Timing of illite authigenesis in well Empress-1A, Officer Basin, Western Australia

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Vertical diamond-drillhole GSWA Empress-1A is situated within the Yowalga Sub-basin of the Officer Basin, Western Australia. Results of a detailed integrated petrographic and K-Ar dating study focusing on authigenic and detrital illite, as well as of two basalt samples from Empress-1A, are discussed. Petrographic investigations reveal that illite is an abundant authigenic mineral phase, causing significant reduction in permeability and porosity. The illite has distinct morphologies, comprising detrital grains, authigenic grains with pore bridging filamentous habit, and tightly packed plates within altered basalt. In total, 28 K-Ar dates were obtained on illite separates and grain-size fractions (<0.1 to 2–6 µm) from mudstone, siltstone, sandstone and two basalt samples. K-Ar illite dates range from 1177 ± 23 Ma (Mesoproterozoic–Stenian) to 388 ± 11 Ma (Early Devonian–Emsian) and are mainly related to the 550 Ma Petermann Orogeny. Deeper buried samples record the Neoproterozoic (650 Ma) Areyonga Movement. A sample of the Table Hill Volcanics contains illite alteration, formed in response to uplift and meteoric-water flushing during the Palaeozoic Alice Springs Orogeny. The illite dates increase with depth and are variously interpreted as: (1) pre-depositional ages of detrital illite; (2) the time at which neoformed illite ceased to grow during the Areyonga Movement and Petermann Orogeny; (3) the timing of volcanic alteration; and (4) having no geological meaning, referring to circumstances where more than one illite type has been sampled, the illite separate is contaminated with detrital illite, mica or K-feldspar, or the K-Ar isotope systematics have been partially reset during deep burial and high temperatures.

Keywords: Western Australia, Officer Basin, Yowalga Sub-basin, Empress-1A, Illite, authigenesis, thermal history, K-Ar, absolute age, dates, X-ray diffraction analysis, petrography, Petermann Orogeny, Areyonga Movement, Alice Springs Orogeny

INTRODUCTION

Isotopic and geochemical studies are important tools for understanding diagenetic histories, with implications for both exploration and reservoir management. Isotopic age data have the potential to yield important information about the origin of hydrocarbons, the timing of fluid flow and related diagenetic events, the nature and distribution of potential formation damage, and the timing of faulting and deformation. Illite contains potassium and is therefore suitable for age determination, using the potassium–argon (K-Ar) geochronometer. Diagenetic illite is of interest to the petroleum industry, because it can provide a K-Ar date constraining a heating and/or fluid flow event within a sedimentary basin (Peverar 1999).

In this study, K-Ar data of authigenic and detrital illite originating from mudstone, siltstone and sandstone, as well as basalt samples from different stratigraphic units covering the whole stratigraphy of the Geological Survey of Western Australia’s (GSWA’s) diamond-drillhole Empress-1A from the Officer Basin are discussed (Figures 1, 2). Initial petrographic observations documented suitable illite material for K–Ar dating (Stevens and Apak 1999). The petrography of the illite was investigated by SEM and TEM, prior to K-Ar dating.

