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DEFORMATION HISTORY OF THE BLUESCHIST-FACIES SEQUENCES FROM THE VILLA DE CURA UNIT (NORTHERN VENEZUELA)

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ABSTRACT

The Serrania del Interior terrane is located in Northern Venezuela, that represents the southern margin of the Caribbean plate. This terrane includes the Villa de Cura unit, which mainly consists of multiple sub-units of metamorphosed and deformed Cretaceous volcano-sedimentary sequences. These sequences are commonly interpreted as generated in a supra-subduction zone setting.

The structural history of the Villa de Cura blueschists-facies units includes four main deformational phases, from D1 to D4. The first D1 phase is mainly represented by a relict S1 schistosity developed under HP/LT conditions. The relic S1 schistosity is deformed by isoclinal to subisoclinal F2 folds showing similar geometry. The F2 folds are characterized by a continuous S2 crenulation cleavage developed under greenschist-facies metamorphism. The parallelism between the A2 axes and the related L2 mineral lineations suggests an interpretation of the F2 folds as sheath folds developed during non-coaxial deformation. The kinematic indicators suggest a top-to-W sense of shear for the D2 phase. The D3 phase is distinguished by asymmetric, parallel F3 folds with a S vergence. Finally, the D4 phase consists of F4 open, gentle folds with high-angle to sub-vertical axial planes.

The collected data suggest a complex deformation history, characterized by coupling of strike-slip tectonics and shortening during the retrograde evolution of the blueschist-facies sequences.

INTRODUCTION

The Caribbean Plate is an independent, small lithospheric fragment located between the Northern and Southern American Plates. The southern boundary of the Caribbean Plate is well exposed in Northern Venezuela (Fig. 1a) where a strongly dismembered orogen of alpine age crops out along a dextral shear-zone, up to 300 km wide. The present-day tectonic setting of Northern Venezuela mainly consists of an assemblage of displaced terranes bounded by strike-slip faults. These terranes consist of amalgamated oceanic and continental units that preserve the records of a complex and long-lived magmatic, tectonic and metamorphic history.

The geodynamic history of the southern boundary of the Caribbean Plate (Frisch et al., 1992; Giunta, 1993; Meschede and Frisch, 1998; Maresch et al., 2000) developed troughout the spreading of the Jurassic proto-Caribbean oceanic basin, which originated as a consequence of the break-up of the Pangea and the following rifting and drifting between the North and South America plates. Subsequently, a change in the main plate motions and the relative north-westward movement of South America with respect to North America, induced the development of Cretaceous intra-oceanic subductions, and related island-arc, fore-arc and back-arc settings. During the Late Cretaceous-Early Tertiary, continuous convergent tectonics led to a further shortening in the southern Caribbean area with large-scale compressive deformations ("eo-Caribbean phase"). In addition, the southern margin of the Caribbean plate was largely controlled, since the Cretaceous, by dextral strike-slip tectonics connected with the progressive eastward shifting of the Caribbean plate with respect to South America, that led to the displacement of the Northern Venezuela terranes.

However, the reconstruction of the geodynamic evolution of the southern margin of the Caribbean plate displays several open problems, owing to the lack of detailed investigations on the structural and metamorphic features of the displaced terranes. At this regard, the high-pressure low-temperature (HP-LT) units may provide important geological constraints for the geodynamic reconstruction, helping to determine the dipping direction of the Cretaceous subduction(s) as well as the exhumation mechanism of the HP-LT rocks.

The petrological features and the metamorphic evolution of the main HP-LT units of Northern Venezuela (i.e., the Margarita Complex, Franja Costiera-Cordillera de la Costa, and Villa de Cura unit) have been recently outlined in detail (Avé Lallemant, 1997; Giunta et al., 1997; Sisson et al., 1997; Smith et al., 1999, Maresch et al., 2000), whereas the deformation histories of these units are still poorly constrained.

In this paper we present the preliminary results of detailed structural analyses of the HP-LT Villa de Cura unit and we discuss the related tectonic implications.

GEOLOGICAL SETTING

The Serrania del Interior (Fig. 1b) corresponds to the southernmost terrane of Northern Venezuela. It represents a 250 km long, W-E trending belt bounded by the Cordillera de La Costa continental basement to the North, and the upper Cretaceous-Paleocene foredeep sequences (Piemontine Nappe) of the South America Plate to the South (Avé Lallemant, 1997; Giunta et al., 1997; Sisson et al., 1997; Smith et al., 1999, Maresch et al., 2000).

