Mineralogy and Petrology of the Cooper Basin Basement Granites

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The Australian continent is tectonically relatively stable in comparison with other continental settings, the radiogenic heat production within the Australian continental crust is significantly high. One region with particularly elevated heat production is the Cooper Basin. The Cooper Basin is an intercratonic basin that contains Late Carboniferous to middle Triassic sedimentary rocks which are mainly of non-marine origin (Hill and Gravestock 1995).

The Cooper Basin overlies granites, which have intruded the Warburton Basin Sediments (Gatehouse et al, 1995, McLaren and Dunlap, 2006, Sun, 1997). The Cooper basin in turn is overlain by the Eromanga Basin (Gatehouse et al, 1995, Sun, 1997).

This paper focuses on three wells (Table 1) in which granites have been intersected. The aim of this study is to characterise the mineralogy and petrology of these granites that may control the heat production in the Cooper Basin.

The data collected in this study will be used to establish an advanced geochemical/isotopic and geochronological database for improving our understanding of existing geothermal resources, and the definition of an investigation procedure that can be applied as a routine exploration tool for Hot Rock geothermal systems in Australia and in similar tectonic environments worldwide.

Petrography

Ten petrographic thin-sections were made from granites sampled in four geothermal wells that intersect the basement of the Cooper Basin.

Eight of the ten samples are highly altered with the predominant minerals being quartz, and a high birefringent clay mineral (illite based on XRD) with minor oxides. In four of the sections, highly altered plagioclase is present (Big Lake-1 and the three McLeod-1 sections, 3745.2, 3745.9 and 3748.3) exhibiting distinct Carlsbad-Albite twinning.

In all the altered sections, three textures (Figure 1-A) can be identified in terms of mineralogy and grain size. The first texture is the primary granite texture. This is characterised by the large grain size of some quartz grains (> 2mm) and the occurrence of pseudomorphic illite, through the replacement of biotite and strongly altered plagioclase in some of the sections. The primary quartz (Figure 1-C) in the sample exhibits extensive undulose extinction with some prominent striations, with the quartz being highly fractured. The second texture is the pervasive alteration. This is exhibited by finely (< 100µm) inter-grown clay minerals with associated fine-grained quartz. The third texture is an intermediate texture; with the dominance of the larger, more crystalline clay minerals. This third texture is characterised by the clay minerals, which have a grain size between 200 µm to 1 mm.

Table 1: Sample Names and sampling depth

Well Name	Sampling Depth (m)	Alteration
Big Lake-1	3057	Pervasive
Jolokia-1	4905	Minor (sericitisation)
McLeod-1	3745.2	Pervasive
	3745.9	Pervasive
	3748.3	Pervasive
Moomba-1	2847.75	Pervasive
	2848.7	Pervasive
	2851	Pervasive
	2857.4	Pervasive
	2895.2	Minor (sericitisation)

In one of the Big Lake 1 samples, a vein (Figure 1-B) occurs that consists of mainly quartz with some illitic clays. This vein varies in thickness from 80µm to 200µm . The vein postdates the predominant alteration of the sample as it crosscuts all alteration minerals in the section.

Some of the quartz grains (McLeod-1_3745.9, McLeod-1_3748.3, Moomba-1_2847.75, Moomba-1_2848.7, and Moomba-1_2851, Figure 1-D) have small inclusions of unaltered biotite and amphibole (hornblende). It appears that the inclusions may have survived the alteration.

The sample also contains some accessory hematite and zircon. Both these minerals seem to be associated with the third texture, which is dominated by intermediate clay minerals. The zircon is mainly locked within the large clay minerals, with minor zircon grains locked in the large quartz crystals. The zircons, which are observed within the illitic clays, tend to occur as fractured euhedral crystals with some grains containing minor opaque inclusions. The zircons occur as locked grains in the clay minerals crosscutting the cleavage lamellae. The zircons also tend to occur as grains attached to quartz and clay mineral grains. Some of the zircons are zoned.

The hematite in the sections occurs as elongated anhedral crystals, with a minority occurring as subhedral grains. The elongated hematite occurs as locked particles along the clay mineral lamellae. Some of the hematite (Moomba-1_2851) occurs in distinct areas not included within a particular clay mineral grain. The hematite is being altered to Fe-oxyhydroxides (goethite/limonite) This is indicated by rims around some of the hematite.

