A newly discovered major Proterozoic granite-alteration system in the Mount Webb region, central Australia, and implications for Cu–Au mineralisation

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The presence of a major granite-related alteration system has been confirmed in the western Arunta Block — in the remote Mount Webb region (WA/NT border; Fig. 1). According to new petrological, geochemical, and geochronological data from the Mount Webb Granite and its comagmatic felsic volcanics in the Pollock Hills Formation, this magmatic system has many similarities to granites in other Australian Proterozoic regions where hydrothermal Cu and or Au deposits have been linked to magmatic sources (e.g., eastern Mount Isa Inlier, Gawler Craton). Key criteria that establish this region as prospective are:

- fractionation trends in the granite, clearly evident in the geochemical data;
- magmatic alteration effects (including sodic–calcic, sericitic, and hematite–K-feldspar) in the granite and country rock; and
- evidence of metallogenically significant hydrothermal interaction with the country rock.

A preliminary interpretation of the results of 12 analyses recorded in AGSO's ROCKCHEM database and in Blake et al. (1977: BMR Bulletin 197) suggested that the Mount Webb Granite and felsic volcanics of the adjacent Pollock Hills Formation potentially had primary and alteration characteristics similar to granites of the metallogenically important Williams Batholith (eastern Mount Isa Inlier) and Hiltaba Suite (Gawler Craton), both of which are closely associated with Cu–Au mineralisation (Wyborn 1994: Centre for Ore Deposit & Exploration Studies, University of Tasmania, Master of Economic Geology Course, Manual 2). Reference to '… thicker quartz veins cutting highly altered and brecciated granite west of Pollock Hills' (Blake & Towner 1974: BMR Record 1974/53) further heightened the intrigue. In May 1996, AGSO staff visited the Mount Webb region to collect a suite of samples (Fig. 2) for magma typing, age determination, and alteration mapping and evaluation.

The results described here focus on the Webb 1:250 000 Sheet area, but the granite system extends westward into the Wilson Sheet area, and eastward into the Macdonald, Mount Rennie, and possibly Mount Liebig Sheet areas (Fig. 1). Both the granite system and the alteration are large by Australian Proterozoic granite standards.

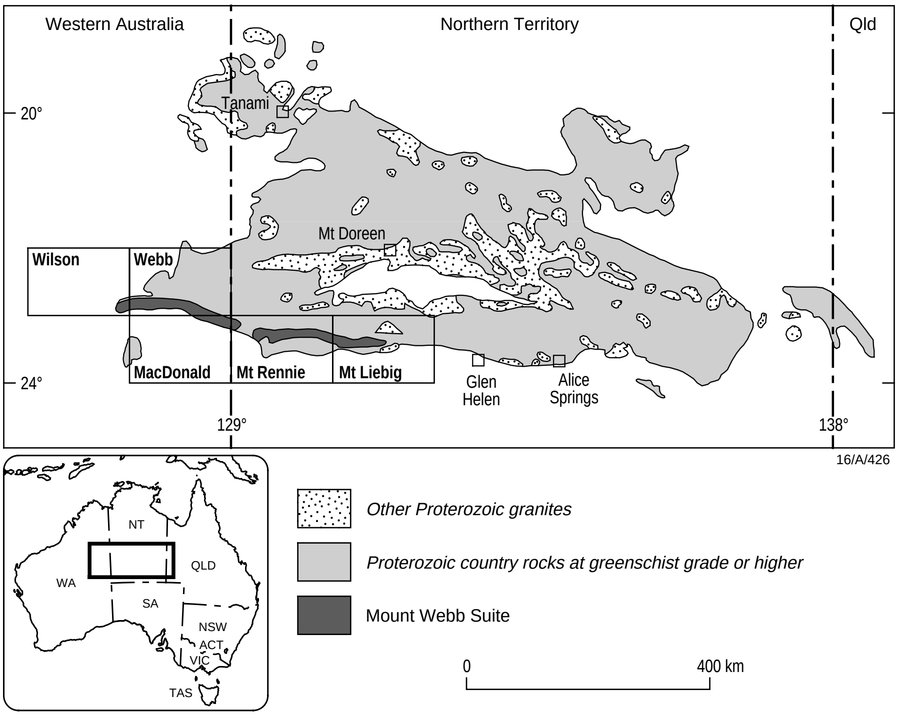

Fig. 1. Location of the Mount Webb region, western Arunta Block.

