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Relationship between karstification and burial dolomitization in Permian platform carbonates (Lower Khuff — Oman)

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ABSTRACT

Large breccia fabrics associated with karst constitute an important structure in massive limestone successions. The dimensions and shapes of breccia structures are controlled by the initial fracture pattern of the limestone and preferential pathways of the karstifying fluids, but subsequently breccia fabrics can also govern the migration of later fluids. Therefore, breccias are highly relevant features to capture for reservoir characterisation. Outcrop analogues for Lower Khuff units in the Middle East present in the Central Oman Mountains reveal brecciated fabrics up to 10s of metres in diameter. These brecciated units are closely associated with dolomite bodies of late diagenetic origin.

Based on an integrated set of data, the breccias are interpreted as collapsed karst cavities either formed by meteoric or hypogenic fluids. The exact origin of the fluids could not be constrained due to an overprint by later dolomitizing fluids. Based on the composition of the clasts and matrix in the breccias, two dolomitization events are interpreted to have affected the succession, one prior to (early diagenetic [ED] dolomite) and one after brecciation (late diagenetic [DT2] dolomite). Dolomite of shallow burial origin (ED dolomite) was only observed as clasts within breccia and is much more frequent than late diagenetic (medium to deep burial) dolomite clasts. Thus, the timing of the brecciation and collapse is assumed to postdate shallow burial early diagenetic dolomitization. Late diagenetic replacive dolomite (DT2 dolomite) forms 90% of the matrix in the breccia fabrics with the exception of a small area that was not affected by dolomitization, but is rarely present as clasts. Stable isotope measurements [$\delta^{18}O$: −2.5‰ to −6‰ VPDB and $\delta^{13}C$: 2.9‰ to 4.8‰ VPDB] suggest a burial origin for the late diagenetic dolomite potentially with the participation of hydrothermal fluids. The dolomitized matrix indicates a migration of late dolomitizing fluids subsequent to or postdating the collapse of the karstic cavities. Thus, early karstification processes seem to have played a big role in controlling subsequent loci of late dolomitization in the Oman Mountains, and potentially in other similar settings elsewhere.

1. Introduction

Breccia fabrics can form in various environments, and hydrocarbon reservoirs-related studies are concerned with the formational processes as well as the fluids involved in brecciation. Brecciation is often triggered by sedimentary, tectonic or diagenetic processes resulting in centimetres to hundreds of metres wide brecciated fabrics that may have contrasting petrophysical properties compared to their host rock. Large-scale breccia fabrics attracted comparatively more attention than small-scale structures in the last decades due to their impact on reservoir models. A vast majority of large-scale breccia structures has been associated with collapse of epigenetic karst structures (Hamilton and Ford, 2002; Lucia, 1995) linked to the migration of meteoric fluids in a downward direction. Recent interpretations considered also the importance of ascending fluids of non-meteoric origin defined as hypogenic karst breccias, for instance as observed in the Middle East (Frumkin and Gvirtzman, 2006; Frumkin et al., 2015), France (Audra et al., 2010), Italy (Tisato et al., 2012), New Mexico, Texas, Nevada (Dublyansky and Spoetl, 2015) and Australia (Osborne, 2001). Often at a smaller scale, migrating warm fluids can also form breccias (Beckert et al., 2015; Frumkin et al., 2015; Hulen and Nielson, 1988) linked to hydrothermal dolomite bodies. However, breccia fabrics associated with dolomite bodies can also be of large sizes, as described for example from the Ramales platform in Spain, where breccias are related to sinistral strike slip deformation (Dewit et al., 2012). Fault controlled breccias linked to dolomite bodies have also been studied in the Zagros Mountains in Iran (Lapponi et al., 2011; Sharp et al., 2010).

The goal of this paper is to elucidate the origin of the breccia fabrics in Wadi Sahtan in the context of Middle Easterns petroleum reservoirs. Although there are hints for karstification and subaerial exposure in the Saih Hatat and in the Musandam Peninsula from Permian to Triassic times (Strohmenger et al., 2002; Weidlich, 2010), there is no evidence yet for large scale karstification in the region during Permian times.

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The occurrence of large-scale breccias observed within reservoir analogue, Khuff-equivalent strata at Wadi Sahtan in the Central Oman Mountains raises the question of which processes lead to their formation, and which parameters control their characteristics. In particular, this study defines the formational setting, characterises the fluids responsible for the dissolution of the host rock and evaluates potential fluid pathways as well as migration directions.

