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Orogenic processes in transpressional regimes

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Abstract: The Uralides and the Hispaniola belts present two well-preserved examples of arc-continent collision orogens formed with different plate convergent angle. Many of the orogenic processes are common to these two orogens, but its consequences are different in some cases. Exhumation of high-pressure rocks is far more complicated in small angle convergent collision zones (Hispaniola). These rocks are transported to wrench fault zones and exhumed along them. However, the main differences in these extreme collisonal orogenic examples are evident in the structure of the belt. Lack of cilindricity of structures, irregular topography of the mountains, lack of a clear sequence of structure formation, coeval development of different structures, development of intramontane subromboidal basins, are characteristics of the deformation of the upper plate in the case of plate collision at very low angle.

Keywords: oblique collision, transpression, orogenic processes, exhumation oh high-pressure rocks.

Comparison between the Uralides and the Hispaniola (northern part of the Caribbean plate) belts allows us to discuss the dominant orogenic processes in each orogen. These orogens are examples of mountain belts formed by arc-continent collision, but with a very different convergence angle. The Uralides were the result of near orthogonal convergence of plates, and the Hispaniola belt is a consequence of a collision with a highly oblique convergence of plates. The purpose of this communication is to identify the collisional processes performed under a transpression regime corresponding to the oblique-convergence of plates.

The Uralides

The tectonic evolution of the Uralides began during the Late Silurian as intra-oceanic subduction formed the Magnitogorsk and Tagil island arcs. The formation of the Uralide orogen began during the late Early Devonian as the continental margin of Baltica entered an E-dipping subduction zone beneath the Magnitogorsk and Tagil island arcs (Fig. 1). The subsequent arc-continent collision resulted in the development and emplacement of an accretionary complex over the continental margin, the development and deformation of a foreland basin, and the extrusion of high-pressure rocks along the arc-continent suture (Brown *et al.*, *in press*).

The first indication of arc-continent collision in the geological record of the Southern Urals is the age of eclogite facies metamorphism from the continental rocks of Maksutovo Complex. Part of the continental crust that had entered the subduction zone had reached at least 50 to 70 km depth by the middle part of the Frasnian. This age is younger than the shift of volcanism (Eifilian/Givetian) which is another indication of the subduction of continental crust. Following the entrance of the continental crust into the subduction zone, the Paleozoic rise and slope sediments of

