Lithos 254–255 (2016) 118–130

Contents lists available at ScienceDirect

Lithos

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

Apatite trace element and halogen compositions as petrogenetic-metallogenic indicators: Examples from four granite plutons in the Sanjiang region, SW China

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ARTICLE INFO

Article history:
Received 24 September 2015
Accepted 17 March 2016
Available online 1 April 2016

Keywords:
Apatite
REE
Halogens
Oxidation state
Adakite
Ore genesis

ABSTRACT

The abundances of trace elements including Sr, Ga and rare earth elements (REE) and halogens in apatite crystals from four intermediate-felsic plutons in the Zhongdian terrane in the Sanjiang region have been determined using electron microprobe and laser ablation inductively coupled plasma mass spectrometry to evaluate the potential of apatite as a petrogenic-metallogenic indicator. The selected plutons include one that is not mineralized (the Triassic Xiuwacu pluton, or the TXWC pluton), one that hosts a porphyry-type Cu deposit (the Pulang pluton, or the PL pluton), one that hosts a porphyry-type Mo deposit (the Tongchanggou pluton, or the TCG pluton), and one that hosts a vein-type Mo deposit (the Cretaceous Xiuwacu pluton, or the CXWC pluton). Except for the CXWC pluton, the other three plutons have adakite-like trace element signatures in whole rocks. The results from this study show that REE, Sr and halogens in apatite can be used to track magma compositions, oxidation states and crystallization history. Apatite crystals from the adakite-like plutons are characterized by much higher Sr/Y and δEu than the non-adakite-type pluton. This means that apatite, which is not susceptible to alteration, is a useful tool for identifying the adakite-like plutons that no longer preserve the initial Sr/Y ratios in whole rocks due to weathering and hydrothermal alteration. Based on apatite Ga contents and δEu values, it is inferred that the parental magmas for the two adakite-like plutons containing porphyry-type Cu and Mo mineralization are more oxidized than that for the non-adakite-type pluton containing vein-type Mo mineralization. Apatite crystals from the vein-type Mo deposit have much lower Cl/F ratios than those from the porphyry-type Cu and Mo deposits. Apatite crystals from the adakite-like pluton without Cu or Mo mineralization is characterized by much lower Cl/F ratios than those from the adakite-like plutons that host the porphyry-type Cu and Mo deposits. The results from this study confirm the apatite is a useful petrogenetic indicator as well as mineral exploration tool.

1. Introduction

Apatite is an important accessory mineral in granite rocks and is a sink for whole-rock P and some rare earth elements (REE) and halogens (Ayers and Watson, 1993; Henerson, 1980; Nagasawa, 1970; Roeder et al., 1987; Warner et al., 1998; Wass et al., 1980). Experiments covering a wide variety of melt compositions, pressure and temperatures (e.g. Harrison and Watson, 1984; Jahnke, 1984; London et al., 1999; Pichavant et al., 1992; Watson, 1979, 1980; Wolf and London, 1994, 1995) have shown that the solubility of apatite in magma decreases with decreasing temperature and increasing polymerization of magma. Therefore, apatite may appear as an early phase on liquidus in non-peraluminous magma (Harrison and Watson, 1984). In view of its stability, which is not susceptible to hydrothermal alteration and metamorphism (Ayers and Watson, 1991; Creaser and Gray, 1992; Ekstrom, 1972), apatite could record and preserve information on parental magma.

Particularly, halogen compositions in apatite have been applied to estimate contents of F, Cl and H_2O in liquid and melt and speculate voliatite saturation according to the changes of halogens ratios(e.g. Boudreau and Kruger, 1990; Boudreau and McCallum, 1989; Boyce and Hervig, 2009; Boyce et al., 2010; Cawthorn, 1994; Elkins-Tanton and Grove, 2011; Meurer and Boudreau, 1996; Schisa et al., 2015; Warner et al., 1998). Trace elements in apatite such as Mn, Sr, LREE, Th, Y, Eu and Ce have been used to indicate magma composition and oxidation state (e.g. Belousova et al., 2001, 2002; Cao et al., 2012; Piccoli and Candela, 2002; Sha and Chappell, 1999; Tepper and Kuehner, 1999).Moreover, $^{87}Sr/^{86}Sr$ of apatite could record initial $^{87}Sr/^{86}Sr$ values in systems providing an additional approach to trace magmatic process

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http://dx.doi.org/10.1016/j.lithos.2016.03.010
0024-4937/

and source (e.g. Creaser and Gray, 1992; Tsuboi, 2005; Tsuboi and Suzuki, 2003; Zhang et al., 2011) In addition, apatites have also been traditionally used for U-Th-Pb dating (e.g. Chew et al., 2011; Corfu and Stone, 1998; Gaweda et al., 2014).

Thus, apatite could be a reliable petrogenic-metallogenic indicator (Belousova et al., 2002; Boudreau, 1993; Coulson et al., 2001; Imai, 2004; Martin and John, 1998; Roegge et al., 1974; Treloar and Colley, 1996; Williams and Cesbron, 1977). To test its applicability and explore some new findings, we have selected four granitic intrusions with various types of mineralization and without mineralization in the Zhongdian arc terrane, a major ore deposits cluster of porphyry-type and hydrotherm-type deposits, in the Sanjiang region in Yunnan, SW China. Although previous studies focusing of these plutons and relevant deposits have determined diagenetic and metallogenic ages, the magma and ore-forming material source and fluid properties (e.g. Leng et al., 2007, 2014, Li et al., 2007, 2014, Wang et al., 2014a, 2014b, Yu and Li, 2014, Zeng et al., 2006), it is still an uncertainty for different properties of magmas formed in different epochs and tectonic background and their metallogenic specificity. The results of our study reported in this paper resolve these issues, which confirm that apatite is not only a reliable petrogenetic indicator but also a useful exploration tool.

