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High-pressure anatectic paragneisses from the Namche Barwa, Eastern Himalayan Syntaxis: Textural evidence for partial melting, phase equilibria modeling and tectonic implications

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ABSTRACT

Rare kyanite-bearing anatectic paragneisses are found as boudins within sillimanite-bearing paragneisses of the core of the Namche Barwa Antiform, Tibet. In the present study, we document an occurrence from the NW side of the Yarlung Zangbo River. These rocks mainly consist of the assemblage garnet + K-feldspar + kyanite ± biotite + quartz + rutile ± plagioclase with kyanite locally pseudomorphed by sillimanite.

The documented textures are consistent with the rocks having undergone biotite-dehydration melting in the kyanite stability field, under high-*P* granulite facies conditions, and having experienced melt extraction. However textures related to melt crystallization are ubiquitous both in polymineralic inclusions in garnet and in the matrix, suggesting that a melt fraction had remained in these rocks.

Phase equilibria modelling was undertaken in the NCKFMASTHO system with THERMOCALC. *P*–*T* pseudosections built with the bulk compositions of one aluminous and one sub-aluminous paragneiss samples predict a biotite–kyanite–garnet–quartz–plagioclase–K-feldspar–liquid–rutile ± ilmenite field, in which biotite-dehydration melting occurs, located in the *P*–*T* range of ~800–875 °C and ~10–17 kbar. In addition, the topologies of these pseudosections are consistent with substantial melt loss during prograde metamorphism. A second set of *P*–*T* pseudosections with melt-reintegrated model bulk compositions were thus constructed to evaluate the effect of melt loss. The integration of textural information, precise mineral modes, mineral chemistry, and phase equilibria modelling allowed to constrain a *P*–*T* path where the rocks are buried to lower crustal depths at peak *P*–*T* conditions higher than 14 kbar and 825 °C, possibly in the order of 15–16 kbar and 850 °C, followed by decompression and cooling to *P*–*T* conditions of around 9 kbar and 810 °C, under which the remaining melt was solidified. The implications for granite production at the NBA and for Himalayan tectonic models are discussed.

1. Introduction

Partial melting of the lower and middle crusts and the resulting granite emplacement in the upper crust are important processes in the evolution of the Earth's continents (e.g. Brown, 2007 and references therein). Moreover, the rheology of melt-bearing rocks plays a major role on the development of orogenic plateaus (e.g. Nelson et al., 1996; Beaumont et al., 2001).

In large and hot orogens, the lower crust is expected to be at high-*P* granulite facies conditions. In Tibet for instance, lower crustal xenoliths entrained to the surface during post-collisional magmatism record *P*–*T* conditions in excess of 17 kbar–850 °C (Hacker et al., 2000; Ducea et al., 2003; Jolivet et al., 2003; Hacker et al., 2005; Ding et al., 2007; Chan et al., 2009). These conditions are more than sufficient for partial melting to take place in a range of quartzo-feldspathic protoliths. Therefore, textures of such rocks may constitute a record of the partial melting (and subsequent melt crystallization) history and provide insights on the *P*–*T* paths as well on the evolution of continental crust during orogenesis.

Broadly pelitic protoliths metamorphosed to high-*P* granulite facies conditions show a diagnostic kyanite–K-feldspar-bearing assemblage (e.g. O'Brien and Roetzler, 2003). However, such rocks seem to be rather rare at the surface of the earth, as expressed by the small number of studies reporting them (for instance Barbey et al. 1990; Godard et al., 1996; Gilotti and Elvevold, 2002; Hollis et al., 2006; Lang and Gilotti, 2007, Indares et al., 2008). Accordingly, partial-melting experimental studies (Vielzeuf and Holloway, 1988; Patino Douce and Johnson, 1991; Carrington and Harley, 1995; Gardien et al., 1995) and phase equilibria modelling (e.g. Spear et al., 1999; White et al., 2001, 2007) with applications to natural pelitic systems (e.g. White et al., 2003, 2004; Johnson and Brown, 2004; Storm and Spear, 2005; Halpin et al., 2007) are mostly focused on middle crustal conditions.

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Recent advances in phase equilibria modelling, including modelling the effect of melt loss in metapelites and metagreywakes *2 (White and Powell, 2002; Johnson et al., 2008) and updated activity–composition relationships for phases of interest in the NCKFMASHTO system (White et al., 2007) provide a framework that is highly relevant to the study of high-*P* anatectic rocks (e.g. Indares et al., 2008).

This contribution focuses on textural analysis and phase equilibria modelling of kyanite-bearing anatectic gneisses from the Namche Barwa Antiform (NBA); Eastern Himalayan Syntaxis (EHS), South-East Tibet, China. These gneisses are found as lenses in lower-*P* country rocks within the core of NBA and constitute a rare example of high-*P*–granulite facies rocks exposed in a rapidly exhuming area of an active orogen. Textures suggestive of partial melting and subsequent melt crystallisation are documented and interpreted within the framework of *P*–*T* pseudosections taking into account the effects of melt loss, and with additional constraints placed by mineral chemistry. The results are interpreted in terms of potential *P*–*T* paths and provide the first comprehensive metamorphic analysis of high-*P* granulites in the EHS.

