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Compositional Structure of Siderite Cement: Evidence of Tectonic Activity during Cement Precipitation

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Abstract

During precipitation of diagenetic minerals, any change in pore water chemistry may have a significant effect on the structure and composition of cement. Compositional zoning and dissolution phases in siderite cements of the Early Permian Tirrawarra Sandstone, Cooper Basin, South Australia have recorded pore water chemistry changes induced by tectonically active and passive conditions. Back-scattered electron images of siderite cement reveal three stages of siderite cement as the early (S1), middle (S2), and late (S3) stages. S1 is a structureless iron-rich siderite and S3 is a relatively homogenous cement without extensive compositional zoning, whereas S2 exhibits a rapid compositional zoning associated with several minor dissolution phases.

Temperatures of formation of siderite cements indicate that the formation of S1 and S3 has been during passive conditions in the Cooper Basin, whereas S2 formed during active tectonism. The use of compositional zoning of siderite cements may help to identify tectonic conditions during precipitation of cement in other basins.

Key words: *Compositional Structure, Siderite Cement, Tectonic Activity, Cooper Basin*

Introduction

Various authigenic minerals have been identified in the Early Permian Cooper Basin sediments in central Australia, including quartz, carbonates, kaolinite, dickite and illite, and locally clinochlore and pyrophyllite (Stanley & Halliday, 1984; Schulz-Rojahn & Phillips, 1989; Rezaee and Schulz-Rojahn, 1998; Rezaee and Tingate, 1997). Carbonate cement types include siderite, ankerite, dolomite, ferroan dolomite, and rarely calcite (Schulz-Rojahn, 1991). Although previous workers have identified several siderite cement morphologies, they considered the pore-filling sparry siderite to be a single-stage precipitate in Cooper Basin sediments (Martin & Hamilton, 1981; Schulz-Rojahn & Phillips, 1989).

The present investigation shows that the siderite cement precipitated in three main stages as an early, homogeneous Fe-rich siderite (S1), followed by a generally more extensive cement stage characterized by a complex compositional zoning (S2), which was in turn engulfed by a late-stage homogeneous siderite cement (S3). It is suggested that different siderite cement stages are precipitated under different conditions in terms of tectonic activity. The interpretation is based on the integration of petrographic and electron microprobe data, back-scattered electron (BSE) images and fluid inclusion studies. The data show that variations in the character of siderite cement are due to variations in cement composition which in turn is a function of fluctuation of pore water chemistry, particularly Fe and Mg content. Rapid variation of cement composition which resulted in compositional zoning and minor dissolution phases in siderite is more likely contemporaneous with the possible oscillatory movement (cf. Siever, 1979) in the Cooper Basin about 200 Ma. Siderite cement with a relatively homogenous nature, however, is considered to be formed during tectonically passive conditions in the Cooper Basin.

Geologic and Tectonic Setting

The Late Carboniferous-Triassic Cooper Basin of central Australia (Fig. 1) is a major hydrocarbon province (Hunt et al., 1989). The Cooper Basin consists of three major synclines which are separated by several ridges (Thornton 1979; Apak 1994). The synclines contain up to 2500m of fluvio-deltaic to lacustrine clastic strata overlain by 2-3 km of Jurassic to Tertiary fluvio-deltaic to marine sequences. The Tirrawarra Sandstone is a fluvio-deltaic interval which was deposited during the Late Carboniferous-Early Permian (Fig. 2). In the present work, the Tirrawarra Sandstone was studied in the Moorari and Fly Lake Fields located in the Patchawarra Syncline (Fig. 1).

