Origin of alunite- and jarosite-group minerals in the Mt. Leyshon epithermal gold deposit, northeast Queensland, Australia—Discussion

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Using the spatial distribution and composition of alunite-group minerals from surface samples, Scott (1990) has argued that the Mount Leyshon gold deposit in northeastern Queensland formed in an acid-sulfate epithermal system related to a Permian volcanic complex. We maintain that Scott has failed to recognize direct geological and isotopic evidence showing that alunite-group minerals at Mount Leyshon formed during Plio-Pleistocene weathering of a Permian magmatic complex and that he has also overlooked ambiguities in some earlier Rb-Sr isotopic work.

DISTRIBUTION OF ALUNITE-GROUP MINERALS

Scott (1990) has used surface traverse sampling to infer the distribution of alunite- and jarosite-group minerals at Mount Leyshon. Detailed surface mapping and logging of drill core (Morrison et al., 1987) provide a three-dimensional pattern that shows the distribution of alunite and jarosite (Scott, 1990, his Fig. 2) is limited to an area containing erosional remnants of a tabular oxidation blanket up to 60 m thick that is underlaid by sulfide-rich rocks. The oxidation blanket is zoned with widespread alunite at the base, through jarosite, goethite, and limonite, to hematite at the surface.

At Mount Leyshon proper, the alunite-bearing oxidation zone is underlaid by the main sulfide ore body, which is a breccia with up to 5% pyrite together with copper, lead, zinc, and bismuth sulfides in cavities and veins. The adjacent unmineralized area, centered on Mount Mawe, is underlaid by shattered basement rocks and porphyry intrusions with up to 2% pyrite that is part of a pervasive quartz-sericite-pyrite alteration zone. All the samples of alunite-group minerals with anomalous concentrations of Ag, Bi, Cu, and Pb come from areas underlaid by sulfide mineralization and not from areas underlaid by sulfide-bearing alteration zones (cf. Scott, 1990, p. 1177–1178). Similarly, Au occurs throughout the oxidation profile, including the alunite-rich zone, but only where there is underlying Au-bearing sulfide mineralization. There is, thus, only a limited and coincidental relationship between the distribution of mineralization and alunite-group minerals.

In the breccia ore body at Mount Leyshon, white porcellanous alunite occurs in a transition zone 4 m thick between sulfide and oxide ore infilling cavities derived from dissolution of hydrothermal carbonate. Rims of chalcocite and covellite occur on pyrite grains (cf. Scott, 1990, Fig. 3), and copper carbonates fill cavities in this zone. These features and the overall enrichment of Cu in this zone are typical of the supergene enrichment blanket formed at or beneath the water table during weathering of many Cu-bearing sulfide ore bodies (Blanchard, 1968). In the barren alteration zone at Mount Mawe, alunite replaces disseminated pyrite and silicate minerals, particularly feldspar. At Mount Leyshon and Mount Mawe, the alunite is extensively replaced by jarosite and goethite. The presence of alunite represents the first stage in the oxidation of sulfide-rich rocks and not a separate hydrothermal episode.

STABLE ISOTOPE EVIDENCE FROM ALUNITES

Scott (1990) refers to only a small part of the published S and H isotopic data on alunite-group minerals from Mount Leyshon (Bird et al., 1989). S isotope values of alunite-group minerals and gypsum from Mount Leyshon show a small range of values ($\delta^{34}S$ = 8.0–9.8; Bird et al., 1989) that overlap or are slightly enriched in ^{34}S, compared with pyrite from the underlying ore ($\delta^{34}S$ = 4.9–8.8; Morrison et al., 1988). The enrichment in ^{34}S of up to 2.5‰ can be readily explained by the small positive fractionation between dissolved sulfate on one hand and alunite or gypsum on the other or the addition of a small component of contemporary sea water sulfate during the weathering of the sulfides.

Alunite-group minerals from Mount Leyshon are strongly enriched in D (δD = −29; Bird et al., 1989) relative to minerals of known hydrothermal origin formed in equilibrium with meteoric H_2O in acid-sulfate deposits of similar age from eastern Australia (e.g., Ashley and Andrew, 1992) but are similar to their contemporary lo-

cal meteoric H_2O ($\delta D = -34$; Bird et al., 1989). That is, the δD values are consistent with isotopic equilibration with contemporary meteoric H_2O, and there is no evidence for the involvement of Permo-Carboniferous meteoric component that would be highly depleted in D.