In the Serrania del Interior terrane four main units, separated by high-angle, south dipping thrusts, have been recog-

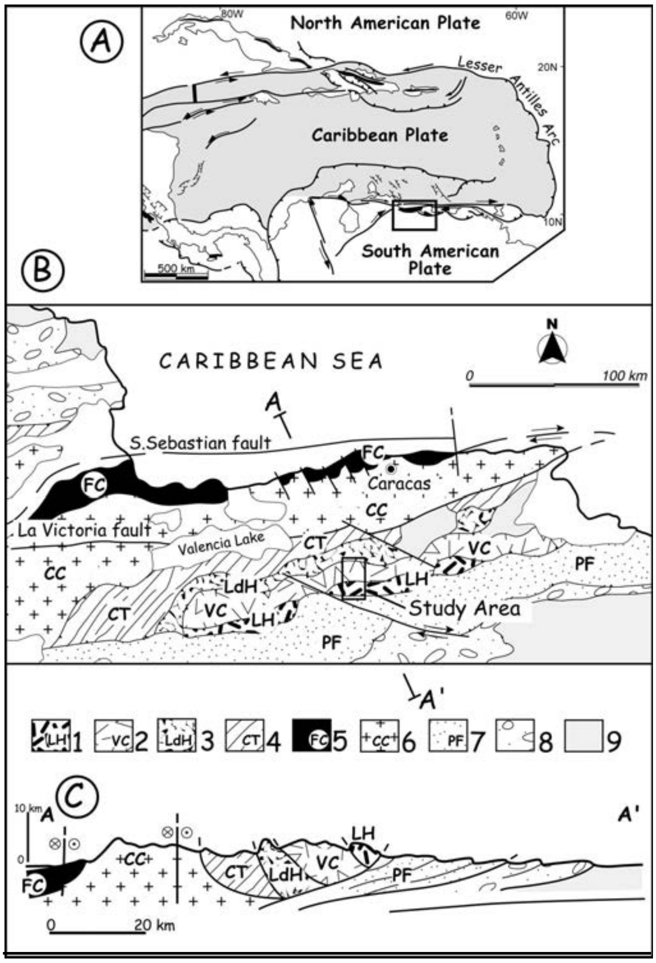

Fig. 1 - A) geodynamic framework of the Caribbean Plate; B) tectonic sketch map of the Northern Venezuela; C) geological section across the Northern Venezuela (1: LH=Las hermanas unit; 2: VC=Villa de Cura unit; 3: LdH=Loma de Hierro; 4: Ct=Cacagua-El Tinaco unit; 5: Fc=Franja Costiera unit; 6: CC=Cordillera de la Costa unit; 7: Piemontine nappe; 8: Folded sedimentary cover of the Guyana shield; 9: Sedimentary cover of the Guyana shield)

nized (Navarro, 1983; Ostos, 1990; Giunta et al., 1997; Smith et al., 1999); from north to south, they are:

