

# MINERALOGY OF THE SILVER KING DEPOSIT, OMEO, VICTORIA

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**ABSTRACT:** The Silver King mine (also known as Forsyths) operated very intermittently between about 1911 and the late 1940s on Livingstone Creek, near Omeo, in northeastern Victoria. The deposit consists of six thin and discontinuous quartz lodes that are variably mineralised. Assays of up to 410 ounces of silver per ton were obtained but there are only a few recorded production figures. Examination of representative ore samples shows that the main silver-bearing minerals in the primary ore are pyrrargyrite, freibergite, andorite and the rare sulphosalt zoubekite, which occur irregularly with pyrite, arsenopyrite, galena and sphalerite. Phase assemblage data indicate that crystallisation occurred over an interval from about 450°C to less than 250°C, with the silver-bearing minerals crystallising at the lowest temperatures. The lodes were formed by the emplacement of hydrothermal solutions into fractures within the Ensay Shear Zone during the Early Devonian Bindian Orogeny. There are similarities in mineralisation and timing of emplacement between the Silver King lodes and the quartz-reef-hosted Glen Wills and Sunnyside goldfields 35–40 km north of Omeo.

**Keywords:** Silver King mine, Omeo, Victoria, hydrothermal, pyrrargyrite, freibergite, andorite, zoubekite

While silver is found in varying proportions alloyed with gold across Victoria, no deposits have been economically mined purely for their silver contents alone. About thirty deposits have been listed as ‘silver-bearing’ in Victoria (Weston 1992), but in only a few have any of the main silver-bearing minerals been identified. These include the gold–silver reefs at St Arnaud in western Victoria and the Glen Wills and Sunnyside goldfields in the northeast.

The Silver King deposit near Omeo is one of those for which limited studies on the ore mineralogy have been undertaken, even if these were not published in a cited journal. Stillwell (1933, 1946) identified pyrrargyrite as the main mineral responsible for high silver contents in the ore, occurring with other sulphide minerals, including ‘tetrahedrite’ and a mineral with optical and chemical properties that resembled lengenbachite (Stillwell 1946). The likelihood of additional silver-bearing phases being present has triggered the current investigation, which may also place the mineralisation in a regional context that includes the silver-bearing assemblages in the Glen Wills and Sunnyside goldfields north of Omeo (Birch 1981, 1992).

## LOCATION AND HISTORY OF DISCOVERY

Quartz veins containing sulphide minerals were discovered by Mr G.W. Forsyth in about 1911, some 5 km south of Omeo, in the Parish of Cobungra, County Benambra, in eastern Victoria (Easton 1936). The veins were exposed in allotment 114, on the steep eastern bank of Livingstone

Creek. Samples submitted by Mr Forsyth to the Geological Survey laboratory for assay yielded grades of up to 410 ounces of silver per ton, as well as gold, so a lease was taken up under the title the Auro-Argentum mine. During further prospecting in 1912, another similar deposit, named the Comstock silver lodes, was discovered about 2 km southeast of Forsyths, close to Three Mile Creek, a small tributary of Livingstone Creek (Kenny 1948) (Figure 1).

In 1913 the Victoria River Shale Oil Company was offered an option to work the Forsyth deposit. However, after tunnelling revealed the discontinuous nature of the mineralisation, the manager, Mr James Hallahan, told a shareholders’ meeting in January 1914 that he could not recommend taking up the option at the price offered (*Bruthen and Tambo Times*, Wednesday 21 January 1914). Further work and a more modest price were to be considered. In about 1916, Mr Forsyth sent some 12 tons of ore for treatment to the Cockles Creek Sulphide Corporation for an average yield of around 100 ounces of silver per ton (Easton 1936).

By the early 1920s, the lease (ML 4661) had been renamed the Silver King mine and six roughly parallel lodes had been recognised, two of which (Nos. 1 and 4) had been accessed by adits and a shallow opencut (Easton 1936) (Figures 2 and 3). A water race had also been constructed from Three Mile Creek to the mine site. Most work centred on the westernmost No. 4 lode, which was the longest and best defined. In his report, based on an inspection in October 1923, Easton considered that the

