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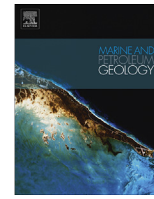

Research paper

Texture and diagenesis of Ordovician shale from the Canning Basin, Western Australia: Implications for elastic anisotropy and geomechanical properties

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A B S T R A C T

Microstructural and textural measurements from two Ordovician shale units (Goldwyer and Bongabinni formations) within the Palaeozoic–Mesozoic Canning Basin indicate that the former unit was affected by mechanical compaction and clay mineral transformation whereas the latter preserves an early fabric due to syn-depositional precipitation of authigenic dolomite and anhydrite. Conventional petrographic analysis coupled with quantitative mineralogy, electron micro probe analyses, X-ray Texture goniometry (XTG) and cathodoluminescence spectroscopy of core samples were used to decipher the post-depositional evolution of marine and supratidal facies in the Goldwyer and Bongabinni formations, respectively. Differences in diagenesis are strongly reflected in the orientation of clay minerals as quantified by XTG: in both cases the c-axes of illite diffract strongest normal to the bedding plane but the measurements clearly illustrate that shale in the Goldwyer Formation has a stronger preferred orientation relative to the Bongabinni Formation, with multiple of random distributions (m.r.d.) values of 5.77 and 2.54, respectively.

Laboratory measurements conducted at 10 MPa effective stress also indicate distinct rock physics signatures: the Bongabinni Formation shows very low anisotropy, whereas the Goldwyer Formation displays a higher degree of elastic anisotropy in terms of both P- and S- waves. The crystallographic preferred orientation of illite, highlighted by the XTG, is likely to contribute to the significant difference in elastic anisotropy observed in the two units. Therefore, the Bongabinni Formation is mechanically stronger and stiffer than the Goldwyer Formation, likely due to the early dolomite and anhydrite cementation of the former providing a rigid microstructure framework.

1. Introduction

Anisotropy in clay-rich sedimentary rocks is receiving increasing attention, particularly as seismic anisotropy is essential in prospecting for hydrocarbons, as well as in time lapse monitoring of fluids in buried reservoirs. It is generally accepted that the intrinsic anisotropy of shaly facies is the result of both the orientation of the rock forming minerals and the presence of aligned elongated pores, plus organic matter when present. Preferred orientation of rock forming minerals, especially phyllosilicates with high single crystal elastic anisotropy, is an almost ubiquitous feature of shales and mudstones and is often reported qualitatively based on microstructural observations.

From the micro-analytical perspective quantification of the crystallographic orientation of clay-rich facies is challenging due to the small grain size and poor crystallinity of clay minerals, which hinders optical and electron microscopy texture

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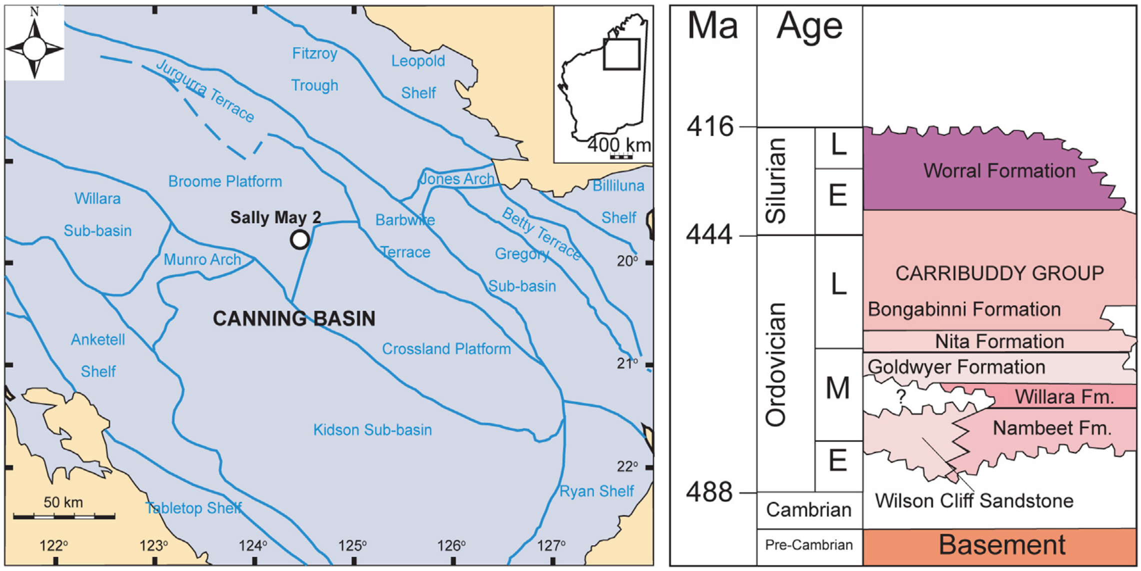

