In situ phosphate dating of orogenic gold mineralization at Paulsens Mine, southern Pilbara

by

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Paulsens is a mesothermal orogenic gold deposit situated on the southern margin of the Pilbara Craton in the northern Capricorn Orogen of Western Australia (Fig. 1) and is the only operational gold mine in the region. The mine is hosted within Archean rocks of the 2775–2629 Ma Fortescue Group in the northwestern part of the Wyloo Inlier (Thorne and Trendall, 2001) and is situated adjacent to the Hardey Fault, a splay of the crustal-scale Nanjilgardy Fault (Johnson et al., 2013) (Fig. 1). Regional-scale deformation is believed to be related to the 2215–2145 Ma Ophthalmia (Martin and Morris, 2010; Rasmussen et al., 2005) and 1820–1770 Ma Capricorn Orogenies (Tyler and Thorne, 1990). Despite its economic importance (total endowment of 1 114 000 ounces of gold) little is known about the absolute timing of gold mineralization. However, it has been considered to be associated with either the 1820–1770 Ma Capricorn Orogeny or synchronous with gold mineralization at Mt Olympus to the southeast, which has been dated at c. 1738 Ma (Şener et al., 2005). Understanding the relationships between the timing of gold mineralization, hydrothermal alteration, and the regional structural evolution will provide a more robust exploration model for the northern part of the Capricorn Orogen.

Ore deposit geology

Gold at Paulsens is hosted in a 40 m-wide quartz–sulfide vein that occurs within a folded and faulted gabbro sill, the c. 2701 Ma Paulsens mine gabbro (Fielding et al., in prep.) within the Hardey Formation of the Fortescue Group. The gold predominantly occurs along the margins of the quartz vein in two lodes termed Paulsens upper zone and Paulsens lower zone.

The two mineralized lodes have unique characteristics making them easy to differentiate (Fielding et al., in prep.). Upper zone mineralization has massive to brecciated pyrite. Visible gold is rarely present in hand specimens, although petrographic studies show that microscopic free gold is present in two distinct styles. Early gold forms as rounded inclusions up to 200 µm in size within the cores of massive pyrite crystals (Fig. 2a). This style of gold has silver contents ranging from 8 – 8.5 wt% and has a simple monocrystalline twinned microstructure (Hancock and Thorne, 2016). The second style of gold is located along the grain boundaries of fractured and brecciated pyrite (Fig. 2b) and represents either a local remobilization of pre-existing gold from the massive pyrite cores, or the introduction of new gold from a secondary hydrothermal event. This style of gold has a lower silver content of 6.6 – 7.2 wt% and has a simple monocrystalline microstructure and some twin planes, suggesting that they were not subject to any major deformation (Hancock and Thorne, 2016).

Lower zone mineralization is predominantly sulfide free, but contains abundant graphitic stylolites and wall rock inclusions of carbonaceous shale that form parallel to the vein margin giving it a laminated appearance (Fielding et al., in prep.). Abundant visible gold forms along the wallrock inclusions and graphitic stylolites. This style of gold is similar to the second phase of gold in the upper zone; it contains a silver content of 6.8 – 7.6 wt% and has a simple polycrystalline microstructure with both polysynthetic and incoherent twins (Hancock and Thorne, 2016).

Age of gold mineralization and hydrothermal activity

Euhedral xenotime crystals interlocking with massive pyrite (Fig. 2c) that contains rounded inclusions of gold were dated at 2403 ± 5 Ma (Fielding et al., in prep.). Additionally, in situ analysis of monazite from hydrothermally altered parts of the Paulsens mine gabbro adjacent to mineralization has been dated at 2398 ± 37 Ma, and monazite intergrown with white mica from highly altered sedimentary rocks surrounding other mineralized veins are dated at 2403 ± 38 Ma (Fig. 2d) (Fielding et al., in prep.). The c. 2400 Ma age is interpreted to date the timing of crystallization of the auriferous quartz–sulfide veins and hence the primary gold mineralizing event.

In areas where the pyrite has been brecciated by subsequent deformation, xenotime grains have undergone dissolution and reprecipitation reactions whereby primary