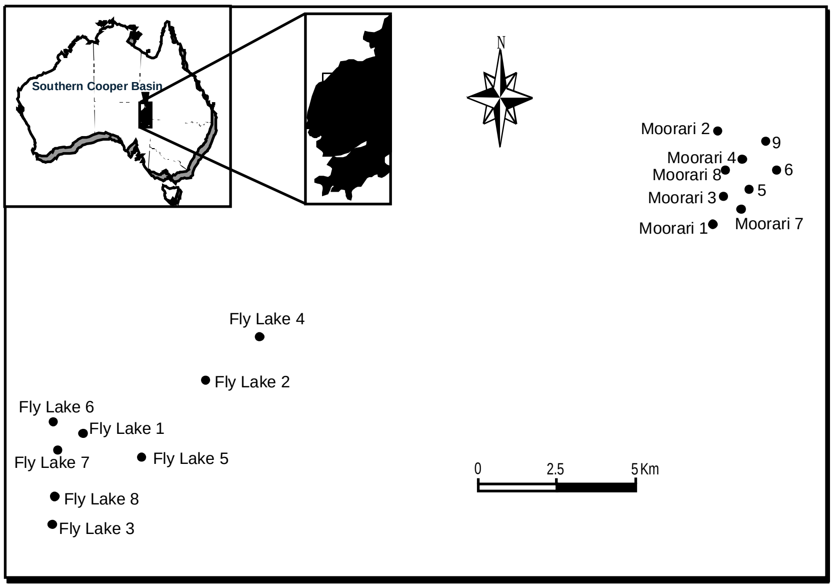


Figure 1- Location of wells studied in the Moorari and Fly Lake Fields

The first major tectonic episode (T1) (Fig. 2) after deposition of Tirrawarra Sandstone occurred in the form of uplifting and erosion after Daralingie Formation (Thornton 1979) although two earlier subtle movements were recorded during deposition of the Patchawarra Formation (Apak 1994). The tectonic activity is attributed to major fault reactivation immediately after deposition of the Daralingie Formation (Gray & Roberts 1984), resulting angular unconformity contact between Toolachee Formation and underlying formations (Wopfner 1966; Kapel 1972; Pyecroft 1973; Thornton 1979). A hiatus of about 12 m.y. is recorded at the end of Early Permian by palynological studies (Thornton 1979). Cooper Basin deposition terminated at the end of the Early-Mid Triassic when widespread compressional folding, regional uplift and erosion occurred (T2) (Battersby, 1976) (Fig. 2). As a result of this tectonic event, in some parts of the basin about 1600 m sediments were eroded (Kantsler *et al.,* 1983; Gray & Roberts 1984, Rezaee *et al.,* 1997). Deposition of Eromanga Basin sediments (Jurassic - Cretaceous) commenced on the erosion surface of Cooper Basin (Kantsler et al. 1983; Heath 1989).

After a rapid subsidence during deposition of Cretaceous sediments, another phase of tectonic activity (T3) (Fig. 2) resulted in folding and faulting (Heath 1989).

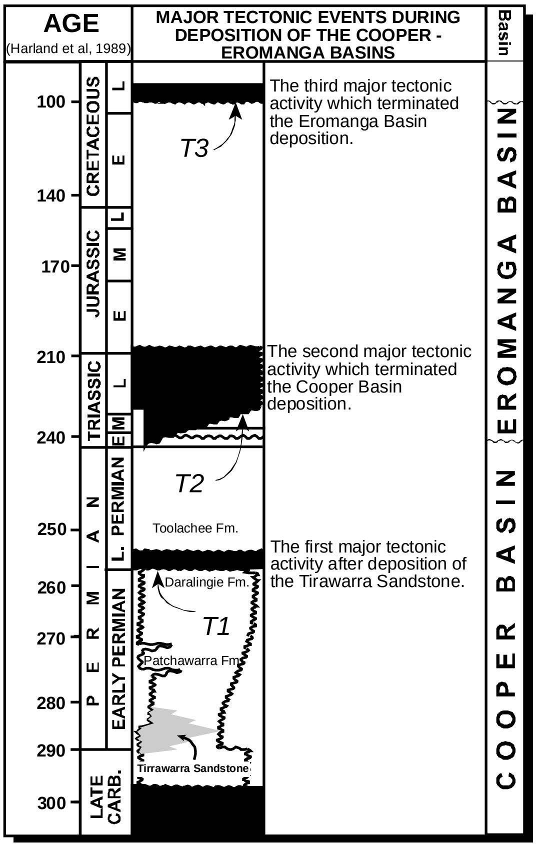


Figure 2 - Major tectonic events, black shaded area, during Cooper - Eromanga Basin deposition which resulted in uplift and erosion. The first major tectonic event (T1) resulted in an angular unconformity (Wopfner 1966; Kapel 1972; Pyecroft 1973; Thornton 1979). The second major tectonic episode (T2) at the end of the Early-Mid Triassic terminated Cooper Basin deposition when widespread compressional folding, regional uplift and erosion occurred (Battersby, 1976). The third major tectonic event (T3) which resulted in folding and faulting, terminating Eromanga Basin deposition.

