

Syn-sedimentary extensional tectonics in the River Tuy Basin, northern Venezuela: implications on basin genesis and southern Caribbean Geodynamics

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Abstract

The River Tuy basin is a Neogene tectonic depression sitting in the Cretaceous metamorphic nappes of north-central Venezuela; thus partly recording the eastward progression of the Caribbean plate along northern Venezuela. This basin formed as a graben and seems to belong to a group of depressions sitting in the same relative position within the nappe complex (from west to east: Nirgua, Miranda, Bejuma, Lake Valencia, Tuy, Barlovento basin, Unare shelf, Cariaco gulf and Paria gulf). This suggests that these basins, more than resulting from local extensional forces as thought before for the Tuy basin at least, should answer to a more regional process: collapse within the orogen. This orogenic collapse is to be necessarily linked to the major geodynamic shift determined throughout northern Venezuela at 17-15 Ma (when major dextral wrenching activates); younger than the Falcón-Bonaire-Blanquilla-Grenada basin complex of late Eocene-early Oligocene age and in a more external position within the accreted "terranes" than the older basins.

Resumen

La cuenca del Tuy medio (Santa Lucía-Ocumare) es una depresión tectónica neógena ubicada dentro del complejo de napas metamórficas cretácicas de la región norcentral venezolana, por lo que ha registrado parcialmente la progresión hacia el Este de la placa Caribe a lo largo del norte de Venezuela. Esta cuenca se formó como graben y pertenece a un grupo de depresiones intramontañas que presentan la misma posición relativa dentro del complejo de napas (de oeste a este: Nirgua, Miranda, Bejuma, Lago de Valencia, Tuy, cuenca de Barlovento, plataforma de Unare y golfos de Cariaco y Paria). Esto sugiere que estas cuencas, más allá de resultar de fuerzas distensivas locales tal como se pensaba para la cuenca del Tuy medio, deben responder a un proceso más regional: colapso dentro de un orógeno. Este colapso orogénico tiene que estar necesariamente vinculado al cambio geodinámico mayor registrado a lo largo de todo el norte de Venezuela ocurrido aproximadamente hace 17-15 Ma (cuando la transurrencia dextral mayor se activa); más joven que el colapso responsable del complejo de cuencas de Falcón-Bonaire-Blanquilla-Grenada de edad Eoceno tardío-Oligoceno temprano y en posición más externa dentro del complejo acretado que las cuencas más viejas.

Introduction

The River Tuy basin is located between the metamorphic Coast and Interior ranges of north-central Venezuela (**Fig. 1**). This basin is a Neogene feature in the geodynamic evolution of the interaction between the Caribbean and South America plates. Therefore, the understanding of the basin formation and evolution should bring light on the plate interactions.



Fig. 1 Geologic and structural map of north-central Venezuela (after Bellizzia et al., 1976). Red box approximately corresponds to Fig. 2 and locates the River Tuy basin within the metamorphic nappes. Numbers label all basins from west to east: 1- Nirgua, 2- Miranda, 3- Bejuma, 4- Lake Valencia, 5- Tuy, 6- Barlovento and 7- Unare shelf

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Geodynamic setting

Present Caribbean-South American geodynamic configuration results from a transpressive evolution that has occurred throughout the Tertiary and Quaternary, initiated as an oblique type-B subduction (NW-dipping, South American-attached oceanic lithosphere under Caribbean plate island arc), which later evolved into a long-lasting east-younging oblique-collision (SSE-vergent Caribbean-affinity nappes overriding destroyed-passive-margin-affinity nappes, all overthrust onto undeformed South America passive margin) and in turn has shifted to transpression when and where collision became unsustainable (for more details refer to Audemard 1993, 1998). Its latest evolutionary stage is still active in Eastern Venezuela and Trinidad, which recreates how this east-younging oblique collision has acted diachronically throughout the evolution of this entire northern portion of the plate boundary (Audemard, 2000). Strain partitioning (NNW-SSE-trending shortening across the entire region from north of La Blanquilla to the southernmost active thrust front of the Interior range and right-lateral strike-slip along the main east-west striking El Pilar and NW-SE striking Los Bajos-El Soldado faults, as well as along other minor parallel and/or synthetic Riedel shear faults) and slab detachment associated with an incipient type-A subduction (e.g., Russo and Speed, 1992; Russo, 1999; responsible for the largest onshore negative Bouguer anomaly of the world, located south of the southern edge of the Interior range) are two of the major involved processes, combined with a plate boundary geometry such as the present one, where the El Pilar fault transfers its slip to one of its synthetic Riedel shears (Los Bajos-El Soldado fault), which is acting as a "lithospheric tear fault", thus separating the transpressional boundary on the west from the conventional type-B Lesser Antilles subduction zone on the east. These two distinct seismogenic domains were originally identified by Pérez and Aggarwal (1981).

