.
	Eocene		Icaiche Fm.	E _{ms}	Gypsum and marls.
		Petén Group	EP _{ms}	Marine sediments. Obduction of the Sierra Santa Cruz and Baja Verapaz ophiolitic complexes.
Cretaceous	Paleocene		Subinal Fm.	LKE _{Srb}	Red beds, mainly Tertiary. Obduction of the Juan de Paz - Los Mariscos ophiolitic complex.
	Late		Verapaz Group Sepur Fm.	LK _{Sms}	Brown clays, shales, siltstones, sandstones and marls, interbedded with lenses of limestone. Obduction of the North and South Motagua complexes.
	Medium		Ixcay Fm.	LKI _{carb}	Cryptocrystalline, bituminous-rich limestone, with no fossils remains, containing xenolites of the basaltic series of the San Lucas Formation. Zacapa Island Arc Granitoid.
Jurassic	Late		San Lucas Fm.	LJSL _{rb}	Conglomerates and siltstone-shales and basaltic tuffs intensively and pervasively weathered to form a reddish clay material. Equivalent to San Ricardo Formation.
Permian	Early?		Chochal Fm.	EP _{CHcarb}	Massive-bedded, cliff forming dolomite and limestone, ranging from grayish-black to brownish medium to dark gray in colour. Possible time of obduction of the Huehuetenango ophiolitic complex.
Carboniferous	Late		Tactic Fm.	LCT _{phyl}	Dark shales and mudstones. Shales, sandstones, conglomerates and phyllites
Devonian	Late		Chuacús Series. Tambor Fm. La Virgen Fm. Sacapulas Fm.	LDCH _{um}	Phyllites, chlorite and garnet schists, quartz-mica-feldspar schists and gneisses, marbles and migmatites. Rabinal granite.

Figure 31. Stratigraphic column for the studied area.

GEOCHEMICAL EVOLUTION OF THE OPHIOLITIC BELTS
IN GUATEMALA

An ophiolite is a thrust sheet of ancient oceanic lithosphere obducted over the continental crust in the course of orogeny. The majority of geologists interpret these sequences as oceanic crustal and upper mantle material that has been pushed up onto continents when slivers of the sea floor were caught between converging plates (Fig. 32). The term "ophiolite" comes from the Greek word "snake stone".

Figure 32. Diagram showing the model of formation of an ophiolitic belt. Photo courtesy of http://volcano.und.nodak.edu/vwdocs/vw_hyperexchange/ophiolites.htm.

An ophiolite is a stratified igneous rock complex composed of upper basalt member, middle gabbro member, and lower peridotite member. Some large complexes measure over 10 km thick, 100 km wide, and 500 km long. Basalt and gabbro are commonly altered into patchy green rocks, and peridotite is mostly changed into black, greasy serpentinite.

The ophiolite succession can be correlated with the seismologic layering of the oceanic lithosphere (Fig. 33). The sedimentary cover corresponds to Layer 1, basaltic pillow lava matches Layer 2, sheeted dikes and gabbro with occasional plagiogranite intrusions are correlated to Layer 3, and ultramafic cumulates and residual mantle peridotite represent Layer 4 (mantle).

Ophiolite succession and seismic layers of oceanic crust

Figure 33. Typical ophiolitic succession.

Ophiolites usually occur as a nappe (intact thrust sheet) or as a *mélange* (tectonic mixture of fragments). In collisional orogenic belts, ophiolites generally lie on older continental basement, while in circum-Pacific orogenic belts ophiolites generally lie on younger accretionary complexes. In Guatemala, they occur as *mélanges* over older rocks (Fig. 34) within a major structural zone named The Motagua Suture Zone (MSZ).

Following is a list of the most common minerals related to the ophiolitic processes. The list is by no means exhaustive and serves only to explain the principal constituents of the ultramafic rocks which maybe involved in the process of serpentinization, or may be present as accessory minerals.

Albite	$\text{NaAlSi}_3\text{O}_4$
Anorthite	$\text{CaAl}_2\text{Si}_2\text{O}_4$
Augite	$(\text{Ca, Mg, Fe, Al})_2(\text{Al, Si})_2\text{O}_6$
Awaruite	Ni_3Fe
Bastite	$\text{Mg}_2\text{Si}_2\text{O}_6$
Brucite	$\text{Mg}(\text{OH})_2$
Chromite	FeCr_2O_4

Clinopyroxene	$\text{Ca(Mg, Fe)Si}_2\text{O}_6$
Diopside	$(\text{Ca, Mg}) \text{Si}_2\text{O}_6$
Fayalite	FeSiO_4
Fe-Chrysotile	$\text{Fe}_3\text{Si}_2\text{O}_5(\text{OH})_4$
Forsterite	MgSiO_4
Garnerite	$\text{H}_2(\text{Ni, Mg})\text{SiO}_4$
Hyperstene	$(\text{Mg, Fe})\text{SiO}_3$
Limonite	$[(\text{Fe, Ni})\text{O}(\text{OH})]$
Magnetite	Fe_3O_4
Millerite	NiS
Orthopyroxene	$(\text{Mg, Fe})\text{SiO}_3$
Pentlandite	$[(\text{Ni, Fe})_9\text{S}_8]$
Serpentine	$\text{Mg}_2\text{Si}_2\text{O}_5(\text{OH})_4$
Siderite	FeCO_3
Talc	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$

Figure 34. Ophiolitic belts in Guatemala.

THE MOTAGUA SUTURE ZONE

Three zones can be identified on the basis of the morphotectonic of the area, as it is shown in Fig. 35: the Northern, Central, and Southern sectors.

Figure 35. Geological-tectonical sketch map of the Motagua Suture Zone in Guatemala.

THE NORTHERN SECTOR

The northern sector of the Motagua Suture Zone (MSZ) is characterized by north and north-east verging folds and by wide carbonate-terrigenous deposits (Petén, Cobán, and Ixcoy Fms.) lying on a Pre-Permian crystalline basement, which locally crops out in a few tectonic windows. This sector is known as the Maya block (or the Yucatán block), which in turn belongs to the North American Plate.

Within this sector, tectonically located between the Polochic Fault to the North and the Río Negro Fault to the South, we have the Polochic Ophiolitic Belt composed of the youngest (Tertiary?) and less metamorphosed ophiolitic complexes – The Baja Verapaz and The Sierra de Santa Cruz hosting most of the large Nickel laterite deposits in Guatemala, and the older post-Permian Huehuetenango ophiolitic complex.

THE CENTRAL SECTOR

Located in the Central Cordillera of Guatemala and limited to the south by the Motagua - Cabañas - Jocotán Faults and to the North by the Polochic - Río Negro Faults, this sector is represented by metasedimentary rocks of the Chuacús Series, as well as by some granitic intrusions, red beds of Late Jurassic – Early Cretaceous age (Todos Santos Fm.), limestones and dolostones intercalated with well developed layers of anhydrites and halites of Mid-Cretaceous age.

This sector is characterized by narrow valleys stretching along the main strike-slip faults of the Polochic, Motagua, Jocotán, and Cabañas Faults; wide plains corresponding to pull-apart basins filled with thick, recent sediments; and narrow reliefs (Fig. 36) constituted by the Paleozoic basement and felsic and mafic intrusions (e.g. Sierra de Chuacús, Sierra de Las Minas, and Montañas del Mico).

Figure 36. Aerial view of Sierra Las Minas looking North from CA-9.

In addition, several large allochthonous Mesozoic-Tertiary ophiolitic bodies crop out along this sector aligned along the faults represented by the Juan de Paz – Los Mariscos and the high pressure - low temperature (HP-LT) North Motagua ophiolitic complexes.

THE SOUTHERN SECTOR

The southern portion of the MSZ is represented by Tertiary to Quaternary volcanic sediments overlying a plateau named The Chortis Block. This continental basement has been progressively incorporated into the Caribbean Plate since the Late Cretaceous. The oldest rocks in this sector (Las Ovejas Group) are represented by Paleozoic metasediments and metagneous complexes, including schists, gneiss, and marbles (Fig. 37). The Southern Sector also includes (HP-LT) metamorphosed ophiolitic bodies from the South Motagua ophiolitic complex.

Figure 37. Metamorphosed granodiorite intrusive outcrops on km 72 of RN 19, south of the Motagua Fault.

THE OPHIOLITIC COMPLEXES

The following ophiolitic complexes have been identified in Guatemala to date:

I. The Motagua Ophiolitic Belt

- a. The South Motagua complex (SM).
- b. The North Motagua complex (NM).
- c. The Juan de Paz – Los Mariscos complex (JPZ).

II. The Polochic Ophiolitic Belt

- d. The Sierra de Santa Cruz complex (SSC).
- e. The Baja Verapaz complex (BVP).
- f. The Huehuetenango complex (HUE).

The locations of these belts can be seen in Figs 34.

THE NORTH AND SOUTH MOTAGUA OPHIOLITIC COMPLEXES

The oldest ophiolitic belts within the Central and Southern Sector are represented by the North and South Motagua units. They outcrop as narrow belts along the Motagua and Cabañas faults within the Motagua valley. Both ophiolitic belts consist of high pressure - low temperature (HP-LT) metamorphosed and serpentinized mantle harzburgites and foliated gabbros (Fig. 38), followed by a thick basaltic pillow lava sequence (Fig. 39) showing mid-ocean ridge affinity of El Tambor Group (Beccaluva et al., 1995). They are both unconformably overlain by the Paleocene polymictic fliishoids of the Subinal Fm (Fig. 40).

Figure 38. Mantle hazburgites from the North Motagua ophiolitic belt.

Figure 39. Pillowed basalts from the North Motagua ophiolitic belt.

Figure 40. A detail of the composition of the Paleocene polymictic flintoid of the Subinal Fm.

The SM unit overthrusts the Paleozoic continental basement of the Chortis block, while the NM unit overthrusts the Paleozoic metamorphic terranes of the Sierra de Chuacús and Sierra de Las Minas. A section of the geological map 1:1 000 000 showing the regional geology of these belts (Fig. 41) and a model of their geological evolution follow (Fig. 42).

Figure 41. Regional geology of the North and South Motagua ophiolitic complexes (Pi), from the regional geological map of Guatemala, scale 1:1 000 000. See legend on Figure 11 on page 27.

Figure 42. Geological model of the evolution of the North and South Motagua ophiolitic complexes.

The petrographic analysis of a group of samples from these complexes shows that the most probable magmatic event was the partial melting process (Fig. 43, Valls, unpublished).

Figure 43. The Rb:Ni ratio indicates that a partial melting was the most probable magmatic event for the North and South Motagua ophiolitic complexes.

Another characteristic of the rocks from the NM complex is their low alkali content when compared to the other complexes in Guatemala (Fig. 44). They are also very different with respect to their REE and trace element composition, as shown in Figures 45 and 46. The NM is the richest in Co, Mn, S, and V of all the ophiolitic complexes.

Figure 44. Major oxide composition of the main ophiolitic complexes in Guatemala.

Figure 45. REE distribution from the NM ophiolitic complex.

Figure 46. Trace element profiles of the different ophiolitic complexes in Guatemala.

Using Daryl Clark's NewPet software (1993) we determine that the ultramafic rocks from the NM complex are all tholeiitic, calc-alkaline, and related to an Ocean Ridge and Floor environment (Debon and Fort, 1983; Irvine and Baragar, 1971; Jensen, 1976; Maniar and Piccoli, 1989; Miyashiro, 1974; Mullen, 1983; Peacock, 1931; Pearce et al., 1977; and Shervais, 1982).

THE JUAN DE PAZ – LOS MARISCOS OPHIOLITIC COMPLEX

The Juan de Paz - Los Mariscos complex (JPZ) is composed of generally serpentinized pyroxenites (lherzolites and dunites), with scarce basalts and andesites. It has been interpreted by Beccaluva et al. (1995) as island-arc magmatic sequences associated with sub-arc mantle rocks. This conclusion is supported by our own data.

All these rocks are tholeiitic, sub-alkaline, and are the result of mantle fractionates. Sample 59057 which was taken from a mylonitic zone, indicates an Ocean Ridge and Floor origin (Pearce et al., 1977). These rocks are richer in REE elements, as it is shown in Fig. 47. This complex has also the highest values of Ni, Zn, Zr, and Y.

Figure 47. REE composition of samples from the JPZ-LM ophiolitic complex.

This unit overthrusts the Paleozoic metamorphic basement of the Sierra Las Minas and Montañas del Mico. The JPZ unit is usually covered by mafic volcanoclastics and andesitic breccias, passing upwards to carbonated breccias and calcarenites, with sandstone and microconglomerates containing felsic volcanic fragments of the Late Cretaceous Cerro Tipón Fm. A section of the geological map 1:1 000 000 showing the regional geology of this belt (Fig. 48) and a model of its geological evolution follow (Fig. 49).

Figure 48. Regional geology of the Juan de Paz-Los Mariscos ophiolitic complex (Pi), from the regional geological map of Guatemala, scale 1:1 000 000. See legend on Figure 11 on page 27.

Figure 49. Geological model of the evolution of the Juan de Paz-Los Mariscos complex.

The JPZ unit is less metamorphosed and shows more boudinage than the other units (Fig. 50). It also shows effects of post-hydrothermal alteration, like the formation of botryoidal masses of magnesite (Fig. 51).

Figure 50. Boudinage in an outcrop next to the village of Juan de Paz.

Figure 51. Hydrothermal magnesite vein within pyroxenites in an outcrop near Los Mariscos village.

The irregular pattern of the Rb:Ni ratio in samples from the JPZ ophiolitic belt indicates the possibility of later mixing event, which was confirmed by the La/Sr vs. 1/La ratio (Fig. 52).

Figure 52. The samples from the Juan de Paz-Los Mariscos complex indicate a later mixing process.

THE SIERRA DE SANTA CRUZ AND THE BAJA VERAPAZ OPHIOLITIC COMPLEXES

These two units within the Polochic Ophiolitic Belt appear to be the least metamorphosed complexes in Central Guatemala. Petrologically, they are similar to the JPZ complex, being composed mainly of pyroxenites (dunites, olivine-rich lherzolite, and lherzolite) with scarce cumulate gabbros and very few basaltic dykes or other volcanic rocks. All known Guatemalan lateritic deposits and most of the new targets are located within these two complexes.

The Sierra de Santa Cruz unit (SCC), which is the main focus of the laterite mining activity to date, overthrusts to the North from the Polochic Fault onto the Late Cretaceous – Paleocene carbonated-terrigenous sequence of the Ixcay Fm. It is locally covered by small outcrops of terrigenous and volcanoclastic sequences including andesitic and dacitic fragments of the Cenozoic San Lucas Fm. The petrological analysis of the data shows that this belt is the result of mantle fractionates associated to an Ocean Ridge and Floor tectonic environment (E.g., sample GU-05 and GU-09). All the rocks are tholeiitic and sub-alkalinic.

The REE pattern is very irregular (Fig. 53) and this complex shows the highest concentrations of almost all trace elements (see Fig. 46).

Figure 53. Irregular pattern of distribution of REE elements at Sierra de Santa Cruz ophiolitic complex.

A section of the geological map 1:1 000 000 showing the regional geology of this belt (Fig. 54) and a model of its geological evolution follow (Fig. 55).

Figure 54. Regional geology of the Sierra de Santa Cruz complex (Pi), from the regional geological map of Guatemala, scale 1:1 000 000. See legend on Figure 11 on page 27.

Figure 55. Geological model of the evolution of the Sierra de Santa Cruz ophiolitic belt.

The Baja Verapaz complex (BVP) clearly overthrusts onto the Paleozoic metasediments of the Chuacús Series to the northwest and onto the Mesozoic evaporite-terrigenous-carbonate deposits of Todos Santos, Ixcoy, and Campus Fms. within the Maya block at the northeast. The lateritic profiles here are more evolved, which could suggest an older age of the protrusion of the BVP ophiolitic complex relative to the SSC belt

The petrological analysis of the samples from this complex shows that these are tholeiitic, sub-alkaline rocks, the result of mantle fractionates formed in an Ocean Ridge and Floor tectonic environment. The BVP complex has one of the richest associations of REE elements (Fig. 56) and trace elements.

Figure 56. REE distribution pattern for the BVP ophiolitic complex.

A section of the geological map 1:1 000 000 showing the regional geology of this complex (Fig. 57) and a model of its geological evolution follow (Fig. 58).

Figure 57. Regional geology of the Baja Verapaz complex (Pi), from the regional geological map of Guatemala, scale 1:1 000 000. See legend on Figure 11 on page 27.

Figure 58. Geological model of the evolution of the Baja Verapaz ophiolitic complex.

Table 1 shows the average composition of the main rocks found in the Motagua Suture Zone. I compiled these chemical compositions from Trusova & Chernov (1982), Giunta *et al.* (2002) and from my own sampling.

Table 1. Major oxides composition of the most common rocks found within the Motagua Suture Zone. All values are expressed in percentages.

Rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	LOI
Andesite	59.59	17.31	6.46	2.75	5.80	3.53	2.04	0.77	1.26	0.18	0.31
Andesite-dacitic tuff	58.45	15.70	8.27	3.59	2.06	1.07	2.36	0.79	0.10	0.09	11.90
Andesitic tuff	63.15	15.38	6.32	2.38	0.66	0.44	1.65	0.82	0.02	0.02	12.70
Basalt	46.64	15.6	9.30	11.17	7.96	2.86	0.46	0.91	0.16	0.15	4.77
Boudine harzburgite	40.49	1.89	7.83	32.19	0.46	0.17	0.09	0.06	0.00	0.23	16.03
Gabbro	49.30	14.87	10.1	7.39	9.61	3.11	0.44	1.04	0.20	0.17	3.77
Granite	69.21	14.41	3.65	1.15	2.19	3.48	4.23	0.41	0.30	0.12	0.85
Greenschist	57.64	17.30	7.48	3.27	1.83	2.17	1.19	0.91	0.05	0.13	8.01
Lherzolite	47.73	12.58	9.49	15.06	7.50	3.50	0.18	0.91	0.14	0.15	2.76
Olivine-rich Lherzolite	43.54	3.99	12.35	34.02	3.46	0.56	0.25	0.81	0.76	0.21	0.05
Olivine-websterite SSC	39.34	1.32	9.02	33.31	3.49	0.26	0.01	0.02	0.01	0.13	14.50
Lherzolite SSC	40.57	1.12	7.66	34.36	0.84	0.16	0.01	0.02	0.01	0.13	14.40
Lherzolite SSC	41.73	0.86	9.01	33.40	1.38	0.27	0.01	0.06	0.02	0.11	13.30
Hazburgite SSC	42.47	1.67	7.97	35.34	0.30	0.20	0.09	0.09	0.01	0.15	12.80
Limestones	7.22	1.64	1.02	1.18	48.37	0.67	0.23	0.06	0.03	0.01	39.90
Limonite	7.40	9.19	22.44	0.83	0.16	0.11	0.15	0.01	0.01	2.29	57.17
Limonite	24.96	20.55	29.51	1.13	0.35	0.13	0.14	0.43	0.03	0.06	20.99
Limonite	30.77	16.43	29.5	4.33	0.72	0.14	0.17	0.56	0.03	0.47	15.64
Limonite	39.30	26.68	7.60	0.61	0.71	0.33	0.73	0.96	0.10	0.35	22.63
Limonite	39.74	25.00	7.73	0.32	0.45	0.78	0.92	0.59	0.06	0.23	24.18
Limonite	57.01	21.4	5.68	0.30	1.26	0.24	0.56	1.08	0.02	0.06	12.37
Magnesite Los Mariscos	1.58	0.07	0.48	35.90	5.07	0.23	0.01	0.01	0.01	0.05	48.20
Mottled Zone	73.80	10.07	5.80	1.16	0.87	0.62	1.39	0.53	0.01	0.15	5.53
Mylonite of lherzolite	44.01	1.67	7.80	30.67	1.11	0.14	0.14	0.05	0.003	0.129	12.60
Lherzolite	42.00	1.41	8.46	31.60	0.84	0.17	0.03	0.03	0.01	0.14	16.20
Olvine websterite	42.82	1.52	9.89	31.59	1.05	0.28	0.17	0.02	0.0009	0.167	8.80
Hazburgite Cahabonsito	41.70	1.57	8.41	31.28	0.65	0.19	0.04	0.04	0.01	0.13	16.40
Lherzolite Los Mariscos	42.29	1.25	8.50	31.92	1.03	0.14	0.01	0.02	0.01	0.15	16.00
Oxidated greenschist	65.68	13.75	6.73	2.40	0.86	1.11	2.64	0.85	0.15	0.07	5.74
Rhyolite	65.56	12.08	1.08	1.56	4.56	0.45	0.29	0.10	0.02	0.01	16.90

Rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	LOI
Rhyolite	72.80	13.49	2.33	0.38	1.20	3.38	4.46	0.33	0.08	0.08	0.00
Si-Fe hydrothermal cap	95.70	0.32	3.61	0.30	0.81	0.21	0.03	0.02	0.10	0.51	2.10
Lherzolite	39.41	1.22	7.34	33.66	1.11	0.13	0.14	0.03	0.01	0.14	16.47
Lherzolite	42.38	1.09	6.42	34.21	1.57	0.12	0.15	0.06	0.00	0.10	13.54
Hazburgite	43.11	1.79	6.91	34.05	0.35	0.16	0.17	0.06	0.01	0.16	12.78
Olivine-rich lherzolite	51.12	1.10	7.97	34.49	1.25	0.24	0.03	0.04	0.01	0.12	3.63
Lherzolite Cahabonsito	40.53	0.51	7.30	35.89	1.46	0.30	0.02	0.01	0.01	0.11	15.20
Hazburgite Los Mariscos	42.07	1.13	6.86	34.66	0.06	0.23	0.02	0.02	0.01	0.10	15.20
White clay	63.32	16.28	6.12	1.97	0.28	0.45	2.67	0.93	0.016	0.037	10.10
Andesite	58.45	15.7	8.27	3.59	2.06	1.07	2.36	0.79	0.10	0.09	11.90
Olivine basalt	7.22	1.64	1.02	1.18	48.37	0.67	0.23	0.06	0.03	0.01	39.90
Dacite	65.56	12.08	1.08	1.56	4.56	0.45	0.29	0.10	0.02	0.01	16.90
Olivine- clinopyroxene	33.58	4.48	5.28	5.65	23.78	0.92	0.27	0.20	0.04	0.07	26.60
Picrobasalt	41.94	6.17	7.10	7.84	13.51	0.94	0.36	0.28	0.03	0.07	22.00
Trachybasalt	12.32	1.74	1.56	1.58	45.36	0.77	0.10	0.06	0.03	0.08	37.50
Alkaline-rhyolite	95.70	0.32	3.61	0.30	0.81	0.21	0.03	0.02	0.10	0.51	2.10
Dacite	63.15	15.38	6.32	2.38	0.66	0.44	1.65	0.82	0.02	0.02	12.70
Lherzolite	40.53	0.51	7.30	35.89	1.46	0.30	0.02	0.01	0.01	0.11	15.20
Hazburgite	41.70	1.57	8.41	31.28	0.65	0.19	0.04	0.04	0.01	0.13	16.40
Lherzolite	40.57	1.12	7.66	34.36	0.84	0.16	0.01	0.02	0.01	0.13	14.40
Olivine- websterite	39.34	1.32	9.02	33.31	3.49	0.26	0.01	0.02	0.01	0.13	14.50
Hazburgite	42.07	1.13	6.86	34.66	0.06	0.23	0.02	0.02	0.01	0.10	15.20
Magnesite	1.58	0.07	0.48	35.90	5.07	0.23	0.01	0.01	0.01	0.05	48.20
Lherzolite	42.29	1.25	8.50	31.92	1.03	0.14	0.01	0.02	0.01	0.15	16.00
Hazburgite	42.47	1.67	7.97	35.34	0.30	0.20	0.09	0.09	0.01	0.15	12.80
Olivine- websterite	41.73	0.86	9.01	33.4	1.38	0.27	0.01	0.06	0.02	0.11	13.30
GUA4	49.53	13.01	11.76	9.36	9.10	2.49	0.10	1.47	0.19	0.19	2.79
GUA18	50.08	15.79	9.53	6.28	7.30	3.65	1.65	1.45	0.15	0.17	3.94
GUA38	47.57	16.10	10.26	8.37	12.02	2.17	0.08	1.36	0.20	0.16	1.73
GUA42A	46.73	19.23	5.87	7.93	8.26	4.72	0.09	0.68	0.07	0.10	6.33
GUA42B	39.21	18.67	12.32	12.88	6.31	2.29	0.42	1.30	0.10	0.15	6.35
GUA44	48.09	13.08	11.27	9.69	10.11	2.58	0.20	1.58	0.18	0.16	3.06
GUA45A	44.73	18.42	9.25	10.47	6.25	3.40	0.02	0.84	0.06	0.18	6.38
GUA47	43.23	15.26	10.22	6.50	9.30	4.88	0.08	2.55	0.65	0.23	7.10
GUA73	43.35	20.38	7.32	11.55	9.04	2.70	0.19	0.73	0.13	0.11	4.51
GUA74	46.86	15.89	10.29	7.87	9.90	3.45	0.26	1.28	0.21	0.16	3.83
GUA75	44.08	20.66	8.90	4.67	9.65	2.74	2.40	0.93	0.40	0.07	5.50

Rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	LOI
GUA76	50.37	15.53	8.75	5.27	9.43	4.55	0.42	2.02	0.28	0.16	3.21
GUA77	43.70	16.96	10.90	8.39	10.56	2.99	0.09	1.40	0.26	0.16	4.60
GUA79	88.00	2.12	1.51	1.03	2.30	1.16	0.17	0.17	0.00	0.09	3.43
GUA8	42.59	12.93	13.95	12.33	12.24	1.88	0.33	1.32	0.34	0.22	1.87
GUA82	40.70	10.67	15.99	11.54	13.04	2.39	0.69	2.50	1.07	0.24	1.17
GUA83	48.11	13.35	13.03	7.56	9.81	4.54	0.42	1.91	0.31	0.16	0.81
GUA48	42.21	1.54	7.16	37.36	0.04	0.00	0.00	0.02	0.00	0.10	11.59
GUA81	50.62	10.56	8.37	2.95	18.73	0.00	0.02	1.02	0.34	0.15	7.25
GUA36	49.96	16.10	9.73	6.04	8.21	5.56	0.22	1.10	0.16	0.14	2.79
GUA51	49.48	16.21	9.55	7.80	9.63	3.04	0.84	0.93	0.12	0.16	2.24
GUA52	52.16	17.38	9.81	4.29	6.26	5.16	1.20	1.10	0.34	0.16	2.11
GUA53	51.21	17.91	10.5	4.01	5.99	5.21	1.44	1.08	0.35	0.16	2.15
GUA64	46.03	16.14	9.44	10.13	7.89	3.58	0.18	0.86	0.16	0.15	5.45
GUA65	47.00	15.53	10.45	9.35	9.33	3.46	0.09	1.05	0.19	0.16	3.40
GUA66	50.42	15.32	10.23	7.34	9.49	3.66	0.22	0.87	0.17	0.15	2.13
GUA67	48.30	15.53	9.00	10.84	8.43	2.78	0.69	0.84	0.14	0.15	3.30
GUA68	47.77	14.63	9.75	8.86	7.97	3.06	0.66	0.95	0.16	0.16	6.03
GUA69	47.78	17.86	11.63	5.67	7.28	4.16	0.77	1.26	0.46	0.19	2.96
GUA20	49.23	13.86	9.35	12.59	7.41	3.17	0.21	0.38	0.05	0.22	3.53
GUA21	48.60	15.43	9.17	9.43	7.46	4.39	0.04	1.03	0.10	0.11	4.24
GUA22	47.74	15.38	8.47	8.15	11.86	3.27	0.14	0.93	0.14	0.14	3.78
GUA23	49.79	16.76	7.95	6.76	7.51	6.17	0.35	0.89	0.15	0.12	3.54
GUA24	39.66	0.62	7.31	39.77	0.23	0.00	0.00	0.01	0.00	0.11	12.29
GUA25	46.86	20.03	8.73	8.98	11.65	1.32	0.12	0.07	0.06	0.15	2.03
GUA32	49.29	15.63	9.17	8.36	12.30	2.47	0.08	0.77	0.12	0.14	1.66
GUA33	39.27	0.47	7.52	40.81	1.450	0.00	0.00	0.00	0.00	0.10	10.37
GUA57	55.83	12.72	8.96	4.29	6.59	3.06	0.81	0.78	0.18	0.38	6.40
GUA58	50.30	15.13	13.00	5.10	6.14	2.70	1.19	1.07	0.18	0.35	4.85
GUA59	44.63	19.40	8.64	10.52	12.93	0.86	0.17	0.06	0.11	0.13	2.55
GUA60	44.96	19.33	8.46	10.83	13.03	1.14	0.15	0.04	0.12	0.12	1.82
GUA61	45.41	17.88	9.58	10.86	7.12	3.00	0.08	0.90	0.14	0.12	4.91
GUA62	46.89	16.23	8.80	11.22	5.87	3.48	0.02	0.88	0.11	0.12	6.38
GUA63	48.83	16.45	8.87	10.08	6.76	4.36	0.02	0.99	0.14	0.12	3.39
GUA49	42.63	0.73	8.43	42.54	1.16	0.00	0.01	0.01	0.00	0.12	4.39
GUA50	41.35	1.27	7.13	38.29	0.02	0.00	0.00	0.03	0.00	0.09	11.81
GU-01	49.69	0.03	1.8	1.9	0.1	33.16	0.21	0.01	0.01	0.01	13.08
GU-02	47.55	0.01	1.25	2.36	0.08	34.82	0.05	0.01	0	0.01	13.86
GU-03	48.75	0.01	0.77	2.7	0.09	33.16	0.09	0.01	0.01	0.01	14.4

Rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	LOI
GU-04	49.77	0.03	1.53	1.98	0.08	33.16	0.18	0.01	0.01	0.01	13.24
GU-05	78.29	0.62	2.83	1.86	0.15	1.99	0.9	0.11	0.09	0.13	13.03
GU-06	55.14	0.02	1.38	3.17	0.21	24.87	0.03	0.01	0	0.01	15.16
GU-07	55.5	0.01	0.66	2.07	0.07	28.18	0.11	0	0	0.01	13.39
GU-08	88.73	0	0.14	0.03	0.04	0.04	0.9	0	0	0.05	10.07
GU-09	58.12	0.01	2.08	2.79	0.23	21.55	0.63	0.01	0.01	0.01	14.56
GU-10	50.23	0	0.21	2.36	0.09	33.16	0.06	0.01	0.01	0.01	13.86
GU-11	44.98	0	0.19	2.45	0.1	38.13	0.14	0	0	0.01	14
GU-12	44.44	0.01	0.87	2.28	0.09	38.13	0.45	0	0	0.01	13.72
GU-13	67.71	0.03	0.98	2.75	0.07	13.93	0.04	0.01	0.01	0.01	14.46
GU-14	69.18	0.55	6.05	2.45	0.13	4.31	2.38	0.12	0.11	0.73	13.99
GU-15	86.34	0.12	1.02	0.55	0.05	0.56	0.21	0.11	0.1	0.03	10.91
GU-17	49.75	0.02	1.12	2.11	0.09	33.16	0.29	0	0	0.01	13.45
GU-18	83.74	0.18	1.78	0.93	0.09	0.99	0.49	0.06	0.05	0.18	11.51
GU-19	44.97	0.01	0.89	2.7	0.08	36.47	0.45	0	0	0.01	14.42
GU-20	81.9	0.02	1.08	2.11	0.05	1.34	0.04	0	0	0.01	13.45
GU-21	58.38	0.01	0.36	3	0.1	23.21	0.04	0	0	0.01	14.89
GU-22	40.22	0	0.04	1.82	0.07	44.76	0.1	0.01	0.01	0.01	12.96

THE HUEHUETENANGO OPHIOLITIC BELT

This belt seems to be the oldest one in Guatemala as well as the best representation of a truly ophiolitic belt with a well developed greenschist zone (Fig. 59), pillowed basalts (Fig. 60), sheeted dikes (Fig. 61), and the presence of cumulate gabbros. Petrologically, it is similar to the Baja Verapaz unit, being composed mainly of pyroxenites (olivine-rich lherzolite/lherzolite/websterite) that are serpentinized (Fig. 62) and are very eroded (Fig 63).

The Huehuetenango unit (HUE) clearly overthrusts onto the Paleozoic metasediments of the Chuacús Series within the Maya block. To the present only one potential laterite pocket has being identified in the area (Fig 64).

Figure 59. Greenschist facies of the Huehuetenango ophiolitic complex.

Figure 60. Pillowed basalts from the Huehuetenango ophiolitic complex.

Figure 61. Basaltic sheeted dike from the Huehuetenango ophiolitic complex.

Figure 62. Strongly serpentinized pyroxenite from the Huehuetenango ophiolitic complex.

Figure 63. The Huehuetenango ophiolitic complex is eroded in a very similar pattern of the North and South Motagua ophiolitic belts, forming these characteristic triangles.

Figure 64. Laterite pocket along an access road at Huehuetenango ophiolitic complex.

Figure 65 shows the REE composition of this ophiolitic complex.

Figure 65. REE distribution on samples from the Huehuetenango ophiolitic complex.

A section of the geological map 1:1 000 000 showing the regional geology of this complex (Fig. 66) and a model of its geological evolution follow (Fig. 67).

Figure 66. Regional geology of the Huehuetenango ophiolitic belt (Pi), from the regional geological map of Guatemala, scale 1:1 000 000. See legend on Figure 11 on page 27.

Figure 67. Geological model of the evolution of the Huehuetenango ophiolitic belt.

PETROLOGIC CLASSIFICATIONS OF OPHIOLITES

Ophiolites may have formed either at divergent plate boundaries (mid-oceanic ridges) or at convergent plate boundaries (supra-subduction zones; i.e. island arcs and marginal basins). They are called MOR and SSZ types, respectively. These types are identified by chemical composition of the rocks and minerals in comparison with those from various tectonic settings on the earth at present.

Ophiolitic mantle peridotite is the refractory residue after extraction of basaltic melt through partial melting processes in the mantle. Although primary mantle peridotite may be lherzolite with abundant clinopyroxene, it changes into clinopyroxene-poor (or -free) harzburgite as the degree of melting increases (Fig. 68). The mantle peridotite samples dredged from the mid-oceanic ridges are mostly lherzolite, while those dredged from supra-subduction zones (trench walls) are mostly harzburgite.

Figure 68. Modal variation of residual mantle peridotite with increasing degree of melting.

In Guatemala, only the South and North Motagua ophiolitic belts are classified as harzburgites (trench wall), while the rest are intrusives alternating dunite, olivine-rich lherzolites; normal lherzolites and olivine websterites more typical of an Island Arc environment.

Ophiolitic igneous cumulates show systematic variation in the crystallization sequence of minerals corresponding to the petrologic diversity of the underlying peridotite mantle. The mineral crystallizing next to olivine typically varies from plagioclase through clinopyroxene to orthopyroxene as the degree of melting in the underlying mantle increases (Fig. 69). The characteristic cumulate rocks correspondingly vary from wehrlite to harzburgite.

