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Timing of subduction and exhumation in a subduction channel: Evidence from slab melts from La Corea Mélange (eastern Cuba)

I.F. Blanco-Quintero [a,*], Y. Rojas-Agramonte [b], A. García-Casco [a,c], A. Kröner [b], D.F. Mertz [b,e], C. Lázaro [a], J. Blanco-Moreno [d], P.R. Renne [e,f]

[a] Departamento de Mineralogía y Petrología, Universidad de Granada, Fuentenueva s/n, 18002-Granada, Spain
[b] Institut für Geowissenschaften, Universität Mainz, D-55099 Mainz, Germany
[c] Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR), Fuentenueva s/n, 18002-Granada, Spain
[d] Departamento de Geología, Instituto Superior Minero-Metalúrgico, Las Coloradas s/n, 83329-Moa, Cuba
[e] Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA
[f] Department of Earth and Planetary Science, University of California, Berkeley, CA 94720, USA

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ABSTRACT

High pressure igneous rocks (tonalites), generated by partial melting of subducted basaltic rocks accreted to the mantle wedge, are present in the La Corea serpentinite-matrix mélange (eastern Cuba) as centimeter- to meter-sized blocks and as concordant to crosscutting veins within high-pressure parent amphibolite blocks. The slab melts have adakitic signatures, in agreement with formation after partial melting of metabasite. Thermobarometric calculations indicate 620–680 °C and 13–15 kbar during crystallization of tonalites and down to 250–300 °C, 6 kbar during retrogression, indicating counter-clockwise P–T paths (hot subduction-cool exhumation). Free water required for melting of amphibolite at moderate temperature (700–750 °C) and moderate pressure (13–16 kbar) close to the wet basaltic solidus is inferred to have been provided after dehydration of sediments, altered basaltic crust and serpentinite of the subducting Proto-Caribbean lithosphere. Single zircon (SHRIMP) and phengite $^{40}Ar/^{39}Ar$ age data constrain the P–T–t evolution of the mélange from the timing of crystallization of melts at ~110–105 Ma to cooling at ~87–84 Ma, ca. 350 °C, ca. 9 kbar. These figures are consistent with subduction of an oblique ridge, shortly before 115 Ma. Furthermore, our data indicate very slow exhumation (ca. 1 mm/yr) in the subduction channel during the oceanic convergence stage (120–70 Ma) until final fast exhumation to the surface occurred at 70–65 Ma during a regional arc-platform collision event.

1. Introduction

The evolution of a subduction zone can be broadly divided into three main phases: (1) onset of subduction, (2) mature stage and (3) cessation of subduction. Exhumation of ancient and recent rock complexes allow a good characterization and recognition of the mature (i.e., volcanic arc development, formation of eclogites and blueschists) and demise (by means of arc-continent, arc-arc, or arc-ocean collision, with termination of volcanic arc activity and emplacement of ophiolites) phases. However, the onset of the subduction phase is less well-known because of the intrinsic complexities of this transient period. It is unclear how subduction zones are initiated (cf. Stern, 2002, 2004) and, in addition, rocks formed during the earliest phases of subduction will normally disappear in the mantle and are therefore not commonly observed on the surface.

According to Stern (2004) subduction is initiated either by convergence of lithospheric plates and blocking of a subduction zone by incoming buoyant continental or oceanic crust (induced onset of subduction) or by gravitational collapse of oceanic lithosphere (spontaneous onset of subduction). Transference or polarity reversal of subduction characterizes the induced type, whereas the spontaneous type occurs at a passive margin or at a transform/fracture zone, normally if the downgoing plate is old (i.e., cold and dense). Both types of onset of subduction are characterized by warm-hot geothermal gradients (relative to mature subduction) along the subduction interface, but spontaneous initiation of subduction of old lithosphere should be characterized by relatively colder conditions (relative to young lithosphere; e.g., Peacock, 2003; Peacock and Wang, 1999). In both types, however, subducted rocks accreted to the upper plate during the early stages of subduction show counter-clockwise P–T (pressure–temperature) paths during exhumation due to the effects of continued refrigeration of the subduction system during the mature stage (Gerya et al., 2002), whereas subducted rocks accreted during the mature stage follow

* Corresponding author at: Departamento de Mineralogía y Petrología, Facultad de Ciencias, Universidad de Granada, Avda. Fuentenueva s/n, 18002 Granada, Spain. Tel.: +34 958 246 613; fax: +34 958 243 368.
E-mail address: blanco@ugr.es (I.F. Blanco-Quintero).