2. Geological background and samples

The Yidun arc is situated between the Songpan-Garzê Fold Belt and the Qiangtang Block of the eastern Tibetan Plateau. The Yidun arc formed as a result of westward subduction of the Garzê-Litang oceanic plate beneath the Zhongza-Zhongdian micro-continental block (Hou, 1993; Li et al., 2007). The Garzê-Litang Ocean formed from Middle to Late Paleozoic by rifting between the Zhongza-Zhongdian block and the Yangtze craton. Oceanic subduction beneath the Zhongza-Zhongdian block in Late Triassic produced the "Indosinian" granodiorite plutons and associated porphyry-type mineral deposits. In late "Yanshanian", the region underwent post-collisional extension. Partial melting of the continental crust in response to regional decompression produced the Yanshanian granitoids and associated porphyry-type or hydrothermal vein-type mineral deposits.

Four intermediate-felsic plutons in the Zhongza-Zhongdian terrane are selected for this study (Fig. 1). Two of them belong to the Indosinian arc magmatism: the Pulang pluton (PL) and the Triassic Xiuwacu pluton (TXWC). The former hosts a porphyry-type Cu deposit whereas the latter does not. The other two selected plutons belong to the Yanshanian post-collisional magmatism: the Cretaceous Xiuwacu pluton (CXWC)

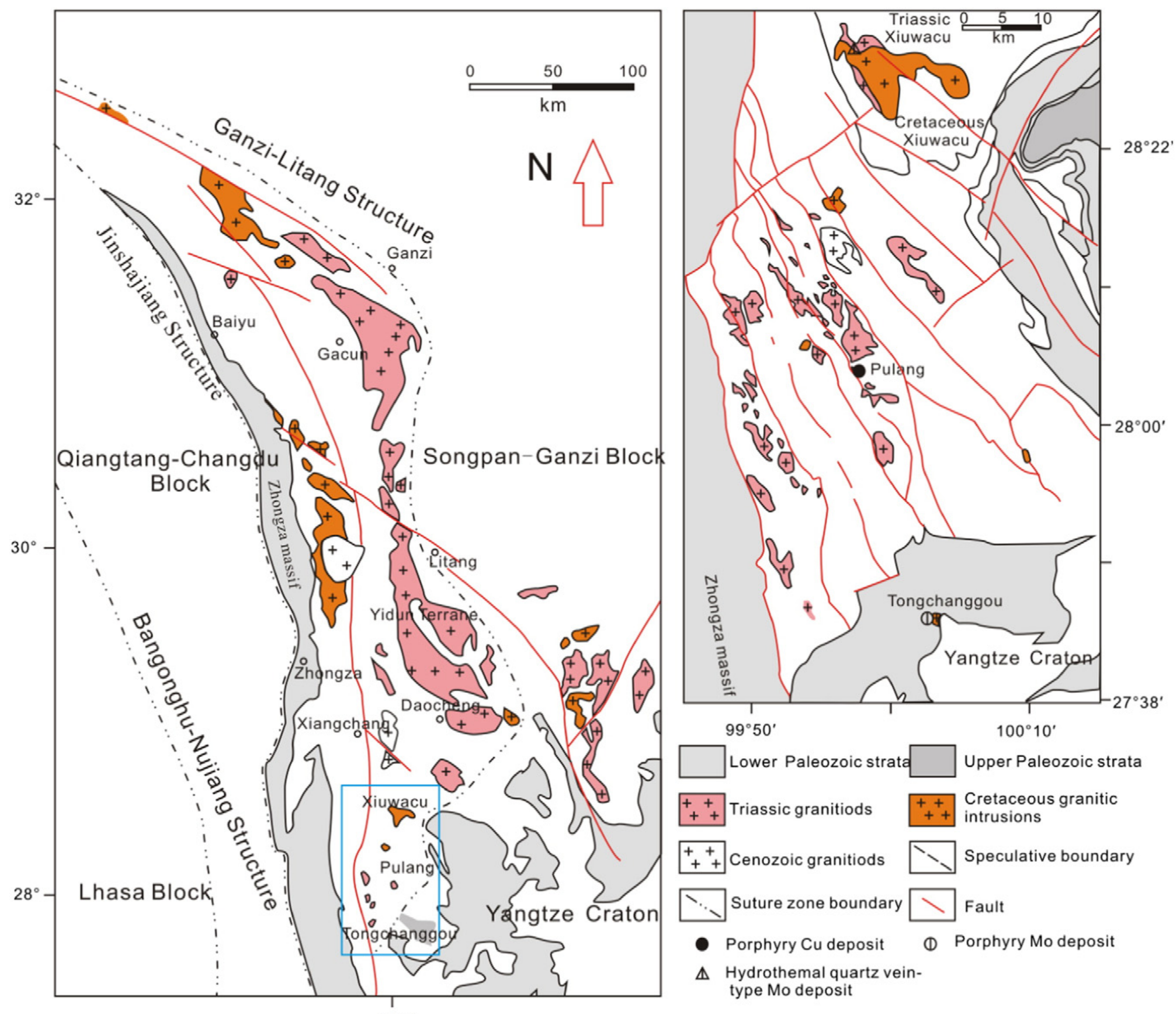

Fig. 1. Regional geological map of the research area, part of the details are based on Wang et al. (2014a). It shows the location of (a) the Yidun arc and (b) the relevant intrusions and deposits.