Preliminary mineralogical investigations of the Paris silver deposit, Northern Eyre Peninsula, South Australia

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1 Introduction

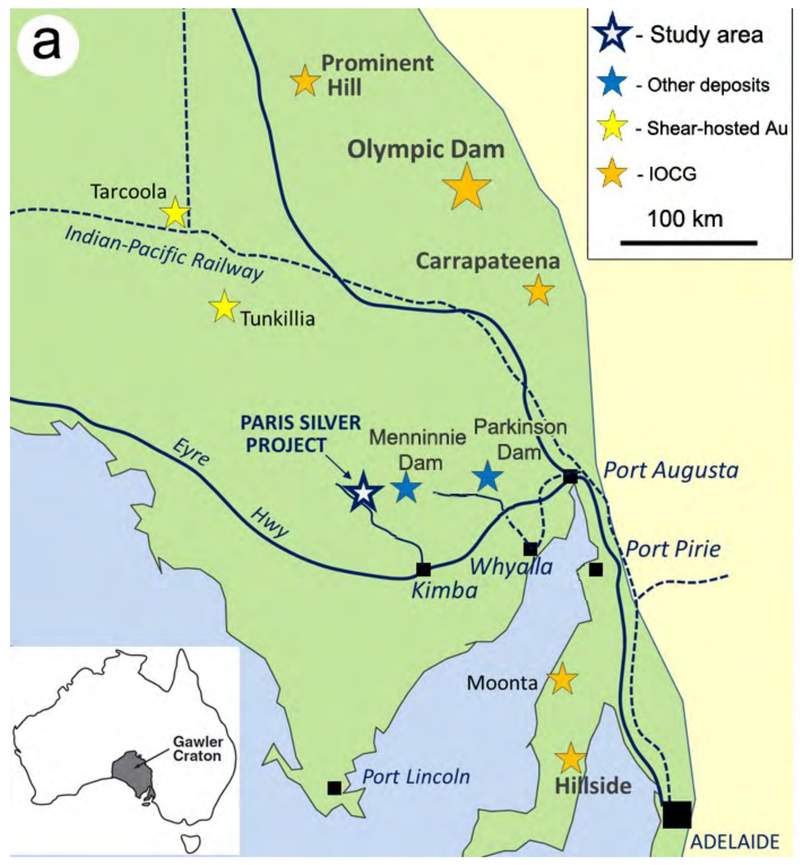


Fig. 1. (a) Map of the southeastern Gawler Craton (green) with Paris and other mentioned deposits located.

The Gawler Craton of South Australia (Fig. 1a) is host to world-class mineral resources, including Olympic Dam, Prominent Hill, Carrapateena, Hillside and Moonta-Wallaroo, which, among others, all fall within the Iron-Oxide-Copper-Gold (IOCG) class of mineralization and define the Olympic Cu-Au Province (Skirrow et al. 2007). IOCG mineralization is genetically associated with a 1.6 Ga LIP represented by Gawler Range Volcanics (GRV) and the contemporaneous Hiltaba Intrusive Suite (HIS). In these deposits, Fe-oxides are conspicuous components, raising the potential for both geochemical fingerprinting and Pb-Pb dating (Ciobanu et al. 2013). Currently of lesser economic importance are shear-hosted Au deposits (e.g. Tunkillia and Tarcoola). These are of comparable, or slightly older age, hosted in 1690-1670 Ma Tunkillia Suite granitoids (Ferris, 2001), and occur within the Yarlbrinda Shear Zone (Fraser et al. 2007). In contrast to these ore systems, an emerging class of prospects, all hosting epithermal and carbonate replacement assemblages, have been discovered in the southern Gawler Craton. These include Parkinson Dam (Au-Ag), Menninnie Dam (Pb-Zn), and the Paris silver deposit, on the northern Eyre Peninsula. These deposits, like the IOCG systems, are spatially associated with granites belonging to the 1595-1570 Ma HIS and voluminous GRV (e.g. Daly et al. 1998). Ore genesis can be broadly related to the Mesoproterozoic HIS-GRV magmatic event given U-Pb SHRIMP ages for a porphyritic monzogranite, interpreted to pre-date the sericite alteration associated with the epithermal mineralisation and a rhyodacite dyke, interpreted to post-date or to be associated with the mineralisation (1593 ± 8 Ma and 1597 ± 14 Ma, respectively; Jagodzinski et al. 2012). No direct age for the mineralization itself is currently available.