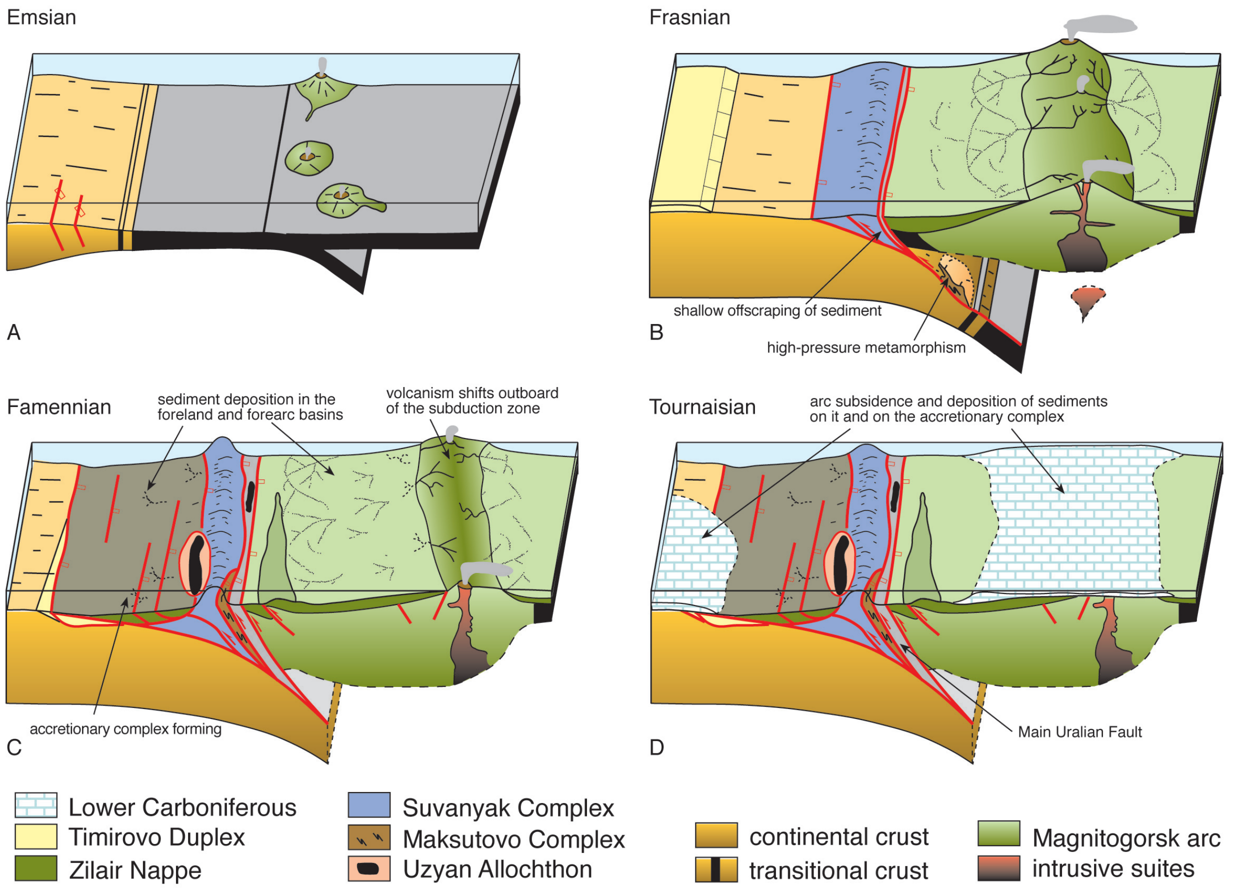

Figure 1. (A) The early convergent history in the Southern Urals is marked by the generation of boninite-bearing arc-tholeiites in the Magnitogorsk forearc, (B) with the entry of the East European Craton continental crust into the subduction zone, volcanism stopped, and high-pressure metamorphism of its leading edge took place, (C) the arrival of the full thickness of the continental crust at the subduction zone is marked by increased sedimentation in the forearc basin and deposition of arc-derived volcaniclastic turbidites across the subducting slab, (D) these, together with offscraped continental material, the exhumed high-pressure rocks, and a lherzolite massif, formed an accretionary wedge. A broad melange zone containing ultramafic fragments separates the forearc basement from the accretionary wedge. Arc-continent collision stopped in the Southern Urals at the end of the Devonian, and Early Carboniferous sediments were deposited on top of the arc. From Brown *et al.* (2006).

the continental margin were shallowly underthrust beneath the crust and upper mantle of the forearc (Fig. 1). Parts of the slope and rise sediments were more deeply subducted, deformed and metamorphosed to lower and middle greenschist facies before being offscraped and exhumed. An indicator of arc-continent collision in the Southern Urals is the onset of deposition of the Zilair Formation (forearc basin) sediments in the latest Frasnian, with clast derived from volcanic, ultramafic, low to medium metamorphic grade, and high-pressure rocks, indicating that by the Late Frasnian the accretionary complex and the volcanic front formed subaerial mountain ranges.

The Main Uralian Fault in the Southern Urals forms the suture zone between the Uralide arc terranes and the paleo-continental margin of Baltica. Arc-continent collision stopped in the Southern Urals at the end of the Devonian, and Early Carboniferous sediments were deposited on top of the arc. From beginning to end, arc-continent collision in the Southern Urals lasted about 20 Ma and possibly as much as 30 Ma. Figure 1 shows a synthesis of some of the orogenic processes recorded in the Southern Urals (Brown *et al.*, 2006).

Hispaniola Island: Caribbean Island Arc-North American Margin collision

The geochemistry of the Caribbean Volcanic Arc rocks, the structure of the arc-continent collision accretionary complex and the forearc, the presence of high-pressure rocks along or near the suture zone, the outcrops of ophiolitic material, and the syn-tectonic sediments show that the tectonic processes recorded in the Hispaniola Island are similar to those described for the Southern Urals. Nevertheless, its manifestation is in many cases quite different.

The Geology of Hispaniola Island results from the oblique-convergence until final collision of the Cretaceous Caribbean island-arc with the continental margin of North America (Mann *et al.*, 1991). Caribbean GPS studies have shown that the Caribbean plate is moving eastnortheastward (N70E) at a rate of >10 mm a^{-1} relative to North America (DeMets *et al.*, 2000; Mann *et al.*, 2002). Hispaniola consists of a tectonic collage of fault bounded igneous, metamorphic and sedimentary rocks of Late Jurassic to Cretaceous age, accreted in an intra-oceanic island-arc setting (Escuder-Viruete *et al.*, 2007). These rocks are regionally overlain by Cenozoic sedimentary sequences that post-date island-arc activity and record the period of dominant left-lateral strike-slip motion between the North America and Caribbean plates (Figs. 2 and 3; Pérez-Estaún *et al.*, 2007).