a) the Cacagua-El Tinaco unit, which probably represents a rifted continental margin, consists of sub-continental mantle and associated sections of lower continental crust. This association is overlain by volcano-sedimentary sequences showing within-plate tholeiitic magmatic affinity (Giunta et al., 1997; Seyler et al., 1998).
b) the Loma de Hierro unit, which is interpreted as a middle-upper Jurassic to Cretaceous mid-ocean ridge ophiolitic sequence. It is mainly consists of serpentinized mantle peridotites, gabbroic cumulates, basalts and cherts topped by upper Cretaceous sedimentary deposits .
c) the Villa de Cura unit (also referred in the literature as Villa de Cura belt), which consists of multiple sheets of metamorphosed and deformed Cretaceous volcano-sedimentary sequences. The protoliths of the meta-sequence of the Villa de Cura unit include: tuffs, cherts, volcanoclastites, and lavas ranging from basalts to rhyolites. On the basis of the geochemical characteristics of the lavas, this sequences have been interpreted as generated in a supra-subduction-zone setting either as a primitive island-arc (Donnelly and Rogers, 1978; Beccaluva et al., 1996) or back arc (Navarro, 1983; Ostos, 1990) environment. The age of the magmatic protoliths has been referred to the “mid” Cretaceous (Beets et al., 1984; Loubet et al., 1985). Shagam (1960) divided the Villa de Cura unit into four lithostratigraphical formations, but further detailed petrological studies on the metamorphic isogrades suggested the occurrence of six (Piburn, 1968; Navarro, 1983) or four (Smith et al., 1999) sub-units (also referred in the literature as sub-belts), each characterized by different metamorphic assemblages. The E-W trending boundaries of these sub-units do not exactly correspond to those of the lithological units previously identified by Shagam (1960). According to the recent subdivision proposed by Smith et al. (1999), the Villa de Cura sub-units are respectively marked, from north to south, by the occurrence of: 1) pumpellyte-actinolite, 2) glaucophane-lawsonite, 3) glaucophane-epidote, 4) barroisite. These syn-tectonic HP-LT metamorphic assemblages record the involvement of the Villa de Cura unit in a subduction zone. Available radiometric ages indicate the “mid” Cretaceous for the peak metamorphism, ranging between a maximum of 101±5.8 Ma (K/Ar method on amphibole: Loubet et al., 1985) or 96.3±0.4 Ma (Ar/Ar method on amphibole: Smith et al., 1999) to a minimum of 79.8±0.4 Ma (Ar/Ar method on white mica: Smith et al., 1999) or 77±5 Ma (K/Ar method on amphibole: Loubet et al., 1985). The shape of retrograde P-T paths of the three northern sub-units have been interpreted as representative of exhumation occurred during an intra-oceanic subduction. By contrast, the occurrence in the southernmost sub-unit of amphibole zoning from barroisitic cores to glaucophanitic rims seems to indicate the occurrence of an anomalously high geothermal gradient coherent with an atypical counterclockwise P-T path (Smith et al., 1999).
d) the Las Hermanas unit, that consists of a sequence of basalts and basaltic-andesites interlayered with volcanic breccias and tuffs. This sequence is commonly referred to as part of a “mid”Cretaceous island arc generated in an intra-oceanic supra-subduction setting (Navarro, 1983; Ostos, 1990; Beccaluva et al., 1996).

DEFORMATION HISTORY

The structural analysis has been performed on the Villa de Cura sub-units (i.e. sub-belts 2, 3 and 4 of Smith et al., 1999) affected by blueschist metamorphism. Four deformation phases, from D1 to D4, have been identified in the field as well as in thin section.

The first D1 phase, is represented by a S1 foliation, which can be observed as a relict only in the hinge zone of F2 folds. This foliation can be classified as a schistosity developed under blueschist-facies conditions. The syn-D1 metamorphic paragenesis generally includes by albite + quartz + chlorite$_1$ ± phengite ± titanite; nonetheless, the presence of other mineralogical relics allows to define at least three different climax assemblages in each subunit, respectively characterized by: 1) Na-amphibole + lawsonite; 2) Na-amphibole + epidote$_1$; 3) Na-/Ca-amphibole + epidote$_1$. In the last case, the observable relationships between the sodic (glaucophanitic l.s.) and the calcic or calco-sodic (barroisitic l.s.) amphiboles are ambiguous. In addition, it is still unclear if the different peak parageneses are representative of a change of the accretion depth or reflect differences in the protolith composition. Nevertheless, the observed blueschist-facies assemblages allow to constrain the climax metamorphic conditions of the Villa de Cura unit in the range of 600 MPa <P< 750 MPa and 375 <T< 450°C. On the S1 foliation, mineral lineations are represented by elongated epidotes, Na-amphiboles and lawsonite showing a N/S, down-dip trend (Fig. 2). Moreover, the quartz veins transposed by S2 foliation can be interpreted as syn-tectonic extensional veins which developed during D1 phase.