Methods

A total of 130 thin sections were studied, taken from cores in 14 wells of the Moorari and Fly Lake Fields. Electron microprobe analysis and fluid inclusion microthermometry were employed to identify the precipitation temperature and composition of the siderite cement. Some selected samples, coated with carbon and gold/palladium, were observed by Phillips XL20 electron microscope connected to a back-scattered electron (BSE) detector to identify textural relationship between different stages of cement.

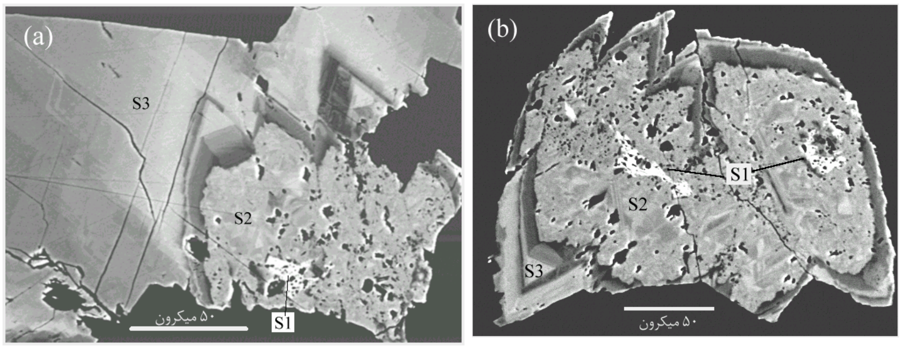
Tirrawarra Sandstone Diagenetic Setting

The Tirrawarra Sandstone consists mainly of medium-grained, moderately sorted sublitharenites (classification of Folk, 1974). A variety of authigenic minerals are recognised, including syntaxial quartz overgrowths, minor illite, patchy kaolin, and siderite. Attention is focused on the siderite and only a short description of the other diagenetic minerals is provided here.

Quartz is the dominant pore-filling cement in most samples. Quartz cementation was initiated prior to major compaction as evident by the loose grain packing of detrital grains, but probably continued until relatively recent times (Rezaee and Tingate, 1997). Pore-filling euhedral and vermiform kaolin booklets are common and are sometimes intergrown with the outer margin of quartz overgrowths. The kaolin is believed to have formed as a replacement product of feldspar and mica, although larger, well formed crystals of dickite probably formed by slow precipitation from solution (cf. Loughnan & Roberts, 1986; Schulz-Rojahn & Phillips, 1989). The authigenic nature of the illite is evident from its fibrous, lath- or lettuce-like habit. The mineral is thought to have largely formed as a replacement product of chemically unstable rock fragments. The siderite cementation and dissolution events occurred between, and synchronous with other diagenetic processes, including quartz cementation, feldspar dissolution and kaolinisation, and illitisation (Rezaee and Lemon, 1996).

Siderite Cement Characteristics

Siderite cement is one of the major cement in the Tirrawarra Sandstone sealing intergranular porosity. When viewed under the electron microprobe using BSE imaging techniques, three main stages of siderite cement are identified, including an early (S1), middle (S2), and late stage cement (S3) (Figs. 3a and 3b). Fluid inclusion data, discussed below, indicate that the different siderite cement stages precipitated under different temperature conditions.



Figures 3a & 3b - BSE image illustrating the cement stratigraphy. S1 is a white whilst the surrounding S2 (medium grey) is characterized by a variable internal composition and complex zoning. S3 is a relatively homogeneous, late-stage pore-filling cement. Note the irregular dissolution boundary between S1 and S2, and between S2 and S3. The cement relationships are typical of the Tirrawarra Sandstone. Scale bar = 50 microns.