The oldest rocks include the Upper Jurassic Jarabacoa-La Vega ophiolite with the Loma Caribe serpentinized peridotite, interpreted as the proto-Caribbean ocean (Escuder-Viruete and Pérez-Estaún, 2006). The Oriental Cordillera contains an Early Cretaceous volcanic Los Ranchos Fm, overlain by a thick sedimentary sequence of Upper Cretaceous rocks; Guayabas Fm. Los Ranchos Fm comprises a sequence of volcanic rocks, including boninites which are interpreted to be the onset of subduction in the proto-Caribbean plate. Guayabas Fm is formed by sediments with clasts of island arc provenance that has been interpreted as part of the forearc of the Upper Cretaceous Caribbean Island Arc. These Upper Cretaceous magmatic sequences, cropping out in Central Hispaniola, are composed of island-arc and back-arc related rocks. North of the Central Cordillera, several Cenozoic sedimentary sequences formed as forearc basins in the acretionary collisional com-

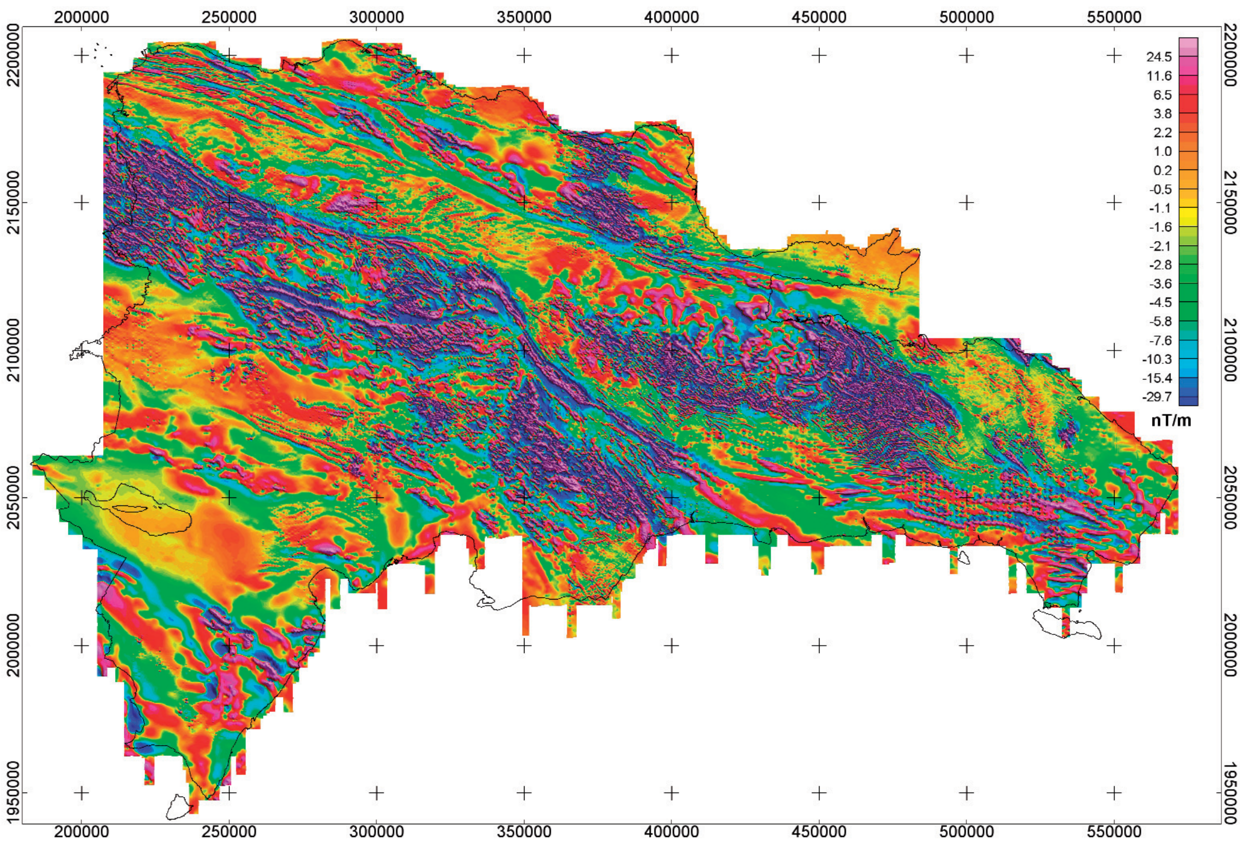

Figure 2. Equal area, shaded relief, vertical gradient of total magnetic field of the Dominican Republic. Major faults (see Fig. 3) and tectonic units can be easily identified (García-Lobón et al., 2007).

