Sedimentary facies and trilobite and conodont faunas of the Ordovician Rann Formation, Ras Al Khaimah, United Arab Emirates

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ABSTRACT

The Rann Formation occurs as unique ‘exotic’ rafts in front of the Semail Ophiolite in the northern Oman Mountains. Its Ordovician age has been poorly constrained and it is often associated with the Ayim rock unit, which has been considered Devonian, Carboniferous or Ordovician by different workers. Here we present new trilobite and conodont evidence for the Ordovician ages of the three members of the Rann Formation, which includes the Ayim. The members are readily distinguishable on sedimentological and faunal grounds.

The Lower Member comprises shales, quartzitic sandstones and thin fossiliferous shell beds. Large *Cruziana* are common, as is lingulacean debris and, at several horizons, possible hyolithids. Assemblages of graptolites, acritarchs, trilobites (*Neseuretus* cf. *arenosus* and *Taihungshania* cf. *miqueli*) and conodonts (*Baltoniodus* sp., *Drepanodus arcaucus*, *Drepanoistodus* sp. and *Protopanderodus* sp., *Scolopodus* sp.) are considered to range in age from Floian to early Dapingian, late Early Ordovician. The Ayim Member (previously formation) consists of fossiliferous shales and griotte-like nodular bioclastic limestones. The member is distinguished by its red colour and by numerous orthoconic nautiloids. Conodont faunas (*Complexodus* cf. *originalis*, *Eoplacognathus protoramosus*, *Dapsilodus* sp., *Cornuodus* sp. and *Panderodus* sp.) imply a late Darriwilian, Middle Ordovician age. The Upper Member consists of siltstones and sandstones generally lacking bioturbation and with rare shell beds and faunas. Trilobites (*Deanaaspis goldfussii seftenbergi*, *Vietnamia teichmulleri* and *Dreyfussina taouzensis*) and chitinozoans are interpreted to indicate an early-middle Katian, Late Ordovician age.

The three members represent shallow-marine deposits on a continental shelf subject to changing sand supply, storm-wave activity and sea-bottom oxygenation. The three periods of deposition, Floian – early Dapingian, late Darriwilian and early – middle Katian, correspond to highstands of Paleo-Tethys that also flooded interior Oman and Arabia. The limited burial and lack of metamorphism of the Rann is remarkable given its proximity to the Semail Ophiolite and to subduction related metamorphic rocks occurring nearby.

INTRODUCTION

The Rann Formation outcrops in the vicinity of wadis Ayim and Kub in the Dibba Zone of the northern Oman Mountains. The most continuous outcrops are on the northern flank of Jabal Ar Raan (25°25'25"N, 56°04'02"E), just south of Wadi Ayim and about 7 km southeast of Idhn village, Ras Al Khaimah (Figure 1). Hudson et al. (1954) made the first high-level description of the Rann Formation in their investigation of the Jabal Qamar structures for the Iraq Petroleum Company. They considered the ‘Rann Grits and Shales’ were 240 m thick, and were of Middle Ordovician age based on *Cruziana* tracks and trilobites. Henson, in the discussion that follows Hudson et al.’s paper, aptly observed ‘that the Qamar area presented to the newcomer an appearance of geological chaos.’ Glennie et al. (1974) adopted much of Hudson et al.’s description for their Rann Quartzite Formation and provided a few further details of the lithologies. Fossils, including cephalopods (*Orthoceras*) were noted from red shales towards the top of the formation.
Omatsola et al. (1981) visited the outcrops at Jabal Ar Raan as part of Petroleum Development Oman’s widening interest in Palaeozoic sandstone reservoirs. They distinguished four units, from apparent base to top:

1. Yellow brown shales, siltstones and quartzitic sandstones containing trilobite fragments (including trinucleids). A chitinozoan assemblage of Late Ordovician age was also recovered from a shale sample.
2. Grey brown quartzitic sandstones with shale intercalations. The sandstones are partly cross-bedded.
3. Very fossiliferous pinkish to red-brown calcareous siltstones and shales grading up into lime mudstones.
4. Yellow brown thin bedded quartzitic sandstones and shales.