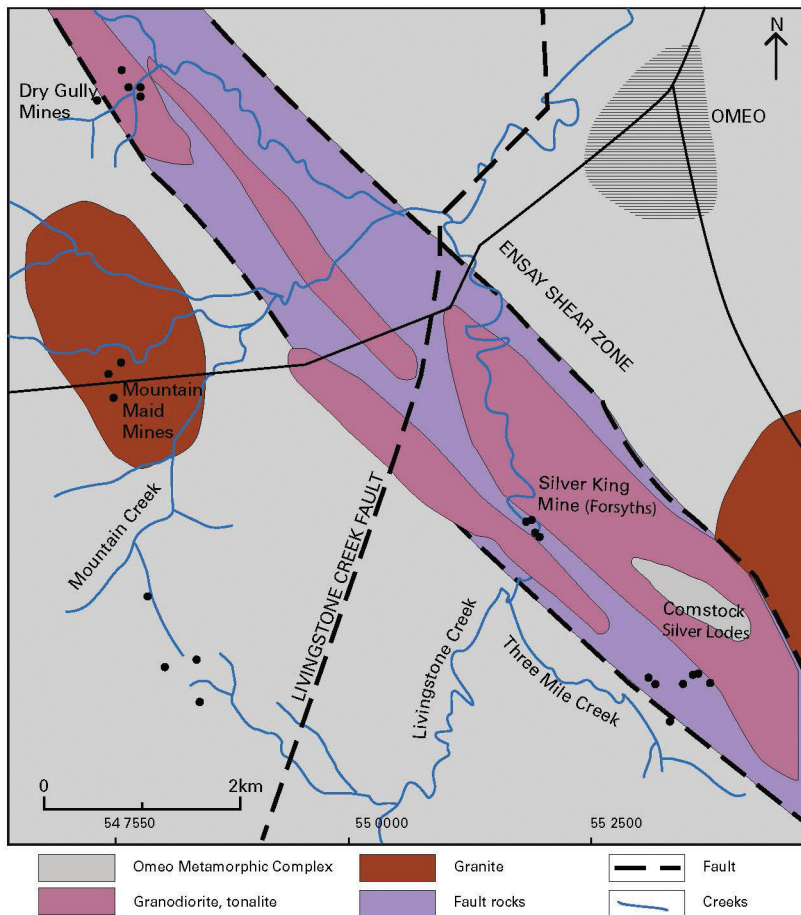


Figure 1: Locality and geological maps of the area around the Silver King mine (based on Willman et al. 1999).



1979 and 1981, Ashton Mining conducted scintillometer and magnetometer traverses, took samples for assay and mapped the ore veins exposed in a track cutting across them along the top of the ridge above the creek (Wong 1981). These surveys demonstrated that no mineralisation existed between the lodes, which themselves offered only small tonnages of medium- to high-grade material. No further work has been undertaken on the deposit, while all traces of the nearby Comstock lodes have been obliterated since the author visited the locality in the late 1970s.

For such a small and remote deposit, a significant number of samples have been assayed at various times. After the first assays carried out by Mr P.A. Bayly in 1912 and reported by Dunn (1917), the local mining inspector, Mr J.C. Grieve, collected several specimens in 1913 and forwarded them to the Mines Department for assay. Eight more assays were obtained from samples collected from No. 4 lode by Easton during his visit in 1923. In November 1932, samples (MD 9051 and 9052) were collected from the Silver King mine by William Baragwanath for the Mines Department and sent for assay, which yielded 153 and 380 ounces of silver per ton, respectively. The ore specimens from the 'east and west adits' (presumably Nos. 1 and 4 lodes) submitted to CSIRO in 1946 assayed between 0.4 and 66 ounces of silver per ton, with those from the No.1

lodes warranted further development, but by whom and for how long they were worked are uncertain. It appears that the deposit regained some interest during the mid-1940s, when a Mr J.C. Oldham sent samples to CSIRO's Mineragraphy section at the University of Melbourne for investigation, which resulted in Frank Stillwell's 1946 report.

A rock-chip sampling and drilling program was undertaken in 1974 by a drilling company and an individual holding a mining licence (Willman et al. 1999), but the results were not officially reported (Wong 1981). Between



Figure 2: Overview of the Silver King mine site on Livingstone Creek, looking southwards (January 2011).

vein generally higher and more uniform (Stillwell 1946). Wong (1981) reported assays of 2.0 and 2.5 ounces of silver per tonne from No. 4 lode and 13 ounces per tonne from No. 2 lode.

### GEOLOGY

The Silver King deposit's lode system is exposed over an area of less than 200 by 200 metres. The lodes consist of multiple thin quartz veins that are variably mineralised, but predominantly grey due to very fine-grained sulphides. They are generally between about 10 and 70 cm thick, although No. 4 lode may reach 2 m in thickness, strike NNW to NNE and dip from 65° E to vertical. They tend to be sinuous and discontinuous due to small-scale faulting, and only No. 4 lode exceeds 30 m in length, having been traced on the surface for about 125 m (Wong 1981).

The host rocks for the lodes range from mylonite to weakly foliated granite within the Ensay Shear Zone (Willman et al. 1999). This is a major structure between 1 and 4 km wide running through the region with a NW–SE trend (see Figure 1). Movement on this shear zone is considered to be Late Silurian to Early Devonian, during the Bindian Deformation (Morand & Gray 1991).

### SAMPLES AND METHODS

This study has only been possible due to the number of specimens from the Forsyths/Silver King lodes presented to various institutions and now held in the collections of Museums Victoria. The earliest of these are two small specimens collected by Edward Dunn in 1912, which were registered in the Victorian Mines Department collections (3580 and 3583). One of the samples collected in 1932 by Baragwanath (9051) has been preserved; the other (9052) was sent to Frank Stillwell at CSIRO for assay and mineragraphic investigation (Stillwell 1933) and has since been lost. However, six specimens and six polished fragments mounted in bakelite blocks from Stillwell's 1933 and 1946 studies have survived (Figure 4). These were in the historic CSIRO mineral collections transferred to Museum Victoria in 2005, along with two batches of Silver King samples from unidentified sources, although one set appears to have been transferred to the CSIRO collection from the Bairnsdale School of Mines at an unknown date.

All available ore specimens were examined under high magnification in order to detect and identify any secondary or supergene minerals occurring as crusts or in cavities. Powder X-ray diffraction was used to identify several of the secondary minerals present.





Figure 3: Adit on the No. 4 lode (January 2011).





Figure 4: The six surviving bakelite mounts from Frank Stillwell's investigations.

For quantitative analysis of ore minerals, four polished sections were prepared from specimens among those registered as E16083 and E13776 in the Museum's collection. In addition, the six polished ore fragments mounted in bakelite blocks prepared by Stillwell for his 1933 and 1946 studies were repolished for examination by reflected light microscopy. Sections and blocks were mapped using back-scattered electron imagery and energy dispersive spectroscopy, enabling representative minerals to be selected for analysis using a Cameca SX50 microprobe in the School of Earth Sciences at the University of Melbourne. Appropriate metals and sulphides were used as standards, with a beam voltage set at 20 kV and specimen current at 35 nA.