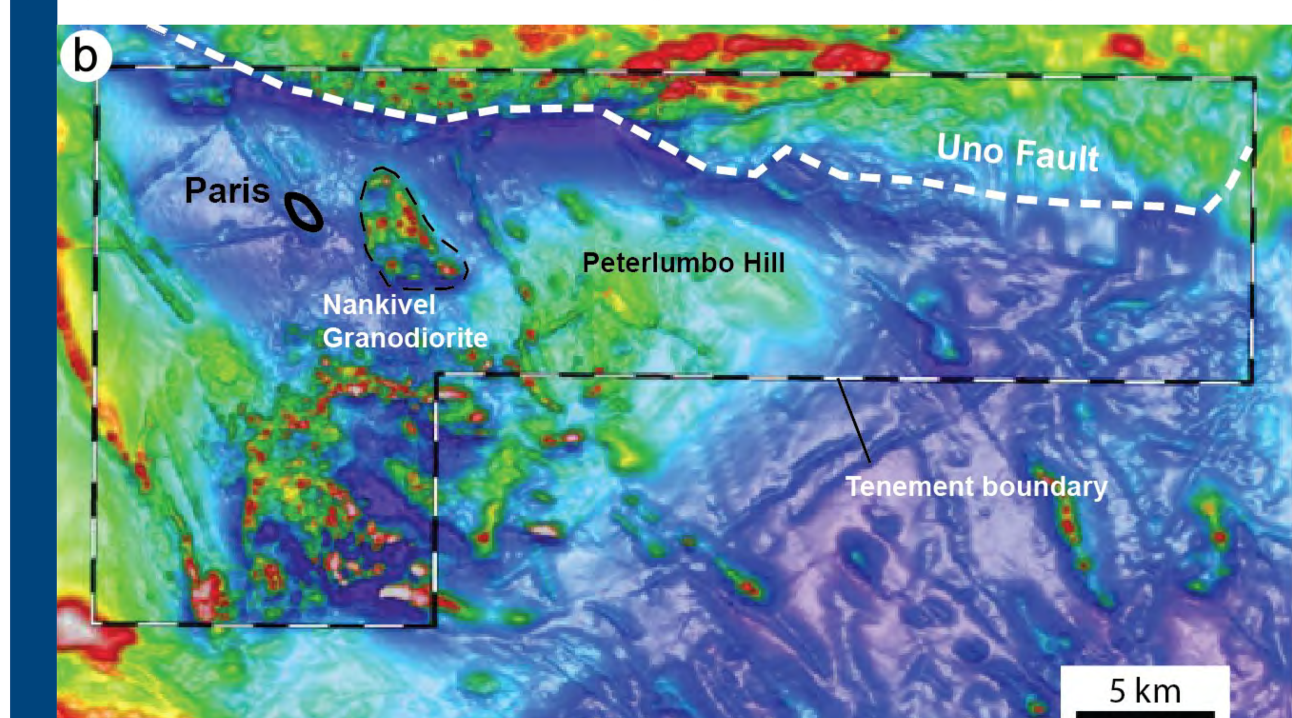


Fig. 1. (b) Magnetic image of Paris and immediate area (Investigator Resources).

