

Minerals of the Queen Sally Mine, North-west Queensland

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Abstract: The Queen Sally deposit is located near Kajabbi, north-west Queensland. Primary cobalt mineralization comprises cobaltite and glaucodot, an assemblage that is consistent with a hydrothermal origin, possibly associated with the emplacement of the nearby Naraku granite. Oxidized cobalt mineralization consists of cobaltian calcite, erythrite and heterogenite-2H, which is unusual in that it carries up to 2.2% by weight of vanadium. Oxidation of V^{3+} in the lattice to V^{4+} may explain an early report of "blue" erythrite in the oxidized zone of the deposit.

INTRODUCTION

The Queen Sally cobalt deposit, discovered in 1922 (Anon., 1923), is situated (54411280E 7779010N) near Sally Creek, a tributary of Cabbage Tree Creek, some 4 km east of the now abandoned Cloncurry-Dobbyn railway line and approximately 13 km south-east of Kajabbi, north-west Queensland. It is one of only three mines (together with Mount Cobalt and the Success) to have recorded production of cobalt in the Mt Isa Block (Carter et al. 1961). There is little mention of the mineralogy of the Queen Sally deposit in the literature but Rayner (1938) reported the occurrence of erythrite, cobaltite, malachite, azurite, chrysocolla and a cobaltiferous "black oxide." We have had occasion to re-examine the deposit, as part of a more extensive study of the geochemistry of cobalt in the Mt Isa Block.

GEOLOGY

The ore deposit occupies a sub-vertical shear striking 155° in foliated quartzite adjacent to a narrow limestone bed, associated with cross-cutting acid pegmatite veins (quartz + orthoclase + tourmaline). Hornblende schists surround these units, and these are intruded by granite to the east and north-east (Rayner, 1938). Mine workings consist of two shafts c. 20 m deep and several shallow pits.

Primary mineralisation is confined to the pink and green stained foliated quartzite, which is well exposed in the northern shaft, and erythrite is common on a nearby cobbling floor. Quartzite on the dump carries a considerable amount of calcite, some of which is cobaltian. Careful examination of the dumps revealed an abundance of heterogenite in oxidized material and the quartzite on the dump around the southern shaft carries patches of gossan associated with scorodite, erythrite and minor secondary copper minerals.

ANALYTICAL METHODS

Polished sections of primary mineralisation and material bearing crystalline heterogenite were inspected by reflected light microscopy and then carbon coated and analysed using a JEOL JXA-8600 electron microprobe, with a beam current of 20 nA. Three wavelength dispersive spectrometers, controlled by JEOL software, and an energy dispersive spectrometer controlled by Moran Scientific software were employed for the analyses, which were calibrated against kaersutite, marcasite and pure metal standards. X-ray powder diffraction measurements were used to identify individual phases and were carried out with a Philips PW1925-20 powder diffractometer using $CuK\alpha$ radiation.

MINERALOGY

A list of all minerals identified in the deposit is given in Table 1. Some of the occurrences and assemblages are worthy of separate comment.

PRIMARY MINERALS

Cobaltite (analysis 3, Table 2) and related sulfosalts are the most common primary metalliferous minerals. Cobaltite, which occurs massive, in stringers and veins and as disseminated euhedral grains, is commonly associated with chalcopyrite, pyrrhotite (inclusions of which in cobaltite carry some 0.8% Co; analysis 13, Table 2), arsenopyrite, pyrite and glaucodot. Disseminated pyrite crystals are embedded in arsenopyrite and cobaltite, and pyrite is an early formed mineral (as judged by textural relationships), that contains only minor amounts of Co. Covellite carrying trace amounts of Co (analysis 15, Table 2) and chalcocite invade fractures in the primary sulfides where they have been supergene enriched. Fine-grained glaucodot commonly fills cracks in cobaltite and pyrrhotite. The arsenopyrite (analysis 6, Table 2) carries only a trace of cobalt. Chalcopyrite occurs as crystals up to 2 mm across in the foliated quartzite, in veins, as inclusions in cobaltite, and in association with pyrrhotite, included galena blebs and veinlets and disseminated subhedral to euhedral 40 micron crystals of low-iron sphalerite. Analyses of chalcopyrite (analyses 1 & 2, Table 2) indicate at least two generations of mineralisation, one carrying higher amounts of Co than the other. Negligible amounts of Ni are present in this or any other analysed phase. Pyrrhotite inclusions in cobaltite are associated with chalcopyrite and glaucodot. Early molybdenite crystals embedded in cobaltite reach 20 microns in size.

