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Middle Miocene near trench volcanism in northern Colombia: A record of slab tearing due to the simultaneous subduction of the Caribbean Plate under South and Central America?

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ABSTRACT

Field, geochemical, geochronological, biostratigraphical and sedimentary provenance results of basaltic and associated sediments northern Colombia reveal the existence of Middle Miocene (13–14 Ma) mafic volcanism within a continental margin setting usually considered as amagmatic. This basaltic volcanism is characterized by relatively high Al_2O_3 and Na_2O values (>15%), a High-K calc-alkaline affinity, large ion lithophile enrichment and associated Nb, Ta and Ti negative anomalies which resemble High Al basalts formed by low degree of asthenospheric melting at shallow depths mixed with some additional slab input. The presence of pre-Cretaceous detrital zircons, tourmaline and rutile as well as biostratigraphic results suggest that the host sedimentary rocks were deposited in a platform setting within the South American margin. New results of P-wave residuals from northern Colombia reinforce the view of a Caribbean slab subducting under the South American margin.

The absence of a mantle wedge, the upper plate setting, and proximity of this magmatism to the trench, together with geodynamic constraints suggest that the subducted Caribbean oceanic plate was fractured and a slab tear was formed within the oceanic plate. Oceanic plate fracturing is related to the splitting of the subducting Caribbean Plate due to simultaneous subduction under the Panama-Choco block and northwestern South America, and the fast overthrusting of the later onto the Caribbean oceanic plate.

1. Introduction

Near-trench volcanism in convergent margins may be related to plate flexure in the downgoing oceanic plate (Hirano et al., 2006), upper plate transtensional rifting (Davis et al., 2010), slab tearing and associated roll back (Gasparon, 2009; Wortel et al., 2009; Yamamoto and Hoang, 2009) or the subduction of an oceanic spreading center (Thorkelson, 1996; Madsen et al., 2006).

Resolving each of these scenarios in younger or ancient orogens is crucial for understanding the long term tectonic evolution of convergent margins and related effects of variable convergence relations in the magmatic record of the upper plate (Cawood et al., 2009).

Cenozoic tectonic reconstructions and geophysical data have suggested that the interactions of the southern margin of the Caribbean plate against northern South America is characterized by an oblique and slow E-SE plate convergence and flat subduction configuration (Van der Hilst and Mann, 1994; Taboada et al., 2000; Corredor, 2003; Cortés y Angelier, 2005; Weber et al., 2001; Vargas et al., 2010; Mantilla-Pimiento et al., 2009; Bernal et al., 2012).

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Associated to this plate convergence a large sedimentary accretionary prism (South Caribbean Deformed Belt: SCDB) has been growing in the Caribbean-South America plate margin since the Eocene (Case et al., 1974; Duque-Caro, 1984, Fig. 1A,B). Due to the slow plate convergence and/or flat slab subduction the continental margin has been considered as amagmatic, with volcanism restricted to transtensional pull-apart basins such as the Falcon Basin in Venezuela (Muessig, 1984).

In this contribution we integrate field, geochemical, geochronological and biostratigraphical data to document the existence of two new exposures of volcanic rocks, in the town of Puerto Escondido-Córdoba and Necoclí-Antioquia (between the hamlet of Mulatos and Zapata), associated to Miocene sediments in the SCDB (Fig. 1C). These results together with new analysis of P-wave residuals of northern Colombia and regional tectonic synthesis are used to discuss the existence of a Middle Miocene near trench magmatism in northern Colombia, associated with the formation of a tear in the subducting Caribbean oceanic plate. The fracturing of the oceanic plate is considered as a major consequence of the subduction of the Caribbean plate under two different margins, the South American and Central American isthmus. This setting follows the collision of the Panama-Choco block against the South American margin and the associated overthrusting of the later over the Caribbean plate.

2. Geological setting

The Southern Caribbean Plate Boundary in northern Colombia is characterized by a series of discontinuous ranges of deformed marine to transitional sedimentary belts and isolated Pre-Eocene crystalline massifs (Fig. 1A,B).

Both the basement of the deformed sedimentary belts and the northernmost segments of the crystalline massifs include the remnants of Cretaceous intra-oceanic basement accreted to the continental margin between the Maastrichtian and the Paleocene (Duque-Caro, 1984; Kerr et al., 1997; Weber et al., 2009, Cardona et al., 2010; Villagómez et al., 2011).

