Georg Forster Research Fellowship

Structural, geochronologic and palaeomagnetic studies in Palaeogene volcanic rocks of eastern Cuba: implications for the evolution of the Caribbean region

By

Dr. Yamirka Rojas-Agramonte

Advisors:

Prof. A. Kröner

Institut für Geowissenschaften, Universität Mainz

Dr. habil. J. Tait

Department für Geo- und Umweltwissenchaften

Ludwig-Maximilians-Universität München

Table of contents

1. Abstract

A structural, geochronologic and palaeomagnetic study will be undertaken on Palaeogene volcanic rocks of eastern Cuba in order to test current tectonic hypotheses on the origin and horizontal motion of crustal units to which these rocks belong. Several tectonic models have been proposed for the Caribbean region but most are highly speculative and controversial, and there is no agreement despite years of research and meetings regarding key aspects in the evolution of the Caribbean region such as, for instance, the polarity of subduction. Our results are likely to provide new constraints on the evolution of the Caribbean realm in Tertiary times and will also contribute to a better understanding of accretionary processes.

The proposed methodology for this project is not available in Cuba but is essential for an understanding of the tectonic evolution of Cuba and, therefore, the Caribbean region. The Cuban geosciences community would benefit significantly from new and precise palaeomagnetic and age data and constraints on tectonic models.

2. Introduction

The geological evolution of the Caribbean region (Fig. 1) is the result of a complex interaction of different lithospheric plates whose movement in the geologic past is still poorly constrained. The island of Cuba, in particular, reflects the accretion of various island arcs of unknown origin, closure of ocean basins of unknown width and final collision of these arcs with the North American continent. Central to these plate interaction processes is the Caribbean Plate to which Cuba belonged. The tectonic evolution of the Caribbean region has been a matter of considerable speculation (Malfait and Dinkelman, 1972; Ross and Scotese, 1988; Pindell and Barret, 1990; Pindell, 1994; Iturralde-Vinent, 1998; Meschede and Frisch, 1998; Kerr et al., 1999), and much of the uncertainty as to its origin is due to a lack of reliable palaeomagnetic data to constrain the relative movement and palaeogeographic evolution of the various tectonostratigraphic units. Palaeomagnetism, in combination with geochronology and structural analysis, is the only method to quantitatively determine palaeogeography and to reconstruct the sense of rotation of lithospheric plates and terranes. It is therefore proposed here to undertake a palaeomagnetic/geochronologic/tectonic analysis of rock units in eastern Cuba to better constrain the evolution of this part of the Caribbean Plate in Tertiary times.

Extensive and well preserved outcrops of Palaeocene to early middle Eocene island arc rocks are exposed in eastern Cuba, and the largest volume of these rocks occurs in the Sierra Maestra mountain range (Fig. 2). The Palaeogene Volcanic Arc (PVA) in this area is represented by the El Cobre Group (with three undifferentiated volcanic units), the Pilón Formation (early Palaeocene to early Eocene) which consists of sedimentary and pyroclastic rocks, and the Caney Formation (middle Eocene), which marks the end of magmatic activity and consists of intermediate lava flows and pyroclastic rocks (Pérez Pérez and García Delgado, 1997). To the north of the Sierra Maestra in the Mayarí-Baracoa area (Fig. 3) the Sabaneta Fm. (early Palaeocene to early Eocene) is well exposed and comprises mainly pyroclastic, volcanomictic and carbonate rocks. To the north of the elevations of Mayarí-Baracoa and close to the coast are the marls, limestones and tuffs of the Castillo de los Indios Fm. (Palaeocene? to middle Eocene), whereas in the Holguín region (Fig. 3) the Vigía Fm. which consists mainly of limestones, marls, sandstones and tuff is exposed (Palaeocene? to middle Eocene). Preliminary field investigations of these rocks (Delgado Damas, et al., 1999; Rojas-Agramonte et al., 2003a, b, c) reveal that the most suitable formations for further palaeomagnetic studies in this region are the El Cobre Group, including the Pilón and Caney Fms. and the Sabaneta Fm. to the north.

Palaeogene volcanic rocks are also found on other Caribbean islands such as Hispaniola, Jamaica, Puerto Rico, Lesser Antilles, Nicaraguan Rise and Aves Ridge. However, in contrast to eastern Cuba the volcanic lithologies in these places are either poorly preserved because of intense deformation or they are not accessible (submerged). This fact makes eastern Cuba the best, if not the only, place in the Caribbean where palaeomagnetic studies can be undertaken in order to constrain the original position of these rocks during that period. Knowledge about the past position of these rocks is of great importance for plate tectonic reconstructions to explain the evolution of the Caribbean region during Tertiary times.

