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Late-stage hydrothermal alteration and heteromorphism of calc–alkaline lamprophyre dykes in Late Jurassic Granite, Southeast China

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ABSTRACT

Three generations of calc–alkaline lamprophyre, occurring as patches or segregations in granite and as dyke swarms with a NNW–SSE trend, are associated with the Late Jurassic Shanqi–Xiaqi granite, SE China. They comprise coarse-grained, hornblende-dominated spessartite and two types of panidiomorphic kersantite: type-1 contains clinopyroxene and biotite phenocrysts, whereas type-2 is fine-grained and plagioclase-rich. The granite is characterised by large feldspar crystals and Al-rich annite. This rare occurrence of outcrops with no influence from atmospheric weathering allows the investigation of extensive alteration from hydrothermal interaction between lamprophyres and granite. At a depth of ca. 18 km, the breakdown of annite in the granite to magnetite + K-feldspar was the result of reheating above 670 °C at oxygen activities $>10^{-17}$ bar. In the lamprophyres, a variety of reactions due to autometasomatism include: breakdown of Ti-rich pargasites to chlorite, epidote, titanite; olivine to talc, tremolite, saponite, beidellite and Fe–Cr spinels; biotite to chlorite and titanite; calcic plagioclase to orthoclase, albite, epidote, chlorite and beidellite. Late-stage magmatic hydrothermal fluids from granite and lamprophyres resulted in redistribution of F, Ba, Sr, and CO_2 with the formation of calcite–fluorite veins. Amphibole-rich spessartite and biotite–diopside dominated kersantite exhibit heteromorphism in that they have similar geochemical characteristics but different mineralogies. The alkali-rich lamprophyric magmas are inferred to have been derived from melting in the mantle wedge during the subduction of the Kula Plate, and show typical backarc rift chemistry. Prior to intrusion of lamprophyre, underplating of large volumes of basaltic magma is thought to have enhanced partial melting in the overlying continental crust resulting in widespread granite magmatism in SE China.

1. Introduction

In the coastal region of Southeast China, Mesozoic granites are widespread and much more abundant than basic rocks that include lamprophyres which typically occur as dykes, often in swarms. Lamprophyres may be classified on the basis of their modal mineral content: rocks with high modal feldspar (33–67 vol.%), less then 25 vol.% clinopyroxene and 20–40 vol.% of amphibole and/or biotite and some olivine are referred to as calc–alkaline lamprophyres. Plagioclase-dominated calc–alkaline lamprophyres with more biotite than amphibole are classified as kersantites, and if hornblende is more abundant than biotite they are known as spessartites. If calc–alkaline lamprophyres have orthoclase>plagioclase, they are referred to as minettes (biotite>hornblende) or vogesites (hornblende>biotite). Despite markedly different mineralogies, calc–alkaline lamprophyre dykes have similar bulk-rock compositions, a phenomenon that is known as heteromorphism. A characteristic feature of lamprophyres worldwide is their alteration (Rock, 1991), which is usually ascribed to subsolidus autometasomatic or deuteric processes in a volatile-rich residual magma following crystallisation of olivine, clinopyroxene, biotite and hornblende (e.g. Lippolt and Siebel 1991; Pivec et al., 2002).

Dykes of kersantite and spessartite, intruded into a Late Jurassic granite in SE China known as the Shanqi–Xiaqi granite (Fig. 1), show evidence of late magmatic hydrothermal alteration, and granite adjacent the lamprophyres has also been hydrothermally altered. In this paper we present the results of a mineralogical and geochemical investigation of the lamprophyre dykes and Shanqi–Xiaqi granite with emphasis on their hydrothermal alteration. As exposures occur in a hydroelectric power construction tunnel system, the rocks are unweathered thus providing the unique opportunity to observe the full range of deuteric/hydrothermal alteration/reactions affecting the lamprophyres and adjacent granite.

2. Geological setting

The South China Block can be subdivided into three major units: the Dabie terrane and the Yangtze craton, both in the North, and Cathaysia in the South (Chen and Jahn, 1998). A large volume of felsic