DATING OF ALUNITES

K-Ar ages of 2.3 to 3.1 Ma for Mount Leyshon (Bird et al., 1990) give direct evidence for a weathering origin. However, Scott (1990) has cited some Sr isotopic data in support of his argument that much of the alunite is hypogene rather than supergene, and he suggested the K-Ar systematics were affected by weathering. Although the Sr isotopic data from one sample can be interpreted as retaining an old age (Whitford et al., 1988), other data from Mount Leyshon are more difficult to reconcile with the hypogene model.

Rb-Sr isotopic data summarized by Whitford et al. (1988) as part of a broader investigation of alunite in the Australian regolith and referred to by Scott (1990) are listed in Table 1. Except for sample LEY 5c, all the alunites are isotopically similar, with measured $^{87}Sr/^{86}Sr$ ratios ranging from 0.730 to 0.751. Concentrations of Rb and Sr are variable. Two of the samples are strongly enriched in Sr and relatively depleted in Rb, resulting in very low Rb/Sr ratios. Sample LEY 5c, a natroalunite, is characterized by a high $^{87}Sr/^{86}Sr$ ratio and a high Rb/Sr ratio, suggesting some geochronological potential in a manner analogous to the determination of an age from mica (Whitford et al., 1988). An age of 216 Ma has been calculated using samples LEY 5c and 104389, and an age of 255 Ma has been calculated using sample LEY 1a. The former is Mesozoic and the latter Upper Permian. Notwithstanding the errors on such calculated ages, both are unreasonably young compared with K-Ar ages of 281 and 280 Ma for muscovite in the hydrothermal alteration zone at Mount Leyshon (Morrison, 1988). Furthermore, there is also no a priori reason to justify calculating such two-point isochrons, especially as the analyzed alunites have not been in isotopic equilibrium with each other, given their presently observed Rb/Sr ratios.

Contrary to Scott's interpretation, the K-Ar age may well be correct (Bird et al., 1990). If so, the usual isotopic character of sample LEY 5c would reflect a very high initial $^{87}Sr/^{86}Sr$ ratio at the time of weathering. Sample LEY 5c is a natroalunite derived from a weathered vein that was clearly related to mineralization at Mount Leyshon. It is not clear if its unusual isotopic character, caused by its high Rb/Sr ratio, is common to all natroalunites, or if it reflects the special conditions prevailing during the formation of this particular sample. If the Rb and Sr presently contained in the alunite were derived from local K-rich micas and feldspars that were enriched in radiogenic ^{87}Sr since mineralization, relatively recent alunite formation in response to weathering could result in a very high initial ratio.

The initial $^{87}Sr/^{87}Sr$ ratios also provide constraints on models of alunite genesis at Mount Leyshon. Except for

TABLE 1.   Mount Leyshon and Kidston alunites: Rb-Sr isotopic results

Location/ sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$ $\pm 2\sigma_m$	$^{87}Sr/^{86}Sr$ $\pm 2\sigma_m$
Mount Leyshon				
LEY 1a	157	76.6	5.97	0.74266 ± 6
LEY 5c	49.4	3.14	46.3	0.88903 ± 46
104389	28.8	62.1	1.34	0.75085 ± 6
Kidston				
KID 1f	13.7	818	0.0486	0.73043 ± 6
KID 1h	10.9	641	0.0496	0.73771 ± 6
KID 1j	24.0	81.2	0.860	0.74240 ± 6

Note: $^{87}Sr/^{86}Sr$ ratios have been normalized to $^{86}Sr/^{88}Sr = 0.1194$. Repeated analyses of E and A ($n = 70$) yield $^{87}Sr/^{86}Sr = 0.708035 \pm 64$ (2σ). Samples analyzed on a VG54E single collector mass spectrometer conducted in automated mode. Rb and Sr concentrations determined by isotope dilution mass spectrometry. Sample numbers as for Bird et al. (1990), except for 104389 (4389 in Scott, 1990).

