Uplift of the Sierra Nevada de Santa Marta and subsidence in the Cesar-Rancheria valley: Rigid-beam pivot model

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INTRODUCTION

The Sierra Nevada de Santa Marta (SNSM), the world's tallest coastal mountain, is a roughly triangular massif in northernmost Colombia with an impressive structural relief of approximately 12 km that paradoxically shows a large Bouguer anomaly high. Immediately southeast of the SNSM, and in structural continuity with it, the Cesar-Rancheria Valley (CRV) preserves a thick sedimentary wedge of Paleocene age. Here, we put forward a conceptual geodynamic model that attempts to explain the creation of a sedimentary wedge next to, and simultaneously with the uplift of a crustal block out of isostatic equilibrium. We propose rotation of a rigid continental plate along a horizontal axis uplifting the SNSM while opening accommodation space in the CRV.

REGIONAL GEOLOGIC SETTING

The CRV is bounded to the northwest by the southeastern foothills of the SNSM, and to the southeast by northwest-verging thrust faults of the Perijá Range (PR). Dextral Oca fault to the northeast, and sinistral Santa Marta-Bucaramanga fault to the southwest, further define this block where the Cerrejón coal mine is located (Fig. 1). The Guasare coal mine, an apparent conjugate of the Cerrejón mine, is located within a syncline in the southeastern flank of the PR in Venezuela. The regional dip in both areas is eastward-southeastward and northwest-directed thrusting locally affects these deposits. Paleogeographic maps (Villamil, 1999) show the SNSM as the northernmost elevation of the ancestral Central Cordillera since the latest Maastrichtian – Early Paleocene time with depositional systems migrating eastward to the Maracaibo lake (Villamil, 1999). Northern South America can be interpreted as a wide plate boundary zone where buoyancy of the Caribbean plate, as a result of its origin as an Pacific oceanic plateau (Kerr et al., 1998), may have imposed an oblique convergence vector to this wide plate boundary zone, with oblique collision, rather than active subduction, as the driving mechanism along the margin (Montes, in press). Buoyancy of the Caribbean plate may additionally provide the mechanism for the uplift of the SNSM and simultaneous creation of an aggradational sedimentary wedge in the CRV.

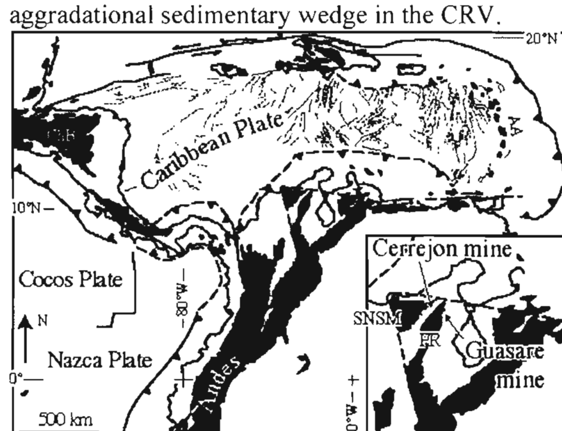

Figure 1: Regional location, Modified from Burke, et al., (1978).

OUTCROP DATA

The northeastern SNSM preserves a thin veneer of gently, southeast-dipping Cretaceous sediments overlapping older unmetamorphosed and metamorphic rocks ranging in age from Precambrian to middle Mesozoic (Tschanz et al., 1974). The PR exposes sedimentary and low-grade metamorphic rocks of

Paleozoic age, as well as volcanic and sedimentary rocks of Mesozoic age (Kellogg, 1984; Ujueta and Llinás, 1990). While the PR is bound by northwest-verging faults, the SNSM shows structural continuity with the CRV. Geologic maps of the SNSM and CRV (Tschanz et al., 1974) show deeper crustal levels exposed in apparent structural continuity as topographic elevation increases. A cross section of the northern CRV-SNSM shows southeast-dipping Paleocene coal-bearing strata in the northern CRV and progressively deeper stratigraphic levels to the west into the SNSM with the same regional dip. This outcrop pattern may be the result of a regional dip slope defining the southeastern flank of the SNSM in structural continuity with the CRV.