## MINERALOGY

### *Historical*

During his treatment of the ore samples provided by Mr Forsyth in 1912, Mr Bayly identified pyrite, galena and jamesonite as constituents. According to Dunn (1917), native silver occurred in the loam and surface stone above the lodes. It was Frank Stillwell's mineragraphic investigation in 1933 that identified pyrargyrite as the main silver mineral present in the ore, determined by its optical properties, including ruby-red internal reflections, softness, etching reactions and microchemical tests for silver and antimony. Stillwell also identified 'tetrahedrite', galena, sphalerite, pyrite and chalcopyrite in unaltered ore samples, with antimony oxides and native silver replacing pyrargyrite in partially oxidised specimens. In his 1946 investigation, Stillwell added arsenopyrite and gold to the suite of ore minerals, as well as a silver-bearing mineral with optical and microchemical properties closely resembling those of lengenbachite, which was only known at that time from quarries in Binnental, Switzerland. Stillwell provided two reflected light photomicrographs that showed the mineral replacing tetrahedrite and sphalerite.



Figure 5: Typical ore samples from the Silver King mine (largest is 6 x 5 cm).

### *Ore textures*

The predominant macroscopic texture shown by surviving ore specimens is of roughly symmetrically crustified veins up to about 5 cm across, with quartz linings up to 10 mm thick enclosing a central zone of fine-grained disseminated sulphide mineralisation, with sporadic coarser patches. Weak rhythmic deposition of sulphides is shown in some samples, while cavities up to a few millimetres across are also present in places. Cross-cutting quartz veins and brecciation textures are indicative of movement after the main vein-filling episode. (Figure 5). The sulphide assemblages vary widely from specimen to specimen, which would account for the range in assay values. Under the microscope, the main ore minerals — pyrite and arsenopyrite — usually form idiomorphic crystals, while other species — such as sphalerite, galena, 'tetrahedrite' and pyrargyrite — tend to occupy interstitial spaces within quartz.

### *Secondary and supergene minerals*

Well-developed zones of oxidation and supergene enrichment are not observed in Silver King ore due to the small size, overall low grade and the non-reactive host quartz. Nevertheless, a number of secondary and supergene minerals have been observed. Supergene minerals occupying small cavities in quartz include radiating sprays of metallic grey acanthite crystals (Figure 6), and scaly aggregates and irregular wires of native silver (Figure 7). In oxidised ore samples, scorodite occurs as white to pale-grey sugary cavity infills and globular greyish brown crusts on fractures, while beudantite forms earthy yellow crusts on fractures (Figure 8) and less commonly yellow-brown drusy linings to cavities in quartz.



Figure 6: Spray of acanthite crystals from a cavity in the Silver King ore. Spray is 2 mm across. MV specimen M53856.



Figure 8: Sample of oxidised ore with yellow earthy crusts of beudantite. Sample is 7 cm across. MV specimen M53864.



Figure 7: Native silver that has replaced pyrargyrite in the Silver King ore. Cavity is 5 mm across. MV specimen M53920.

#### Primary minerals and chemistry

Textural relationships between all the sulphide minerals, as revealed by scanning electron microscopy (Figure 9), are quite complex, with many showing small-scale intergrowths and varying inclusion assemblages. Pyrite dominates the sulphide assemblage, as euhedral crystals from about 0.1 to 2 mm across dispersed through the mineralised portions of the quartz veins. The crystals may occur singly or as stringers and dense clusters tending to massive. The pyrite is generally free of inclusions, although Stillwell observed replacement by galena and tetrahedrite. Microprobe analysis during this present study reveals that the margins of pyrite crystals may contain up to 1.7 atomic per cent arsenic (Table 1). Disseminated arsenopyrite is also very widespread but in much smaller crystals, generally less than 0.01 mm, and frequently as inclusions. Microprobe analyses show generally uniform compositions, yielding a formula  $\text{Fe}_{1.01}\text{As}_{0.89}\text{S}_{1.11}$ , which is slightly non-stoichiometric (Table 1). Sphalerite is relatively abundant, occurring as irregular patches up to 1 mm, and in places as massive aggregates. It occurs with

Table 1: Analyses of pyrite, arsenopyrite and sphalerite.

Wt%	1	2	3
S	51.93	22.38	32.68
Mn	0.00	0.01	0.01
Fe	46.94	35.41	1.85
Cu	0.04	0.08	0.10
Zn	0.06	0.14	66.07
As	1.17	41.65	0.02
Ag	0.03	0.03	0.09
Sb	0.01	0.50	0.02
Au	0.02	0.04	0.00
Pb	0.01	0.06	0.01
Total	100.22	100.30	100.59
Atom%			
S	65.33	36.81	49.33
Mn	0.00	0.01	0.01
Fe	33.91	33.43	1.61
Cu	0.03	0.07	0.08
Zn	0.04	0.11	48.92
As	0.63	29.32	0.01
Ag	0.01	0.02	0.04
Sb	0.00	0.22	0.01
Au	0.00	0.01	0.00
Pb	0.00	0.02	0.00
Formula			
Fe	1.03	1.01	0.03
Zn	0.00	0.00	0.99
Cu	0.00	0.00	0.00
Pb	0.00	0.00	0.00
Sb	0.00	0.00	0.00
As	0.02	0.89	0.00
S	1.98	1.11	1.00

1. Pyrite (average of 17)

2. Arsenopyrite (average of 16)

3. Sphalerite (average of 12)



most of the other phases (Figure 9A) and a few grains have been observed with a thin reaction rim of silver and copper sulphides (Figure 9B). Its macroscopic pale-brown colour is consistent with low iron contents of 0.02 to 0.04 apfu revealed by microprobe analysis (Table 1). Galena is less abundant than sphalerite and forms irregular grains up to about 1 mm (Figures 9A, C), as well as irregular inclusions in pyrrargyrite (Figures 9D, E). No chalcopyrite or gold, noted by Stillwell (1946), was seen in any sections in the present study.