GEOLOGICAL SETTING AND SAMPLING

Diamond-drillhole Empress-1A is situated in the Yowalga Sub-basin within the central part of the Officer Basin in Western Australia (Figure 1), and was designed to test the hydrocarbon source-rock potential of Neoproterozoic successions in the region. The Officer Basin is part of the Neoproterozoic Centralian Superbasin, which included the then-interconnected Amadeus, Ngalla and part of the Georgina basins (Walter and Gorter 1994, Lindsay 2002). This superbasin comprises Neoproterozoic to Phanerozoic strata within a large, episutural intracratonic structure, extending from the southeastern flank of the Pilbara Craton to the West of South Australia. Empress-1A was continuously cored from 201.5 to 1624.6 m, and according to Stevens and Apak (1999), penetrated unnamed Cenozoic strata, overlying the Carboniferous to Permian Paterson Formation, Devonian Lennis Sandstone, Palaeozoic Table Hill Volcanics, an unnamed Neoproterozoic unit, the ‘?Lupton Formation (Superequence 3 of the Centralian Superbasin), the Kanpa, Hussar, Browne, and ‘?Lefroy Formations (Superequence 1 of the Centralian Superbasin), and pre-Officer Basin strata (Figure 2). Bagas (2004) summarised the Proterozoic evolution and tectonic setting of North Eastern Australia, including the Officer Basin, and provided age references for the Petermann Orogeny, the Areyonga Movement and the Alice Springs Orogeny. Palaeozoic synorogenic sedimentation in central and northern Australia is discussed in detail by Haines et al (2001). High-grade metamorphic events in the Musgrave Province, north of the Officer Basin, were investigated by Camacho et al (1997) and Schmidt et al (2006). Tingate and Duddy (2002) investigated the thermal history of the eastern Officer Basin in South Australia and documented evidence from apatite fission track analysis that indicated a number of distinct thermal episodes, which can be supported by organic maturity data.

Empress-1A was selected for this pilot study, because extensive core and geochemical data, as well as basin modelling results, are documented within the literature (Apak and Moore 2000, Ghori 2002, Carlson et al 2003). Fifteen core samples were collected from the drillhole, based on the initial petrography report listed in Stevens and

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Apak (1999). After further petrographic investigations, ten samples were selected for illite separation and K-Ar age dating, to investigate the timing of illite authigenesis and detrital illite sources within this part of the Officer Basin.

**ANALYTICAL METHODS**

Samples, consisting of approximately 100 g of Empress 1A drill core, were crushed to rock chips with maximum dimensions of <10 mm, and were then gently disaggregated using a repetitive freezing and thawing technique, to avoid artificial reduction of rock components and contamination with K-bearing minerals such as K-feldspar (Liewig et al. 1987). Grain size fractions (<2 and 2–6 µm) were separated in distilled water, according to Stokes's law, with the efficiency of this separation controlled using a laser granulometer. Additional grain-size fractions (<0.1 and 0.4 µm) were separated using a high-speed centrifuge. The mineralogy of the size fractions was determined by X-ray diffraction (XRD) on air-dried samples and after exposure to ethylene glycol. Progressive size reduction down to the 0.1 µm fraction increased the proportion of illite in the clay component and minimised contamination by other mineral components.

Freshly broken surfaces of sample chips were carbon-coated and analysed by a Philips 300 SEM equipped with an energy dispersive system X-ray analyser (EDS), in secondary and backscattered electron mode. A JEOL JEM 2010 200KV TEM was used for detailed grain-by-grain morphological characterization of the <0.1, <0.4 and selected <2 µm clay fractions and for control of grain-size distribution within the fractions. Samples were prepared by placing one drop of clay solution on a micro carbon grid film and drying under air. The composition of individual particles was investigated by an attached EDS system.

The K-Ar dating technique followed standard methods described in detail elsewhere (Dalrymple and Lanphere 1969, Faure 1986). Potassium content was determined by atomic absorption using Cs ion suppression. The pooled uncertainty of duplicate K determination of all samples and standards is better than ±2%. Argon isotopic determinations were performed using a procedure similar to that described by Bonhomme et al. (1975). Samples were pre-heated under vacuum at 80°C for several hours, to reduce the amount of atmospheric Ar adsorbed onto the mineral surfaces during sample handling. Argon was extracted from the fractions by sample fusion within a vacuum line serviced by an on-line 38Ar spike pipette. After fusion of the sample in a low blank resistance furnace, the released gases were subjected to a two-stage purification procedure, using a CuO getter for the first step and two Ti getters for the second step. The isotopic composition of the spiked Ar was measured with a high sensitivity on-line VG3600 mass spectrometer.