The unusual silver - base metal mineralisation in the Paris district, and the clear structural control of these deposits contrasts, however, with known metallogenic models for the region. To address this, a sound understanding of the mineralisation itself, zonation at the deposit- and district-scales, as well as relationships between mineralization and alteration are essential for establishing a sustainable genetic model for Paris, as well as for constraining Mesoproterozoic metallogenetic provinces within the Gawler Craton. The Paris silver deposit was discovered in 2011 when Investigator Resources drilled a silver-in-soil geo-chemical anomaly and applied an exploration model of epithermal Hiltaba-aged mineralization. The deposit was recognized as predominantly hosted in volcanic breccias laterally rimming a collapsed vent breccia at the base of the GRV pile. An inferred resource of 20 Moz Ag consisting of a tonnage of 5.9 Mt @ 110 g/t Ag, including 38 Kt Pb @ 0.6 wt% Pb, is currently defined Investigator Res. 2013a). Preliminary metallurgical work indicated good first-pass recoveries that improve with silver grade (Investigator Res. 2013c). Paris is located close to the Uno Fault (Fig. 1b), an interpreted E-W structure marking the southern margin of the GRV massif. The Mesoproterozoic palaeosurface at the base of the GRV is preserved near surface and generally under thin sand cover and basal volcanics along the southern side of the Uno Fault, a region referred to by Investigator as the Uno Province. The province is highly prospective as evidenced by the mineral discoveries through cover thus far, associated with fertile Hiltaba intrusives and extensive hydro-thermal alteration assemblages (Anderson 2014). Paris has many features of an epithermal deposit, and may be a distal member of a larger, zoned Ag-Pb-Cu-Au system centered on a HIS granodiorite with potential for intrusive-related breccia or porphyry-style Cu-Au deposits in the region (Investigator Res. 2015). The inferred Paris resource currently extends over a 1200 x 400 m area, and to a depth of 150 m. The deposit consists of a series of laterally extensive hydrothermal and volcanic breccias, possibly fed by a central diatreme, topped by flow-banded and/or layered volcanic rocks, within a basement of dolomite marble, graphite-bearing metasediments and banded iron metasediments. Flow-banded ignimbritic GRV is unconformably covered by silcrete, gravels and soils (Fig. 2). Although subject to extensive diamond and reverse circulation drilling, limited prior petrographic and microanalytical work has carried out on the deposit.

2 Geological setting

The host Katunga dolomitic marble of the Paleoproterozoic Hutchison Group has been meta-morphosed to amphibolite facies, with a retrogressive greenschist overprint during the 1730 to 1690 Kimban Orogeny, and syn-metamorphic intense isoclinal folding and faulting (Vassallo and Wilson 2001). These folds and faults may have been reactivated providing structural conduits for metalliferous fluids. (Investigator Res. 2013b). The presence of sulfide-rich vein mineralization within dolomite, and in particular, immediately above the thin plug-like granitoid intrusives clearly shows percolation of mineralized fluids. Ore minerals include pyrite, marcasite, arsenopyrite, sphalerite, galena, chalcopyrite, pyrrhotite, acanthite, magnetite and minor native silver. Jalpaite has also been identified (Mason 2012). Gangue minerals include quartz, talc, graphite and carbonates.

Primary lithologies identified by Investigator geologists (Fig. 2) include flow-banded volcanics (GRV), and an iron-reaction zone, characterized by jasperoidal iron, hematite and goethite, occurring at the unconformity between the altered dolomite and volcanic breccias. The discordant breccia, contains coarse fragments of sericite-altered felsic lavas and graphitic metasediments in a fine-grained matrix composed of quartz, sericite, chlorite, graphite and sulfides (pyrite, sphalerite and galena). The most economically significant unit, the polymict breccia, contains mineralized massive sulfide clasts, hydrothermal silica clasts, felsic volcanic clasts and granitoid clasts.

Our study has recognized skarn assemblages in the minor basement-hosted mineralization beneath the unconformity. These display a pronounced manganese signature. Minerals recognized in the skarns include parvo-manganotremolite and rhodonite, in addition to several Mn-bearing carbonates (rhodochrosite, kutnohorite and manganocalcite). Superimposed replacement relationships between different carbonates are observed.