3. Short overview of Cuban geology

Two structural units have been recognized in the geological evolution of Cuba, namely the Fold Belt and the Neoautochthon (Iturralde-Vinent, 1996; Fig. 2). The Fold Belt has a complicated structure and is composed of latest Triassic (?) to late Eocene deformed and partly metamorphosed continental rocks of the Bahamas Platform, Mesozoic metamorphic complexes in SW Cuba, as well as oceanic terranes such as the Northern Ophiolite, the Cretaceous Volcanic Arc and the Palaeogene Volcanic Arc. The Neoauthochton is composed of latest Eocene to Recent rocks of the post-orogenic phase, which unconformably overlie the Fold Belt sequences with a generally gentle dip of almost undeformed strata (Iturralde-Vinent, 1996).

Continental units within the Fold Belt

The Bahamas Platform (Fig. 2)

The Bahamas Platform belongs to the Florida Strait Block and is exposed in the northern sector of Cuba. Shallow-water carbonates and evaporites are dominant, but deep-water carbonates and cherts (channel facies) are also present, with ages ranging from Jurassic to late Cretaceous. The platform is surrounded by deep-water carbonates, shales and cherts reprsenting a slope and deep basin facies. Pre-Triassic basement rocks of the Florida Strait Block crop out in Cuba at several localities. They are represented by Grenville-age marbles and metamorphic siliciclastic rocks, which are intruded by small granitic bodies of mid-Jurassic age (Socorro Complex). This basement is covered by arkosic palaeosoil and late Tithonian to early Cretaceous carbonates and siliciclastic sediments (Iturralde-Vinent, 1996).

Mesozoic metamorphic complexes (Fig. 2)

Composite tectono-metamorphic complexes, recently interpreted as terranes, occur at three localities in southwestern Cuba, namely Guaniguanico, Pinos, and Escambray. The tectonostratigraphy of these complexes is very complicated with juxtaposition of different rock-types which have subsequently been strongly deformed and metamorphosed. Mesozoic continental margin deposits are the most widespread rocks. They are present in all three complexes and show many common characteristics. Dismembered ophiolitic rocks (serpentinite, gabbro, diabase and basalt) appear on thrust planes in Guaniguanico and Escambray, in the latter showing a high-P/low-T metamorphic history. Volcanic sequences have been described from both the Escambray and Guaniguanico complexes. These metamorphic complexes are thought to have been part of the Mayan (Yucatan) borderland in Mexico (Iturralde-Vinent, 1996).

Oceanic units within the Fold Belt

The northern ophiolitic mélange (Fig. 2)

An allochtonous ophiolitic mélange occurs in the northern half of Cuba and has been thrust onto the Guaniguanico terrane, the Bahamas Platform, the Cretaceous Volcanic Arc and sediments of late Cretaceous age. The ophiolites are composed of a melanocratic basement composed of ultramafic and mafic igneous rocks of latest Triassic (?) to early Cretaceous age, and an oceanic sequence composed of Hauterivian-Turonian tholeiites interbedded with radiolarites, limestones and shales. The emplacement and main deformation in the mélange occurred progressively from south to north and lasted from the late Campanian to the late Eocene.

The Cretaceous Volcanic Arc (CVA) (Fig. 2)

Cretaceous island arc rocks are widespread in Cuba. The basement of the arc consists of pre-Aptian oceanic crust that has been recognized in parts of central and eastern Cuba. The island arc is composed of extrusive, volcaniclastic and granitoid rocks of Aptian (?) to late Campanian age with typical tholeiitic to calc-alkaline and alkaline compositions. The ophiolites and volcanic arc suites occur tectonically above the sections of the Bahaman and Yucatan borderlands.