In general, ophiolitic basalt also varies from alkali basalt or high-alumina basalt (like mid-ocean ridge basalt (MORB)) through low-alumina basalt (like island-arc tholeiite (IAT)) to boninite (high-magnesia andesite) in correspondence with the petrologic variation of the underlying members.

Petrologic Type of Ophiolite	Liguria (Poroshiri)	Yakuno	Papua (Horokanai)
Basaltic Volcanics and dikes	Alkali Basalt MORB	MORB Arc Tholeiite	Arc Tholeiite Boninite
Mafic-Ultramafic Cumulates	↑ Cpx PI Ol	↑ Opx, PI Cpx Ol	↑ Cpx, PI Opx Ol
Residual Mantle Peridotite	Lherzolite	Cpx-bearing Harzburgite	Cpx-free Harzburgite
	————— degree of mantle melting —————→		
Examples	Alps Trinity Bay of Islands	Oman Vourinos Troodos	Adamsfield Gora Krasnaya

Figure 69. Systematic variations of the ophiolitic igneous cumulates.

The Guatemalan ophiolitic belts are characterized by extreme petrologic diversity. Juxtaposition of olivine- depleted websterites and olivine-rich Lherzolites is common for the youngest belts. The absence of plagioclase is also common among these rocks.

OPHIOLITIC PHASES

The following petrologic assemblages are usually associated with an ophiolitic profile (Fig. 70).

Figure 70. Representation of the ocean crust. The seismic structure (from seismic experiments) is combined with the lithology of ophiolites.

The Pillow Basalt Layer (PBL) is well represented in some ophiolitic belts in Guatemala, while it is absent (or I have not yet found them) in others. The best example of the PLB can be found associated to the Huehuetenango ophiolitic belt (Fig. 71). Pillow lavas can be also found associated to the North Motagua ophiolitic belt (Fig. 39).

Figure 71. Outcrop of pillow basalts of the Huehuetenango ophiolitic belt.

According to the established model (Fig. 72), we can find VMS type of deposits associated to the PBL. The Sierra de Santa Cruz ophiolitic belt hosts such type of deposit, the Cyprus type copper deposit of Oxec.

Figure 72. Schematic ophiolitic complex.

The Sheeted Dike Layer (SDL) is best represented again at the Huehuetenango ophiolitic belt (Fig. 73). The unit consists of 100% dikes with no intervening screens of other rocks. Possibly related to the underlying gabbros, they are not derived directly from them.

Figure 73. The sheeted dike layer of the Huehuetenango ophiolitic belt.

The Cumulate Gabbro Layers (CGL) are generally mafic at the base and grade upward to more feldspathic rocks. Olivine becomes progressively more iron-rich, reaching Fo70 in the uppermost gabbros. Orthopyroxene is present but far less abundant than in the underlying deformed ultramafic rocks. Diopside augite is the principal pyroxene. Toward the top of the layered gabbros, irregular intrusive bodies of plagiogranites occur. These are thought to be the final differentiation product of the gabbroic magma, which gave rise to layered rocks (Fig. 74).

Figure 74. Plagiogranites associated to the south Motagua ophiolitic complex near Jalapa, Guatemala.

In Guatemala we have found cumulate gabbros only near the River Cahabón and the road to Bongo village within the Sierra de Santa Cruz ophiolitic belt (Fig. 53).

Figure 75. Leucocratic gabbro at Sierra de Santa Cruz ophiolitic belt on the road to Benque village.

The Ultramafic Cumulate Layers (UCL) are usually located below the lowest layered mafic, the transition to the harzburgitic mantle section, and are usually marked by the occurrence of plastically deformed dunites. The deformation, which is characteristic of the underlying harzburgite, dies out in this transition zone (Fig. 76). In terms of mineral composition, the mafic-ultramafic transition is smoothed by the presence of ultramafic layers, gabbro dikes, sills and impregnations in the dunites and the uppermost harzburgites. The amount of clinopyroxene and plagioclase increase upward through the zone. Thus, dunite (olv) at the base passes up through wherlite (olv+cpx) to clinopyroxenite and troctolite (plag+olv). With the decrease in the amount of olivine, then, the degree of deformation decreases.

Figure 76. Plastically deformed harzburgites from the North Motagua ophiolitic belt.

The Metamorphic Envelope (ME). These are dynamometamorphic rocks welded to the base of ophiolites (metamorphic soles or dynamothermal aureoles). They are generally believed to have formed during detachment and/or emplacement of oceanic lithosphere into orogenic belts. The rocks found here range from mylonitic peridotites to garnet amphibolites, epidote amphibolites, and greenschists. In Guatemala we find greenschist facies associated to all ophiolitic belts (Figs. 77 - 78), garnet amphibolites associated to the North Motagua ophiolitic belt (Fig 79), and the best example of mylonitization can be found at the Juan de Paz – Los Mariscos ophiolitic belt (Fig. 80).

Figure 77. Greenschist facies at Huehuetenango ophiolitic belt.

Figure 78. Greenschist facies of the South Motagua ophiolitic belt.

Figure 79. Garnet amphibolites associated with the North Motagua ophiolitic belt.

Figure 80. Zone of intense mylonitization at the Juan de Paz - Los Mariscos ophiolitic belt.

OPHIOLITIC AGES

Reported formation ages of ophiolites show three distinct peaks at about 750, 450 and 150 Ma, respectively (Fig. 81). These are called ophiolite pulses. Each pulse corresponds to the period of worldwide magmatic event as represented by voluminous granite intrusions. Production rate of oceanic crust was distinctly high during the 80 and 120 Ma interval of Cretaceous time, as evidenced by wide area of the ocean floor formed in this interval. This interval corresponds to the later half of the Mesozoic ophiolite pulse.

Figure 81. Ophiolitic "pulses" in Earth's history.

Age determinations from micas from the ultramafic rocks from the North Motagua and the Juan de Paz – Los Mariscos ophiolitic complexes have shown ages varying in a west-east direction towards younger rocks (Fig. 82). The same trend is observed in Cuba. Following the same logic I expect the Huehuetenango ophiolitic complex to be older than the Baja Verapaz complex, and in turn older than the Sierra de Santa Cruz ophiolitic complex at the eastern end of the Polochic Fault.

Figure 82. Age determinations of the ophiolites within the Caribbean Plate according to Harlow, E.G. et al., 2004.

OPHIOLITES AROUND THE WORLD

Ophiolites issued by each pulse tend to form a particular ophiolite belt. Late Proterozoic (ca. 750 Ma) ophiolites are distributed in the Pan-African orogenic belt, early Paleozoic (ca. 450 Ma) ophiolites appear in the Appalachian-Caledonian-Uralian belt, and Mesozoic (ca. 150 Ma) ophiolites dominate the Alpine-Himalayan belt (Fig. 83).

Figure 83. Distribution of ophiolitic belts.

It is interesting to note that within Guatemala we could have had the development of two pulses of ophiolites: older ones related to the Circum-Pacific Phanerozoic belt and younger ones from the Alpine-Himalayan Mesozoic pulse. This could explain the older age of the Huehuetenango and of the North and South Motagua ophiolitic complexes.

For this comparison, I will introduce three models of Alaskan ophiolitic belts that could be used as general models for the ophiolitic belts of Guatemala.

THE NORTH AND SOUTH MOTAGUA OPHIOLITIC COMPLEX

It is my working theory, that the oldest ophiolitic complexes in Guatemala are represented by the North and South Motagua complexes within the Central Sector. They outcrop as narrow belts along the Motagua and Cabañas faults within the Motagua valley. Both ophiolitic belts consist of high pressure - low temperature (HP-LT) metamorphosed and serpentinized mantle harzburgites and foliated gabbros, followed by a thick basaltic pillow lava sequence (Fig. 84) showing mid-ocean ridge affinity of El Tambor Group (Beccaluva et al., 1995). They are both unconformably overlain by the Eocene continental flischoid polymictic sandstones and conglomerates of the Subinal Fm (Fig. 85).

Figure 84. Pillowed basalts from the south Motagua ophiolitic complex.

Figure 85. Flischoid polymictic sandstones and conglomerates of the Paleocene Subinal Fm. crops out between kms. 146-151 of the CA 9 road in Guatemala.

The SM unit overthrusts the Paleozoic continental basement (Las Ovejas Group) of the Chortis block, while the NM unit overthrusts the Paleozoic metamorphic terraines (Chuacús Series) of the Sierra de Chuacús and Sierra de Las Minas.

The petrographic analysis of a group of samples from these belts shows that the most probable magmatic event was the partial melting process (Valls, unpublished) as shown in Fig. 43.

Figure 86 shows a comparison between the Motagua ophiolitic complexes to the Union Bay ultramafic complex from Alaska. We can observe a general similarity in the zonal distribution of the more olivine rich rocks towards the centre of the complex, surrounded in a metamorphic envelope of greenschists.

Figure 86. Comparing the Motagua complexes to the Union Bay ultramafic complex from Alaska.

THE JUAN DE PAZ - LOS MARISCOS OPHIOLITIC COMPLEX

The Juan de Paz – Los Mariscos ophiolitic belt (JPZ) is composed of usually serpentinized lherzolites and websterites, layered gabbros, dolerites, basalt, and scarce andesites (Fig. 87).

Figure 87. Incipient budinage on the lherzolites of the Juan de Paz - Los Mariscos ophiolitic complex.

It has been interpreted by Beccaluva et al. (1995) as island-arc magmatic sequences associated with sub-arc mantle rocks. This unit overthrusts the Paleozoic metamorphic basement (Chuacús Series) of the Sierra Las Minas and Montañas del Mico. The JPZ complex is usually covered by mafic volcanoclastics and andesitic breccias, passing upwards to carbonated breccias and calcarenites, with sandstone and microconglomerates containing felsic volcanic fragments of the Late Cretaceous Cerro Tipón Fm.

The JPZ complex is less metamorphosed than the Motagua complexes and shows more budinage than the other complexes. It also shows effects of post-hydrothermal alteration, like the formation of botryoidal masses of magnesite (Fig. 51).

The irregular pattern of the Rb:Ni ratio in samples from the JPZ ophiolitic complex indicates the possibility of later mixing event, which was confirmed by the La/Sr vs. 1/La ratio (Fig. 52).

Figure 88 shows a transverse comparison between The Juan de Paz – Los Mariscos and Sierra de Santa Cruz ophiolitic complexes with the Goodnews Belt ultramafic complex in Alaska.

Figure 88. The cross section of the Goodnews Bay ultramafic complex compares well to a N-S section across the Lake Izabal and the Juan de Paz - Los Mariscos and the Sierra de Santa Cruz ophiolitic belts.

THE SIERRA DE SANTA CRUZ OPHIOLITIC COMPLEX

This complex appears to be the least metamorphosed in the Motagua sector. Petrologically it is similar to the JPZ complex, being composed mainly of a juxtaposition of olivine-rich lherzolites and dunites with olivine-rich websterites and normal lherzolites with scarce cumulate gabbros and very few basaltic dykes or other volcanic rocks. All known Guatemalan lateritic deposits and most of the new targets are located within this complex.

THE SECHOL UNIT

The Blashke Islands complex with its circular structures is very similar to the Sechol unit within the Sierra de Santa Cruz ophiolitic complex (Figs. 89 - 90).

Figure 89. Circular structures at Sechol unit within the Sierra de Santa Cruz complex.

Figure 90. Circular structures at Blashke Islands complex in Alaska.

Once the general characteristics of the ophiolitic complexes have been introduced, I would like to present in more detail one of the most important geological processes in the formation of lateritic deposits - the serpentinization of these rocks.

PRODUCTS OF SERPENTINIZATION

Serpentinization requires large amounts of water ranging from 9% for a websterite, 15% for a lherzolite, and up to 19% for a dunite. The serpentinization is triggered by the percolation of sea water into the rocks and it also triggers an increase in the volume of the ultramafic rocks. The resulting stress could be an obduction/displacement mechanism within the ultramafic belt.

The final product of the serpentinization of an ultramafic intrusive depends on the petrology of the initial rock. Table 2 summarizes these products.

Table 2. Results of the serpentinization of ultramafic rocks.

Original petrology	Name of the rock	Water, %	Results of the serpentinization	Observations
Olivine (Forsterite)	Dunite	19	Serpentinite and brucite	Québec (Lac Chrysotile, See eq. 1)
Olivine + clinopyroxene	Peridotite (Lherzolite)	15	Serpentinite	Guatemala (See eq. 2)
Olivine + Ortho and clinopyroxene	Pyroxenite (Websterite)	9	Serpentinite and talc	Guatemala (See eq. 3)

Equation 1. Serpentinization of dunites (Dunites, Olivine-rich Lherzolites).

Equation 2. Serpentinization of peridotites (Lherzolites).

Equation 3. Serpentinization of pyroxenites (Websterites).

Table 3 and Fig. 91 show the systematic used in naming these ultramafic rocks.

Table 3. Field name equivalents for ultramafic rocks in Guatemala.

Field Name	Proper Name	Observation
“Dunite”	Dunite or Olivine-rich Lherzolite	Fig. 92
“Peridotite”	Lherzolite	Fig. 93
“Pyroxenite”	Olivine-rich Websterite	Fig. 94

Names of Ultramafic Rocks				
Field Names		Olivine, %	Composition	Name
Dunite		85 - 100	Olivine	Dunite
Peridotite	Olivine Peridotite	70 - 85	Olv + OPX	Harzburgite
	Peridotite	30 - 70	Olv + CPX	Werlite
Pyroxenite			Olv + OPX + CPX	Lherzolite
	Olivine Pyroxenite	10 - 30	Olv + CPX	Olivine Clinopyroxenite
			Olv + OPX	Olivine Orthopyroxenite
			CPX	Clino-pyroxenite
	Pyroxenite	0 - 10	OPX	Ortho-pyroxenite
			CPX + OPX	Websterite

Figure 91. Systematics of the ultramafic rocks used during the exploration of ophiolitic belts in Guatemala.

Figure 92. Olivine-rich lherzolite (field name "dunite") showing the characteristic alteration rim that helps its easy identification.

Figure 93. Normal lherzolite (field name "peridotite"). These rocks usually have a very limited lateritic development on top of them.

Figure 94. Olivine-websterite (field name “Pyroxenite”), with no presence of weathering.

If pentlandite or any other nickel sulfide is present during the serpentinization, then we can get the formation of awaruite and pyrite (see equation 4), as it has been found on some rocks from the Sierra de Santa Cruz ophiolitic complex (Fig. 96).

Equation 4. Formation of awaruite and pyrite from the serpentinization of pentlandite.

The variably altered ultramafic rocks were classified on the basis of their original mineralogy (prior to alteration), using the Streckeisen's ternary diagram (Fig. 95).

Figure 95. Streckeisen's ternary diagram used in the classification of the rocks.

Based on their primary mineralogy, the ultramafic rocks are classified as Dunite, Olivine-rich Lherzolite, Lherzolite, Harzburgites, and Olivine-rich Websterite. Both, primary and secondary minerals in the present suite of samples are remarkably similar (including the Ni-bearing phases), with the exception of the saprock. Due to these similarities, and to similarities in the type and degree of alteration, the lack of variation in the nature and concentration of Ni-bearing minerals between samples is not surprising. Alteration ranges from 20% to 50%, excluding the saprock, where alteration is 100%.

Most of the rocks from the SSC and the JPZ complexes contained Ni-bearing minerals in the form of Ni-Fe alloys (Awarite), sulfides (pentlandite, millerite), silicates (serpentine) and oxides (goethite). These minerals were identified as the major Ni-bearing minerals by electron microprobe.

Olivine, serpentine and selected magnetite-hematite were analyzed in the altered ultramafic rocks for NiO. The NiO content of olivine plays an important part in estimating the potential of an ultramafic body for hosting a Ni-laterite deposit. As it was expected, olivine has the highest NiO content in the dunite and serpentine has the highest NiO content in partly serpentinized and oxidized lherzolites and dunites. Most of the Ni in the magnetite and altered chromite, as well as sulphides and awarite are from rocks from the Sierra de Santa Cruz and the Juan de Paz – Los Mariscos complexes.

The ultramafic rocks are variably serpentinized and some are oxidized. According to the study completed by Dr. Schandl (2005) there were two episodes of serpentinization that are recorded by some of the rocks. During the first event, mesh rim lizardite and hourglass lizardite replaced olivine, and bastite replaced the orthopyroxene. A few small lizardite veins also crystallized during this early episode. Subsequent, second event of serpentinization at somewhat higher temperatures was associated with tectonism. This later event resulted in the deformation of early serpentine veinlets, the deformation of bastite (after orthopyroxene) and the partial recrystallization of mesh lizardite serpentine to antigorite. Large serpentine veins that cross-cut the rock fabric also crystallized during this later episode.

Awaruite (Fig. 96) occur as minute discrete grains, on the partially serpentinized rim of olivine, as inclusions in magnetite within the Lherzolite, and the Olivine-rich Websterite.

Figure 96. Creamy white awarutite (Ni-Fe alloy) and fine grained pentlandite are included in magnetite in this olivine websterite (peridotite).

Pentlandite was identified in almost all rocks. Most pentlandite grains occur as inclusions in magnetite, as rims on magnetite or they are intergrown with magnetite (Fig. 97). Some serpentine veinlets contain free pentlandite grains. The NiO concentration in serpentine varies between 0.28 to 1.75 wt%. Goethite in the saprock contains 0.7 wt% NiO (Fig. 98).

Figure 97. Olivine is partially replaced by magnetite and magnetite is rimmed by awaruite and pentlandite.

Figure 98. Goethite (white) in a 100% weathered saprock.

As the initial stage of serpentinization provides a favorable (reducing) environment for the precipitation of native metals, it is not surprising that awaruite and native Cu are present in the partly serpentinized rocks (Fig. 99).

Figure 99. Free awaruite in a serpentine vein filling a fracture in a Lherzolite.

