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Research paper

Organic geochemistry of the Silurian Tanezzuft Formation and crude oils, NC115 Concession, Murzuq Basin, southwest Libya

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ABSTRACT

Thirty-six Silurian core and cuttings samples and 10 crude oil samples from Ordovician reservoirs in the NC115 Concession, Murzuq Basin, southwest Libya were studied by organic geochemical methods to determine source rock organic facies, conditions of deposition, thermal maturity and genetic relationships. The Lower Silurian Hot Shale at the base of the Tanezzuft Formation is a high-quality oil/gas-prone source rock that is currently within the early oil maturity window. The overall average TOC content of the Hot Shale is 7.2 wt% with a maximum recorded value of 20.9 wt%. By contrast, the overlying deposits of the Tanezzuft Formation have an average TOC of 0.6 wt% and a maximum value of 1.1 wt%. The organic matter in the Hot Shale consists predominantly of mixed algal and terrigenous Type-II/III kerogen, whereas the rest of the formation is dominated by terrigenous Type-III organic matter with some Type II/III kerogen. Oils from the A-, B- and H-oil fields in the NC115 Concession were almost certainly derived from marine shale source rocks that contained mixed algal and terrigenous organic input reflecting deposition under suboxic to anoxic conditions. The oils are light and sweet, and despite being similar, were almost certainly derived from different facies and maturation levels within mature source rocks. The B-oils were generated from slightly less mature source rocks than the others. Based on hierarchical cluster analysis (HCA), principal component analysis (PCA), selected source-related biomarkers and stable carbon isotope ratios, the NC115 oils can be divided into two genetic families: Family-I oils from Ordovician Mamuniyat reservoirs were probably derived from older Palaeozoic source rocks, whereas Family-II oils from Ordovician Mamuniyat–Hawaz reservoirs were probably charged from a younger Palaeozoic source of relatively high maturity. A third family appears to be a mixture of the two, but is most similar to Family-II oils. These oil families were derived from one proven mature source rock, the Early Silurian, Rhuddanian Hot Shale. There is a good correlation between the Family-II and -III oils and the Hot Shale based on carbon isotope compositions. Saturated and aromatic maturity parameters indicate that these oils were generated from a source rock of considerably higher maturity than the examined rock samples. The results imply that the oils originated from more mature source rocks outside the NC115 Concession and migrated to their current positions after generation.

1. Introduction

With 44 billion barrels of oil and over 54 trillion cubic feet of natural gas, the largest proven reserves of hydrocarbons in Africa occur in Libya, an important founding member of the Organization of Petroleum Exporting Countries (OPEC). From the exploration perspective, the country is divided into four major basins, three of which, Ghadames, Murzuq and Al Kufra, are essentially Palaeozoic basins. The fourth, Sirte, is primarily a Mesozoic–Cenozoic basin (Fig. 1A). The Ghadames Basin continues westwards into Tunisia and Algeria where it attains its greatest depth. By contrast, the Murzuq Basin terminates against the Tihemboka Arch and does not extend into Algeria (Fig. 1B). It continues southwards into Niger, where it eventually pinches out onto basement.

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Libya has 29 oil fields with greater than one billion barrels of oil originally in place; 22 of these fields lie in the Sirte Basin, six in the Murzuq Basin (Hallett and Clark-Lowes, 2016) and one, Bouri, in the Sabratah Basin, offshore northwest Libya. The reserves of the Murzuq Basin are now second only to those of the Sirte Basin. A recent estimation of hydrocarbons in place for the Murzuq Basin is 6.0 billion barrels of oil and 1.0 trillion cubic metres of gas, which represents about 6.5% of the Libya's total production. Since oil exploration began in 1957, 62 wildcat wells resulted in the exploitation of 11 oil fields in the basin (Rusk, 2001), several of which, including El Sharara, and El Feel (Elephant), are giant fields. The focus of this paper is the NC115 Concession in the northwestern part of the basin, some 800 km south of Tripoli. It covers approximately three-quarters of the area between latitudes 26°08′ and 26°38′N and longitudes 11°30′ and 12°30′E (Fig. 1C). Within the concession three major oil fields, -A, -B and -H, were developed in this part of the Sahara Desert. The B-field is the most southwesterly of these. It is approximately 50 km southwest of the A-field, which in turn is approximately 10 km west of the H-field (Fig. 1D; RRI, 1998). REPSOL is the operator of the NC115 exploration block, and its partners are OMV and TOTAL. Austria's OMV has been present in Libya since 1975 and started production in 1985.

Previous studies of the Murzuq Basin mainly focused on the geochemical characteristics of hydrocarbon fluids or on source rock evaluation, with only limited correlation between them (e.g., Lüning et al., 2000, 2003; Belaid et al., 2010; Hall et al., 2010; Hodairi and Philp, 2011, 2012; Butcher, 2013; Loydell et al., 2013; Meinhold et al., 2013, and references therein). The main goals of this study are to determine (1) environments of deposition, thermal maturity and hydrocarbon potential of the Silurian Tanezzuft and its basal Hot Shale Member in the context of resource assessment, and (2) the molecular and isotopic characteristics of a suite of crude oils and their genetic relationships.

