Geological evolution of the NW corner of the Caribbean Plate

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Abstract: The Caribbean Plate consists of a plateau basalt, formed probably in the Middle Cretaceous, complicated by a continental block, Chortís, several magmatic arcs, strike–slip motions along major fault systems such as the Motagua–Polochic fault zone in Guatemala, the pull-apart basin of the Cayman Trough and subduction zones below Central America and the Lesser Antilles. Five major collisional events have been identified: (i) Late Paleocene–Middle Eocene collision of the Greater Antilles with the Bahamas platform; (ii) Late Cretaceous collision of Chortís with the Maya Block; (iii) emplacement of nappes upon the Venezuelan foreland in the Cenozoic; (iv) collision of the Western Cordillera oceanic complex with the Central Cordillera of Colombia; and (v) Miocene collision of the eastern Costa Rica–Panama arc with the Western Cordillera. All these 'orogenic events' show an eastward movement of the Caribbean Plate relative to the Americas. Migration of the Jamaica Block from the Pacific caused obduction of the oldest ophiolites of Huehuetenango at the western end of the Polochic–Río Negro faults in Guatemala. South-southwest migration of the Chortís Block from west of Mexico and northward towards the Maya Block destroyed a trench associated with the Motagua–Jalomáx fault system and caused the Chuacús Orogeny, emplacing Guatemalan ophiolite complexes and metamorphosing the rocks from the Chuacús Series.

The Caribbean Plate

Roughly 3.2 million square kilometres in area, the Caribbean Plate (Fig. 1) is the result of the pre-Cretaceous to 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, followed by tensional and strike–slip tectonics.

The Caribbean Plate is mostly oceanic, consisting of a plateau basalt formed probably in the Middle Cretaceous, complicated by the presence the continental Chortís Block, several magmatic arcs, a combination of a strike–slip motions along major fault systems, such as the Motagua–Polochic fault zone in Guatemala and the Oriente fault in Cuba, the pull-apart Cayman Trough and subduction zones Central America and the Lesser Antilles. Although the Caribbean 'is a single place in the planet, surely with a single history' (Iturralde Vinent 2004) two conflicting theories regard its formation as allochthonous or in-place. This paper contributes data from Guatemala to the current discussions.

Morphotectonic units

Guatemala is physiographically divided into four main morphotectonic units: (1) a narrow Pacific Coastal Plain on the west; (2) a NW-trending Volcanic Province; (3) an east–west trending Central Cordillera centred on the Motagua Suture Zone; and (4) the Petén Lowland to the north.

The Pacific Coastal Plain is about 50 km wide and consists mainly of andesitic and basaltic alluvial pebbles and conglomerates derived from the Volcanic Province. It is the fore-arc basin of the Central American subduction zone.

The Volcanic Province is a chain of active volcanoes to the south and Cenozoic igneous rocks to the north. Magmatic activity results either from subduction or to collision of the Caribbean and North American plates. Volcanism has migrated southwards, becoming more basic. Cretaceous granites are present in the north and Cenozoic granites in the south. Quaternary volcanoes reach up to 4200 m high, and at least seven have been active or in the fumarole stage during the present century. The 80 000 year old Atitlán and Ayarza Lakes occupy calderas.

The Central Cordillera, with the oldest rocks in Guatemala, is composed mainly of Palaeozoic schists, pegmatites, Cretaceous carbonates and pre-Cretaceous to Cenozoic Ophiolite complexes. This area is crossed by the arcuate Motagua–Polochic fault system, considered to be the westward continuation of the Cayman Trench.

The Petén Lowland is the foreland of Palaeozoic 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. Abundant Cenozoic rhyolitic tuffs occur near the contact with ophiolites of the Polochic Belt (Valls 2006).

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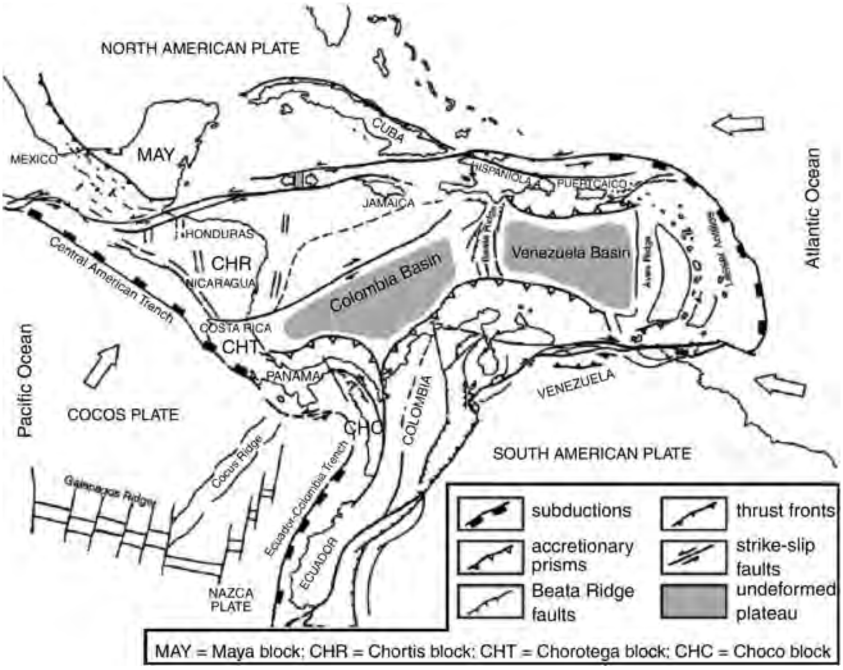

Fig. 1. Structural sketch map of the Caribbean area (from Giunta *et al.* 2002). Arrows show the drifting direction of the main plates. In red is the location of the area of the current study.

Guatemalan stratigraphy

The stratigraphy of Central Guatemala (Fig. 2) is described by Vinson (1962) and the stratigraphic lexicon of SE-central Guatemala (Millan 1985). Following is a brief description of the main stratigraphic units of Central Guatemala.