Blanks for the extraction line and mass spectrometer were

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**Figure 1.** Location of study area showing petroleum exploration wells and Empress-1A.
systematically determined, and the mass discrimination factor was determined periodically by airshots. Argon analyses required 10 to 20 mg of sample material. During the course of the study, seven international age standards, comprising five GLO (Odin et al. 1982) and two HD-B1 (Hess and Lippold 1994) sample splits, were analysed. The uncertainty for Argon analyses is below ±1.0% and the 40Ar/36Ar value for airshots averaged 294.22 ± 0.18% (n=9). K-Ar ages were calculated using the 40K abundance and decay constants recommended by Steiger and Jäger (1977). K-Ar age uncertainties are quoted at the 2σ level.

CLAY MINERALOGY

SEM petrographic investigation reveals that illite is present in four different forms in Empress-1A. These are as: (1) platy detrital grains; (2) smaller platy grains, thought to be diagenetic; (3) pore-bridging, authigenic filamentous grains that, in some instances, extend out from the edges of earlier platy diagenetic grains; and (4) tightly packed arrangements of platy morphology, comprising the main alteration product in a volcanic sample (Figure 3). Transmission electron microscopy (TEM) investigations were used to identify and distinguish authigenic clays from contaminants, by individual grain analysis, for purity control as proposed by Hamilton et al. (1992). Typical TEM images of illite grains are illustrated in Figure 4. TEM observations of the separated clay fractions of the different stratigraphic units indicate that there are three distinct groups of particles. These are: (1) idiomorphic illite fibres, with elongated, sharp filamentous shapes (Figure 4a, b); (2) idiomorphic platy illite flakes, together with hexagonal idiomorphic chlorite...
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Figure 3. SEM images. (a) Altered basalt sample 415 at 282.3 m depth, illustrating typical aggregations of platy, dense authigenic illite particles, formed as an alteration product. (b) Sample 416 at 667.8 m depth, illustrating mixture of platy and fibrous illite particles. (c) Sample 418 at 669.4 m depth illustrating grain-coating authigenic honeycomb-structure chlorite, with minor fibrous illite/smectite extensions at the edges of chlorite particles. (d) Sample 419 at 800.0 m depth, illustrating platy and compacted detrital illite. (e) Sample 420 at 864.30 m depth illustrating typical fibrous, pore-bridging authigenic illite in sandstone. (f) Sample 421 at 980.9 m depth, illustrating platy and compacted detrital illite. (g) Sample 422 at 1125.0 m depth illustrating a mixture of platy and fibrous authigenic illite. Fibrous illite is extending from platy particles into the pore space. (h) Sample 424 at 1232.4 m depth, illustrating a mixture of platy and fibrous authigenic illite. Fibrous illite is extending from platy particles into the pore space. (i) Sample 425 at 1251.0 m depth, illustrating a mixture of authigenic fibrous and platy detrital illite. (j) Sample 427 at 1542.7 m depth, illustrating platy and compacted detrital illite, as well as a minor amount of fibrous authigenic illite, extending from the edges of larger platy illite particles.
Timing of illite authigenesis in Empress-1A, Officer Basin

with clear sharp crystallized edges (Figure 4c, d); and (3) detrital electron-dense dark particles, with diffuse and irregular edges (Figure 4e, f) that were more common in coarser fractions. Detrital clay particles are volumetrically larger than neoformed illite particles in the <2 µm and are characterized by different morphological shapes. Detrital illite shows irregular edges, whereas neoformed illite particles have sharp and well-defined edges (Hunziker et al 1987, Clauer and Chaudhuri 1995). The fibrous and platy idiomorphic shape of the illite suggests \textit{in situ} neoformation.