Petrological data

Country rock

In the Webb Sheet area (Blake & Towner 1974: op. cit.; Blake 1977: Webb 1:250 000 Geological Series —explanatory notes, BMR/AGSO), the Mount Webb Granite intrudes 'unnamed Archaean?' rocks (mainly interbedded quartzite and mica schist, and some amphibolite). Near the inferred contact between granite and amphibolite at the southernmost part of one Archaean? outcrop at Pokali Hills (20 km east of Mount Webb), quartz veins and minor ironstones are prominent, and so too is an overprint (metasomatic?) of quartz, biotite, and magnetite replacing all the primary minerals. Away from the inferred contact, constituents of the country rock in this outcrop are mainly amphibole and plagioclase in the central part, and chlorite, actinolite, and minor greenish biotite in the north, suggesting that the granite has both contact-metamorphosed and metasomatically altered the country rock. The country rock elsewhere in the Sheet area is dominated by quartzite and mica schist; late-stage quartz and quartz–tourmaline veins are abundant, and the rock is locally brecciated (Blake & Towner 1974: op. cit.).

Mount Webb Granite

The Mount Webb Granite is heterogeneous, comprising several types of unaltered granite, sodic–calcic-altered granite, sericite-altered granite, and aplite. Most altered samples are from near the Mount Webb Shear Zone (Fig. 2). All samples are recrystallised, and most have a distinct foliation, suggesting that the granite has been affected by a post-intrusion metamorphic event.

Essentially ***unaltered granite*** ranges from mafic diorite/tonalite through granodiorite, monzogranite (dominant), and syenogranite, to aplite. Some late felsic fractionated phases contain fluorite and nodules of tourmaline ± quartz. These rocks have a typical I-type mineralogy, and are composed of hornblende, biotite, magnetite, plagioclase, K-feldspar, and quartz. Magnetite, generally with exsolution lamellae of ilmenite, is common in most samples, but is more abundant in the diorite/tonalite; sulphides are extremely rare. Rimming of the magnetite by titanite is one of the tangible effects of alteration.

Sodic–calcic alteration is characterised by the assemblage diopside + epidote ± tremolite (only present in the more deformed samples). This alteration type is prominent in a linear shear zone trending 310° both to the northwest and southeast of Mount Webb. Few quartz veins bisect the rocks affected by this alteration type, and open spaces were not observed. Most samples contain titanite, and have albite/oligoclase as their only feldspar. Neither sulphides nor anomalous concentrations of elements are apparent in the samples.

Sericite alteration is more restricted than the sodic–calcic alteration, and is usually associated with brecciated and fractured granite cut by quartz veins with open spaces. A higher modal abundance of sulphides accompanies this type of alteration. In thin section, the sericite consists mainly of fine grains concentrated in veins aligned parallel to the foliation. Opaque phases are rare: some samples have magnetite or small pyrite grains; one has chalcopyrite. Two weathered samples containing visible malachite have Cu concentrations of 348 and 278 ppm; thin sections show that they consist mainly of goethite, which was probably formed as a weathering product of primary sulphides.

Quartz veins carrying sulphides are more prominent in the areas of sericitic alteration, where the granite also tends to be more brecciated and bears tourmaline and fluorite. The sulphides are mainly pyrite, though galena was observed in one sample with 1800 ppm Pb, and another sample has 145 ppm Mo.

Aplite veins, common in the more felsic granite, are probably the products of late-stage magmatic processes.

Pollock Hills Formation

The felsic volcanics of the Pollock Hills Formation consist mainly of black porphyritic dacite and rhyodacite overlain by tuffaceous and non-tuffaceous sedimentary rocks (Blake & Towner 1974: op. cit). Alteration is less pervasive in the volcanics than in the Mount Webb Granite, and two alteration types are evident: hematite and epidote. Overall, even the least altered volcanic samples have a markedly recrystallised texture in thin section, suggesting that they are metamorphosed.