Chuacús Series (Lower Palaeozoic)

McBirney (1963) named this series of metamorphic rocks in the Central Cordillera, between the Maya and Chortís Blocks. Rocks include schist, gneiss, amphibolites and marbles. Chuacús Series sediments accumulated during Devonian, derived from a Precambrian landmass; U–Pb age dating of zircon, biotite–albite gneiss and biotite–albite–epidote gneiss gives a Proterozoic age of 1075 ± 25 Ma (Gomberg *et al.* 1968). There are three metamorphic zones. A chlorite-sericite zone of sericite schists, metagreywackes, meta-arkose, granitoids quartzites and crystalline limestone is located around the city of Salamá. A biotite zone, composed of biotite–muscovite–hornblende–epidote schist is found in the area of El Chol (El Chol Schist). A garnet–kyanite–muscovite–hornblende zone occurs near Palibatz (Palibatz Schist).

Chiocol Formation (Upper Palaeozoic)

The Chiocol Formation is a sedimentary sequence that crops out on both sides of the Chitxoy–Polochic fault zone, east and SE of San Sebastian Huehuetenango. This formation is a distinctive sequence of interbedded greenish-grey, grey and light blue-grey conglomerate and sandstone, grey-green, grey and maroon tuffs and volcaniclastic beds and less common andesite breccia. Thickness of the formation is in the order of 1000 m and its age is Ordovician–Permian.

Sacapulas Formation (Upper Palaeozoic)

The Sacapulas Formation, along the Chitxoy–Polochic fault zone 35 km to the east of San Sebastian Huehuetenango, consists of 600 m of conglomerates transitional into slate and sandstone with local volcanic and metavolcanic interbeds. The Sacapulas formation is a unit of Santa Rosa Group.

Tactic Formation (Upper Palaeozoic)

The type locality of Tactic Formation lies east of Tactic, Alta Verapaz. The formation is widespread in the Sierra de Los Cuchumatanes. It is also

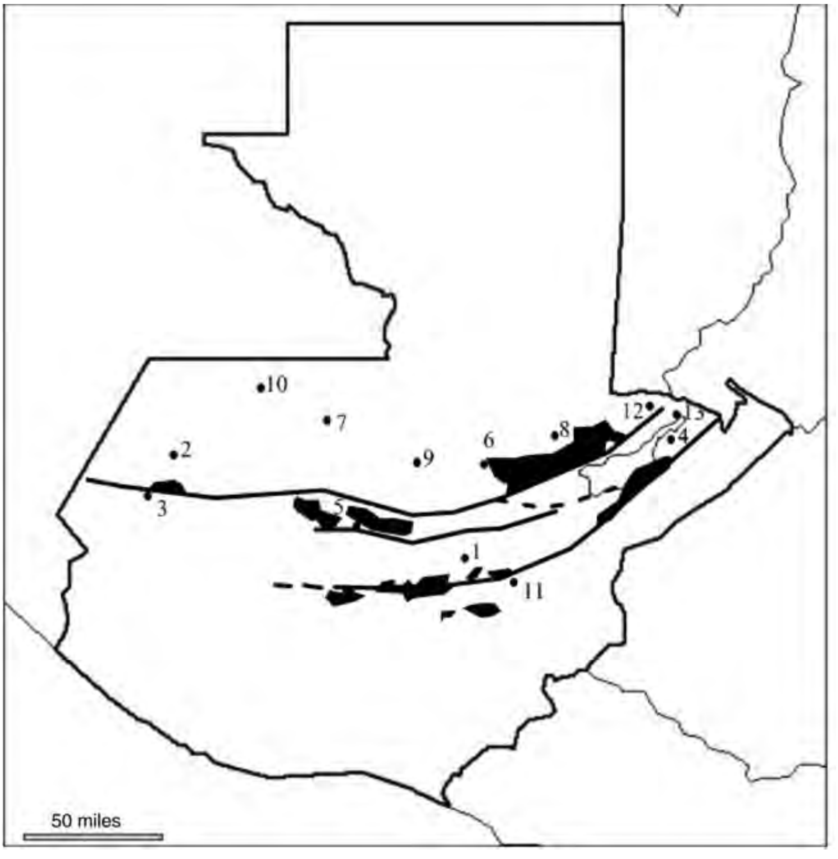

Fig. 2. Typical localities of Guatemalan Formations, also showing the location of the main fault systems and the ophiolite complexes: 1, Chuacús Series, Palaeozoic metamorphic; 2, Chiocol, Sacapulas, Tactic and Esperanza Fms, Carbon–Permian sedimentary rocks; 3, Chochal Fm, Permian sedimentary; 4, Macal Fm, Carbon–Permian sedimentary; 5, Todos Santos Fm, Jurassic–Cretaceous sedimentary rocks; 6, San Lucas Fm, Jurassic volcano-sedimentary rocks; 7, Cobán Fm, Cretaceous sedimentary rocks; 8, Ixcoy Fm, Cretaceous sedimentary rocks; 9, Campur Fm, Cretaceous sedimentary rocks; 10, Verapaz Group, Cretaceous–Cenozoic sedimentary rocks; 11, Subinal Fm, Cretaceous–Cenozoic sedimentary rocks; 12, Desempeño and Lacantun Fms, Cenozoic sedimentary rocks; 13, Caribe, Río Dulce, Herrería and Armas Fms, Cenozoic sedimentary rocks.

recognized in a belt extending across the southern part of the Petén basin from Chiapas, Mexico in the west to the Caribbean Sea in the east. The 800 m thick formation consists of brown to black shale and mudstone with local thin quartzite bed and rare limestone and dolomite. It grades to the overlying Esperanza Formation with gradually increasing limestone. Fossils in the upper part of the formation indicate a Permian age.