In the first ore sample examined by Stillwell (1933), pyrrargyrite formed minute particles as small as 0.004 mm and sporadic larger grains to 1.3 mm, readily identified by their brilliant ruby-red internal reflections between crossed nicols. The grains occupied irregular interstices between quartz crystals, in places arranged linearly along grain boundaries, and were commonly associated with tetrahedrite. The distribution of pyrrargyrite appears to be irregular however, as it is absent from most of the sections examined in this study, although several larger patches to about 0.5 mm were observed. Scanning

electron microscope imagery shows the pyrrargyrite may contain inclusions of galena (Figure 9E) as well as itself being included in tetrahedrite (Figure 9F). Based on his observations, Stillwell concluded that the pyrrargyrite and possibly tetrahedrite were chiefly responsible for the high

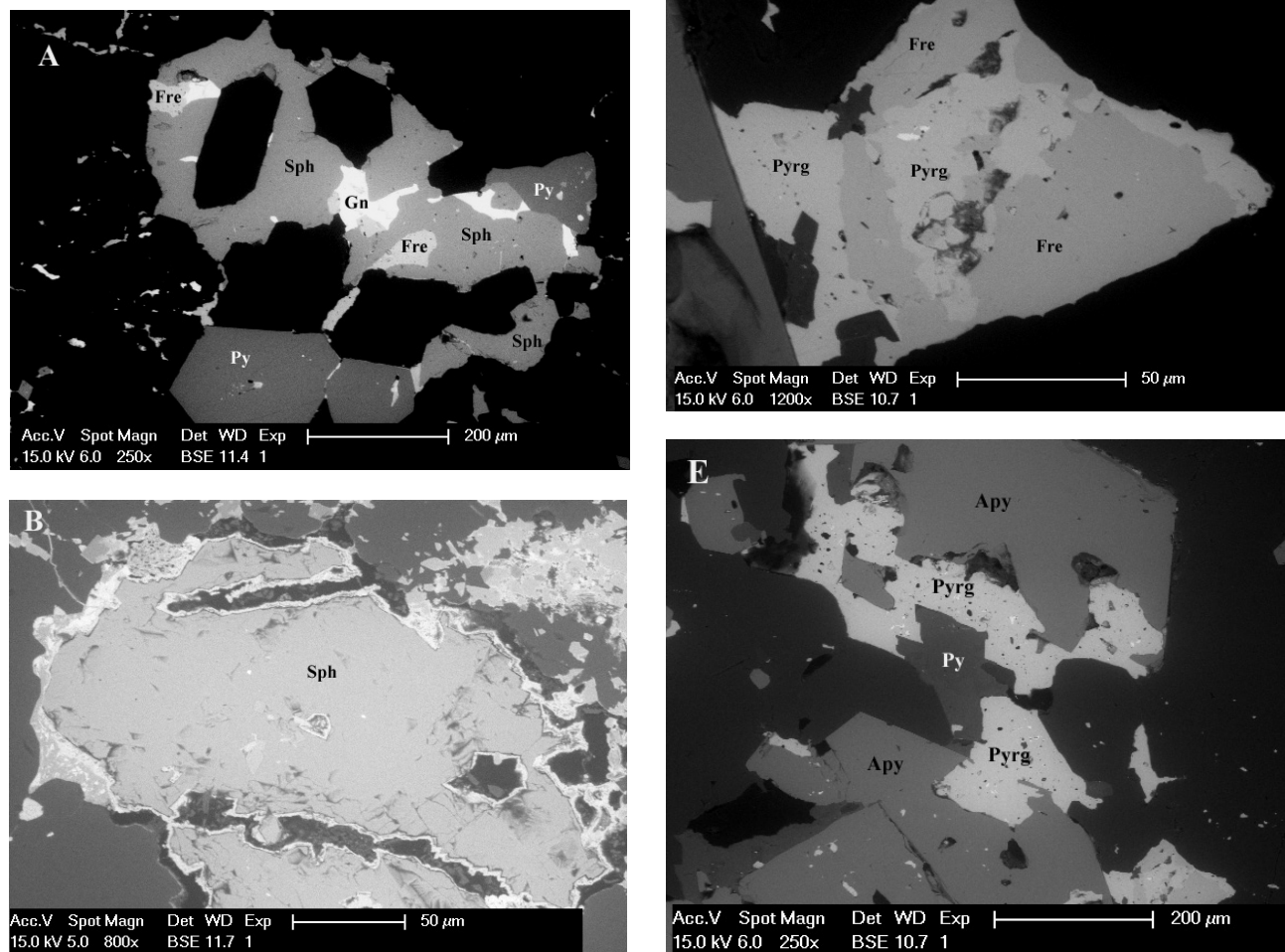


Figure 9 (A–E): Representative back-scattered electron images of Silver King mine minerals. A: Composite patch consisting mainly of sphalerite with pyrite, galena and freibergite (E1). B: Sphalerite grain with thin reaction rim of Ag sulphide (brighter) and Cu sulphide (probably covellite) (SK1). C: Sphalerite grain with inclusions of arsenopyrite, freibergite and galena (SK1). D: Composite grain of freibergite and pyrrargyrite with several galena inclusions (bright) (9052). E: Grains of pyrrargyrite attached to pyrite and arsenopyrite and with tiny inclusions of galena (bright). (9052).

