Helium and argon in ore fluids: so what?

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The isotopic composition of He and Ar trapped in crustal fluids and fluid inclusions carries a signature of the source of the fluids and the processes which have affected them. There are three distinct sources of the noble gases; atmosphere, crust and mantle. Atmospheric gases carried in groundwaters are characterised by the presence of ^{36}Ar and ^{40}Ar and minor amounts of helium (^{3}He/^{4}He = 1.39×10^{-6} = Ra). The crust is a source of radiogenic ^{40}Ar and ^{4}He, very low levels of ^{3}He (~0.01–0.05 Ra) and no ^{36}Ar. The prime signature of the mantle is helium with a high ^{3}He content (e.g. ^{3}He/^{4}He$_{MORB}$ ~ 8 Ra), together with ^{40}Ar and, in most situations, negligible ^{36}Ar (^{40}Ar/^{36}Ar $\geqslant$ 40,000). Fluids trapped in ore minerals frequently carry all three components (Stuart *et al.*, 1995).

We have investigated He and Ar isotopes, sometimes in combination with halogens, trapped in ore fluids from a variety of areas and types of mineralisation. Our aims have been to see what qualitative aspects of the mineralisation processes are reflected in noble gas patterns and to what extent these can be used to resolve conflicting interpretations, what aspects can be understood in a quantitative way, and whether these can be used, for example, to model the large scale features of specific ore deposits. In this report we contrast the He and Ar isotope observations from two widely separated porphyry-Cu deposits (PCD) with those from an MVT deposit. The Machangqing PCD deposit in West Yunnan province, China, is part of the Ailaoshan-Jinshajiang alkali-porphyry intrusive zone of Eocene age formed in an extensional setting. The mantle derived magmas intrude lower Ordovician microclastic rocks and Devonian limestone and appear to have assimilated some crustal material. The Sungun PCD is located in NW Iran and is associated with a series of calc-alkaline hypabyssal igneous intrusions of Oligo-Miocene age. The magma was emplaced in a continental margin tectonic setting related to the subduction and assimilation of the Persian plate during the major Alpine orogenic phase. The Sungun porphyries occur as stocks and dykes intruding a series of Oligocene dacitic breccias, tuffs and trachyandesitic lavas, Eocene arenaceous-argillaceous rocks, and Upper-Cretaceous limestones.

The He and Ar compositions of gases released by crushing sulphides from the two deposits are shown in Figs. 1 and 2. ^{40}Ar is the only isotope present in high abundance in all components and consequently this is the only method of representing all the data, end members and processes in a single figure.

Mixtures of three end members define a mixing plane, while elemental fractionation of He and Ar drive compositions radially from, and perpendicular to, the ASW axis. In both figures the data lie on 3-component mixing planes. The three end members are fluids enriched respectively in atmosphere (ASW), mantle helium and argon (labelled EARLY) and crustal helium (labelled LATE). The ^{3}He/^{4}He ratios, 1.2 Ra (Machangqing) and 2.25 Ra

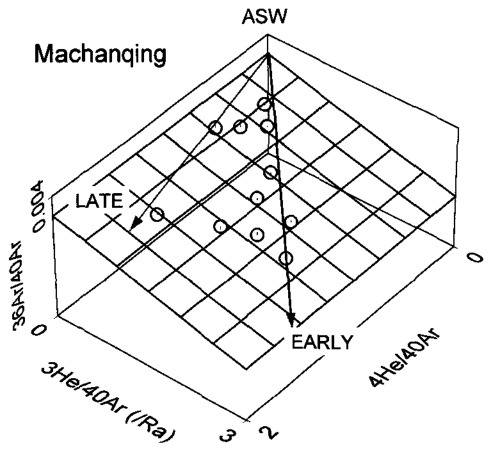

FIG. 1.

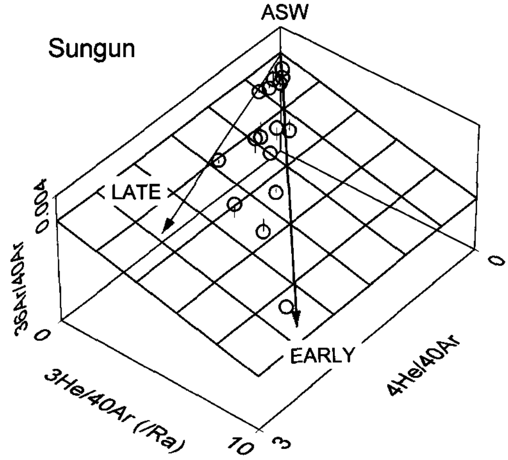

FIG. 2.