The crystallization of the metals was contemporaneous with the initial stage of serpentinization. This is evident from the close relationship between magnetite, which crystallized during the breakdown of olivine to serpentine and the native metals. The Ni released from the olivine was incorporated into Ni-Fe alloys. Because some of the orthopyroxene and unserpentinized olivine contain inclusions of pentlandite, the origin of at least some of the sulfides was probably magmatic.

Subsequent oxidation of magnetite resulted in the release of pentlandite and awaruite inclusions from the magnetite. Therefore, free pentlandite and free awaruite are more common in the oxidized (and previously serpentinized) rocks, than in the lesser oxidized rocks where magnetite is preserved.

Oxidation of some of the serpentinized rocks resulted in the partial breakdown of magnetite and the Ni-rich metals, incorporating Ni into serpentine that originally contained the awaruite and pentlandite-bearing magnetite.

The following selection of petrological descriptions are based on a study completed by University of Toronto specialist Dr. Eva E. Schandl of several samples from the Guatemalan ophiolitic belts (Schandl, 2005).

OLIVINE-RICH LHERZOLITE

Sample number: 59068; UTM: 800164E 1682852N

Estimated mineralogy of the original rock prior to serpentinization: 70% olivine, 20% orthopyroxene, 10% clinopyroxene + chrome spinel.

The rock consists predominantly of olivine, lesser clinopyroxene, orthopyroxene, serpentine and some Cr-spinel (Fig. 100). Coarse grained. Olivine is fragmented and granulated and the fragmented grains are cross-cut by narrow serpentine veinlets. The pyroxenes (ortho and clino) are partly serpentinized and some contain olivine inclusions. Fine-grained magnetite that crystallized from the breakdown of olivine and the pyroxenes, is variably oxidized and occur as fine-grained narrow seams. Granulation of the rock is apparent from the presence of fine-grained, anhedral, granulated, and unserpentinized olivine aggregates which formed from the partial breakdown of the larger grains. Serpentine also occurs as massive veins that cross-cut the rock fabric, and contain minute, anhedral magnetite. The pyroxenes are partly or completely replaced by lizardite bastite, and olivine contains fracture-filling lizardite veinlets.

Figure 100. Serpentinized olivine with black (oxidized) magnetite veins. Width of the photo: 4 mm Crossed Nichols.

LHERZOLITE

Sample number: 59070; UTM: 800164E 1682852N

Estimated mineralogy of the original rock was: 55% olivine, 35% orthopyroxene, 10% clinopyroxene + chrome spinel.

Partially serpentinized, fragmented olivine, fractured and deformed orthopyroxene and clinopyroxene make up the rock. Coarse grained. Mesh texture lizardite (serpentine) is Fe-stained and serpentine veins that cross-cut the rock fabric contains fine-grained, partly oxidized magnetite seams in the center. Coarse-grained orthopyroxene with exsolution lamellae show evidence of extensive deformation, as the lamellae are strongly deformed, fractured, and the fractures are filled by fine-grained granular secondary clinopyroxene within the serpentine veins (Fig. 101).

Figure 101. Large deformed orthopyroxene (with exsolution lamillae) cut by serpentine and small clinopyroxene veinlets. Width of the photo: 4 mm. Crossed Nichols.

OLIVINE-RICH WEBSTERITE

Sample number: 59076; UTM: 798951E 1684986N

Estimated mineralogy of the original rock was: 35% olivine, 40% orthopyroxene, 25% clinopyroxene + chrome spinel.

The protolith is difficult to determine, due to the oxidation of serpentinized grains (which destroyed the diagnostic birefringence of the minerals) and the oxidation of serpentine. Relict orthopyroxenes are partly altered to bastite and mesh texture serpentine completely replaced what may have been originally olivine (Fig. 102). Orthopyroxene with narrow exsolution lamellae predominates over clinopyroxene in the rock. Two serpentine generations were identified; the first generation is the replacement mesh lizardite after olivine and bastite after the pyroxenes, and the second generation serpentine is represented by cross-cutting veinlets consisting of nickeliferous (up to 1.59% NiO) spherulitic serpentine. These veins are rimmed by Ni-free serpentine.

Figure 102. Bastite (yellow-orange) replaces orthopyroxene on this olivine-websterite. Width of photo: 4 mm. Crossed Nichols.

HARZBURGITE

Sample number: BVP Doc 1; UTM: 798689E 1684223N

Moderately serpentinized, coarse-grained harzburgite (Figs 103 - 106). The rock consists predominantly of olivine, orthopyroxene, and minor clinopyroxene. Anhedral and symplectic chromite are interstitial to the pyroxenes. Mesh lizardite rims the fragmented olivine and also occur as veins that cross-cut domains within the thin section. Some are serrate veins and form a network within olivine and pyroxene grains. Fe-staining of serpentine is common. Magnetite is relatively rare, suggesting that the rock is either Fe-poor or the magnetite that was produced during serpentinization, was later oxidized, locally giving the serpentine a rusty color. The rock shows evidence of partial recrystallization, as some olivine recrystallized to fine-grained aggregates.

Olivine and serpentine in the rock contain 0.4 and 0.6 wt% NiO, respectively. A few small pentlandite grains are interstitial to the serpentinized olivine. They are fragmented and the fractures are filled by hematite.

Figure 103. Olivine (NiO=0.4 wt%) with network of oxidized serpentine (NiO=0.59 wt%). Width of photo: 2.3mm. XN.

Figure 104. Aggregate of olivine, orthopyroxene and clinopyroxene.

Figure 105. Fine-grained fragmented pentlandite in center. Width of photo:

Figure 106. Chromite. Width of photo: 0.45mm. Ppl.

Table 4 shows the geochemical characteristics of some these samples.

Table 4. Geochemical characteristics of some of the petrological samples described above.

Sample	SiO ₂	Al ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	Fe ₂ O ₃
59068	39.61	1.07	0.85	40.03	0.009	0.04	7.97
59070	42.93	1.5	0.98	36.38	0.009	0.04	10.33
59076	41.91	1.5	0.63	34.62	0.009	0.04	7.86

Sample	MnO	TiO ₂	P ₂ O ₅	Cr ₂ O ₃	L.O.I.	Sum
59068	0.12	0.04	0.009	0.4	9.7	99.77
59070	0.14	0.03	0.009	0.5	6.2	98.94
59076	0.09	0.04	0.009	0.43	11.5	98.54

Sample	Ni	Co	Cr	Cu	Zn	Nd
59068	2200	120	2680	16	29	0.2
59070	8180	133	3070	24	47	134
59076	>10000	97.9	2880	16	35	160

Sample	Pr	Rb	Sm	Tb	Tm	Y	Yb
59068	0.07	0.8	0.09	0.04	0.04	0.6	0.09
59070	37.3	0.7	19	3.27	1.47	148	8.5
59076	40.2	0.6	31.1	5.5	2.28	301	9.4

Sample	Cs	Dy	Er	Eu	Ga	Gd
59068	0.09	0.08	0.09	0.04	1	0.06
59070	0.6	17.5	12	4.45	2	21.3
59076	0.7	29.7	22.3	7.96	2	38.5

Sample	Ge	Hf	Ho	In	La	Lu	Zr
59068	0.9	0.9	0.04	0.1	0.3	0.04	3.2
59070	2	0.9	3.87	0.1	237	1.35	2.6
59076	1	0.9	7.29	0.1	193	1.57	2.3

On the basis of the data presented in Table 1, I completed a petrochemical analysis of the different rock types present at these belts. Figures 107 through 109 highlights the geochemical differences between the lherzolites and olivine lherzolites. In general, olivine lherzolites are enriched in Al_2O_3 , Fe_2O_3 , MnO , Cr_2O_5 , and LOI and their nickel content is almost twice as high as in the websterites. They are also generally depleted in MgO , CaO , Na_2O , TiO_2 , and P_2O_5 when compared to the lherzolites.

Figure 107. Normalized distribution of Ni, Co, Al, Fe, and Mg for olivine-rich lherzolites and lherzolites.

Figure 108. Trace element composition of lherzolites and olivine-rich lherzolites from Guatemalan ophiolitic belts.

Figure 109. Major oxide distribution average for lherzolites and olivine-rich lherzolites.

SO WHERE THE NICKEL IS COMING FROM?

It has been well established that all or practically all of the nickel in the lateritic ores was originally present in the olivine.

During serpentinization about half of the nickel remains in the structure of the serpentine minerals (garnerite, gohetite, etc.), and the other half is present as free metal. Both iron and nickel are usually rejected by the serpentine minerals during serpentinization, leading to the formation of Ni-rich magnetite, awaruite, etc.

Studies completed by Noll P. Kicher demonstrated in 1952 that Ni actually replaces magnesium. The degree of replacement depends on the particular conditions of composition, temperature, pressure, and/or time, prevailing during the serpentinization.

It is generally believed that low NiO content in olivine suggests the separation and removal of an immiscible sulfide liquid during fractional crystallization of the magma, whereas high NiO content in olivine suggests that sulfide liquid separation has not occurred (Shandl, 2005). Thus, keeping this in mind, a potential Ni-laterite deposit is expected (a) to form after an ultramafic body where NiO content of olivine is high (and sulfide separation has not occurred), or (b) where limited sulfide separation has occurred, but the sulfide liquid has not been removed and the host rock contains small droplets of interstitial Ni-sulfides. In either instance, late hydrothermal fluids can scavenge the Ni from olivine and the sulfide droplets, and concentrate it to economic grade during the various episodes of serpentinization and oxidation – which may be associated with tectonism.

The presence of Ni in early mesh and hourglass lizardite suggests that, some Ni was incorporated into serpentine during the initial serpentinization of olivine. However, a moderately serpentinized dunite from the JPZ complex contains late oxidized serpentine veins having 0.83 wt% NiO. Evidently, oxidizing conditions favored the mobilization and incorporation of Ni into some of the late serpentine veins. Similar scenario was observed in a Lherzolite from the SSC complex, where the oxidized serpentine contains up to 1.2 wt% NiO.

PHASE I – MAGMATIC CHAMBER

The first stage of the evolution of these ophiolitic belts, took place in a hot and isolated magmatic chamber, where a low rate cooling combined with fractional crystallization created the original ultramafic rocks.

The crystallization followed the Bowen's series and the precipitation of minerals within the chamber followed the specific gravity of the formed minerals as shown in Figure 110.

Figure 110. Crystallization and precipitation of olivine and pyroxenes as temperature in the magma chamber drops to 1050°C. Notice that plagioclase will tend to concentrate at the top of the chamber due to their lower density.

The fact that the described rocks only show the presence of olivine and pyroxenes indicates that the crystallization process stopped at a temperature over 1050°C. Their coarse grains also indicate a slow rate of cooling.

PHASE II – OBDUCTION

The second phase was the obduction of the ultramafic rocks. This obduction was related to the collision of the NW end of the Caribbean Plate with the Maya and the Chortis Continental Blocks. While there are differences in the age of obduction of different complexes along the Motagua and Polochic Faults, the general conditions of pressure and temperature after the obduction process should have been similar to all complexes (Fig. 111) and were very favorable for the start of the serpentinization process.

Figure 111. Obduction of the ultramafic rocks along the main sinistral faults of Central Guatemala.

In these conditions, both varieties of olivine started to react with the heated sea water as shown in equations 5 and 6.

Equation 5. Reaction of Fayalite with heated sea water during the obduction process.

Equation 6. Reaction of Forsterite with heated sea water during the obduction process.

PHASE III – SERPENTINIZATION PROCESS

The third phase is the serpentinization of the obducted rocks. The general equations for dunites, peridotites (lherzolites), and pyroxenites (websterites) were presented earlier (Equations 1 – 3). Following are more detailed equations of the reactions that took place under these conditions.

We will start first with the continuation of the reactions represented in equations 5 and 6 (see equations 7 and 8).

Equation 7. Formation of Fe-Chrysotile from Fayalite.

Equation 8. Formation of Serpentine from Forsterite.

Equation 9. Formation of Garnierite from olivine.

Equation 10. Formation of Bastite from orthopyroxene.

Equation 11. Formation of Brucite from Clinopyroxene.

The fact that none of these reactions continued to their completion, e.g. we still have plenty of magnetite and even sulphides and olivine relicts in the weathered rocks, is an indication that the serpentinization process was interrupted (end of heat source? sea regression?).

Of special interest is the production of $\text{H}_2(\text{g})$ in equation 7. Gibbs and Hui (1971) stipulated that the H_2 could react with effusive CO in the presence of nickel as a catalyzer to form hydrocarbons.

PHASE IV – OXIDATION PROCESS

Oxidation represents the fourth phase of this process (see eq. 12 and 13). Weathering affected more strongly the olivine rich rocks within these belts, where full laterite profiles were formed (Geosol Izabal).

Equation 12. Formation of goethite from magnetite.

Equation 13. Oxidation of sulphides to form goethite.

After studying several lateritic profiles in the Sierra de Santa Cruz ophiolitic complex and using the definitions established by the North American Stratigraphic Code, I defined a new pedostratigraphic unit, The Izabal Geosol (UTM E: 260530, UTM N: 1723990; Valls, 2002, 2003). This Geosol represents the most complete profile of laterites in the SSC unit. It is composed of five pedological horizons:

- I. Si-Fe Hydrothermal Cap (not always present).
- II. Limonite Horizon (sometimes partially eroded).
- III. Stoneline Horizon.
- IV. Mottled Zone Horizon.
- V. Saprolite Horizon.

The Saprolite Horizon marks the bottom part of the Izabal Geosol and lies directly over the Saprock Horizon (Fig. 112) which continues into the less weathered bedrock.

Figure 112. Saprock sample from the Sierra de Santa Cruz ophiolitic belt.

The most complete profiles are usually present over weathered dunites and olivine-rich lherzolites and serpentinites, while on top of the less altered olivine-rich websterites and lherzolites we usually found only a small Limonite Horizon.

Fragments of the Si-Fe Hydrothermal Cap have been found only within the Sierra de Santa Cruz ophiolitic complex, east of El Estor village (Fig. 113). I believe that they are the result of the hydrothermal assimilation of the upper Limonitic Horizon near hot spots areas, like the one located near the village El Paraiso, famous for the presence of hot springs of sulphide-rich waters. Grab samples taken from these iron-silica rich formations showed traces of gold and PGM, as shown in Table 5.

Figure 113. These Iron Caps are found only within the ophiolitic belt of Sierra de Santa Cruz and probably are the result of hydrothermal activity.

Table 5. Grab samples taken from the area show the presence of precious metals.

Sample	UTM E	UTM N	Elevation	Au	Pt	Pd	PGM	Au+PGM
B1	258030	1722400	55	0.004	0.015	0.012	0.027	0.031
B2	258750	1722540	5	0.002	0.009	0.01	0.019	0.021
B3	259480	1722550	10	0.002	0.009	0.007	0.016	0.018
B4	261210	1722960	34	0.002	0.008	0.006	0.014	0.016
B5	263120	1724420	21	0.004	0.023	0.02	0.043	0.047
B6.1	264870	1724450	30	0.003	0.005	0.006	0.011	0.014
B6.2	264860	1724460	31	0.002	0.006	0.005	0.011	0.013
B7	261040	1723080	110	0.003	0.007	0.004	0.011	0.014
B8	260530	1723990	180	0.002	0.005	0.004	0.009	0.011

The Limonite Horizon is usually red to brown-red in color, with concentrations of MgO of less than 5% and a thickness varying from 1.2 to 7.5 meters (Fig. 114). Sometimes it contains small veinlets of crystalline and amorphous quartz. This zone develops where the iron nodules become abundant and eventually coalesce into an indurated, conglomeratic, iron-rich crust. Further hydration and replacement of aluminous hematite by aluminous goethite results in the formation of a pisolitic iron crust. In well developed (mature) profiles, these pisolites eventually diminish in size and become separate to form a pebbly ferruginous layer at surface, which is not the case of the Izabal Geosol.

Figure 114. Limonite sample from the Sierra de Santa Cruz ophiolitic belt.

The Stoneline Horizon marks the position of the paleo water table, and is composed of silicified fragments of rocks in a silicified matrix that can be consolidated or not. The thickness of the Stone Line Horizon varies from 0 to 1 or 2 metres, and is where most of the heavy metals (e.g. PGM, Au, etc.) are concentrated.

The Mottled Zone Horizon (Fig. 115) is characterized by concentrations of MgO ranging from 5% to 10% and by lower concentrations of iron and Ni. Its thickness varies from 0 to 7 meters, and it is easily identified by the mottled character of the coloration. This

zone always forms above the water table. The pre-existing macrostructure of the host rock is being progressively destroyed. Water percolation creates a series of voids and channels which can become filled with secondary kaolinite and ferruginous spots and nodules. These nodules become more abundant and indurated near the top of this zone so that the pre-existing lithostructures become completely obliterated.

Figure 115. Typical laterite profile at Sierra de Santa Cruz ophiolitic belt.

The Saprolite Horizon forms on top of the serpentinitic ultramafic rocks (Fig. 116). It is characterized by greater than 10% concentrations of MgO, as well as by increased amounts of Ni. This zone is yellowish to greenish-yellow in color, with a usual thickness ranging from 0 to 10 meters, where only resistant minerals such as chromite and tourmaline remain unweathered.

Figure 116. Sapolite sample from the Sierra de Santa Cruz ophiolitic belt.

UNIQUE CHARACTERISTICS OF THE GEOSOL IZABAL

When comparing the laterites from the SSC complex with other wet and dry laterites of the world, the uniqueness of this deposit becomes clear (Fig. 117).

Figure 117. Comparison of the Izabal Geosol with other dry and wet laterites of the world.