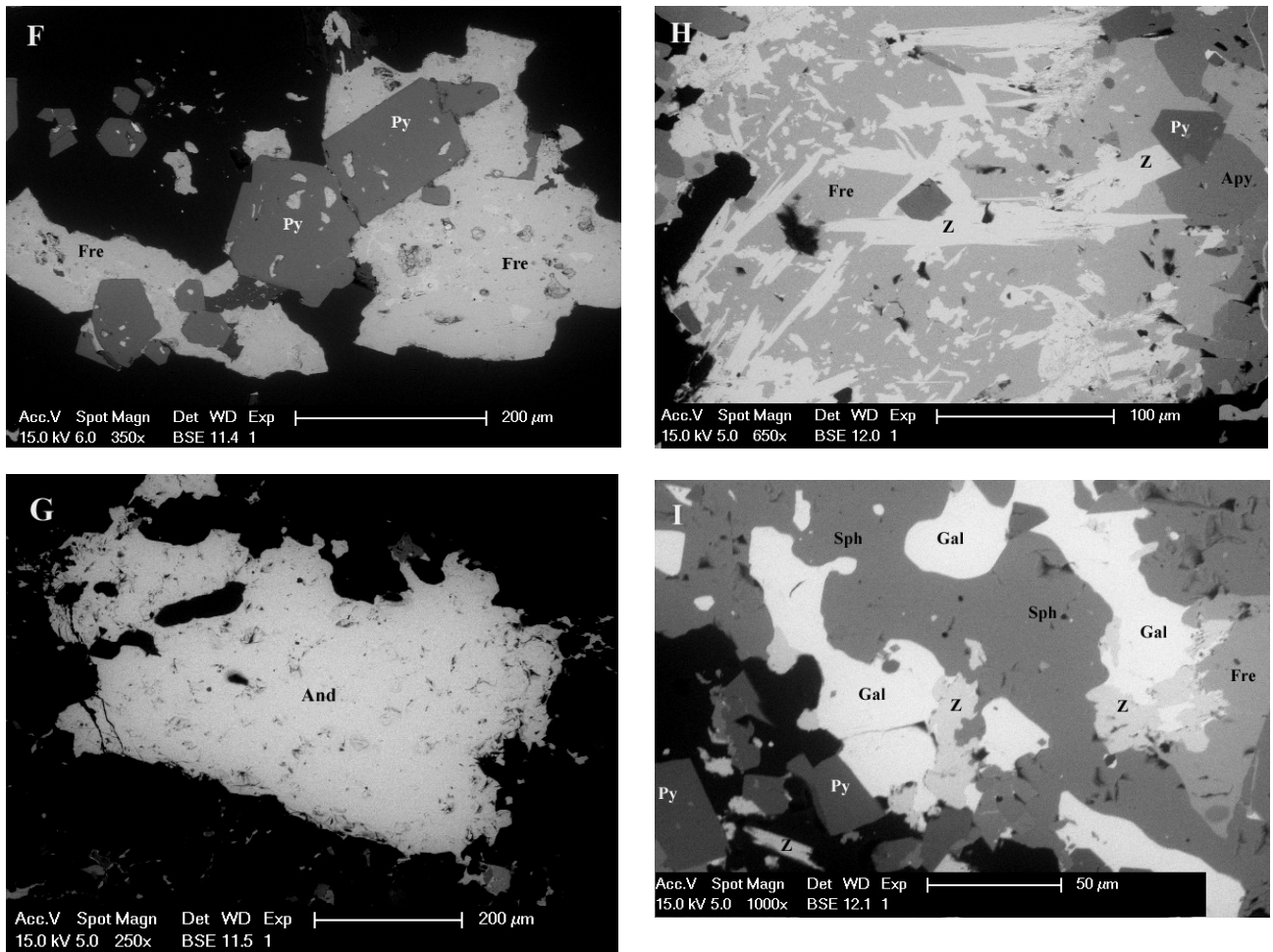


Figure 9 (F–I): F: Complex patch mainly of freibergite with pyrite, both hosting inclusions of pyrrargyrite. (9051). G: Andorite grain, free of inclusions. (SK1). H: Freibergite grain with bladed inclusions of zoubekite. (SK2). I: Sphalerite enclosing galena, freibergite and zoubekite. (SK2).