The ***least altered volcanics*** are mainly porphyritic ignimbrites with phenocrysts of plagioclase, magnetite, and quartz in decreasing order of abundance. Phenocrysts of ferromagnesian silicate minerals (altered to epidote and/or biotite) are rare. The ignimbrites comprise two broad types: those with abundant lithic fragments and crystals, and those with a lower crystal and lithic content. The lithic-poor ignimbrites contain flattened pumice clasts and abundant spherulites in the matrix; the spherulites indicate that the matrix comprises devitrified volcanic ash. Lapilli tuffs were observed at one locality. Fine-grained magnetite is scattered throughout the groundmass, which is commonly recrystallised. Although, small grains of pyrite/chalcopyrite occur in the spherulite-bearing volcanics, most of the volcanics have magnetite as the dominant opaque mineral; primary sulphides are rare, reflecting the high oxidation state of the magma.

Hematite alteration in the volcanics is possibly related to two events. Firstly, as noted by Blake & Towner (1974: op. cit.), hematite alteration is more prominent at the top of the volcanics, near their contact with the sedimentary rocks of the Pollock Hills Formation. Red hematite-rich layers interspersed with these sedimentary rocks suggest that oxidising atmospheric conditions prevailed during sedimentation and extrusion, so the hematite may be related to meteoric fluids rather than to hydrothermal/magmatic processes. Some of this early hematitic alteration is also cut by late epidote alteration.

Secondly, hematite alteration is evident in highly sheared volcanics sampled away from the sediment/volcanic interface. At one locality, northwest of Kiwirrkurra, a hematite-rich, K-feldspar-altered volcanic rock associated with an

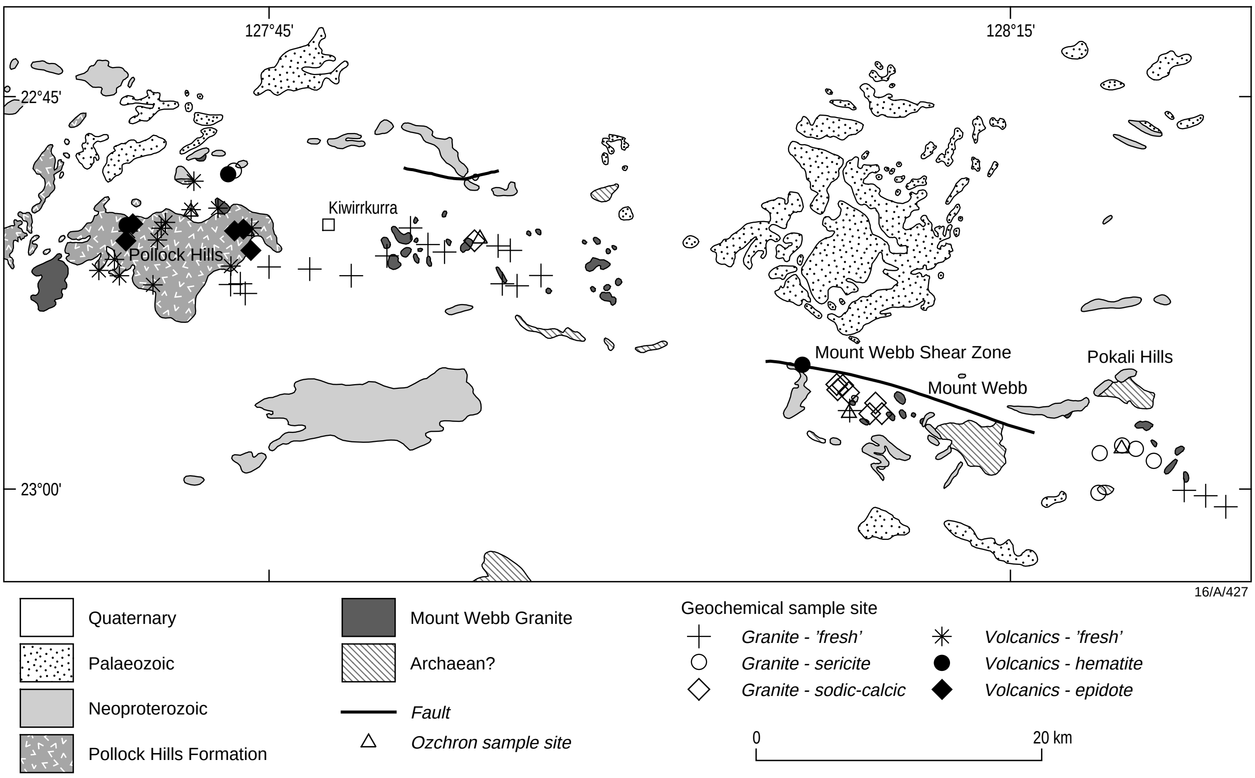

Fig. 2. Geology of the Mount Webb region (based on Blake 1977: op. cit.).

