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Strontium isotopes correlation of the Tunisian Late Cretaceous Abiod Formation: Comparison to previous biostratigraphic assignments

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The Tunisian topmost Le Kef Formation and Abiod Formation were the focus of strontium isotopes numeric age dating. A representative outcrop section in NW Tunisia near Le Kef town (El Djebil section) constituted the main study material. In addition, a small outcrop section (Kodiet ez Zarbia) in NW Tunisia, equivalent of the base of the overlying El Haria Formation, was also examined. Results were compared to previous numeric dating by Mabrouk et al. (2005) of the Aleg (lateral equivalent of Le Kef Formation), Abiod and El Haria formations in four offshore wells from the Miskar Gas Field (Miskar W1, W2, W3, and W4), Gulf of Gabes, SE Tunisia. Strontium isotopes stratigraphy, overall, supports the previous biostratigraphic assignments and indicates that: (i) the age ranges of the Abiod Formation at El Djebil section and in the Miskar Field are very similar; (ii) the age of the Le Kef Formation at El Djebil section is younger than its equivalent Aleg Formation in the Miskar Field; (iii) the El Haria Formation, cored in Miskar W3 and sampled at Kodiet ez Zarbia, is of approximately the same age. The strontium isotopes dating concurs with biostratigraphic assignments and suggest that the Abiod Formation in Miskar W1 (SE) corresponds to most of that occurring at El Djebil section (NW) and is therefore a condensed chalk sequence that was deposited through Campanian–Early Maastrichtian time.

1. Introduction

The provision of a reliable time framework is an essential element of any geological study. Biostratigraphic data tied to absolute ages derived from radiogenic isotope studies of reference sections (e.g. Gradstein et al., 2012) provide the most common method of obtaining dates and deriving a timescale for a sedimentary sequence. However, such methods require the presence of key taxa and the identification of biostratigraphic datums that have been assigned. Dates are generally only available at stage boundary resolution (Gradstein et al., 1995, 2012; Harland et al., 1990) for the Late Cretaceous, and cannot be derived easily for rapidly deposited sequences of limited stratigraphic extent.

The identification of secular variation in the strontium isotopic composition of marine sediments had led to the development of strontium isotopes stratigraphy (SIS) which has been used to correlate sequences and can be used to derive numerical age by comparison with $^{87}Sr/^{86}Sr$ ratios from well-dated international reference sections (i.e. Wickman, 1948; Peterman et al., 1970; Dasch and Biscaye, 1971; Veizer and Compston, 1974; Burke et al., 1982; Koepnick et al., 1985; De Paolo and Ingrim, 1985; De paolo, 1986; Hess et al., 1986, 1989; Miller et al., 1988, 1991; Hodell et al., 1989; Hodell and Ciesielski, 1990, 1991; Jones, 1992; McArthur et al., 1992, 1993a,b, 1994, 1998; Jones et al., 1994; McArthur et al., 2001; Mabrouk et al., 2005; McArthur et al., 2012). Strontium isotopes is thought to provide an alternative method to biostratigraphy for dating sedimentary sequences.

Strontium has four naturally occurring stable isotopes, ^{84}Sr, ^{86}Sr, ^{87}Sr, and ^{88}Sr. These isotopes present different isotopic abundances (Debievre and Barnes, 1985) which are quantified as follows: $^{84}Sr = 0.56\%$, $^{86}Sr = 9.86\%$, $^{87}Sr = 7.00\%$, $^{88}Sr = 82.6\%$. Variation in the strontium isotopic ratio $^{87}Sr/^{86}Sr$ in geological samples is related to the production of radiogenic ^{87}Sr by beta decay from ^{87}Rb (rubidium) which is known to be concentrated into the continental crust, leading to the accumulation of higher $^{87}Sr/^{86}Sr$ ratios than in the oceanic crust. Strontium in the oceans has two main origins: strontium originating from hydrothermal reactions with oceanic crust at mid-ocean ridges and bearing low $^{87}Sr/^{86}Sr$ ratios; and strontium derived from continental weathering which is characterised by high $^{87}Sr/^{86}Sr$ ratios. Therefore, $^{87}Sr/^{86}Sr$ of the oceans changes through time in response to the varying influence of these

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two factors; $^{87}Sr/^{86}Sr$ of seawater can be described as a balance between ocean crust derived $^{87}Sr/^{86}Sr$ and continental crust derived $^{87}Sr/^{86}Sr$ (Palmer and Elderfield, 1985).

