1. Introduction

The Pine Creek Geosyncline is at present receiving renewed attention with the opening of old gold mines and several new discoveries eg. Mt. Todd, Union Reefs and Brocks Creek. This highly productive metallogenic province contains occurrences of gold, base metals, tin, tungsten, tantalum, platinum, palladium and uranium. These resources have been exploited over the past century with periods of major interest during the turn of the century and during the past 20 years (Fig. 1).

A variety of genetic models, ranging from magmatic through hydrothermal to syngenetic, have been postulated in the past for the formation of gold deposits in the Pine Creek Geosyncline. The first discussion on the regional geological factors that control ore deposition in the Brocks Creek-Howley District was by Sullivan and Iten (1952). They recognised that the most important ore deposits are associated with anticlinal and domal structures and that granites may be a controlling factor in the localisation of the mineralisation. Crohn (in Warpole, 1968) classified the deposits into a broad group of hydrothermal, precious and base metal deposits associated with granitoids.

More recently, a group of authors, Needham and Roarty (1980), Goulevitch (1980), Nicholson and Eupene (1984), and Kruse et al. 1990 have suggested an exhalative syngenetic origin, or remobilised syngenetic during dolerite intrusion and/or regional deformation, for gold mineralisation, especially those associated with South Alligator Group lithologies (eg., Mt. Bonnie group of mines and Cosmopolitan Howley).

Studies carried out by Northern Gold NL and Reynolds, Northern Territory over the last three years suggest that syngenetic models for gold mineralisation are less relevant to gold mineralisation in the Howley District than first thought (Wall, 1989; Partington, 1990). Hydrothermal deposits are often found in close association with granites. In general, the driving force for the hydrothermal distribution of metals within and/or outside granitic plutons is either the initial heat content of the plutons or the later addition of heat produced by the radioactive decay of potassium,uranium

