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Chemostratigraphy, tectonic setting and provenance of the Cambro-Ordovician clastic deposits of the subsurface Algerian Sahara

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ABSTRACT

The Cambro-Ordovician sandstones are one of the main oil reservoirs in Algeria. They are, in the most part a braided fluvial system and the reservoir is subdivided into four lithozones (R3, R2, Ra, Ri) based on grain size and wireline logs signatures. Geochemical analysis has been applied to these units with no or very poor biostratigraphic control for more detailed and accurate stratigraphy and correlations. Several Wells are selected from the northern part of the Saharan Platform. Geochemical data have been acquired from cores with 20 elements being determined. A new nomenclature of sequences or subunits, based on chemostratigraphy and sedimentology, is established from base to top for the Cambrian and the Lower Ordovician. The majority of sandstones have an average SiO_2 content between 86.4 wt% and 96.8 wt%, i.e. quartz-rich. Cambro-Ordovician sandstones are therefore quartz arenites in their majority. The evolution of the two ratios SiO_2/Al_2O_3 and K_2O/SiO_2, which are significant variables for differentiating between the Cambro-Ordovician units, display an increase in the maturity of sandstones from the base to the top. Ferro-magnesian content and trace elements such as Ni, Co and Cr show that a significant contribution from volcanic rocks is unlikely. Mineralogical maturity of the analysed rocks along with the occurrence of zircon is consistent with a felsic plutonic or reworked sedimentary source rocks. Sediments were derived mainly from deeply weathered cratonic landmasses or recycling sediments. A passive margin origin for the Cambro-Ordovician sandstones is indicated by the discriminant plot of K_2O/Na_2O vs. SiO_2. The maturity of these sandstones is characteristic of cratonic environments, where sedimentary recycling is an important process. The tectonic setting and the provenance of Cambro-Ordovician clastic deposits conform to a passive margin setting. However, sequence isopachs and sedimentary architectures indicate that the Hassi Messaoud area was locally unstable during the Cambrian.

1. Introduction

The tectonic evolution of the Algerian Sahara involved multiple periods of extension and compression ranging from the Pan-African orogeny (Bertrand and Caby, 1978), to the Alpine tectonic event (Follot, 1952; Boudjema, 1987; Makhous and Galushkin, 2003; Mitra and Leslie, 2003; Fabre, 1988, 2005). During most of the Early Palaeozoic, the Saharan Palaeozoic basins were part of a large, inter-connected North African shelf system that was in a sagging stage after an Infracambrian extensional phase (Craig et al., 2004). At the end of the Palaeozoic, collision between the Gondwana and Laurasian plates resulted in uplift of North Africa. Widespread erosion followed, resulting in the formation of the Hercynian unconformity (Follot, 1952; Underdown and Redfern, 2007), which cut deep into the Palaeozoic section (Haddoum et al., 2001; Zazoun, 2001; Mitra and Leslie, 2003). A number of previous studies relating to the tectonic setting of the Cambro-Ordovician clastic deposits have been carried out (Debyser et al., 1965; Beuf et al., 1971; Rognon et al., 1972; Fabre, 2005). The Cambro-Ordovician sequence is one of the main reservoir intervals in Algeria. It was deposited either directly on igneous and metamorphic basement or, in some cases, onto sedimentary rocks of Precambrian age. The Cambro-Ordovician tends to be barren of fossils and, as a result, precise biostratigraphic determinations are impossible. Early workers in the area tried to integrate outcrop and borehole lithostratigraphy to help understand the geology of the newly discovered oil reservoirs (Gevin, 1960; Legrand, 1962; Legrand and Nabos, 1962; Freulon, 1964; L'Homer, 1967), while the first major synthesis of the Cambro-Ordovician was undertaken by Beuf et al. (1971). Later work on the sedimentology and reservoir geology of the Cambro-Ordovician of the super giant Hassi Messaoud oil field and the surrounding Saharan Platform (Balducchi and Pommier, 1970; Aliev et al., 1971; Whiteman, 1971; Ali, 1973; Chiarelli, 1978). The most recent publications have used palynology and sequence stratigraphic approaches to try and correlate the Cambro-Ordovician sequences (Legrand, 1985; Fekirine

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and Abdellah, 1998; Vecoli et al., 1995; Vecoli and Playford, 1997; Vecoli et al., 1999; Vecoli, 2000; Carr, 2002; Ghienne et al., 2007). The first biostratigraphic evidence of Middle to Late Cambrian sedimentation in the Algerian subsurface resulted from the palynological analysis of pre-Ordovician clastic sequences penetrated by borehole AMG-1 in northwestern Algeria (Vecoli et al., 2008). Despite the efforts of many workers, the common correlation scheme of the Cambro-Ordovician in Algeria is based on a subdivision into four informal lithozones which are from base to top: R3, R2, Ra (anisotropic reservoirs-supposed Lower Cambrian) and Ri (isotropic reservoir-supposed Ordovician). These subdivisions are based on grain size sorting and wireline log signatures.

