Journal of Asian Earth Sciences xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Different stages of chemical alteration on metabasaltic rocks in the subduction channel: Evidence from the Western Tianshan metamorphic belt, NW China

Yuanyuan Xiao[a,b,c,*], Yaoling Niu[a,b,d], Kuo-Lung Wang[c], Yoshiyuki Iizuka[c], Jinyan Lin[e], Dong Wang[a,b], Yulong Tan[e], Guodong Wang[a,b]

[a] Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China
[b] Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266061, China
[c] Institute of Earth Sciences, Academia Sinica, Taipei 11529, Taiwan
[d] Department of Earth Sciences, Durham University, Durham DH1 3LE, UK
[e] Department of Geology, Northwest University, Xi'an 710069, China

A R T I C L E I N F O

Keywords:
Subduction
Channelized glaucophane-rich rims surrounding omphacite-rich interiors
Mass transfer
Subduction zone magmatism
Mantle heterogeneity

A B S T R A C T

To understand the geochemistry of subduction zone metamorphism, especially the large-scale mass transfer at forearc to subarc depths, we carried out a detailed study of a ~1.5 m size metabasaltic block with well-preserved pillow structures from the Chinese Western Tianshan high- to ultrahigh-pressure metamorphic belt. This metabasaltic block is characterized by omphacite-rich interiors gradually surrounded by abundant channelized (veins) glaucophane-rich patches toward the rims. The glaucophane-rich rims share the same peak metamorphic conditions with omphacite-rich interiors, but have experienced stronger blueschist-facies overprinting during exhumation. Representative samples from the glaucophane-rich rims and omphacite-rich interiors yield a well-defined Rb-Sr isochron age of 307 ± 23 Ma, likely representing this overprinting event. Both glaucophane-rich rims and omphacite-rich interiors show elevated K-Rb-Cs-Ba-Pb-Sr contents relative to their protolith, reflecting a large-scale enrichment of these elements and formation of abundant phengite during subduction. Compared with the omphacite-rich interiors, the glaucophane-rich rims have gained rare earth elements (REEs, > 25%), U-Th (~75%), Pb-Sr (> 100%) and some transition metals like Co and Ni (25–50%), but lost P (~75%), Na (> 25%), Li and Be (~50%); K-Rb-Cs-Ba show only 10% loss. These chemical changes would be caused by serpentinite-derived fluids during the exhumation in the subduction channel. Therefore, there are two stages of fluid action in the subduction channel. As the formation of phengite stabilizes K-Rb-Cs-Ba at the first stage, the residual fluids released from the phengite-rich metabasaltic rocks would be depleted in these elements, which are unlikely to contribute to elevated contents of these elements in arc magmas if phengite remains stable at subarc depths. In addition, the decrease of U/Pb ratios as the preferred enrichment of Pb over U in the eclogitic rocks during the first stage chemical alteration may further lead to the lower radiogenic Pb isotope component of the deeply subducted ocean crust with time, which is inconsistent with the high radiogenic Pb isotope component of high μ (= $^{238}U/^{204}Pb$) basalts.

1. Introduction

The subduction zone metamorphism and related geochemical processes are significant for arc magmatism and mantle heterogeneity, which have attracted much attention in recent years (e.g., Kerrick and Connolly, 2001; Kelley et al., 2005; Keppler, 1996; McCulloch and Gamble, 1991; Niu et al., 2002; Niu and O'Hara, 2003; Niu, 2009; Tatsumi, 2005; John et al., 2012; Bebout, 2014; Marschall and Schumacher, 2012; Spandler and Pirard, 2013; Zheng and Chen, 2016). These studies have found that the geochemical behaviors of chemical elements during subduction zone metamorphism are much more complex than previously inferred through subduction zone magmatism, and they are not only controlled by the presence and stability of variable minerals (e.g., El Korh et al., 2009; Hermann and Rubatto, 2009; Spandler et al., 2003; Xiao et al., 2012, 2013, 2014, 2016) but also affected by the thermal structure of subduction zones (van Keken et al., 2011; Zheng et al., 2016) and the physicochemical properties of fluids, e.g., fluids with dissolved Na-Al silicates or halogen, supercritical fluids