The second D2 phase, is characterized by isoclinal to subisoclinal F2 folds with similar geometry and subrounded to subangular hinges (Fig. 3). The folded surfaces are quartz veins or layers with different lithological composition and /or grain size. The F2 folds, generally rootless, have thickened hinges and boudinaged limbs. The limbs generally show well-developed pinch-and-swell structures. Mullion structures are also present. In the related stereonet (Fig. 2), the distribution of A2 axes is scattered, even if a cluster corresponding to a SE-NW trend can be easily identified. The F2 folds are characterized by a well-developed and continuos S2 axial plane foliation, that is a continuos crenulation cleavage developed under greenschist-facies conditions. At the mesoscale, this foliation occurs as the main structural surface, and it is everywhere parallel to the boundaries among the blueschist-facies sub-units. The syn-D2 metamorphic assemblage, marked by albite + chlorite$_2$ + quartz + actinolite ± pumpellyite ± white mica ± calcite ± epidote$_2$, suggests T< 300°C and P< 550-600 MPa. A composite foliation, resulting from overprinting of the S1 foliation by the S2 one, is well recognizable in the limbs of the F2 folds. The L2 mineral lineations consists of elongated minerals such as chlorite and white mica aligned along the S2 foliation; the related stereonet (Fig. 2) reveals that the L2 trend ranges from ESE/WNW to ENE/WSW. On the whole, the F2 axes trend is roughly parallel with the related L2 mineral lineations (Fig. 2). Furthermore, the boudins long axes are usually coaxial with the F2 axes. This feature seems to suggest an interpretation of the F2 folds as sheath folds developed during a non-coaxial deformation history. The kinematic indicators, mainly s-type porphyroclasts of magmatic pyroxenes and s-type porphyroblasts of epidote$_1$, suggest a top-to-W sense of shear (Fig. 4).

The D3 phase is characterized by asymmetric F3 folds, with approximately parallel geometry and rounded hinges. The S1 and S2 surfaces are folded by F3 folds (Fig. 2). The F3 folds, ranging from subisoclinal to open folds, are cilindrical, with east-west trend of the A3 axes (Fig. 2). The axi-

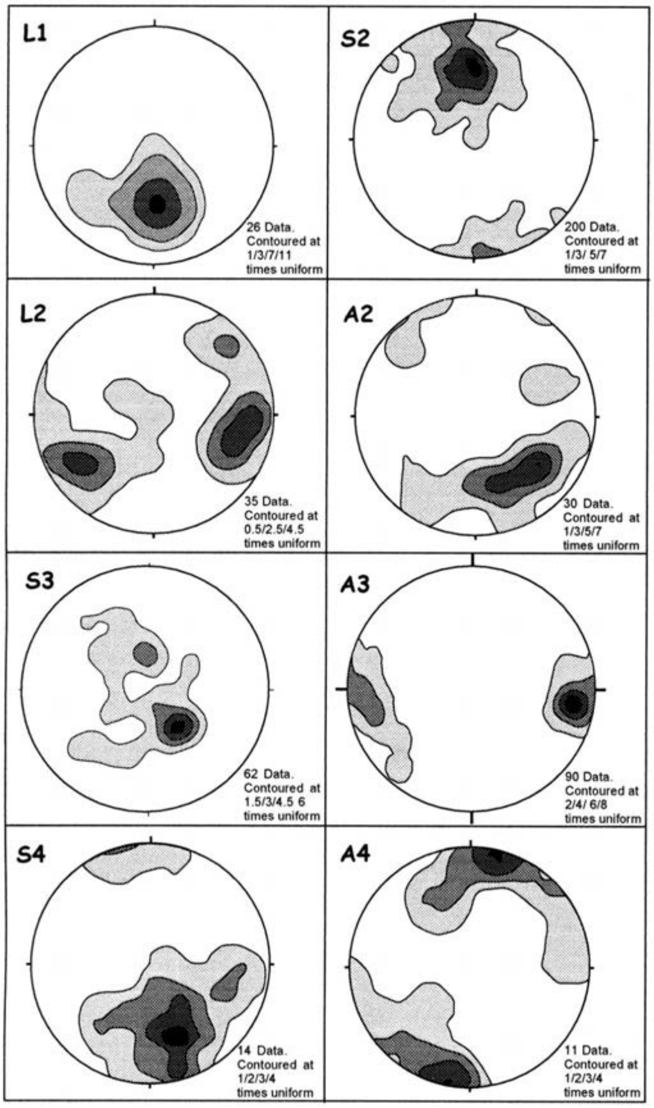

Fig. 2 - Equal-area, lower hemisphere stereographic representation of the structural data. (L=mineralogical and stretching lineations; S=foliation; A=fold axis)