Figure 1: Location map of the Rann outcrops in the Dibba Zone of the United Arab Emirates, which occur between the northernmost limits of the Semail Ophiolite and the carbonate massif of Musandam. Based on Searle et al. (1983) and Dunne et al. (1990). The Asimah-Masafi and Wadi Bani Hamid outcrops may include metamorphosed Rann shales, quartzites and carbonates.
Searle et al. (1983) and Robertson et al. (1990) described the broader context of the Rann Formation outcrops in the Dibba Zone. They considered the overlying red calcareous rocks as a separate formation, the Ayim. Whereas the ca. 80 m-thick Rann was regarded as Ordovician, the ca. 25 m Ayim was undated, possibly Devonian, based on its red griotte-like character and comparison with similar lithologies in the Mediterranean region. The Rann and Ayim occur as rafts and blocks in a highly disrupted melange, the Kub Melange, equivalent to the Haybi Complex between the Hawasina sediments and the Semail Ophiolite elsewhere in the Oman Mountains. The presence of rafts of older Palaeozoic ‘exotics’ in the Kub Melange is a unique aspect of these outcrops (Searle and Graham, 1982; Pillevuit et al., 1997). The Rann and Ayim are only known from this geographically limited area, though Searle and Cox (2002) suggest that quartzites and carbonates (possibly Rann, Searle, pers. comm.) were the protoliths of the wadi Bani Hamid / Madhah granulites, quartzites and calc-silicates (Figure 1).

Niko et al. (1997) described nine species of nautiloid and bactritoid cephalopods from the Ayim in the Jabal Qamar South area. Based on this assemblage, and the context of underlying Ordovician and overlying Lower Permian strata, the formation was interpreted to be of early Carboniferous age. Pillevuit, in Niko et al. (1997) mapped the Rann and Ayim outcrops as more continuous laterally than the isolated rafts depicted by Robertson et al. (1990). Hamdan and Mustafa (2009) described an assemblage of receptaculitids, orthoconic nautiloids and trilobites collected from outcrops of the upper Rann and lower Ayim in the Jabal Qamar South area in the period 1980–1994. They interpreted these faunas to be of Middle Ordovician age.

Goodenough et al. (2006) remapped the geology of this area of the United Arab Emirates and recognised that even the most complete sections of the Rann and Ayim on Jabal Ar Raan, are repeated by thrusting and disrupted by brittle high-angle faulting. They concluded that stratigraphic relationships and thicknesses were uncertain and recommended caution over the composite stratigraphy of Robertson et al. (1990). Conodonts extracted from bioclastic limestones and red calcareous shales containing nautiloid cephalopods were interpreted to indicate a Late Ordovician age.

The origins of this paper stemmed from the chance discovery of a graptolite in 2005 in a quarry at Jabal Ar Raan (Rickards et al., 2010) and then finding trilobite traces and faunas in the vicinity. It is also important that these stratigraphically interesting and unique outcrops are better documented before they are quarried away for the manufacture of ceramic products. Much of the central area of Rann rafts shown in Robertson et al.’s (1990) figure 14 and the main section illustrated by Pillevuit et al.’s (1997) figure 5 have now been quarried away. The quarries are being extended progressively towards the southeast.

MEMBERS OF THE RANN FORMATION

The most complete outcrops on the flank of Jabal Ar Raan are shown in the panorama of Figure 2. In detail though the section is considerably deformed with tight folds in shalier intervals such that within a few metres beds may be the right-way-up, or overturned based on Cruziana tracks, sole marks or other sedimentary features. Even thicker quartzitic sandstone intervals are folded and cut by brittle faults. Elsewhere in Wadi Kub, the rafts of Rann and Ayim are smaller, boudinaged and sometimes isoclinally folded. However, the thicker quartzite rafts of the Rann and the red coloured rafts of Ayim are still readily distinguished. Given the state of local deformation, which appears to be of tectonic origin, it is remarkable that sedimentary features and fossils show little sign of distortion. Dunham, in the discussion that follows Hudson et al. (1954), commented that the Rann in the Jabal Qamar area showed no petrographic evidence of metamorphism, other than cataclasis on a micro-scale. The colour alteration index (CAI) for the conodonts obtained from both the Rann and the Ayim is less than 1.0 and reflects palaeotemperatures of less than 100°C.

Our fieldwork in the Jabal Ar Rann, Wadi Ayim and Wadi Kub area presently indicates three members of the Rann Formation (sensu Goodenough et al., 2006) based on sedimentary facies associations, trace fossils, faunal assemblages and dateable faunas. From base to top these are:
(1) Lower Member: Green shales and interbedded brown-white quartzitic sandstones, fossiliferous shell beds, *Cruziana* spp.