In addition to these two main origins of strontium into the oceans, the upward diffusion of pore-waters from marine carbonate sediments constitutes an additional major input of the element (Elderfield and Gieskes, 1982). This input, termed the diagenetic return flux (with $^{87}Sr/^{86}Sr$ values intermediate between those originated from the continental crust and those originated from oceanic crust), is derived from pore fluids rich in strontium and results from the diagenetic conversion of strontium-rich aragonite and high-Mg calcite to strontium-poor low-Mg calcite.

Strontium isotope stratigraphy (SIS) aims to correlate sequences and make age determinations using $^{87}Sr/^{86}Sr$ based on the observation that the residence time of strontium in the oceans (1 Myr) is three orders of magnitude greater than the oceanic mixing time (1–2 kyr), which means that oceans are homogenous with respect to $^{87}Sr/^{86}Sr$ at any given time. This makes it possible to correlate biogenic carbonates, provided that they record unaltered fully marine strontium isotope signals. The variation of $^{87}Sr/^{86}Sr$ through time can be discerned from the analysis of well-preserved biogenic marine carbonates of known age. These are known as standard seawater $^{87}Sr/^{86}Sr$ curves, and can be used to date carbonate sequences by comparing $^{87}Sr/^{86}Sr$ ratios of a sample to standard seawater $^{87}Sr/^{86}Sr$ curves (Elderfield, 1986; Veizer, 1989; McArthur et al., 1993a; McArthur et al., 1994; McArthur et al., 2001; McArthur et al., 2006; McArthur et al., 2012). However, this age assignment bears errors that are related to: (i) errors in age assignments of the $^{87}Sr/^{86}Sr$ analyses which make up the standard seawater curve; (ii) the analytical precision of $^{87}Sr/^{86}Sr$ measurements; (iii) and errors induced by diagenetic alteration.

The method is highly suitable for dating marine carbonate rocks ranging from Palaeozoic to Pleistocene age as marine $^{87}Sr/^{86}Sr$ is rarely altered at salinities above 20 psu, (McArthur et al., 2012).

Aiming to derive numerical ages using strontium isotope stratigraphy, representative carbonate-rich intervals were selected from the Kef, Abiod and El Haria formations of the El Djebil and Kodiet ez Zarbia sections (Fig. 1). The sections have been previously studied from a sedimentological, geochemical and carbon isotopes point of view by Jarvis et al. (2002) and Mabrouk El Asmi (2014). A comparison will be made to published strontium isotopes data (Mabrouk et al., 2005) of the Abiod Formation in four wells (W1, W2, W3, and W4) of the Miskar Field, located in the Gulf of Gabes, southeastern Tunisia (Fig. 1).

2. Material

The Le Kef of the "Tunisian Trough", NW Tunisia, contains some of the thickest Cretaceous and Tertiary successions in Tunisia (Jarvis et al., 2002). The Abiod Formation is abnormally thick around Le Kef and its three common members are particularly well developed; with a lower and upper chalky units and an intercalating marly member (Jarvis et al., 2002; Mabrouk El Asmi, 2014). The area contains outcrops ranging in age from Triassic to Quaternary (Fig. 1). The section at El Djebil exposes the uppermost part of the Coniacian-Santonian Kef Formation (lateral equivalent of the Aleg Formation), the commonly known Campanian–Maastrichtian Abiod Formation, and the basal few metres of the overlying Maastrichtian-Paleocene El Haria Formation. The latter is weathered and not well-exposed in this area, and consequently was logged at Kodiet ez Zarbia (Fig. 1), located about 10 km south-west of El Djebil (Mabrouk El Asmi, 2014).