The most important differences here are the age of intrusion and the degree of metamorphism of the SSC unit. As shown previously in Figure 82, the ages of the ultramafic complexes seems to grow older in a west – east direction. The North and South Motagua ophiolitic complexes are representative of zones of HP-LT conditions, while the degree of metamorphism at the Juan de Paz – Los Mariscos is more limited to zones of intense mylonitization. According to my mapping, the intrusion of the SSC unit occurred during the Early Tertiary and here the metamorphism was limited to the selective serpentinization of the complex.

Another indication of the immaturity of these laterites is the presence of up to 30% of magnetite as an average for the whole profile of the Geosol, as well as the absence of the pisolitic iron crust.

We recently completed a study of the magnetic fractions of samples from different belts in Guatemala at Inotel Lab, in Sherbrooke, with Dr. Jean-Marc Lalancette (Figures 118 - 125).

Figure 118. Dr. Jean-Marc Lalancette mixes a bag with pulverized material before taking a sample.

Figure 119. An initial sample of 75 grams was taken from each rock.

Figure 120. Mixing the sample with water, prior to the magnetic separation.

Figure 121. Separation of the magnetic fraction with a magnet and water.

Figure 122. Filtering the non magnetic fraction in a vacuum filter.

Figure 123. Magnetic (left) and non magnetic fractions after 5 hours of drying at 91°C.

Figure 124. Weighing the magnetic fraction.

Figure 125. Weighing the non magnetic fraction.

Table 6 shows the results of this study and also includes historical data from the Tailings from Quebec.

Table 6. Results of the analysis of the magnetic composition of samples from Guatemala and Quebec.

Lithology	Location	Total weight, g	NMgt, g	Mgt, g	Mgt, %
Lherzolite	Juan de Paz	75	50.1	22.4	30%
Olivine lherzolite	Juan de Paz	75	61	12.6	17%
Websterite	Juan de Paz	75	58.3	15.1	20%
Boudine	Sierra de Santa Cruz	75	66.3	6.1	8%
Websterite	Sierra de Santa Cruz	75	49.7	18.7	25%
Olivine lherzolite	Sierra de Santa Cruz	50	34.4	11.2	22%
Harzburgite	North Motagua	75	24.5	48.9	65%
Limonite	Sierra de Santa Cruz	250	87.5	162.5	65%
Saprolite	Sierra de Santa Cruz	278	191.8	86.2	31%
Tailings	Lac Chrysotile				35%
Tailings	J-M				28%
Tailings	Carey				43%
Tailings	Maternal				29%
Tailings	BC-1				19%
Tailings	BC-2				28%
Tailings	Beaver				25%
Tailings	Nomandie				19%
Tailings	Bell				25%
Tailings	Average value				28%

Another interesting difference is the grain size of these saprolites. As shown in Table 7, even at -60 Mesh there is abundant still sandy material in these saprolites.

Table 7. Granulometric analysis of saprolites from the Geosol Izabal.

Sample	+10 Mesh	+40 Mesh	+60 Mesh	-60 Mesh	Total, g
74755	767	333	116	195	1411
74753	610	402	104	169	1285
73807	501	494	159	162	1316
73801	336	257	83	164	840

Sample	+10 Mesh	+40 Mesh	+60 Mesh	-60 Mesh
74755	54%	24%	8%	14%
74753	47%	31%	8%	13%
73807	38%	38%	12%	12%
73801	40%	31%	10%	20%

	+10 Mesh	+40 Mesh	+60 Mesh	-60 Mesh
Average	44.97%	30.75%	9.57%	14.70%
St. deviation	7.45%	5.70%	1.86%	3.27%
Variability	16.57%	18.54%	19.46%	22.27%
Maximum	54.36%	37.54%	12.08%	19.52%
Minimum	38.07%	23.60%	8.09%	12.31%

Finally, the fact that most of these laterites develop mainly over dunites and olivine-rich lherzolitic rocks, with very limited to non-existent development over lherzolites and olivine-rich websterites, is also an indication of the young age of this deposit.

Next, I will present the results of several transects across Central Guatemala and the Motagua Suture Zone, which summarizes our most current understanding of the regional geology in this area.

The map on Fig. 100 shows the main road crosscuts we have completed during the last two years of working in Guatemala.

Figure 126. Road geology of Central Guatemala.

The route in red is the most current field trip for the study of five of the six ophiolitic belts in Guatemala (we are studying the possibility of including also the Huehuetenango ophiolitic belt to this 831 km route). For this itinerary, we exit Guatemala City to the North to take the Central American Highway 9 (CA 9) connecting the capital of Guatemala with Puerto Barrios on the west coast. This route runs through the Volcanic Province and the Motagua Suture Zone (MSZ) as well as the major faults of Cabañas and Motagua. Associated to the Motagua Fault, there are three ophiolitic belts: The South and North Motagua and the Juan de Paz – Los Mariscos ophiolitic belts. Further west along CA-9, at km 171.3, there is a detour to the south (right) along RD 5 to Gualán, where you could visit the Zacapa Batholite.

At the village La Ruidosa we turn north (CA-13) to the village of Río Dulce crossing all the Tertiary to Quaternary sediments associated with the Lake Izabal. Next we turn west on route 7E crossing first along the south border of Sierra de Santa Cruz Ophiolitic belt and then the Baja Verapaz ophiolitic belt along its north contact with the limestones units of the Ixcoy Fm. We then turn south along CA-15 back to Guatemala City

The route in blue shows a cross section of the western end of the North Motagua ophiolitic belt, then it runs across the Chuacús metamorphic series towards the north until the eastern part of the Baja Verapaz ophiolitic belt, which hosts some of the largest laterite deposits in Guatemala. We travel from Guatemala City along CA-9, making a detour to the north at km 85.5 before the village El Rancho along the CA-5 to the village of Tactic, for a total of 156 km.

Another fine intersection of the Chuacús metamorphic series is represented by the route in green. For this we exit Guatemala City to the northwest to find Route 5. From San Juan de Sacapulas to the village of Salamá we will be traveling across the Chuacús Series. At Salamá we turn north on Route 17 to San Cristobal (a total of 192 km) passing again through the eastern border of the Baja Verapaz ophiolite belt.

The route in yellow departs from Tactic to cross in a north-south direction the Baja Verapaz ophiolitic belt until the village of Salamá along Route 17, then turn west on Route 5 until the Cubulco Damp almost at the centre of the BVP belt for a total of 87 km. Along this road we will intersect not only rocks from the ultramafic complex, but also some intrusive probably related to the obduction process, as well as several schist sequences of the Chuacús Series and more recent effusive rocks, mainly rhyolitic ignimbrites and pomex.

The orange route is a transect across the South Motagua, with a series of great intersections of the pillowed basalts and the source of the material for the polymictic Subinal Fm. We will also intersect a granitoid unit.

Finally, the black route is a transect across the Volcanic Province along the CA-1 towards the units of the Huehuetenango Complex and the Cobán Limestones and the metamorphic units of the Chuacús Series.

Fig. 127 shows the main stops along the red route which is the main objective of this guide (see also the pocket in the back of this publication).

Figure 127. Location of the main stops planned for this trip.

RED LINE ROAD GEOLOGY

Location	Lithology	Observations
CA-9, km 0-17	Ignimbrites (welded rhyolitic tuff)	Fig. 128.
(11.2-11.5)	Basaltic dike	Fig. 129.
Km 17-20.5	Limestones and marls from the Virginia Formation	Fig. 130.
Km 20.5, 1 km north.	Diatomeas formation with abundant vegetation imprints. Located behind rhyolitic ignimbrites.	Fig. 131. UTM E: 782580 UTM N: 1627911 Zone 15
Km 20.5-23.5	Yellow-cream-white-pink fine grained rhyolitic tuffs. Bedding varying from flat to 45°. Pink rhyolite is slightly enriched in Rb, very depleted in Mo and Fe, and relatively depleted in Mn, Zr, and Sr compared to the white rhyolites	
Km 21	Phyllites from El Tambor Fm.	

Location	Lithology	Observations
Km 23	Ignimbrites (welded rhyolitic tuff)	
Km 23.5-24	Andesite-dacite lava flow.	
Km 24-25.8	Pyroclastic poorly sorted volcanic breccia, varying from more mafic units at the base of the profile to more felsic units at the top.	
Km (24.5-25.5)	Transitional contact between fine-grained banded rhyolitic tuffs with rhyolitic tuffs carrying obsidian inclusions.

Figure 128. Rhyolitic ignimbrites.

Figure 129. Basaltic dike.

Figure 130. Limestones and marls from La Virgen Fm.

Figure 131. Diatomites with abundant vegetal impints along the CA-9 in Central Guatemala.

Location	Lithology	Observations
(Km 25)	Obsidian hills	Fig. 132 (UTM E 784667, UTM N 1630432, 993 m, Zone 15.)
Km 25.8-26	Fine grained tuff bedded at 30°.	
Km 26-32	Limestones and marls of the Virginia Fm with fine grained tuff on top showing incipient bedding varying from 20° to 30°.	
(Km 26 – 29)	Pillowed basalts.	
Km 32-32.1	Basaltic dike.	
Km 32.1-33	Red Beds Fm. Polymitic sandstone, fine grained, well sorted, compacted, red in color with concoidal fracture	Fig 133.
Km 34-35	Phylites from El Tambor Fm.	UTM E 795365, UTM N 1637633, 739 m, Zone 15.
Km 35	Rhyolites	
Km 35-36	Greenschists of the South Motagua ophiolitic complex.	
Km 36-37	Phylites from El Tambor Fm.	
Km 37-43	Greenschists of the South Motagua ophiolitic complex.	
Km 43-46.5	Massive, blocky andesite, alternating with white-red felsic tuffs.	
Km 46.5-50.5	Phylites from El Tambor Fm.	
Km 50.5-52	Pillowed basalts.	Amygdaloidal and vesicular.
Km 52-55	Mostly mafic tuffs alternating with andesitic blocks and yellowish felsic tuff.

Figure 132. Unique outcrop of reddish-brown obsidians at km 25 on the CA-9 route.

Figure 133. Red beds formation.

Location	Lithology	Observations
Km 55-56.5	Yellowish fine-grained volcanic tuffs alternating with small andesitic dykes.	
Km 56.5-57	Greenschist.	South Motagua ophiolitic complex.
Km 57-58	Harzburgites.	Centre of the South Motagua ophiolitic complex.
Km 58-60.5	Greenschist with reddish brown tuff on top.	South Motagua ophiolitic complex.
Km 60.5-61.5	Limestones and marls.	La Virgen Fm.
Km 61.5-63	Sandstones intruded by dykes of massive andesite.	
(Km 62-62.5)	Yellow brown fine-grained and well sorted felsic tuffs.	
Km 63-70	Silicified limestones and marls with bryozoa fossils.	La Virgen Fm.
(Km 66.5-67.5)	Massive basalts and andesites.	
Km 70-72	Yellow and brown fine-grained and well sorted tuffs with some white rhyolitic tuff on top.	
(Km 70.8-71)	Andesite dike.	
Km 72-74	Rhyolitic tuffs.	Ignimbrites covering other older units.
Km 74-76	Basalts.	
Km 76-81	Synforms and antiforms of flyschoid polymictic conglomerates, with flat laying red tuff on top of them. Paleocene molasses that cover the south border of the North Motagua and Juan de Paz - Los Mariscos ophiolitic complex.	Fig. 134. (UTM E 816625, UTM N 1647381, 594 m, Zone 15).
(Km 78.5-79.5)	Mafic volcanics with conglomerates.	
Km 81-82	White/reddish felsic tuffs.	Fig. 135.
Km 82.5-83.5	Greenschists of the North Motagua ophiolitic complex.	
Km 83.5-87	White/reddish felsic tuffs.	
Km 87-88	Greenschists of the North Motagua ophiolitic complex.	
Km 89.8-90.5	White/reddish felsic tuffs.	
Km 92.3	Sericitic schists from the Chuacús Series.	
Km 90.5-97	Harzburgites corresponding to the nucleus of the North Motagua ophiolitic complex with reddish brown tuffs on top	Fig. 136 (UTM E 178991, UTM N 1653120, 413 m, Zone 16).

Figure 134. Paleocene flyshoidal polymictic molasses formation covering the south border of the Motagua ophiolitic complex.

Figure 135. Sequence of white and pink rhyolitic tuffs.

Figure 136. Discussing the geology of the North Motagua ophiolitic belt with mining analyst Michael Hitch.

Location	Lithology	Observations
Km 97-100.1	White/reddish felsic tuffs.	
Km 102.5	Fresh outcrop of harzburgites.	
Km 102.5-106.2	Phyllites from El Tambor Fm. with intervals of multicolored tuffs at the top.	
Km 106.2-110	Greenschist from the North Motagua ophiolitic complex with yellow tuffs on top.	
Km 110-111	Pillow lava basalts.	
Km 111-114	Reddish brown tuffs.	
Km 114-120	Reddish brown tuffs with boulders, especially at the transition point, with abundant fragments and conglomerates.	Sacapulas Fm.
Km 120-129	Alternating yellow and reddish felsic tuffs with boulders.	Sacapulas Fm.
Km 131-133	Metamorphic megaconglomerates.	Sacapulas Fm.

Location	Lithology	Observations
Km 133-142.5	Rhyolitic tuffs with layers of conglomerates.	Note to your left an abandoned plane on km 141.5.
Km 142.5-146	Metamorphic megaconglomerates.	Sacapulas Fm. Extremely large blocks between kms. 144 and 145 (Pebble Beach).
Km 146-151	Synforms and antiforms of flyschoid polymictic conglomerates, with flat laying red tuff on top of them.	Paleocene molasses that cover the south border of the North Motagua and Juan de Paz-Los Mariscos ophiolitic complexes.
Km 151-153.8	Rhyolitic tuffs.	
Km 153.8-154	Metamorphic megaconglomerates.	Sacapulas Fm.
Km 154-156	Rhyolitic tuffs.	
Km 156-159	Metamorphic megaconglomerates.	
Km 159-162	Felsic tuffs with intervals of mega boulders, some of basaltic composition.	This sequence is due to the variations on the hypsometric position of the road.
Km 162-186.3	Flyschoid polymictic sandstones and conglomerates in an antiform, sometimes covered by tuffs.	Paleocene molasses.
(Km 163)	Basalt-andesitic lava flow.	
(Km 165)	Detour to the Zacapa Granitoids of Gualán.	
(Km 165-168)	Reddish tuffs.	Perhaps the difference of coloration between these tuffs was due to changes on the climatic conditions, since their chemical composition is almost the same.

Km 186.3-187	Western end of the Juan de Paz – Los Mariscos ophiolitic complex	Fig. 137. A classical zone of mylonitization and budinage, that regrettably was covered by an access road. (UTM E 262524, UTM N 1685128, 168 m, Zone 16).
Location	Lithology	Observations
Km 187 – 193	Reddish tuffs.	
(Km 182)	Andesitic dike.	
Km 194-199.	Antiform composed by flyschoid polymictic sandstones and conglomerates .	Paleocene molasses
Km 199 – 216	Red tuff with a minor conglomerate unit at the bottom.	
(Km 204.6)	Detour to Quiriguá.	Turn right after the gas station.
(Km 205 – 206)	Flyschoid polymictic sandstones and conglomerates in an antiform, sometimes covered by tuffs.

Figure 137. This mylonitic zone marks the western end of the Juan de Paz - Los Mariscos ophiolitic complex. Regrettably, this wonderful outcrop was recently destroyed during some construction works.

Location	Lithology	Observations
Km 216 - 260	Juan de Paz – Los Mariscos ophiolitic complex.	(UTM E 283096, UTM N 1701930, 145 m, Zone 16).

(Km 228, 232)	Lateritic pockets.	La Virginia license, JNI.
(Km 246.2)	Lateritic pockets.	La Ruidosa license, JNI (UTM E 304384, UTM N 1716214, 58 m, Zone 16).

Location	Lithology	Observations
UTM E 281017, UTM N 1729776. 50 m, Zone 16	Typical low-sulphide ephythermal alteration associated with deposits of precious metals at Río Azúl license.	Fig. 138.
UTM E 262199, UTM N 1724015. 30 m, Zone 16	Evidence of hydrothermal activity (skarn).	Fig. 139.

Figure 138. Typical ephythermal low-sulphide type of alteration over precious metal mineralization, Río Azúl, SSC.

Figure 139. Fragments of a grossularite skarn at Río Azúl, SSC.

Location	Lithology	Observations
UTM E 253404, UTM N 1721428. 108 m, Zone 16	Mylonitic flat zone of the Sierra de Santa Cruz ophiolitic complex.	
UTM E 259917, UTM N 1724292. 290 m, Zone 16	Protolaterites from an olivine lherzolite at Sierra de Santa Cruz ophiolitic complex.	Fig. 140.
UTM E 253932, UTM N 1724924. 263 m, Zone 16	View of laterite outcrops at El Bongo village.	Fig. 141.

Km 177 UTM E788583, UTM N 1692542, 1528 m, Zone 15.	Flat laying lutites and schist.	Fig. 142. Chuacús Fm.
Km 182 UTM E 785584, UTM N 1695080, 1479 m, Zone 15.	Ixcoy limestones laying flat on top of schists from the Chuacús Series.	Fig. 143.
Location	Lithology	Observations
Km 186-187 UTM E 782135, UTM N 1695627, 1455 m, Zone 15.	Rhyolitic ignimbrites.	Fig. 144.

Figure 140. Protolaterites from olivine-rich lherzolites from the Sierra de Santa Cruz ophiolitic complex.

Figure 141. Laterite development over Chinabénque I license, Sierra de Santa Cruz, near El Bongo village.

Figure 142. Lutites and carbonaceous schists from the Chuacús Series.

Figure 143. Contact between limestones from the Ixcoy Fm and schists from the Chuacús Series.