Two of the samples, Jolokia-1 and Moomba-1_2895.2, have less pervasive alteration compared with the other eight samples. The alteration in Jolokia-1 appears to have affected only the biotite and amphibole as they have been replaced by a highly birefringent clay mineral. In the Moomba-1_2895.2 (Figure 1-F) section, the biotite and amphibole exhibit only small amounts of alteration, evidenced by the discoloration along the grain boundaries. The plagioclase in both these samples exhibits some degree of alteration as there is some sericitisation. Primary microcline is also present and exhibits similar alteration as the plagioclase. In the Jolokia-1 sample, evidence of eutectic crystallisation of quartz and microcline is present. In both these sections, the opaques and zircon are observed with the clay alteration mineral (Jolokia-1) and the biotite and amphibole (Moomba-1_2895.2).

Hydrothermal alteration and deformation

Thin section optical microscopy shows that the granite samples have been severely fractured, and that the fracturing was accompanied by significant hydrothermal alteration. Fracturing in the granite occurs mostly as irregular micro-fractures and veining as well as planar micro-deformation structures in quartz (Figure 1-G, H). This indicates that the granite has been subjected to a significantly high stress regime of an unknown origin with a subsequent hydrothermal fluid circulation along micro-crack systems. Hydrothermal alteration mineralogy consists largely of a single phyllosilicate phase (illite). In many cases, all feldspars and micas in the granite have been completely altered to illite.

The Distribution and intensity of alteration mineralogy is irregular with depth, with some deeper samples only slightly altered (e.g., Moomba 1 at 2895.20 and Jolokia 1 at 4005 m) in contrast to the shallow granites showing intense fracturing and hydrothermal alteration (e.g., Moomba 1 at 2847.75 m). The alteration mineralogy of the overlying sedimentary rocks consists of mainly illite, and unlike the granite, also some chlorite and kaolinite.

Illite crystallinity

Illite crystallinity values, which were determined by XRD, can be used as a semi-quantitative geothermometer for burial and hydrothermal metamorphism (Frey, 1987; Ji and Browne, 2000). Illite crystallinity is defined as the width of the first order illite basal reflection (10 Å peak) at half height and expressed usually in $\Delta 2\theta$ values. Illite crystallinity values decrease with increasing illite crystallinity. In this study, illite crystallinity values were measured mainly on samples of <2 μm size fraction and they broadly indicate that temperatures during the hydrothermal process in the granite ranged from 250°C (in Moomba 1 and Big Lake 1) to 350°C (in McLeod 1 and Jolokia 1). Crystallinity of the illite in the sedimentary rocks is lower in comparison to those in the granite samples. This together with the occurrence of chlorite and kaolinite indicates that a different fluid chemistry and lower temperature regime has prevailed during fluid flow events in the Cooper Basin sediments than in the underlying granite.

Further work

Our next step will be to constrain the timing of granite generation and hydrothermal alteration events. We hope to achieve this by dating zircon from the granite, and illite found in the sedimentary rocks of the Cooper Basin. Combined studies of geochemistry, alteration mineralogy and geochronology are crucial in establishing spatial and temporal relationships between granite generation, enrichment of heat-producing elements, and secondary thermal and/or hydrothermal alteration events.

Further analyses include additional detailed X-Ray powder Diffraction (XRD), Scanning Electron Microscope Cathodo-Luminescence (SEM-CL), and Electron Microprobe Analysis (EPMA). The XRD will be performed to further constrain the mineralogy of the granite, and EPMA will be performed to constrain the chemical compositions of the major, minor and trace minerals. With this we hope to constrain the mineralogy of the granites and further improve our understanding of their emplacement. With the SEM-CL we hope to constrain the quartz groupings and deformation features observed under polarized light. In conjunction with these analytical measurement ICP-MS will also be conducted on the bulk rock. Here two types of experiments will be conducted; in the 1st all the minerals be dissolved, in the 2nd the zircons will not be dissolved. This approach will assist in establishing whether the U content in the granites is associated to zircon and/or to other mineral phases.