Basin stratigraphy

The River Tuy basin is a tectonic depression that shows good exposures of deformed Neogene and Quaternary continental deposits. The exposed sedimentary sequence of the basin essentially covers the upper Miocene-Holocene interval and comprises lake and alluvial facies deposited in an endoreic basin. The oldest sedimentary unit, which mainly crops out in the northeastern part of the basin, is a thinly laminated (varved) lacustrine sequence that has been ascribed to the Pliocene (Siquire Formation), whereas the rest of the basin exposes the Plio-Pleistocene Tuy Formation (Figs. 2 and 3) that comprises both lake deposits (in the middle of the basin) and alluvial beds (Beck, 1980). These formations are unconformably overlain by a set of younger (up to Holocene) alluvial terraces along present drainage (Fig. 2).

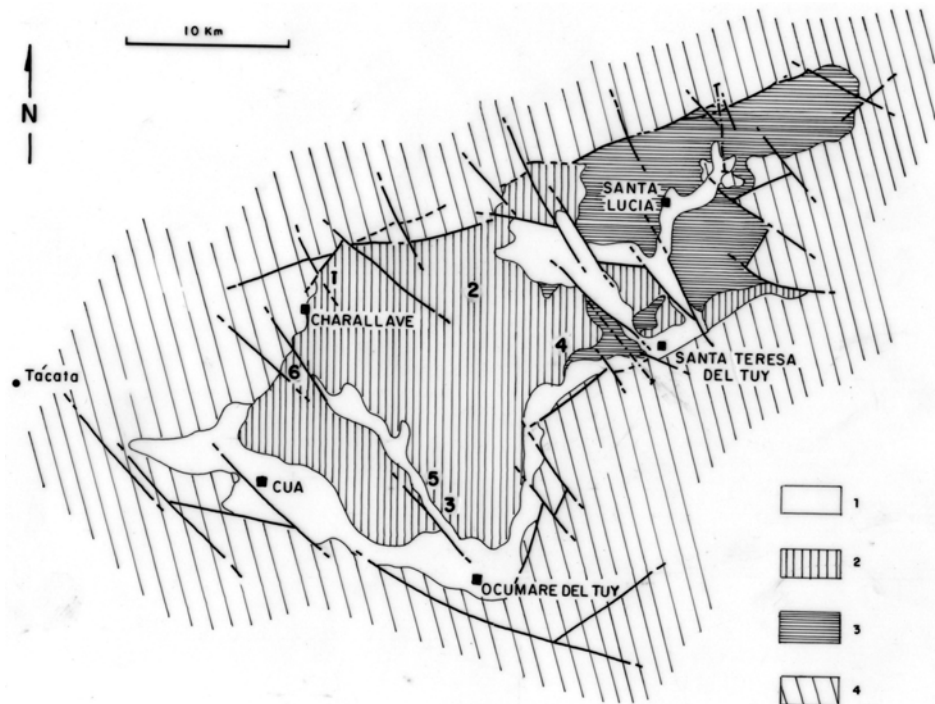


Fig. 2 Simplified geologic map of the River Tuy Basin (after Beck, 1980). Numbers identify outcrop locations. Legend: 1. Recent alluvial deposits; 2. Plio-Pleistocene (Tuy Formation); 3. Pliocene (Siquire Formation); 4. Igneous-metamorphic basement.

