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Muddy and dolomitic rip-up clasts in Triassic fluvial sandstones: Origin and impact on potential reservoir properties (Argana Basin, Morocco)

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ABSTRACT

The significance of rip-up clasts as sandstone framework grains is frequently neglected in the literature being considered as accessory components in bulk sandstone composition. However, this study highlights the great value of muddy and dolomitic rip-up clast occurrence as: (a) information source about low preservation potential from floodplain deposits and (b) key element controlling host sandstone diagenetic evolution and thus ultimate reservoir quality. High-resolution petrographic analysis on Triassic fluvial sandstones from Argana Basin (T6 and T7/T8 units) highlights the significance of different types of rip-up clasts as intrabasinal framework components of continental sediments from arid climates. On the basis of their composition and ductility, three main types are distinguished: (a) muddy rip-up clasts, (b) dolomitic muddy rip-up clasts and (c) dolomite crystalline rip-up clasts. Spatial distribution of different types is strongly facies-related according to grain size. Origin of rip-up clasts is related to erosion of coeval phreatic dolocretes, in different development stages, and associated muddy floodplain sediments. Cloudy cores with abundant inclusions and clear outer rims of dolomite crystals suggest a first replacive and a subsequent displacive growth, respectively. Dolomite crystals are almost stoichiometric. This composition is very similar to that of early sandstone dolomite cement, supporting phreatic dolocretes as dolomite origin in both situations. Sandstone diagenesis is dominated by mechanical compaction and dolomite cementation. A direct correlation exists between: (1) muddy rip-up clast abundance and early reduction of primary porosity by compaction with irreversible loss of intergranular volume (IGV); and (2) occurrence of dolomitic rip-up clasts and dolomite cement nucleation in host sandstone, occluding adjacent pores but preserving IGV. Both processes affect reservoir quality by generation of vertical and 3D fluid flow baffles and barriers that compartmentalize the reservoir. These findings may provide quantitative useful data for the better understanding of reservoir quality in analogous hydrocarbon-bearing basins such as the Bay of Fundy, Nova Scotia (Canada).

1. Introduction

Calcretes and dolocretes have been widely recognized in ancient fluvial sediments deposited under relative arid climates and saline/evaporate conditions (Goudie, 1983; Wright and Tucker, 1991; Milnes, 1992; Kraus, 1999). They may form as vadose (pedogenic) or phreatic (groundwater) mineral precipitates (Arakel, 1986; Wright, 1994; Colson and Cojan, 1996; Chen et al., 2002). Genesis of dolocretes has been attributed to similar formation mechanisms of calcretes. Several processes to generate near-surface and soil-related dolomite accumulations by increasing Mg/Ca ratio of phreatic solutions have been suggested: (1) mixing of saline brines and fresh groundwater (El-Sayed et al., 1991; Colson and Cojan, 1996); (2) calcite precipitation from nearby groundwater resulting in Ca^{2+}-depleted but Mg^{2+}-enriched groundwater (Hutton and Dixon, 1981; Spötl and Wright, 1992; Armenteros et al., 1995); and (3) fluid movements through Mg-rich clays (Pimentel et al., 1996). Examples of phreatic dolocretes in Permo-Triassic fluvial sediments have been reported in the Paris Basin (Spötl and Wright, 1992), Sherwood Sandstones in the Corrib Field (W Ireland; Schmid et al., 2004, 2006), Wessex basin (S England; Mader, 1986; McKie et al., 1998), Abo-Tubb interval (NE New Mexico, USA; Kessler et al., 2001), Orenburg region (South Urals, Russia; Kearsey et al., 2012) and Argana Basin (Brown, 1980), among others.

Deposits generated above mean channel depth in fluvial systems (floodplain sediments and paleosols–calcrete and dolocretes) are prone to be incised and eroded during channel migration and base-level fall (Miall, 2006). Then, these penecontemporaneus reworked grains become part of fluvial sandstone framework as intrabasinal components, being called as “intraclast” or “rip-up clasts”. They usually concentrate in particular depositional facies such as channel-lags

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deposits (Allen and Wright, 1989; Garzanti, 1991). Its grain size distribution, mostly greater than other framework components according to their lower density (Zuffa, 1980, 1985), may result in a significant volume of sandstone framework represented by such clasts. Thus, rip-up clast occurrence has an important significance on paleoclimatic and paleogeographic reconstructions, by testifying the existence of coeval primary dolocretes, preserving provenance signature of intrabasinal sediments (Garzanti et al., 1989; Garzanti, 1991; Odin, 1985; Zuffa, 1980, 1985; Purvis and Wright, 1991; Spötl and Wright, 1992). In addition, there are evidences of the impact exerted by these grains on diagenetic evolution of host sandstones and, eventually, on reservoir quality through: (i) favoring mechanical compaction with a consequent drastic loss of intergranular space (Rittenhouse, 1971; Pittman and Larese, 1991; Gluyas and Cade, 1997; Paxton et al., 2002; Mousavi and Bryant, 2013); and (ii) sourcing eodiagenetic carbonate cements that reduce original porosity (Burley, 1984; Schmid et al., 2004, 2006; Morad et al., 2010; De Ros and Scherer, 2012).