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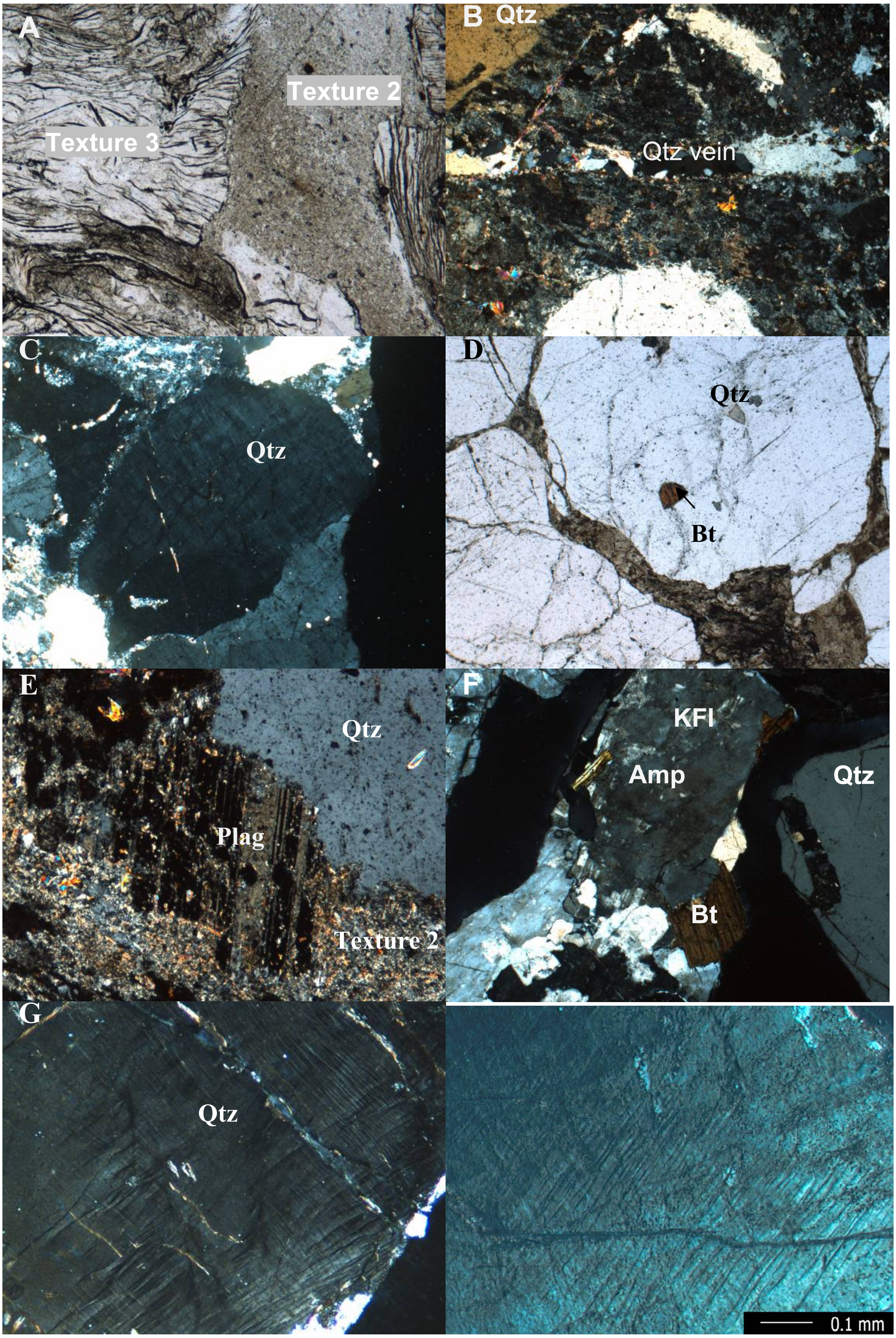

Figure 1: Transmitted light photomicrographs of some of the features observed in the various sections. Field of view in each image is 3417 m for photos A-F. A) A Plane Polarized Light (PPL) image of the relation between Texture 2 and 3. B) Vein in Big Lake-1 3057. C) quartz (qtz) grain with undulatory extinction and with “striations” visible in extinction under crossed Nichols (XPL). D). inclusion of an unaltered Biotite (Bt) in a Quartz grain (PPL),E) Altered plagioclase (Plag) present in Moomba 1 sections. F) Relatively fresh sample from Moomba 1 2895.2, G) Planar micro-deformation structures observed in quartz.