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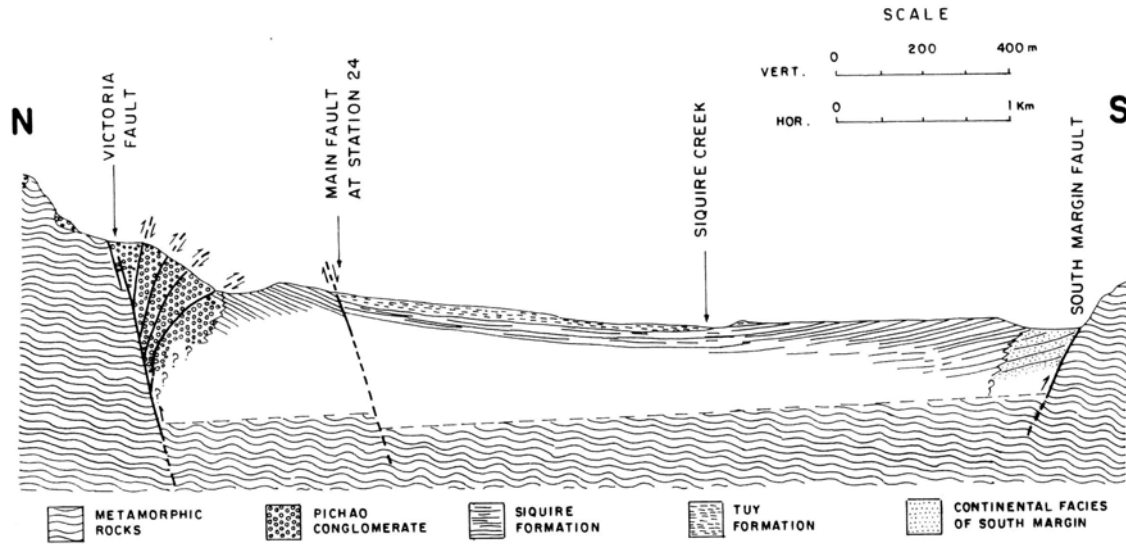


Fig. 3.- Schematic interpreted cross-section of the northeastern part of the River Tuy Basin (after Audemard, 1984), showing possible facies relations and major structural features.

Tectonic analysis

The micro- and meso-structural assessment of several man-made outcrops in this basin has revealed the occurrence of deformations which are partly synchronous to deposition of the Tuy Formation (Fig. 3). Deformations are essentially of the brittle type, clearly dominated by normal faulting as revealed by the analysis of fault-plane kinematic indicators (tectoglyphs) such as: steps, recrystallizations, strololites, synthetic and antithetic Riedel shears, stylolitic peaks and tool marks. Occasionally, these fault planes have been later reactivated along strike, which allowed Audemard (1984; 1985) to propose two consecutive tectonic phases at basin scale: first, a Plio-Pleistocene extensional phase characterized by a NE-SW trending minimum horizontal stress ($\sigma_1 = \sigma_3$) that may have no regional significance; replaced by a Quaternary NNW-SSE oriented compressional phase.

Sedimentation-tectonic interplays

Sense of motion on faults determined from tectoglyphs is also confirmed by sedimentary criteria that simultaneously prove the syn-tectonic character of the sedimentary process. The main evidence of ongoing tectonic activity during sedimentation of the Tuy formation are: (a) the presence of much thicker beds in the down-thrown block but no significant difference in sediment grain-size between equivalents beds on each side of the fault is observed (outcrops 1, 2 and 3 of Fig. 4), implying that sediments tried to blanket the last fault vertical throw; (b) coarser sedimentation in the hangingwall block that means that sediment transport in that compartment had a higher energy gradient due to tectonics (exposures 4 and 5 of Fig. 4); (c) more frequent coarser beds in hangingwall but both compartments exhibit a similar sedimentary sequence (outcrops 2 and 6 of Fig. 4), proving that sediment transport was occasionally fault-bounded (available space for deposition controlled by faults); and (d) vertical throw of fault diminishes up section (fault on left side of outcrop 4 in Fig. 4). The opposite to case (d) could also occur, though it has not been observed in the study area, which would suggest in relative terms that fault slip rate gets progressively much faster than sedimentation rate, assuming that the latter one is about constant. Case (a) implies that sedimentation can (or tend to) keep up with topographic modifications produced by tectonics; consequently, sedimentation and tectonic vertical slip rates are about the same. Cases (b) and (c) imply that normal fault slip rates are faster than sedimentation rates; rate difference is larger in case (b). Case (d) indicates that extensional tectonics at the study scale is dying out.