In a BSE image, S1 is white and appears homogenous (Figs. 3a and 3b). Electron microprobe analyses for S1 show a high Fe/Mg ratio. The average composition of S1 is $(Fe_{96\%}Mg_{1\%}Ca_{1.7\%}Mn_{1.3\%})CO_3$. Where other siderite cement stages are present, S1 generally represents the substrate or nuclei for the middle stage of siderite cement precipitation (S2) (Figs. 3a and 3b). The boundary between S1 and S2 is not always distinct but typically is characterized by irregular and serrated edges, indicating partial dissolution of S1 prior to S2 cementation (Figs. 3a and 3b). In a BSE image, S2 displays a distinct and relatively rapid compositional zoning (Fig. 4), indicating pore fluid chemistry fluctuations occurred during cementation. The zonations are absent in both S1 and S3. Average composition of S2 is

$(Fe_{74\%}Mg_{24\%}Ca_{0.8\%}Mn_{1.2\%})CO_3$. Homogenization temperatures of S2 fluid inclusions range from 66 to 76°C, with a median temperature around 68°C (Fig. 5). BSE images show that S3 is a relatively homogenous cement phase, characterized by an initial high Mg content (pistomsite) grading into a relatively thick, homogenous sideroplesite cement (Figs. 3a and 3b). Electron microprobe analyses indicate extensive substitution of Mg for Fe, with an average composition of $(Fe_{75.5\%}Mg_{23\%}Ca_{0.5\%}Mn_{1\%})CO_3$ for S3. Fluid inclusion results from S3 indicate a homogenization temperature of between 98 and 114°C, with a median of about 102°C (Fig. 5).

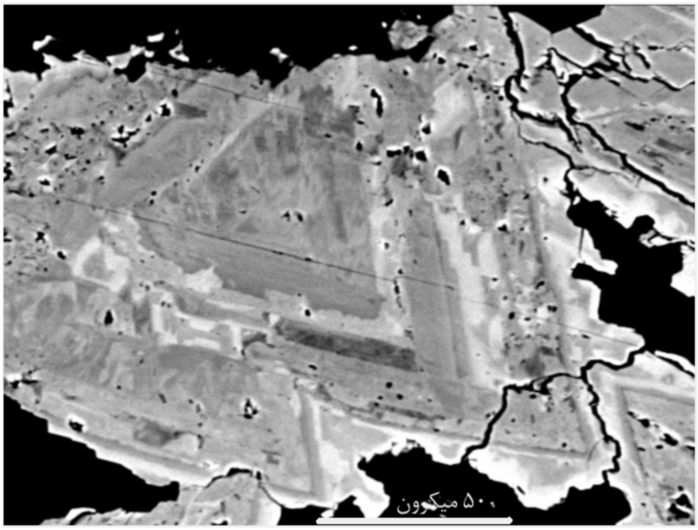


Figure 4 - A closeup view of BSE image of the middle stage of siderite cement (S2) showing distinct compostional zoning and minor dissolution. Sample M1-9598, Moorari-1, 2966.3 m. Scale bar = 50 microns.

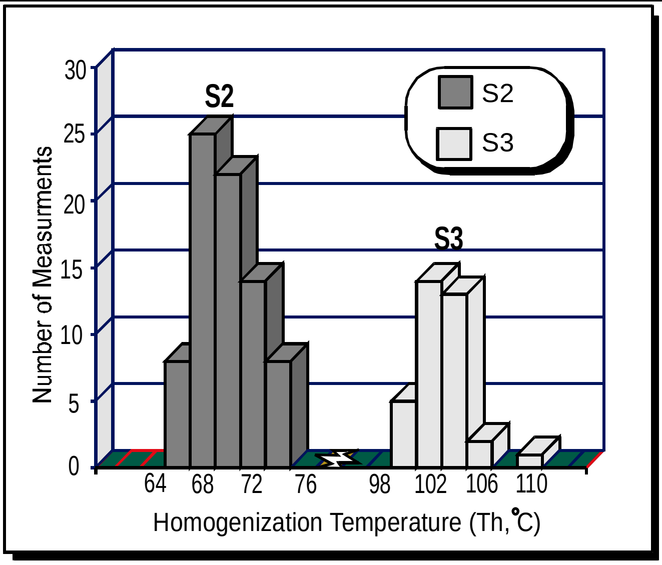


Figure 5 - Fluid inclusion homogenization temperatures for the middle (S2) and late (S3) stages of the Tirrawarra Sandstone siderites. The early stage of siderite cement (S1) is devoid of visible fluid inclusions.

