

EVIDENCE OF A GRANITE-RELATED SOURCE FOR THE BRAIDWOOD-ARALUEN-MAJORS CREEK GOLDFIELDS, NSW, AUSTRALIA

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Introduction

More than 40 tonnes of gold have been produced from alluvial placer deposits in the Braidwood-Araluen area of southeastern New South Wales (Middleton, 1970). Most of this gold appears to have been derived from the roof zone of the Braidwood Granodiorite. Granite-hosted vein and disseminated lode deposits are also preserved within the pluton, particularly in the Majors Creek area. Evidence from Dargues Reef and other deposits at Majors Creek indicates that igneous-hydrothermal processes accompanying emplacement and crystallisation of the Braidwood Granodiorite were fundamental in the formation of these deposits.

The Braidwood Granodiorite is a major pluton comprising the northern part of the essentially I-type Bega Batholith (Chappell et al., 1988). The pluton is a multiple intrusion formed by at least two separate injections of magma of very similar composition. Both are magnetite-bearing, metaluminous and unfractionated with high K, Rb, REE, Ba and Sr and $\text{Fe}_2\text{O}_3/\text{FeO}$ ratios of 0.45 to 0.70 (Wyborn and Owen, 1986). They now form two meridionally trending phases separated in places by narrow screens of Ordovician metasedimentary rocks. The main Majors Creek lode gold deposits occur within the western phase of the intrusion, but small deposits are also recorded from the more central part of the pluton and within the eastern phase (Gilligan, 1974). Recorded gold production from the Majors Creek lodes is 0.85 tonnes (NSW Depart. Min. Resources, 1997).

Primary gold mineralisation

The gold deposits at Majors Creek consist of mineralised alteration zones in granodiorite and associated aplites, as well as discrete quartz and quartz-calcite veins in granodiorite and the immediately adjacent country rocks (Gilligan, 1975, Wake and Taylor, 1988). These are essentially gold-dominant deposits but with minor base metals, particularly Cu but also including As, Bi, Mo, Pb and Te. The Dargues Reef deposit at Majors Creek has been studied in greatest detail (McQueen and Perkins, 1995) and provides evidence on the general ore-forming processes for these deposits. Lodes at this deposit consist of narrow zones (0.6-10 m wide) of intense sericitic alteration and pyritisation (15-30% pyrite) enclosed in areas of propylitic alteration. Deposition of barren euhedral-subhedral pyrite accompanied early-stage alteration and was followed by deposition of irregular pyrite containing numerous small inclusions of silicates, calcite, chalcopyrite, Bi sulfosalts, galena, gold, trace tellurides, native bismuth and pyrrhotite. The gold varies in fineness from 810-940. Separate aggregates of chalcopyrite, Bi sulfosalts and tetrahedrite are intergrown with the silicate alteration minerals. The unaltered host rock at this deposit is a light coloured, equigranular granodiorite containing normally zoned plagioclase (An_{30-60}), K feldspar, quartz, brown-green hornblende, minor chlorite-altered biotite and accessory magnetite, apatite, sphene, zircon and trace pyrite. This rock shows obvious hydrothermal alteration around the deposit extending up to 80 m from the lodes. Major mineralisation and accompanying alteration are localised on the northern side of a diorite dyke with some minor mineralisation sporadically developed along

the southern margin. Small aplite dykes and pegmatite veins are also a feature of the mineralised zones. These are unaffected by the intense sericitic alteration and appear to have accompanied introduction of the hydrothermal alteration fluids. The geochemistry of variably altered rocks at Dargues Reef indicates that the main chemical changes during wall rock alteration involved progressive loss of Na₂O and some CaO, resulting in relative enrichment in K₂O and Al₂O₃, and addition of CO₂, S and possibly some SiO₂. This is consistent with conversion of a dominantly quartz-plagioclase-K feldspar-hornblende-magnetite assemblage to a quartz-sericite-calcite-lesser K feldspar and pyrite assemblage in the most intensely altered sericitic zones. Other areas of sericitic alteration with disseminated barren euhedral-subhedral pyrite occur along the western margin of the Braidwood Granodiorite. Some of the gold-bearing quartz-calcite veins in the Majors Creek area also grade laterally or at depth into low grade or barren, coarse-grained pyrite mineralisation.

Origin of primary mineralisation

Dating of sericite (K-Ar method) from the intense alteration zones surrounding two of the lodes at Dargues Reef has provided dates of 411±5 Ma and 400±4 Ma (McQueen and Perkins, 1995). These dates overlap within error, and are also statistically indistinguishable from established ages for the Braidwood Granodiorite of 401-415±4 Ma (by K-Ar), 399±6 Ma (by Rb-Sr; Wyborn and Owen, 1986) and 402±6 Ma (preliminary SHRIMP dating of zircons, I. Williams pers. com., 2003). This is consistent with the mineralisation occurring close to the time of crystallisation of the Braidwood Granodiorite and would rule out a previous suggestion that the Dargues Reef deposit could be related to Late Devonian epithermal mineralisation in the Eden-Yalwal rift (Wake and Taylor, 1988).