ironstone cuts a chlorite/sericite-altered volcanic rock, and is therefore later in the paragenesis. At another, an isolated volcanic outcrop northwest of Mount Webb, hematite alteration is also apparent in a sample of K-feldspar-bearing rock containing anomalously high potassium. Shearing at both localities suggests that this type of hematite alteration is due to another event, distinct from that formed at the sediment/water interface early in the paragenetic history.

Epidote alteration is common in the volcanics. In thin section, it is pervasive and texturally destructive. It progressively destroys any original igneous textures, and produces an end-member assemblage of epidote + quartz. Mineralogically and chemically it closely resembles the sodic–calcic alteration of the Mount Webb Granite, and both are focused in shear zones trending ca 310°.

Mafic dykes

Mafic dykes with a prominent north-northwesterly trend are prominent in the

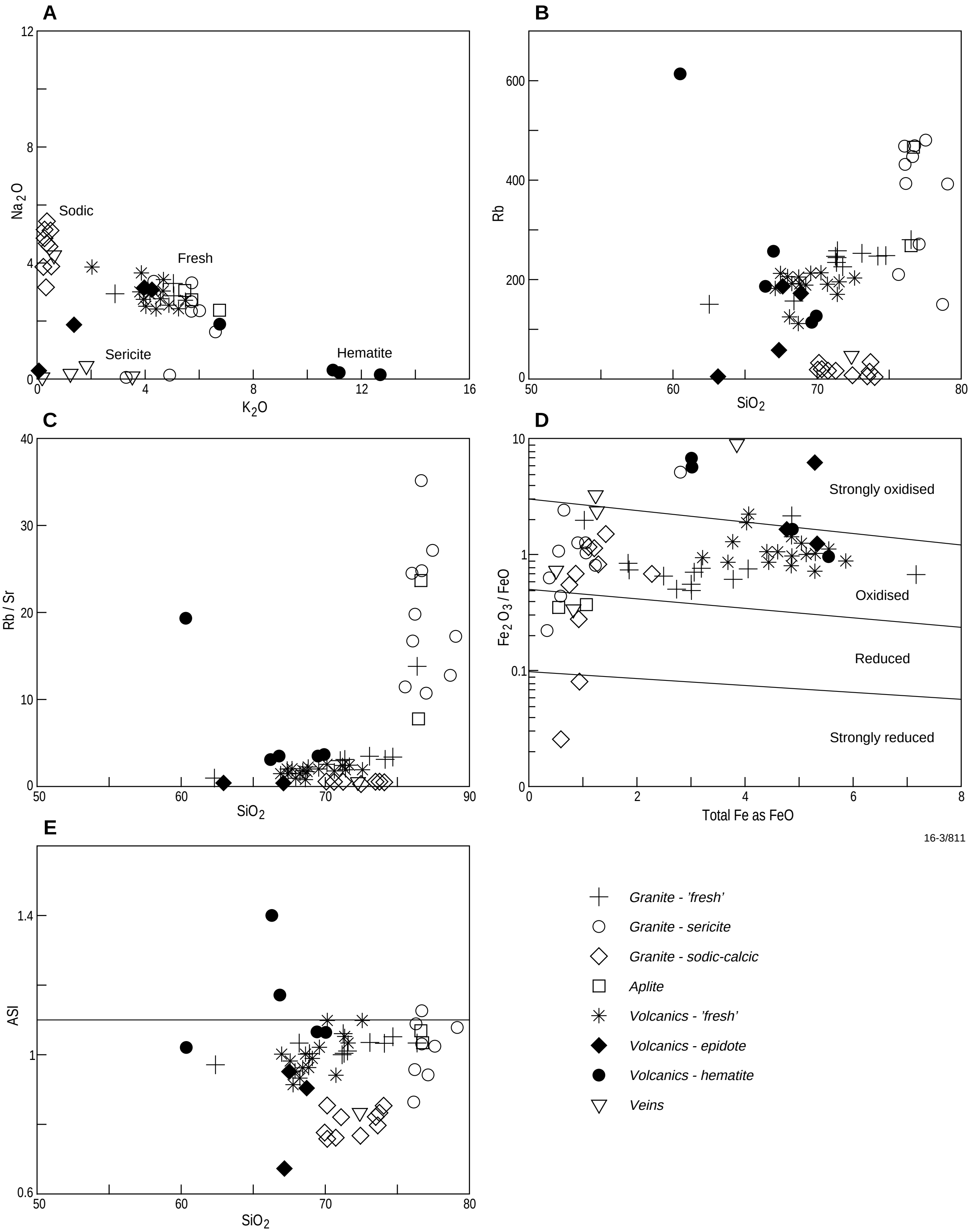

Fig. 3. Geochemical variation diagrams for whole-rock geochemical data from the Mount Webb region.

Table 1. Summary of new U–Pb SHRIMP and Sm–Nd results from the Mount Webb region

Sample no.	*Rock unit*	*Rock type*	*SiO_2*	*Age (Ma)*	*Xenocrysts*	*εNd_i*	*T_{DM} (Ma)*
96496035	Mount Webb Granite	monzogranite	74 wt %	1643 ± 4	1680–1690 Ma (4 grains), ~1775 Ma (2 grains), 1860–1870 Ma (2 grains)	–2.1	2327
96496028A	Mount Webb Granite	granodiorite	68 wt %	1639 ± 5	1690 Ma (1 grain)	–2.0	2322
96496011	Mount Webb Granite	sericite-altered granite	77 wt %	1639 ± 5	Complex with inheritance patterns at ~1680, ~1760, and 1830–1877 Ma		
96496024	Pollock Hills Formation	lithic-rich ignimbrite	68 wt %	1643 ± 13 (NB: one grain only)	Complex populations 1680–1690, 1862 ± 4 (dominant), single grains at 1966, 2590 Ma	–1.5	2325