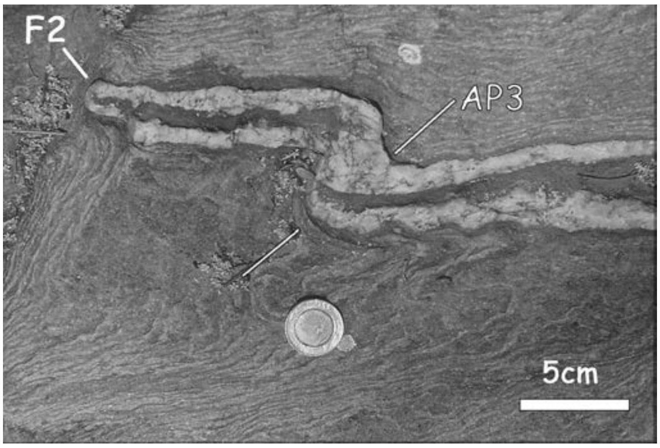

Fig. 3 - Isoclinal F2 fold deformed by a F3 fold in metabasite (the related axial plane AP3 is indicated). The folded layer is represented by a quartz vein.

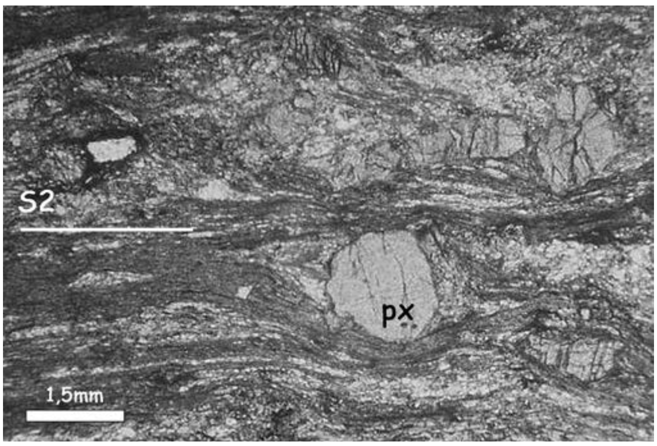

Fig. 4 - S2 greenschists-facies foliation containing σ-type porphyroclasts of magmatic pyroxenes (px). Thin section parallel to L2 mineralogical lineations and normal to S2 foliation.

al plane foliation consists of a spaced S3 crenulation cleavage, which occurs as sub-horizontal surface. During the D3 phase recrystallisation of quartz + albite + stilpnomelane ± white mica occurred. The asimmetry of the F3 folds consistently indicates a southward vergence.

The D4 phase is represented by F4 open, gentle folds with high-angle to sub-vertical axial planes. The F4 folds show a scattered trend, but a cluster corresponding to a NNE/SSW trend can be observed also (Fig. 2). A well-spaced disjunctive cleavage represents the axial-plane foliation associated to the F4 folds.

The SE/NW trending faults and the associated sub-vertical quartz veins are the youngest tectonic structures.

DISCUSSION AND CONCLUSIONS

The outlined structural evolution of the Villa de Cura HP-LT sub-units implies a complex deformation history, here described in detail for the first time. This history consist of four phases mainly developed during retrograde metamorphism, from blueschist-facies to very low-grade conditions. The deformations features allow some considerations about the geological history of the blueschist-facies sequences.

Firstly, the parallelism between the S2 foliation and the boundaries of the Villa de Cura sub-units suggest that all these sub-units were coupled during the D2 phase, that largely obliterated the previous deformations achieved during the D1 phase.

In addition, the D1 phase is clearly related to subduction of the Villa de Cura sub-units which show blueschist-facies metamorphism, as suggested by Navarro (1983), Ostos (1990), Beccaluva et al. (1996) and Smith et al. (1999). The only D1 phase relicts, mainly represented by the S1 foliation, as well as rare quartz veins, do not allow determination the sense of shear during the D1 phase. Thus, the dip of the subducting slab where the blueschist-facies sub-units were involved remains undetermined. Moreover, the D2 phase is characterized by sheath folds associated to L2 mineral lineations showing a rough east-west trend. This trend is parallel to the present-day strike-slip faults that are in turn parallel to the boundaries of the main Northern Venezuela terranes, as discussed also by Smith et al. (1999). This suggests that the exhumation of the blueschist sub-units during the D2 phase was probably largely controlled by strike-slip tectonics. On the contrary, the structural evidence for the D3 phases reveals a clear top to S sense of shear, that suggests a southward displacement of blueschist-facies sub-units during their final stage of the retrograde metamorphic history. The collected data suggest a transpressive deformation history, where strike-slip tectonics was coupled with ductile shortening during the whole retrograde evolution of the Villa de Cura blueschist-facies sub-units.

