Abstract

The Lower Proterozoic Cullen Batholith in the Pine Creek Geosyncline is associated with a very broad scale of hydrothermal deposits (gold, tin, tungsten, base metals, tantalum, and uranium) which show contrasting geological relationships, spatial distribution and style, temperature and timing of the mineralisation. High heat production (HHP) granites of the batholith (average 5.79 $\mu W/m^3$) are responsible for considerable prolongation of the high heat regime inside and around the batholith and extent of the thermal aureole. Tin, gold, base-metals, uranium, epithermal deposits and thermal springs are the products of the intermitent thermal activity of the batholith over a very broad time span since emplacement in ca. 1 835 Ma up to the present.

The batholith consists of a large cluster of plutons, representing individual magma pulses broadly concentrated into two major magmatic events. Individual plutons are almost tabular discordant intrusions with subhorizontal (ethmolitic) bottoms and roofs. Outward and inward- dipping contacts have been recognized in the geometry of the batholith roof. Inward-dipping contacts of granites are indicated by overlaps of magnetic anomalies and the narrow width of their thermal aureole.

The zonation of the plutons mostly shows cryptic layering and ghost stratigraphy within their shallowly unroofed tops. The Early and Transitional Igneous Suites (EIS and TIS) comprise dominant parts of the major plutons. EIS plutons are usually intruded by the TIS magmas and represent the sub-horizontally stratified roof of the batholith. TIS outcrops either as independent younger intrusions or occupy the internal parts of the batholith, usually underneath the EIS. The Young Igneous Suite (YIS) is an independent group of plutons which intrude either the Early and Transitional Igneous Suites, or occur as satellite bodies, particularly in the northern periphery of the batholith. YIS plutons intrude both the earlier EIS and TIS and show differences in composition and fractionation patterns.

1. EIS granites are mesocratic hornblende-biotite or biotite, undifferentiated, late-orogenic, tin-barren ± metaluminous, monzogranodiorite.
2. TIS granites are biotite, coarse-equigranular, poorly differentiated, late-orogenic, stanniferous peraluminous, monzogranite.
3. YIS granites are medium to fine grained, equigranular, moderately differentiated, post-orogenic, stanniferous, peraluminous, monzosyenogranite.

According to data presented by Stuart-Smith et al. (1993), the emplacement age of EIS is 1 835 Ma (Fingerpost Granodiorite), TIS 1 818–1 825 Ma, and YIS 1 800 Ma (Burnside Granite). Magmatic events spanned time intervals up to 35 Ma. Cooling of the batholith from 800 °C to 300 °C lasted over 100 Ma. Long-term thermal effects on country rocks are manifested by intense magnetization (pyrrhotisation) of the host rocks. Subhorizontal roofs of plutons are characterized by non-magnetic plateaus in the regional magnetic field.

Economic tin and gold mineralisation is located within the inner zone of the thermal aureole spatially and temporally related to the 1 800–1 835 Ma Cullen Batholith. Spatial distribution of both types of deposits is generally controlled by the geometry of the granite contact. The granite contacts may be either inward or outward dipping. Generally older tin mineralisation occurs within endo- and exo-contact areas, mostly associated with TIS plutons. Economic gold mineralisation is more distal, mostly located within the country rocks of the batholith.Tin mineralisation is genetically related to the late YIS granites as their post-magmatic continuum, showing definite distribution patterns along their endo- and exo-contact. On a regional scale the gold mineralisation shows similar zonation, more distal from the granite roof and/or contact, but in detail more controlled by depositional "traps". Fluid inclusion data indicate high-medium formation temperatures for tin mineralisation (500–300 °C) and gold mineralisation (300–100 °C). The main period of gold deposition is younger than high temperature greisen-type tin mineralisation. The age history of the Cullen Batholith fully covers the timing of the tin and gold mineralisation. The age-thermal history of the Cullen Batholith is within the range from 1 835 Ma at about 800 °C, to 1 650 Ma at about 300 °C. It may indicate a time gap between magmatic and hydrothermal temperatures within the Cullen Batholith: about 20 Ma for tin deposition, and about 40 Ma for gold deposition. The hypothermal-mesothermal gold mineralisation in the Pine Creek Geosyncline is a multistage (sedimentary preparation, metamorphic upgrading and hydrothermal mobilisation by the heat of the batholith), long-term process which is represented by a number of quartz vein generations. It is interpreted to have started prior to the Cullen Batholith emplacement (stage I and II), culminated during the heating and subsequent cooling of the country rock around the batholith (stage III) and ceased after the batholith roof cooled below 300 °C. The end of the process is documented by late quartz veins containing gold which crosscut the YIS plutons (eg, Mount Shoobridge Granite). The scenario which has been recognized for the origin of the gold deposits in the Pine Creek Geosyncline is generally compatible to a number of major styles of gold deposits in Australia (Tanami, The Granites, Selwyn and Telfer).

Lead isotope studies of ore sulphides and the YIS Burnside Granite, together with available data from the Mt Bundey Granite and the Proterozoic succession, indicate that the granites were not a significant contributor of Pb to the ore fluids which formed gold deposits. Further, many of the gold deposits have a relatively homogeneous Pb isotope signature and

require broad coeval mineralisation and a homogeneous Pb source on a regional scale. The inferred source is the Archaean basement or its derived sediments which form the lower units of the Proterozoic succession.

A small number of deposits contain galena which is extremely radiogenic. A dyke crosscutting the Burnside Granite contains galenas from different locations which suggest that the dyke represents a feeder zone to an epithermal system which was active in relatively recent times. Galena data from other deposits may be similarly interpreted.The long term of the high temperature regime within and around the Cullen Batholith can be explained by high heat flow as a result of the high heat production of its granites. The occurrence of thermal ground waters in the Douglas Hot Springs, Daly River and Adelaide River Hot Springs, and palaeothermal vents nearby the Old Boiler gold deposit (Marshall et al., 1988) suggests that a component of low-temperature hydrothermal convection associated with the Cullen Batholith was not necessarily restricted to the times when the granites intruded and cooled. Epithermal mineralisation can be traced to recent times.

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