**XRD DATA**

XRD analyses identify illite, chlorite, and kaolinite as the major clay mineral phases in the various fractions, with
variable amounts of quartz and traces of titanite, goethite, and K-feldspar (Table 1). Glycolated XRD analyses were carried out to investigate the potential occurrence of expandable mixed-layer illite/smectite, but only minor amounts of smectite could be identified. The detection limit for the XRD technique is ca 5 wt%. The coarser 2–6 and 6–10 µm fractions contain traces of K-feldspar, but none was observed in the finer <0.4 to <0.1 µm fractions, which was confirmed by TEM investigations. Illite crystallinity values confirm the authigenic origin of most of the illite and correspond to diagenetic to anchizonal grades (Kübler 1968). Based on initial polytype investigations, analysed illite fractions are composed mainly of the 1Md and 2M1 polytypes, suggesting temperatures of about 100–200°C during mineral formation (Merriman and Kemp 1996). However, limited sample sizes made XRD clay polytype investigations problematical, due to noisy traces.

### K-AR DATA

K-Ar ages (Table 2) of illite separates have a total age range from 1177 ± 23 Ma [Stenian (Mesoproterozoic)] to 388 ± 11 Ma [Emsian (Early Devonian)]. Radiogenic ⁴⁰Ar ranges from 99.3 to 37.6%, indicating negligible to low atmospheric ⁴⁰Ar contamination and reliable analytical conditions for most analyses, with the exception of sample 415 <2 µm (282.3 m), which contains only 34.1% radiogenic Ar. The reliability of the data is confirmed by the agreement within 2σ analytical uncertainties for duplicate analyses of three sample fraction duplicates (see Table 2). K concentration ranges from a low 0.17 wt% for a basalt illite to about 6 wt% for authigenic fibrous pore-bridging illite for sample 420 <0.4 µm. Sample 421 2–6 µm contains the highest K concentration of 7.25 wt%, caused by detrital K-feldspar contamination, as identified by XRD. The relatively high K-contents for most illite fractions are consistent with XRD analyses indicating high illite contents. Lower K-concentrations in some size fractions is caused by detrital K-feldspar contamination, as identified by TEM investigations of three sample fraction duplicates (see Table 2). K-feldspar is present as the K-bearing phase in the analysed fraction (e.g. no smectite, or a mixture of illites formed at different times).

### MAXIMUM AGE CONCEPT

For neoformed illite, the finest separated particle size is derived from the ends of filamentous grains and should represent the most recently grown illite. Conversely, coarser size fractions formed earlier during the illite formation process should yield older ages. However, there is also evidence that illite can recrystallise and coarsen by Ostwald ripening processes in burial systems similar to the one considered in Empress-1A (Eberl and Środoń 1988, Eberl et al 1990). In reality, grain-size fractions of neoformed illite are mixtures of illite particles formed at different times during growth and this growth history is usually investigated by dating a range of different grain-size fractions. Small amounts of detrital contaminants that may include radiogenic or excess Ar in fluid inclusions, such as detrital illite, K-feldspars and quartz, will influence the age of the mineral fraction. The resultant dates are therefore averages, interpreted as maximum ages (Pevear 1999), that approximate the time of cessation of illite growth in hydrocarbon reservoirs (Lee et al 1985).