Discussion and Conclusions

Results from the present investigation show that the pore-filling siderite precipitated in three main stages in the Moorari-Fly Lake area. An early, homogeneous Fe-rich siderite (S1) was followed by a generally more extensive siderite cement stage characterized by complex compositional zoning (S2), which was in turn engulfed by a late-stage homogeneous siderite cement (S3).

The fluid inclusion data indicate that S2 precipitated at a mean water temperature of about 68°C whilst S3 formed at about 102°C (Fig. 5). The crystallization temperatures of S1 cannot be determined since no fluid inclusion data are available, but the cement stratigraphy would suggest it was lower than the temperature conditions for S2, i.e. less than about 68°C. According to O and C stable isotope analysis, S1 is formed at temperature less than 30°C (Rezaee and Schulz-Rojahn, 1998)

Plotting different stages of siderite cement on the time-temperature path of the Tirrawarra Sandstone (Fig. 6) indicates that the formation of S1 is almost immediately after Tirrawarra Sandstone deposition and is before the first major tectonic activity (T1). S2 is coincident with the Early-Mid Triassic (T2) when widespread compressional folding, regional uplift and erosion occurred in the Cooper Basin (Battersby, 1976). The formation of the late stage of siderite cement (S3) is around 100 Ma, before T3 commenced (Fig. 6), during passive conditions in the Cooper Basin.

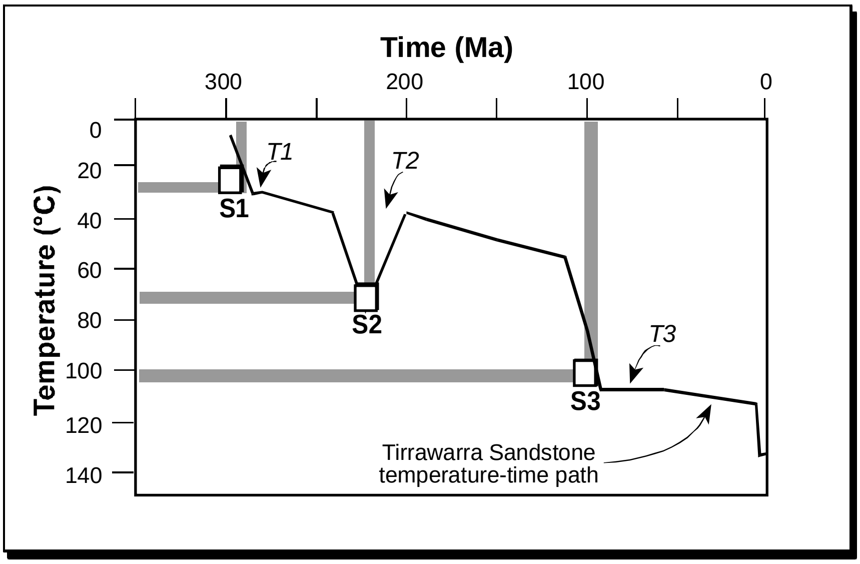


Figure 6 - Schematic thermal history of the Tirrawarra Sandstone. Time and temperature of formation of the siderite cement stages and the three main tectonic episodes which resulted in uplift and erosion in the Cooper - Eromanga Basins, are illustrated on the diagram. T1 = the first tectonic event, T2 = the second tectonic event and T3 = the third tectonic event, S1 = early stage of siderite cement; S2 = middle stage of siderite cement; S3 = late stage of siderite cement.

It is suggested that the structure of siderite cement in the Tirrawarra Sandstone has been controlled by tectonic activity. Oscillatory movements of the basin during tectonically active conditions have affected the pore-fluid chemistry which subsequently has led to compositional zoning of the siderite cement. On the other hand, during passive conditions when there is no extensive fluctuation of pore- fluid chemistry, the siderite cement exhibits a relatively homogenous structure.

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