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hairpin P–T paths (Ernst, 1988; Wakabayashi, 2004). In addition, convective circulation of the subducted and accreted materials in the subduction channel can be produced (Blanco-Quintero et al., 2011a).

During the onset of subduction, the fluids released from subducted sediments, altered basaltic crust and serpentinitic abyssal peridotite begin fluxing the upper plate. Much of the upper plate lithospheric mantle is characterized at this stage by hydrous peridotite, because the temperature at relatively shallow depth is above the stability field of antigorite (>650 °C; Ulmer and Trommsdorff, 1995). During the mature stage antigorite serpentinite forms in the upper plate mantle down to ca. 100 km depth, because continued subduction produces the refrigeration of the interface (Gerya et al., 2002). This process triggers the formation of a buoyant serpentinitic subduction channel at the plate interface which provides the medium for syn-subduction exhumation of accreted high-pressure rocks (Gerya et al., 2002; Guillot et al., 2000; 2001). Hence, exhumation of high-pressure rocks accreted to the upper mantle during the onset of subduction is delayed until the mature phase when the subduction channel is formed. This has important consequences for early accreted rocks, which undergo near-isobaric cooling at the upper plate before exhumation in the channel begins (i.e., counter-clockwise PT paths; Gerya et al., 2002).

Serpentinite mélanges bearing high-pressure blocks are commonly considered to represent exhumed fragments of subduction channels (Agard et al., 2009; Guillot et al., 2000; 2001). In these mélanges, the timing of exhumation of subducted mafic oceanic crust relative to the onset of subduction is highly variable, though it appears that in most cases exhumation is episodic (Agard et al., 2009). In the northern Caribbean (Fig. 1a), high-pressure blocks in serpentinite mélanges record a protracted history of subduction and continued exhumation lasting for ca. 60 Ma, from onset of subduction until final exhumation to the Earth's surface (Krebs et al., 2008; Lázaro et al., 2009). Early subducted rocks record hot geothermal gradients along the plate interface during the onset of subduction (García-Casco et al., 2008a; Lázaro et al., 2009). In eastern Cuba, the Sierra del Convento and the La Corea mélanges (Fig. 1b) record the rare case of partial melting of subducted basaltic crust at relatively shallow depth (ca. 50 km), documenting hot conditions related to subduction of very young lithosphere or even a ridge (Blanco-Quintero et al., 2010; 2011b; García-Casco et al., 2008a; Lázaro and García-Casco, 2008). Such a young age for the subducting lithosphere would indicate induced rather than spontaneous onset of subduction. Lázaro et al. (2009) dated blocks of high-pressure amphibolite and associated tonalitic–trondhjemitic rocks formed after partial melting of the former and provided a comprehensive P–T–t path for the Sierra del Convento mélange. The data presented by Lázaro et al. (2009) indicate that onset of exhumation was delayed by <ca. 10 Ma since accretion of subducted crust occurred and that syn-subduction exhumation in the channel continued for ca. 40 Ma at very slow rates (0.7 mm/yr). We report new petrological, geochemical and geochronological (SHRIMP zircon and phengite $^{40}Ar/^{39}Ar$) data for tonalite rocks of the La Corea mélange, eastern Cuba, in order to provide clues for deciphering the nature and age of hot, deep-seated processes that occurred during subduction of young oceanic lithosphere in the Caribbean realm.

2. Geological setting

The Greater Antilles belt accreted to the southern margin of the North American plate in the Tertiary (Iturralde-Vinent et al., 2008; Pindell and Kennan, 2009; Pindell et al., 2006; Fig. 1a). It evolved during the Mesozoic–Tertiary along the northern edge of the Caribbean plate margin where Proto-Caribbean (i.e., Atlantic) lithosphere was consumed and a complex intra-oceanic volcanic arc (or arcs) developed (Pindell and Kennan, 2009; Pindell et al., 2006 and references therein). Onset of subduction of the Proto-Caribbean has been inferred to have occurred as a consequence of a polarity reversal (implying induced onset of subduction), but the timing of this process remains uncertain. Krebs et al. (2008), Lázaro et al. (2009), Pindell and Kennan (2009), Pindell et al. (2005, 2006) suggested an Albian age (ca. 120 Ma), whereas Burke (1988), Duncan and Hargraves (1984); Hastie and Kerr (2010); Kerr et al. (2003) suggest an Upper Cretaceous age (ca. 85 Ma).

