



Sequence Stratigraphy and Chemostratigraphy Interpretations Based on Stable Isotope and Gamma Ray: An Example from the Early Triassic Lower Mahil Formation [Upper Khuff Outcrop Equivalent (KS1)], al Jabal Al-Akhdar, North Oman, Sultanate of Oman

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Abstract

This study aims to integrate facies distribution, stable isotope, spectral and total gamma rays to build high-resolution sequence stratigraphy of the Early Triassic Lower Mahil Formation [Upper Khuff outcrop equivalent (KS1)]. The Lower Mahil Formation was deposited on a carbonate ramp in Al Jabal al-Akhdar of North Oman. Saiq Plateau and Wadi Sahtan sections of the Lower Mahil Formation were logged and measured along a depositional dip cross section. A detailed sedimentological description for studied sections was performed using Dunham's classification, isotope samples were taken every 50 cm, and spectral gamma ray measurements were taken every 10 cm. The Lower Mahil Formation is a third-order sequence consisting of inner-ramp and mid-ramp carbonate facies. Several lithofacies were identified, including breccia, packstone/grainstone, and mudstone. The top of the breccia marks the top of the third-order sequence with normal carbon isotope and low gamma rays and shows a sharp change in lithology. However, the base of this sequence is a transition contact with a gradual decrease in the carbon isotope and gamma ray curves. An increasing

trend of both carbon isotope and gamma ray curves marks the maximum flooding surface zone.

Keywords

Saiq Plateau • Wadi Sahtan • Lower Mahil • Oman • Third-order sequences • Al Jabal al-Akhdar

1 Introduction

This study presents the stratigraphic framework integrated with high-resolution carbon isotopes for the Early Triassic Lower Mahil Formation (Upper Khuff outcrop equivalent (KS1)) within the Al Jabal al-Akhdar of North Oman. The stratigraphic sequence framework presented here builds on the rock-based stratigraphic framework, carbon stable isotope chemostratigraphy, gamma ray, and available biostratigraphic data. Based on the lithology, wireline logs, and faunas, the Khuff Formation has been subdivided into Upper Khuff, Middle Khuff, and lower Khuff. The lower and middle Khuff is equivalent to the Saiq Formation in Jabal al-Akhdar (Alsharhan, 2006). Simultaneously, the upper Khuff is equivalent to the Lower Mahil Formation, which overlies the Saiq Formation (Alsharhan, 2006). The Khuff Formation represents one supersequence, which comprises six transgressive/regressive sequences (KS6–KS1) (Koehrer et al., 2010). On the Saiq Plateau of the Al Jabal al-Akhdar, Oman, the Upper Saiq Formation is time equivalent to the Lower and Middle Khuff Formation (K5–K3), and the Lower Mahil Member is the time equivalent to the Upper Khuff Formation (K2–K1) (Koehrer et al., 2010). This study will focus on the Lower Mahil Formation (upper Khuff outcrop equivalent (KS1)). Studying this supersequence may help in

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understanding the sequence stratigraphy of the Lower Mahil Formation (upper Khuff outcrop equivalent (*KS1*)). The initial goal of this work is to do a sequence stratigraphic interpretation of the Lower Mahil Formation based on bed-by-bed measured sections (Saiq Plateau and Wadi Sahtan).

2 Geological Setting

The Akhdar Group comprising the Saiq and Mahil Formation in the Al Jebel Akhdar area was deposited due to the initial phase of the breakup of the supercontinent Pangaea. During the lower Paleozoic, Oman was a passive margin. This stable phase ended with the collision of Gondwana and Laurasia during the Carboniferous Hercynian event that created the base Haushi unconformity. Following the widespread Hercynian event, the northern Gondwanan terranes rifted with the opening of the Neo-Tethys Ocean in the Late Carboniferous/earliest Permian. The sediments above the Hercynian unconformity in Oman are represented by the clastics of the Haushi Group. From the middle Permian to middle Cretaceous times (ca. 267–91 Ma), a passive margin developed with extensive carbonate deposition, comprising the Akhdar, Sahtan and Kahmah, and Wasia Groups. The Khuff Formation was deposited on an epeiric carbonate platform under arid conditions dominated by carbonate sedimentation due to a significant transgression.

3 Results

Several lithofacies were identified, including breccia, packstone/grainstone, and mudstone. The Lower Mahil Formation is a third-order sequence consisting of backshoal, shoal, to foreshoal depositional settings. Inside this third-order sequence is fourth- and fifth-order sequences with 23 distinguished parasequences (Fig. 1a–c).