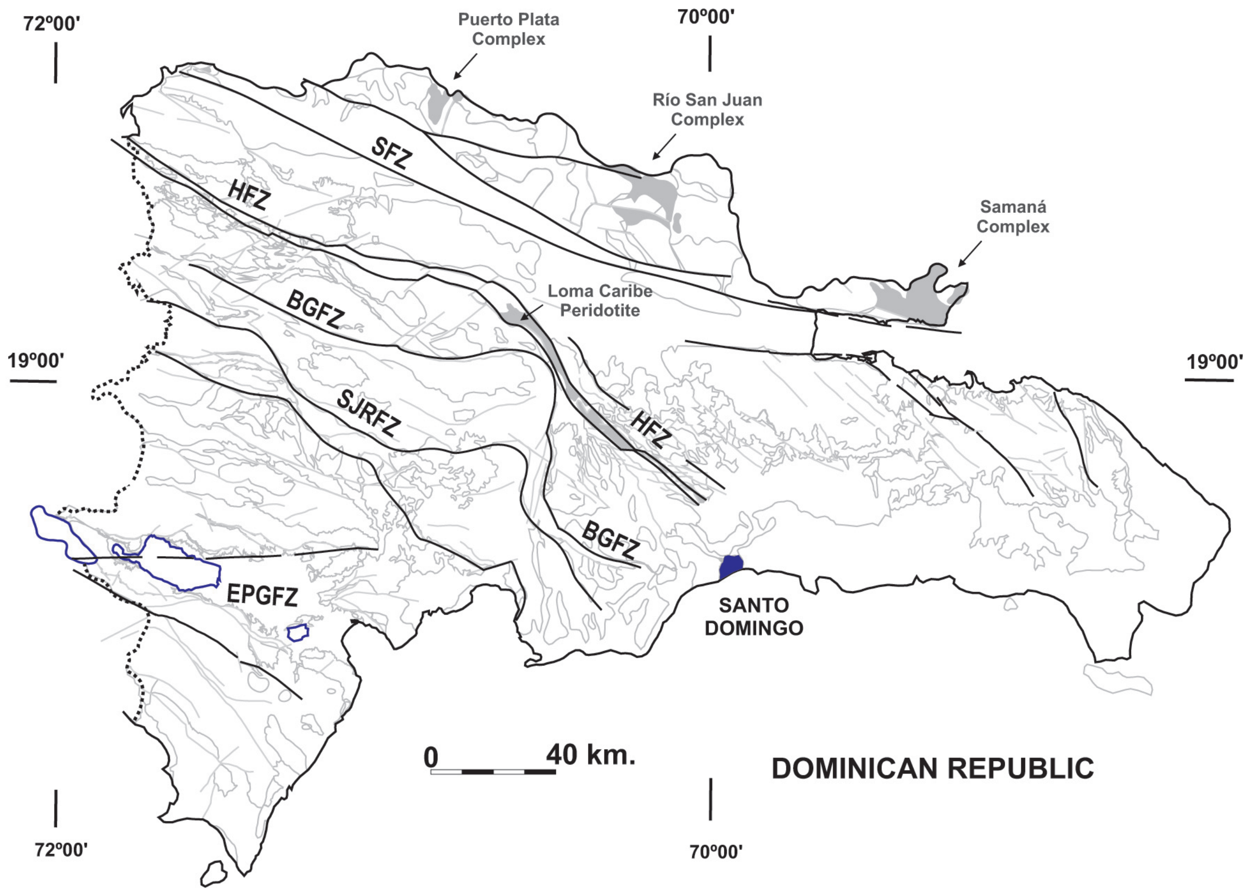

Figure 3. Location of the main fault zones and complexes with high-pressure rocks in the Dominican Republic. SFZ: Septentrional fault zone; HFZ: Hispaniola fault zone; BGFZ: Bonao-La Guácara fault zone; SJRFZ: San Juan-Restauración fault zone; EPGFZ: Enriquillo-Plantain Garden fault zone.

plex are present. At the same time, in south Central Hispaniola, back arc and post-arc sedimentary basins were developed.