The Palaeogene Volcanic Arc (PVA) (Fig. 2)

Palaeocene to early middle Eocene island arc assemblages are well known in southeastern Cuba but are not found elsewhere on the island. The axial portion of the arc is located in the Sierra Maestra and is composed of tholeiitic extrusive and pyroclastic rocks, intruded by calc-alkaline plutons of tonalitic to trondhjemitic composition (Rojas-Agramonte et al., 2003a). To the north of eastern Cuba only Palaeogene pyroclastic rocks and sediments are present, whereas to the west, in central and western Cuba, Palaeogene volcanism is represented by thin tuffaceous intercalations within some sedimentary sections. The PVA and CVA were deformed during the "Cuban orogeny" when the PVA was thrust over the CVA assemblages and the Northern Ophiolite mélange, and accreted to the North American continental margin. More detail on the Palaeogene Volcanic Arc in the Sierra Maestra is provided below.

The Neoauthochton (Fig. 2)

No magmatic activity is recorded during upper Eocene to Recent times, when new sedimentary basins evolved above the deformed belt with deposition of clastic and carbonate rocks. Throughout this time, uplift and erosion dominated the overall tectonic evolution.

The Cuban Orogeny

The Cuban orogeny occurred in two phases, between late Campanian to late Eocene, with an eastward age migration across the island. The first tectonic phase led to consolidation of a southern oceanic structure in the late Cretaceous, towards the end of magmatic activity and extinction of the CVA, and resulted in tectonic juxtaposition of the CVA with the Northern Ophiolite mélange, i.e., both complexes were deformed together. During this phase a terrigenous flysch-type orogenic complex, Campanian-Maastrichtian in age and composed of ophiolites and Cretaceous volcanic olistoliths, was deposited in central western Cuba and was deformed together with the above pre-orogenic oceanic complexes. During the Maastrichtian to early middle Eocene, molasse basins with terrigenous clastic and carbonate sediments developed on top of this consolidated accretionary complex, and basin development began before the onset of the second orogenic phase (García-Delgado et al., 1998).

The second phase is related to NE-movement and oblique collision of the combined CVA/Northern Ophiolite mélange complex with the Bahamas continental margin and occurred between the late Palaeocene and middle Eocene. Foreland basins with olistostrome components are witness to this phase and were deposited on top of the Bahamas margin following this collision. Thus the Cuban Fold Belt was created (García-Delgado et al., 2003).

The PVA in the Sierra Maestra was generated during southward subduction of the North American plate below the Caribbean plate, coinciding partly with the second orogenic phase, but in eastern Cuba this orogeny continued into the late Eocene when the PVC was accreted to the Cuban territory, uplift occurred and coarse clastic sediments were deposited (Pindell and Kennan, 2001; Rojas-Agramonte et al., 2003c).

Post-orogenic phase

Since the latest Eocene - Oligocene, Cuba has been part of the North American continental margin. Oligocene to Recent sediments are characterized by mild deformation, generally along the trend of major wrench faults associated with the development of the Oriente Transform Fault which developed on the southern Cuban coast. These post-collisional movements are associated with transpressional and transtensional stress generated by movement along the E-trending Oriente Transform Wrench Corridor (Rojas-Agramonte et al., 2003b).

4. Summary of previous work on the Palaeogene rocks of eastern Cuba

The most relevant and recent investigations carried out in eastern Cuba were undertaken by Iturralde-Vinent, 1996, 1998 (regional geology); Kysar Mattietti, 2001 (geochemistry, geochronology and petrography); Cazañas et al., 1998 (geochemistry) and Rojas-Agramonte et al., 2003a, b, c (structural geology, palaeostress, geochemistry and geochronology). These investigations have contributed to a better understanding of the controversial PVA in Cuba and the Caribbean region.

As stated before, the most prominent outcrops of Palaeogene volcanic rocks appear in the Sierra Maestra mountain range and were thoroughly studied as part of my doctoral dissertation. This range consists of igneous and sedimentary rocks which have been interpreted to represent late Cretaceous and Palaeogene intra-oceanic volcanic arc sequences, accreted to the North American continental margin (Bahamas Platform) in the Eocene (Iturralde-Vinent, 1996; Pindell and Barret 1991). The Palaeogene volcanic arc successions were intruded by calc-alkaline I-type granitoids during the final stages of accretion and collision. Geochronological analysis and geobarometric investigations on samples from Eocene granitoids were carried out as part of my doctoral research. U-Pb SHRIMP zircon dating of five granitoids yielded $^{206}Pb/^{238}U$ emplacement ages between 60.5 ± 2.2 and 48.3 ± 0.5 Ma. These granitoids are the result of subduction magmatism and have typical geochemical characteristics of intra-oceanic island-arcs such as the Lesser Antilles, Aleutians and Marianas (Rojas-Agramonte et al., 2003a). Ar-Ar and fission track cooling ages suggest fast cooling and exhumation during collisional processes in the Eocene and early Oligocene (Rojas-Agramonte et al., 2003c).