Esperanza Formation (Upper Palaeozoic)

The Esperanza Formation occurs in the Altos Cuchumatanes between the Chitxoy–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. The unit consists of brown to black fossiliferous shale, mudstone and siltstone with limestone and dolomites interbeds. Thickness in the Altos Cuchumatanes is more than 470 m.

Chochal Formation (Upper Palaeozoic)

The Chochal Formation is widespread along the southern Río Ocho and Chixoy–Polochic fault zones. It extends eastward to the Cobán–Purulhá and Senahú area of Alta Verapaz and westwards towards Mexico. The formation consists of massive-bedded, cliff-forming, greyish-black to brownish medium to dark grey dolomite and limestone. The Chochal lithology is similar to the Esperanza Fm.

The unit ranges from 500 m thick to as much as 1000 m along the southern flank of the Cuchumatanes. An angular unconformity separates it from the overlying Todos Santos Formation. The Chochal Formation is part of the Santa Rosa group.

Macal Formation (Upper Palaeozoic)

The Macal Formation extends from the Maya Mountains of Belize to eastern Guatemala. Various authors correlate the Macal Formation with Santa Rosa Group of Guatemala. Fossils indicate an Upper Permian to Pennsylvanian age.

Todos Santos Formation (Triassic–Jurassic)

The Todos Santos Formation lies unconformably on the Chochal and Macal–Santa Rosa formations or on metamorphic basement. The unit comprises a dominant conglomerate member and siltstone-shale member (Richard 1963). The upper part of the Todos Santos Formation is composed of siltstone, sandstone, and dolomite rocks. The unit ranges in thickness from a few metres to at least 1240 m near La Ventosa. Vinson (1962) and Walpe (1960) dated the Todos Santos as the upper Jurassic in northern Guatemala while the type section of central and southeast Guatemala is Middle Jurassic to Middle Cretaceous in age (McBirney 1963).

San Lucas Formation (Upper Jurassic?)

This unit has not been described before though reports from geological companies mention the Jalomáx volcanic unit. The best example is found close to San Lucas. The formation is composed of a thick lower series of conglomerates and siltstone–shales and an upper series of mafic tuffs intensively and pervasively weathered to reddish clay. Fragments of the formation occur as xenoliths in the limestones of the Ixcoy Formation at San Lucas, within the Sierra de Santa Cruz ophiolite complex.

Cobán Formation (Lower to Middle Cretaceous)

Sapper (1937) gave the name Cobán to limestones near Cobán, Alta Verapaz. This thick series of limestones, dolomites and argillaceous to arenaceous clastics, unconformable above the Todos Santos Formation, represents nearly continuous deposition throughout the Cretaceous (Neocomian–Turonian). An evaporitic part of the unit is probably lower Cretaceous in age.

Ixcoy Formation (Middle Cretaceous)

The bituminous, cryptocrystalline Ixcoy Formation, described by Termer (1932) in the Department of Huehuetenango, was thought to be a lower part of the Cobán Formation. This paper observes that it is younger than the Cobán Formation. The unit is very common and spreads to the east central part of Guatemala.

Campur Formation (Upper Cretaceous)

Vinson (1962) proposed this name for Senonian rocks which conformably and gradationally overlie the Cobán Formation in the Alta Verapaz area. The type section occurs along the Cobán-Sebob road approximately 3–6 km south of Finca Campur. The unit consists mainly of gray, gray-brown and dark brown reef limestones and minor dolomites interbedded with thin streaks of shale, siltstone, and limestone breccia or conglomerate.

Verapaz Group (Upper Cretaceous)

According to Vinson (1962) this unit comprises the Chemal, Sepur and Lacandon Formations. Its name comes from Baja and Alta Verapaz, where the group is best developed. The formations consist predominantly of clastic material including shale, sandstone, siltstone, limestone, and conglomerate. Thickness is approximately 600–700 m and rich foraminiferal assemblages give a Campanian–Maastrichtian age.

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 95 m. 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. The Chemal is differentiated from the Sepur by 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 600 m. The formation lies unconformably on the Upper Cretaceous (Senonian) limestones of the Campur Formation.

Lacandon Formation

The Lacandon Formation occurs in the Lacandon region in northwestern Petén, overlying the Sepur with either gradational contact or local unconformity. This is a thick series of detrital carbonates with local algal beds and microcrystalline limestone of light yellow to light cream color. It is a composite section consisting of three units with thicknesses of 650 and 600–400 m near Lacandon, Petén.

Subinal Formation (Paleocene)

Previously described as a molasse unit, this formation consists of a series of flyschoid, polymictic conglomerates, commonly overlying the ophiolites associated with the Motagua and the Río Negro-Polochic faults. A typical section, at km 77 of the CA-9, close to Guastatoya (UTM E: 816603, N: 1647109), consists of three flyschoid sequences: a fine-grained consolidated polymictic conglomerate, a coarse-grained polymictic conglomerate and a fine-grained unconsolidated sequence.

A possible source for the Subinal Fm is seen south of the Motagua Fault at UTM E: 815968, UTM N: 1636071. This is a polymictic conglomerate, very hard and silicified, which crops out on top of schists of the Chuacús Series and also occurs as big boulders in creek beds. Gold, in many creeks and rivers, may be related to the quartz fragments found on these conglomerates.

Petén Group (Lower Eocene)

Vinson (1962) divided the Petén group into five units, the Cambio, Reforma, Teledo, Santa Amelia and Buena Vista formations, on the basis of tectonic and palaeontological facies. The description of the Petén Group is based on the report compiled by Millan (1985).

Icaiche Formation (Upper Eocene)

This unit was described first by Millan (1985). It is composed mainly of gypsum and marls.