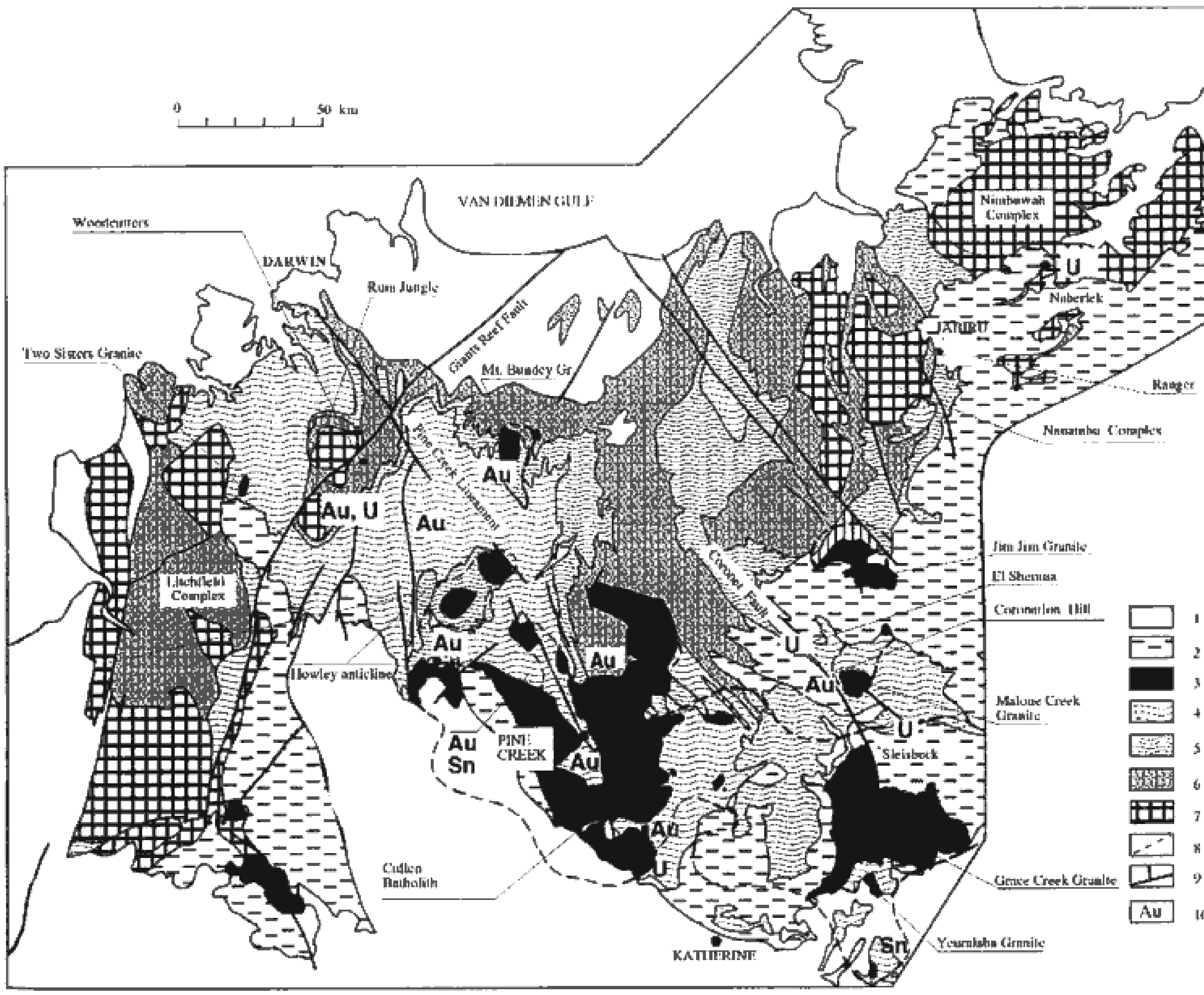

Figure 1. The Pine Creek Plutonic Complex, Northern Territory, Australia. 1 – Mesozoic & Palaeozoic cover, 2 – Upper & Middle Proterozoic, 3 – Granite Batholiths, 4 – 6 Early Proterozoic, 4 – Finness River Group, 5 – South Alligator Group, 6 – Partridge Group & Namoona Group, 7 – Archaean ± Early Proterozoic Metamorphic Complexes, 8 – Outline of the Pine Creek Plutonic Complex at ~ 1 km depth, 9 – Tectonic lineament, 10 – Main mineral centres, Au – gold, Sn – tin, U – Uranium.

thorium and their daughter products inside of the plutons.

Recent studies suggest that the gold mineralisation is related to a mixing of fluids, which produce distinctive fluid inclusions in quartz associated with the gold mineralisation (Sheppard et al., 1991). The gold mineralisation has a distinctive geochemical association, which in combination with the fluid inclusion data provides a preliminary method of assessing the economic potential of anomalous mineralisation. The fluid inclusion and geochemical studies both implicated a significant input from a granite source during mineralisation. Two studies were then commissioned to assess the role of granites belonging to the Cullen Batholith had in the formation of ore deposits in the Pine Creek Geosyncline; especially gold mineralisation. The main aims of the study were to provide a set of criteria that could be used to prioritise exploration targets in the Pine Creek Geosyncline and possibly in other Precambrian terrains.

The Cullen Batholith in the Pine Creek Province is associated with a very broad scale of hydrothermal deposits showing contrast in spatial distribution and style, temperature and timing of the mineralisation (Fig. 2). The association of the mineralisation with the granites and their thermal aureole suggests that many of the mineral deposits were formed during the initial intrusive and the following cooling phase of the Batholith. In particular, deposits characterised by relatively high-medium formation temperatures such as the tin and gold mineralisation must have been associated with these stages. There exists, however, evidence that other deposits were formed at significantly later times than the original intrusions (eg uranium and epithermal lead mineralisation).

The majority of the granites in the Cullen Batholith have a concentration of radioactive elements significantly above that typical of granites (Plant et al. 1985). As a consequence, they are characterised by unusually high heat production and heat flow rates. Because they also are in an advanced state of fracturing and weathering, these granites are potential sites for post-magmatic hydrothermal convection in response to radioactive heat production.