Structural studies reveal several distinct phases of deformation in the rocks of the Sierra Maestra (D_1 - D_6), ranging from middle Palaeocene to late Eocene in age. These deformation phases occurred in response to arc accretion and subsequent disruption of the arc by initiation of the North Caribbean Transform Fault (Rojas-Agramonte et al., 2003c). These structural and tectonic data record the transition from collision to accretion and strike-slip tectonics.

Iturralde-Vinent, (1996, 1998) interpreted the Palaeogene rocks of the Sierra Maestra to be the axial part of the PVA and the pyroclastic-sedimentary rocks to the north (Sabaneta, Castillo de los Indios and Vigía Fms.) as part of a back-arc basin. The stratigraphy of the Sabaneta Fm. has been study in detail by Delgado Damas et al., (1999) and the one from Castillo de los Indios and Vigía Fms by Iturralde-Vinent (1976, 1977). However, a detailed structural study of these rocks has never been undertaken.

Results of a palaeomagnetic study, including the Sabaneta Fm. in eastern Cuba (Pérez Lazo et al., 1995), shows northeast-directed horizontal motion of the Caribbean block in the Caribbean and the Greater Antilles during the Palaeogene. This study also shows certain relations between the Greater Antilles since Cretaceous time and assumes a common motion of Cuba, Jamaica and Haiti until the middle Miocene, with Jamaica and Haiti having been permanently situated south of Cuba. The above authors also concluded that Palaeocene changes in motion of the Caribbean plate from an original southwestern direction into east-northeast direction began in the early Tertiary by rotation about a rotation pole φ_{rp} = 14.5° N and λ_{rp} = 75.3° W. Their results also indicate that Cuba did not form part of the North

American continent since post-Palaeocene time, suggesting that this displacement, which began in the Palaeocene, reflects a period of initial opening of the Cayman trough. However, all these results and interpretations require revision since they are based on poor or incorrect geological observations and data. Furthermore, it is difficult to judge the quality of the palaeomagnetic data as the authors do not present their data in full and the study does not appear to meet modern reliability standards. While it would appear that primary directions of magnetisation have been identified, none of the directions are supported by field tests to constrain the relative age of magnetisation. It is of prime importance, therefore, to carry out a modern and detailed palaeomagnetic study of these sequences.

5. Problem formulation

Previous work in eastern Cuba as well as my own research during the doctoral dissertation led to a variety of speculative tectonic models that cannot be verified by classical geological methods. One of the main unresolved problems, for instance, is whether arc accretion resulted from southward-subduction of the North American plate beneath the Caribbean plate (e.g. Pindell and Barret, 1990; Pindell, 199; Pindell and Kennan, 2001) or from northward-subduction of the Caribbean plate below the North American plate (e.g. Cobiella, 1988; Iturralde-Vinent, 1994, 1996, 1998). Furthermore, the origin and the amount of horizontal movement of both the CVA and PVA in Cuba are highly speculative and unconstrained. Palaeomagnetism, combined with precise geochronology, is a very effective technique not available in research institutes in Cuba, and the anticipated results will provide important constraints with which to test and refine current tectonic models.

6. Research objectives

We suggest to undertake combined palaeomagnetic, geochronologic and structural studies on suitable late Cretaceous and Tertiary rock units in eastern Cuba in order to obtain reliable palaeopoles and to better constrain horizontal movements of parts of the Caribbean plate. These results will enable us to test various (unconstrained) tectonic models and will also contribute to a better understanding of the geodynamic evolution of the Caribbean region. Furthermore, the proposed study will enable me to learn new methods and techniques which are currently not available in Cuba and to work in two leading German research institutions.

7. Methodology

Palaeomagnetism, in combination with precise geochronology and structural studies, is a highly successful, modern tool in geodynamic research and has led to major new discoveries in the global effort to reconstruct plate movements and orogenic processes (see for example Powell et al., 1990, Sengör et al., 1993, Layer et al., 1998, Buchan et al., 2001, Li and Powell, 2001). Such work is so far lacking in the Caribbean region and will help to constrain currently popular but highly speculative tectonic models. We have undertaken a pilot palaeomagnetic study on rocks in eastern and central Cuba in 2003, and our preliminary results indicate stable magnetic behaviour of most rock units tested (see attached summary). We are therefore confident that the above techniques will provide new and highly significant data. The laboratories in Munich (palaeomagnetism) and Mainz (geochronology) are leading institutions in their respective fields, and our proposed methodology is novel to earth science research in the Caribbean.