Desempeño Conglomerate Formation (Upper Oligocene)

This formation consists predominantly of massive and hard, grey to black channel conglomerates of quartzitic and siliceous pebbles ranging up to 10 cm in diameter. It occurs as a wedge shaped mass, with a maximum thickness of 200 m, in a low-lying erosional pocket on the south flank of La Libertad arch. The pebbles are very similar to those found in the Caribe and Lacantun Formations and may have the same source.

Lacantun Formation (Upper Oligocene)

The predominantly red bed formation overlying the Petén Group is the Lacantun Formation, with a type locality near the mouth of Río Lacantun in southwestern Petén and eastern Chiapas. Up to 500 m thick, the unit 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 the most complete section, more than 800 m thick, is seen. It also occurs in the adjoining regions of Alta Verapaz and El Quiche. Vinson (1962) suggested it is a time equivalent to the Río Dulce Formation of eastern Guatemala. 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 only from the Amatique embayment area of eastern Guatemala. It is characterized by light buff, tan and cream-coloured limestone unconformable on Permian, Cretaceous and Eocene rocks. The type locality of the formation is just above sea level along Río Dulce, upstream from the Town of Livingston, Izabal. The Río Dulce Formation is overlain by the Herrería Formation of Pliocene (?) age, following a low angle unconformity.

Herrería Formation (Pliocene)

The Herrería Formation consists of a long, narrow, north–south strip of clastics overlying the Río Dulce limestone east of Río Dulce gorge. The unit was named by J. P. Gallegher in a private oil company report cited by Vinson (1962) and described by Millan (1985) as poorly consolidated claystones, siltstones, marls and sandstones, which are characteristically conglomeratic. The type section extends from Punta Herrería SW to the contact with the Río Dulce Formation, a distance of about 1 mile. Formation thickness is 240 m.

Armas Formation (age?)

The Armas Formation, composed of red bed and deltaic claystone, siltstone and sandstones, occurs in Motagua River valley in Izabal. The formation is a thick series of young or fresh-appearing strata lying on metamorphic basement and Cretaceous limestones. The unit is divided into two subunits that consist sedimentary rocks derived from the volcanic, metamorphic and sedimentary rocks. Total estimated thickness is 2500–3000 m.

Figure 3 shows a stratigraphic column based on work by Millan (1985) and the author.

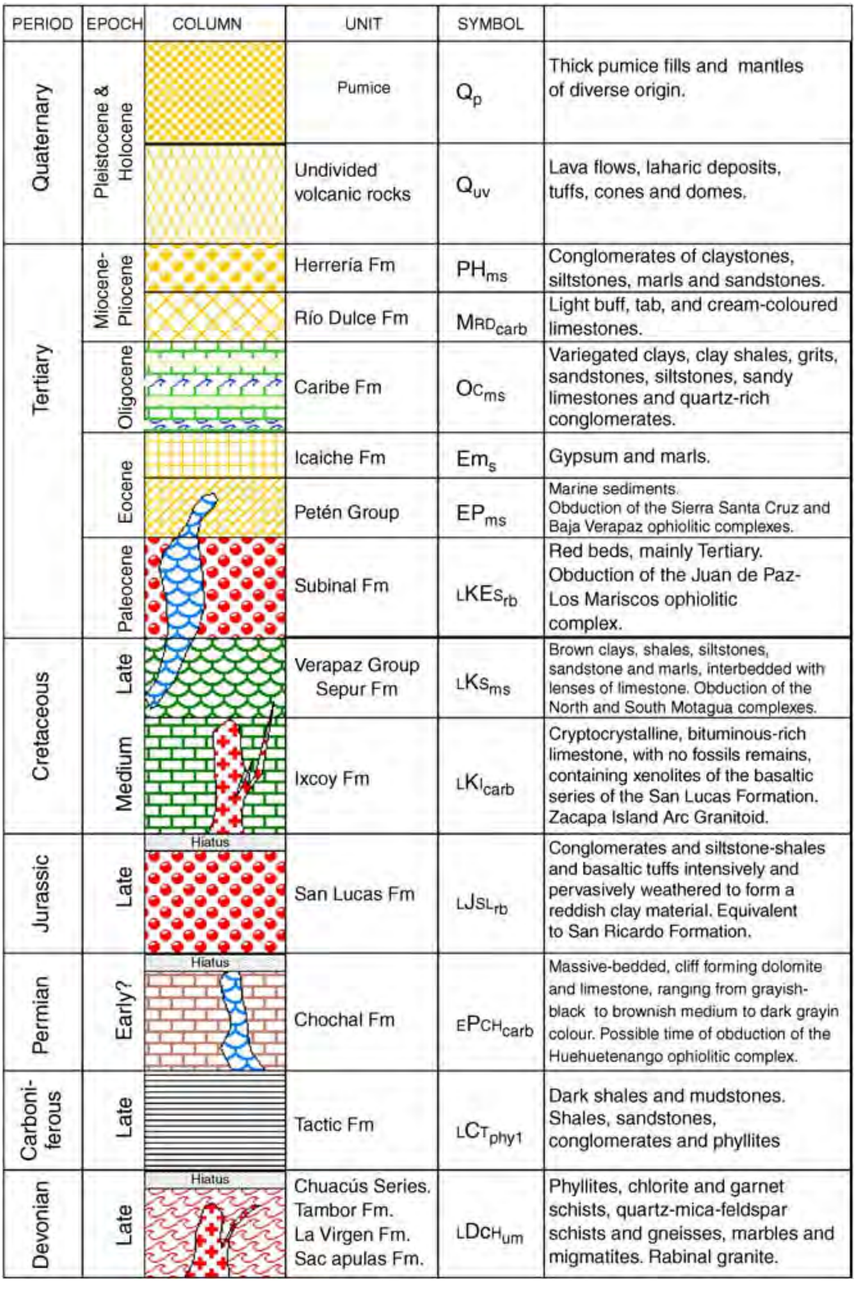

Fig. 3. Stratigraphic column for the studied area.