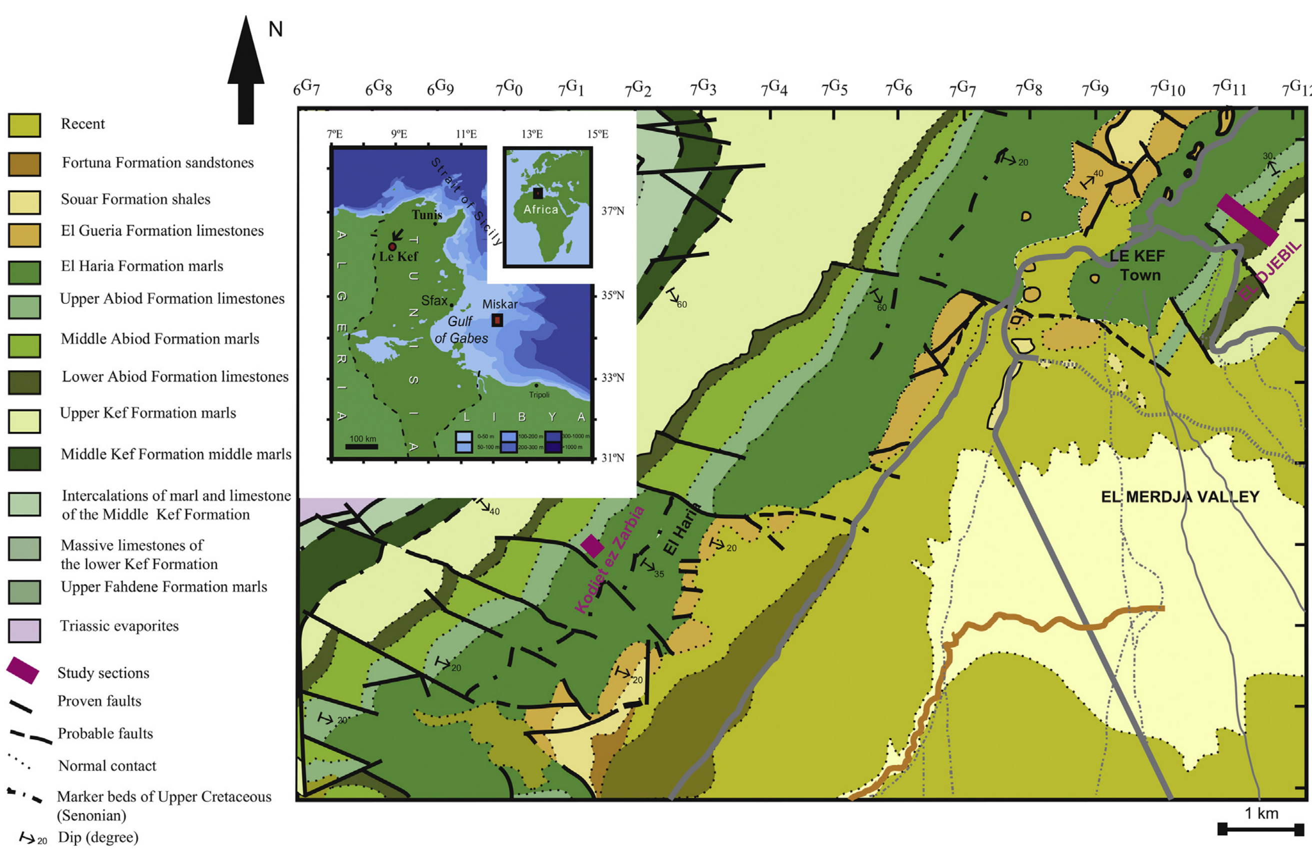

Fig. 1. Location map for the Le Kef sections at El Djebil and at Kodiet ez Zarbia (after Mabrouk El Asmi, 2014). Geology after the geological map (1/50 000) of Le Kef area (after "Le Service Géologique de la Tunisie").