sample LEY 5c and, to a lesser extent, sample LEY 1a, measured $^{87}Sr/^{86}Sr$ ratios are close to their initial $^{87}Sr/^{86}Sr$ ratios irrespective of the age of the alunite. The initial $^{87}Sr/^{86}Sr$ ratios of 0.72–0.75 are high when compared with most crustal samples. More importantly, they are considerably higher than those of upper Paleozoic volcanic and related intrusive rocks from the Georgetown–Mount Garnet–Herberton areas of North Queensland, which are characterized by initial ratios of 0.707–0.717 (Black, 1974), and higher than those of basement granitoids near Mount Leyshon, which have initial ratios of 0.7053–0.7054 (Wyatt et al., 1971). If the alunite were primary, the Sr in the alunite would have to be derived, at least in part, from Sr derived from a source external to the local volcanic complex and the immediate basement rocks. Such a model is not supported by stable isotope results, which imply that mineralization is purely magmatic. On the other hand, if the alunite were derived by relatively recent weathering of preexisting K-rich phases in the primary alteration zone related to the mineralization, high initial $^{87}Sr/^{86}Sr$ ratios would be expected.

DISCUSSION

Scott (1990) considers Mount Leyshon an epithermal deposit of the acid-sulfate type, using as a basis an inferred association of Au with alunite and kaolinite, the Cu-rich character of the deposit, the presence of bismuthinite, the replacement of potassium feldspar by alunite, and general comparison with the models of Hayba et al. (1986) and Stoffregen (1987). Studies of the geology and geochemistry of the deposit (Morrison et al., 1987, 1988; Wormald et al., 1991; Hodkinson and Kay, 1991) are not consistent with this interpretation.

There is no specific relationship between Au mineralization and alunite- or kaolinite-bearing rocks at Mount Leyshon. Alunite-bearing rocks are widespread outside the mineralized zone, and within the mineralized zone only contain ore when they directly overlie sulfide ore.

A section of the ore body up to 4 m thick is enriched with secondary Cu minerals in the alunite zone, but the bulk of the ore body is in the sulfide zone, which is several

hundred meters thick and has a polymetallic character (Zn-Pb-Cu-Bi-Mo-Ag-Au). All these elements are anomalous in the mineralized part of the alunite zone and, apart from Cu, have similar relative abundances to the underlying sulfide ore. A Bi-Au association is recognized in the sulfide ores at Mount Leyshon (Morrison et al., 1987) and is typical of the porphyry-type deposits at Kidston, Red Dome, and numerous other Permo-Carboniferous Au occurrences in north Queensland (Morrison, 1988). None of the known Permo-Carboniferous epithermal deposits, including some of acid-sulfate type, has this geochemical association (G. Morrison, unpublished data).

Typical acid-sulfate deposits have Au associated with pyrite and enargite that coexist with quartz and alunite. Au is also found in structurally controlled pods of quartz mantled by kaolinite and commonly in pyrophyllite-diaspore alteration (Hayba et al., 1986; Stoffregen, 1987). At Mount Leyshon, alunite and kaolinite are a minor part of a zoned oxide blanket in which alunite replaces sulfides and in which there is no enargite, replacement silica, or pyrophyllite-diaspore alteration.

In addition, the geological and geochemical observations at Mount Leyshon (Morrison et al., 1988) do not support an acid-sulfate epithermal environment of mineralization. The association of porphyritic intrusions, stockwork Cu-Mo veinlets, potassic-sericitic alteration, and a Zn-Pb-Cu-Bi-Mo-Ag-Au element, high fluid-inclusion temperatures and salinities, and magmatic O isotope signatures for all the stages of mineralization suggests a porphyry environment and a predominantly magmatic ore fluid. Alunite formed from a magmatic vapor plume would be characterized by a $\delta^{34}S$ signature significantly enriched in ^{34}S compared with sulfides, a Permian age, and H isotope values unrelated to the δD value of contemporary meteoric H_2O (Hayba et al., 1986). None of these isotopic features typifies Mount Leyshon alunites.

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