The geological evolution of Central Guatemala

The stratigraphy of Central Guatemala described above suggests the geological evolution shown in Figure 4. The oldest rocks are Palaeozoic schists and other metamorphic rocks of the pre-Permian Chuacús Series, accompanied by granitic and dioritic batholiths (Fig. 4a). Around 300 Ma, during the Carboniferous, shallow marine sediments and conglomerates were followed by deeper sandstones and shales at greater depths (Santa Rosa Group) (Fig. 4b). During the Early Permian (Fig. 4c), limestones and other carbonate rocks accumulated (Chochal Formation).

A hiatus of nearly 51 million years marks the Triassic Period, when the sea retreated and no significant deposition occurred. In this paper, I am suggesting that the pre-Cretaceous passing by of the Jamaica Block from somewhere in the Pacific Ocean on its way to its present location south of Cuba was the responsible for the obduction of the oldest ophiolites of Huehuetenango in the western end of the Polochic–Río Negro faults in Guatemala.

Late Jurassic red beds of the Todos Santos Fm possibly record tropical oxidizing conditions. Volcanic rocks from the San Lucas Fm formed at this time. The Late Cretaceous to Early Cenozoic periods (Fig. 4d) were recorded by carbonate sediments (Cobán Fm, Ixcoy Fm, Petén Fm, Campur Fm and others) and the intrusion of granitic and dioritic bodies of the Zacapa Island Arc. They were followed by marine clastic sediments of the

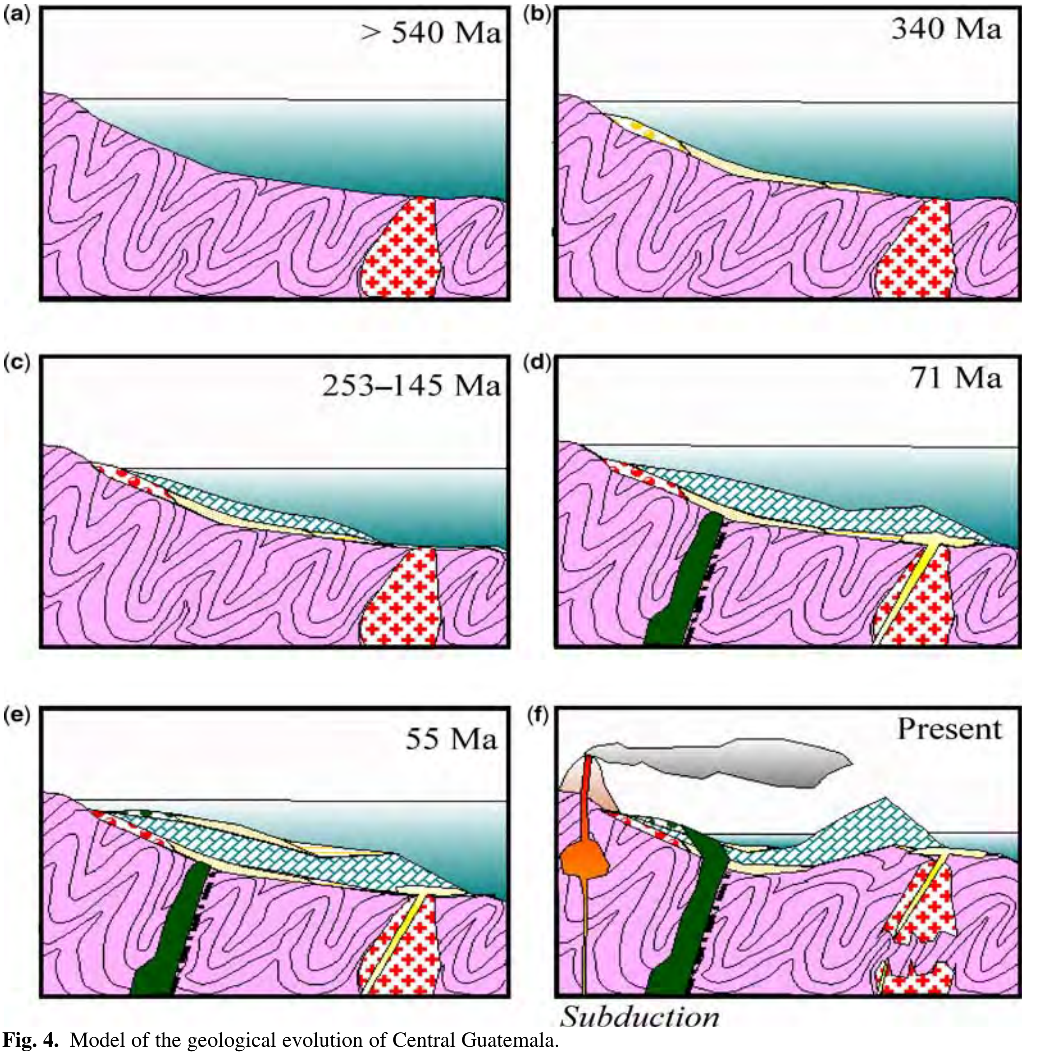

Fig. 4. Model of the geological evolution of Central Guatemala.

Verapaz Group and obduction of the North and South Motagua ophiolite complexes and the Juan de Paz–Los Mariscos ophiolite complex. These were later covered by the red beds of the Subinal Fm, which suggest another period of regression.

The Paleocene witnessed deposition of more marine sediments, mainly shallow marine conglomerates, with deeper sandstones and shales. Obduction of the Sierra de Santa Cruz and the Baja Verapaz ophiolite complexes occurred at this time (Fig. 4e).

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

Finally, 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 intrusives that had undergone serpentinization before were oxidized, resulting in the formation of Ni lateritic zones (Fig. 4f).