Interpretation and implications

The "local" extensional regime observed in the River Tuy basin has significant implications on the origin of this tectonic depression. Schubert (1986; 1988) has proposed that this basin is a fault-wedge pull-apart basin produced at the Tácata and La Victoria fault divergence; based only on the geometric pattern. However, no evidence of strike-slip faulting contemporaneous to the extensional phase has been reported within the basin fill. Cross-cutting relations between the two striation generations show that vertical slip always preceded strike slip. Furthermore, the Pichao

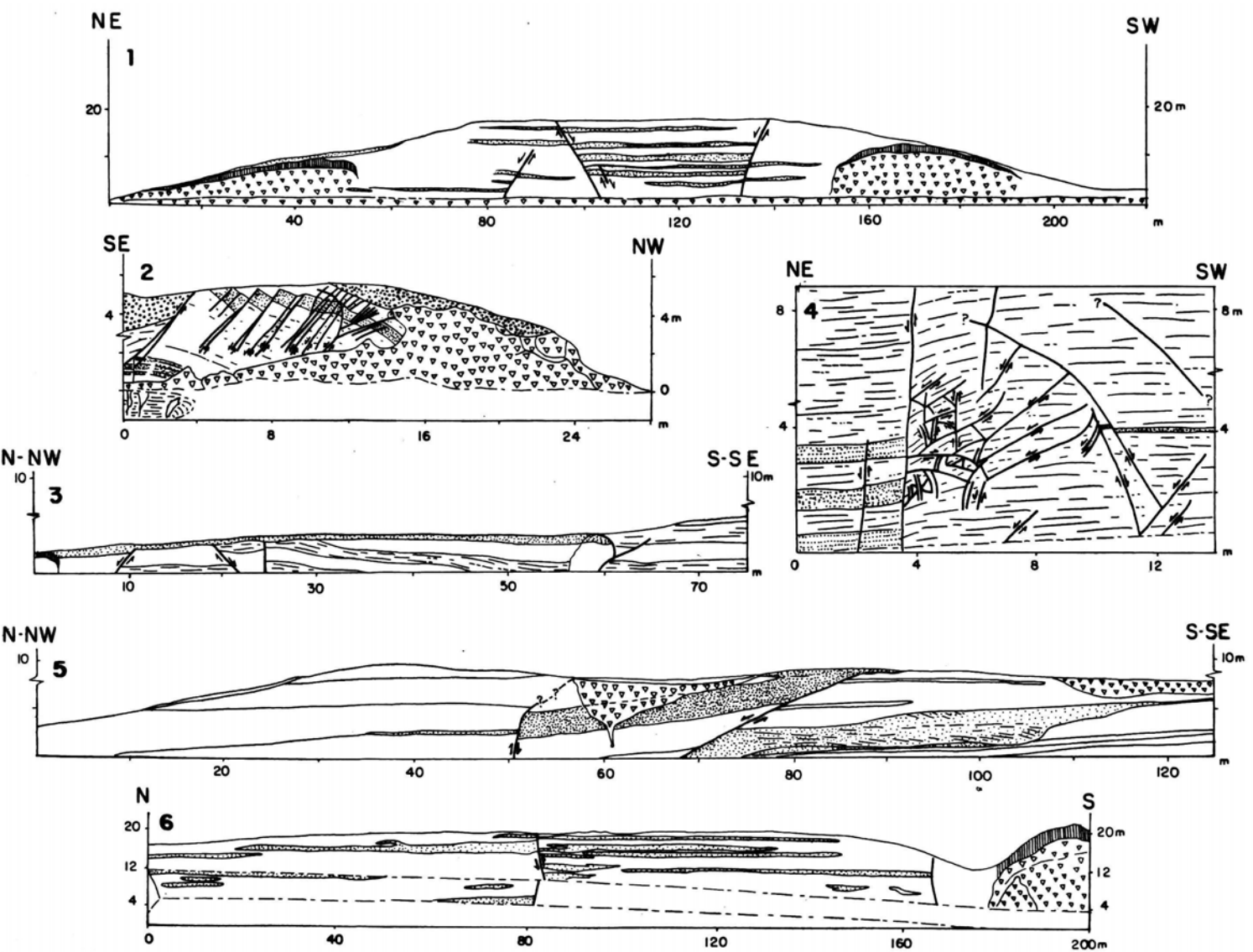


Fig. 4. Exposures of deformed sedimentary rocks (after Audenard, 1984), reported as Plio-Pleistocene Tuy Formation. Refer to **Figure 2** for relative location: (1) Road cut of the La Peña-Charallave motorway; (2) Clay pit at La Verota (Charallave-Santa Teresa road); (3) NW of Ocumare del Tuy, close to Los Piloncitos; (4) Road cut of access to jail, north of Santa Teresa-San Francisco de Yare road; (5) similar to exposure 3; and (6) Tuy Industrial Complex, south of Charallave.

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conglomerate, which is highly tectonized by the basin-bounding La Victoria fault at the Pichao bridge, shows sub-vertical (pitch $\geq 80^\circ$) normal striations, prior to dextral slip, indicating that this fault behaved as a normal fault during basin formation, taking into account that the Pichao conglomerate is considered as the basal unit of the basin sequence, and is definitively a basin marginal facies (Figs. 1 and 2). Moreover, the fault-wedge pull-apart model claims that the basin has to be at the fault divergence. This is not the case for the River Tuy basin because the wedge near the divergence of the Tácata fault from the La Victoria fault shows a rather rough relief zone –not very different from surrounding relief–, west of an imaginary line drawn between the towns of Charallave and Cúa, where the basin western edge definitely is. Consequently, Schubert's model does not seem to be the most appropriate to explain the basin genesis (Audemard, 1996). Therefore, Audemard (op. cit.) indicates that the Plio-Pleistocene local extension recorded in the sedimentary fill of the River Tuy basin could be related to the orogenic collapse of the