### Table 1. Semi-quantitative XRD results.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Sample depth (m)</th>
<th>fraction (µm)</th>
<th>illite</th>
<th>chloride</th>
<th>kaolinite</th>
<th>quartz</th>
<th>K-feldspar?</th>
<th>Remarks</th>
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<td>415</td>
<td>282.3</td>
<td>&lt;2</td>
<td>40</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>no smectite</td>
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<tr>
<td>416</td>
<td>667.8</td>
<td>&lt;0.4</td>
<td>60</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>no smectite</td>
<td></td>
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<tr>
<td>418</td>
<td>669.4</td>
<td>&lt;2</td>
<td>60</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>no smectite</td>
<td></td>
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<tr>
<td>419</td>
<td>800.0</td>
<td>&lt;2</td>
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<tr>
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<td>864.3</td>
<td>&lt;0.4</td>
<td>80</td>
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<td>20</td>
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<tr>
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<td>&lt;2</td>
<td>70</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>goethite</td>
<td></td>
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<tr>
<td>421</td>
<td></td>
<td>2–6</td>
<td>60</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>goethite</td>
<td></td>
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<tr>
<td>422</td>
<td>1125.0</td>
<td>&lt;2</td>
<td>50</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>goethite</td>
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<tr>
<td>424</td>
<td>1232.4</td>
<td>&lt;2</td>
<td>60</td>
<td>10</td>
<td>30</td>
<td>40</td>
<td>goethite</td>
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<tr>
<td>425</td>
<td>1251.0</td>
<td>&lt;2</td>
<td>70</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>goethite</td>
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<tr>
<td>427</td>
<td>1542.7</td>
<td>&lt;0.4</td>
<td>70</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>goethite</td>
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<td></td>
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<td>2–6</td>
<td>60</td>
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<td>40</td>
<td>goethite</td>
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<td></td>
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<td>2–6</td>
<td>50</td>
<td>25</td>
<td>20</td>
<td>40</td>
<td>goethite &gt;5%</td>
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</table>

### Interpretation of illite K-Ar data

The correlation of K-Ar ages from illite separates with geologically meaningful events requires careful consideration of the assumptions underlying the method. Clauer and Chaudhuri (1995) and Meunier and Velde (2004) discussed in detail the validity and importance of the assumptions involved in K-Ar dating of authigenic illite (e.g. contamination, closed system behaviour, excess Ar). Firstly, the most important assumption is that there has been no loss or gain of either ⁴⁰K or ⁴⁰Ar after illite formation, (e.g. closed system behaviour). Ar is the most likely component to be lost, especially as the result of thermal diffusion and by exchange with hydrothermal fluids (Villa 1998). Secondly, it is crucial that only one illite generation is present as the K-bearing phase in the analysed fraction (e.g. no contamination by other K-bearing phases). This can be a major problem in regards to the acquisition of meaningful K-Ar ages, particularly in samples containing small amounts of K-bearing detritus, or a mixture of illites formed at different times.
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SHRIMP U-Pb investigations of detrital zircons strongly suggest that some of the sedimentary successions encountered within Empress-1A are Neoproterozoic in age. For example, SHRIMP U-Pb dating of detrital zircons within a coarse-grained sandstone from Empress-1A, at 320 m depth, from a unit tenuously correlated with the Wahлу Formation, indicated a maximum depositional age of 691 ± 22 Ma (Nelson 2003). Stevens and Apak (1999) reported K–Ar and U-Pb age dates for two samples of basalt, of 484 ± 4 Ma for the Table Hill Volcanics at 215 m, and 1058 ± 13 Ma for unassigned volcanic rocks within the pre-Officer Basin succession at 1601 m.

NEW BASALT K-AR DATES

Two basalt samples from the Table Hill Volcanics were investigated in this study. The first sample, from 282 m (Figure 3a) originates from the deeper part of the Table Hill Volcanics, close to the ?Lupton Formation boundary. This sample is strongly altered, with illitic clay identified as an alteration product. K-AR dates obtained from this sample range from 388 ± 11 Ma for the <0.4 μm fraction, 407 ± 9 Ma for the <2 μm fraction, and 444 ± 10 Ma for the coarse 2–6 μm fraction. Illite alteration seems to have ceased at ca 100 to 80 Ma, after the basalt emplacement and during subsequent uplift, and could represent the timing of alteration in response to meteoric flushing in relation to the Alice Springs Orogeny (Ghori 2002). A second basalt sample, originating from a depth of 1593 m, yielded a whole rock K-AR age of 969 ± 19 Ma. This sample is not altered and is from 8 m above the sample dated at 1058 ± 13 Ma by Stevens and Apak (1999). The K-AR dates do not agree within 2σ uncertainty, but the discrepancy between these ages is not large and the significance for regional geologic correlation is unclear.