2. Geological context

The Eastern Himalaya Syntaxis (Fig. 1) is located at the eastern end of the Himalayan range, in the region where the NE corner of the Indian plate is actively indenting in the Asian plate. This region is characterized by a sharp southward bend of the E–W trend of the main Himalayan structures and of topographic features such as the Yarlung Zangpo River. The EHS is centered on the NBA which exposes the easternmost extension of three major lithotectonic domains of the Tibet–Himalaya system. Towards the core of NBA, these are: (a) the Lhasa block, which was accreted to the Eurasian margin prior to the final collision with India; (b) highly deformed remnants of the Yarlung Zangpo Suture Zone (YZSZ) which represents the boundary between the Asian and Indian plates; and (c) high-grade metamorphic rocks and orthogneisses, commonly referred to as Namche Barwa massif (Geng et al., 2006). The latter is inferred to represent the NE extension of the Greater Himalayan Sequence (GHS), based on Precambrian and Panafrican inheritances in some zircon ages (Ding et al., 2001; Booth et al., 2004, Liu et al., 2007). Evidence of high-*P* metamorphism is locally preserved in this domain (Liu and Zhong, 1997; Ding and Zhong, 1999).

2.1. The Namche Barwa massif

Despite the poor accessibility of the NBA, a number of studies were published in the last decade or so (Liu and Zhong, 1997; Burg et al., 1998; Ding et al., 2001; Booth et al., 2004; Geng et al., 2006; Booth et al., 2009; Zhang et al., 2010). Although most workers agree that the Namche Barwa massif mainly consists of high-grade rocks and felsic orthogneisses, there are some significant differences in the subdivisions proposed in the literature. For instance Liu and Zhong (1997) make a distinction between a “granulite group” to the north and an “amphibolite” group to the south, separated by a major shear zone, the Namula thrust (not shown). This division was also adopted by others including Booth et al. (2004, 2009). Locally, in the granulite group were recognized tectonic lenses and boudins of calcsilicate garnet–clinopyroxenite, garnet–clinopyroxene amphibolite and kyanite–garnet-bearing gneiss, inferred to represent high-*P* granulites, variably overprinted by high-*T*–lower-*P* mineral assemblages (Liu and Zhong, 1997; Ding and Zhong, 1999).

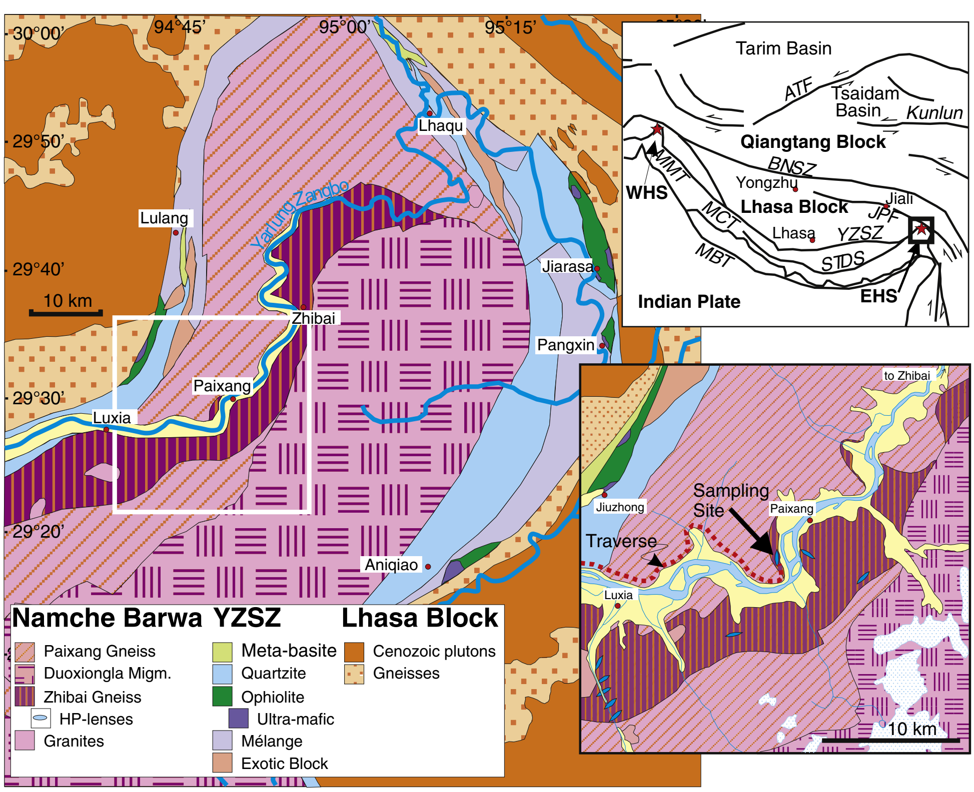

Fig. 1. Lithotectonic map of the Namche Barwa Antiform (NBA) modified from Geng et al. (2006). Upper right corner inset: location of the Himalayan Syntaxes with major Himalayan–Tibetan tectonic features. Lower right corner inset: Sampling location with high-*P* occurrences. YZSZ = Yarlung Zangbo Suture Zone; ATF = Altyn Tagh Fault; BNSZ = Bangong Nujiang Suture Zone; JPF = Jiali Parlung Fault; MMT = Main Mantle Thrust; MCT = Main Central Thrust; STDS = South Tibetan Detachment; MBT = Main Boundary Thrust; WHS = Western Himalayan Syntaxis; EHS = Eastern Himalayan Syntaxis.