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REFERENCES

Avé Lallemant H.G., 1997. Transpression, displacement partioning, and exhumation in the eastern Caribbean/South America plate boundary zone. Tectonics, 16, 272-289.

Beccaluva L., Coltorti M., Giunta G., Iturralde-Vinent M., Navarro E., Siena F. and Urbani F., 1996. Cross sections through the ophiolitic units of the southern and northern margins of the Caribbean plate in Venezuela (Northern Cordilleras) and central Cuba. Ofioliti, 21, 85-103.

Beets D.J., Maresch W.V., Klaver G.T., Mottana A., Bocchio R., Beunk F.F. and Monen H.P., 1984. Magmatic rock series and high-pressure metamorphism as constraints on the tectonic history of the southern Caribbean, in Bonini W.E., Argraves R.B., and Shagam R., eds., The Caribbean-South America Plate boundary and regional tectonics. Geological Society of America, Memoir, 162, 95-130.

Donnelly T.W. and Rogers J.J.W., 1978. The distribution of igneous rocks throughout the Caribbean. Geology en Mijnbouw, 57, 151-162.

Frisch W., M. Meschede and M. Sick, 1992. Origin of the Central American ophiolites: evidences from paleomagnetic results. Geological Society of America Bullettin, 104(10), 1301-1314.

Giunta G.,1993. Los margenes mesozoicos de la Placa Caribe: Problematicas sobre nucleacion y evolucion. Memoria, Congreso Colombiano de Geologia, 6th: Medellin, Societad Geologica Colombiana, 3 (8), 1-14.

Giunta, G., Beccaluva L., Coltorti M. and Siena F., 1997. Ophiolitic units of the Southern margin of the Caribbean Plate in Venezuela: A rappraisail of their petrogenesis and original tectonic setting. Memorias Congreso Geologico Venezolano, 8th, Porlamar: Caracas, Sociedad Venezolana de Geologos, 1, 331-337.

Loubet M., Montigny R., Chahati B., Duarte N., Lambert B., Martin C. and Thuizat R., 1985. Geochemical and geochronological constraints on the geodynamic development of the Caribbean chain of Venezuela, in A. Mascle, ed., Symposium on Caribbean geodynamics: Paris, Edition Technip,, 553-566.

Maresch W.V., Stockhert B., Baumann A., Kaiser C., Kluge R., Kruckhans-Lueder G., Brix M.R., and Thomson S., 2000. Crustal history and plate tectonic development in the Southern Caribbean. Zeitschrift fur Angewandte geologie, Sonderhft SH 1, 283-289.

Meschede M., and W. Frisch, 1998. A plate-tectonic model for Mesozoic and Early Cenozoic evolution of the Caribbean plate. Tectonophysics, 296, 269-291.

Navarro E., 1983. Petrologia y petrogenesis de las rocas metavolcanicas del gruppo Villa de Cura. GEOS (Caracas, Escuela de Geologìa y Minas, Universidad Central de Venezuela), 28, 170-317.

Ostos M., 1990. Evolucion tectonica del margen Sur-Central del Caribe, basados en datos geoquìmicos. GEOS (Caracas, Escuela de Geologìa y Minas, Universidad Central de Venezuela), 30, 1-294.

Piburn M.D., 1968. Metamorphism and structure of the Villa de Cura Group, northern Venezuela. Ph.D. dissert.: Princeton, New Jersey, Princeton University, 148,

Seyler M., Paquette J.L., Ceuleneer G., Kienast J.R. and Loubet M., 1998. Magmatic underplating, metamorphic evolution and ductile shearing in a Mesozoic lower-crustal-upper mantle unit (Tinaquillo, Venezuela) of the Caribbean Plate. Journal of Geology, 106, 35-58.

Shagam R., 1960. Geology of the central Aragua State, Venezuela. Geological Society of America Bulletin, 71, 249-302.

Sisson V.B., Evren Ertan I. and Ave' Lallemant H.G., 1997. High-pressure (-2000 MPa) kyanite- and glaucophane-bearing pelitic schist and eclogite from Cordillera de la Costa Belt, Venezuela. Journal of Petrology, 38, 65-83.

Smith C.A., Sisson V.B., Avé Lallemant H.G. and Copeland P., 1999. Two contrasting pressure-temperature paths in the Villa de Cura blueschist belt, Venezuela: possible evidence for Late Cretaceous initiation of subduction in the Caribbean. Geological Society of America Bulletin, 111, 831-848.