(2) Ayim Member: grey-red shales, bioclastic and nodular limestones, fossiliferous and notable for its orthoconic nautiloids.

(3) Upper Member: Yellow-brown silts and sands lacking bioturbation and with rare fossiliferous shell beds and intervals containing fauna.

With the exception of the base of the Ayim, contacts between the members are not seen and generally believed to be tectonic (Figure 3). The Ayim was designated a formation by Robertson et al. (1990), but given its Middle Ordovician age (Rickards et al., 2010, and elaborated here), it appears more appropriate to consider it a distinctive member of the Rann Formation.

Thicknesses of the Rann Formation are difficult to estimate due to the deformation, certainly less than the 240 m of Hudson et al. (1954) and possibly around 100 m. It represents a much thinner Ordovician succession than the > 3,000 m Amdeh Formation or Haima Supergroup in Oman, and is more comparable with the ca. 900 m thickness of the Saq and Qasim formations in Saudi Arabia (Figure 3). The little information there is for the Fars Province of Iran suggests ca. 750 m of marine? shales and micaceous sandstones of the Sayahoo/Zard-e-Kuh formations (Bordenave, 2008).

**Lower Member: Green shales and interbedded brown-white quartzitic sandstones, fossiliferous shell beds, *Cruziana* spp. (Figures 4 and 5).**

Several lithologies are present: green-grey listric shales, < 0.1–5 m thick brown-white quartzitic sandstones, and thin, orange-brown, partly decalcified shell beds (Figure 4). Sandstones increase in abundance towards the top of the interval (Figure 5). Many of the sandstone beds are sharp based with trace fossils, tool marks and small phosphatic pebbles. The sands are fine- to medium-grained with horizontal lamination, low-angle swaley cross-stratification and wave ripples. Thicker sandstone beds show occasional sets of trough cross-stratification. Shell concentrations occur as layers or lenses at the base, within or at the top of sandstone beds. Sometimes shells are packed convex-up and elongate shells are orientated. Shells consist of bivalves, trilobite fragments, small brachiopods and possible hyolithid cones. Broken shells of lingulacean bachiopods are ubiquitous and locally concentrated towards the tops and at the bases of sandstone beds. Trace fossils are common with *Cruziana* being abundant (*C. furcifera* and *C. rugosa*). *Rusophycus* traces, in contrast, are relatively uncommon. *Planolites* is also common locally, along with *Skolithos* and *Arenicolites* in the sandier intervals.

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Figure 2: Panorama of the most extensive remaining outcrops of the Rann Formation on the flanks of Jabal Ar Raan and Jabal Qamar South. Faunal locations are designated by letters A-D, see also Appendix A. Locations A and B are 250 m apart.
Figure 3: Ordovician stratigraphy and formations for Oman and Saudi Arabia to show the Rann Formation and its equivalents. Modified from Rickards et al. (2010). The colours on the stratigraphical columns are yellow=sandstones, blue=siltstones and shales, and white with a blocky symbol=limestone. Interestingly the sea-level curve that best fits the Oman and Rann stratigraphy is that of Nielsen (2004) established from the Baltic region, on the opposite side of Paleo-Tethys. Given the punctuated deposition now apparent in the Ordovician of Oman and the UAE, perhaps the apparently continuous sequence in Saudi Arabia contains yet to be identified disconformities.
The sediments are shallow-marine and storm/wave-dominated, deposited in water depths of a few 10s of metres (Cruziana and Skolithos ichnofacies). The thinner bedded quartzitic sands and shell beds are typical storm tempestites. The shales must have been sufficiently organic-rich to sustain the deposit feeding appetites of the large trilobites or arthropods that created the Cruziana traces. Shales containing graptolites are likely to have been the deepest water facies.