8. Research time table

During the one-year period covered by the scholarship (July 2005 - June 2006) we plan to undertake the following research and write two papers to be published in international scientific journals. I propose the following time table after consultation with my prospective advisors:

July 2005 and August 2005: Familiarization with palaeomagnetic and geochronologic studies and techniques in the respective laboratories in Mainz and Munich.

September 2005: Field work in Cuba. Drilling of palaeomagnetic samples, collection of samples for geochronology, structural observations. Airfreight of rock samples from Havana to Mainz.

October 2005: Sample preparation for laboratory work. Mineral separation for geochronology. Interpretation of structural data obtained during fieldwork.

November and December 2005: Laboratory work in the palaeomagnetic laboratory of Munich University and interpretation of data.

January and February 2006: SHRIMP and conventional zircon geochronology.

March to June 2006: Final interpretation of data, writing of two research papers..

9. Expected results

Our preliminary palaeomagnetic study indicates stable magnetic behaviour of most of the rock units so far drilled in Cuba (see appendix in section 11). We expect a similar pattern in rocks of the Sierra Maestra and the Sabaneta Fm. to the north, and we are therefore confident to be able to define reliable palaeopoles with appropriate ages for the Tertiary. This should enable us to test current tectonic hypotheses on the origin and movement of the PVA. Since the tectonic evolution of the Caribbean region is highly controversial, our results are likely to provide new constraints and will also contribute to a better understanding of accretionary processes.

10. References cited

Buchan Kenneth, L., Ernst, R.E., Hamilton, M.A., Mertanen, S., Pesonen, L.J., Elming, Sten, A., 2001. Rodinia; the evidence from integrated palaeomagnetism and U-Pb geo-chronology. Precambrian Research, v. 110, p. 9-32.

Cazañas, X., Proenza, J.A., Matietti Kysar, G, Lewis, J., and Melgarejo, J.C., 1998. Rocas volcánicas de las series Inferior y Media del Grupo El Cobre en la Sierra Maestra (Cuba Oriental): volcanismo generado en un arco de islas tholeiítico. Acta Geologica Hispánica, v. 33, p. 57-74.

Cobiella, J.L., 1988. El vulcanismo paleogénico cubano. Apuntes para un nuevo enfoque. Revista Tecnológica, v. 18, p. 25-32.

Delgado Damas, R., García Delgado, D.E., Díaz Otero, C., 1999. Propuesta de hipoestrato-tipos de la formación Sabaneta de Cuba Oriental. Unpublished report, Instituto de Geo-logía y Paleontología, Havana, Cuba.

García-Delgado, D.E., Delgado-Damas, R., Rojas-Agramonte, Y., Millán-Trujillo, G., Peñalver, L.L., Cabrera, M., Padilla, I., Díaz-Otero, C., Torres-Silva, A.I., Furrazola-Bermúdez, G., Llanes, A.I., Torres, M., Pérez-Aragón, R., Bernal, L., Morales, R., 2003. Mapa geológico de la región Habana-Matanzas a escala 1:100 000 en base digital. V Congreso de Geología y Minería, La Habana, Cuba.

García Delgado, D.E., Delgado Damas, R., Millán Trujillo, G., Díaz de Villalvilla, L., Sukar Sastroputro, K., Llanes, I., Bernal, L., Rojas Y., Pérez Pérez, C., Díaz Otero, C., Furrazola Bermúdez, G., Peñalver, L., García Cádiz, I., Pardo, M., Suárez, V., Duani, E., 1998. Mapa Geológico de Cuba Central (Provincias Cienfuegos, Villa Clara y Sancti Spiritus) a escala 1:100 000. Memorias del III Congreso Cubano de Geología. v. I, 263-266.

Iturralde-Vinent, M.A., 1998. Synopsis de la constitución geológica de Cuba: Acta Geológica Hispánica, v. 33, p. 9-56.

Iturralde-Vinent, M.A., 1996. Introduction to Cuban geology and geophysics, *in* Iturralde-Vinent, M.A., ed., Cuban ophiolites and volcanics arcs: Miami Florida, International Geological Correlation Programme 364, Contrib. 1, Museo Nacional de Historia Natural, Habana, Cuba, p. 3-35.

