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Contrasting exhumation P–T paths followed by high-P rocks in the northern Caribbean subduction–accretionary complex: Insights from the structural geology, microtextures and equilibrium assemblage diagrams

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ABSTRACT

The Río San Juan metamorphic complex exposes a segment of a high-pressure subduction–accretionary complex built during convergence between the Caribbean island arc and the North America continental margin. It is composed of accreted arc- and oceanic-derived metaigneous rocks, serpentinized peridotites and minor metasediments forming a structural pile. Combined structural geology, microtextural relations, multi-equilibrium calculations and thermodynamical modelling, together with published isotopic ages, allow reconstructing the metamorphic P–T–t paths of each nappe/unit and their links to the structural evolution. In all units of the complex, three major stages (M1 to M3) in the tectonothermal evolution have been distinguished. The M1 stage corresponds to the prograde evolution towards the pressure-peak of metamorphism under blueschist or eclogitic-facies conditions. The M2 stage is related to the main retrogressive event and is characterized by the S2–L2 fabric development in all lithologies and at all scales. The M3 stage represents continuous exhumation from ductile to ductile–brittle deformation regimes. However, the shape of the retrograde P–T path, the age of the exhumation-related D2 structures and the tectonic significance of D2 deformation are different in each structural unit.

In the upper structural levels of the Jagua Clara serpentinitic-matrix mélange, the counter-clockwise P–T path of the eclogite blocks is typical of rocks exhumed in the early stages of intra-oceanic subduction zones. The clockwise P–T path obtained for the lower Cuaba unit is characterized by a strong isothermal decompression from the garnet-epidote amphibolite and eclogite-facies pressure-peak. This P–T evolution can be explained by rapid exhumation caused by extensional tectonics, in relation to a major modification of convergence conditions across the subduction zone. The P–T path also explains local syn-M2 partial melting processes, because it crosses the wet solidus for IAT mafic compositions. The P–T path obtained for the high-P Guineal Schists, with exhumation trajectory following the burial trajectory, can be related to exhumation during active subduction. This exhumation was most likely driven by a combination of underthrusting of tectonic units and erosion processes.

Available geochronological data and T–t/P–t estimates reveal a Late Campanian to Maastrichtian retrograde M2 metamorphism in the lower structural units of the complex during a consistent D2 top-to-the-NE/ENE tectonic transport. A similar tectonic transport has also been recognized in the metasedimentary nappes of the Samaná complex during Eocene to earliest Miocene. These relations indicate a northeastward progradation of deformation during the successive tectonic incorporation of arc, oceanic and continental-derived terrains to the developing Caribbean subduction–accretionary complex.

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1. Introduction

Eclogite facies rocks have been widely documented in regions of former subduction and plate collision. Their exposure at the Earth's surface provides compelling evidence that crustal rocks are subducted to mantle depths and subsequently brought back to the surface. Petrological and geochronological studies of eclogite facies rocks represent the principal tools for elucidating this evolution. They also provide valuable information on the thermal, mechanical and petrological characteristics of paleo-subduction zones and their variations in space and time.

How crustal rocks are exhumed from high- and ultrahigh-P depths remains one of the most crucial tectonic problems (e.g. Hacker et al., 2010). In intra-oceanic subduction zones, the exhumation of high-P metamorphic rocks from mantle depths requires a combination of initial buoyancy-driven upward flow (e.g. Chemenda et al., 1995; Hilairet

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and Reynard, 2009; Schwartz et al., 2001) followed by erosional/extensional unloading or forced corner flow in a wedge-shaped subduction channel (Agard et al., 2009; Cloos and Shreve, 1988; Gerya and Stöckhert, 2006). Gerya et al. (2002) investigated numerically the self-organizing evolution of the accretionary wedge and the subduction channel during intra-oceanic subduction. In the 2-D modeled evolution, upward migration of the aqueous fluid released from the subducting slab and progressive hydration of the mantle wedge play a dominant role, because they cause the progressive modification of the thermal, petrological and rheological structure of the subduction zone. The main conclusions of this relatively simple serpentinized subduction channel model, in particular those related to the exhumation of eclogites, have been recently supported by studies of subduction-related serpentinite mélanges (e.g. Federico et al., 2007; Krebs et al., 2008; Lázaro et al., 2009). The low-viscosity subduction channel model may be a good representation of some serpentinite-matrix mélanges characterized by the occurrence of rigid sub-spherical eclogite blocks of relatively small size, but does not adequately account for the characteristics of coherent eclogitized oceanic units of kilometer to tens of kilometers in size. Thin-aspect ratio, ductile-deformed nappes and thrust slices formed in subduction channels make up the upper crustal architecture of most recovered high- and ultrahigh-P complexes. Ascent to shallow crustal levels seems to have been due to one or more of the following processes: tectonic extrusion, corner flow blocked by a hanging wall backstop, underplating combined with extensional or erosional collapse, and/or buoyant ascent (e.g. Agard et al., 2009; Gerya, 2011; Guillot et al., 2009). Knowledge of the pressure–temperature–time (P–T–t) path followed by the eclogite facies rocks and, in particular, the mineral assemblages present when their subduction ceases and exhumation begins are keys to establish the uplift processes and the rock physical properties that drive exhumation.