Current models for the Caribbean Plate

There are basically two groups of ideas with respect to the formation of the Caribbean Plate. One group defends the idea of the *in situ* formation of the Caribbean Plate (Fig. 5) in contrast to complex Pacific

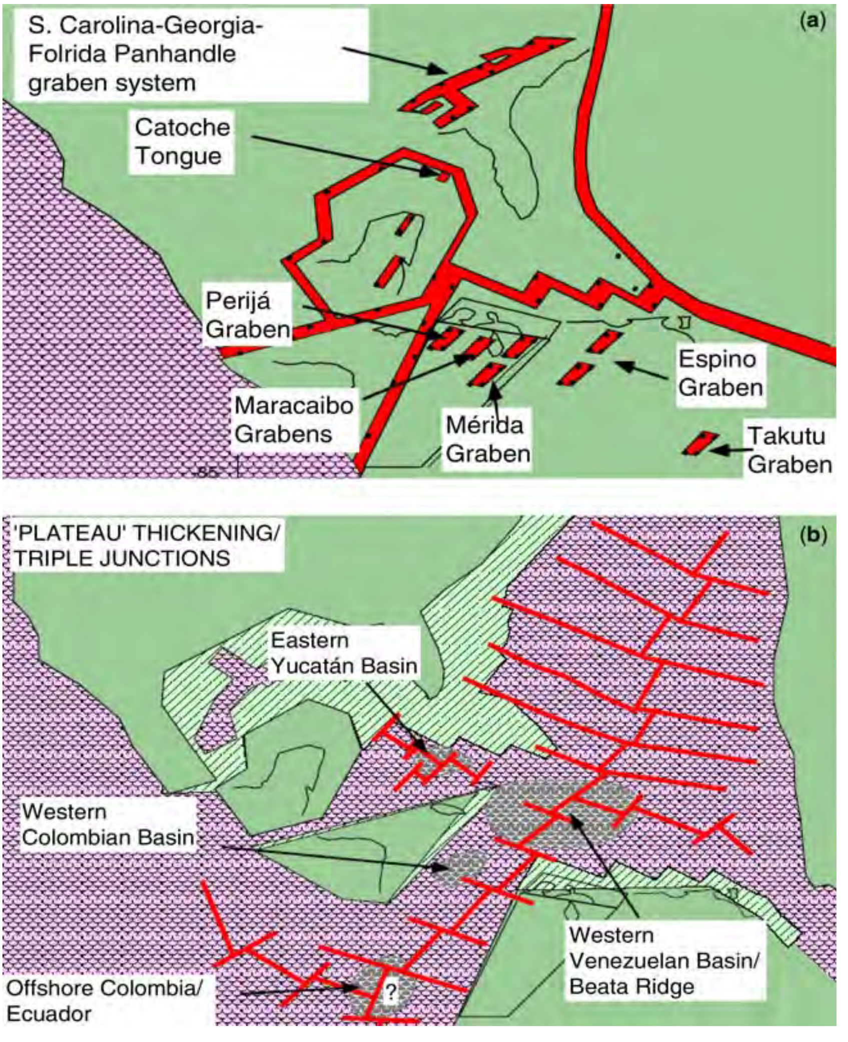

Fig. 5. (**a**) Triassic–Early Jurassic rifting of Pangaea; (**b**) Late Jurassic–Early Cretaceous opening of the area between North and South America during drift. Analogy with the Scotia Plate suggests that the Beata Ridge was a spreading centre and that continental fragments lie on the plate margins and interior. From James (2005).

models that require major block rotations, plate migrations, hotspots or plumes (James 2005).

The other group (Pindell 1993; Pindell *et al.* 2000) defends the idea that at least parts of the Caribbean Plate have migrated several thousands of kilometres into its inter-American location from the Pacific (Fig. 6). Let us see now some of the geological features that our current knowledge of the stratigraphy of Guatemala indicates that existed in the area.

The model

Interoceanic channel

The stratigraphy of Central Guatemala calls for the existence of an interoceanic channel since the Early Proterozoic. This is suggested by the presence of sedimentary units along the central part of Guatemala, now constituting the metamorphic