Figure 144. Rhyolitic ignimbrites at Baja Verapaz complex.

Figure 145. Zone of brecciation and silicification within limestones.

Location	Lithology	Observations
Km 191 UTM E 777138, UTM N 1696867, 1425 m, Zone 15.	Outcrop of silicified breccias of limestones.	Fig. 145.
Km 198-206	Ferruginous schists.	Chuacús Series.
(Km 199)	Rhyolitic ignimbrites.	
UTM E 766289, UTM N 1700969, 1493 m, Zone 15.	Limestones of the Ixcoy Fm.	Before that mostly ferruginous schists.
UTM E 765356, UTM N 1701443, 1460 m, Zone 15.	Intensively and pervasive silicified limestone (Ixcoy Fm.).	With potential for copper mineralization (skarn?).
Km 227. UTM E 763795, UTM N 1701414, 1411 m, Zone 15.	Flat laying limestones of the Ixcoy Fm., sometimes with layers of gyps.	Fig. 146.
Km 228	Rhyolitic dike.	
UTM E 751655, UTM N 1698778, 643 m, Zone 15.	Alluvial conglomerates from Río Negro.	Fig. 147.
UTM E 738199, UTM N 1697151, 1387 m, Zone 15.	Websterites of the Baja Verapaz ophiolitic complex covered by rhyolitic tuffs. There is abundant magnetite and sulphides on these rocks.	Fig. 148.

Location	Lithology	Observations
UTM E 730239 UTM N 1695318 1758 m, Zone 15	Contact of the websterites from the Baja Verapaz ophiolitic complex with brecciated limestones from the Ixcoy Fm.

Figure 146. Flat laying limestones of the Ixcoy Fm.

Figure 147. Layers of gyps hosted by the limestones of the Ixcoy Fm.

Figure 148. Conglomerates from the Río Negro.

Figure 149. Rhyolitic tuffs covering websterites from the BVP ophiolitic belt.

Note: To avoid unnecessary repetitions, we are including in this list only those points not mentioned in the official stops of the field guide tour included in this publication.

BLUE LINE ROAD GEOLOGY

The description of these transects starts at the detour from CA-9 to Route 17 before the village El Rancho.

Location	Lithology	Observations
Km 83.5-87	Basalts.	
Km 88	Chuacús metasedimentary series.	
Km 99-100	Harzburgites of the North Motagua ophiolitic complex.	Fig. 150.
(Km 108)	Basalts.	
Km 110-112	Harzburgites of the North Motagua ophiolitic complex.	
Km 117	Andesite.	
Km 121-124.5	Chuacús metasedimentary series.	
Km 129.8	Northern limit of the North Motagua ophiolitic complex in contact with ferruginous schists.	
Km 129.8-147	Chuacús metasedimentary series.	
Km 148	Southern limit of the Baja Verapaz ophiolitic complex.	Fig. 151. UTM E 803368, UTM N 1675087, 1518 m, Zone 15. The contact is marked by rhyolitic ignimbrites.

Figure 150. Outcrops of the North Motagua ophiolitic complex on road CA-5 to Cobán.

Figure 151. Rhyolites at the contact between the Chuacús Series and the southern limit of the Baja Verapaz ophiolitic complex.

Location	Lithology	Observations
UTM E 803612, UTM N 1675609, 1577 m, Zone 15.	Laterites from Niño Perdido village.	Fig. 152.
Km 151 UTM E 799934, UTM N 1679891, 1657 m, Zone 15.	Laterite deposit from La Unión-Barrios.	Fig.153.
Km 155	Laterite deposits of Quisés-Matanzas licenses, JNL.	Fig.154.

Figure 152. Laterites from Niño Perdido village, BVP.

Figure 153. Lateritic pocket at La Unión-Barrios, BVP.

Figure 154. Lateritic pocket at Quisés, BVP.

Location	Lithology	Observations
UTM E 791855, UTM N 1687957, 1574 m, Zone 15.	Contact between the Baja Verapaz (BVP) ophiolitic complex and limestones from the Ixcoy Fm.	Fig. 155. Notice the vertical layering of these usually flat laying limestones, indicating that the protusion of the Baja Verapaz complex probably occurred against these rocks.

Location	Lithology	Observations
Km 171.2	<p>Contact between the Cobán limestone Fm. (bottom portion) and the Ixcoy limestone Fm.</p> <p>The limestones of the Cobán Fm. (K₂) are very rich in fossils. I believe that as the result of the Polochic Fault and the subduction event prior to the protrusion of the Baja Verapaz ophiolitic complex, the area was submerged below the sunshine line, and most of the coral life died. This could explain the fine grained and bituminous nature of the limestones of the Ixcoy Fm.</p>	Fig. 156.

Figure 155. Vertical laying limestones of the Ixcoy Fm at the north contact of the Baja Verapaz ophiolitic complex.

Figure 156. Contact between the limestone of the Ixcoy Fm. (upper) and the Cobán Fm. (bottom).

GREEN LINE ROAD GEOLOGY

Location	Lithology	Observations
RD-6 UTM E 753838, UTM N 1628801, Zone 15.	Basaltic dikes among rhyolites.	
Km 34.5-35.5 UTM E 753792, UTM N 1630174, Zone 15.	Pillowed basalts.	Fig. 157. They appear to be higher than the rhyolites.
Km 35.5.	Rhyolite ingimbrites.	
Km 42 UTM E 754157, UTM N 1634990, 1561 m, Zone 15.	Tres Sábanas Granitoid Intrusive.	Fig. 158.
(Km 43).	Pillowed basalts.	
Km 44.	Detour to Cobán.	Dirty road.
Km 46 UTM E 754549, UTM N 1638197, 1579 m, Zone 15.	Granitoid intrusive.	Fig. 159.
Km 48.9	Detour to Salamá.	Dirty road.

Figure 157. Pillowed basalts on RD-6.

Figure 158. Tres Sábanas Granitoid.

Figure 159. Granitoid intrusive at RD-6.

Location	Lithology	Observations
Km 50 UTM E 756023, UTM N 1640642, 1290 m, Zone 15.	Mica-schist with abundant quartz fragments from the Chuacús Series.	Fig. 160.
Km 52. UTM E 756017, UTM N 1641113, 1212 m, Zone 15.	Metaandesites.	Fig. 161.

Figure 160. Mica-schist of the Chuacús Series with abundant quartz fragments.

Figure 161. Meta-andesites of the Chuacús Series.

Location	Lithology	Observations
Km 53.2 UTM E 756487, UTM N 1641461, 1179 m, Zone 15.	Limestones and marls from la Virgen Fm.	Fig. 162.
Km 60. UTM E 759288, UTM N 1642295, 925 m, Zone 15.	Limestones and marls from la Virgen Fm. with abundant foraminifera.	
UTM E 759822, UTM N 1644412, 688 m, Zone 15.	Antiform composed by flyschoid polymictic sandstones and conglomerates .	Fig. 163. Same Eocene molasses that cover the south border of the North Motagua ophiolitic belt.
Km 66 UTM E 760066, UTM N 1645854, 740 m, Zone 15.	Silicified limestones and phylites of El Tambor Fm.	Fig. 164.
Km 67.1 UTM E 761024, UTM N 1646007, 839 m, Zone 15.	Greenschist facies of the North Motagua ophiolitic belt showing abundant boudinage.	Fig. 165.

Figure 162. Limestones and marls of la Virgen Fm.

Figure 163. Paleocene continental molasses cover the south border of the North Motagua ophiolitic complex.

Figure 164. Phylites and silicified limestones of El Tambor Fm.

Figure 165. Greenschist facies of the North Motagua ophiolitic complex with abundant boudinage.

Location	Lithology	Observations
Km 67.3 UTM E 761134, UTM N 1646107, 866 m, Zone 15.	Limestones of El Tambor on top of hazburgites of the North Motagua ophiolitic complex.	Tectonic emplacement or evidence of a Pre-PZ age?
Km 67.5 UTM E 761147, UTM N 1646318, 878 m, Zone 15.	Harzburgites of the North Motagua ophiolitic complex.	Fig. 166.
Km 68.4 UTM E 761544, UTM N 1646592, 875 m, Zone 15.	Mylonitic zone with fragments of Jadeite.	Fig. 167.
Km 70.7	Limestones.	
Km 71-71.6	Greenschist facies of the North Motagua ophiolitic complex.	
Km 72 UTM E 762565, UTM N 1648470, 838 m, Zone 15.	Mica-schist and gneises from the Chuacús Series.	Fig. 168.
Km 73.2 UTM E 763270, UTM N 1648524, 897 m, Zone 15.	Metasediments of the Chuacús Series.	Fig. 169.

Location	Lithology	Observations
Km 73.4	Greenschist of the North Motagua ophiolitic complex.

Figure 166. Harzburgites of the North Motagua ophiolitic complex.

Figure 167. Mylonitic zone within the harzburgites of the North Motagua ophiolitic complex.

Figure 168. Mica-schist and gneisses from the Chuacús Series.

Figure 169. Metasediments of the Chuacús Series.

Location	Lithology	Observations
Km 74.5 UTM E 764780, UTM N 1648832, 991 m, Zone 15.	Mica-schists from the Chuacús Series on top of oxidized greenschist facies from the North Motagua ophiolitic complex.	Fig. 170. Tectonic emplacement or evidence of a Pre-PZ age?
UTM E 768590, UTM N 1649275, 689 m, Zone 15.	Pegmatite Mine Noelia.	Fig. 171.

Location	Lithology	Observations
Km 79.9 UTM E 767233, UTM N 1650485, 1018 m, Zone 15.	Mica-schists of the Chuacús Series.	Fig. 172.
Km 132-133 UTM E 769979, UTM N 1665816, 1174 m, Zone 15.	Limestones on top of schists of the Chuacús Series.	
UTM E 802370, UTM N 1673066, 1487 m, Zone 15.	Detour to El Chilasco.

Figure 170. Is the presence of this schist from the Chuacús Series on top of oxidized greenschist of the North Motagua ophiolitic belt an evidence of the Pre-PZ age of this ophiolitic belt?

Figure 171. The Noelia Mine is one of the many pegmatite mines in the area.

Figure 172. Folded mica-schist of the Chuacús Series.

YELLOW LINE ROAD GEOLOGY

Location	Lithology	Observations
UTM E 792016, UTM N 1687422, Zone 15.	Compact, reddish, sericitic-rich, medium grained sandstone (?)	Fig. 173.
UTM E 792010, UTM N 1687303, Zone 15.	Sericitic-schist (220°/55°) of the Chuacús Series.	Fig. 174.
UTM E 791806, UTM N 1686667, Zone 15.	Limestones from Ixcay Fm.	Fig. 175.
UTM E 791496, UTM N 1686432, 1640 m, Zone 15.	Rhyolitic ignimbrites.	Fig. 176.
UTM E 789280, UTM N 1686160, 1445 m, Zone 15.	Limestones from Ixcay Fm. (40°/85°).	
UTM E 791628, UTM N 1685067, 1546 m, Zone 15.	Websterites.	Fig. 177.
UTM E 790720, UTM N 1683854, 1337 m, Zone 15.	Websterites with layers of olivine-rich lherzolites.	Fig 178.

Figure 173. Sandstone formation.

Figure 174. Sericitic schist of the Chuacús Series.

Figure 175. Limestones of the Ixcoy Fm.

Figure 176. Ignimbrites at Baja Verapaz.

Figure 177. Outcrop of websterites at Baja Verapaz.

Figure 178. Olivine ilherzolite layers (dark brown) within websterites.

Location	Lithology	Observations
UTM E 793196, UTM N 1676165, 1095 m, Zone 15.	Bituminous-rich, cryptocrystalline limestones of the Ixcoy Fm.	
UTM E 779292, UTM N 1670353, 969 m, Zone 15.	Sericitic schist of the Chuacús Series.	Fig. 179. From Salamá to this point outcrops are basically ignimbrites.
UTM E 778025, UTM N 1671763, 1145 m, Zone 15.	Chlorite-schistose-talc.	Fig. 180.
UTM E 776077, UTM N 1670587, 1402 m, Zone 15.	Granitoid intrusive.	Fig. 181.
UTM E 763120, UTM N 1670158, 1018 m, Zone 15.	Sericitic schists of the Chuacús Series.	Fig. 182. Abundant ignimbrites covering most of the outcrops.

Figure 179. Sericitic schists of the Chuacús Series.

Figure 180. Outcrop of chlorite-schistose-talc.

Figure 181. Granitoid intrusive south of the Baja Verapaz ophiolitic complex.

Figure 182. Sericitic schists of the Chuacús Series.

Location	Lithology	Observations
UTM E 760035, UTM N 1670540, 1011 m, Zone 15.	Rhyolitic ignimbrites.	Fig. 183.
UTM E 757938, UTM N 1671711, 996 m, Zone 15.	Chloritic schists.	
UTM E 757663, UTM N 1673193, 993 m, Zone 15.	Ferruginous schists with abundant quartzite fragments.	Fig. 184.
UTM E 757122, UTM N 1676212, 987 m, Zone 15.	Boulders of quartzites.	Fig. 185.
UTM E 757473, UTM N 1677554, 728 m, Zone 15.	Granitoid intrusive with aplites.	Fig. 186.

Figure 183. Ignimbrites regularly cover most of the formations at the south border of the Baja Verapaz ophiolitic complex.

Figure 184. Ferruginous schist with abundant quartzite.

Figure 185. Boulders and fragments of quartzites.

Figure 186. Dikes of aplites intersecting this granitoid intrusive.

Location	Lithology	Observations
UTM E 755788, UTM N 1680053, 934 m, Zone 15.	Websterites covered by ignimbrites.	Fig. 187.
UTM E 757517, UTM N 1677481, 916 m, Zone 15	Sericitic schists deeping south in contact with deformed granitic rocks.	
UTM E 753619, UTM N 1682912, 817 m, Zone 15.	Damp at Cobulco village.	Fig. 188.
UTM E 756140, UTM N 1679797, 921 m, Zone 15.	Limonite over leucocratic gabbro, covered by rhyolitic ignimbrites.	Fig. 189.
UTM E 756381, UTM N 1679187, 896 m, Zone 15.	Limonite over a leucocratic gabbro, covered by rhyolitic ignimbrites.	Fig. 190.

Figure 187. Websterites covered by Tertiary rhyolitic ignimbrites.

Figure 188. Hanging bridge at the Cobulco Damp.

Figure 189. Oxidized leucocratic gabbro covered by ignimbrites.

Figure 190. Another extension of the same oxidized gabbro.

As described above, the Chuacús schists are the most abundant rocks in the area. I have so far identified four members of this group:

- a. Sericitic (Mica) schist.
- b. Sericitic schist with quartzite veinlets and boulders.
- c. Chloritic schists.
- d. Ferruginous schists¹.

¹ The ferruginous schist, when weathered, forms a red soil very similar to laterites.

These schists are usually covered by Tertiary-Q rhyolitic tuffs (ignimbrites). The abundance of ignimbrites in the area can be explained only by the existence of a volcanic source in the area.

We have seen several places where within the belt with olivine lherzolites but no development of laterites. This is due to the steepness of some of these mountains which facilitated the erosion of the soil down to the valleys. Fig. 191 shows an erosion analysis completed using SURFER with vectors indicating in green the possible present location of these lateritic soils (Figs. 192-193).

Figure 191. Erosional analysis of the Baja Verapaz area.

Figure 192. Eroded laterite from the olivine lherzolites at the eastern border of the Baja Verapaz ophiolitic belt.

Figure 193. The lateritic soil has been deposited down hill over less steep slopes.

On the basis of these field observations a geological map of the Baja Verapaz area is presented in Figure 194.

Figure 194. Regional geology of the Baja Verapaz area.

ORANGE LINE ROAD GEOLOGY

The description of these transects starts at the detour from CA-9 to RN 19 at Km. 52.8 going to Jalapa.

Location	Lithology	Observations
Km 54	Rhyolitic ignimbrites.	
Km 59 UTM E 804112 UTM N 1634606 786 m,	Quartz-rich schist alternating with ferruginous schists, deeping south.	Fig. 195.
Km. 66.	Chloritic schist from the Chuacús Series.	
Km. 67.	Ferruginous schist covered by alluvial conglomerates.	Fig. 196.
Km. 68.	Rhyolitic ingimbrites.	
Km. 71.5	Silicified limestones of La Virgen Fm.	Fig. 197.
UTM E 815968 UTM N 1636071 640 m, Zone 15	Original source of the Paleocenic continental molasses of the Subinal Fm. The material contains 27% of iron and some ppm of Zr (211), Sr (55), Rb (56), Zn (84), Mn (470), As (10), Pb (7), Cu (36), Ni (89), Cr (135), and Se (12).	Fig. 198.
UTM E 815909 UTM N 1635802 644 m, Zone 15	Flat laying quartz schist in contact with the previously described molasses.	There are boulders of a granodiorite intrusive on the bed of the river (Fig. 199).
UTM E 814225 UTM N 1634277 713 m, Zone 15	White and pink rhyolitic tuffs. The red unit is richer in Fe (9850 ppm), Mo (4 ppm) and Cu (114 ppm), while the white unit is richer in Zn (13 ppm) and Mn (470 ppm)	Fig. 200.

Figure 195. Quartz-rich schists from the Chuacús Series.

Figure 196. Alluvial conglomerates covering ferruginous schists from the Chuacús Fm.

Figure 197. Silicified limestones from La Virgen Fm.

Figure 198. Possible source of the Subinal Fm.

Figure 199. Boulders of a granodiorite intrusive are found on the bed of the river.

Figure 200. Pink and white rhyolitic tuffs.

