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Co-rich sulfides in mantle peridotites from Penghu Islands, Taiwan: Footprints of Proterozoic mantle plumes under the Cathaysia Block

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ABSTRACT

Abundant primary sulfides occur as inclusions in silicates and as discrete grains in mantle-derived spinel lherzolite xenoliths from Miocene intraplate basalts on the Penghu Islands, Taiwan, which is located at the southeastern margin of Cathaysia Block. These sulfides are dominantly mixtures of Fe-rich and Ni-rich monosulfide solid solutions (MSS), with minor pentlandite, millerite and chalcopyrite, and are considered to represent sulfide melts crystallized at high temperatures (>900 °C). Some sulfides from the Tungchiyu (TCY) islet (37 out of 118 grains) have remarkably high Co contents resulting in subchondritic Ni/Co ratios (<21; 5–20, median = 12), distinct from the superchondritic values (Ni/Co = 48–157, median = 83) typical of mantle sulfides worldwide. The Co-rich nature of the TCY sulfides is considered to be a primary characteristic as no secondary processes can be identified to account for the feature. They are similar to Ni–Co-rich sulfides from Lac de Gras, Slave Craton (Aulbach et al. (2004) Chemical Geology 208, 61–88) interpreted as being derived from the lower mantle. Experimental studies suggest that the sulfide melt/silicate melt partition coefficient of Ni becomes lower than that of Co at pressures greater than 28 GPa, similar to recent estimates of the magma ocean conditions. Os model ages of the TCY Co-rich sulfides reveal four episodes of generation: 2.0, 1.7, 1.4 and 0.8 Ga; this is consistent with the age pattern of all Penghu sulfides, indicating significant lithosperic mantle formation, melt extraction or metasomatic events at these time periods. These events closely correspond to the global 1.9-Ga superplume event related to the assembly of the Nena/Columbia supercontinent, a minor 1.7-Ga superplume event in SW Laurentia prior to breakup of Nena/Columbia, the 1468 Ma Moyie event in the Belt Basin region in western Laurentia and the ~0.8 Ga breakup of Rodinia, with which the Cathaysia Block was associated at various stages during its Proterozoic evolution (Li et al. (2008) Precambrian Research 160, 179–210 and references therein). Olivine in a peridotite sample from the TCY locality has distinctly high $^{3}He/^{4}He$ (11 R_A), whereas other peridotites from the KP and TCY localities have $^{3}He/^{4}He$ ~6.7 R_A, lower than MORB. The high $^{3}He/^{4}He$ further suggests that materials from the deep mantle have interacted with the host peridotite of Co-rich sulfides. We thus propose that the Co-rich sulfide melts may have been trapped in the lower mantle during core–mantle differentiation and then transported to shallow depths by mantle plumes that entrained lower mantle materials at several different time periods. This study provides the first substantial evidence from the lithosperic mantle beneath the Cathaysia Block to support the activity of mantle plumes related to the breakup of the supercontinents Nena/Columbia and Rodinia in Proterozoic time.

1. Introduction

The lithospheric mantle is one of Earth's most significant geochemical reservoirs due to its non-convecting character. It is geochemically complex with a depleted composition overprinted by multiple melt/fluid processes, and carries the history of its stabilization and subsequent events that affected the whole lithosphere.

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This relatively rigid uppermost part of the mantle, the subcontinental lithospheric mantle (SCLM), acts as roots of the continents and contributes to the stability and longevity of continents (e.g. O'Neill et al., 2007; Poudjom Djomani et al., 2001; Griffin et al., 2008 and references therein). The SCLM may have formed as partial melting residues from primordial mantle, by cooling of upwelling asthenosphere, or by plume accretion to existing lithosphere (e.g. O'Reilly and Griffin, 2006 and references therein). Such processes could be related to the formation of the overlying crust and correspond to growth and evolution of the crust. Thus, the SCLM records the cumulative geochemical effects of large-scale tectonic events, and affects the response of the crust to tectonic stresses. The evolution of the SCLM is of essential importance to understanding the growth and stability of continents and long-term mantle evolution.

Whole-rock Re–Os isotope data from mantle-derived peridotites have contributed much information on the age of the SCLM. However, Os in these rocks is concentrated in sulfide phases and that these can be mobile within the SCLM, so that whole-rock Re–Os model ages may reflect mixing processes, rather than single melting events (Alard et al., 2002; Griffin et al., 2002). The development of *in situ* analysis of elemental and Re–Os isotopic compositions in single sulfide grains makes it possible to explore the heterogeneity of different generations of sulfides and to unravel some of the complexity contained in mantle-derived samples (Alard et al., 2000, 2002; Aulbach et al., 2004; Griffin et al., 2002, 2004; Lorand and Alard, 2001; Luguet et al., 2001; Pearson et al., 2002). The base metal sulfides (BMS), in the form of monosulfide solid solution (MSS) in mantle rocks, have compositions suggesting equilibrium with a sulfide melt (Craig, 1973) and commonly are interpreted as residual from partial melting (Lorand, 1987) or as crystallisation products of sulfide liquids trapped during partial melting (Mitchell and Keays, 1981). Studies of these mantle sulfides may provide critical constraints on metasomatic processes and the evolution of the lithospheric mantle (Aulbach et al., 2004; Griffin et al., 2002, 2004; Wang et al., 2003a,b, 2009).