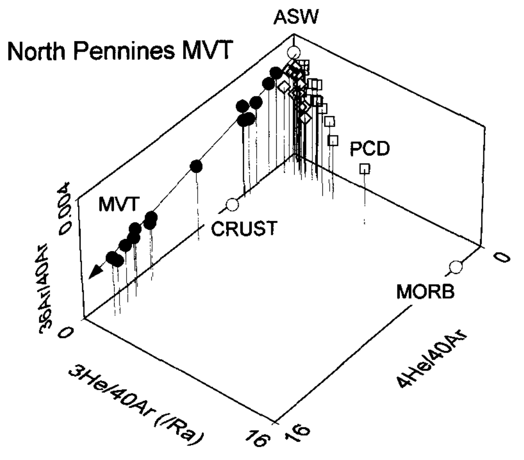

FIG. 3.

(Sungun) in the mantle enriched component, correspond to contributions of mantle ^{4}He of around 15% and 28% respectively. ^{40}Ar/^{4}He for the mantle end members are roughly comparable with estimated upper mantle production ratios of ~0.5. These compositions are assumed to represent the main mineralising fluids which have interacted with the intrusion. In contrast the components enriched in crustal helium are interpreted as later meteoric fluids which have acquired radiogenic ^{4}He from the crust. Radiogenic ^{40}Ar is virtually absent from this component (slope in ^{4}He/^{40}Ar–^{36}Ar/^{40}Ar plane ~ 0) as would be expected for fluids below the blocking temperature of argon but above that for helium. This crustal component is similar to that observed in fluids trapped in fluorite veins of the North Pennine Pb-Zn MVT mineralisation (Fig. 3)

Here the mineralising fluid is a low temperature gravity fed connate/meteoric brine devoid of mantle ^{3}He. As for the late PCD fluids, however, low temperatures have led to a very low ^{40}Ar/^{4}He ratio, 0.025, an order of magnitude less than the crustal production ratio of ~ 0.2 and an absence of mantle ^{3}He.

Can these observations be understood quantitatively? The key isotopes are ^{36}Ar, ^4He_C (crustal and ^4He_M (mantle). ^{36}Ar contents of sediments are characteristically of the order of 10^{-8} ccSTP/g (corresponding to contributions from ASW at the percent level). A typical ^{4}He concentration in a mantle melt, as characterised by MORB, is ~3×10^{-5} ccSTP/g. Crustal ^{4}He is the product of U and Th decay with a typical production rate (corresponding to 1 ppm U) of ~ 2×10^{-7} ccSTP/g. The lowest ^{36}Ar/^4He_C ratios for the mineralising fluids at all three deposits are close to 0.002. This would be generated by 25 Ma of ^{4}He production using the above figures, not unreasonable for Sungun, but too low for Machangqing and the North Pennines, possibly due to ^{4}He loss from the crust and an underestimate of the ^{36}Ar content of the country rocks. Estimates of the relative masses of mantle and crust sampled by the (PCD) mineralising fluids require a significant mantle contribution (13–25%). The requirement that the intrusion supply the heat necessary to raise the temperature of the surrounding mineralised crust by several hundred degrees would clearly require a mantle input of this order and explains why high R/Ra values appear to be a common feature of hydrothermal systems. The observation that ^{3}He/^{4}He ratios are uniform in these PCD (and other) systems over a wide area also implies that crust and mantle components were well mixed during the major mineralising phase.

On a global scale helium and heat fluxes are linked, both being the product of radioactive decay. The link is direct at mid ocean ridges, where both helium and heat are carried by hydrothermal fluids emerging from the oceanic crust (e.g. Turner and Stuart, 1992). In a continental intrusive setting, fluid rock ratios are much lower and helium flow and heat flow are decoupled, the former being transported by fluids, the latter by conduction in the solid rock. While this leads to a concentration of mantle helium into the fluids, proportional to the rock-fluid ratio, we anticipate that on the scale of the mineralised system as a whole, the helium/heat ratio for the mantle component would be comparable to the global value.