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Bruno Granier, R.G. Peebles, N.J. Sander. Discussion on the Jurassic evolution of the Arabian carbonate platform edge in the central Oman Mountains. *Journal of the Geological Society*, 2006, 163 (6), pp.1047-1050. <10.1144/0016-76492005-151>. <hal-00111154>

HAL Id: hal-00111154

<https://hal.science/hal-00111154v1>

Submitted on 30 Sep 2024

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Discussion on the Jurassic evolution of the Arabian carbonate platform edge in the central Oman Mountains

Journal, Vol. 162, 2005, pp. 349-362

B. R. C. Granier, R. G. Peebles and N. J. Sander write: The model proposed by Rousseau *et al.* (2005) for the Jurassic evolution of the Arabian carbonate platform edge is in part based on field observations made in Jabal Akhdar, central Oman (Fig. 1), and on material collected there. Some of their conclusions based on these data are sound, but they are not original: for instance, the diachroneity of the main pre-Kahmah Group unconformity and the extent of the associated hiatus were documented in the seminal memoir published by Glennie *et al.* (1974), and illustrated by Murriss (1980, fig. 24) and by Hughes Clarkes (1988, fig. 27), among many others. Although these three references were cited by Rousseau *et al.*, the authors omit aspects of this published previous work that does not support their own interpretations. Similarly, published micropalaeontological data

(calpionellids) that constrain these time relationships in onshore Abu Dhabi (de Matos 1994) are not incorporated into their interpretations. Published work that documents sedimentary breccias (Fig. 2) just above the main unconformity (at the base of the Rayda Formation; Hudson & Chatton 1959; Toland *et al.* 1993), is also not cited. This omission is unfortunate, because the occurrence of these sedimentary breccias does not fit well with their model. The lack of any discussion of pre-existing models and the omission or inappropriate use of published regional data undermines Rousseau *et al.* (2005)'s efforts to provide a satisfactory new model of Late Jurassic events in the Jabal Akhdar area in the context of the Arabian carbonate platform margin. In consequence, their conclusions based on supra-regional correlations or comparisons (with Saudi Arabia,