4 Discussion

4.1 Depositional Environment

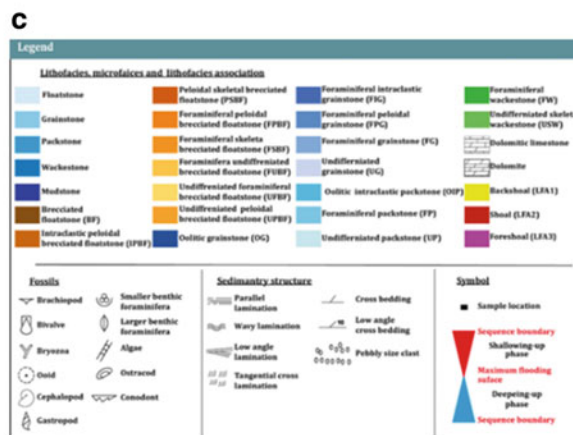
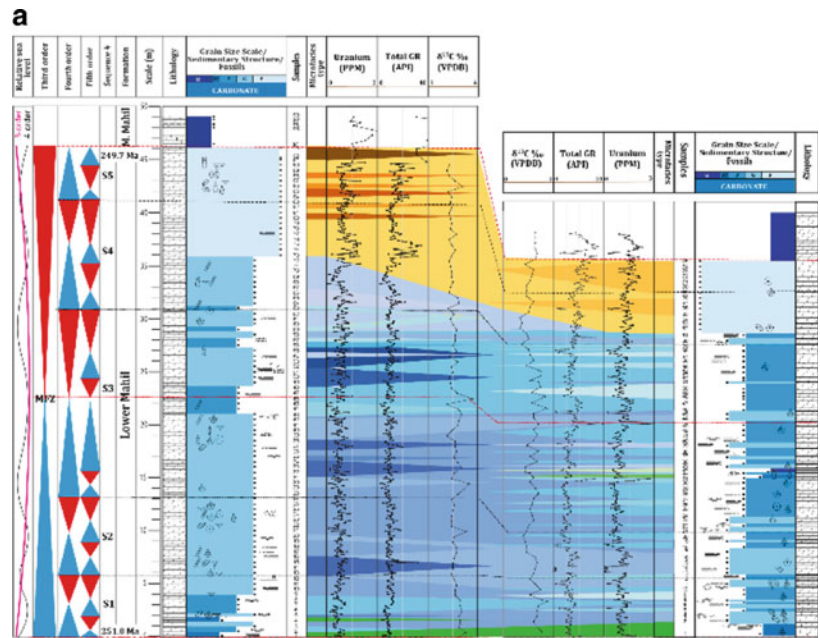
The Lower Mahil Formation lithofacies were identified, including breccia, packstone/grainstone, and mudstone (Fig. 1c). Studying these facies indicates that the Lower Mahil Formation deposited within shallow ramp setting limited to backshoal, shoal to foreshoal ramp facies, similar

to previous studies (Koehrer et al., 2010). The shoal facies dominate the Saiq Plateau section. The source of the breccia is unknown (Koehrer et al., 2010). However, this study shows normal carbon isotope patterns (Fig. 1a) and no indications of subaerial unconformity (Forbes et al., 2010; Koehrer et al., 2012) in response to the breccia facies. These isotopic results confirm that there are no unconformity or diagenetic effects of breccia facies. Therefore, the source of the breccia can be tectonic/syntectonic (?) with no clear evidence from the field.

4.2 Lower Mahil Composite Sequence Duration

The Lower Mahil is Early Triassic, which is time equivalent to the Upper Khuff Formation in the subsurface. However, this study focuses only on the lower member of the Mahil Formation (*KS1* sequence equivalent), which has been dated previously (Koehrer et al., 2010) as Late Induan. The Lower Mahil was deposited during the late Induan with a ~ 1 m.y (Gradstein et al., 2012), making it a third-order sequence (Goldhammer et al., 1990). Each of the three sequences of the Lower Mahil Formation has a duration of 0.3 m.y, making them fourth-order sequences. Each of the eight sequences has a duration of 0.1 m.y, making them a fifth-order sequence. In greenhouse times, cycles are likely dominated by high-frequency, low-amplitude sea-level changes driven by precession (Read, 1985, 1998). Therefore, one would expect to find many more parasequences in the one m.y. The duration of parasequences in the Lower Mahil Formation is challenging to evaluate, as they are rarely regionally mappable. The maximum number of parasequences (23) occurs in the Lower Mahil Formation. Given the one m.y. duration of formation, this would suggest that the parasequences are ~ 43 k.y. The Lower member of the Mahil Formation [(Upper Khuff outcrop equivalent (*KS1* sequence))] is made up of two-cycle sets composed of 8 fifth-order cycles (Fig. 1a). The maximum flooding surface MFS zone of the Lower Mahil Formation is placed within the wackestones lithofacies (Fig. 1a). The thick brecciated bed defines the upper sequence boundary, which represents the boundary between the Lower Mahil Member (Khuff Formation equivalent) and the overlying Middle Mahil Formation (Sudair Formation equivalent) (Fig. 1a). At the same time, the lower sequence boundary represents the normal contact between *KS1* and the underlying *KS2* sequence.

Fig. 1 Third-, fourth-, and fifth-order sequences of the Lower Mahil formation (a) and the breccia facies (b) with the facies code (c)



5 Conclusions

1. The Lower Mahil Formation lithofacies were identified, including breccia, packstone/grainstone, and mudstone. Studying these facies indicates that the Lower Mahil Formation deposited within shallow ramp settings is limited to backshoal–shoal to foreshoal ramp facies.
2. Carbon isotope shows standard patterns and no indication of subaerial unconformity in response to the breccia facies. These isotopic results support the possible tectonic origin of the breccia.
3. The Lower Mahil Formation is a third-order sequence consisting of backshoal, shoal, to foreshoal carbonate facies.

Acknowledgements This study is supported by the Research Council (TRC) Grant Fund # RC/RG-DVC/ESRC/18/01.

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