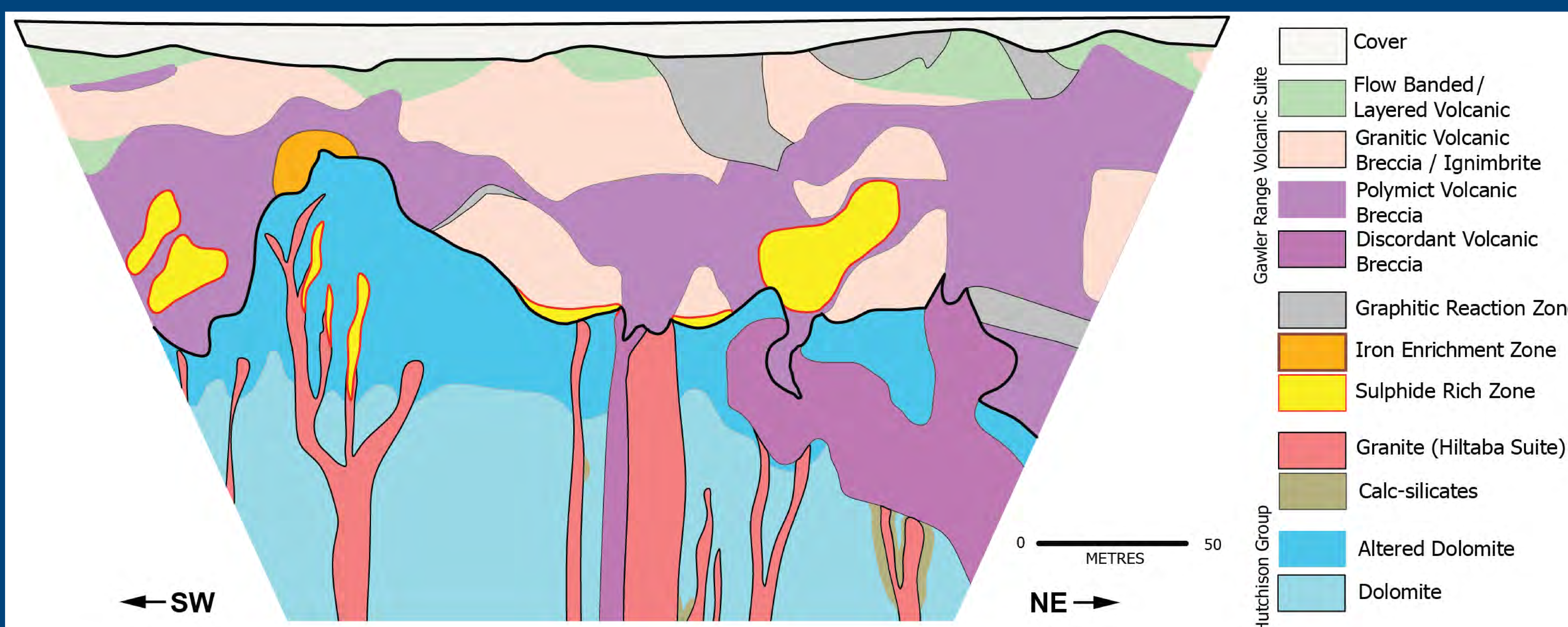


Fig. 2. Schematic cross-section of the Paris deposit (from Investigator Resources).

3 Approach and methodology

To date, petrography and mineralogy has been deter-mined on a suite of 43 samples from 13 drillholes representative of key lithologies in the Paris deposit (Fig. 2). Analysis has been undertaken using optical microscopy, Scanning Electron Microscopy (SEM), Electron MicroProbe Analysis (EMPA) and Laser Ablation Inductively-Coupled Plasma Mass Spectrometry (LAICPMS).