2. Structural/stratigraphic framework

Oceanic anoxic events leading to oxygen depletion and deposits with high total organic carbon (TOC) content occurred in parts of the world's oceans several times in the past (Klemme and Ulmishek, 1991; Lüning et al., 2000, 2003, 2005). In North Africa and Arabia much of the Palaeozoic oil resources resulted from the maturation and migration of hydrocarbons generated from Silurian organic-rich marine shales (Klemme and Ulmishek, 1991; Boote et al., 1998; Lüning et al., 2000, 2003; Peters and Creaney, 2004; Loydell et al., 2009; İnan et al., 2016). The intracratonic Murzuq Basin is no exception.

Regional tectonic events and changes in relative sea level had a significant impact on stratigraphic settings in this basin and the NC115 study area. Precambrian tectonic activity led to vertical basement N–S trending faults that were counterbalanced by conjugated faults trending in a NE–SW direction (Goudarzi, 1980; Echikh and Sola, 2000). Several subsequent compressional and extensional tectonic episodes have generally been assigned to the Caledonian (Wenlock, late Early Silurian), Hercynian (Middle–Late Carboniferous) and Alpine (intra-Cenozoic, Bellini and Massa, 1980; Aziz, 2000; Echikh and Sola, 2000) orogenies.

The Murzuq Basin is situated between three major defining tectonic elements; the Al Qarqaf High to the north, the Tibisti High to the east, and the Tihemboka High to the west (Fig. 1B). These prominent highs resulted from various tectonic events from mid-Palaeozoic to Tertiary times, but the main periods of uplift took place during the mid-Cretaceous and Paleogene when the chief influence on sedimentation was probably a NNW–SSE structural trend (RRI, 1998). This was disrupted by a number of later strike-slip faults of mainly dextral displacement that trend approximately perpendicular to the main structures in an ENE–WSW orientation (Fig. 2A).

Within the NC115 Concession a strike-slip fault (Fig. 2A) runs from near the southwestern corner to the northeastern corner, and all discovered oil fields are to the northwest of this fault. The majority of the fields are located in basinal areas with the exception of the B-field toward the southwest of the concession, which is on a localized positive area bounded by two sub-parallel NNE–SSW-oriented normal faults.

The geology of the NC115 license area is generally typical of the Murzuq Basin as a whole (Fig. 2B) in comprising Precambrian to Cretaceous rocks (Figs. 2B and 3), formation thicknesses being broadly similar throughout the concession (RRI, 1998; Aziz, 2000; Hallett, 2002). The deposits consist mainly of marine shale, siltstone, and sandstone unconformably overlying the Precambrian basement complex. Their total thickness exceeds 3500 m in the central part of the basin. The hydrocarbons in Ordovician reservoirs in the basin were derived from Silurian source rocks (Boote et al., 1998; Davidson et al., 2000; Echikh and Sola, 2000): our discussion of the stratigraphic setting of the Murzuq Basin will, therefore, focus on these rock units.

The Ordovician rocks of this area were first described by Massa and Collomb (1960). They are widespread over large portions of the North African craton (Pierobon, 1991). Four formations represent the sequence, namely Ash Shabiyat (Lower Ordovician), Hawaz (Middle Ordovician), Melaz Shuqran and Mamuniyat (Upper Ordovician) (Lüning et al., 2000). We focus here on the Hawaz and Mamuniyat formations, which are important reservoirs (Fig. 3).

The Hawaz Formation was first described and named after Jebel Hawaz on the Al Qarqaf High by Massa and Collomb (1960). In the NC115 Concession, it is overlain by the Ordovician Melaz Shuqran Formation (Fig. 3), where it reaches 150 m in thickness. Its probable mid-Ordovician age is based on palynological evidence (Hallett, 2002). The formation consists of fine- to medium-grained quartzitic sandstone that is moderately to well cemented by siliceous material. It is kaolinitic in parts, has poor visual porosity, and contains thin streaks of moderately- to well-compacted, sub-fissile to fissile shale (Hallett, 2002; Ramos et al., 2006). These deposits reflect the onset of the first major Palaeozoic marine transgression in the region (Echikh and Sola, 2000; Ramos et al., 2006; de Gibert et al., 2011).

The name Mamuniyat Formation is derived from the type section on the Al Qarqaf Arch. The names of most stratigraphic units in the Lower Palaeozoic of Libya are based on locations either in wadis (e.g., Tanezzuft Formation) or on arches (Mamuniyat Formation), as reported by Le Heron et al. (2010). In common with the underlying units, the Upper Ordovician glacially-related strata occur on the Al Qarqaf Arch where two formations are formally recognized in both surface (Massa and Collomb, 1960) and subsurface (El-ghali, 2005) mapping, namely the Melaz Shuqran Formation and the overlying Mamuniyat Formation (Gundobin, 1985). The latter is predominantly a sandstone unit with subordinate siltstone and shale interbeds (Aziz, 2000; Davidson et al., 2000). The sandstone is fine-grained, off-white, medium hard to hard, and moderately to well cemented by siliceous material. It also includes thin layers of fissile to sub-fissile grey shales. The lower and middle parts of the formation represent glacial deposits associated with relative sea-level fall (El-ghali, 2005). The upper units comprise a prolific reservoir unit in the B-oil field, and are in direct contact with the overlying source rock, the Silurian (Llandovery–Wenlock) Tanezzuft Formation (Hallett, 2002). The sandstones of the Mamuniyat Formation are the primary reservoir in the Murzuq Basin. The fluvial and shallow marine sandstones of the Hawaz Formation are secondary in this respect. Oil discoveries in the NC115 Concession seem to follow a NW–SE trend. This regional trend is probably related to the