This assemblage is indicative of mesother-

mal to hypothermal regimes (Park and MacDiarmid, 1970; Vaughan and Craig, 1978), and is consistent with the geological setting. Further, the primary mineralisation is compatible with acid hydrothermal activity, in common with other related deposits of the eastern section of the Mt Isa Block (Nisbet et al. 1983; Wyborn, 1998) and points to the nearby Naraku granite of the Eastern Fold Belt (Perkins and Wyborn, 1998) as the source of the metals. Some of the accessory minerals identified in the lode lend support to this kind of origin, as does the composition of the pegmatite intrusions nearby (Rayner, 1938).

Analyses of cobaltite and glaucodot (analyses 3-5, Table 2) reinforce a number of these conclusions. Two generations of glaucodot are clearly represented in the deposit and both are compatible with temperatures of crystallisation of around 400-500°C, by reference to the geothermometer developed by Klemm (1965), whereas cobaltite analyses suggest a lower temperature of formation of around 200°C. Several pulses of primary mineralization occurred.

ERYTHRITE

Erythrite is the most conspicuous secondary mineral in the deposit and occurs as crusts of acicular crystals to 10 mm on quartzite and heterogenite. Of particular interest is the oxymoron report of "an earthy blue mineral simulating azurite . . . it is an unusual form of the ordinary pink hydrous arseniate (erythrine)" from the Queen Sally (Saint-Smith, 1925). No material fitting such a description was identified. Dehydration of erythrite gives a blue product (Palache, et al. 1951) and it is perhaps possible that this was the origin of the earthy blue mineral noted by Saint-Smith. However, analyses of heterogenite suggest a more plausible explanation (see below).

A. Primary rock-forming and accessory minerals	
Albite	$\text{NaAlSi}_3\text{O}_8$
Allanite	$(\text{Ce,Ca,Y})_2(\text{Al,Fe})_3(\text{SiO}_4)_3(\text{OH})$
Biotite	$\text{K}(\text{Mg,Fe}^{2+})_3(\text{Al,Fe}^{3+})\text{Si}_3\text{O}_{10}(\text{OH,F})_2$
Calcite	CaCO_3
Epidote	$\text{Ca}_2(\text{Fe,Al})_3(\text{SiO}_4)_3(\text{OH})$
Fluorapatite	$\text{Ca}_5(\text{PO}_4)_3\text{F}$
Orthoclase	KAlSi_3O_8
Quartz	SiO_2
Rutile	TiO_2
Titanite	CaTiSiO_5
Zircon	ZrSiO_4
B. Primary metallic minerals	
Arsenopyrite	FeAsS
Chalcopyrite	CuFeS_2
Cobaltite	CoAsS
Galena	PbS
Glaucodot	$(\text{Co,Fe})\text{AsS}$
Molybdenite	MoS_2
Pyrite	FeS_2
Pyrrhotite	FeS
Sphalerite	$(\text{Zn,Fe})\text{S}$
C. Secondary minerals	
Azurite	$\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$
Chalcocite	Cu_2S
Conichalcite	$\text{CaCu}(\text{AsO}_4)(\text{OH})$
Copper	Cu
Covellite	CuS
Erythrite	$\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$
Goethite	$\text{FeO}(\text{OH})$
Hematite	Fe_2O_3
Heterogenite-2H	$\text{CoO}(\text{OH})$
Malachite	$\text{Cu}_2(\text{CO}_3)(\text{OH})_2$
Scorodite	$\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$

Table 1: Minerals of the Queen Sally deposit, with idealised formulae.