4 Ore minerals and textures

The majority of the Ag-ore at Paris is a polymict breccia producing the run-of-deposit silver grades of about 110g/t Ag. Smaller (~10% of the deposit) sulfide-rich zones within the polymict breccia can attain higher grade (1 m core lengths assaying >1% silver in places) and contain massive sulfide clasts in which galena is ubiquitous and the dominant sulfide (Investigator Res. 2013b). An important observation is the occurrence of laurionite [PbCl(OH)], within vugs in the massive, sulfide-dominant clasts, and as infill in galena (Fig. 3B). The typical assemblage for the clasts is galena, arsenopyrite and sphalerite ± chalcopyrite. These clasts had interpreted to have been sourced from sulfide-rich veins in the altered dolomite (Mason 2012); however they have been found by this study to be different in composition and texture.

In altered dolomite, intimate relationships between pyrite and galena are seen, notably abundant and unusual symplectite-like intergrowths of pyrite and galena (Fig. 3A). Two main types of pyrite are recognized and often co-exist: porous; and non-porous (Fig. 3C). The porous pyrite displays evidence for the brecciation and milling of a pre-existing pyrite+arsenopyrite assemblage. Importantly, the porous, reworked pyrite contains swarms of Ag-mineral inclusions (Fig. 3C). This is considered as important evidence that primary pyrite concentrated silver, even if some was later released, thus contributing to elevated Ag-grades.

