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Subduction & orogeny: Introduction to the special volume

ABSTRACT

Subduction processes play a major role in plate tectonics and the subsequent geological evolution of Earth. This special issue focuses on ongoing research in subduction dynamics to a large extent (oceanic subduction, continental subduction, obduction...) for both past and active subduction zones and into mountain building processes and the early evolution of orogens. It puts together various approaches combining geophysics (imaging of subduction zones), petrology/geochemistry (metamorphic analysis of HP-UHP rocks, fluid geochemistry and magmatic signal, geochronology), seismology and geodesy (present-day evolution of subduction zones, active tectonics), structural geology (structure and evolution of mountain belts), and numerical modelling to provide a full spectrum of tools that can be used to constrain the nature and evolution of subduction processes and orogeny. Studies presented in this special issue range from the long-term (orogenic cycle) to short-term (seismic cycle).

1. Introduction

The outcome of this special issue is to provide new insights into our understanding of processes acting in subduction zones, and during the building of active margin mountain belts and early collisional belts, based on a large variety of active and fossil subduction zones. This issue benefited from a conference session held in the RST 2014 (Pau, France).

The aim of this issue is to address some of the currently debated questions about the relationships between subduction and orogenesis. Among them, it especially focuses on the following points:

- How can we reconcile the data obtained from geodesy and seismology with the long-term evolution of subduction zones?
- What is the nature, the composition and the geometry of the subduction zone interplate contact? What is the meaning of 'Subduction Channel'?
- How did syn-subduction exhumation processes happen? What is recorded by HP-UHP rocks and what is the role of deep-slab deformation?
- What is the link between slab dehydration, mantle serpentinization and the deep sediment wedge in the exhumation of deeply subducted rocks? What are their impact on seismicity?
- Concerning obduction processes, this volume brings new insights on still remaining questions related to obduction initiation and the mechanisms allowing for its propagation far from a suture zone.
- Finally, important points regarding the transition from subduction to collision are also presented. Hence, question such as: Is collision a continuum of subduction? What controls the fact that continental subduction continues or stops (e.g., Himalaya vs. Central Asia) and what are the consequences? are herein addressed.

2. Contributions to this volume

The following sections present how the papers are arranged to reflect the different approaches covered by this special issue.

2.1. *Uplift of the upper plate related to subduction dynamics*

Orogeny along subduction zones may be driven by the subduction zone dynamics (e.g., Platt, 1986; Gephart, 1994; Sobolev and Babeyko, 2005; Schellart et al., 2007; Capitanio et al., 2011). In their article, Martinod et al. (2016) show how subduction processes contribute to the forearc uplift based on the example of the South Andes. They present numerical models to investigate the relationships between the subduction zone and the observed Quaternary uplift of the Andes. On the basis of geological observations, a general uplift of the South American Pacific coasts is observed between 16 and 32° S since the Lower Pleistocene. Uplift occurs at rates larger than 0.2 mm/year, following a period of stability of the forearc region. Their models confirm that local uplift is expected to occur in response to the subducting plate buoyancy. Especially, uplift occurs above subducted ridges, this phenomenon being predominant in central Peru where the Nazca Ridge is subducting. The effects of slab pull are also investigated, as the interplate friction and convergence velocity exert a role on the vertical displacements of the overriding plate. From their results they propose that the global tendency to coastal uplift is accompanying the deceleration of the Nazca-South America convergence that occurred in the Pleistocene. In contrast, forearc subsidence may accompany increasing convergence velocities, as suggested by the subsidence history of the South American active margin.

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2.2. Lithological nature of the subduction interface: the subduction channel

The Subduction Channel is thought to play a major role in subduction dynamics by promoting slab coupling or decoupling and element transfer from the Lower to the Upper plate (e.g., Baker Hebert et al., 2009; Guillot et al., 2009; Angiboust et al., 2011). However, there still are few exhumed examples of such geological objects (e.g., Vannucchi et al., 2012; Bachmann et al., 2009; Angiboust et al., 2014), while the bearing of such lithologies for the understanding of interplate deformation processes is important (e.g., Guillot et al., 2000; Gerya and Stöckhert, 2002; Angiboust et al., 2012). The major causes of strain localization along the plate boundary include both the subducted lithologies originating from the sea-floor, and the fluids that circulate and concentrate along it. In this issue, a well preserved exhumed subduction channel is presented from the Caucasus region by Hässig et al. (2016a). From this field example the subduction channel is a narrow geological object of about 500 m in width, which was formed at an approximate depth of 10 km along an Andean-type subduction zone. The nature of the channel is complex, it is formed (i) by an upper 'sedimentary' channel with detrital and volcanic rocks thrusted on top of pelagic sediments scrapped off the oceanic floor. This sedimentary mélange is thrusted on top of (ii) an intensely deformed tectonic mélange. The tectonic mélange comprises blocks of basalt from the oceanic floor and a focussed deformation zone 50–100 m in width, cross-cut by numerous chlorite-carbonate-epidote-albite veins. This latter entity overlies an undeformed ocean floor section. The study of veins, including stable isotopes, provide evidence for high fluid/rock ratios, which agrees with fluid mixing between deep (lower crust/mantle) and shallow (pelagic sediments) reservoirs along the subduction interface. These data show that several fluid reservoirs situated along the interplate boundary could have been connected by high-magnitude co-seismic displacements along the subduction zone. These subduction channel features are compared to other similar fossil examples and current settings, such as the Andes accretionary prism to propose a reconstructed geometry of the interplate contact zone from the surface to the base of the crust.