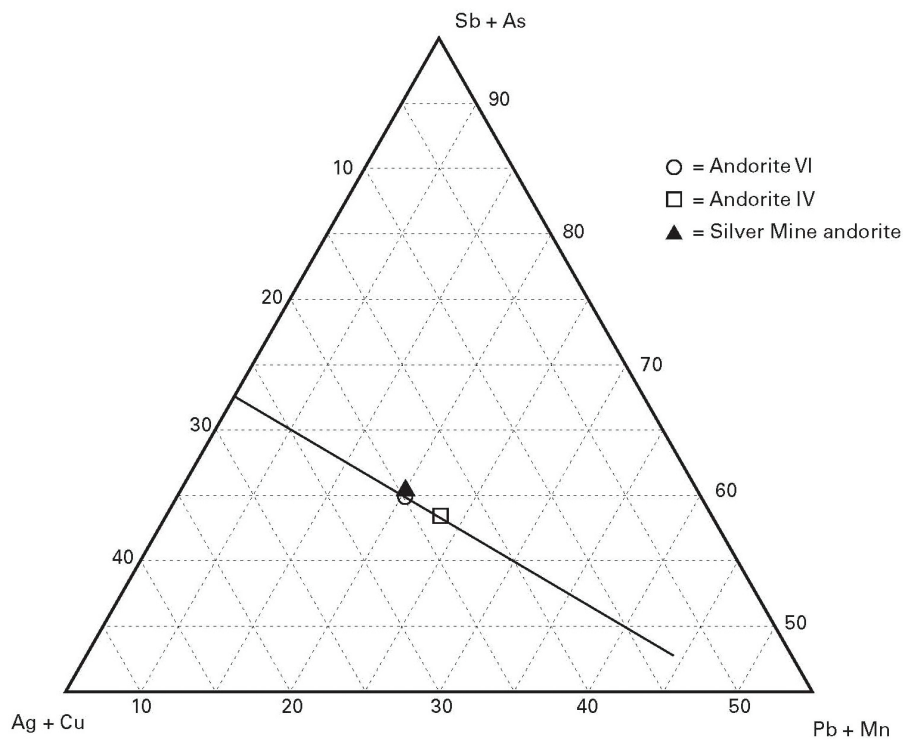


Figure 10: Plot showing average composition of Silver King andorite in relation to theoretical compositions of andorite IV and andorite VI (modified from Makovicky & Topa (2014)).



Table 2: Analyses of freibergite, andorite and zoubekite.

Wt%	1	2	3
S	21.74	20.95	18.45
Mn	0.01	0.01	0.00
Fe	2.43	0.02	0.07
Cu	20.80	0.26	0.27
Zn	4.35	0.01	0.38
As	0.92	1.14	0.73
Ag	22.89	11.54	6.58
Sb	26.90	41.83	29.32
Au	0.04	0.04	0.04
Pb	0.04	23.66	44.17
Total	100.12	99.46	100.01
Atom%			
S	43.41	52.77	51.76
Mn	0.01	0.01	0.01
Fe	2.79	0.03	0.11
Cu	20.94	0.33	0.38
Zn	4.27	0.02	0.52
As	0.79	1.23	0.88
Ag	13.63	8.64	5.49
Sb	14.15	27.74	21.67
Au	0.01	0.02	0.02
Pb	0.01	9.22	19.18
Formula			
Ag	3.92	3.84	1.04
Cu	6.04	0.15	0.07
Fe	0.80	0.00	0.10
Zn	1.23	0.00	0.02
Pb	0.00	4.09	3.64
Sb	4.08	12.34	4.12
As	0.23	0.55	0.17
S	12.52	23.46	9.83

1. Freibergite (based on Ag+Cu+Fe+Zn=12) (average of 8)

2. Andorite (based on As+S=24) (average of 14)

3. Zoubekite (based on As+S=10) (average of 7)

silver values, although he had no chemical data for the tetrahedrite, which he described as large irregular patches intimately associated with pyrargyrite and galena (Figure 9D), in places replacing pyrite and sphalerite. Microprobe analyses reveal that the mineral is actually freibergite, as all compositions plot in the silver-rich field of the tetrahedrite–freibergite solid solution series (Table 2).

Grains of andorite *per se* up to about 1 mm and largely inclusion-free were detected in one of the specimens (SK1), which also contains minor pyrite and sphalerite (Figure 9G). The name applies to a discrete phase on a series line in the Ag–Sb–Pb(–S) system, where the historic ‘grandfathered’ names andorite IV and andorite VI represent limits of a very small substitution range (Makovicky & Topa 2014).

Microprobe analyses (Table 2) of the Silver King andorite show little variation in composition, with the average plotting closer to the well-defined andorite VI formula of  $\text{Pb}_{24}\text{Ag}_{24}\text{Sb}_{72}\text{S}_{144}$  (Figure 10). It is possible that Stillwell observed andorite but misidentified it as tetrahedrite. The Silver King deposit is the second occurrence of andorite in the Omeo region, with the mineral being the main silver-bearing phase in a late-stage quartz vein found in the Meerscham mine on the Mt Wills goldfield (Birch 1981).