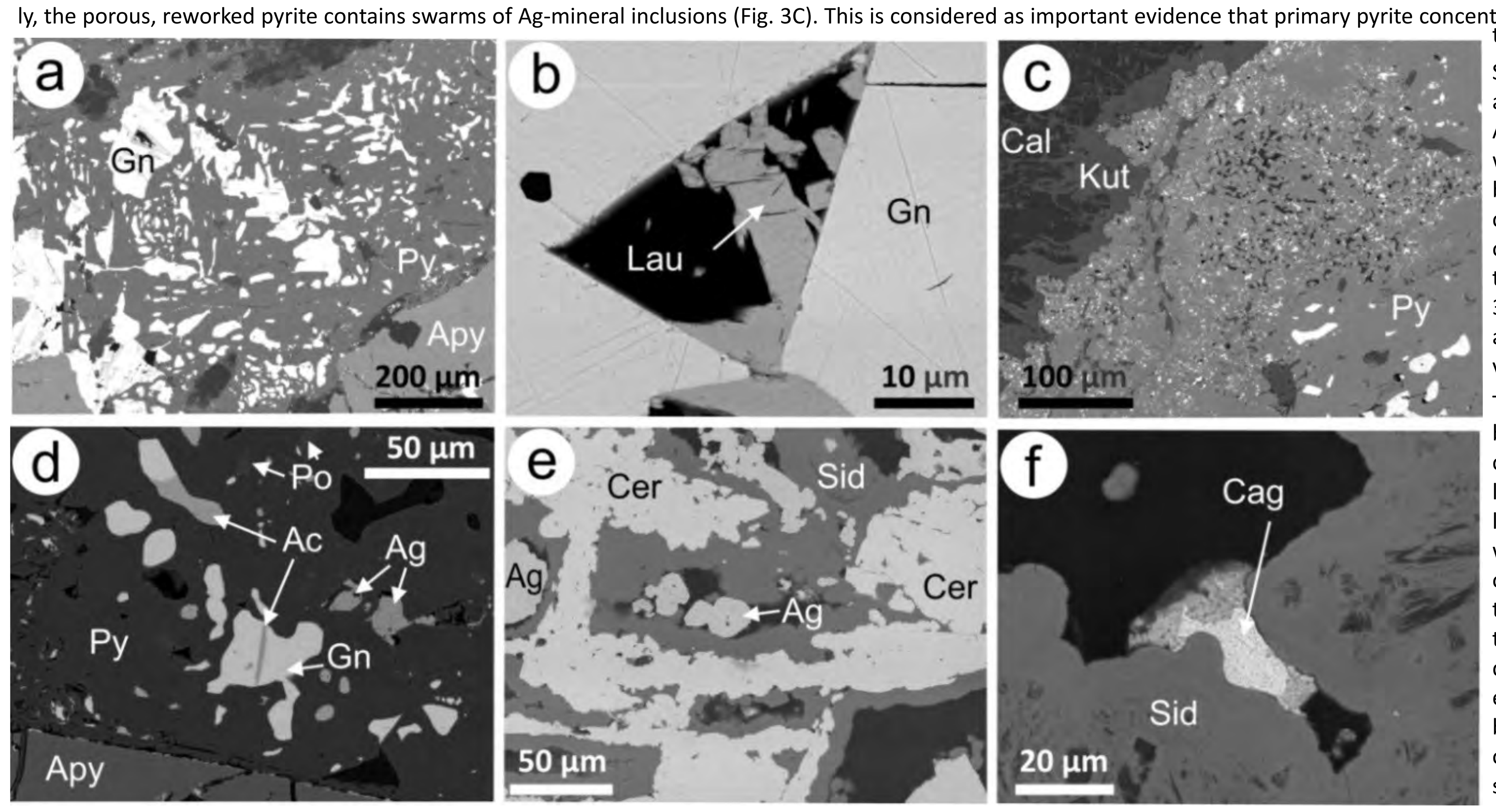


Fig. 3. Secondary electron images of (A) Myrmekitic galena in pyrite, (B) Infill of laurionite in galena, (C) Porous pyrite with galena inclusions, (D) Galena and acanthite with diffuse boundaries and native silver in pyrite, (E) Native silver with cerussite and siderite, (F) Chlorargarite in banded siderite.

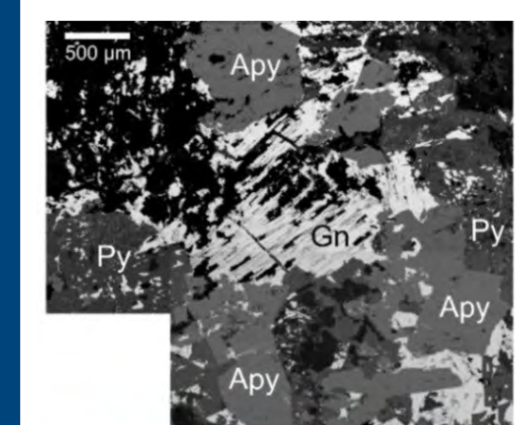
Silver occurs as native silver, subordinate acanthite, and minor chlorargyrite (AgCl). Acanthite commonly occurs in association with galena, locally sharing a diffuse mutual boundaries (Fig 3D), suggesting co-crystallization at equilibrium. Native silver occurs throughout the mineralized zones, typically as small inclusions in pyrite (Fig. 3C), and also in association with cerussite and rhodochrosite in the upper clay-altered volcanic breccias (Fig. 3E).

The minor chlorargarite is associated with banded siderite (Fig. 3F), also occurring in clay-altered breccias. The presence of the latter provides a connection between the laurionite-filled vugs in galena and the reworking of pyrite. We interpret the presence of such Cl-rich minerals as suggesting either the involvement of high-salinity brines at the time of primary mineralization, or a subsequent superimposed event affecting pre-existing mineralization. Collectively, assemblages and textures indicate that a primary ore underwent reworking or overprinting at some time after initial deposition.

5 Mineralogical distribution of silver

Although silver occurs as dominant acanthite and native silver, and minor chlorargarite (recognized here for the first time), there is clear textural evidence that co-existing sulfides (galena, pyrite and arsenopyrite) may also be Ag-carriers. To address the potential role of sulfide minerals as hosts for lattice-bound silver, galena and arsenopyrite from the sulfide-rich intervals were analyzed by laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS).