Iturralde-Vinent, M.A., 1994. Cuban geology: A new plate tectonic synthesis. J. Petroleum Geol. v. 17, p. 39-70.

Iturralde-Vinent, M.A., 1976, 1977. Estratigrafía de la zona Calabazas-Achotal, Mayarí Arriba, Oriente. Rev. La Minería en Cuba, Part I: v. 5, p. 9-23, Part II: v. 6, p. 32-40.

Kerr, A.C., Iturralde Vinent, M.A., Saunders, A.D., Babbs, T.L., and Tarney, J., 1999. A new plate tectonic model of the Caribbean: Implications from a geochemical reconnaissance of Cuban Mesozoic volcanic rocks, Geological Society of America Bulletin, v. 111, p. 1581-1599.

Kysar Mattietti, G., 2001. The role of Paleogene magmatism in the evolution of the northern Caribbean margin, (the Sierra Maestra southern Cuba). Unpubl. dissertation, George Washington University, USA.

Li, Z.X., Powell, C.M., 2001. An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic. Earth-Science Reviews, v. 53, p. 237-277.

Layer, P.W., Lopez Martinez, M., Kröner, A., York, D., McWilliams, M., 1998. Thermochronometry and palaeomagnetism of the Archaean Nelshoogte Pluton, South Africa. Geophysical Journal International, v.135, p.129-145.

Malfait, B.T. and Dinkelman, M.G., 1972. Circum-Caribbean Tectonic and Igneous Activity and the Evolution of the Caribbean Plate, Geological Society of America Bulletin, v. 83, p. 251-271.

Meschede, M., and Frisch, W., 1998. A plate-tectonic model for the Mesozoic and early Cenozoic history of the Caribbean plate, Tectonophysics, v. 296, p. 269-291.

Pérez Lazo, J., Fundora Granda, M., García, A., Kropácek, V., Horácek, J., 1995. Paleomagnetic investigations in Cuba from late Jurassic to middle Eocene times and tectonic implications: Acta Universitatis Carolinae Geologica, v. 38, p. 3-19.

Pindell, J., and Kennan, L., 2001. Kinematic evolution of the Gulf of Mexico and Caribbean. 21st Annual GCSSEPM Research Conference, December 2-5, Houston, Texas.

Pindell, J.L., 1994. Evolution of the Gulf of Mexico and the Caribbean, in S.K. Donovan and T.A. Jackson (eds.), Caribbean geology: An Introduction, 13-39, University of the West Indies Publisher's Association, Kingston, Jamaica. QE 220 C34 1994.

Pindell, J. L., and Barrett, T., 1990. Geological evolution of the Caribbean region; a plate tectonic perspective. *In* Dengo, G., and J. Case, eds. The geology of North America: v. H, The Caribbean Region. Geol. Soc. America, p. 405-432.

Powell, C.M., Li, Z.X., Thrupp, G.A., Schmidt, P.W., 1990. Australian Palaeozoic palaeomagnetism and tectonics: Tectonostratigraphic terrane constraints from the Tasman fold belt. Journal of Structural Geology, v. 12, p. 553-565.

Rojas-Agramonte, Y., Neubauer, F., Kröner, A., Wan, Y. S., Liu, D. Y., Garcia-Delgado, D. E., Handler, R., 2004a. Geochemistry and age of late orogenic island arc granitoids in the Sierra Maestra, Cuba: evidence for subduction magmatism in the early Palaeogene. Chem. Geol. (in press).

Rojas-Agramonte, Y., Neubauer, F., Handler, R., García-Delgado, D. E., Friedl, G., and Delgado-Damas, R., 2003b. Variation of paleostress patterns along the Oriente Transform Fault, Cuba: Significance for Neogene-Quaternary tectonics of the Caribbean realm: Tectonophysics (re-submitted).

Rojas-Agramonte, Y., Neubauer, F., García-Delgado, D.E., Handler, R., Friedl, G., and Delgado-Damas, R. 2003c. Tectonic evolution of the Sierra Maestra mountain range, Cuba, during Tertiary times: implications for the northern Caribbean realm. Geol. Soc. America Bull. (re-submitted).

Ross, M.I., and Scotese, C.R., 1988. A hierarchical tectonic model of the Gulf of Mexico and Caribbean region, Tectonophysics, 155, p. 139-168.