This older accretionary event is linked to the northeastern advance and collision of the allochthonous Caribbean plate from a Pacific position (Burke, 1988; Pindell et al., 1998, 2005; Pindell and Kennan, 2009). Subsequent Cenozoic oblique convergence between the Caribbean and the South American plates has ended in the growth of several transpressional orogens, the formation and lateral migration of different sedimentary accretionary prisms, and the growth of different rotational and pull-apart basins (Toto and Kellogg, 1992; Duque-Caro, 1984; Macellari, 1984; Pindell et al., 1998; Flinch, 2003; Flinch et al., 2003; Montes et al., 2010).

The northernmost and youngest of these sedimentary prisms already presented as the SCDB (Fig. 1A,B; Case, 1974) extends along the offshore margin of the northern South American Plate with thickness up to 5000 m. Its deformational history and tectonic position have been interpreted as a major expression of an accretionary prism that grew due to the plate convergence between the Caribbean and South American plates (Toto and Kellogg, 1992; Duque-Caro, 1984; Flinch, 2003; Flinch et al., 2003). In northern Colombia the onshore exposure of this highly deformed belt include Oligo-Pliocene sediments grouped in the Sinú belt (Fig. 1B, Duque-Caro, 1984). This belt was deposited in transitional to marine environments and was deformed during the Pliocene-Pleistocene associated with significant mud diapirism (Toto and Kellogg, 1992; Duque-Caro, 1984; Cerón et al., 2007; Mantilla-Pimiento et al., 2009).

Modern geodynamic configuration of the plate boundary zone in the northern Colombia is characterized by oblique east-southeast plate convergence at slow rates of ~20 mm/y (Kellogg and Vega, 1995; Taboada et al., 2000; Perez et al., 2001; Weber et al., 2001; Trenkamp et al., 2002; Colmenares and Zoback, 2003). Although still controversial, geophysical constraints suggested the existence of a very flat subduction angle (~12–19°) of the Caribbean slab beneath the continent in Northwestern Colombia (Van Der Hilst and Mann, 1994; Corredor, 2003; Cortés y Angelier, 2005; Vargas et al., 2010; Mantilla-Pimiento et al., 2009; Bernal et al., 2012).

Seismicity defines a Wadati–Benioff zone dipping southward beneath the Panama block, indicating the presence of active subduction along the trailing edge of the Caribbean plate, with earthquakes penetrating as far as 80 km depth and 150 km south of the trench (Camacho et al., 2010). This tectonic configuration may have started at least since the Early Miocene when increased convergence velocity between the Americas may have caused the onset of underthrusting of the Caribbean oceanic crust below the South America borderland with East–West migration of the Caribbean plate (Müller et al., 1999), which may have also brought the Panama block in collision course with northwestern South America (Farris et al., 2011; Montes et al., 2012a,b).

3. Methods

3.1. Petrography and heavy minerals

Seventeen representative samples were selected for petrographic analysis, including massive volcanic rocks (eight samples), siliciclastic sediments associated (five samples) and volcanic blocks from peperitic facies (four samples) which are considered as rocks formed essentially in situ by disintegration of magma intruding and mingling with unconsolidated or poorly consolidated, typically wet sediments (White et al., 2000; Skilling et al., 2002).

Sandstones were point counted to determine their composition and provenance, following framework analysis after Folk (1980) and Dickinson (1985). Three sandstone samples associated with the basalts were selected for heavy mineral analysis. Heavy minerals were concentrated with sodium poly tungsten (LST®) at a density of 2.9 g/cm^3 and mounted in a resin (Meltmount®) with a refraction index of 1.539. Data analysis was performed by the counting and identification of 350 grains following the Ribbon-Counting method (Mange and Maurer, 1992).

3.2. Ar–Ar geochronology

^{40}Ar–^{39}Ar analyses of plagioclase were carried out on three volcanic rocks samples.

Minerals were pretreated and concentrated by standard laboratory techniques and later selected by handpicking under a binocular microscope. Analytical results are presented in Table 1.

Two samples from the Puerto Escondido outcrop (Fig. 1C) were selected for analysis. One sample from the massive volcanic facies and the other a volcanic block within the peperitic facies. Ar–Ar step heating analysis were performed at the Geochronology Laboratory of the Departamento de Geología, CICESE, Baja California, Mexico. The argon isotope experiments were conducted on mineral grains with a coherent Ar-ion Innova 370 laser extraction system on line with a VG5400 mass spectrometer. All the samples and irradiation monitors were irradiated in the U-enriched research reactor of the University of McMaster in Hamilton, Canada, at position 5C in capsule CIC-66 for 10hr. To block thermal neutrons, the capsule was covered with a cadmium liner during irradiation. As irradiation monitors, aliquots of standard FCT-2 sanidine (27.84 ± 0.04 Ma) were irradiated alongside the samples and distributed among them to determine the neutron flux variations. Upon irradiation the monitors were fused in one step