96496009	unnamed dolerite	dolerite	48 wt %	976 ± 3 (zircon) 972 ± 8 (baddelyite)	~1630 Ma	2.3	

area, particularly in the granite outcrops east of the Pollock Hills, but do not intrude the Neoproterozoic and younger sequences (Blake 1977: op. cit.). In thin section, most appear to be pristine, consisting of plagioclase, clinopyroxene, and orthopyroxene; they also contain sulphides (mostly pyrite, but some chalcopyrite). A few of them evince pronounced alteration effects, and are probably older, but they all lack deformational and metamorphic effects, suggesting that they are much younger than the granite.

Geochemistry results

Sixty samples were collected for analysis: 28 granites, nine aplites and quartz veins, 18 volcanic rocks, and five dolerites. The alteration effects in the granites and volcanics are clearly shown in a plot of Na_2O vs K_2O (Fig. 3A). The sodic–calcic-altered samples are depleted in K_2O, whereas the more strongly sericite-altered samples have lost Na_2O. In contrast, the hematite-altered samples show a marked enrichment in K_2O, similar to that in the ~1500-Ma granites in the Cloncurry district (Wyborn in press: Australian Journal of Earth Sciences).

The plots for Rb and Rb/Sr show exponentially increasing values with increasing SiO_2 (Figs. 3B and C). On the Fe_2O_3/FeO vs total Fe as FeO plot (Fig. 3D) of Champion & Heinemann (AGSO Record 1994/11), most samples lie in the oxidised field. The ASI values (molecular $Al_2O_3/[K_2O + \{CaO - 1/3P_2O_5\} + Na_2O]$) are <1.1, indicating that the samples are metaluminous to weakly peraluminous. All these features are characteristic of granites associated with Cu–Au mineralisation in the Proterozoic (see also Wyborn 1994: Geological Society of Australia, Abstracts, 37, 471–472.)