	1	2	3	4	5	6	7	8
As	< 0.05	< 0.05	43.7	51.0	46.6	45.1	45.16	
S	34.8	34.4	20.1	16.1	17.1	19.9	19.32	34.94
Fe	29.5	29.2	1.3	25.5	15.1	34.2		30.43
Co	< 0.05	1.6	34.1	9.2	20.1	0.1	35.52	
Ni	< 0.05	< 0.05	0.3	< 0.05	0.2	< 0.05		
Cu	34.7	33.3	< 0.05	< 0.05	< 0.05	< 0.05		34.63
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		
Zn	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		
Total	99.0	98.5	99.5	101.8	100.1	99.3	100.00	100.00
	9	10	11	12	13	14	15	16
As	< 0.05		< 0.05		< 0.05		< 0.05	
S	32.3	32.90	54.0	53.45	38.3	36.47	30.1	33.54
Fe	2.4		46.7	46.55	59.4	63.53	0.5	
Co	0.1		0.2		0.8		0.2	
Ni	< 0.05		< 0.05		< 0.05		< 0.05	
Cu	0.7		< 0.05		< 0.05		70.3	66.46
Sb	< 0.05		< 0.05		< 0.05		< 0.05	
Zn	64.3	67.10	< 0.05		< 0.05		< 0.05	
Total	99.8	100.00	100.9	100.00	98.5	100.00	101.1	100.00

Table 2: Analyses of primary ore minerals (wt%), Queen Sally mine. 1: Low-Co chalcopyrite, average of three analyses; 2: high-Co chalcopyrite, average of two analyses; 3: cobaltite, average of 16 analyses; 4: high-Fe glaucodot; 5: low-Fe glaucodot, average of 5 analyses; 6: arsenopyrite, average of 5 analyses; 7: calculated for CoAsS; 8: calculated for CuFeS₂; 9: sphalerite, average of two analyses; 10: calculated for ZnS; 11: pyrite, average of nine analyses; 12: calculated for FeS₂; 13: pyrrhotite, average of two analyses; 14: calculated for FeS; 15: covellite; 16: calculated for CuS. Values denoted as < 0.05 are not included in totals.

HETEROGENITE-2H

Heterogenite-2H (confirmed by X-ray diffraction) is very common in the dump and occurs as earthy slugs, masses and coatings, veins and stringers, as well as aggregates of plates up to 3 mm across; it was one of the main Co ore minerals of the deposit (Rayner, 1938). Microprobe analyses (Table) gave an Fe₂O₃ content of no more than 0.6% in the heterogenite, but analyses of crystalline heterogenite revealed unusually high V₂O₃ contents, up to 3.2% by weight. No other phase was detected by X-ray powder diffraction and thus it is concluded that the

vanadium is substituted in the heterogenite lattice. Montroseite (VO(OH)), paramontroseite (VO₂) and goethite (FeO(OH)) are isomorphous, space group *Pbnm*, while heterogenite-2H is hexagonal, space group *P6₃/mmc* (Anthony et al. 1997). While the structures of the CoO(OH) and VO(OH) end-members of the solid solution are different, there is no chemical reason which would serve to prohibit the substitution of some vanadium in the heterogenite lattice. We do not know the origin of the vanadium, and the geochemical association is unusual, although not unprecedented in the Mt Isa Block (Wyborn, 1998).

	1	2	3
Co ₂ O ₃	86.6	86.4	90.20
Fe ₂ O ₃	0.6	0.4	
V ₂ O ₃	2.7	3.2	
H ₂ O (by difference)	10.1	9.8	9.80
Total	100.0	100.0	100.00

Table 3. Analyses of crystalline heterogenite, Queen Sally mine.

1: Heterogenite; idealised formula (Co_{0.960}V_{0.033}Fe_{0.007})_{Σ1.000}O(OH);

2: Heterogenite; idealised formula (Co_{0.957}V_{0.039}Fe)_{Σ1.000}O(OH);

3: calc. for CoO(OH).

Oxidation of low-iron montroseite involves oxidation of V³⁺ to V⁴⁺ accompanied by replacement of OH⁻ by O²⁻ to form blue paramontroseite (Forbes and Dubessy, 1988). Thus it seems possible that the earthy blue material mentioned by Saint-Smith (1925) was a surface coating of paramontroseite formed as a oxidation product of vanadium-rich heterogenite.

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