Fluid inclusion data for alteration quartz intergrown with sericite, calcite and sulfides in the lodes at Dargues Reef indicate CO₂-bearing fluids of low to moderate salinity (<16 equiv. wt% NaCl) and medium to low temperature (<350° C, Wake and Taylor, 1988; McQueen and Perkins, 1995). Some CO₂-rich fluid inclusions that homogenise in the vapour phase, would have formed from very dense vapour, suggesting fairly high pressures (>500 bars). There is evidence for multi-stage fluid evolution from inclusions in different generations of quartz. These types of fluids closely match those commonly responsible for mesothermal gold mineralisation, including in intrusion-related gold systems (Lang et al., 2000; Groves et al., 2003).

Stable isotope data for Dargues Reef indicate, or are consistent with, a granite-related origin for the mineralisation at this deposit. Sulfur isotope ratios in pyrite from the mineralisation ($\delta^{34}\text{S}$, -0.4 to -3.4‰) and disseminated pyrite in the host granodiorite ($\delta^{34}\text{S}$, 1.4 to 2.5‰) are consistent with a magmatic source of the sulfur. Carbon isotope determinations for calcites from the mineralisation indicate $\delta^{13}\text{C}$ values for the fluid close to 0 ‰, consistent with a magmatic C source. Oxygen isotope data for calcites from the ores (6.5-10.9‰) and late-stage veinlets (6.5‰) indicate fluid $\delta^{18}\text{O}$ values of between 0.5-7.1‰ (for the temperature range 250-350° C) and implicate fluids similar to those in intrusion-related systems, with some possible limited intermixing of isotopically lighter, probably meteoric fluid (McQueen and Perkins, 1995).

A detailed Pb isotope study has been previously carried out on the Braidwood Granodiorite and gold mineralisation at Dargues Reef (Ho et al., 1995). This involved Pb isotope determinations on whole rock, K-feldspar and dispersed pyrite samples from throughout the

intrusion and on pyrite samples from the mineralisation. The data show that the dominant Pb in pyrite at Dargues Reef, including in minor lead-mineral inclusions, is indistinguishable from that in the host granodiorite at the time of emplacement, consistent with derivation of Pb from this source. Intruded rocks include predominantly Ordovician metaturbidites and some Silurian felsic volcanic and minor metasedimentary rocks. This package would have different Pb isotopic characteristics.

The intimate spatial association of primary gold mineralisation with the Braidwood Granodiorite and late aplitic and pegmatitic phases, the style of alteration, the mineralisation geometry, fluid characteristics and stable and Pb isotope features all support a genetic association. The mineralisation was clearly introduced after crystallisation and cooling of the main granodiorite in the western phase of the Braidwood pluton and after emplacement of minor diorite dykes. The presence of crosscutting aplite dykes and pegmatite veins suggests a connection with very late-stage magmatic hydrothermal activity in the already crystallised roof zone or with under cooled upper parts of the granodiorite intrusion. This is also consistent with the fluid temperature and compositional evolution.

Implications for exploration and the source of alluvial gold

Geophysical modelling of the magnetic fabric in the Braidwood Granodiorite (Lackie and Flood, 1991) indicates that the eastern contact of the pluton dips steeply to the east whereas the western contact dips at a low angle to the west. The modelling combined with aspects of the regional geology, also shows that the western phase of the pluton could extend for up to 10 km to the west at shallow depth beneath its coeval volcanics. This geometry is consistent with the intrusion having been tilted about 15-20° to the west after emplacement. It also implies that the Majors Creek lode deposits lie close to the roof zone of the intrusion and that most of this zone has been eroded away in the areas to the east. This would in turn suggest that areas to the west of Majors Creek are prospective for additional granite-related gold mineralisation in the shallow subsurface roof zone of the intrusion and in vein and possibly skarn systems in the overlying rocks.

Erosion of large areas of granite containing small but widespread gold deposits, similar to those at Majors Creek, most likely provided the large amount of alluvial gold found in the regional drainage developed in and around the Braidwood Granodiorite. Much of this gold occurred in high level gravels in Tertiary basins and older terraces along the Shoalhaven catchment. For example, alluvial terraces up to 46 m deep covered an area of about 3,400 hectares on the western side of the Shoalhaven River. These are estimated to have contained 75 million m³ with an average gold content of 0.125 g/m³ (NSW Dept. Min. Resources, 1996). Extensive erosion of the Braidwood Granodiorite dates to at least the Mesozoic and the major alluvial deposits in the Shoalhaven plain are Eocene in age (Ruxton and Taylor, 1982). Progressive reworking of these deposits produced some of the younger placers exploited during early mining. Block faulting and westward tilting during the Tertiary as well as significant capture-initiated drainage changes likely resulted in varying deposition, preservation and reworking of alluvial materials. Much of the gold in the Braidwood-Araluen alluvials is reported to have been very fine-grained and widely distributed. This is consistent with the character of the gold in the known lode deposits, which typically occurs as small inclusions (generally <100 µm and commonly 5-30 µm) in pyrite.

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