On the basis of the double applied interest of rip-up clasts, occurrence and abundance of different types of such grains in Triassic fluvial deposits of Argana Basin (S Morocco; Fig. 1A) provide a great scenario to evaluate these questions. Thus, by coupling high-resolution petrographic and chemical analysis, this paper aims at: 1) characterizing origin and source of such clasts; and 2) evaluating their impact on host sandstones postdepositional evolution by examining their behavior during diagenesis. The proved correlation between the Argana Basin and the hydrocarbon-bearing Bay of Fundy Basin in Nova Scotia (Canada; Smoot and Castens-Seidell, 1994; Olsen, 1997; Calder et al., 1998; Hofmann et al., 2000; Letourneau and Olsen, 2003) reveals the relationship between spatial distribution of the different rip-up clast types and depositional facies as particularly interesting for a better understanding of fluid flow heterogeneity and reservoir compartmentalization.

2. Geological setting

The Triassic Argana Basin is located in the Western High Atlas of Morocco and is up to 20 km in width and extends over 85 km (Fig. 1A). It forms the eastward extension of the hydrocarbon-bearing Essaouira Basin (Medina, 1988; Broughton and Trépanier, 1993; Ellouz et al., 2003) which corresponds to the conjugate Atlantic passive continental margin of the Bay of Fundy Basin in Nova Scotia, Canada (Calder et al., 1998; Olsen et al., 2000; Letourneau and Olsen, 2003). Both basins show remarkable similarities in sedimentary facies and stratigraphy throughout their thick Late Permian–Early Jurassic successions suggesting a predrift proximity (Fig. 1B; Smoot and Castens-Seidell, 1994; Kent et al., 1995; Olsen, 1997; Hofmann et al., 2000). In Argana Basin, estimated maximum burial depth is about 1600–2000 m with a maximum temperature at the base of the stratigraphic sequence (ca. 6000 m thick) ranging between 150 and 250 °C (Leikine et al., 1996). Hydrothermal processes are not completely discarded by some authors (Lahcen et al., 2007). Argana Basin consists of a half-graben basin with 5–30° tilted blocks towards the NW that has experimented two main phases of extension, influencing sediment distribution patterns (Brown, 1980; Medina, 1991, 1995). First (pre-rifting) phase of extension only affected deposition of Late Permian sediments (Medina, 1991, 1995) whereas the second phase is considered coeval to Triassic deposition (syn-rift) by some authors (Brown, 1980; Laville and Petit, 1984; Medina, 1991, 1995) or later to that time (post-rift) by others (Hofmann et al., 2000; Baudon et al., 2012).

At the end of the Triassic, Argana and Fundy Basins were situated in the subtropical belt at about 20°N paleolatitude, where deposition took place under semi-arid to arid climates (Hay et al., 1982). In the Argana Basin, a long-term change in paleoclimate that ranges from semi-arid conditions with seasonal precipitation (Early to Middle Triassic) towards an arid, non-seasonal climate (Late Triassic) is preserved within the sedimentary cycles developed during several million years (Hofmann et al., 2000). A short-lived event of increased precipitation within the general trend of aridification is identified during the Carnian Pluvial Episode (Arche and López-Gómez, 2014 and references therein).

2.1. Stratigraphy

Continental red beds of the Argana Basin are represented by a ca. 5000-m-thick succession of Permo-Triassic sedimentary rocks (Tixeront, 1973, Brown, 1980) capped by the Argana basalt (205 ± 16 Ma; Fiechtner et al., 1992; Fig. 2). This stratigraphic succession is

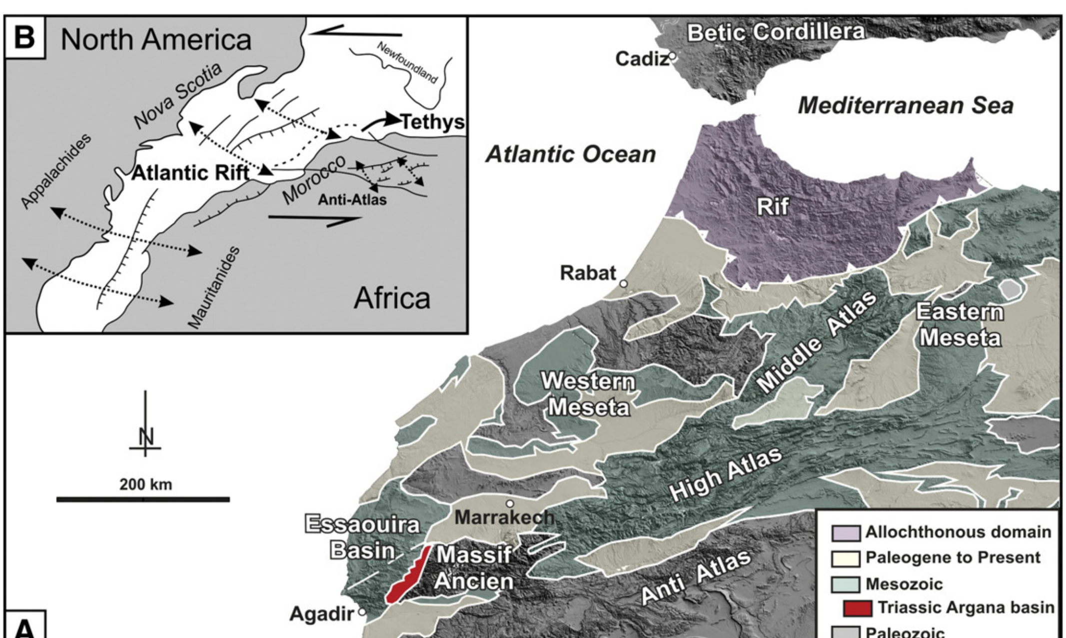

Fig. 1. A) Geological map of Western High Atlas showing present location of the study area. B) Paleogeographic map of Morocco at Triassic time (modified after Laville and Pique, 1991).