The Cullen Batholith is associated with radioactive heat generation between 4.02–9.96 ± $\mu W/m^3$ or 9.6–23.9 HGU (1 HGU = 0.417 ± $\mu W/m^3$ = 3.16 cal/m^3/year) generated by approximately 12 ppm U, 40 ppm Th and 4 % K. With the average heat production value of 5.79 ± $\mu W/m^3$ (13.9 HGU or 44 cal/m^3/year) the Cullen Batholith is over two times higher than the average granite heat production at 2.5 ± $\mu W/m^3$ (equivalent to 19 cal/m^3/year).

As discussed above granitoids and their contact halos appear to be important in the genesis of most if not all mineral deposits in the Pine Creek Geosyncline. This may be due to heat input, fluid input or gold source. Field observations indicate that gold deposits occur within or just outside the contact metamorphic halos of granites. Regional structure, particularly regional anticlines associated with duplex thrust fault systems, appear to be the main control on mineralisation. However the reasons for this association are not clear and this will be addressed in this study.

2. Regional Geology, Stratigraphy and Geochemistry

2.1. Geology and Stratigraphy

The Pine Creek Geosyncline is an Early Proterozoic inlier of approx. 66 000 km^2 in area (Needham et al., 1980 and Stuart Smith et al., 1993). The geosyncline comprises a supracrustal sequence that consists predominantly of fine grained clastic sediments, BIF's, minor evaporites and platform carbonates, acid volcanics and basic intrusive rocks which overlay granite migmatite complexes of Archaean age (ca 3300–2400 Ma using Sm-Nd age dating, Rb-Sr whole rock ratios and zircon U-Pb ion microprobe zircon ratios as dating methods). Sedimentation and volcanism occurred between 2 000 to 1870 Ma forming an intracratonic basin, approximately 10 kilometres thick, by crustal extension of the predominantly Archaean granitic basement. This was followed by the intrusion of dolerite sills, complex multiple deformation, regional metamorphism and granitoid intrusion with associated contact metamorphism. The intrusion of granitoids was accompanied by the extrusion of felsic volcanic rocks in the Katherine region. These volcanics rest unconformably on the Early Proterozoic metasediments as do the largely undeformed Middle and Late Proterozoic, Palaeozoic and Mesozoic strata as well as Cainozoic sediments and laterite.

The stratigraphy of the Pine Creek Geosyncline is summarised in Table 1. The age of basement granitoids in the Nanambu Complex and the intrusive Nimbuwah Complex confine the depositional age of the strata between 2470 Ma and 1870 Ma (Stuart Smith et al., 1993). Age determinations from a tuffaceous unit in the Mt. Bonnie formation gave 1885 ± 2 Ma, which constrains the depositional environment between 2000 Ma and 1880 Ma.

The oldest unit preserved locally is the Namoona Group, which contains the Masson Formation and Stag Creek Volcanics. A broad two fold stratigraphic sequence has been recognised in the Masson Formation with a lower unit of shale and siltstone with rare dolomite interbeds and an upper carbonaceous shale and siltstone sequence. About a fifth of the formation comprises quartz-feldspar sandstone and pebble conglomerate similar to the Mundogie Sandstone.

The Noonamah Group also contains minor tuff, tuffaceous siltstone and greywacke of the Stag Creek Volcanics. These are poorly exposed and deeply weathered. Clastic and minor chemical sediments of the Mount Partridge Group either unconformably or disconformably overlie the Noonamah Group units. This group consists of the Mundogie Sandstone and the Wildman Siltstone. The Mundogie Sandstone ranges in thickness from less than 300 metres east of the Mary River to 1200 metres in the Mt. Masson area. The unit comprises an interbedded sequence of psammite and minor conglomerate and pelite. Over 50 % of the formation comprises coarse to pebbly feldspathic quartz sandstone and arkose. The remainder of the formation comprised of siltstone and rare pyritic shale. The Wildman Siltstone is