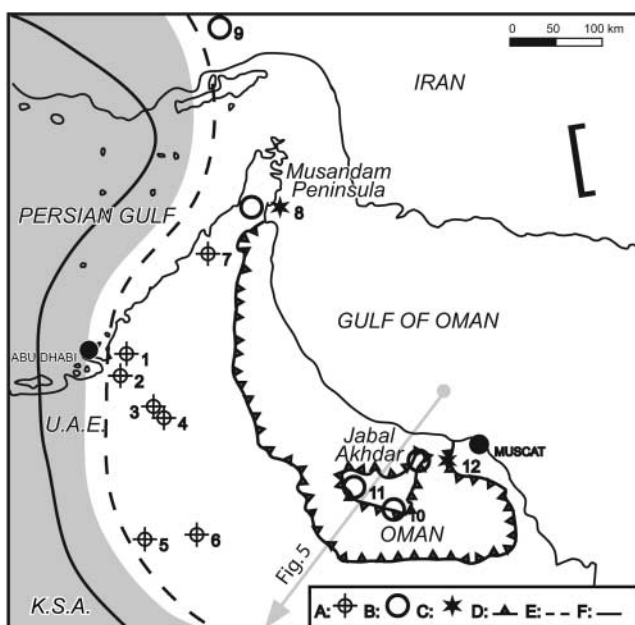


Fig. 1. Simplified geological map of the Oman mountains and adjacent areas: Occurrences of Calpionellids (A) in deep wells and (B) in outcrop, (C) sedimentary breccias above the unconformity terminating the Sahtan Group (after Hudson & Chatton 1959; Toland *et al.* 1993), (D) limits of the Hawasina Nappes, (E) the maximal westward extent of the porcelanite Rayda basinal facies (Tithonian/Berriasian age) fronting the BuHaseer Platform facies (in grey), and (F) the maximal eastward extent of the Hith platform facies (or='Hith edge'; Kimmeridgian/Tithonian age) are shown. Numbers refer to sites used in this study. Wells: 1, Sweihan; 2, Jarn Yaphour; 3, LI-A; 4, Bida Hamama-1; 5, Mender-1; 6, Dhulaima-4; 7, Sajaa-1; 2 and 3. Outcrops: 8, Al Khatt (Musandam peninsula); 9, Kuh-e Ginau (Iran); 10, Wadi Kahmah, Wadi M'iadin=Mu'aydin; 11, Wadi Nahr-Jabal Shams; 12, Wadi Khubrah-Wadi Taww (all in the Jabal Akhdar area). Location of Figure 5 is shown.



Fig. 2. Contact of the basal Rayda polygenetic breccia (left) with Kimmeridgian limestones in Wadi Hagil, Musandam peninsula (photo courtesy of Robert Boichard).

Iran, Tunisia, Algeria, Morocco, Yugoslavia and France) are also not sustainable. We present alternative interpretations below that incorporate all available published data for the poorly documented platform margin.

Stratigraphic settings. The regional stratigraphic nomenclature of Oman and the neighbouring emirates has been standardized for some time, as summarized in Figure 3 and discussed below. The Hith, Sulaiy and Yamama formations were created by Steineke *et al.* (1958) in Saudi Arabia but were later amended by Powers *et al.* (1966). The Sahtan and Kahmah groups were introduced by Glennie *et al.* (1974) for the Oman succession while the Rayda, Salil and Habshan formations were established by Hassan *et al.* (1975) for both Oman and Abu Dhabi. Awabi and Birkat formations are later synonyms for Rayda and Salil formations.

Granier (2000) demonstrated that most of these lithological entities may be categorized as ‘unconformity-bounded units’. With the exception of the Rayda and Salil formations, which represent basinal and basinal-to-platform-margin facies respectively, all were defined in platform settings. Because of the existence of significant discontinuities within the ‘Habshan’ in the Abu Dhabi offshore oil fields this formation was split into three units, Habshan, Bu Haseer and Belbazem, each of formational rank (Granier 2000).

In addition, Granier (2000) integrated both revised and new biostratigraphic findings into the lithostratigraphic framework. The Hith-Sulaiy boundary in Saudi Arabia equates to the Hith-Habshan boundary in Abu Dhabi, based on the occurrence of *Anchispirocyclus lusitanica* in Saudi Arabia (Powers *et al.* 1966), in Qatar (Henson 1948) and in Abu Dhabi (Granier 2000). The Sulaiy *pro parte* and the Habshan are ascribed a Tithonian age; the Tithonian-Berriasian boundary almost certainly is within the Bu Haseer Formation.

Within this reframing of the regional stratigraphic nomenclature, regional geometric and stratigraphic relationships can be defined more precisely. More specifically, the finding of Late Tithonian ammonites above the pre-Kahmah unconformity by Rousseau *et al.* (2005) does not add credence to their hypothesis that ‘the lowermost Rayda of central Oman is... the outer equivalent of the uppermost Hith Formation of Abu Dhabi’. Tentatively the base of the Rayda Formation in Oman might be an equivalent of the base of the Bu Haseer Formation in Abu Dhabi (Fig. 3).

Environmental-structural settings. According to Rousseau *et al.* (2005) the pre-Kahmah unconformity represents a Late Jurassic ‘subaerial exposure’ surface which ‘is sealed by the coastal onlap of the Rayda Formation that developed throughout the Tithonian, showing vertically a gradual transition from a... shallow-water to a... pelagic limestone’. They also stated that ‘erosion mainly involved subaerial dissolution, in association with a gentle uplift

of the carbonate platform edge’ and concluded ‘the basal beds of the Rayda Formation... should now be considered to be... distal, and not deep, marine’ facies. However, their own reports of belemnites, ammonites, saccocoids and calpionellids in the Rayda Formation, all classical markers of deep-water environments, suggest that these interpretations of environment are strongly biased to fit their hypothesis of subaerial exposure.