Geophysical data

Parts of the hydrothermal alteration system occur in the Webb and Wilson Sheet areas, for which no airborne geophysical data are in the public domain. We recorded ground magnetic observations on a Geoinstruments susceptibility meter (model JH–8). Susceptibilities range from 200 to 600 SI units × 10^{-5} for the (dominant) monzogranite, and 2000–5000 SI units x 10^{-5} for the tonalite/diorite, reflecting increasing modal abundance of magnetite with decreasing SiO_2. The felsic volcanics also have high susceptibilities, generally from 3000–5000 SI units x 10^{-5}, mirroring the abundant magnetite phenocrysts and the ubiquitous fine-grained magnetite in the groundmass.

Alteration zones in both the granite and the volcanics have much lower magnetic susceptibilities (generally <40 SI units x 10^{-5}), reflecting the destruction of magnetite in the areas of sodic–calcic alteration. Although magnetite is generally absent from the sericite-altered areas, some high-susceptibility localities are apparent there.

The country rock generally has low measured susceptibilities, except amphibolite in the Pokali Hills area, where susceptibilities are variable and range from 200–5000 SI units x 10^{-5}. Those rocks with particularly high susceptibilities had metasomatic biotite and magnetite in thin section. The fresh mafic dykes, including the dated sample, have high susceptibilities (>4000 SI units x 10^{-5}); altered dykes have low susceptibilities.

Geochronology results

Page et al. (1976: BMR Journal of Australian Geology & Geophysics, 1, 1–13) obtained a combined Rb–Sr isochron age of 1494 ± 25 Ma (recalculated with the 1.42 x 10^{-11} yr^{-1} constant for Rb^{87}) and an initial Sr^{87}/Sr^{86} ratio of 0.7114 ± 0.004 for the Pollock Hills Formation and

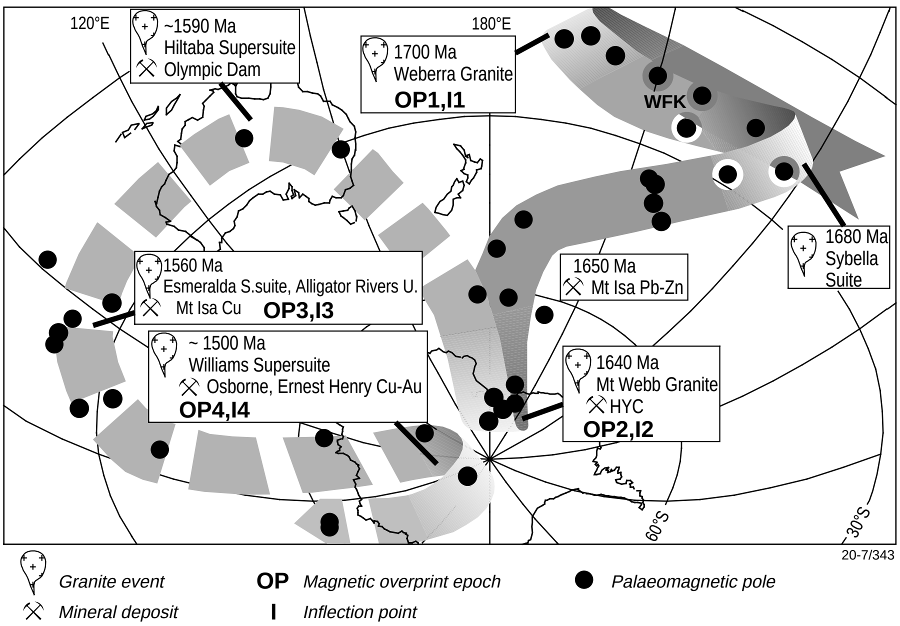

Fig. 4.

The Proterozoic APWP for Australia showing the locations of palaeomagnetic poles. Major granite and ore deposit events are also shown (based on Loutit et al. 1994: op. cit.).

Mount Webb Granite. Such a high initial ratio for an I-type granite suggests that the Rb–Sr data have been reset, so samples (five) were selected for SHRIMP U–Pb zircon dating (Table 1).

The three granite samples yield ages of 1643 ± 4, 1639 ± 5, and 1639 ± 5 Ma, indicating that they all belong to the one magmatic system. Inherited zircon populations include 1680–1690, 1775–1769, and 1830–1877 Ma. A corollary to these results is that the anomalously young Rb–Sr age might reflect the ubiquitous late metamorphic overprint of both the volcanics and granite.