2. Geologic setting

2.1. Depositional and structural characteristics of the Central Oman Mountains

The Central Oman Mountains constitute an integral part of the continental Arabian plate (Searle and Cox, 1999) which stretches from the Gulf of Aden spreading axis, to the Red Sea spreading centre, the Zagros–Biltis suture and to the Owen fracture zone (Stern and Johnson, 2010) in the east. The lithological succession in the Oman Mountains is represented by well-bedded layer-cake platform carbonates (Aigner and Dott, 1990; Koehrer et al., 2011, 2012). The deposition of these extensive platform carbonates was initiated from Middle Permian to Early Triassic times (Callot et al., 2010; Weidlich and Bernecker, 2011) triggered by the rifting of the Neo-Tethys ocean (Koehrer et al., 2011; Pillevuit, 1993; Stampfli and Borel, 2002) and the fragmentation of the supercontinent Pangaea (Ruban et al., 2007; Sharland et al., 2001). The more than 2000 km wide extension of the platform allows the study of stratigraphically equivalent sediments to Oman in the subsurface of Bahrain, UAE, Qatar, Saudi Arabia and Kuwait (Weidlich and Bernecker, 2011) (subsurface Khuff Formation). In the outcrop area in Wadi Sahtan the basement underlying the platform carbonates is of Precambrian age (Fig. 1A) with lithologies ranging from diamictites with granite boulders to siltstones, greywackes and sandstones generally known as the autochthonous Mistal Formation (Beurrier et al., 1982–1985) (Table 1). Precambrian units are separated from the Lower to Middle Permian carbonates (Saiq Formation) by an extensive unconformity present across the Central Oman Mountains (Beurrier et al., 1982–1985; Rabu et al., 1982–1983; Villey et al., 1982–1985). The Saiq Formation in Wadi Sahtan (about 640 m thick (Koehrer et al., 2010)) comprises Roadian to Changhsingian-age beds (Beurrier et al., 1982–1985; Koehrer et al., 2012; Ziegler, 2001) [some authors include Induan and partly Olenikian-age beds in to the Saiq Formation e.g., Al-Husseini (2006) and Weidlich and Bernecker (2011) (Fig. 2B)] characterised by numerous depositional environments and lithofacies types. In detail, from Roadian to Wordian times the depositional environment is characterised by a shoal to offshoal system (Table 1). In this system, shoal to backshoal units contain microbial mats to bedded oolites and a crinoidal to peloidal shoal facies (Bendias et al., 2013). Foreshoal units comprise graded storm beds and bioclastic sheets whereas bioturbated (*Zoophycus*) mudstones are evident in the offshoal areas (Bendias et al., 2013). From Capitanian to Induan times the depositional

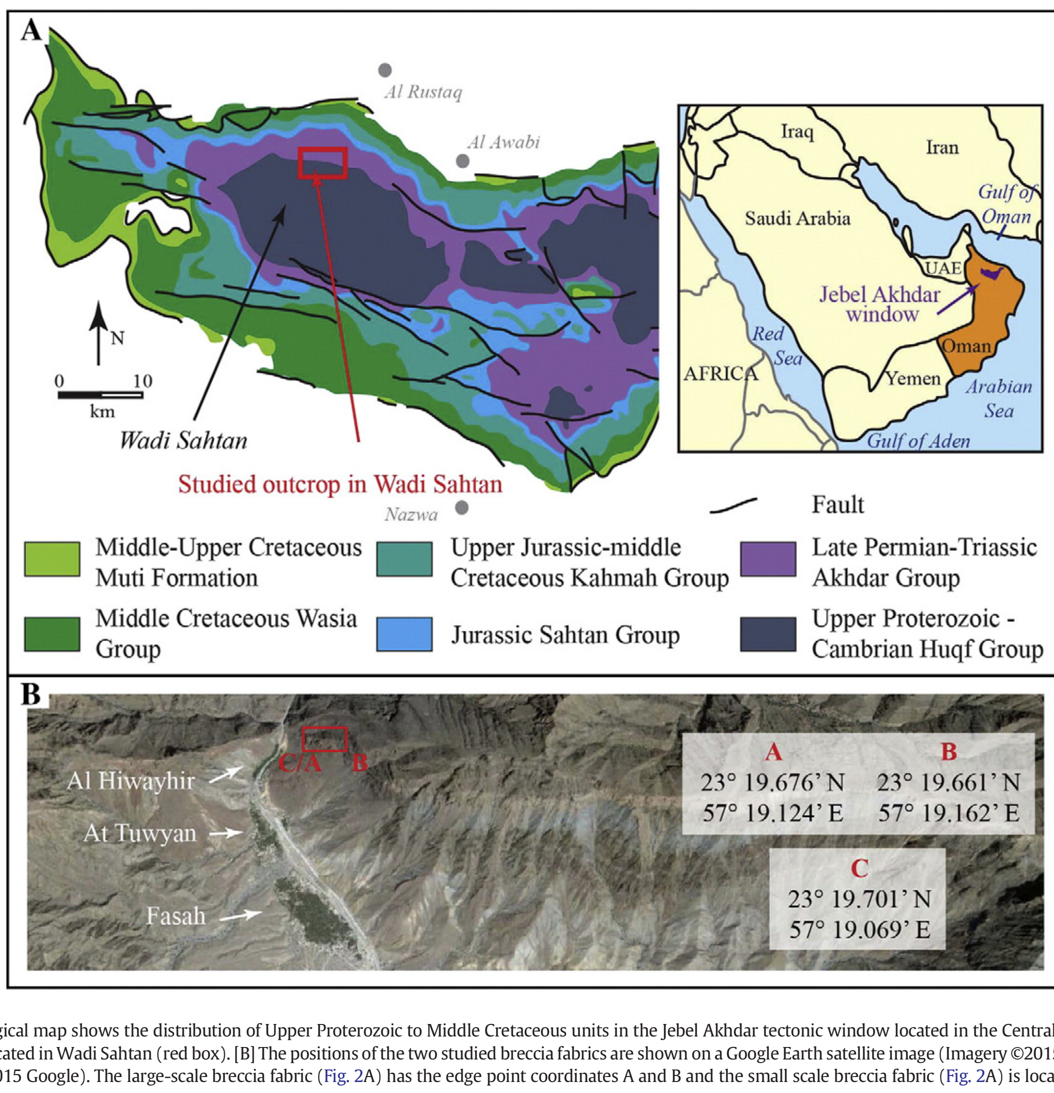

Fig. 1. [A] The geological map shows the distribution of Upper Proterozoic to Middle Cretaceous units in the Jebel Akhdar tectonic window located in the Central Oman Mountains. The studied outcrop is located in Wadi Sahtan (red box). [B] The positions of the two studied breccia fabrics are shown on a Google Earth satellite image (Imagery ©2015 CNES/Astrium, Digital Globe, Map data ©2015 Google). The large-scale breccia fabric (Fig. 2A) has the edge point coordinates A and B and the small scale breccia fabric (Fig. 2A) is located at point C.