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Hydrocarbon source rock potential and elemental composition of lower Silurian subsurface shales of the eastern Murzuq Basin, southern Libya

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ABSTRACT

A shallow borehole was drilled in lower Silurian (Rhuddanian–lower Aeronian) Tanezzuft Formation siliciclastic sediments at the eastern margin of the Murzuq Basin. Shale samples were retrieved from the borehole to study their source rock potential and trace element geochemical composition. Thirty shale samples analysed from borehole CDEG-2a reveal three geochemically distinct intervals. Shales from the top (23–38 m) interval are weathered and have negligible organic content. Shales from the middle (38–42 m) interval have moderate to good organic richness (0.6–1.7 wt.% TOC) with Hydrogen Index (HI) values up to 443 mg S2/g TOC. Shales from the bottom (42–51 m) interval have poor to moderate organic richness (0.07–0.8 wt.% TOC) with HI values up to 277 mg S2/g TOC. All samples have limited source rock potential and are immature to early mature for hydrocarbon generation. It is unlikely that they have ever been buried deeper than ~2 km. Low TOC values (<2 wt.%) together with low concentrations of uranium (<10 ppm) indicate the absence of organic-rich black shale ('hot shale') source rocks in the studied interval.

Inorganic geochemical redox proxies (Ce-anomaly, authigenic U, Th/U, V/Cr, Ni/Co, and V/Sc) indicate that the lower Silurian Tanezzuft Formation shales from borehole CDEG-2a were deposited under oxic bottom waters, explaining their relatively low TOC values. Deposition took place in a shallow marine environment, in a proximal position with regard to an early Silurian palaeo-shoreline. This combined Rock-Eval pyrolysis and whole-rock geochemical study provides new insights into the Silurian source rock distribution and hydrocarbon prospectivity in central North Africa.

1. Introduction

The intracratonic Murzuq Basin is located in the southwest of Libya (Fig. 1) and has been the focus of gas and oil exploration, particularly since the discovery of the El Sharara (Block NC-115) and the Elephant (Block NC-174) oil fields in 1980 and 1997 respectively (Aziz, 2000; Davidson et al., 2000; Echikh and Sola, 2000; Lüning et al., 2000a; Hallett, 2002). A key risk for hydrocarbon exploration in southern Libya is the presence or absence of lower Silurian organic-rich black shales ('hot shales') of the Tanezzuft Formation (e.g., Lüning et al., 1999, 2000a, 2003a,b; Fello et al., 2006; Lüning and Fello, 2008; Belaid et al., 2010). These 'hot shales' form the major source rock for Palaeozoic-sourced hydrocarbons in North Africa (e.g., Boote et al., 1998; Lüning et al., 2000a,b; Craig et al., 2008). The genesis of such shales have been a topic of lively debate for several decades (e.g., Vine and Tourtelot, 1970; Berry and Wilde, 1978; Tourtelot, 1979; Brumsack, 1986, 2006; Lüning et al., 2000a,b; Lüning et al., 2003a,b; 2005; Harris, 2005; Armstrong et al., 2005, 2009; Page et al., 2007; Loydell et al., 2009; Negri et al., 2009, and references therein).

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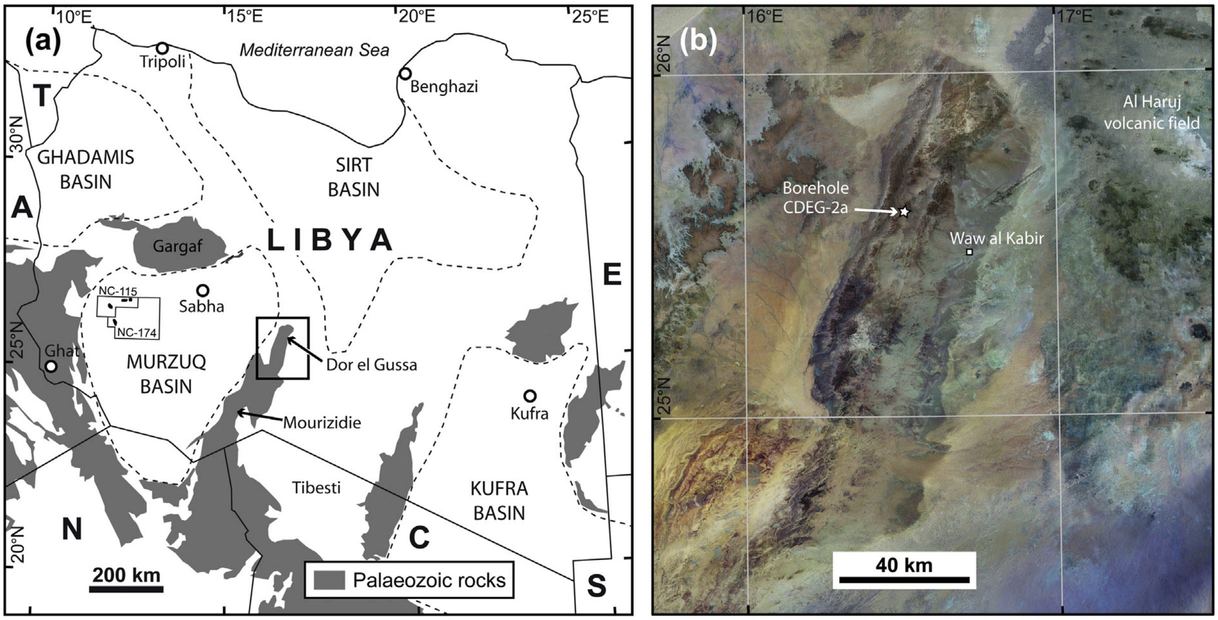