Figure 1. Left: Location and main structural features of the Canning Basin, the approximate location of the Sally-May 2 well is indicated with the white dot. The inset map shows the position with respect to Western Australia (modified after Haines, 2009). Right: Generalized stratigraphic column of the lower part of the Palaeozoic sedimentary infill (modified after Zhan and Mory, 2013).

measurements methods. Whereas X-ray diffraction techniques are helpful to analyse clay mineral orientations, they are not free of limitations, such as peak broadening due to small particles size, stacking disorder, polytypism, inter-layering and micro-strain contributing to peak overlaps in the diffraction spectra which are difficult to deconvolve. Nevertheless, laboratory based X-ray transmission techniques have been developed to study the orientation distribution of basal planes of sheet silicates and successfully applied to shales (e.g. Sintubin, 1994; van der Pluijm et al., 1994; Ho et al., 1999; Aplin et al., 2006; Day-Stirrat et al., 2008a, 2008b). More recently high energy synchrotron X-ray diffraction, has been used to obtain 3D crystal orientation distributions but the range of samples analysed to date is limited (Lonardelli et al., 2007; Wenk et al., 2008; Kanitpanyacharoen et al., 2011).

It is generally reported that phyllosilicate minerals show a strong preferred orientation with dominant axially symmetric pole figures typically showing the (001) maximum normal to the bedding plane and rotational freedom of (100) (e.g.Wenk et al., 2007). By comparison, non-clay minerals such as quartz, feldspar and carbonate show close to random distributions. This observation supports the assumption of transverse isotropy (T.I.) commonly used in the description of the elastic properties of shaly rocks (Thomsen, 1986).

The depositional and subsequent mechanical compaction processes recorded within sedimentary rocks are often responsible for the observed iso-alignment of phyllosilicates (Bjorlykke, 2013). Diagenesis can enhance or diminish such preferred orientations through dissolution–precipitation reactions or by early cementation which preserves the pre-compacted microstructural arrangement of the sediment. The texture or microstructure of a rock will dictate its physically measureable properties such as porosity, strength and stiffness, and as such is of primary interest when interpreting those measurements from either field, borehole or laboratory investigations.

This case study presents different microstructural and textural measurement techniques applied to understand the diagenetic history of shale formations deposited in different geological settings from the Canning Basin in Western Australia. The effect of the different geological evolution of the two shales is then related to their geomechanical behaviour and rock physics properties based on high pressure laboratory measurements.

2. Samples and geological setting

The shale specimens for this study are from core in an onshore wildcat well, Sally May-2 (Lat: 19 48 5.00; Long: 124 27 27.00; Fig. 1), drilled in 2009 in the Canning Basin (northern Western Australia). This large Palaeozoic–Mesozoic basin shows a multiphase depositional history extending from the Early Ordovician into the Caenozoic. Deposition in the Canning Basin began in response to extensional tectonics and rapid subsidence which was followed by four major and several minor phases of deposition and erosion (Ghori and Haines, 2006). The palaeothermal history of the succession is constrained by apatite fission track and vitrinite reflectance analyses, and indicates a maximum burial depth of approximately 2500 m in the Early Jurassic and maximum temperatures in excess of 100 °C (Duddy et al., 2005; Ghori and Haines, 2006).

Recently the subsalt Ordovician stratigraphic section has been the target of renewed interest in the area owing to the demonstrated potential for shale gas and oil production from shales in the Ordovician Goldwyer and Bongabinni formations. Core samples from these two formations in Sally May-2 are the focus of this study (Fig. 2).

The Middle Ordovician Goldwyer Formation, varies from mudstone dominated in basinal areas to limestone-dominated in some platform and terrace areas, and is interpreted as of open marine to intertidal origin (Haines, 2004). The Bongabinni Formation, the basal unit of the Ordovician to Early Silurian Carribuddy Group, comprises redbed evaporitic mudstone, carbonate and sandstone. The Bongabinni Formation contains mostly oxidised marginal marine to supratidal facies deposited under low palaeotopography conditions and with minimal influx of coarse grained siliciclastic detritus into the basin. The lack of marine fauna and bioturbation and the presence of evaporite minerals suggest at least periodically hypersaline conditions (Haines, 2009).