This reconnaissance study showed Ag concentrations of up to 393 ppm in galena and 1,720 ppm in arseno-pyrite. The distribution of silver among these phases is illustrated by LA-ICP-MS maps of pyrite (both porous and non-porous), arsenopyrite and galena (Fig. 4). Porous pyrite is by far the most significant host for silver, although the majority, if not all silver in pyrite is contained as inclusions of native silver and more rarely acanthite, which extend down to the sub-µm scale, rather than in the crystal lattice. Silver concentrations in galena are uniform with no evidence of grain-scale zoning.



A further finding is that arsenopyrite is compo-sitionally zoned with respect to gold (Fig. 4). This is further strong evidence that the primary sulfides contain precious metals. These precious metal distributions contrast markedly with those seen in ~1.6 Ga IOCG systems in the region, which typically contain gold in native form, and where arsenopyrite is both rare and never shows such stunning concentrations of Ag and Au.

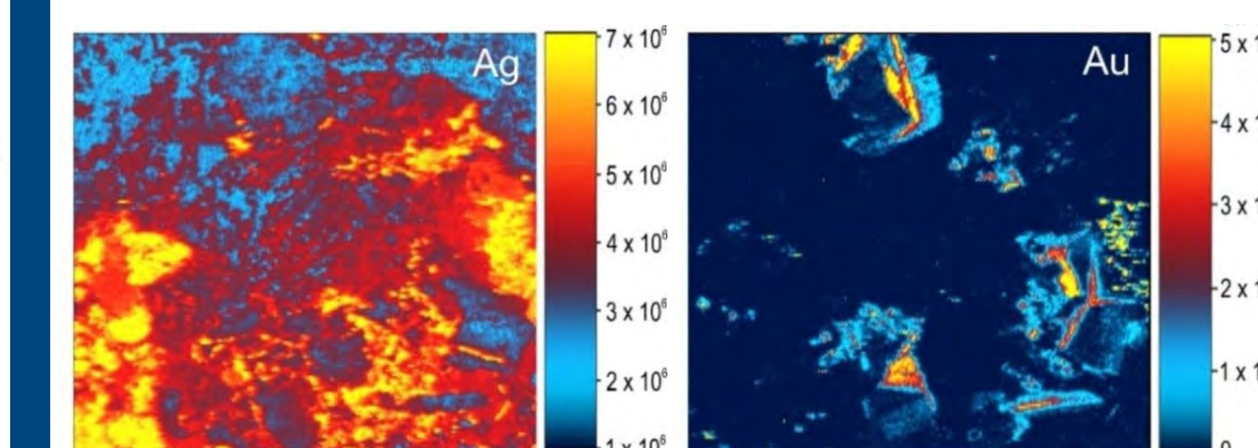


Fig. 4. BSE image (top) and LA-ICP-MS element maps for Ag and Ag in an assemblage containing pyrite (Py), galena (Gn), and arsenopyrite (Apy). Silver preferentially occurs as very fine inclusions of native silver in pyrite (e.g. bottom left of Ag map). Scales in counts-per-second.

6 Discussion

The Paris silver deposit exhibits a number of features that makes it distinct from other Mesoproterozoic deposits in the Gawler Craton. Among the several unanswered questions about the deposit is the timing of mineralization, and the relative timing of the identified paleosupergene processes that gave rise to the chlorine-bearing minerals and oxidized ores.

Ongoing exploration drilling in the vicinity of the deposit and our ongoing petrographic studies will doubtless resolve these questions in the future as we work towards a paragenetic scheme that correlates observed mineral assemblages with the sequence of events that led to the unusual Ag-enrichment, and also explains why this took place. We believe that Fe-oxide-bearing assemblages in the skarn will play an important role in achieving these goals.

7 Conclusions

Based on data presented here, the Paris silver deposit is a complex, poly-stage system, with silver present as inclusions of native silver, acanthite and chlorargyrite. Some silver occurs substituted within common sulfides - primarily in galena, arsenopyrite and pyrite. The deposit features a pronounced Mn-rich signature that can be related to skarn in a distal setting relative to the source intrusive, as well as a characteristic enrichment in halogens. Brecciation of early-formed sulfide clasts is suggestive of overprinting.

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