Figure 1. (a) Map of Libya showing the outcrop extent of Palaeozoic rocks (dark grey colour) and the location of Dor el Gussa at the eastern margin of the Murzuq Basin. The El Sharara (Block NC-115) and the Elephant (Block NC-174) oil fields (after Davidson et al., 2000) are shown as *black spots*. Basin outlines (after Boote et al., 1998) are shown as dashed lines. Abbreviations: A – Algeria, C – Chad, E – Egypt, N – Niger, S – Sudan, T – Tunisia. (b) Landsat image (NASA Landsat Program) of Dor el Gussa showing the location of borehole CDEG-2a.

In Libya, the Tanezzuft Formation 'hot shales' are patchily distributed in the subsurface (e.g., Davidson et al., 2000; Lüning et al., 2000a), and the collection of fresh material through drilling is both expensive and logistically difficult. Therefore, a hand-held gamma-ray spectrometer commonly is used to infer the distribution of 'hot shales' by measuring the uranium (U) content of outcrop samples as proxy for total organic carbon (TOC) content. Because there is a positive correlation between U content and TOC content (e.g., Stocks and Lawrence, 1990; Lüning and Kolonic, 2003; Lüning et al., 2003a; Fello et al., 2006; Lüning and Fello, 2008), the presence of shales with a high U content is commonly seen as evidence for former high TOC content and therefore of an oil- and gas-prone source rock in the subsurface below the weathering zone. Such a correlation seems plausible since U is removed from the ocean water by diffusion across the sediment–water interface and eventual reduction and residence in organic-rich shales (Klinkhammer and Palmer, 1991). Shales with U values of >10 ppm are designated as 'hot shales' (Lüning et al., 2003a; Lüning and Fello, 2008).

The Tanezzuft Formation 'hot shales' are rarely exposed, and when they are, outcrops are commonly intensely weathered. Surface shale samples have typically lost all organic matter through oxidation (Lüning and Kolonic, 2003; Lüning et al., 2003a), and range from pale grey, green, red and whitish yellow in colour. The CASP drilling programme in southern Libya demonstrated that desert weathering affects rocks to depths of at least 35 m (Paris et al., 2012; Meinhold et al., 2013). Weathering of sedimentary rocks may cause mobilisation of U and redeposition at the redox front because U is remobilised under oxidising conditions but precipitates in an oxygen-poor environment (e.g., Rogers and Adams, 1969a; Hobday and Galloway, 1999). Therefore, some caution should be exercised when using U content measured by a hand-held gamma-ray spectrometer on surface exposures to study 'hot shale' distribution. Furthermore, U-bearing minerals (e.g., zircon) can be an additional source of U in the sediment (Serra, 1984; Belousova et al., 2002).

Shales designated as 'hot' are known from the western margin (e.g., Fello et al., 2006; Lüning and Fello, 2008) and the subsurface of the Murzuq Basin (e.g., Aziz, 2000; Davidson et al., 2000; Lüning et al., 2000a; Belaid et al., 2010). It is therefore reasonable to speculate that such shales may also be present in the eastern Murzuq Basin. Unfortunately, no source rock data have yet been published from this part of the basin, leaving a gap in our knowledge of the distribution of the Tanezzuft Formation 'hot shales' in southern Libya. To overcome this problem, and the problem with weathering at outcrop, it was decided to drill through the weathered zone in the eastern Murzuq Basin to recover fresh samples for source rock analysis. This was achieved by borehole CDEG-2a (geographic coordinates: 25°36′19.27″N, 16°30′47.75″E), drilled to a depth of 50.7 m by CASP in central Dor el Gussa in spring 2008 (Fig. 1). Rock-Eval pyrolysis and whole-rock geochemical data for selected major and trace elements, including rare earth elements (REE), were obtained for 30 shale samples from the Tanezzuft Formation at depths between 23 and 50.7 m. Although borehole CDEG-2a did not encounter 'hot shales', it provides the first investigation of potential source rock intervals within the Silurian succession in the eastern Murzuq Basin. This area has previously been overlooked because outcrops are severely weathered. The new data are used to test the relationship between the TOC content and the actinide metal U, to identify variations in major and trace element concentrations with increasing depth through the surface weathering profile, and to study their relationships with Rock-Eval pyrolysis and kerogen data.

2. Regional geology

The Murzuq Basin (Fig. 1) is an erosional remnant of a large Palaeozoic and Mesozoic sedimentary basin that originally extended over much of North Africa (Boote et al., 1998; Davidson et al., 2000). A simplified stratigraphic column of the eastern Murzuq Basin is shown in Figure 2. The eastern margin of the Murzuq Basin is formed by a low mountain range, called Dor el Gussa, which is dominated by a siliciclastic sedimentary Cambrian to Carboniferous succession (e.g., Klitzsch, 1964; Klitzsch and Ziegert, 2000; Meinhold et al., 2011; Morton et al., 2011; Le