* Corresponding author at: Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China.
E-mail address: yuanyuan_xiao@foxmail.com (Y. Xiao).

http://dx.doi.org/10.1016/j.jseaes.2017.06.001
Received 10 January 2017; Received in revised form 31 May 2017; Accepted 5 June 2017
1367-9120/

(Gao et al., 2007; Gao and Klemd, 2001; Haase et al., 2015; Hermann et al., 2006; John et al., 2008, 2012; Rubatto and Hermann, 2003; Schmidt et al., 2004; Spandler and Hermann, 2006; Zack and John, 2007; Zheng et al., 2011). The complex subduction-exhumation processes (i.e., multiple subduction-exhumation cycles) in subduction channels proposed in recent studies may lead to more complicated geochemical processes and consequences (Rubatto et al., 2011; Zheng and Hermann, 2014; Li et al., 2016; Xiao et al., 2016). Hence, the information on large-scale fluid-rock interactions in subduction channels is critically needed for understanding of large-scale mass transfer from the subducting slab to the overlying mantle wedge, which is essential towards a genuine understanding of arc magmatism and mantle heterogeneity.

It has been proposed that large-scale fluid fluxes and channelized fluids can facilitate element mobility in subduction zones (e.g., Ague, 2011; Bebout, 2007; Herms et al., 2012; John et al., 2008; Spandler and Hermann, 2006; Zack and John, 2007; Li et al., 2013; Bebout and Penniston-Dorland, 2016). In order to better understand the large-scale mass transfer from the subducting slab to the overlying mantle wedge, it is best to study subduction-zone metamorphic rocks affected by large-scale fluid flows, the conduit of which is manifested by large-scale veins (e.g., John et al., 2012; Spandler and Hermann, 2006; van der Straaten et al., 2008, 2012). This study focuses on a ~1.5 m size metabasaltic block with well-preserved pillow structures from the Chinese Western Tianshan high-pressure (HP) to ultrahigh pressure (UHP) metamorphic belt (Figs. 1 and 2). Through a combined study of mineralogy, petrology and geochemistry, we discuss the behaviors of chemical elements in response to different stages of large-scale fluid-rock interactions, which offer insights into the possible large-scale mass transfer, contributing to our understanding of subduction zone magmatism and mantle heterogeneity.

2. Field Geology and petrography

The Western Tianshan HP-UHP metamorphic belt in NW China (Fig. 1) represents a paleo-convergent plate margin associated with successive northward subduction of the South Tianshan ocean crust beneath the Tarim Block during the Carboniferous (Gao and Klemd, 2003; Gao et al., 1999; Su et al., 2010; Klemd et al., 2011; Yang et al., 2013). This HP-UHP metamorphic belt is composed of pelitic schist, marble, serpentinite, blueschist and eclogite (Gao and Klemd, 2001; Wei et al., 2009; Li et al., 2012; Lü et al., 2013; Shen et al., 2015; Klemd et al., 2011; Yang et al., 2013) with protoliths of sandstone, pelite, carbonates, peridotite and basalts respectively (Ai et al., 2006; Gao and Klemd, 2003; Xiao et al., 2012). The Sm-Nd isochron age of ~343 Ma indicates the time of subduction metamorphism (Gao and Klemd, 2003), whereas the $^{40}Ar/^{39}Ar$ and Rb–Sr ages of ~310 Ma for white mica are thought to represent the time of retrograde overprint during exhumation (Klemd et al., 2005). Based on recent findings of coesite and their distributions (e.g., Lü et al., 2008, 2009, 2013, 2014; Lü and Zhang, 2012), the Chinese Western Tianshan metamorphic belt has been classified into HP and UHP metamorphic sub-units (Fig. 1; Lü and Zhang, 2012).