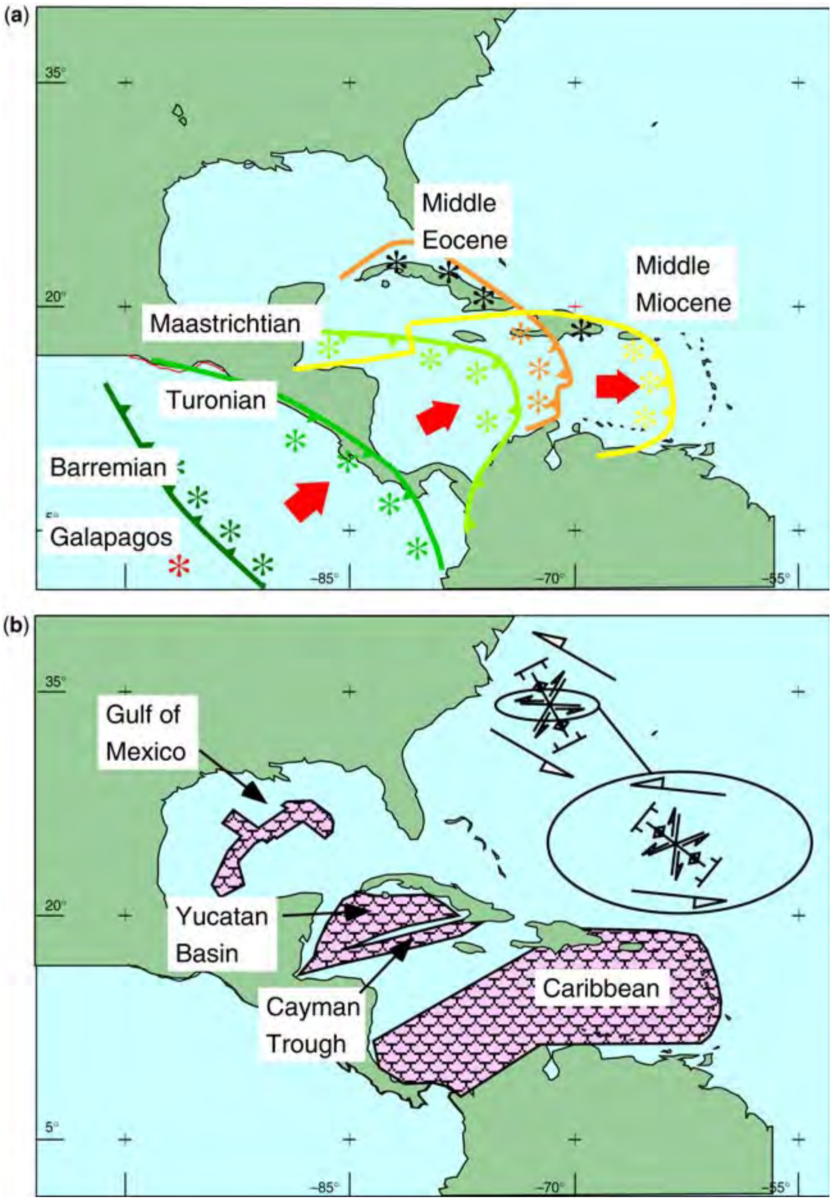

Fig. 6. (**a**) Migration of the Caribbean Plate from the Pacific (red arrows), preceded by a leading edge volcanic arc (colours indicate progress); (**b**) genesis of the Caribbean Plate oceanic crust in place along with the Gulf of Mexico, Yucatán Basin and Cayman Trough during extension as North America drifted NW from South America. From James (2005).

Chuacús Series (Fig. 7). It is generally accepted that both Jamaica and Chortís were located at this time somewhere west of Mexico.

Subduction arcs

Figure 8 shows the location of all volcanoes in Guatemala, Salvador and Honduras. The arcs indicate two subduction zones and the remains of a trench, now collapsed, that can be seen in the ocean floor.

Volcanic activity south of the Maya Block

In 2006, the author discovered vast amounts of rhyolitic tuffs among areas previously believed to be composed only of limestones (Fig. 9) on the northern border of the Polochic Belt ophiolite complex.

Fig. 7. During the Early Proterozoic there must have been an interoceanic channel were continental sediments from the Maya Block were deposited. Note that the position of Jamaica and of the Chortís Block west of Mexico is just a suggestion.

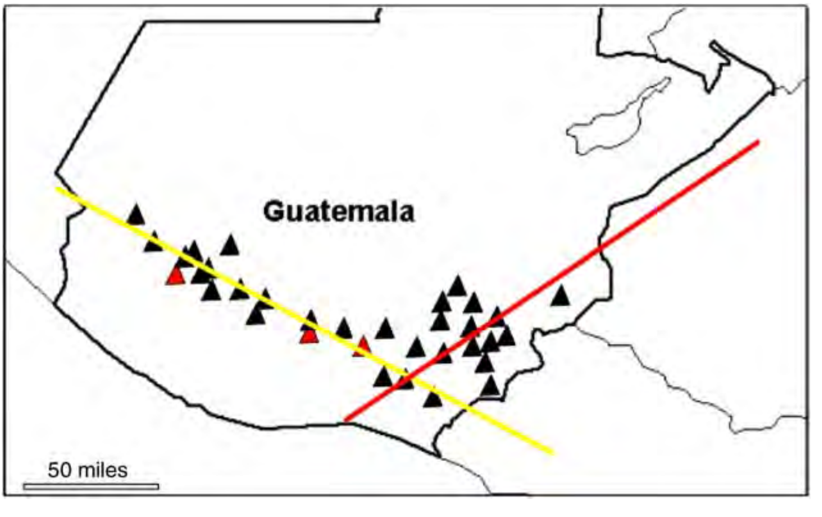

Fig. 8. Position of the two subduction zones, west and south of Guatemala, which are identified by the presence of two different chains of volcanoes.

Fig. 9. Recently discovered massive flows of rhyolite on top of Cretaceous limestones of the Ixcoy and Cobán Formations north of the ophiolites of the Polochic Belt.

These, together with those found above the Baja Verapaz ophiolite complex, record a volcanic arc associated with flat subduction of the Caribbean Plate below the Maya Block.

Interpretation

To explain the geology of the NW corner of the Caribbean Plate, I propose that an orogenic event, the Chuacús Orogeny, coeval with Laramide Orogenesis in North America, occurred as shown in Figures 10–13. If the recently discovered rhyolites on top of the Cretaceous Cobán and Ixcoy limestones north of the Polochic Ophiolite Belt evidence a subduction arc, it is possible that the Caribbean Plate was expanding northwards and southwards. The spreading ridge is represented today by the Lake Izabal graben. The model suggests that the angle of subduction to the north was much shallower than to the south, limiting volcanic activity south of the Maya Block. Figure 10 shows that the Jamaica Block interacted with the Maya Block along the eastern part of the Motagua Suture Zone sometime before the Cretaceous. It was responsible for the obduction of the Huehuetenango ophiolite complex.

After the migration of Jamaica, the Chortís Block followed in a SE direction. This movement provoked the obduction of the North and South Motagua ophiolite complexes and the fragmentation of the South Motagua ophiolite complex. During the Cenozoic, the Chortís Block was located south of the Maya Block, moving northwards. The subduction zone to the north was more active and the angle of subduction increased, resulting in increasing volcanic activity (Fig. 11).

During the Late Cenozoic northward movement of Chortís intensified, resulting in obduction of the Baja Verapaz complex followed by the Juan de Paz–Los Mariscos and Sierra de Santa Cruz ophiolite complexes. This marked the beginning of the Chuacús Orogeny in the Motagua Suture Zone (Fig. 12).

Finally, collision of the continental blocks activated late volcanic activity over the Maya Block, terminating the Chuacús Orogeny with formation of the different metamorphic rocks of the Chuacús Series (Fig. 13).

