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

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The paper by Scott (1990) sought to reconcile apparently conflicting data about surficial alunites at the Mount Leyshon deposit. Critical features were a weathering age of 2–3 m.y. determined by K-Ar methods (Bird et al., 1987, 1990) and a Permian age determined from Rb-Sr data (Whitford et al., 1988). In their discussion of my paper, Andrew et al. (1992) have restated their belief that all the alunite at Mount Leyshon is secondary and, by reassessing the Rb-Sr data on alunites at the deposit, concluded that ages cannot be accurately determined from such data. Thus they maintain that the variable compositions of alunites at Mount Leyshon are simply the result of the weathering of a zoned alteration system.

Study of unweathered material suggests that the Au is associated with quartz, chlorite, sericite, carbonate, and sulfide assemblages (Morrison et al., 1987; Wormald et al., 1991). Sulfide contents (pyrite and base metals and bismuth sulfides) are up to 5% at Mount Leyshon proper but are generally less than 2%, and include only pyrite, in the surrounding areas. Weathering, according to Andrew et al. (1992), produced a blanket up to 60 m thick and zoned vertically from alunite through jarosite to hematite at the surface. They consider that the base metals and Bi contents found in alunites from the surface at Mount Leyshon represent metals freed during weathering of the sulfides (as also considered by Scott, 1990). However their model also requires that the Na present in natroalunite at the surface in the Mount Leyshon–Mount Hope area is derived from preexisting hydrothermal alteration minerals during weathering. Such a derivation requires "an unusual fluid composition with a particularly high Na/K ratio" (Bird et al., 1989). Of the hydrothermal minerals observed at depth, quartz, chlorite, sericite, carbonate, potassium feldspar, and biotite (the last two being associated with an early formed Cu-Mo stockwork rather than with Au; Morrison et al., 1987), none is capable of providing a Na-rich fluid during weathering. Detailed electron microprobe work has shown, however, the presence of albite as inclusions in pyrite in material at the base of the alunite zone within the open pit. This suggests that Na was available at the time of alteration and mineralization, i.e., Na was available to form hypogene alunites.

Examination of the alunite surrounding weathering pyrite reveals a void about the pyrite, jarosite replacement of alunite, and Fe = 0.34 mol in the residual alunite (sample 4229; Scott, 1990, his Fig. 6). However, in sample 4389 where pyrite is unweathered, it is in direct contact with alunite with only 0.10 mol Fe (Scott, 1990, his Fig. 3). Thus weathering of pyrite associated with alunite seems to result in the incorporation of additional Fe into the alunite structure. Subsequent to the initial study of surficial alunites, three samples from the base of the alunite zone were analyzed. These are composed mainly of alunite, kaolinite, muscovite-illite, quartz, pyrite, and supergene copper sulfides. The alunites are generally potassian natroalunite or sodian alunite (i.e., Na-rich), with low Fe and base metal contents (Table 1). No jarosite was observed, and the pyrite is euhedral. Despite the location of these samples in the transitional zone between sulfide and oxide ore, none of the above features is inconsistent with an initial hypogene origin for the alunite.

Sample 109945 also contains calcian alunite (intimately associated with pyrite, Fig. 1) and potassian woodhouseite (intimately associated with digenite, Fig. 2). These Ca- and P-rich compositions are consistent with formation by the destruction of apatite under advanced argillic alteration conditions (cf. Stoffregen and Alpers, 1987). Such Ca- and P-rich material was invoked as the hypogene material from which plumbogummite and

Table 1. Composition of alunite-group minerals ~60 m below the original surface, Mount Leyshon

Sample	No. of analyses	A site			B site					(XO_4) sites		(OH)	Name
		Na	K	Ca	Sr	Al	Fe	Cu	Zn	SO_4	PO_4		
109943	8	0.51	0.24	0.02	0	2.96	0.03	0.01	0	1.95	0.05	5.73	potassian natroalunite
	2	0.53	0.25	0.07	0.01	2.96	0.02	0	0.01	1.90	0.10	5.80	potassian natroalunite
109944	12	0.63	0.14	0.02	0	2.93	0.05	0.01	0	1.97	0.03	5.74	potassian natroalunite
109945	12	0.29	0.54	0.06	0	2.87	0.05	0.01	0.01	1.88	0.12	5.63	sodian alunite
	4	0.05	0.72	0.13	0	2.92	0.07	0.01	0	1.68	0.32	5.70	calcian alunite
	2	0.07	0.47	0.32	0.01*	2.89	0.04	0.07**	0	1.43	0.57	5.58	potassian woodhouseite

* Also contains 0.01 Ba.
** Possibly high because of its intimate association with digenite (see Fig. 2).