Numerous studies have shown large-scale fluid-rock interactions in the Chinese Western Tianshan HP-UHP metamorphic belt (Gao and Klemd, 2001; Gao et al., 2007; John et al., 2008, 2012; van der Straaten et al., 2008, 2012; Beinlich et al., 2010; Lü et al., 2012; Li et al., 2013, 2016). Our sampling location is along the Atantayi River (Fig. 1). The studied metabasaltic block with well-preserved pillow structures (Fig. 2) is a boulder, which has recently rolled from the steep mountain slope, and has omphacite-rich domains in the interiors, gradationally surrounded by abundant channelized glaucophane-rich patches toward the rims (Figs. 2a–c and 3a). Both omphacite-rich interiors and channelized glaucophane-rich rims are characteristically dominated by omphacite, glaucophane, phengite, and epidote as well as locally accumulated garnet plus some quartz, apatite, and carbonates, but glaucophane and epidote modes increase with decreasing omphacite mode toward rims (e.g., Fig. 2d–g).

Samples for this study are taken as a drilling core from this metabasaltic block with well-preserved pillow structures, ~10 cm long with a diameter of 2.5 cm (Fig. 2). The drilling core is divided into 4 sections for convenience, labelled as 22A, 22B, 22C and 22D from the rim surface to the interior (Fig. 2c). These four rock samples contain similar mineral assemblages with varying modal abundances. Samples 22C and 22D represent the omphacite-rich domain dominated by omphacite and phengite (Fig. 2d and e), while 22A and 22B represent the glaucophane-

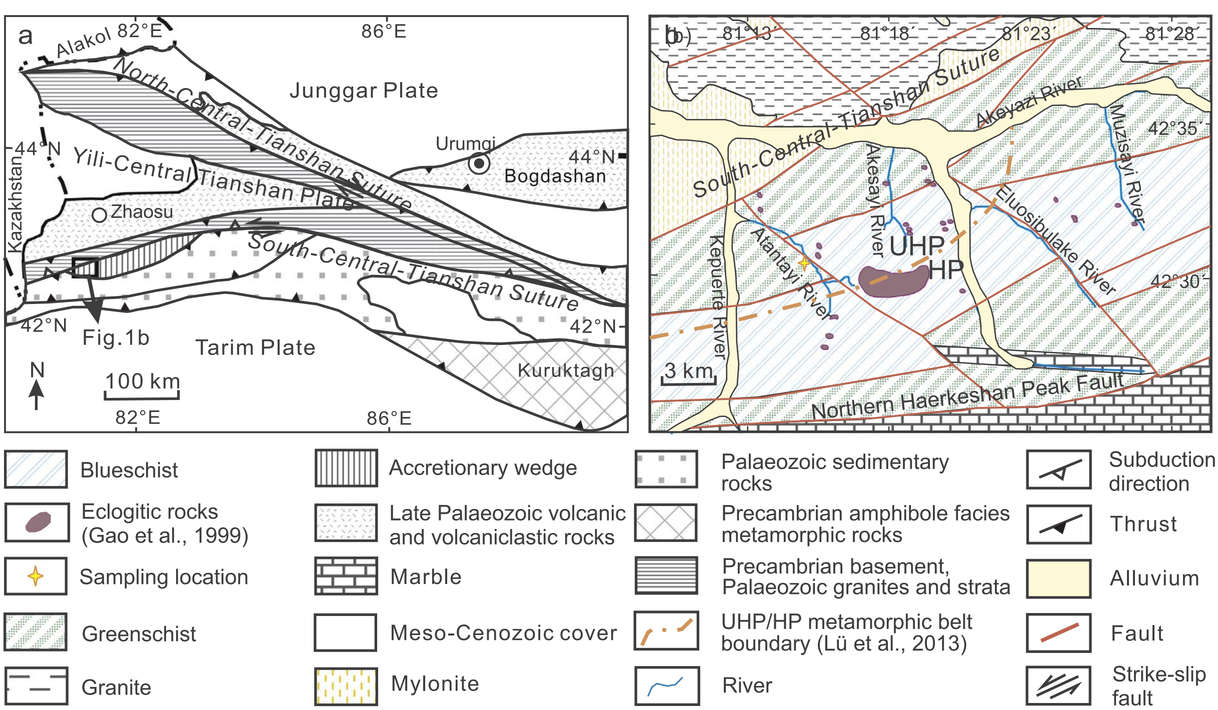

Fig. 1. Geological sketch of the Chinese Western Tianshan HP-UHP metamorphic terrane (after Lü et al., 2013; Li et al., 2013) and our sampling location for this study.