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Research paper

Remobilization of deep basin brine during exhumation of the Illizi Basin, Algeria

Kara L. English [a, b, *], Joseph M. English [a], Jonathan Redfern [b], Cathy Hollis [b], Dermot V. Corcoran [a], Norman Oxtoby [c], Rachida Yahia Cherif [d]

[a] Petroceltic International Plc, 3 Grand Canal Plaza, Grand Canal Street Upper, Dublin 4, Ireland
[b] School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, United Kingdom
[c] Department of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, United Kingdom
[d] Direction Coordination Groupe Associations — Sonatrach, Djenane El-Malik, Hydra, Algiers, Algeria

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A B S T R A C T

Understanding the processes that drive fluid flow in sedimentary basins has important implications for models of metallic ore and petroleum migration and accumulation in the subsurface. Potential drive mechanisms include gravity-driven flow, compaction-driven flow, and density-driven convection. In this study, we demonstrate that the brine hosted in Ordovician sandstone in the Illizi Basin in Algeria is genetically linked to Triassic-Liassic evaporites deposited >400 km to the north in the Berkine Basin. This observation confirms that long distance, lateral, brine migration has occurred within the basin in the past. We assess the hydrogeologic record preserved in aqueous fluid inclusions within the Ordovician sandstone, document a marked increase in formation water salinity during cooling and exhumation, and evaluate the drive mechanisms for late-stage remobilization of deep brines within the basin. It is hypothesized that the release of overpressure during exhumation of the Illizi Basin may have been a critical contributor to updip fluid flux. This model could be applicable to other exhumed basins worldwide.

1. Introduction

Understanding the processes that drive fluid flow in sedimentary basins has important implications for models of metallic ore and petroleum migration and accumulation in the subsurface. A number of different mechanisms have been proposed for driving regional fluid flow in sedimentary basins (e.g. Bethke, 1985, 1989; Bjørlykke, 1993, 2015; Cathles and Adams, 2005; Chi and Xue, 2011; Frazer et al., 2014): (1) topographic or gravity-driven flow, (2) sedimentary or tectonic compaction-driven flow, and (3) thermal- or salinity-driven convection. In this study, we present new compositional analysis of formation water hosted in Ordovician sandstone in the Illizi Basin in Algeria, and demonstrate that this brine is genetically linked to Triassic-Liassic evaporites deposited in the Berkine Basin to the north (Fig. 1). Building on previous thermal history modelling of the area (English et al., 2016b, 2016c), we assess the hydrogeologic record preserved in aqueous fluid inclusions in order to constrain the timing of brine migration into the Ordovician sandstone in the Illizi Basin, and we evaluate overpressure dissipation during exhumation as a potential drive mechanism for late-stage remobilization of deep brines. This model could be applicable to other exhumed basins worldwide and has implications for the timing and direction of major fluxes of deep basin brines in the geological record.

2. Geological history of the Illizi Basin

Following the Late Neoproterozoic Pan-African orogeny, the northern margin of Gondwana was characterized by a vast clastic-dominated Paleozoic sedimentary basin on the edge of the Proto-Tethys (Beuf et al., 1971; Stampfli and Borel, 2002; Guiraud et al., 2005). During the collision of Gondwana with Laurasia, the Late Carboniferous-Early Permian Hercynian (Variscan) Orogeny caused

* Corresponding author. Petroleum Affairs Division, Department of Communications, Climate Action & Environment, 29-31 Adelaide Road, Dublin 2, D02 X285, Ireland.
E-mail address: kara.english@yahoo.ca (K.L. English).

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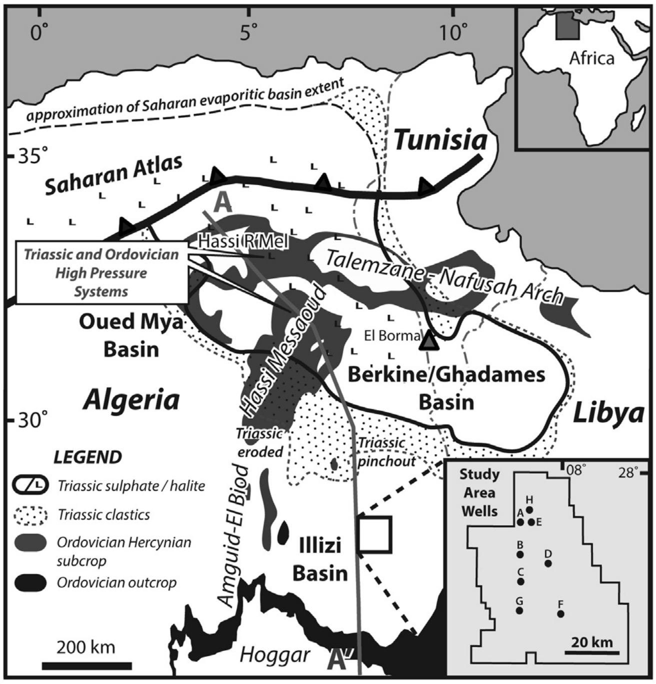

