Diagenetic clay mineral distribution in Mesoproterozoic sandstones of the Cariewerloo Basin, South Australia – implications for uranium mobilisation

John L. Keeling[1], Alan J. Mauger[1], Tania Wilson[1] and Mark D. Raven[2]

[1]Geological Survey of South Australia, DMITRE, 101 Grenfell Street Adelaide SA 5000.
john.keeling@sa.gov.au
[2]CSIRO Land and Water, Private Mail Bag No 2, Glen Osmond, SA 5064

Introduction

A thick sequence of largely undeformed red-bed sandstones of Mesoproterozoic age, collectively termed the Pandurra Formation, overlies a wide area of crystalline basement of the central and eastern Gawler Craton. The predominantly fluvial quartz sandstones are a remnant of the continental Cariewerloo Basin deposits that extend from Whyalla in the south, northwestly for some 430 km, and up to 170 km wide, to be truncated by fault surfaces now buried beneath Mesozoic sediments of the Eromanga Basin, just to the south of Prominent Hill (Fig. 1). The full extent of the original basin is uncertain. Drill hole data indicate that the eastern margin, in particular, is disrupted by post-depositional faulting and the sandstone was extensively eroded prior to marine transgression in the Neoproterozoic, at the end of the Sturtian glaciation. The timing and duration of sedimentation is also poorly constrained with a single, whole-rock Rb-Sr isochron from interbedded shale and siltstone that gave a minimum age of deposition of 1424±51Ma (Fanning et al., 1983). The sandstones were intruded subsequently by an extensive dyke swarm, the Gairdner Dolerite, dated at 827±6Ma (Wingate et al., 1998). Thickest intersection of Pandurra Formation is 1180 m in drill hole SH 7, in the northeast of the basin. In this area, thicknesses in excess of 1500 m are interpreted from regional magnetic data. The geological setting and age of the basin are similar to that of the Athabasca Basin in Canada and McArthur Basin in Northern Territory, both of which have associated high-grade ‘unconformity style’ uranium mineralisation. Economic uranium mineralisation has not been discovered in the Cariewerloo Basin, but uranium occurrences and anomalous levels of uranium are present in the source rocks, predominantly Gawler Range Volcanics and Hiltaba suite granitoids, which supplied much of the basin sediment. Fluids circulating within the basin possibly mobilised uranium to be concentrated and preserved in suitable trap sites. The present investigation examines the diagenetic minerals in Pandurra Formation sandstone as a guide to the burial and hydrothermal conditions within the basin.

Methods

The investigation was part of a multidisciplinary study of the Cariewerloo Basin involving 3D modelling, lithostratigraphic, geophysical and chemical approaches (Wilson et al., 2010).

Fig. 1. Locality plan Cariewerloo Basin.

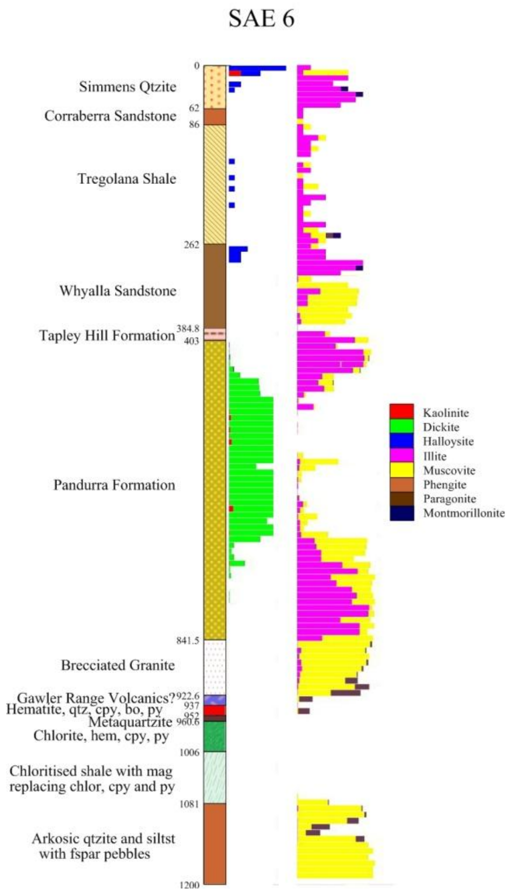

Fig. 2. Dickite / white mica distribution in SAE6.

Mineralogical variation across the basin was determined for 70 selected cored drill holes by spectral analysis using the HyLogger™ automated core scanner. The HyLogger™ measures reflected light to record spectra in the VNIR and SWIR region of the electromagnetic spectrum (380-2500 nm) at 1cm intervals along the drill core. Process software 'The Spectral Geologist' (TSG Core™) was used to obtain semi-quantitative estimates of minerals having characteristic absorption features in the spectral range (Fig. 2). These data were incorporated into the 3D model of the basin. The spectral results were used to identify key sample intervals for additional analyses to either validate or further investigate the mineralogy. This was done using X-ray powder diffraction (XRD) and scanning electron microscopy (SEM), and included samples from holes SAE6, LY2 and RL1 (Figs 1, 2).

Results

Throughout the basin the upper portion of the Pandurra Formation sandstone is characterised by diagenetic clay cement largely composed of dickite, with or without well-crystalline kaolinite. This zone is thickest along the central eastern margin of the basin, exceeding 500 m in LY2, but reduces to only a few 10s of metres in drill holes along the western basin margin. Illite/muscovite group minerals are the pervasive diagenetic phase throughout the basin. These generally form deeper in the sequence and at the expense of dickite and kaolinite, although the relationship in individual drill cores can be complex, especially through the transition zone. XRD analysis of core from SAE6 confirmed dominantly 1M muscovite in the upper 50 m of the Pandurra Formation followed by almost 300 m of dickite clay cement, with the basal 80 m of sandstone containing predominantly 2M1 muscovite (refer log in Fig. 2). SEM investigation showed the 1M muscovite to be fine laths of illite infilling between quartz grains coated with fine platy hematite (Figure 3a). Below this zone, dickite is dominant as euhedral crystal stacks of variable-thickness platelets intergrown with thin illite laths. The dickite shows evidence of incipient dissolution and quartz grains are noticeably embayed. Towards the base of the sandstone, illite/muscovite is dominant as ragged-edge platelets of several microns diameter.