We list below four lines of evidence to support a diametrically opposed hypothesis for the milieu of deposition during the Tithonian-Berriasian.

(1) During the time in question there is no record of either subaerial exposure at the unconformity or of an overlying transgressive lag deposit in the Jabal Akhdar area (or on the Musandam peninsula, Fig. 1).

(2) West of the area under review, sedimentation was fairly continuous and erosion was moderate during deposition of the carbonate platform facies of the Bu Haseer Formation, which is a time and facies equivalent of the lower Kahmah Group (Fig. 3; Granier 2000), despite common epikarst (Fig. 4).

(3) The Rayda Formation is recognized in subsurface wells and at outcrops in the UAE and Oman. It thus extends a considerable distance west and north of the Jabal Akhdar area studied by Rousseau *et al.* (2005), which was located some 250 km from the Bu Haseer carbonate platform (Fig. 1). The Rayda Formation is regarded as a facies equivalent of the Majolica (Rabu 1988; Rabu *et al.* 1990), a deep-water carbonate facies deposited above the calcite compensation depth (Fig. 5).

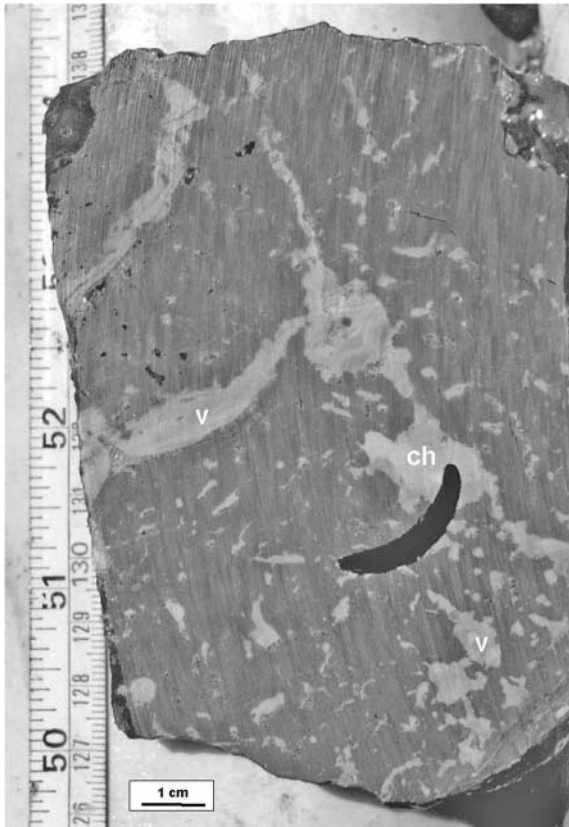
(4) According to Rabu (1988) and Rabu *et al.* (1990), block faulting took place in Late Tithonian times (Fig. 5). The sedimentary breccia facies of the basal Rayda Formation (Fig. 2; Hudson & Chatton 1959; Toland *et al.* 1993) provides indirect evidence of unstable palaeoslopes or active fault escarpments. Also, neptunian dykes penetrating the Sahtan Group have been reported by Pratt & Smewing (1990, fig. 6c) and De Matos (1997, fig. 5.7). Both of these phenomena strongly suggest that a hypothesis involving an extensional setting, and not ‘uplifting of the platform edge’ as interpreted by Rousseau *et al.* (2005), provides a valid explanation for the observed lithological and paleobiological relationships.

Conclusion. Rousseau *et al.* (2005) confirm that the pre-Kahmah unconformity in the Jabal Akhdar area represents a geologically substantial hiatus. However the timing of some events in their interpretation is faulty in the context of biostratigraphic data that they did not consider. Most significantly, the end of Hith Formation deposition is not coincident with the start of Rayda Formation deposition. Instead, we demonstrate that the time elapsed between the two events is the equivalent of a stage or substage (i.e. the length of time required for the deposition of the Habshan Formation).