It has been proposed that the Cathaysia Block, as part of the larger South China Block, was probably associated with western Laurentia when the supercontinent Nena (Gower et al., 1990) or Columbia (Rogers and Santosh, 2002) formed in Paleoproterozoic time (Li et al., 2008; Rogers and Santosh, 2002; Zhao et al., 2004). Until the Neoproterozoic supercontinent Rodinia formed and before it broke up, the Cathaysia Block was still located between Laurentia, Australia and probably Siberia (Li et al., 1995, 1996b). Although there is more evidence to clarify the location of the Cathaysia Block during the Neoproterozoic, poor exposure of early Proterozoic basement rocks makes it difficult to reconstruct its relationship with other cratons and blocks during that time. As a counterpart of crustal rocks to form the tectonic plate, lithospheric mantle should accompany the processes to assemble and breakup of a supercontinent. Thus, the evolution of the lithospheric mantle beneath the Cathaysia Block may record a similar tectonic history to the overlying crust.

In this study, we document and characterise major-element and Os isotopic compositions of mantle sulfides, describe an unusual suite of Co-rich sulfides, and present the noble gas compositions of the sulfide-bearing peridotites from the Penghu Islands, Taiwan. We propose a plume-related model for the formation of these sulfides and use their Os model ages to correlate them with known Proterozoic mantle plumes on supercontinents Nena/Columbia and Rodinia.

2. Geological background and sample description

The South China Block comprises the Yangtze craton in the northwest and the Cathaysian foldbelts (Cathaysia), including the Cenozoic mountain ranges of Taiwan, in the southeast (Fig. 1). The Yangtze craton has a late Archean-Paleoproterozoic (⩾1.7 Ga) nucleus surrounded by late Mesoproterozoic orogenic belts; the Cathaysia Block is generally considered to be floored by Paleo- to Mesoproterozoic continental crust (Chen and Jahn, 1998) although our studies (Wang et al., 2009) and other recent

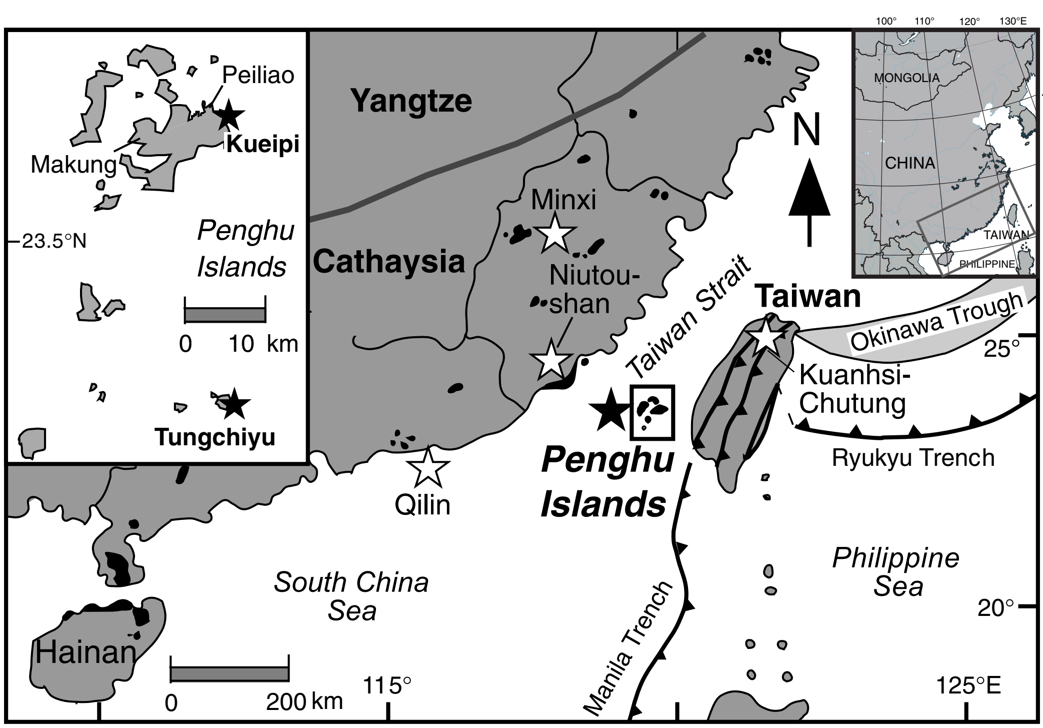

Fig. 1. Tectonomagmatic map of southeastern China. Black areas—late Cenozoic intraplate basalts; stars—localities of mantle xenoliths; solid star—locality of xenoliths in this study. Insets: main sample localities in the Penghu Islands and the regional map.