Location	Lithology	Observations
UTM E 813613 UTM N 1632690 760 m, Zone 15	Sharp contact between the rhyolitic tuffs on top of quartz schists at the bottom.	Fig. 201.
Km. 72. UTM E 813599 UTM N 1632199 833 m, Zone 15	Granodiorite intrusive with 19% of Fe and some ppm values of Cu (83), As (17), Mn (125), Cr (156), Zr (163), Sr (93), Rb (17), and Mo (1.3).	Fig. 202.
Km. 73.9. UTM E 814268 UTM N 1631570 761 m, Zone 15	Andesite dike with signs of hydrothermal alteration.	
Km. 75.7	Quartz schists of the Chuacús Series.	
Km. 76.9	Andesite dike.	
Km. 77.3	Fragments of basalt in reddish tuffaceous material	Fig. 203.
Km. 80. UTM E 817352 UTM N 1629702 1133 m, Zone 15	Same formation as before.	
Km. 83.	Microdiorite intrusive.	
Km. 84.2	Ferruginous schists of the Chuacús Series.	
Km 85.8.	Granodiorite intrusive.	
UTM E 818575 UTM N 1628227 1279 m, Zone 15	Inclusions of black obsidian in a rhyolitic matrix and pomex on top.	Fig. 204.
Km. 87.8	Continental molasses.	Subinal Fm.
Km 90.3	Pillowed basalts	Fig 205.
Km. 96.	Rhyolitic tuffs covering basaltic flows.	Fig. 206 showing the southern flank of the Jumay volcano in the area.
UTM E 818842 UTM N 1620470 1803 m, Zone 15	Rhyolitic ingimbrites.	
UTM E 816883 UTM N 1620122 1918 m, Zone 15	Red soils over a basaltic lava flow.	
UTM E 815751 UTM N 1619752 1935 m, Zone 15	Rhyolitic ingimbrites.	
UTM E 814540 UTM N 1619630 1985 m, Zone 15	Red soils over a basaltic lava flow.

Figure 201. Contact between white rhyolitic tuffs on top of quartz-rich schists of the Chuacús Series.

Figure 202. Granodiorite intrusive south of the Motagua Fault.

Figure 203. Basalt fragments on a tuffaceous matrix.

Figure 204. Black obsidian in a rhyolitic matrix.

Figure 205. Perfect example of pillowed basalts most probably associated to the South Motagua ophiolitic complex.

Figure 206. Volcano Jumay showing an open caldera to the south.

Location	Lithology	Observations
Km. 124 UTM E 813255 UTM N 1613587 2194 m, Zone 15	Granodiorite intrusive.	Fig. 207
UTM E 812259 UTM N 1611251 2825 m, Zone 15	Granodiorite intrusive.	
UTM E 806180 UTM N 1609137 2379 m, Zone 15	Granodiorite intrusive.	Fig. 208.
UTM E 804608 UTM N 1608763 1998 m, Zone 15	Granodiorite intrusive.	
CA-1 UTM E 804362 UTM N 1600428 1337 m, Zone 15	Rhyolitic ingimbrites.	
CA-1 UTM E 773445 UTM N 1590231 1071 m, Zone 15	Basaltic scoria on top of rhyolitic ingimbrites.	
CA-1 UTM E 770937 UTM N 1602524 1704 m, Zone 15	Rhyolitic ingimbrites.

Figure 207. Granodiorite intrusive south of the Motagua Fault.

Figure 208. Another outcrop of the same intrusive.

A series of 23 stops have been selected within the Motagua Suture Zone to familiarize you with the petrological and structural characteristics of its main geological units, and to show the Ni lateritic potential of the area (see Figure 101, page 107 and attached maps in the back pocket). Three days are necessary for the complete trip.

**Ciudad de Guatemala – Km 25 (Obsidian Hills) – San Agustín de Acasaguastlán –
Quiriguá – Los Mariscos – Río Dulce.**

Main Topics: The North Motagua (NM) and the Juan de Paz (JPZ) ophiolitic units.

STOP 1. CA-9 (CARRETERA ATLÁNTICA-9), KM 25

Short stop to observe a geological curiosity – black and reddish-brown obsidian inclusions in a rhyolitic matrix of the Tertiary – Quaternary volcanics of the Volcanic Province of Guatemala (Figs. 193 and 194).

Figure 209. Reddish and black obsidians outcrop on km 25 of the CA-9.

Figure 210. Rhyolitic matrix hosting the obsidian inclusions.

This rhyolitic matrix in comparison with the obsidians is enriched on all elements but Zn. The black obsidian is depleted in manganese and enriched in Zn, while the reddish obsidian is depleted in lead, zinc, and zirconium, while enriched in strontium.

Please be careful if you are taking samples... There is a very good reason why the Mayans used the sharp edges of these stones as scalpels.

STOP 2. CA-9, KM 34

Short stop to observe the horizontal sequence of the rhyolitic ignimbrites covering the megaconglomerates of the Sacapulas Fm and the volcano-sedimentary units of the Chiocol Fm (Fig. 167).

Figure 211. The Sacapulas and Chiocol PZ Formations lie horizontally across all the Motagua Suture Zone.

These formations develop horizontally across the whole Motagua Suture Zone, and are intersected at different elevations by the road.

STOP 3. CA-9, KM 76

A stop to study the Eocene molasses that cover the south border of the North Motagua and Juan de Paz-Los Mariscos ophiolitic belt. These are synforms and antiforms of a flischoid polymictic poorly sorted conglomerate, with fragments of quartz, basalt, andesites, and sedimentary units (Fig. 168).

Figure 212. Julio Roberto Perez observes the ripples of the paleo water surface at the Palocenic molasses that cover the south border of the North Motagua ophiolitic belt.

It is clear from the outcrops that this was a binary event with sharp difference in the grain size, not the composition, of the sediments.

As a curiosity, sometimes we can observe the effect of the ripple of the sea surface at the bottom of this formation.

STOP 4. SAN AGUSTÍN DE ACASAGUASTLÁN (CA-9, KM 89, RD-3, KM 89.2), THE NORTH MOTAGUA UNIT (NM)

The North Motagua Unit (NM) crops out on the hydrographic left side of the Río Motagua, and is exposed several times along the CA-9 highway (Fig. 169).

The NM unit consists of several tectonic sheets, often chaotic and pervasively deformed along the shear surfaces (Fig. 170). Southward it is unconformably overlain by Eocene continental molasses of the Subinal Fm. and by Tertiary and Quaternary clastic sequences of the Motagua Valley.

The lithostratigraphic sequence of the NM unit is represented by El Tambor group, with its stronger degrees of tectono-metamorphic deformations. Highly serpentinized harzburgites represent its main lithology, which includes boudins and blocks of jadeites, albites, metabasites, and amphibolites.

Figure 213. Topographic map of the San Agustín de Acasaguastlán area with the stop location on the NM unit. Each square is 1 km².

Figure 214. Pervasively deformed shear surfaces of the North Motagua ophiolitic belt (CA-9, km 77).

The NM unit has been clearly affected by HP-LT metamorphism during the Cretaceous tectonic phases (Fig. 171). The presence of jadeites indicates a pressure range between 5 and 11 Kbar and temperatures not higher than 400°C. The subsequent replacement of jadeite by analcime and albite suggests that both pressure and temperature decreased towards values of less than 300°C and 7.5 Kbar.

Figure 215. Outcrop of the HP-LT North Motagua ophiolitic belt near San Agustín de Acasaguastlán.

STOP 5. (CA-9, KM 136.5, CA 10, KM 142) PALEONTOLOGICAL MUSEUM

On our way to Río Dulce we will have a 30 minute stop to see an amazing paleontologic collection that includes mastodons, whales, and the Giant Caribbean rat (Perezoso Gigante), among other fossils and human remains (Fig. 172).

Figure 216. The paleontological museum of Estanzuela showing left to right a whale, the Perezoso Gigante and a reconstructed mastodon.

STOP 7. QUIRIGUÁ (CA-9, KM 204), A MAYA SITE

This is an optional 30 minutes stop to visit an important site of the Mayan culture, showing “estelas” (Fig. 200), zoomorphic figures (Fig. 201), and a typical ball field (Fig. 202). In observing these monuments, I has always amazed by what appears to be an Egyptian influence on this structures. On Fig. 203, notice the similarity in the posses, the eyes, and very specially the beards, which according to Spanish records, were unknown to the Mayans.

Figure 217. One of the many "Estelas" found among the ex-United Fruit banana plantation at the Quiriguá Maya site.

Figure 218. A zoomorf of a jaguar and a frog at Quiriguá.

The site includes a Mayan ball field and is located in the heart of an enormous banana plantation previously owned by United Fruits.

Figure 219. Typical ball field at Quiriguá, Guatemala.

Figure 220. Extraordinary similarities can be observed between these Mayan monuments and older Egyptian ones.

[illegible]

Suggested activity: Stop for lunch at Longarone, Km 126.8. Excellent Italian food and fresh fish and shrimp.

STOP 8. JUAN DE PAZ (CA-9, KM 186.3, RD 4, KM 218.6), THE JUAN DE PAZ - LOS MARISCOS UNIT (JPZ)

The western end of the Juan de Paz – Los Mariscos ophiolitic belt is clearly shown on this outcrop (Fig. 177). Is a zone of mylonitization with abundant budinage, indicating zones of intense dynamo-metamorphism.

Figure 221. This mylonitic zone marks the western border of the Juan de Paz - Los Mariscos ophiolitic belt south of Lake Izabal.

STOP 9. LOS MARISCOS (CA-9, KM 215, RD 4, KM 218.6), THE JUAN DE PAZ – LOS MARISCOS UNIT (JPZ)

The Juan de Paz unit (JPZ) crops out some 50 km eastwards from the NM unit in a series of ophiolitic bodies located along the main Motagua Fault on the hydrographic left side of the Río Motagua. The main outcrops are close to Juan de Paz, Los Amates, Los Mariscos (Figs. 178-179), and Morales villages as far as the southern coast of Izabal Lake. Smaller outcrops are also found within the Quaternary plains near Puerto Barrios.

Figure 222. Topographic map of Los Mariscos area showing the location of the stop on the JPZ unit. Each side of the square is 10 km.

Figure 223. Outcrop of the Juan de Paz ophiolitic belt near Los Mariscos.

The JPZ unit shows island-arc magmatic affinity characterized by the crystallization order of olv-cpx-plg. The upper part of the unit has island-arc calc-alkaline character, while its base has more affinity to an island-arc tholeiitic sequence.

The JPZ unit overthrusts the Sierra Las Minas Paleozoic basement and is subdivided in several thrust sheets. The unit is overlain by the molasses of the Subinal Formation.

Main lithological type is a serpentinitic lherzolite, strongly boudinaged with indications of hydrothermal alteration represented by inclusions of magnesite (Fig. 210).

Figure 224. Magnesite veins are common at the Juan de Paz-Los Mariscos ophiolitic belt.

Within this complex we can observe some laterites outcrops between Kms. 224 and 226 of the road to the lake from the Montufar license from CGN-Skye Resources Inc (Fig. 212).

Figure 225. Laterites from the Motagua license at the Juan de Paz - Los Mariscos ophiolitic complex (UTM E: 279129, UTM N: 703073, Elevation: 93 m, Zone 16).

[illegible]

Suggested activity: Visit the Castillo de San Felipe, a fortress built to protect El Estor from pirates and buccaneers.

FIELD TRIP DAY 2

**Río Azúl - El Bongo - El Túnico - Exmibal – Sechol - Marichaj - San Lucas - La Unión-
Barrios (Baja Verapaz)**

**Main Topic: The Geosol Izabal and The Sierra de Santa Cruz (SSC) ophiolitic unit and the
eastern border of the Baja Verapaz ophiolitic belt.**

STOP 10. RN 13 (RUTA NACIONAL 13), RÍO AZÚL

The Río Azúl property (Fig. 182) has an area of 42 km². It is located at the NE corner of Lake Izabal, among the mafic volcanoclastic unit of the San Lucas Fm. and sedimentary units of the Río Dulce Fm to the south and the ultramafic rocks of the Sierra de Santa Cruz ophiolitic belt to the north.

Figure 226. Location of the Río Azúl license.

There is also the presence of a more felsic unit (Fig. 183). The area has potential for gold associated to the volcanic rocks and nickel associated to the SSC unit.

Figure 227. Contact of a rhyolitic lava flow with sediments of the Río Dulce Fm. at Río Azúl in a typical low sulphidation epithermal environment.

The presence of hydrothermal activity in the area has contributed to the formation of Iron Caps on top of the laterites and skarns on other carbonatic rocks (Fig. 184).

Figure 228. Grossularite-rich skarns within Río Azúl license.

Río Azúl was initially look at as a nickel target, but the thick “laterite” profiles observed on cuts of the road, under closer inspection, resulted to be a clayish iron-rich andesitic tuff of the San Lucas Fm.. However, the presence of silica-iron caps, quartz veining and other signs of alteration indicate the potential of this property as a gold target. Also, more to the north, we can see the ultramafic rocks of the Sierra de Santa Cruz ophiolitic belt, so there is also potential for finding other laterite pockets in the area.

Figure 229. Geological interpretation of Río Azúl.

STOP 11. A TRAVERS THROUGH THE SIERRA DE SANTA CRUZ OPHIOLITIC BELT

A summary of the road geology across a section of the Sierra de Santa Cruz ophiolitic belt (Fig. 186) is presented in Table 8.

Table 8. Road geology across the Sierra de Santa Cruz ophiolitic belt.

POINT	UTM E	UTM N	ELEVATION	DESCRIPTION	FIG. #
P.11.a	25343	172141	53	Zone of millonitization with fragments of lherzolite and anorthosite (?)	187
P.11.b	25356	172205	176	Zone of development of a proto-laterite over lherzolites, still showing millonitic texture. Very abundant chromite on surface.	188
P.11.c	25440	172525	282	Quartz vein (56°/90°) with strong Fe-K alteration, within what appears to be an incipient iron cap. There is also asbest and zeolite alteration.	189
P.11.d	25414	172529	125	Lateritic cut @ 320° from this point, across the Sauce River.	190

Figure 230. Access road to the village El Bongo across the Sierra de Santa Cruz ophiolitic belt. Each side of the square is 10 km.

Figure 231. Zone of millonitization with fragments of websterite and anorthosite.

Figure 232. Proto-laterite over lherzolites.

Figure 233. Quartz vein associated to a zone of intense Fe-K alteration.

Figure 234. Lateritic cut across the Sauce River, past the El Bongo town.

STOP 12. RN 13, EL TÚNICO LATERITIC TARGET.

El Túnico is located east of El Estor village (Fig. 191).

Figure 235. Topographic map of the western portion of El Túnico lateritic area showing the location of the stop No. 5 on the SSC unit. Each side of the square is 10 km.

Interestingly, El Túnico is the only place where we have found a well developed Iron Cap, probably associated to hydrothermal activity from the sulphide-rich thermal waters from the tourist resort El Paraíso (UTM N 172486; UTM E 26314; Zone 16) and elsewhere in the area (Fig 192).

As mentioned before, El Túnico is the only place with confirmed values of gold and PGM associated with the laterites (Fig. 193).

Figure 236. Iron caps formed at El Túnico helped conserve the full laterite profile.

Figure 237. PGM anomaly related to an olivine lherzolite layer within El Túnico. Its epicentre coincides with the gold, nickel, and cobalt anomalies in the area. The black dots represent the location of the grab samples.

STOP 13. RN 13, EL ESTOR – EXMIBAL (FENIX PROJECT) DEPOSIT.

El Estor is the main village in the area (Fig. 194). It was the base for the operations of the Exmibal S.A. when they were developing La Gloria deposit (Fig. 195) to produce nickel matte at their plant (Fig. 196).

Figure 238. Topographic map of El Estor village showing the location of the stop No. 6 on the SSC unit. Each side of the square is 10 km.

Figure 239. La Gloria bench showing the limonitic horizon.

Figure 240. The Exmibal plant which cost \$220M, produced nickel matte between 1977 and 1980 before stopping operations due to the oil crisis and the fall of nickel prices.

The area of the Sechô license is located to the north of the Polochic fault immediately in the South limit of the Mayan Block and includes the eastern part of the Sierra de Santa Cruz ophiolitic belt (SSC) of the homonymous mountain range (Fig. 197). This belt is constituted mainly by layered serpentinitized ultramafic rocks represented by alternations of olivine lherzolites, lherzolites, and olivine websterites, with subordinate amounts of gabbros and basalts. The obduction of this ophiolitic belt probably took place towards the Lower Tertiary age throughout and to the north of the Polochic fault.

The most advanced mapping has been completed at Sechol. I completed a lineament analysis combined with field observations and the interpretation of geochemical and lithogeochemical data to create a surficial (Fig. 198) and a bedrock map of the property (Fig. 199).

Figure 242. Surficial geological map from Sechol.

Figure 243. Bedrock geological map of Sechol.

Within the Measured Resources I identified a rich lateritic pocket of 5 MT grading 2.1% Ni and 0.08% Co which we named “El Inicio” (Fig. 41).

Figure 244. El Inicio looking east from the road.

Most of the initial exploration completed in the area involved the use of manual augers (Fig. 201). This highly portable equipment allowed a 100% recovery with no contamination at a rate of 5 metre per hour, but usually it could not penetrate beyond the Stoneline horizon. The augering defined a second large target in Sechol named El Segundo (Fig. 202), which was probably connected to El Inicio.

Figure 245. A 10 metre hole using a manual auger at El Segundo.

El Segundo

Figure 246. The new lateritic pocket El Segundo located two km southwest of El Inicio. The thicknesses reported here are only of the limonite horizon, since the manual augers usually get stopped by the Stone line horizon.

Finally, just north of Sechol, we have another target named Seamay (Fig. 203).

Figure 247. Seamay license located north of Sechol at Sierra de Santa Cruz ophiolitic belt.