Sengör, A.M.C., Natalin, B.A., Burtman, V.S., 1993. Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. Nature, v. 364, p.299-307.

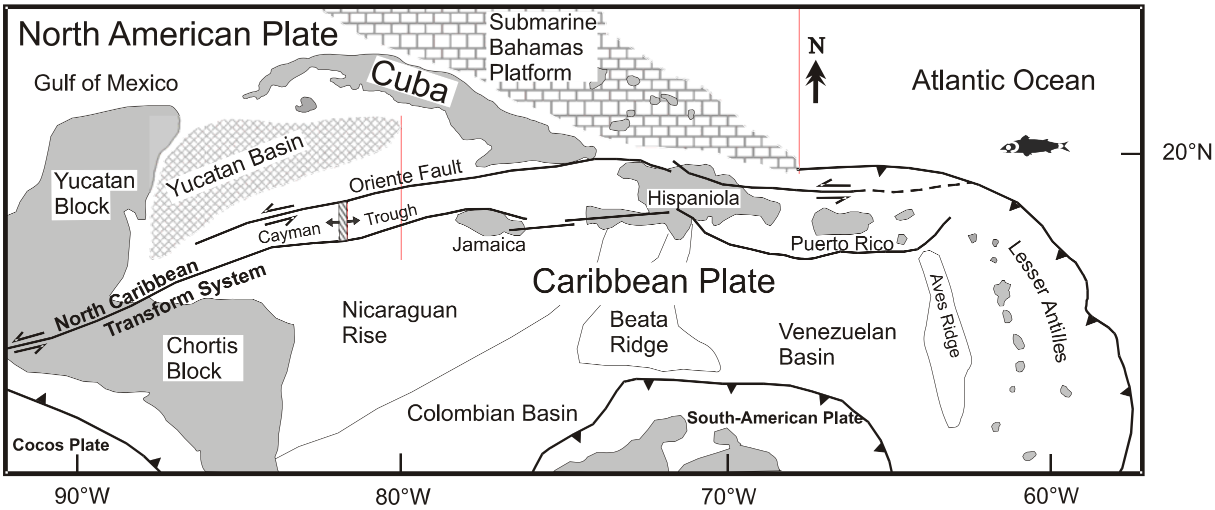

Fig. 1. Simplified map of the Caribbean realm.

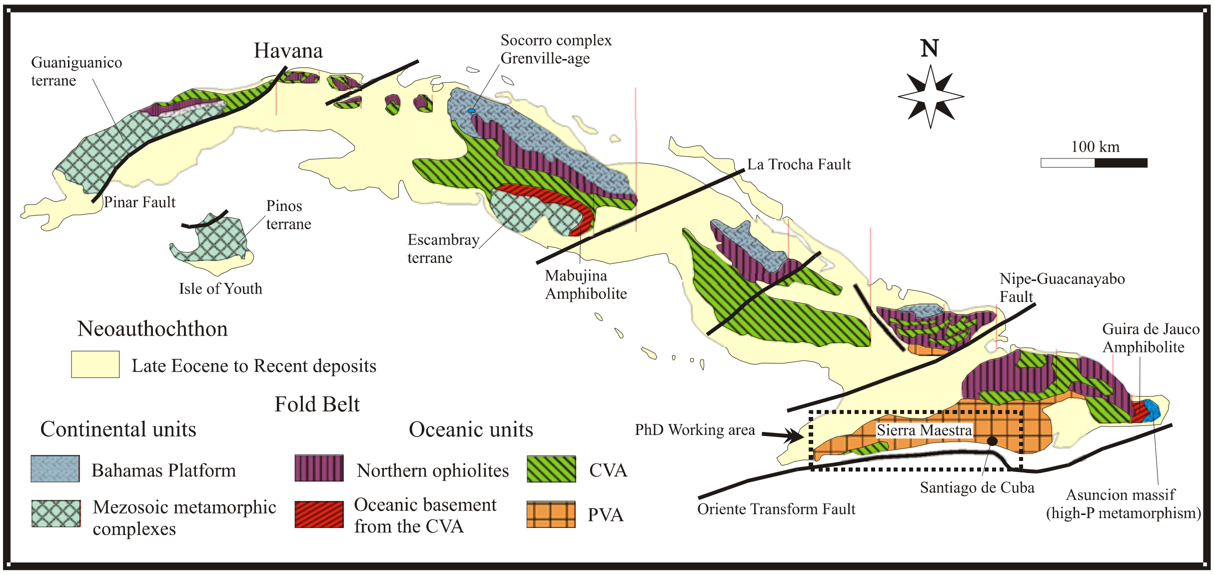

Fig. 2. Geological sketch map of Cuba (after Iturralde-Vinent, 1996). CVA – Cretaceous Volcanic Arc, PVA – Paleogene Volcanic Arc.