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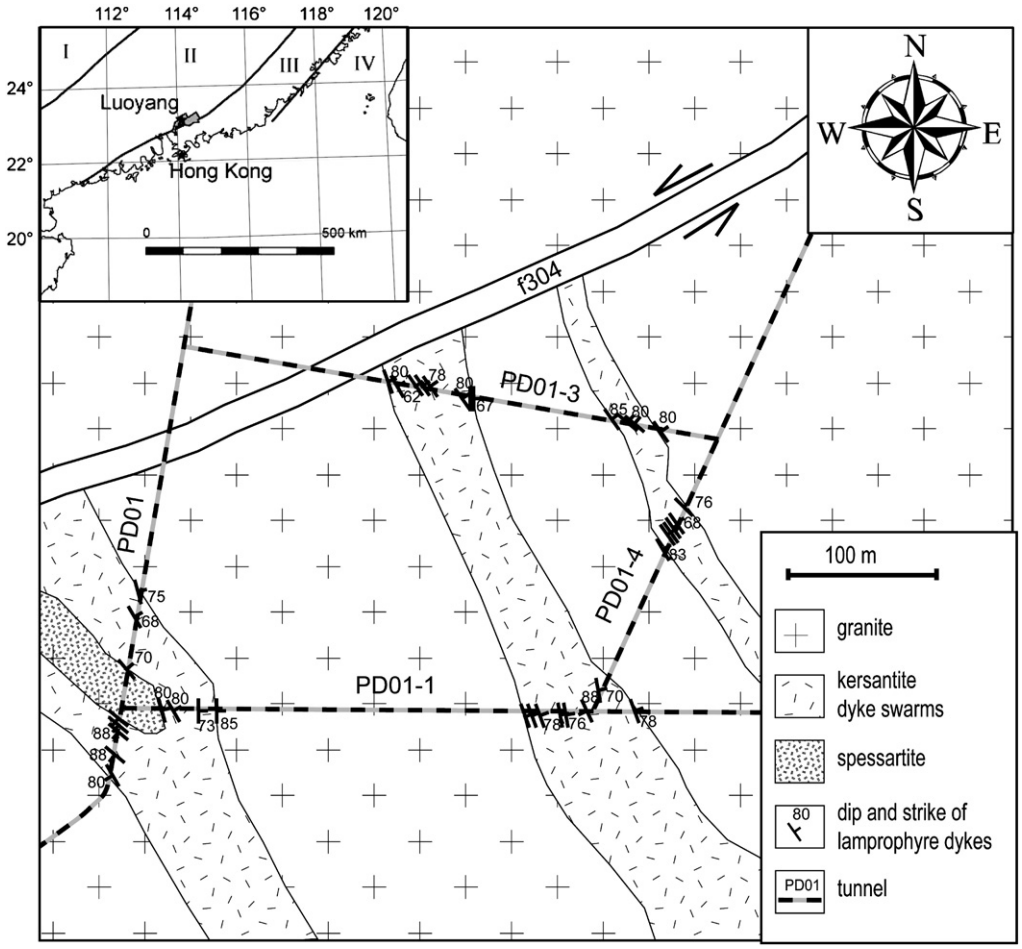

Fig. 1. Schematic map of the study area (underground tunnel system) near the city of Luoyang (23°15′ N and 114°20′ E) showing the distribution of the lamprophyre dykes. Inset map showing the location of the Shanqi–Xiaqi composite-granite body and the tectonic units of Southern China: I = Yangtze block; II, III and IV belong to the Cathaysia block, II = Cathaysia Interior; III = East Fujian; IV = coastal Fujian and Taiwan.

rocks of predominantly Mesozoic age are thought to have been generated by partial melting of continental crustal basement during subduction of the Paleo-Pacific or Kula Plate (Gilder et al., 1991, 1996; Chen and Jahn, 1998; Zhou and Li, 2000; Chen et al., 2003). Subduction of the Kula Plate beneath Cathaysia during the Mesozoic led to the formation of granitic and volcanic rocks that are now exposed over a large area of Southeast China (Chen and Grapes, 2007). The igneous rocks form a belt of several hundred kilometres width parallel to the coast, and have a total outcrop area of some 240,000 km^2 in the provinces of Zhejiang, Fujian, Jiangxi, and Guangdong (Zhou and Li, 2000). Magmatic activity was associated with the formation of W and Sn ore deposits that are associated with smaller amounts of Bi, Be, Nb, Ta, U, REE, Cu, Mo, Pb, and Zn (Gilder et al., 1996; Chen and Grapes, 2007). The Shanqi–Xiaqi granite complex of this study was formed during the Mesozoic Yanshanian period at about 147 Ma. In the Late Cretaceous, an inferred increase in the subduction angle of the Kula Plate is considered to have induced "slab-rollback" leading to the formation of NE–SW trending extensional basins (Gilder et al., 1996; Chen and Jahn, 1998), which are occupied by red-bed sandstones associated with evaporites and, locally, volcanic rocks (Zhou and Li, 2000; Chen and Grapes, 2007). Dehydration of the subducted Kula Plate generated basaltic melts in the overlying mantle wedge resulting in elevated temperatures that enhanced the partial melting of crustal rocks and the formation of migmatites and granitoids. Zhou and Li (2000) consider that thinning of the crust and lithospheric mantle due to extension in Southeast China was accompanied by bimodal mafic–felsic magmatic activity that included the intrusion of lamprophyre dykes.

3. Field relations

The area of this study is part of a tunnel system associated with the construction of a hydroelectric power plant near the city of Luoyang (23°15' N and 114°20' E), located about 100 km east of Guangzhou (Canton) in SE China (Fig. 1). The lamprophyre dyke swarms have a NNW trend and are almost vertical. Three types of lamprophyres can be distinguished on the basis of their megascopic appearance (Table 1):

(i). Coarse-grained spessartite dominated by idiomorphic hornblende, forming thin needles of 0.5 mm in greenish "patches" (Fig. 2a), and exclusively in contact with other lamprophyre dykes (Fig. 2b).
(ii). Type-1 kersantite: grey-black, fine-grained lamphrophyre dykes, individually up to 5 m thick, that contain phenocrysts of clinopyroxene and biotite within a groundmass of biotite and feldspars. The dykes show chilled margins with the granite (Fig. 2c).
(iii). Type-2 kersantite: thinner dykes of greenish, very fine-grained lamprophyre characterised by the presence of thin veins and amygdules of calcite (Fig. 2d).