The mineral tentatively identified by Stillwell (1946) as lengenbachite formed individual and clusters of needle-like crystals replacing tetrahedrite and sphalerite. The exact areas shown in the two photomicrographs he presented showing the textural relationships could not be recognised in any of his surviving mounts. However, very similar intergrowths were observed in one new section in this study, in which bladed or lath-like crystals are enclosed in freibergite grains and show orientations that appear to reflect crystallographic influence by the host (Figure 9H). The same mineral was also detected as irregular grains associated with other sulphides (Figure 9I), broadly in accordance with Stillwell’s observations. Microprobe analyses of this phase (Table 2) show it contains major Pb, Sb, Ag and S, with smaller amounts of As, Cu and Zn, yielding an empirical formula of  $[\text{Ag}_{1.04}(\text{Pb}_{3.64}\text{Zn}_{0.10}\text{Cu}_{0.07}\text{Fe}_{0.02})_{\Sigma 3.83}\text{Sb}_{4.12}(\text{S}_{9.83}\text{As}_{0.17})_{\Sigma 10.00}]$ , very close in stoichiometry to the rare sulphosalt zoubekite,  $\text{AgPb}_4\text{Sb}_4\text{S}_{10}$  (Megarskaya et al. 1986). Stillwell used positive microchemical tests for Ag, Pb, As and Cu in order to compare his mineral with lengenbachite, which is an arsenide, but appears not to have tested for Sb. This could account for the apparent chemical distinction between his identification and the result from this study. Zoubekite bears a very close chemical relationship with owyheeite,  $\text{Ag}_3\text{Pb}_{10}\text{Sb}_{11}\text{S}_{28}$ , and there is very little difference in their compositions derived from their ideal formulae. Additional complexity arises when there are substituting elements such as Cu, Zn and As to incorporate into the empirical formula calculation. While the crystal structure of owyheeite has been determined (Laufek et al. 2007; Makovicky & Olsen 2015), that for zoubekite has not, probably due to the lack of suitable crystals. Based on the Silver Mine phase’s predominant habit of long lath-shaped grains, and the better fit between its simplified formula and the ideal formula for zoubekite rather than for owyheeite (Table 2), zoubekite would appear to be the more likely identification. However, until the crystallographic relationship between the two phases is clarified, the identification of the Silver King mineral as zoubekite must remain doubtful. The mineral has been reported from only four other localities worldwide, including the type locality of Příbram, now in the Czech Republic.

## PARAGENESIS

*Phase relations and formation temperatures*

The common assemblage pyrite–arsenopyrite may provide a mechanism for estimating sulphur activities and initial crystallisation temperatures, using experimental phase relations in the Fe–As–S system (Kretschmar & Scott 1976). Arsenopyrite is a refractory phase, which does not readily re-equilibrate during cooling, so its composition is sensitive to formation temperature or pressure (Clark 1960; Barton 1969; Scott 1983). Natural arsenopyrite itself can be ‘non-stoichiometric’, in that its composition can vary between  $\text{FeAs}_{1.2}\text{S}_{0.8}$  and  $\text{FeAs}_{0.9}\text{S}_{1.1}$  and arsenian arsenopyrite is commonly observed in hydrothermal ore deposits (e.g. Reich et al. 2005; Sharp et al. 1985). The average Silver King arsenopyrite composition is very close to the arsenic-deficient limit of the range. However, the range in composition observed, while small, may indicate that the arsenopyrite has not attained complete equilibrium.

The upper stability limit for the pyrite–arsenopyrite assemblage at pressures less than 2 kbar is known to be about 520°C (Clarke 1960). For hydrothermal deposits that formed under these conditions, the effect of pressure on arsenopyrite composition is small and can be ignored (Sharp et al. 1985). Applying the arsenopyrite geothermometer to the Silver King assemblage yields a range from about 400°C to less than 350°C. Cooling temperatures within this range are probably accompanied by a slight reduction in sulphur activity, reflected in the small amount of arsenic substitution for sulphur observed in the margins of pyrite crystals.

The presence of a buffering phase such as löllingite or arsenic coexisting with pyrite–arsenopyrite is required to more accurately estimate temperature (Scott 1983). These minerals are generally uncommon in ores; however, sphalerite is a refractory mineral that often coexists with pyrite and arsenopyrite, and can be regarded as an alternative buffering phase (Scott 1983). Phase relations in the Fe–Zn–As–S system at low pressure (1 bar) were obtained by Scott by combining phase diagrams plotting  $\log a_{\text{S}_2}$  versus temperature ( $1000/T(\text{K}^{-1})$ ), contoured with isopleths for mole % FeS in sphalerite and atomic % As in arsenopyrite. A simpler plot of atomic % As in arsenopyrite versus temperature (°C), contoured in mole % FeS in sphalerite, can be constructed, which overlooks the pressure dependence of sphalerite composition in the Fe–Zn–S system. Average compositions for coexisting arsenopyrite and sphalerite in the Silver King ore yield figures of 29.3 atomic % As and 1.64 mole % FeS respectively. Examination of the combined phase equilibria plot shows that sphalerite coexisting with pyrite and arsenopyrite must contain at least 10 mole % FeS, regardless of temperature. Therefore, the much lower FeS content of the Silver King sphalerite indicates an assemblage that is not in equilibrium. This implies that sphalerite and the other phases such as galena, pyrrargyrite, freibergite and andorite were introduced into the ore veins during a later and lower temperature episode of hydrothermal mineralisation. This is in keeping with these phases occupying interstices between quartz crystals, rather than forming euhedral crystals.

Temperature–composition relations in the simple system  $\text{Ag}_2\text{S}–\text{Cu}_2\text{S}–\text{ZnS}–\text{FeS}–\text{Sb}_2\text{S}_3$  have been established