STRATIGRAPHY

The chronostratigraphic and tectonic framework of Paleocene beds in the CRV and northern PR in Venezuela was constrained using detailed definition of biozones, patterns of deposition, and petrofacies in Paleocene Manantial and Cerrejón Formations in the Cerrejón coal mine in Colombia, and the Guasare and Marcelina Formations in the Guasare coal mine in Venezuela. In both areas, Eocene (?) coarse-grained sandstones and mudstone of alluvial environments cover disconformably coal-bearing strata.

Lithofacies, sedimentary structures and vertical stacking patterns indicate that a mixed platform was covered and buried by coal-bearing siliciclastic strata. Thin to medium-strata in the 450-m-thick Manantial and Guasare Formations include fossiliferous packstones and wackestones interbedded with calcareous sandstones and mudstones. These deposits accumulated in a mixed shallow platform to fine-grained subtidal environments (lagoons), crossed by subtidal channels to the top. In both mines, siliciclastic strata have a dominant aggradational to slightly progradational pattern, and are interpreted here to have accumulated in tidal-flat plains and later in littoral coastal plains. The stratigraphic thickness of coal-bearing strata is over 900 m at the Cerrejón Formation to less than 600 m at the Marcelina Fm.

Palynological assemblages were studied in 200 samples collected at the Cerrejón coal mine. They correspond to the *F. perforatus* zone defined by Germeraad et al., (1968) and the zone Cu-02 of Jaramillo et al., (in press). Pollen species *F. perforatus* and *B. annae* occur in the entire studied interval. This zone is presently dated as Late Paleocene (Muller et al., 1987). This detailed palynological study allowed the definition of 13 biozones in the Cerrejón Formation, which are characterized by unique assemblages of pollen, spores and dinoflagellate cysts. Twenty-five palynological samples collected at the top of the calcareous Guasare Fm and at the lower Marcelina Fm indicate that these rocks are in the *F. perforatus* zone. Based on these palynological results we may conclude that coal-bearing strata of the Cerrejón Fm. correlates to the east with mixed calcareous-siliciclastic strata of the Guasare Fm and lower Marcelina Fm in Venezuela.

Argillaceous sandstones of the Cerrejón, upper Guasare and Marcelina Formations are texturally and compositionally immature, and becoming increasingly immature upsection. Composition of upper Manantial – lower Cerrejón sandstones varies from quartzarenites to subquarzose calcareous sandstones. Sandstone composition in the middle Cerrejón and upper Guasare-lower Marcelina is more mixed varying from subquartzose to feldspathic litharenites. Sandstones of the upper Cerrejón and Marcelina show an increasing content of feldspars and volcanic rock fragments. This assemblage suggests that first-cycle sandstones were supplied from basement-involved blocks and buried rapidly.

TECTONIC MODEL

From the above discussion it can be suggested that Manantial-Cerrejón and Guasare-Marcelina Formations are part of a Paleocene synorogenic wedge preserved on both flanks of the PR. Tectonic subsidence rates for the Paleocene increased from 48m/m.y in early Paleocene to 87m/m.y in the late Paleocene. Such synorogenic wedge would have had its sediment source in the metamorphic-igneous complex of the SNSM to the northwest, and not the PR since the latter exposes only shallow crustal levels. Creation of accommodation space for this mixed carbonate and clastic synorogenic wedge remains a puzzle since flexural loading of the CRV by the SNSM cannot be claimed, as structural continuity between these domains is evident (Tschanz et al., 1974).