1.1. Objectives and purpose

Chemostratigraphy involves the application of whole rock geochemical data to the characterization and correlation of sediments in petroleum basins. The geochemistry of sediments is highly variable and is sensitive to subtle changes in composition (Wright et al., 2006). Inorganic geochemistry can be useful when applied to sequences with very poor biostratigraphic control. The technique has been extensively employed by the petroleum industry, but only a few studies have been published. Description of its application and utility in a variety of circumstances are given in Pearce and Jarvis (1995), Roser et al. (1996), Preston et al. (1998) and Pearce et al. (1999). Applications of chemostratigraphic techniques to correlate the Cambro-Ordovician of Algeria have been undertaken at the *Centre of Research and Development* of *Sonatrach* since 1993. This paper describes the results of a chemostratigraphic study of the Cambro-Ordovician sequence in seven wells from oil and gas fields in Algeria (Hassi Messaoud, Hassi R'Mel, Ain Romana and Hassi Touila). The location of these fields is shown in Fig. 1. Previous studies on sandstones (Al-Gailani, 1980; Bhatia, 1983; Bhatia and Crook, 1986; Ehrenberg and Siring, 1992; Roser et al., 1996; Ratcliffe et al., 2004) but very few concentrated on its use in hydrocarbon exploration and production (Ratcliffe et al., 2002; Pearce et al., 2005). The common subdivision of the Cambro-Ordovician in Algeria into R3, R2, Ra and Ri units is difficult to use for a productive field. Chemostratigraphy provides a complementary tool along side sedimentology and petrography. According to Wright et al. (2006), hydrocarbons reservoirs within low accommodation fluvial depositional environments are notoriously difficult to understand in a rigorous stratigraphic framework (Ratcliffe et al., 2004, 2006). However, in order to exploit these reservoirs it is essential to have high resolution stratigraphic correlations

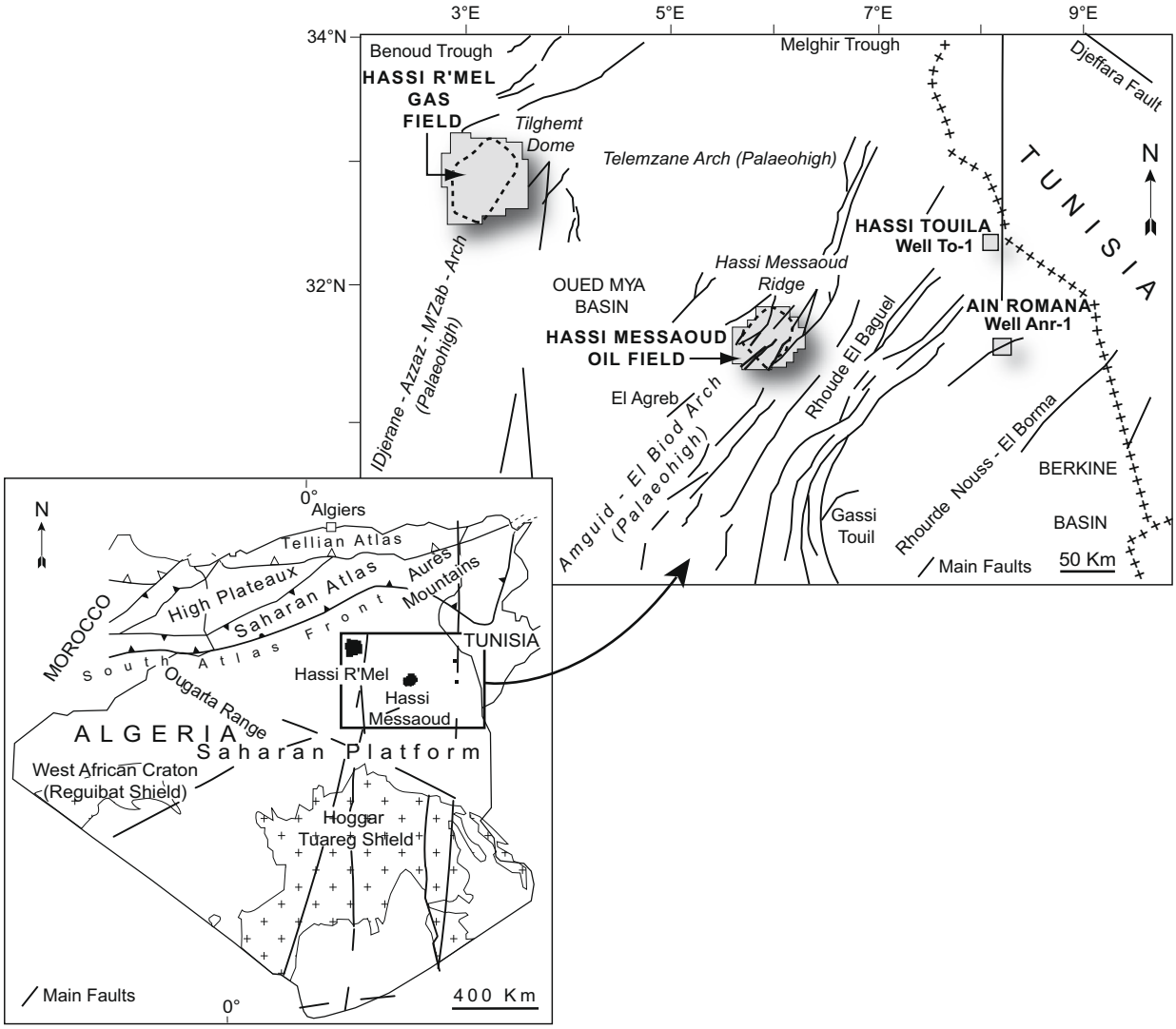

Fig. 1. Regional map showing location of study area (after unpublished Sonatrach reports, modified).