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Table 3. Summary of the illite age data from Empress-1A.
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contamination below XRD and TEM detection limits, or by Oswald ripening processes.

Sample 418 – 669.4 m: Kanpa Formation – mudstone
Sample 418 is mainly comprised of authigenic chlorite with minor amount of fibrous illite. Diagenetic chlorite coats detrital grains and illite/smectite is present in minor amounts (Figure 3c). Filamentous clay extensions from the authigenic chlorite meshwork comprise more illitic compositions, as confirmed by EDS spectra. This feature has been observed in other parts of the Officer Basin and is indicative of a process of illitisation of the grain-coating honeycomb chlorite structure (Hamilton et al 2004). The <2 µm illite fraction yielded a K-Ar date of 560 ± 11 Ma.

Sample 419 – 800.0 m: Kanpa Formation – mudstone
Sample 419 contains platy, flaky, dense illite particles of detrital origin (Figure 3d). The <2 µm illite K-Ar date is 630 ± 13 Ma and documents a detrital illite origin.

Sample 420 – 864.3 m: Hussar Formation – sandstone
Sample 420 contains fine-grained authigenic filamentous illite as well as larger flaky authigenic illite (Figure 3e). Within this sample, the youngest K-Ar dates were obtained for fine-grained, authigenic, fibrous illite separates at 501 ± 10 Ma and are interpreted as approximating the time at which illite growth ceased. This time interval is coincident with maximum burial for the Hussar Formation of this part of the Officer Basin (Ghorı 2002). K-Ar dates for different size fractions range from 546 ± 11 Ma for the 0.1 µm fraction to 501 ± 10 Ma for the <0.4 µm fraction, 535 ± 11 Ma for the <2 µm fraction and 543 ± 11 Ma for the 2–6 µm fraction (Figure 6). As for sample 416, the inverse illite age trend could have been caused by minor amounts of contamination below XRD and TEM detection limits, or by Oswald ripening processes as discussed above. The K-Ar dates should be interpreted as maximum ages.

Sample 421 – 980.9 m: Hussar Formation – mudstone
Sample 421 contains platy, dense, flaky illite particles of detrital origin (Figure 3f). The <2 µm illite K-Ar date of 691 ± 14 Ma is interpreted to reflect a detrital illite origin.

Sample 422 – 1125.0 m: Hussar Formation – sandstone
Sample 422 contains fine-grained authigenic platy illite (Figure 3g). The <2 µm fraction yielded a K-Ar date of 550 ± 11 Ma, approximating the time at which growth of illite ceased.

Sample 424 – 1232.4 m: Hussar Formation – siltstone
Sample 424 contains a mixture of authigenic clay minerals, mainly illite, kaolinite and quartz (Figure 3h). Illite comprises mainly platy authigenic particles, although minor amount of fibrous illite can be identified using SEM. The <2 µm illite fraction yielded a K-Ar date of 696 ± 14 Ma.

Sample 425 – 1251.0 m: Hussar Formation – siltstone
Sample 425 (as per sample 424) contains a mixture of authigenic and detrital clay minerals, such as illite, kaolinite and quartz (Figure 3i). Illite comprises platy detrital and fibrous particles, indicating an authigenic origin. The <2 µm illite fraction yielded a K-Ar date of 707 ± 14 Ma.

Sample 427 – 1542.7 m: Pre-Officer Basin – siltstone
Sample 427 contains fine-grained, detrital platy illite, as well as authigenic fibrous illite identified by SEM (Figure 3j) and

Figure 6. K-Ar ages of various size fractions versus depths (in meters) for Empress-1A.
TEM (Figure 4c). Dates for different size fractions range from 1026 ± 20 Ma for the 0.1 µm fraction to 915 ± 18 Ma for the <0.4 µm fraction, 1017 ± 20 Ma for the <2 µm fraction and 1177 ± 23 Ma for the 2–6 µm fraction (Figure 6). As for samples 416 and 420, the inverse illite age trend could be caused by minor amount of contamination below XRD and TEM detection limits or by Oswald ripening processes. The deeply buried sample from 1524 m depth contains minor authigenic illite, as confirmed by fibrous morphologies, and yielded an age of 1017 ± 20 Ma, which is interpreted to reflect a detrital origin.