An alternative way of explaining mixed carbonate and clastic synorogenic wedge in structural continuity with the southeastern flank of the SNSM is to take into account the outcrop pattern mapped in the northeastern SNSM-CRV by Tschanz et al. (1974). This pattern can be conceptualized as a southeast-dipping rigid beam of crustal dimensions with its northwestern edge exposing deeper crustal levels at high altitude in the SNSM, and dipping southeastward into the CRV (Fig. 2). Pivoting such a beam along a northeast-southwest trending horizontal axis would generate the phenomena observed, creating accommodation space to the southeast (CRV) where aggradation of a coal-bearing sequence took place, while simultaneously raising the northwestern end (SNSM) where vertical uplift and unroofing of a basement massif occurred. The Paleocene Manantial and coal-bearing clastic synorogenic wedge would mark the time of initiation of tilting of the rigid beam, and the maximum onlap of this wedge towards the SNSM would constrain the location of the horizontal pivoting axis for this time. Angular velocity may have remained constant, but the distance to the axis dictated the lineal velocity, and therefore the rates of uplift or subsidence. The further away from the axis, the greater the rates of subsidence or uplift. The axis itself should have behaved as a null point where no change in accommodation space took place. High rates of sediment supply by rapid erosion and transport from the SNSM to the CRV and PR took place due to rainforest-type climate rather than by increased topographic relief of the source area. A preliminary analysis of the paleotemperature and paleoprecipitation of the Cerrejón Formation using the Leaf Margin and Leaf Area Analyses indicates that climate was similar to a modern tropical rainforest with high rates of rainfall and warm temperatures (Herrera, 2004).

Pivoting of the rigid beam may have been caused by collision and thrusting of the SNSM over the buoyant oceanic Caribbean oceanic plateau (Burke et al., 1978). A large Bouguer anomaly high of some 170 mGals relative to adjacent basins coincides with the topography of the SNSM, suggesting lack of local isostatic compensation. An anomalously shallow Moho under the SNSM would indicate that the entire massif is a crustal block isolated from, and possibly foreign to, the surrounding crust, and would imply a predominately vertical tectonic motion as inferred from the rigid-beam model. On the basis of a 3-D inversion of the gravity data, this scenario appears likely as the gravity anomaly can be explained by some 8 km of Moho relief relative to the adjacent offshore areas and the Lower Magdalena Basin.

Seismic refraction studies may prove useful in providing necessary evidence for the definition of true Moho geometry under the SNSM. This model may satisfactorily explain: 1) Upper Cretaceous strata onlapping northwestward onto the SNSM in structural continuity with the CRV; 2) a large gravity anomaly high; 3) aggradational strata with extremely high subsidence rates in the CRV; 4) upsection increase of clastics derived from basement rocks in the CRV; 5) southeastward advance of the synorogenic clastic wedge; and 6) the spectacular topographic expression of the SNSM.

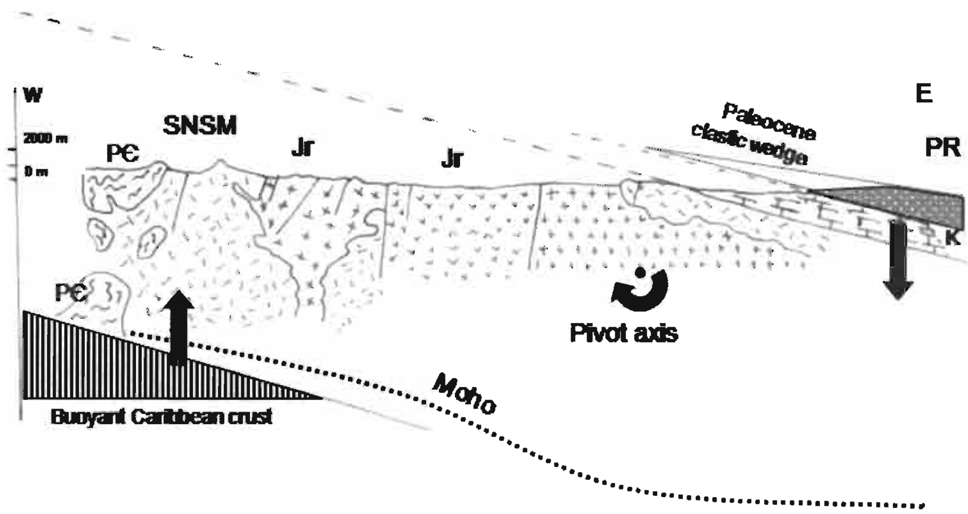

Figure 2: Conceptual model of pivoting of a rigid crustal beam.

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