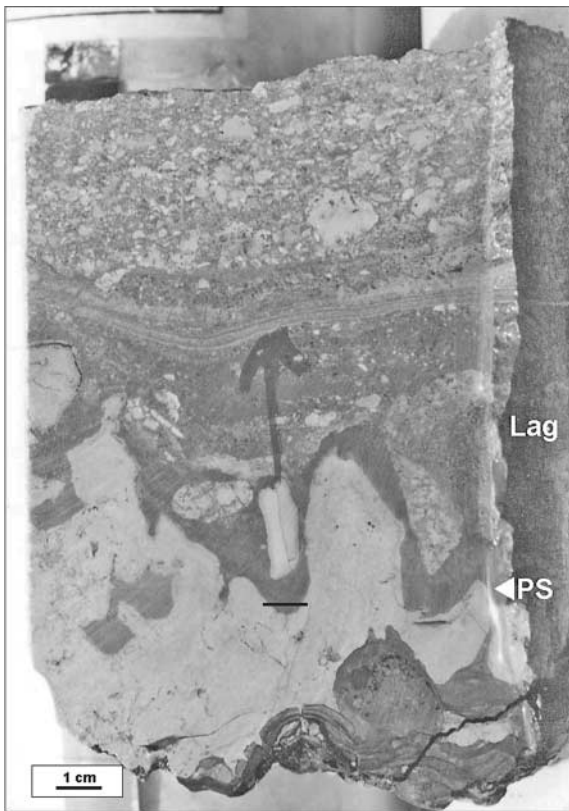
In addition, we conclude that the erosion reported by Rousseau *et al.* (2005) was caused mainly by chemical sub-

K.S.A.	ABU DHABI		OMAN			
Yamama Fm	"Thamama IV"	Zakum Fm	Kahmah Grp	Salil Fm	Birkat Fm	Lower Valanginian
		Belbazem Fm				
Sulaiy Fm	"Thamama V"	Bu Haseer Fm	Sahtan Grp	Rayda Fm	Awabi Fm	Berriasian
	"Thamama VI"	Habshan Fm				
	v v v v	Hith Fm				Tithonian

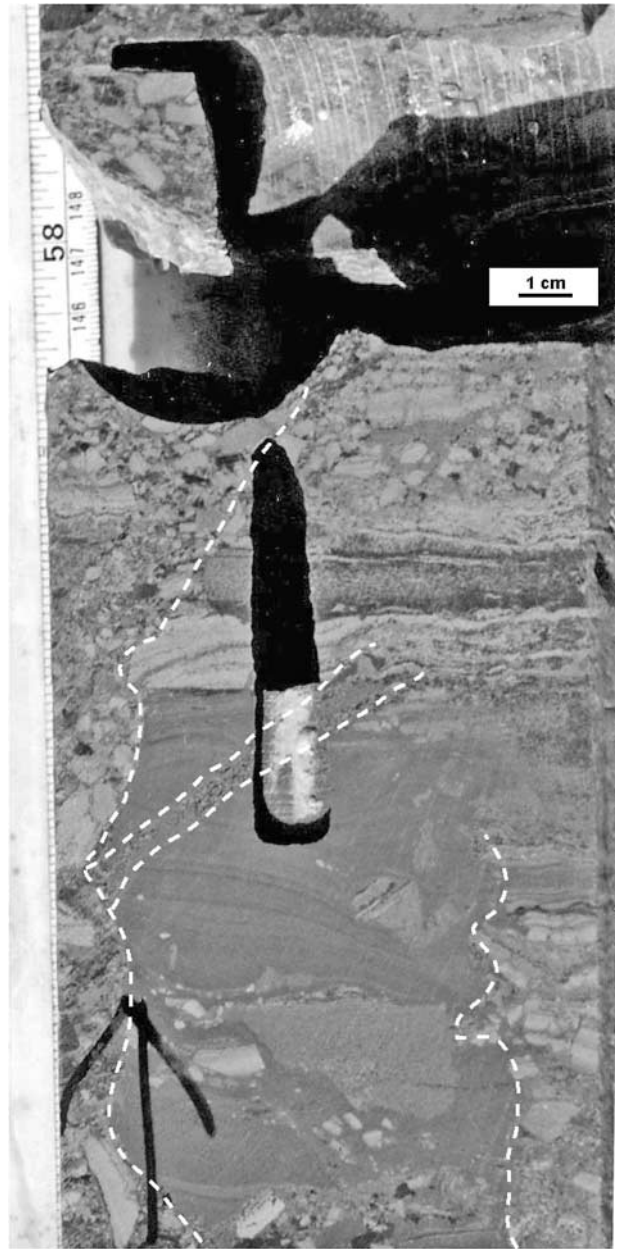
Fig. 3. The extant stratigraphic classification in Oman, Abu Dhabi and Saudi Arabia (modified from Granier 2000). The Sulaiy-Yamama boundary was not included as it requires further biostratigraphic investigation.