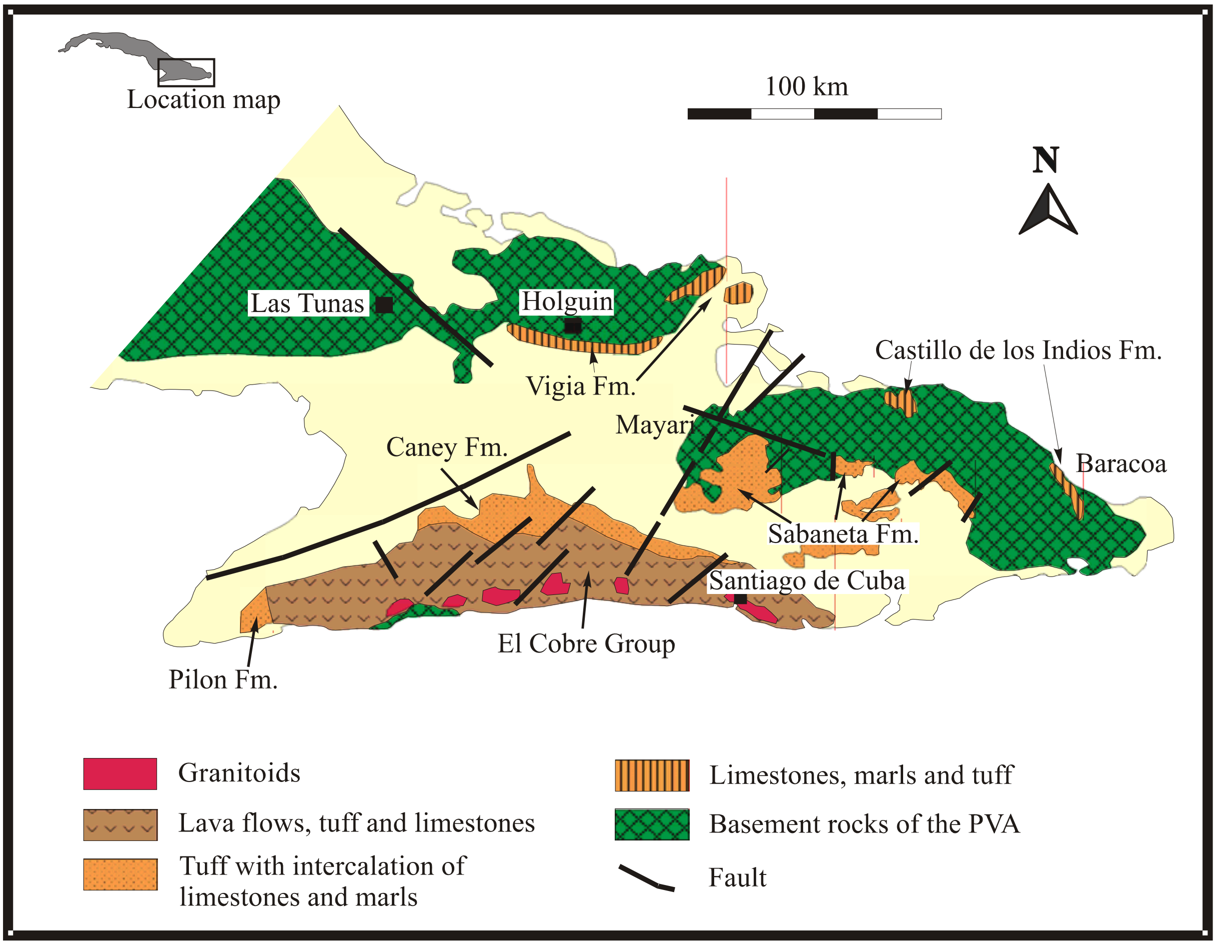

Fig. 3. Sketch map of the PVA in eastern Cuba, after Iturralde-Vinent, 1996.