2.3. Obduction: another type of subduction?

The process of obduction might just be regarded as a variation of subduction, i.e., '*continental subduction*' at least for short distances of obduction (Agard et al., 2014; Edwards et al., 2015). However, the case of the Caucasus Belt poses a problem considering the presence of a large obduction of Jurassic crust, transported over more than 300 km a long time before the final Arabia-Eurasia collision (Rolland et al., 2007, 2009; Sosson et al., 2010; Hässig et al., 2013, 2015, 2016a,b,c).

Obduction processes are discussed by Hässig et al. (2016b). These authors performed two-dimensional thermo-mechanical numerical modelling in order to investigate obduction dynamics in this specific context. The results indicate that a thermal rejuvenation of the oceanic domain and extension induced by far-field plate kinematics are essential ingredients for obduction as already suggested in other ophiolitic systems (e.g., in Oman; see Duretz et al., 2016). On one hand, thermal rejuvenation (i.e. mantle upwelling) of the oceanic lithosphere allows to reduce the negative buoyancy and strength of magmatically old lithosphere (~80 Ma). Such a process, which likely occurred in the Caucasian ophiolites, dictates whether oceanic plates subduct or obduct during convergence. On the other hand, the occurrence of kinematic extension facilitates the thinning and propagation of the ophiolite on the continental domain, as well as the exhumation of continental basement beneath the ophiolite. In the Caucasus context, such an extensional event is likely triggered by far-field plate kinematics and particularly linked to the resumption of oceanic subduction of the northern boundary of Neotethys beneath Eurasia (Meijers et al., 2015; Hässig et al., 2015). From this case example, the involvement of the mantle convection in obduction processes seems likely (Jolivet et al., 2015).

2.4. Effects of continental subduction

The transition from subduction to collision is named 'continental subduction' or "soft collision". The first conclusive evidence for burial and subsequent exhumation of the continental crust to depths >90 km was provided by the discovery of coesite-bearing metamorphic rocks in the Dora Maira massif of the Western Alps (Chopin, 1984), and was further confirmed by numerous petrologic studies and seismic imaging in this chain (e.g., Zhao et al., 2015).

In his contribution, Massonne (2016) investigates the consequence of the descending plate on the upper plate hydration at the beginning of continent–continent collision, mainly based on pressure (*P*), temperature (*T*) and T-H_2O pseudosections modelling. On the basis of these calculations, different collisional scenarios are discussed highlighting the role of hydrated lithospheric mantle. Further suggestions are that (1) the lower crustal plate in a continent–continent collisional setting penetrates the lithospheric mantle, which is hydrated during the advancement of this plate, (2) the maximum depths of the subduction of upper continental crust is below 70 km and (3) hydrated mantle above the descending crustal plate is thrust onto this continental crust. This process best explains the piling up of backthrusted units close to the initial collision zone of a continent–continent collision as observed in the Himalayas (De Sigoyer et al., 1997; de Sigoyer et al., 2004 2004; Guillot et al., 1997). The process of shear backthrusting is thought to necessitate the underthrusting of the lower continental crustal plate as suggested by Ernst (2001) and numerical modelling experiments (e.g., Stöckhert and Gerya, 2005; Warren et al., 2008; Yamato et al., 2008).

Such a scenario could be the norm for the initial stages of any collisional event, as field examples of such continental subduction become more and more widespread. In their contribution Loury et al. (2016) document for the first time continental subduction in the geological record in the Chatkal Range of the Kyrgyz Tien Shan. Using an approach combining field mapping, micro-mapping, thermo-barometry, and in situ allanite U-Pb dating, Loury et al. (2016) describe highly retrogressed eclogites which document the Tarim underthrusting below the Middle Tien Shan to the west of the Talas Ferghana Fault. The retrogressed eclogites likely represent the leading edge of the subducted Tarim continent, which suffered high-metamorphic peak conditions, which culminated at $490 \pm 50\,^{\circ}C$ and 18.5 ± 2 kbar (about 60 km). They were subsequently followed by higher temperature retrogression during their exhumation (~560 °C at 11–7 kbar) in contrast to what is described to the east in Kyrgyzstan and China. These rocks pin-point the final accretion event of the Central Asian Orogenic Belt (CAOB), when the Tarim block collided with the Kazakh Platform. Lateral correlations show that this event is 20 Ma younger than to the east of the Talas-Ferghana Fault, which suggests that it already was a transform fault before being a major strike-slip fault. This study allows a tectonic reconstruction featuring lateral variations in the oceanic domain. The ocean width varied due to offset by the Talas-Ferghana Fault, which acted as a transform fault, resulting into diachronic collision of the Tarim Block. This case example shows that convergence and deformation did not continue in the Tien Shan after the continental subduction stage. Following the continental underthrusting at c. 300 Ma, the subduction zone jumped to the south of the Tarim Block.