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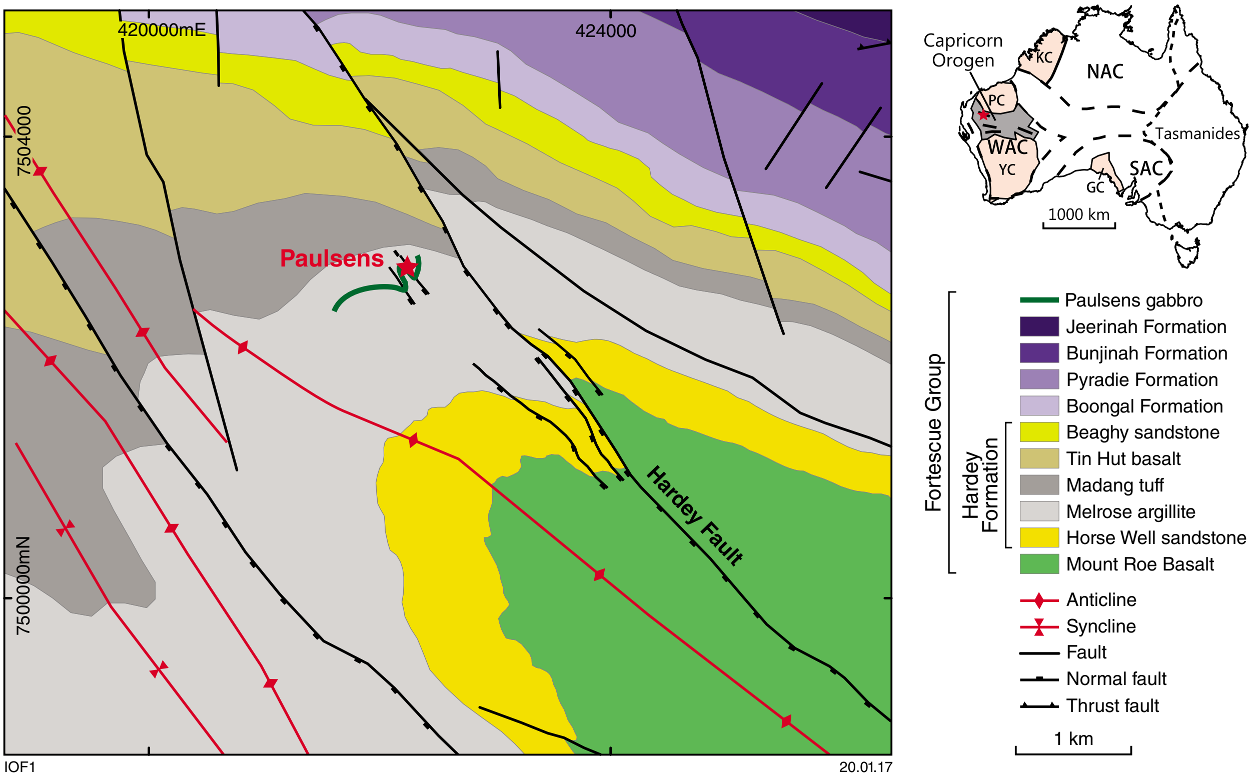

Figure 1. Local geology map showing the Paulsens gold mine in the northwestern part of the Wyloo Inlier and the stratigraphy of the Hardey Formation subdivided into five informal members. Abbreviations: GC, Gawler Craton; KC, Kimberley Craton; NAC, North Australian Craton; PC, Pilbara Craton; SAC, South Australian Craton; WAC, West Australian Craton; YC, Yilgarn Craton (after Fielding et al., in prep).

xenotime cores dated at c. 2403 Ma are surrounded by newly grown xenotime dated at 1680 ± 9 Ma (Fig. 2e) (Fielding et al., in prep.). Additionally, euhedral xenotime from a calcite vein associated with gold values of 48 ppm Au is dated at 1655 ± 37 Ma (Fielding et al., in prep.). The c. 1680 Ma age is interpreted to date the timing of deformation and hydrothermal activity associated with pyrite brecciation and the growth of secondary gold that forms along fractures and grain boundaries, as well as the emplacement of auriferous calcite veins. However, it is not certain if the gold has been remobilized locally from the massive pyrite grains during deformation or if the event represents the introduction of new gold during hydrothermal activity.

Additional hydrothermal activity in the region is recorded within two carbonaceous phyllites containing monazite–florencite porphyroblasts (Fig. 2f). Monazite within the porphyroblasts yielded dates of 1730 ± 28 Ma and 1721 ± 32 Ma (Fielding et al., in prep.) indicating hydrothermal activity at this time.

Regional-scale tectono-thermal activity

The ages obtained for the two main hydrothermal alteration and gold mineralizing events are intriguing as they do not correspond to any of the known tectono-thermal events in the northern Capricorn Orogen including the Ophthalmia and Capricorn Orogenies. However, they can be correlated to events elsewhere in the Pilbara Craton and Capricorn Orogen. At c. 2400 Ma widespread hydrothermal activity is recorded throughout the western Pilbara by the growth of monazite in low-grade phyllitic schists (Rasmussen et al., 2005), as well as by the resetting of high uranium zircons from tuffaceous mudstones of the Hamersley Group (Pickard, 2002). The growth of monazite–florencite porphyroblasts at c. 1730 Ma is coeval with the timing of gold mineralization and dextral strike slip faulting at the Mt Olympus deposit (Şener et al., 2005) to the southeast. The timing of gold mineralization, deformation and hydrothermal activity at c. 1680 Ma is synchronous with 1680–1620 Ma Mangaroon Orogeny that affected rocks of the Gascoyne Province farther to the south (Sheppard et al., 2005), and is synchronous with the growth of hydrothermal monazite and xenotime within crustal scale faults at Tom Price and the Soansville Group in the Pilbara Craton (Rasmussen et al., 2007a,b). These results suggest that lithospheric-scale faults such as the Nanjilgardy Fault, or their splays such as the Hardey Fault, were reactivated multiple times, each time acting as a conduit for potential mineralizing hydrothermal fluids.