The eastern Cuban block (Meyerhoff and Hatten, 1968), between the Nipe-Guacanayabo and Oriente faults, is representative of the Greater Antilles geology. It includes several tectonic units (Fig. 1b) of different paleogeographic and paleotectonic environments including fragments of the Caribeana terrane (Asunción terrane; García-Casco et al., 2008b), the Mayarí-Baracoa ophiolitic belt (MBOB; Marchesi et al., 2007; Proenza et al., 2006), subduction-related metamorphic complexes (La Corea and the Sierra del Convento mélanges; García-Casco et al., 2006; Somin and Millán, 1981), two volcanic arc complexes of Cretaceous and Paleogene age, respectively, and syn- and post-orogenic sedimentary deposits (Cobiella et al., 1977, 1984; Iturralde-Vinent, 1998; Iturralde-Vinent et al., 2006). The rocks and the geological evolution of the eastern Cuba block have been correlated with northern Hispaniola (e.g., Iturralde-Vinent and MacPhee, 1999).

Serpentinite-matrix mélanges containing subduction-related metamorphic blocks (La Corea and Sierra del Convento mélanges) appear at the bottom of the Mayarí-Baracoa ophiolite belt. The La Corea mélange is related to the Mayarí-Cristal ophiolite massif (Fig. 1c) and is tectonically located between the latter (top) and the Cretaceous Santo Domingo volcanic arc formation (bottom). The mélange represents a section of the Caribbean Cretaceous subduction channel which experienced partial melting of the accreted materials from the subducted slab (Blanco-Quintero et al., 2010). Exotic blocks of various origins and compositions (garnet-amphibolite, blueschist and greenschist) occur within a serpentinite-matrix. Foliated fine- to medium-grained epidote ± garnet amphibolite is the predominant rock type within the mélange (Fig. 2a). Geochemical data indicate an N-MORB (normal mid-ocean ridge basalt) signature for the amphibolites (Blanco-Quintero et al., 2010). The serpentinitic matrix of the mélange is mainly composed of antigorite (94 vol.%) formed after hydration of the mantle wedge by fluids released from the slab (Blanco-Quintero et al., 2011c). Blocks of serpentinite-bearing antigorite-lizardite and clinopyroxene (relictic and deformed) represent abyssal rocks incorporated from the incoming plate into the subduction channel at shallow depths (Blanco-Quintero et al., 2011c).

Dykes and veins of intermediate to felsic (tonalitic–trondhjemitic–granitic) composition occur intimately associated with the amphibolites and show concordant to cross-cutting relationships relative to the main foliation of the amphibolites (Fig. 2a–d). The volume of melt segregated is 5–10% relative to the high pressure blocks. These rocks can be separated into two groups: 1) medium-grained tonalitic–trondhjemitic rocks with a primary (magmatic) assemblage of Pl + Qtz + Czo + Phe ± Amp and overprinted by retrograde Chl + Phe + Czo + Ab ± Lws, and 2) granitic rocks, commonly pegmatitic, composed of magmatic Pl + Qtz + Phe [Mineral abbreviations are after Kretz (1983) except for amphibole-Amp and phengite-Phe]. All types of rocks are crosscut by quartz-veins.

Geochronological data for the La Corea mélange are scarce and imprecise. Somin and Millán (1981) reported K–Ar whole-rock ages of 104 ± 12 and 67 ± 7 Ma for blocks of metachert material, and Adamovich and Chejovich (1964) and Somin and Millán (1981) reported K–Ar muscovite ages on pegmatites of 125 ± 5 and 119 ± 10 Ma and an age for an unknown rock type of 96 ± 4 Ma.

3. Analytical techniques

3.1. Microprobe analyses

Mineral compositions were obtained by Wavelength Dispersive Spectroscopy (WDS) with a CAMECA SX-100 microprobe (Centro de Instrumentación Científica – CIC – from University of Granada), operated at 15 kV and 15 nA, with a beam size of 5 μm and standards used