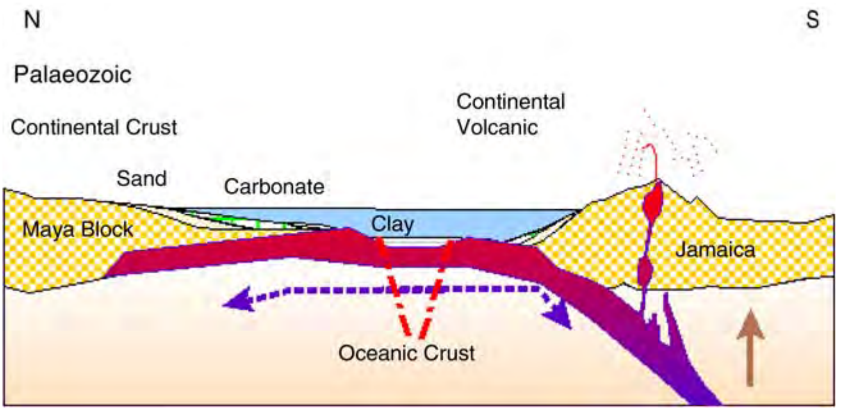

Fig. 10. Initial development of the subduction zones and volcanic arcs during the Palaeozoic.

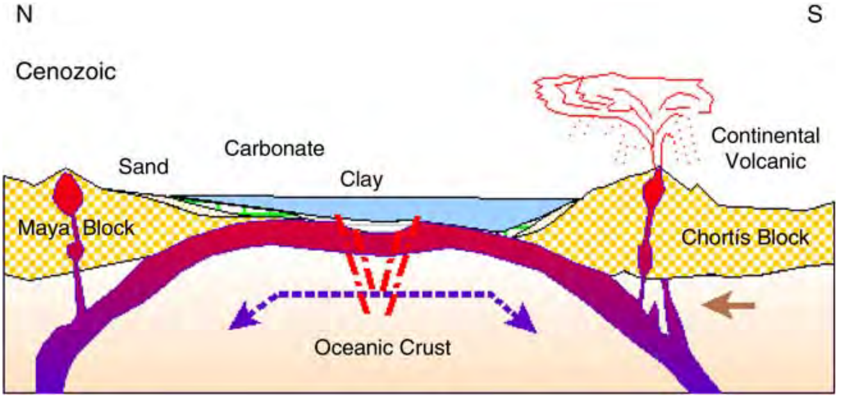

Fig. 11. North–south cross section between the Maya and Chortís Block during Early Cenozoic.

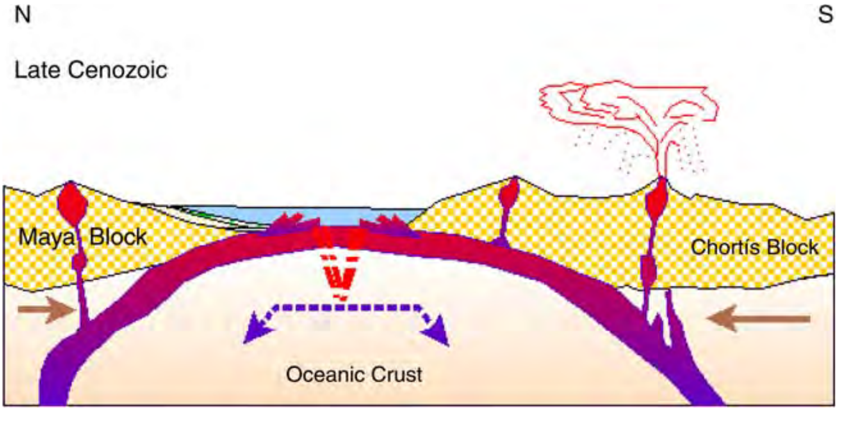

Fig. 12. Continuation of the closure of the interoceanic channel during the Late Cenozoic together with the initiation of the Chuacús Orogeny.

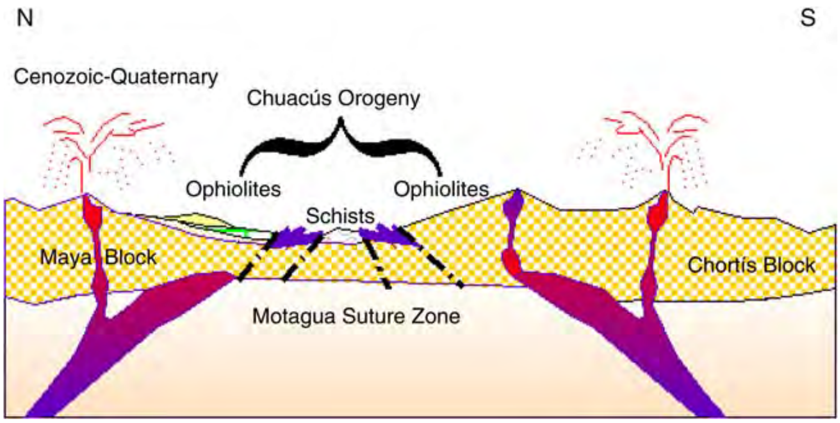

Fig. 13. Collision of the continental blocks and the completion of the Chuacús Orogeny within the Motagua Suture Zone.

Conclusions and recommendations

This paper suggests that the geology of Central Guatemala supports the allochthonous origin of the Caribbean Plate. Further evidence should be sought not only in Guatemala, but also in Honduras and Mexico or even in Jamaica.

This paper was improved by conversations with a large number of people who helped debug it. Particular thanks to K. James, who re-read and revised the manuscript in more than one occasion until it was in compliance with the requirements of the GSL. Also a big thanks goes to Giuseppe Giunta, with whom I had the opportunity to discuss many of the ideas presented in this paper. I am also grateful to my colleagues from Guatemala for their support and their many contributions.

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