STOP 15. MARICHAJ LATERITIC TARGET

One of the best examples of laterite development within the Sierra de Santa Cruz ophiolitic belt is found in the vicinity of Chiis (Fig. 204), where 3 pits and an auger program using a 200 x 200 m grid were completed (Fig. 205).

Figure 248. Topographic map of the Marichaj lateritic target showing the location of the stop No. 15 on the SSC unit as well as the location of the three pits and the area covered by the 200 x 200 m auger program. Each square is 1 km².

Figure 249. Preparing a pit for sampling at Chiis.

The program defined the presence of another large and thick lateritic pocket in the area.

STOP 16. WESTERN SECTION OF THE SSC OPHIOLITIC BELT.

The laterites from San Lucas are the most western targets that I have so far located within Sierra de Santa Cruz ophiolitic belt (Fig. 206). The area is very promising with large lateritic pockets like La Ponderosa, La Bonanza, (Fig. 207) and La Esperanza.

Figure 250. Topographic map of the San Lucas lateritic target showing the location of the stops No. 16a and 16b on the SSC unit, as well as the location of the three lateritic pockets (minimum thickness of the lateritic horizon equal 7 metres).

Figure 251. Drilling at La Bonanza within the San Lucas lateritic target area.

Point 16a is a short stop to look at the relationship between the mafic volcanoclastics of the San Lucas Fm. with the bituminous limestone of the Ixcoy Fm (Fig. 207). The presence of fragments of the San Lucas Fm. within the limestone indicates that these volcanic rocks are older than the Ixcoy bituminous limestone. A few metres ahead of this point, we can also observe the tectonic contact between the San Lucas Fm. and the ultramafics of the Sierra de Santa Cruz ophiolitic belt (Fig. 208).

Figure 252. A close-up of a well preserved basaltic fragment of the San Lucas Fm in the bituminous limestone of the Ixcoy Fm.

Figure 253. Clear tectonic contact between the San Lucas volcanoclastic formation and the SSC unit at San Lucas.

Finally, we will stop at a perfect example of the selective development of laterites over olivine-lherzolites (Fig. 210).

Figure 254. Typical example of a laterite pocket developed over olivine-rich lherzolites in contact with a websterite.

STOP 17. RN 13, FROM EL INICIO TO COBÁN.

From San Lucas we will return to RN 13 and continue west in the direction of Cobán. Although the landscape is impressive (Fig 211), we will be traveling along limestones of the Ixcoy Fm., so no stops are considered at this time.

Figure 255. Waterfall from the limestones of the Ixcoy Fm. at Sierra de Santa Cruz.

STOP 18, CA 13, KM 151 – 155, LA UNIÓN-BARRIOS.

From RN 13 we take south at CA 14 until km 151. This is a large laterite pocket located at the south-west border of Nichromet's reconnaissance license (Fig. 212). The pocket extends north for 4 km.

Figure 256. Laterite pocket at La Unión-Barrios, at the south-west border of the Baja Verapaz ophiolitic belt.

In situ determinations using a portable XRF have demonstrated the presence of nickel on surface (0.2%), chromium (1.25%) and iron (15%).

STOP 19. CA 14, KM 141-148. QUISÍS LATERITIC TARGET

Located on the CA 14, north of the Matanzas village (Fig. 213), these two claims show a considerable lateritic development that can be observed from artificial cuts on the flanks of the Baja Verapaz belt (Fig. 214).

Figure 257. Topographic map of the Quisís license showing the location of the stop No. 19 on the Baja Verapaz ophiolitic belt. Each square is 1 km².

Figure 258. Limonitic horizon of the laterites near Matanzas within the Baja Verapaz belt.

STOP 20. CA 14, KM 148-170. RÍO COLORADO

Located to the north of the Quisis license (Fig. 215), the Río Colorado target is one of the biggest and most impressive lateritic bodies within the Baja Verapaz belt (Fig. 2166). Here, the BVP unit is in tectonic contact with the limestones of the Ixcoy Fm. to the east of the Colorado River.

Figure 259. Topographic map of the Río Colorado lateritic target, showing the location of the stop No. 20 on the Baja Verapaz belt. Each square is 1 km².

[illegible]

Suggested activity: Go to sleep early... tomorrow is another big day.

FIELD TRIP DAY 3

La Perseverancia – Granitoid Unit – Chuacús Series — Guatemala City

STOP 21. 7W, SOUTH OF USPANTÁN, LA PERSEVERANCIA

Following the 7W to the west we travel almost parallel to the contact of the Baja Verapaz ophiolitic belt against the bituminous limestones of the Ixcoy Fm. the Polochic Fault (Fig. 216).

Figure 260. The Río Negro runs along the Polochic Fault, north of the Baja Verapaz ophiolitic belt.

La Perseverancia is by far the largest and most exiting target we have discovered so far within the Baja Verapaz ophiolitic unit and it is a classical example of the successful application of the exploration model to explore in this targets:

1. Find the proper rocks (olivine lherzolites, Fig. 217)
2. Find the proper slope (Fig. 218)
3. Look for staining due to the presence of Cr and Ni. (Fig. 219)
4. Keep looking; laterites are not far away (Fig. 220).

Figure 261. Olivine lherzolites layer within websterites near La Perseverancia at Baja Verapaz ophiolitic belt.

Figure 262. Slopes of less than 45° are necessary for the laterites to remain in place.

Figure 263. Staining is one of the key elements on locating laterites.

Figure 264. Laterites from La Perseverancia, one of the largest targets found so far within the Baja Verapaz ophiolitic belt.

STOPS 22 AND 23. RN 15. GRANITOID UNIT AND THE CHUACÚS SERIES

On our way back to Guatemala City, we will pass by a very large granitoid unit (Fig. 221) that could be a source of other types of deposits (Cu and Au) and we will cross again the schists of the Chuacús Series (Fig. 222).

Figure 265. Granitoid unit west of Baja Verapaz ophiolitic belt.

Figure 266. Sericitic schist of the Chuacús Series.

[illegible]

Suggested activity: Dinner at Los Ranchos, the best Argentinean meat in Guatemala.

And do not leave Guatemala without visiting Antigua at least for half a day.

STOP 24. TOUR OF ANTIGUA

Located only 42 km from Guatemala City, Antigua is a most see place for all visitors. Crossing over a short stone bridge at the entrance of Antigua will allow you to jump centuries into the past. From ruins (Fig.223) and museums (Fig. 224) to modern hotels (Fig. 225) and spectacular views (Fig. 226), you will enjoy this visit and very probably come again.

Figure 267. One of the churches destroyed by the earthquake of September 11, 1850.

Figure 268. One of the most interesting exhibits of the Jade Museum at Antigua, showing jade fillings on the teeth of this skull.

Figure 269. Casa Santo Domingo in Antigua.

Figure 270. View of the Volcán de Agua from the Hotel Casa Santo Domingo.

REFERENCES

- Anderson, T.H.**, 1967. Geology of the central third of La Democracia quadrangle. M.A. Thesis, Austin, Texas University.
- Beccaluva L., S. Bellia, M. Coltorti, G. Dengo, G. Giunta, J. Mendez, J. Romero, S. Rotolo, and F. Siena**, 1995. The northwestern border of the Caribbean Plate in Guatemala: new geological and petrological data on the Motagua Ophiolitic belt. *Ofioliti*, 20 (I):1-15.
- Blount, D.**, 1967. Geology of the Chiantla quadrangle, Huehuetenango, Guatemala. Ph.D. Thesis, Louisiana State University.
- Boyd, A.**, 1966. Geology of the western third of La Democracia quadrangle. M.A. Thesis, Austin, Texas University.
- Clarke D.**, 1993, NewPet for DOS, Memorial University of Newfoundland, Department of Earth Sciences, Centre for Earth Resources Research, <http://www.gli.cas.cz/lang/Newpet/newpet.exe>.
- Cox, K. G., J.D. Bell and R.J. Pankhurst**, 1979. "The Interpretation of Igneous Rocks", George Allen and Unwin, London.
- Davis, G.H.**, 1966. Geology of the eastern third of La Democracia quadrangle. M.A. Thesis, Austin, Texas University.
- Debon, F. and P. Le Fort**, 1983. A chemical-mineralogical classification of common plutonic rocks and associations, *Transactions of the Royal Society of Edinburgh Earth Sciences*, vol.73, pp.135-149.
- Gibbs, G.W., H.Y. Hui**, 1971. The organic content of Canadian chrysotile, in *American Industrial Hygiene Association Journal*, Vol. 32, No. 8, 519 - 528 pp.
- Giunta G., L. Beccaluva, M. Coltorti, D. Cutrupia, B. Mota, E. Padoa, F. Siena, C. Dengo, G. E. Harlow, and J. Rosenfield**, 2002. The Motagua Suture Zone in Guatemala, Field Trip – Guide Book, publication supported by Ofioliti Int. Journal (M. Marroni and L. Pandolfi eds.).
- Gomberg, D.N., P.O. Banks, A.R. McBirney**, 1968. Guatemala: Preliminary zircon ages from Central Cordillera, in *Science*, Vol. 161, No. 3849, 121 - 122 pp.
- Harlow, E.H., S.R. Hemming, H.G.A. Lallement, V.B. Sisson, S.S. Sorensen**, 2004. Two high-pressure-low-temperature serpentinite-matrix mélange belts, Motagua fault zone, Guatemala: A record of Aptian and Maastrichtian collisions, in *Geology*, January 2004, V. 32, No. 1, 17 - 20 pp.
- Irvine, T. N. and W.R.A. Barager**, 1971. A guide to the chemical classification of the common volcanic rocks, *Canadian Journal of Earth Sciences*, vol.8, pp.523-548.
- Jensen, L. S.**, 1976. A New Cation Plot for Classifying Subalkalic Volcanic Rocks, Ontario Division of Mines, MP 66, 22p.
- Korea International Cooperation Agency and the Korean Institute of Geology, Mining, and Materials**, 1998. The Geochemical Exploration Project in the Volcanic and

Metamorphic Area in the Motagua Basin of Guatemala, Integrated Report, Ministry of Energy and Mines, Dirección General de Minería, Guatemala.

Maniar, P. D. and P.M. Piccoli, 1989. Tectonic discrimination of granitoids, Geological Society of America Bulletin, vol.101, pp.635-643.

McBirney, A. R., 1963. Geology of a part of the Central Guatemalan Cordillera, in University of California Publication Geological Science, Vol. 38, 177 - 242 pp.

Millan, S.M., 1985, Preliminary Stratigraphic Lexicon North and Central Guatemala (a compilation under a contract with the United Nations Development Program).

Miyashiro, A., 1974. Volcanic rock series in island arcs and active continental margins, American Journal of Science, vol.274, pp.321-355.

Mullen, E. D., 1983. MnO/TiO₂/P₂O₅: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis, Earth and Planetary Science Letters, vol.62, pp.53-62.

Peacock, M.A., 1931. Classification of igneous rock series, Journal of Geology, vol.39, pp.54-67.

Pearce, T.H., B.E.Gorman and T.C.Birkett, 1977, The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks, Earth and Planetary Science Letters, vol.36, pp.121-132.

Richard, H.G., 1963. Stratigraphy of the earliest Mesozoic sediments in southwestern Mexico and western Guatemala, in American Association of Petroleum Geological Bulletin, Vol. 47, 1861 - 1870 pp.

Sapper, K., 1937. handbuch der regionalen geologie: Mittelame-rika, Heidelberg, Bd. 8, Abt. 4a, Heft. 29.

Schandl, E.S., 2005. Detailed petrography and mineralogy of ultramafic and other rocks from the ophiolitic belts in Central Guatemala. Internal report for Nichromet Extraction Inc.

Shervais, J. W., 1982. Ti-V plots and the petrogenesis of modern and ophiolitic lavas, Earth and Planetary Science Letters, vol.59, pp.101-118.

Termer, F., 1932. Geologie von Nordwest-Guatemala Zeit-Schr. Grssel: f. Erdkunde. Berlin, num 7 - 8, 241 - 248 pp

Trusova I. F. and V. I. Chernov, 1982. Petrografia magmaticeskij i metamorficheskij gornij parod (in Russian). Nedra, Moscow, 272 pp.

Valls Alvarez, R. A., 2002. Summary Report on the Geology and Mineral Resources of the Sechol Nickel-Magnesium Laterite Deposit. Guatemala, Central America. SEDAR, 332 pp.

Valls Alvarez, R. A., 2003. The Geosol Izabal – a different type of nickel-cobalt laterite in Central America, Internal Report for Jaguar Nickel Inc.

Valls Alvarez, R. A., (unpublished). Field Petrology. A Practical Approach to the Study of Petrological Data. 350 pp.

Vinson, G.L., 1962. Upper Cretaceous and Tertiary stratigraphy of Guatemala, in American Association of Petroleum Geologists Bulletin, Vol. 44, 1273 - 1315 pp.

Walpe, J.L., 1960. Geology of the Coban-Purulha Area, Alta Verapaz, Guatemala, in Bulletin of the American Association of Petrology Geologists, Vol. 44, No. 8, 1273 - 1315 pp.

APPENDIX 1. CURRENT APPLICATIONS OF NICROMET GUATEMALA, S. A.

UTM E	UTM N	Vértice	Licencia
240000	1736000	1	Chinabenque I
243000	1736000	2	Chinabenque I
243000	1729900	3	Chinabenque I
251000	1729900	4	Chinabenque I
251000	1727300	5	Chinabenque I
256000	1727300	6	Chinabenque I
256000	1724000	7	Chinabenque I
251000	1724000	8	Chinabenque I
251000	1725000	9	Chinabenque I
247000	1725000	10	Chinabenque I
247000	1726000	11	Chinabenque I
240000	1726000	12	Chinabenque I
256000	1727300	1	Chinabenque II
275000	1727300	2	Chinabenque II
275000	1726000	3	Chinabenque II
256000	1726000	4	Chinabenque II
275180	1741700	1	Coatepeque
279500	1741700	2	Coatepeque
279500	1737500	3	Coatepeque
284000	1737500	4	Coatepeque
284000	1736000	5	Coatepeque
278000	1736000	6	Coatepeque
278000	1736500	7	Coatepeque
275180	1736500	8	Coatepeque
262000	1697800	1	Los Amates
275300	1697800	2	Los Amates
275300	1684500	3	Los Amates
262000	1684500	4	Los Amates
262000	1687000	5	Los Amates
264000	1687000	6	Los Amates
264000	1688000	7	Los Amates
266000	1688000	8	Los Amates
266000	1688500	9	Los Amates
268000	1688500	10	Los Amates
268000	1689000	11	Los Amates
269000	1689000	12	Los Amates
269000	1690000	13	Los Amates
271000	1690000	14	Los Amates
271000	1690500	15	Los Amates
273000	1690500	16	Los Amates
273000	1692000	17	Los Amates
271000	1692000	18	Los Amates
271000	1694000	19	Los Amates
274000	1694000	20	Los Amates

UTM E	UTM N	Vértice	Licencia
274000	1696000	21	Los Amates
262000	1696000	22	Los Amates
243000	1733500	1	Sierra de Santa Cruz
245000	1733500	2	Sierra de Santa Cruz
245000	1733000	3	Sierra de Santa Cruz
246000	1733000	4	Sierra de Santa Cruz
246000	1732400	5	Sierra de Santa Cruz
247000	1732400	6	Sierra de Santa Cruz
247000	1732000	7	Sierra de Santa Cruz
247800	1732000	8	Sierra de Santa Cruz
247800	1731500	9	Sierra de Santa Cruz
248600	1731500	10	Sierra de Santa Cruz
248600	1731000	11	Sierra de Santa Cruz
249600	1731000	12	Sierra de Santa Cruz
249600	1730400	13	Sierra de Santa Cruz
251000	1730400	14	Sierra de Santa Cruz
251000	1730200	15	Sierra de Santa Cruz
251400	1730200	16	Sierra de Santa Cruz
251400	1729800	17	Sierra de Santa Cruz
252000	1729800	18	Sierra de Santa Cruz
252000	1729200	19	Sierra de Santa Cruz
253000	1729200	20	Sierra de Santa Cruz
253000	1728600	21	Sierra de Santa Cruz
254000	1728600	22	Sierra de Santa Cruz
254000	1728000	23	Sierra de Santa Cruz
255000	1728000	24	Sierra de Santa Cruz
255000	1727600	25	Sierra de Santa Cruz
259000	1727600	26	Sierra de Santa Cruz
259000	1727800	27	Sierra de Santa Cruz
261000	1727800	28	Sierra de Santa Cruz
261000	1728200	29	Sierra de Santa Cruz
262000	1728200	30	Sierra de Santa Cruz
262000	1728500	31	Sierra de Santa Cruz
263000	1728500	32	Sierra de Santa Cruz
263000	1728700	33	Sierra de Santa Cruz
265500	1728700	34	Sierra de Santa Cruz
265500	1730500	35	Sierra de Santa Cruz
266400	1730500	36	Sierra de Santa Cruz
266400	1731000	37	Sierra de Santa Cruz
271000	1731000	38	Sierra de Santa Cruz
271000	1731400	39	Sierra de Santa Cruz
272000	1731400	40	Sierra de Santa Cruz
272000	1731600	41	Sierra de Santa Cruz
275000	1731600	42	Sierra de Santa Cruz
275000	1727300	43	Sierra de Santa Cruz
251000	1727300	44	Sierra de Santa Cruz
251000	1729900	45	Sierra de Santa Cruz

UTM E	UTM N	Vértice	Licencia
243000	1729900	46	Sierra de Santa Cruz
274980	1731480	1	Río Azul
280151	1731568	2	Río Azul
280410	1727690	3	Río Azul
275153	1727777	4	Río Azul

Figure 271. Location of Nicromet Guatemala S.A. licenses with respect to Exmibal's main target- La Gloria pit.