No satisfactory igneous crystallisation age was obtained for the volcanics of the Pollock Hills Formation, as the zircon populations in the sample studied are exceedingly complex. This sample is dominated by inherited ~1860-Ma zircon; a population at ~1680–1690 Ma is also prominent; older inheritance at ~1970 Ma and 2590 Ma is also apparent. These populations are distinctly older than those of the granite; only one grain analysed from the volcanic sample was close to the age of the granite (~1640 Ma). The dated sample has abundant lithic fragments, and is likely to have xenocrystic zircon populations derived from these fragments. Jagodzinski (1992: AGSO Record 1992/9; see also pp. 23–25 in this newsletter) has reported a similar case in the Coronation Hill region (NT), where an ignimbrite dominated by lithic fragments yielded mainly xenocrystic zircon populations and only a few magmatic grains.

Nd isotopic data from the samples of the Mount Webb Granite and volcanics gave εNd_i values of –1.5 to –2.1 and single-stage T_{DM} model ages of ~2320 Ma (Table 1), similar to those obtained elsewhere in the Arunta Block (Sun et al. 1995: Precambrian Research, 71, 301–314). They indicate that the felsic magmas were derived from a pre-existing crustal source.

Both magmatic zircon and baddelyite were dated from an unmetamorphosed dolerite dyke. They recorded Neoproterozoic ages of 976 ± 3 and 972 ± 8 Ma respectively, dispelling the notion of any connection between the dykes and the Mount Webb Granite. These dykes are considerably younger than the Stuart Pass Dolerite, which is abundant throughout the Arunta Inlier and has a well-defined Sm–Nd mineral isochron age of 1076 ± 33 Ma (Zhao & McCulloch 1993: Chemical Geology, 109, 341–354).

Implications of the 1640-Ma age for the Mount Webb Granite

The new age for the Mount Webb Granite is similar to the 1640 ± 7-Ma age of tuffs in the HYC orebody at McArthur River (Page & Sweet in press: Australian Journal of Earth Sciences). Although the similarity may be purely coincidental (not all tuffs in the north Australian Proterozoic sequences have known Australian sources), it does raise the possibility that the HYC tuffs were derived from the Mount Webb region, especially considering the size of the intrusive event.

It is interesting to note that Loutit et al. (1994: Australasian Institute of Mining & Metallurgy, Publication Series, 5/94, 123–128) observed that most major granite and major ore-forming events correspond to major inflections in the Australian apparent polar-wander path (APWP; Fig. 4). However, no major granite event was then known to correspond to the major hairpin bend at ~1640 Ma. The new data from the Mount Webb Granite provide evidence for such an event. Loutit et al. (1994: op. cit.) asserted that APWP inflections correspond to changes in the direction of crustal plate movement and, therefore, changes in the stress field within the plate. Such changes in stress could allow granitic melts to ascend from the lower crust, explaining the formation of major batholiths at these times.

Mineral potential of the Mount Webb region

Although the present results are preliminary, the primary and alteration geochemistry of the felsic magmas of the Mount Webb region resemble those of other Proterozoic Cu–Au mineralised areas. There is evidence of extensive magmatic alteration (sodic–calcic and sericitic) at some localities, particularly within the more felsic varieties of the granite. Within the sericite-altered granites, fluorite, tourmaline, and sulphides are common accessories, and some of the samples have anomalous F, Cu, and S. Cross-cutting veins also have elevated Mo and Pb values. There is also evidence of metasomatic alteration of the adjacent country rock.

Recent exploration results have confirmed that this truly ‘greenfield’ area may have some economic significance. Semicontinuous rock-chip sampling returned results of 9.1% Cu, 3 g/t Ag, and 0.38 g/t Au over a true width of 4 m, and 0.3% Cu and 8 g/t Ag over a true width of 10 m. An aircore-drilling program has confirmed the presence of three Cu–Au–Ag anomalous areas, of which the largest returned peak values of 0.21 ppm Au and 896 ppm Cu on three adjacent 800-m-spaced grid lines (Aurora Gold Ltd, quarterly report, December 1997).

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