Outcropping in the Cordillera Septentrional of Hispaniola, high-pressure complexes with eclogites, blueschists facies metamorphic rocks and ophiolitic mélanges are present (Samana, Rio San Juan, and Puerto Plata complexes). These complexes form part of the accretionary wedge, formed in a subduction zone in which WSW to SW-migrating proto-Caribbean lithosphere was subducted beneath the Caribbean plate from Cretaceous to Paleocene times (Joyce, 1991; Draper and Nagle, 1991) and were exhumed during the collision between the North American and the Caribbean plates. The entrance of the continental margin of North America in the subduction zones is evidenced by the shift of the subduction related volcanism and the change of geochemical characteristics in the uppermost Cretaceous times. Volcanism continues in disperse areas later on but it is not subduction-related.

Eclogite and garnet glaucophanite lenses from the Punta Balandra unit of the Samana complex (northern Hispaniola) reach conditions of P=22-24 kbar and T=610-625 ºC. The subsequent retrograde P-T path entered the epidote-blueschist (garnet-free) facies and ended within the greenschist facies. The Samana complex is an imbricate stack of discrete tectonic units, forming part of a flower structure associated with the Neogene movement of the Septentrional fault. The other two high-pressure complexes outcrop in a asimilar structure in Puerto Plata, and in a restraining bend in Rio San Juan. It is still unknown if these wrench structures with the melanges are placed along the suture zone or if they just cross it. Krebs *et al.* (2008) estimated minimum ages of ~124 Ma (Lower Cretaceous) for the initiation of subduction bellow the Caribbean island-arc, and ages of ~74-62 Ma (Late Cretaceous) for cooling below 400 °C during exhumation of the eclogite and blueschist blocks in the Jagua Clara serpentinitic-matrix mélange of the Río San Juan complex. In the Samaná complex, $^{40}Ar/^{39}Ar$ plateau ages in the (35-25 Ma time interval) Late Eocene to earliest Miocene were obtained on phengite and interpreted to record cooling during decompression that is contemporaneous with nappe-stacking. These ages are consistent with sedimentary data from the forearc sequences. Clasts of high-pressure rocks and serpentinites are present in sediments of Lower Eocene Imbert Fm and in other Eocene-Oligocene sequences of the accretionary complex. Considering these data, and the fact that convergence continues today, collision has been active for more than 50 Ma.

In the same way than the Uralides, following the entrance of the continental crust into the subduction zone, the rise and slope sediments of the North American continental margin were underthrust beneath the crust and upper mantle of the forearc, and metamorphosed to lower and middle greenschist facies before being offscraped and exhumed to form the marbles of the Samana Peninsula.

Vertical shear zones, sub-parallel to the orogenic belt, oblique arrangement of the structural grain en echelon with respect to the shear zone, rotational S-shaped fold traces, rhomb basins and uplifts forming positive and negative flower structures, restraining bends, are fundamental structural features of transpressional tectonics in the shallow crust (Fig. 3). A prevailing transpressional setting, including partitioning of deformation in space and time, is present in the Hispaniola Island during Cenozoic times. The topography of the island is also an evidence of this kind of deformation: mountain chains ending laterally in an abrupt manner; a topographic section of the mountain belt show high mountains and rhomboidal valleys filled by basins, not developing the typical wedge-shape of an orogenic transect. Many of the mentioned structures are active today, and there is not a clear deformation sequence.

The angle of convergence, in oblique collision, is one of the factors controlling the nature of the deformation in transpressional settings (Tikoff and Teyssier, 1994; Tikoff y Greene, 1997). Application of these kinematic models to the collision of the northern part of the Caribbean plate (convergence angle of 20º), predicts that transpression should be dominated by simple shear with a high-grade of partition. Nevertheless, what can be seen in the upper plate of this collisional orogen is a regional distribution of structures, wrench fault dominated in the area closed to the suture zone (Septentrional Cordillera), and a more partitioned deformation that is regionally distributed, towards the south, far from the suture.

Conclusion

The Uralides and the Hispaniola belt are examples of mountain belts formed by arc-continent collision with different convergence angle. Many of the orogenic processes are common to these two orogens, but its consequences are different in some cases. Exhumations of high-pressure rocks are far more complicated in small angle convergent collision zones (Hispaniola). These rocks are transported to wrench fault zones and exhumed along them. In small angle convergent collision, sequences forming foreland basins developed as part of the accretionary complex, migrate along and parallel to the suture zone and are usually bounded by synsedimentary strike-slip faults. However, the main difference in these extreme collisonal orogenic examples is the structure of the belt. Lack of cilindricity of structures, irregular topography of the mountains, lack of a clear sequence of structure formation, coeval development of fold, thrust, normal and wrench faults, development of intramontane subromboidal basins, are characteristics of the deformation of the shallow crust of the upper plate in the case of plate collision of very low angle.