ILLITE AGES IN RELATION TO BURIAL HISTORY AND TECTONIC EVENTS

Ghori (2002) compiled burial histories for several drillholes in the Officer Basin, reconstructing stratigraphy and lithologies. The main elements for the burial history of Empress-1A are shown in Figure 7 (Ghori 2002). The modelling suggests rapid subsidence during the Neoproterozoic (800–750 Ma), and uplift, possibly during the Areynoga Movement, at the end of deposition of Supersequence 1. The morphology and isotopic records of authigenic illite in deeper-buried samples document the Areynoga Movement (Figures 7, 8). A second major subsidence phase, related to the 550 Ma Petermann Orogeny, occurred at the end of the Neoproterozoic. This second subsidence phase buried rock units into the illite formation window, caused widespread authigenesis and is well documented within the investigated samples. The Petermann Orogeny was also responsible for later uplift and the cessation of illite authigenesis (Figure 7). The 450–300 Ma Alice Springs Orogeny (cf Haines et al 2001), considered to be the most intensive Palaeozoic tectonic episode in central Australia, folded the Table Hill Volcanics. This event causes further uplift and widespread alteration within the volcanic succession by an influx of meteoric water. Overall, the illite age data are consistent with the proposed burial history model for Empress-1A, as suggested by Ghori (2002), and the model is further supported by Apatite Fission Track Analysis (AFTA) cooling data (Hegarty et al 1988). Based on illite K-Ar data, the main illitisation event seems to have affected the Kanpa, Hussar and Browne formations during the Petermann Orogeny. Deeper-buried samples might have been overprinted by the initial Areynoga Movement and later by the Petermann Orogeny, partially resetting the illitic clay and its isotopic signature. The Alice Springs Orogeny has folded the Table Hill Volcanics and subsequent uplift triggered extensive alteration of these rocks by influx of meteoric waters.

![Figure 7](image-url) Figure 7. Empress-1A burial history and main K-Ar age groups (burial history modified from Ghori 2002).
Summary

The main illitization events of the Officer Basin, as identified from the Empress-1A drillhole samples, are related to basin subsidence and tectonic events, such as the Areyonga Movement, and the Petermann and Alice Springs orogenies. The significant features of this study with regard to the origin of illite in Empress-1A are as follows:

1. Authigenic illite occurs in most sedimentary samples, in platy and fibrous pore-bridging morphologies and is mainly related to subsidence in the Neoproterozoic. Illitisation ceased during the Petermann Orogeny.
2. Some samples contain a mixture of authigenic illite from different events. Deeper-buried samples might have been overprinted initial by the Areyonga Movement and, subsequently, by the Petermann Orogeny partially resetting the illitic clay and its isotopic signature. The obtained ages might be mixed.
3. Some samples contain a mixture of authigenic and detrital illite. The K-Ar dates obtained for these samples will have no geological meaning, as the illite separates are contaminated with detrital illite, mica or K-feldspar.
4. Illite alteration of the Table Hill Volcanics might be traced to the Alice Springs Orogeny and influx of meteoric water.

The integration of detailed petrography, XRD analysis and K-Ar dating has enabled the elucidation of some important aspects of the origin of illites in this part of the Officer Basin. This is despite the fact that there appear to be multiple origins for illite that, in different areas, might have experienced different maximum burial temperatures. This study demonstrates the potential of illite K-Ar geochronology to unravel the timing of diagenetic and thermal history processes within this part of the Officer Basin.
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