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Fig. 1. Calcian alunite (gray) associated with pyrite (white) in matrix of sodian alunite (mottled gray). (BSE image, sample 109945.) Scale bar ≡ 100 μm.

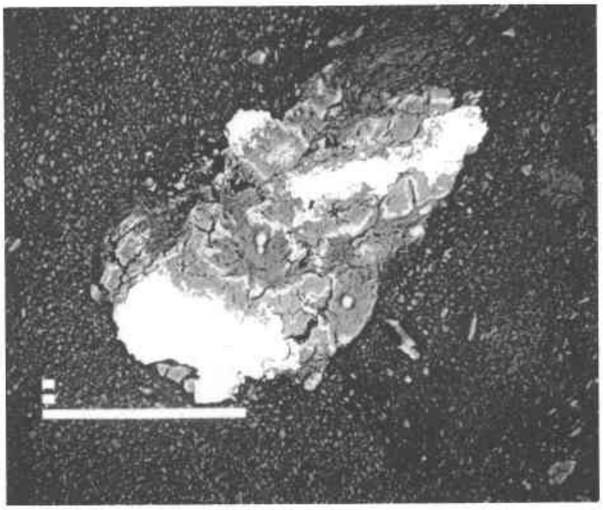

Fig. 2. Digenite (white) associated with potassian woodhouseite (gray) in matrix of sodian alunite (mottled gray). (BSE image, sample 109945.) Scale bar ≡ 100 μm.

hinsdalite formed during weathering at Mount Leyshon (Scott, 1990). Furthermore, X-ray diffractometry suggests that this sample may contain pyrophyllite—a mineral that generally forms at greater depth and higher temperature than alunite (Stoffregen and Alpers, 1987). If this occurrence can be confirmed, its presence at the base of the alunite zone would be significant, and it certainly should be searched for at deeper levels of the deposit.

Of the three isotopically analyzed samples from Mount Leyshon, one (4389) contains pyrite and alunite with the S of the alunite being marginally isotopically heavier than that of the pyrite. Using the S isotopic and Rb-Sr data, I argued that this alunite formed by oxidation of H_2S at the water table (cf. Hayba et al., 1986). Now that the work of Andrew et al. (1992) has discredited Rb-Sr ages at Mount Leyshon, there is clearly a need for more age and H isotope data on such pyritic-alunite samples. The other two isotopically analyzed samples have undoubtedly been affected by weathering, but the K-Ar age and δD data on these two samples do not distinguish between (1) derivation by weathering of hypogene alunite and (2) formation of alunite exclusively by weathering of sulfides. As one of these samples is compositionally natroalunite (Bird et al., 1989), I would suggest, on the basis of the arguments above, that it was initially formed under hypogene conditions and subsequently isotopically modified during weathering, i.e., compositional data can potentially resolve such problems.

Although the work of Andrew et al. (1992) removes age data that were consistent with my contention that most alunites at Mount Leyshon were originally hypogene and often affected by subsequent weathering (Scott, 1990), they have presented no new isotopic data to convince me otherwise.

Their model implies that, if all the alunite at the deposit were secondary, the Na-rich material would directly underlie the Mount Leyshon–Mount Hope area. However, they have not given any indication of the source of the Na that is present in many of the alunites. Experimental studies indicate that natroalunite with $Na/K \geq 2$ (Table 1) forms from solutions with $Na/K \geq 9$ (Parker, 1962). Such sodic solutions can exist when albite is being altered under conditions of advanced argillic alteration. However, when the rocks are dominated by muscovite after alteration, such sodic material is not available to weathering solutions. Even in the highly saline groundwaters in the oxidized zone in the Eastern Goldfields of Western Australia, alunites formed during weathering have only $Na/K \leq 0.6$ (Scott, unpublished data).

Clearly, additional mineralogical characterization of the deposit (including looking for pyrophyllite at depth) is needed to resolve unanswered questions about the alunite. Further K-Ar and δD data on alunite from alunite-pyrite veins may also help. In the absence of such data, I am not convinced that my original hypothesis has been disproved by Andrew et al. (1992).

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