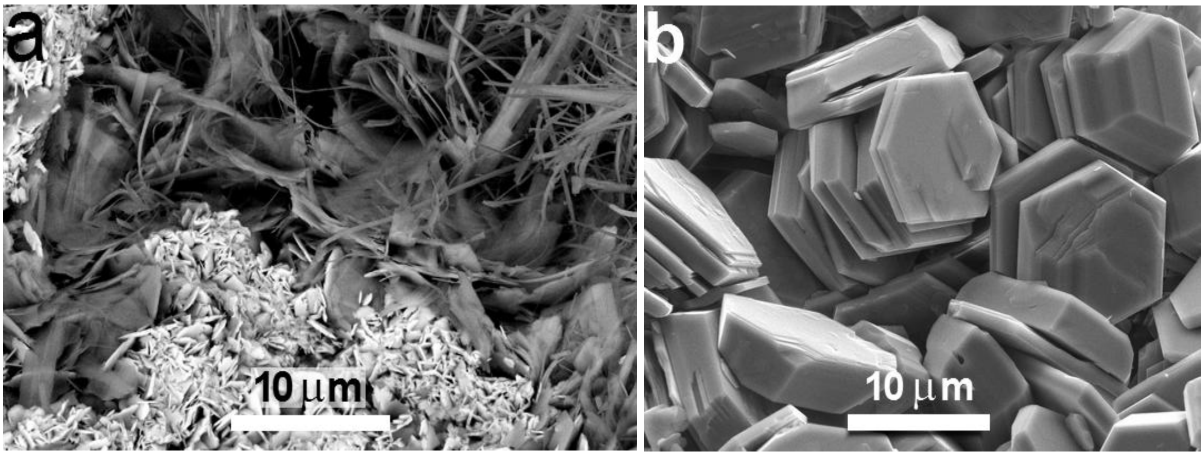

Fig. 3. a) Drill hole SAE6 (423m) laths of "hairy' illite on platy hematite (white) - backscattered electron image b) LY2 (629.3m) blocky dickite crystals showing evidence of dissolution - secondary electron image

In LY2, Pandurra Formation includes a 500 m-thick section of dickite-cemented sandstone. Near the base of the section, spectral data indicate approximately equal amounts of muscovite and paragonite, together with dickite. The dickite crystals are blocky, typically 1-5 µm in thickness, and show minor dissolution (Figure 3b). XRD and SEM analysis failed to confirm the presence of paragonite. However, mica with a wavelength absorption feature at around 2192 nm is present in at least 13 of the drill holes scanned and may reflect Na substitution for K, but requires additional analyses to confirm. Two holes scanned with the HyLogger showed the presence of pyrophyllite in Pandurra Formation with the thickest intersection of ~170 m in RL1. This was confirmed by XRD and SEM on selected samples. The pyrophyllite is present as thin flakes around 10 µm across, together with muscovite, in a zone of highly altered, open kaolinite and dickite crystal stacks, intergrown with illite laths.

Discussion

An argument put forward for the lack of evidence of 'unconformity-style' uranium deposits associated with the Cariewerloo Basin is that the basin was not buried to sufficient depth to raise pore fluid temperatures to around 200°C, necessary to release uranium from resistate host minerals such as monazite and zircon (Kyser pers comm., 2010). Maximum diagenetic temperatures of around

160±30°C were inferred from depth of burial estimates based on 'illite crystallinities' measured on samples from drill hole HDD1 (Fig. 1) (Kyser op cit.). Mineralogical variation recorded from spectral data, however, indicates that conditions of maximum diagenesis varied across the basin. This may be due to local thermal anomalies and/or a change in relative 'base level' within the basin as the result of post-depositional faulting. Also 'illite crystallinity' as a measure of depth of burial was developed using the transformation of smectite to illite in shale interbeds in basin sediments (Kübler, 1968). In dominantly sandy units, illite crystallises from kaolin dissolution and may require feldspar as a source of potassium ions. This reflects different crystallisation conditions than that for illite to smectite transformation. According to Lanson et al. (2002, p.15), in this environment "illitization of kaolin, although frequent is not always observed in deeply buried sandstones and there seems to be no systematic relationship between temperature and intensity of kaolin illitization". The thick blocky dickite crystals in LY2 (Fig. 3b), and associated coarse illite flakes, are similar to North Sea samples, illustrated in Lanson et al. (2002), from depths of 4,000-5,000 m. Also the incorporation of Na in the illite structure, inferred from the spectral shift to shorter wavelength mica, is consistent with temperatures approaching 200°C (Frey, 1987). Higher temperatures of crystallisation, between 200-300°C, are indicated by the presence of pyrophyllite (Ruiz Cruz et al., 2009). Spectral data confirm, however, that mafic intrusions, equated with the Gairdner dolerite, are present in the two drill holes containing pyrophyllite, and this may be a factor influencing the alteration mineralogy. The results, overall, demonstrate that spectral logging is a rapid and cost-effective technique to map mineral alteration, which can be correlated with thermal activity. This provides a means to focus the search for 'unconformity-style' uranium trap sites in areas of the basin where uranium is more likely to have been leached and mobilised within the sediments.

Acknowledgements

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Notes