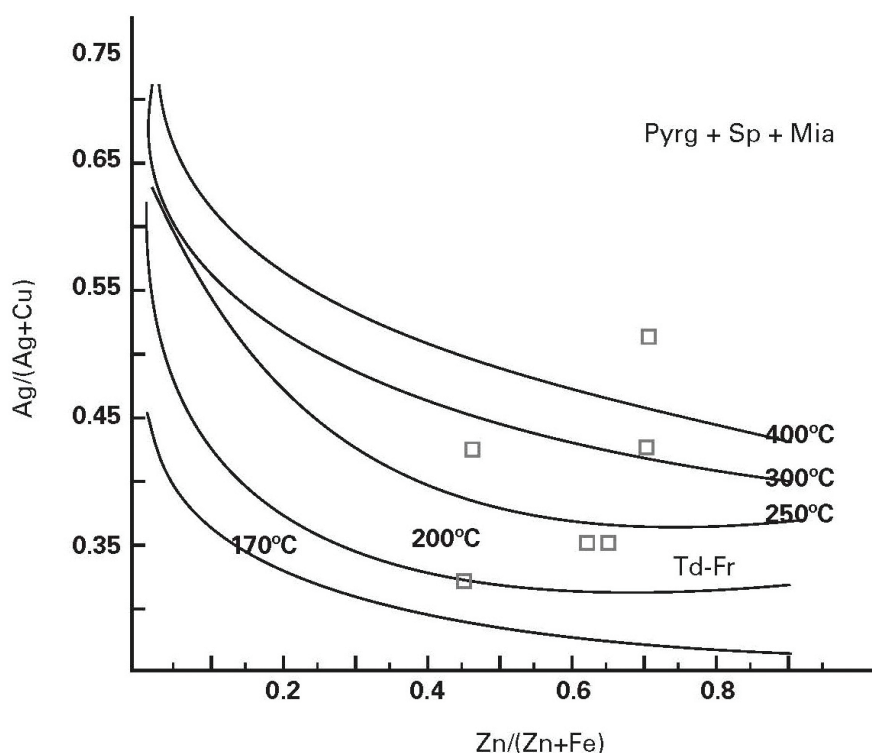


Figure 11: Composition/temperature/phase assemblage diagram for ‘fahlore’ after Sack et al. (2002, 2003), with Silver King mine freibergite analyses plotted (squares). (Fr=freibergite, Td=tetrahedrite, Pyrg=pyrrargyrite, Sp=sphalerite, Mia=miargyrite).



for the tetrahedrite–freibergite ('fahlore') series by Sack et al. (2002) and applied to a number of natural assemblages containing sphalerite, pyrrargyrite and galena (Sack et al. 2003). Most compositions, expressed in terms of Ag/(Ag+Cu) and Zn/(Zn+Fe), are consistent with temperatures in the range 250–310°C, although some zinc-rich, high-Ag compositions require temperatures exceeding 400°C (Sack et al. 2003). All but one of the Silver King freibergite compositions plot in the range from 300°C to below 200°C (Figure 11). Andorite *per se* has a large stability field and can occur with many other lead and silver sulphosalts (Hoda & Chang 1975).

The overall phase relationships are consistent with ore formation in the temperature range from around 400°C for the initial pyrite–arsenopyrite assemblage, to 200°C and less for the silver-bearing minerals.

#### *Regional comparison*

The nearest known hydrothermal silver-bearing deposits are in the Glen Wills and Sunnyside goldfields on the southern and eastern slopes of Mt Wills, some 35–40 km north of Omeo. Mining operations in these goldfields were mostly between about 1891 and 1918, although the largest mine, the Maude and Yellow Girl at Glen Wills, continued into the 1950s. The gold occurred in several parallel systems of quartz reefs emplaced into the metasediments of the Omeo Metamorphic Zone and the granitic intrusion of Mt Wills (Dunn 1906; Crohn 1958; Willman et al. 1999). The total recorded production from both fields is 200,000 ounces of gold, while around 150,000 ounces of silver were obtained from the Maude and Yellow Girl mine (Edwards 1958).

There are broad similarities in ore mineralogy between the Silver King deposit and the reef systems at Glen Wills and Sunnyside. In ore from the Maude and Yellow Girl mine, Edwards (1958) observed arsenopyrite, pyrite, sphalerite, chalcopyrite and galena accompanying early gold that was relatively poor in silver. Later crystallisation involved silver-rich gold associated with a suite of antimony-bearing sulphosalts, including bournonite, boulangerite, 'tetrahedrite' and pyrrargyrite. Edwards calculated the average gold fineness as 725, based on the composition of bullion recovered from the concentrates between 1942 and 1952. However, there are no quantitative analyses of either the gold or the tetrahedrite to enable modelling of the distribution of silver in the ore. Silver yields from the Sunnyside mines to the north were not reported, but silver sulphosalt minerals have been recorded from a number of the reefs (Birch 1992). Chief among these was a late-stage vein in the Meerschaum mine containing an early pyrite–arsenopyrite–sphalerite assemblage followed by andorite, freibergite, miargyrite and owyheeite (Birch 1981).

The timing and structural settings of the silver deposits also appear similar. Willman et al. (1999) described the Glen Wills reefs as occupying brittle faults that post-date high grade metamorphism and intrusion of the Mt Wills Granite and associated pegmatites, which indicates a mineralisation event during the Late Silurian to Early Devonian. Wong (1981) suggested the Silver King lodes filled tension gashes associated with movement on the Ensay Shear Zone during the Early Devonian Bindian Orogeny. While it appears that different fault systems were involved in allowing transport of hydrothermal fluids, the same deep-seated source for the silver was available over a distance of some 40 km.

### CONCLUSIONS

The assemblage pyrrargyrite–freibergite–andorite–zoubekite–native silver is responsible for locally high assays of silver in the historic Silver King (Forsyths) deposit near Omeo, Victoria. The mineralisation event occurred during movement on the Ensay Shear Zone in the Early Devonian, commencing with pyrite–arsenopyrite, followed by galena, sphalerite and the silver-bearing phases, accompanying emplacement of silica-rich fluids. Sulphide geothermometry suggests crystallisation occurred over an interval from around 450°C to less than 200°C. It is likely that the source of the silver for the Silver King deposit was also responsible for the ore assemblages on the Glen Wills and Sunnyside goldfields to the north, where a more detailed investigation is warranted.

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