Coast Range of north-central Venezuela. This hypothesis could be additionally supported by the fact that several other Neogene-Quaternary basins are also centered along the main axis of this orogen (Lake Valencia and Barlovento-Unare shelf basins and a set of smaller depressions: Nirgua, Miranda and Bejuma), suggesting that this extensional phase might not be a local event but of regional scale. Moreover, the Cariaco (?) and Paria gulfs may be interpreted as the easternmost equivalents of this orogenic collapse in eastern Venezuela, implying some diachronism (younger to the east). Therefore, the orogenic collapse must respond to a major change in the geodynamics of the southern Caribbean plate boundary. Then, the collapse may be envisaged as a further effect of the major shift, indicated by Audemard (1993), from oblique collision (last stage of a long-lasting oblique subduction) to transpression *s.l.*, which results from a sub-normal σ_H reduction (horizontal decompression) in the metamorphic nappes of the Coast Range of northern Venezuela. Audemard (1993; 1995; 1998) established that such major shift in northwestern Venezuela happened at about 17-15 ma ago; and this process had progressively taken place in the east slightly later (Audemard & Giraldo, 1997). This could account for an initial stage of basin sinking in the Late Miocene, when deposition of the Siquire Formation and the Pichao marginal facies started in the River Tuy basin. Later on, probably in early Quaternary times, compression resumes, thus giving an end to the “locally”-prevailing extensional phase. For the River Tuy basin is clear that a stress permutation takes place because the stress orientations are kept the same from extension into compression but the vector magnitudes do relatively change. The maximum stress (σ_1) permutes with the intermediate stress (σ_2) from vertical to the NNW-SSE direction, from a “local” extensional phase to a compressional phase generalized to the entire northern coast of Venezuela from Goajira to Paria. This stress permutation is another supporting evidence for such a geodynamic change limited in time and space within a more dominant long-lasting compression related to the eastward migration of the Caribbean plate along northern Venezuela during the whole Tertiary.

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