(a)



(b)



(c)

Fig. 4. Photos of core slabs illustrating karstic features (exposure surfaces, microkarst infills, cave collapse breccias) observed in the shallow-water platform facies of the Bu Haseer Formation. During Late Tithonian and Early Berriasian times, repeated low amplitude sea-level changes generated a succession of metre-scale sequences bounded by exposure surfaces (Granier 2000). (a) Dark mudstone with vugs of various sizes and shapes (v, vugs; ch, channel) filled by geopetal micritic to microsparitic internal sediments. (b) Pitted surface (PS) capping a 'Purbeckian' sequence with a typical lag deposit above (reworked material includes clasts with charophyte remains). (c) Alternations of small scale cave-collapse breccias and layered micritic to microsparitic infills.

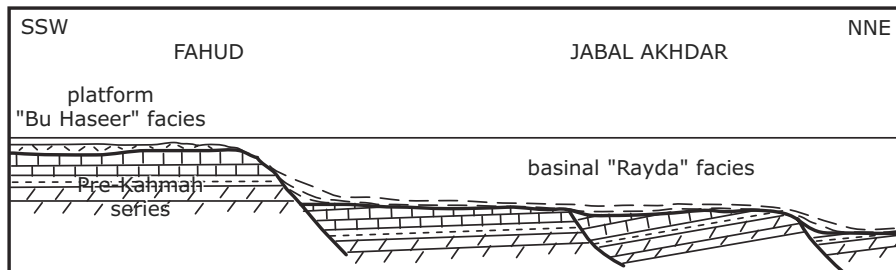


Fig. 5. Reconstructed palaeogeographic profile (see Fig. 1 for approximate location) of the Oman mountains at the Tithonian-Berriasian boundary (modified from Rabu 1988).

marine dissolution (subsolution) along the Jurassic palaeoshelf margin (see also Murriss 1980) or on the basin floor, not by 'subaerial carbonate dissolution maintained by a general uplift of the platform edge'. The change from a erosional and/or non-depositional hiatus to the overlying Rayda porcelanite may have formed in response to regional Late Tithonian distensive tectonic movements (Rabu 1988; Rabu *et al.* 1990). Finally, the litho- and bio-facies of the Rayda Formation are typical of deep-water environments; therefore if 'onlap of the Rayda upon the Sahtan limestone' occurred it was a basinal onlap (see Haan *et al.* 1990), not 'coastal onlap'

We express our warmest thanks to José De Matos (Lisbon, Portugal), Dominique Rabu (Nantes, France), and Christopher Toland (Cheltenham, UK) for fruitful discussions and comments. We are very grateful to Gary Hampson (London, UK), JGS Subject Editor, for suggestions that greatly improved the original manuscript.

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