References

Brown D., Puchkov, V. N., Álvarez-Marrón, J., Bea, F. and Pérez-Estaún, A. (2006): Tectonic processes in the Southern and Middle Urals: an overview. In: D. Gee and R. A. Stephenson (eds): *European Lithosphere Dynamics*, Geol. Soc. London Mem., 32: 407-419.

Brown, D., Juhlin, C., Ayala, C., Tryggvason, A., Bea, F., Álvarez-Marrón, J., Carbonell, R., Seward, D., Glasmacher, U., Puchkov, V. and Pérez-Estaún, A. (in press): Mountain building processes during continent-continent collision in the Uralides. *Earth Sci. Rev.*

DeMets, C., Jansma, P., Mattioli, G., Dixon, T., Farina, F., Bilham, R., Calais, E. and Mann, P. (2000): GPS geodetic constraints on Caribbean-North America plate motion, *Geophys. Res. Lett.*, 27: 437-440.

Draper, G. and Nagle, F. (1991): Geology, structure, and tectonic development of the Río San Juan Complex, northern Dominican Republic. In: P. Mann, G. Draper and J. F. Lewis (eds): *Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola*, *Geol. Soc. Am. Spec. Paper*, 262: 77-95.

Escuder-Viruete, J. and Pérez-Estaún, A. (2006): Subduction related P-T path for eclogites and garnet glaucophanites from the Samana Peninsula basement complex, northern Hispaniola. *Int. J. Earth Sci.*, 95: 995-1017.

Escuder-Viruete, J., Contreras, F., Stein, G. P., Joubert, M., Pérez-Estaún, A., Friedman, R. and Ullrich, T. D. (2007): Magmatic relationships and ages between adakites, magnesian andesites and Nb-enriched basalt-andesites from Hispaniola:

record of a major change in the Caribbean island arc magma sources. *Lithos*, 99: 151-177.

García-Lobón, J. L., Ayala, C., Rey-Moral, C. and Padín-Debén, A. (2007): *Cartografía Geotemática de la República Dominicana: "Proyecto 2007-2010" (con zonas de ampliación)*. PROGRAMA SYSMIN, 7ACP DO 024, IGME, Informe 63355, 128 pp, 54 figures and 70 maps.

Joyce, J. (1991): Blueschist metamorphism and deformation on the Samana Peninsula; a record of subduction and collision in the Greater Antilles. In: P. Mann, G. Draper and J. F. Lewis (eds): *Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola*, *Geol. Soc. Am. Spec. Paper*, 262: 47-76.

Krebs, M., Maresch, W. V., Schertl, H.-P., Baumann, A., Draper, G., Idleman, B., Münker, C. and Trapp, E. (2008): The dynamics of intra-oceanic subduction zones: A direct comparison between fossil petrological evidence (Rio San Juan Complex, Dominican Republic) and numerical simulation. *Lithos*, 103: 106-137. doi:10.1016/j.lithos.2007.09.003.

Mann, P., Calais, E., Ruegg, J. C., DeMets, C., Jansma, P. and Mattioli, G. (2002): Oblique collision in the northeastern Caribbean from GPS measurements and geological observations. *Tectonics*, 21, 6: 1- 26.

Mann, P., Draper, G. and Lewis, J. F. (1991): Geologic and tectonic development of the North America-Caribbean plate boundary in Hispaniola. *Geol. Soc. Am. Spec. Paper*, 262, 401 pp.

Pérez-Estaún, A., Hernaiz-Huerta, P. P., Lopera, E. Joubert, M. and Grupo SISMYN (2007): Geología de la República Dominicana: de la construcción de arco-isla a la colisión arco-continente. *Bol. Geol. Minero*, 118, 2: 157-174.

Tikoff, B. and Greene, D. (1997): Stretching lineations in transpressional shear zones: an example from the Sierra Nevada Batholith, California. *J. Struct. Geol.*, 19, 1: 29-39.

Tikoff, B. and Teyssier, C. (1994): Strain modeling of displacement-field partitioning in transpression orogens. *J. Struct. Geol.*, 16, 11: 1575-1588.