Fig. 1. Location of the study area in the Illizi Basin, Algeria. Extent of Triassic-Jurassic evaporitic basin and clastics adapted from Turner and Sherif (2007) and Galeazzi et al. (2010). Regions of present-day high pressured Triassic and Ordovician systems from Chiarelli (1978). Transect line corresponds to Fig. 5.

extensive uplift and erosion along north–south trending arches in northwest Africa (Aliev et al., 1971; Burollet et al., 1978; Boote et al., 1998; Acheche et al., 2001). Erosion removed the post-Cambro-Ordovician sequence on some of these uplifted arches, but the majority of the Paleozoic sequence was preserved in the Illizi Basin (Galeazzi et al., 2010; English et al., 2016c, Fig. 2). Renewed deposition of the Mesozoic–early Cenozoic "Tethys Supersequence" (Boote et al., 1998) in North Africa followed the opening of the Tethyan seaway, and a Triassic salt basin developed to the north of the Illizi Basin in the Berkine and Oued Mya basins (Turner and Sherif, 2007; Galeazzi et al., 2010). Mesozoic-Cenozoic deposition in the region was punctuated by Early-Mid Aptian transpression and strike-slip deformation during the Austrian event (Boudjema, 1987; Galeazzi et al., 2010), and by Mid-Late Eocene inversion that caused growth of the Atlas range to the north (Echikh, 1998). Intraplate uplift and magmatism also initiated in North Africa during the Mid-Late Eocene (Wilson and Guiraud, 1992; Wilson et al., 1998; Liégeois et al., 2005) leading to the development of numerous topographic swells and large-scale exhumation of flanking sedimentary basins such as the Illizi and Tim Mersoï basins (English et al., 2016b).

The new data in this study comes from an Ordovician sandstone reservoir in a gas-condensate field located in the southern Illizi Basin (Fig. 1). Previous studies have constrained the burial and thermal history of the study area through integration of regional stratigraphy, sonic compaction analysis, biostratigraphy, thermal maturity, fluid inclusion microthermometry, and apatite fission-track data (English et al., 2016b, 2016c). These studies confirmed that the preserved Paleozoic sequence in the Illizi Basin was subjected to elevated temperatures in the past, initially because of additional burial prior to Hercynian exhumation, and again during reburial in the Mesozoic and early Cenozoic (Fig. 2). The available data indicate that maximum burial most likely occurred during the early Eocene, prior to uplift of the Hoggar massif and northward tilting of the Illizi Basin (English et al., 2016b). Based on 1-dimensional (1D) modelling, maximum burial depths for the Top Ordovician are estimated at 2.95 km in the northern part of the field (Well A) and 3.37 km in the southern part of the field (Well G), and the corresponding estimates of maximum paleotemperature are 140 °C and 156 °C respectively (English et al., 2016c). The magnitudes of subsequent Cenozoic exhumation are estimated at 1.0 km and 1.4 km for the northern (Well A) and southern (Well G) areas respectively. Based on the modelling of English et al. (2016c), hydrocarbon generation from the lower Silurian source rocks is interpreted to have started during the Carboniferous, ceased temporarily during Hercynian exhumation, and subsequently

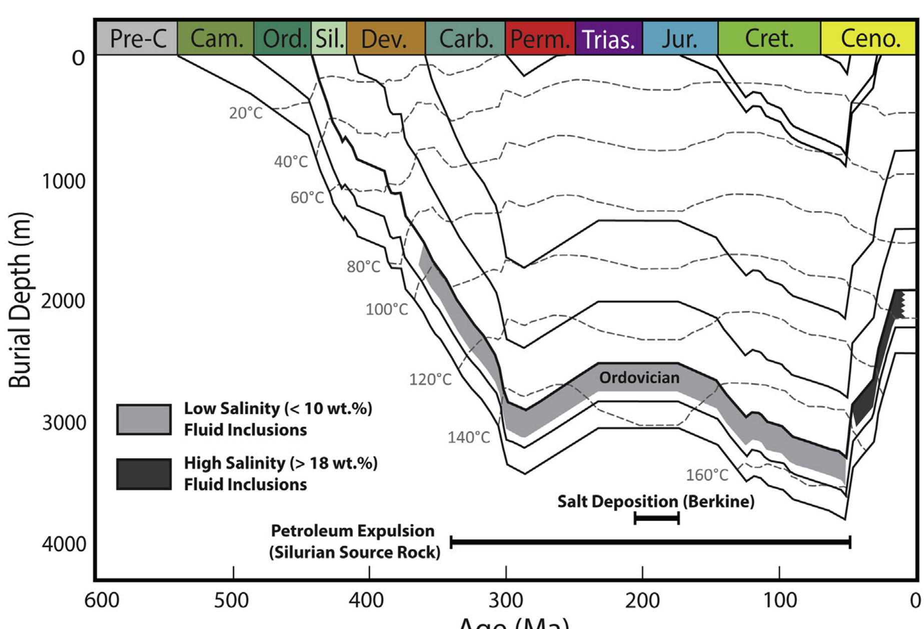

Fig. 2. 1D burial history model (Well G) for the study area in the Illizi Basin (modified from English et al., 2016c).