In the Río San Juan complex (RSJC), the metamorphic P–T histories of eclogitic rocks have been achieved using conventional and/or multi-equilibrium thermobarometry applied to preserved mineral assemblages (e.g. Abbott and Draper, 2007). However, the composition of the minerals in equilibrium can be modified during the retrograde metamorphic evolution and, in this case, inverse methodologies alone may be insufficient to reconstruct the complete P–T paths. Recent significant advances in thermodynamic models for minerals with complex solid solutions (Diener and Powell, 2012; Powell and Holland, 2008) permit pseudosection modeling of high-P metabasites in systems that closely approximate those found in nature. These advances enabled modelling of the RSJC eclogites using complementary forward and inverse methodologies and to propose exhumation mechanisms (e.g. Krebs et al., 2008, 2011). Pseudosection modeling can also provide information on other aspects of the rock evolution such as the amount of structurally-bound H_2O content, the melting rate and the phase density.

In this study, we have reconstructed the metamorphic evolution of each nappe/unit of the RSJC in the form of P–T–t paths and their links to the structural evolution, which has been recently established and in time constrained by Escuder-Viruete et al. (2012a,b). The metamorphic P–T paths were obtained using equilibrium mineral assemblages, thermobarometric calculations by multi-equilibrium techniques and thermodynamical modelling. The tectonometamorphic history that we have unravelled provides an updated outlook on the tectonic setting of the RSJC complex within the framework of northern Caribbean tectonics and the contrasting exhumation P–T–t paths followed by the high-P rocks in an evolving subduction–accretionary complex.

2. Regional setting

Located on the northern margin of the Caribbean plate (Fig. 1), the Island of Hispaniola is a tectonic collage produced by the oblique convergence to final collision of the Caribbean island-arc/backarc system with the North American plate which began in the Lower Cretaceous (Draper et al., 1994). The presence of ophiolitic mélanges in northern Hispaniola indicates that an intermediate proto-Caribbean oceanic basin was consumed/subducted during convergence (Draper and Nagle, 1991; Escuder-Viruete et al., 2011c; Lewis et al., 2006; Pindell and Kennan, 2009; Saumur et al., 2010). The Caribbean arc-related rocks are regionally overlain by Paleocene/Lower Eocene to Holocene siliciclastic and carbonate sedimentary rocks that post-date the volcanic activity (Draper et al., 1994). This cover records the oblique arc–continent collision in the northern Hispaniola area, as well as the intra-arc and retroarc deformations in the central and southern areas of the island.

In northern Hispaniola, the Cordillera Septentrional-Samaná Peninsula domain is composed of arc, oceanic and continental margin derived units assembled during arc–continent convergence. The accreted units form several inliers, termed El Cacheal, Palma Picada, Pedro García, Puerto Plata, Río San Juan and Samaná complexes, which constitute the pre-Eocene igneous and metamorphic substratum of the domain. These six complexes form the Caribbean subduction–accretionary complex in Hispaniola (Escuder-Viruete, 2009) and include: metasedimentary rocks of the subducted continental margin of North America; ophiolitic fragments of the proto-Caribbean lithosphere; serpentinitic-matrix mélanges, containing blocks of blueschists and eclogites; plutonic and volcanic rocks related to the Caribbean island-arc; and non-metamorphic rocks deposited in pre-collisional forearc sedimentary basins. In the Puerto Plata and Río San Juan complexes, the first foreland deposits with record of the collisional process are the Paleocene/Lower Eocene olistostromes of the Imbert Formation (Draper et al., 1994), which contain clastic elements derived from the Cretaceous volcanic arc and the metamorphosed ophiolites.

The Río San Juan complex has been divided into three distinct parts, showing a general increase in the metamorphic grade from north to south (Draper and Nagle, 1991; Fig. 1). The greenschists and lower amphibolite-facies serpentinites of the northern Gaspar Hernández serpentinized peridotites, passes to the mafic blueschist and eclogite blocks enclosed in the central Jagua Clara and Arroyo Sabana tectonic mélanges, to the amphibolites and mafic gneisses of the southern La Cuaba unit, which contains lenses of serpentinites, retrograded eclogites and several types of garnet peridotites and garnet clinopyroxenites (Abbott et al., 2006; Hattori et al., 2010; Krebs et al., 2008, 2011; Saumur et al., 2010). These parts of the RSJC were juxtaposed by faulting probably in the Paleogene (Draper et al., 1994). Saumur et al. (2010) showed that the serpentinites originated by hydration from abyssal peridotites and forearc mantle peridotites. Recent work by Escuder-Viruete et al. (2011c) indicate that the large-scale internal structure of the northern half of the complex consists of an imbricate stack mostly of high-P rocks derived from both the Caribbean island arc and the proto-Caribbean lithosphere.

The high-P metamorphism of the RSJC rocks has been interpreted to be the result of SW-directed subduction in the Cretaceous (Draper et al., 1994). In the northern half of the complex, detailed thermobarometric and geochronological studies by Krebs et al. (2008, 2011) on eclogite and blueschist blocks of the Jagua Clara mélange show that high-P metamorphism took place in the Late Cretaceous and retrograde exhumation during the latest Cretaceous. In the southern half of the complex, the origin, petrological interpretation and the type of the exhumation process for the garnet-bearing ultramafic rocks of the Cuaba unit is controversial (Abbott and Draper, 2010; Gazel et al., 2011; Hattori et al., 2010). Following Abbott et al. (2006), the garnet peridotites equilibrated at ultra high-P conditions of 807–838 °C and 27–30 kbar during their incorporation into the Cuaba oceanic unit in the deep subduction environment. Abbott and Draper (2007) estimated minimum metamorphic conditions of 18 kbar and 730 ºC for the Cuaba unit, corresponding to eclogite-facies. The exhumation of the mafic-ultramafic unit took place following a near isothermal evolution in the subduction channel to 600–700 °C and 10–12 kbar P–T conditions. Hattori et al. (2010) modelled similar peak metamorphic conditions of 25–35 kbar and 650–750 °C for the mafic eclogites.

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