At the Paulsens gold mine, two mineralizing events are defined at c. 2400 and 1680 Ma. With this knowledge, the exploration search area can be extended to include older rocks in the Pilbara region while focusing exploration efforts around major lithospheric-scale faults and their splays.

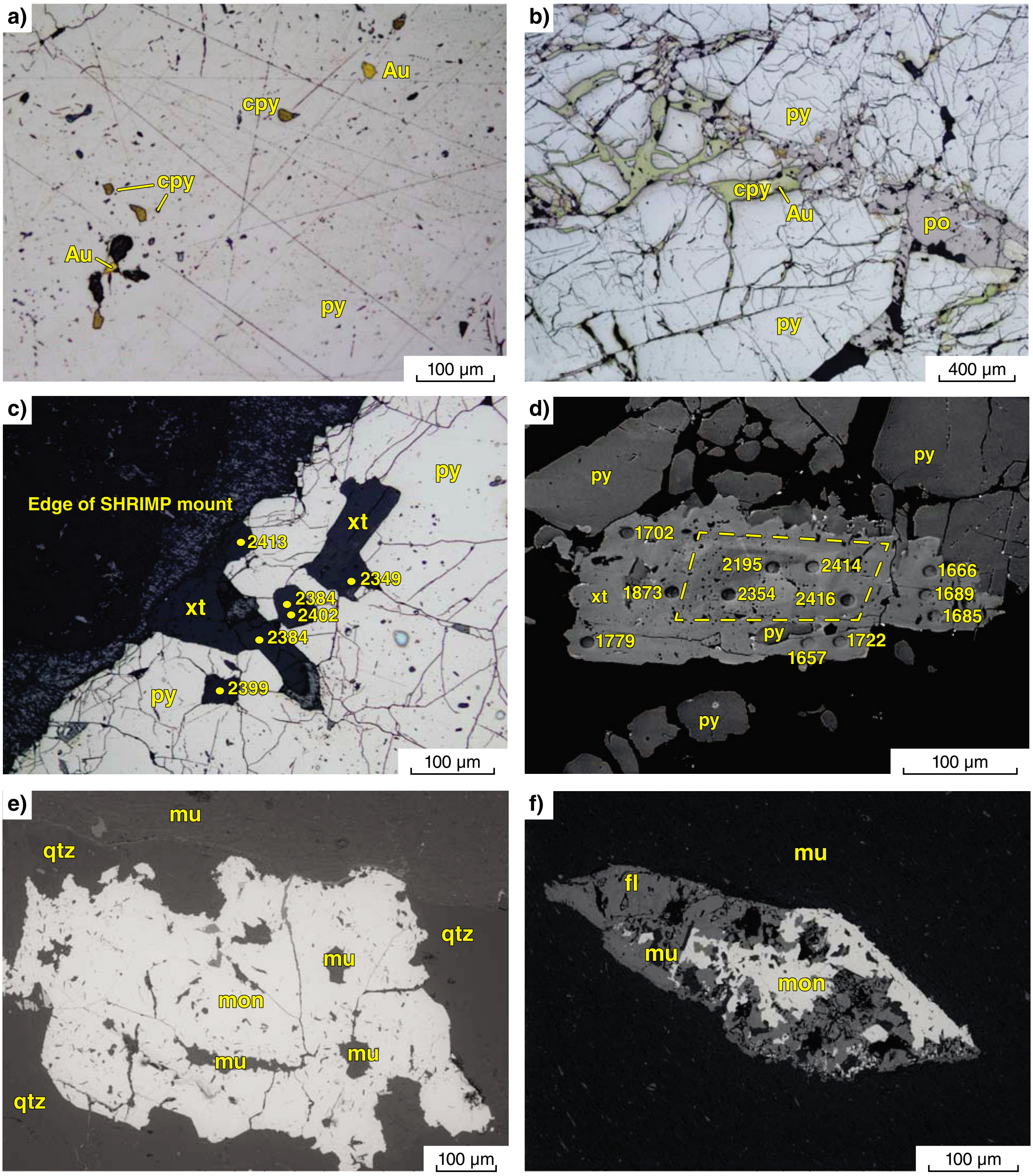

Figure 2. a) Rounded inclusions of gold and chalcopyrite contained within pyrite; b) brecciated pyrite with free gold, chalcopyrite and pyrrhotite along the fractures; c) reflected light image (RFL) of interlocking crystals of euhedral xenotime and pyrite, SHRIMP analysis spots shown by yellow dots; d) high-contrast back scattered electron scanning microscope (BSE-SEM) images of subhedral xenotime crystals that have undergone dissolution and reprecipitation reactions resulting in c. 2400 Ma cores surrounded by newly grown c. 1680 Ma rims. The oval pits are SHRIMP analysis sites; e) BSE-SEM image of monazite intergrown with muscovite and quartz from the alteration zone surrounding a mineralized quartz vein; f) BSE-SEM image of monazite-florencite porphyroblasts within a carbonaceous phyllite. Abbreviations: Au, gold; cpy, chalcopyrite; fl, florencite; mon, monazite; mu, muscovite; po, pyrrhotite; py, pyrite; qtz, quartz and xt, xenotime

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