Graptolites (Baltograptus deflexus, and fragments of dichograptids) and acritarchs (Polygonium spp., Coryphidium bohemicum, Striatotheca principalis sp., Petaliferidium bulliferum, Veryhachium trispinosum, Stelliferidium striatulum, Athabascaella rossii, Petenosphaeridium exornatum, Striatotheca rugosa, Arbusculidium sp., Cymatiogalea spp. and Baltisphaeridium sp.) occur locally in the olive-green shales (Rickards et al., 2010). These have been interpreted to be of middle Floian to early Dapingian age, late Early Ordovician (Figure 3). The stratigraphical relationship of the graptolite-bearing shales exposed

Figure 4: Facies of the Lower Member, Jabal Ar Rann, all photos from the vicinity of the described trilobite and conodont faunas.
(a) Deformed shales and 10–20 cm thick sandstones with shell beds. Bedding is picked out in several places to highlight the deformation that appears to be tectonic rather than slumped. Light coloured limestone blocks are rockfall from overlying Permian – Triassic Limestones.
(b) Tempestite sandstone, with Cruziana visible on its base (arrowed) and partly decalcified shell debris at several horizons. Lens cap is 5 cm.
(c) Preferentially orientated moulds of cone-shaped hyolithid? shells, which abound in some shell beds. These are large, typically 10 cm, lack septae, have external transverse ribs and have features resembling the phragmocone of a coleoid. Millimetre-wide borings remain crossing the decalcified phragmocones of many specimens. Lens cap is 5 cm.
(d) Enlargement from block above showing darker filled borings. Coin is 2 cm in diameter.
(e) Multiple tracks of Cruziana furcifera (arrowed) on the bases of beds just below the level from where the trilobite fauna was collected. There is a discrepancy in scale between these dm-wide Cruziana and the cm-size of the trilobite fossils collected. What created the Cruziana? Hammer is 28 cm long.
Figure 5: Sandier facies of the Lower Member, Jabal Ar Rann.
(a) Quartzitic sandstone dominated interval showing brittle deformation. Sandstones near the base are unusual in showing channelisation, other beds are more tabular. Thin shell beds and *Cruziana* continue to occur, but the dominant trace fossils are *Skolithos* and *Arenicolites*. Fence posts, lower right, are 1.6 m high.
(b) Isolate cross-bed set 70 cm thick orientated toward the north occurring towards the top of the quartzitic sandstone interval shown in (a) (this cross-bedded interval is traceable laterally over several hundred metres). A softer weathering *Skolithos* interval occurs below and horizontally laminated and swaley cross-stratified sandstones above.
(c) *Skolithos* extending through a 25 cm thick sandstone bed and show no evidence to being re-oriented around into any cleavage direction, as occurs commonly in the Amdeh 3 and 4 intervals in Oman.
(d) Lingulacean debris is common in the sandstones of the Rann Lower Member. It is always intensely broken, never occurring as complete shells. Here it occurs at several levels near the top of the quartzitic sandstone outcrop shown in (a). Lens cap is 5 cm.

Trilobite Fauna (Plates 1 and 2; Appendix A for location)
The trilobite material is meagre, consisting of external moulds of fragmentary material on the surface of sandstone blocks. Nonetheless the combination of *Neseuretus* cf. *arenosus* Dean and *Taihungshania* cf. *miqulii* (Bergeron) is characteristic of the Early Ordovician of the Mediterranean region and more particularly the earlier part of the Arenig Stage of the Gondwana Ordovician standard (or Floian, in terms of the international standard, see Cocks et al., 2010). Because of imperfections in the material it is not possible to be absolutely certain of the species identification. However, it is noted below that identical pygidal fragments from the Montagne Noire, southern France, were figured under
the name *Taihungshania ogivalis* by Courtesole et al. (1985) where they occur in the early Arenigian Schistes à lingules along with *Cruziana* trace fossils. *Neseuretus arenosus* occurs immediately above this but we note differences in the anterior border from the Rann material. Trace fossils including *Cruziana furcifera* and *C. rugosa* co-occur with the trilobites in the Rann Formation. In combination, this is good

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Plate 1: Figs 1–4. *Neseuretus* cf. *N. arenosus* Dean, 1996. Rann Formation: Lower Member. (1) Latex cast of incomplete cranidium, NHMUK PI It 28743. (2) Latex cast of incomplete thorax, NHMUK PI It 28744. (3) Latex cast of incomplete cranidium, NHMUK PI It 28745. (4) Latex cast of incomplete pygidium, NHMUK PI It 28746. Scale bar is 5 mm.
evidence for an early Arenigian (= early Floian) age for this part of the Rann Formation probably somewhat older than the conodont age (to be described) and the graptolite-acritarch assemblage, despite the outcrops being in close proximity.

Plate 2: Figs 1–2. *Neseuretus* cf. *N. arenosus* Dean, 1966. Rann Formation: Lower Member. (1) Latex cast of incomplete cranidium, NHMUK PI It 28336. (2) Latex cast of incomplete cranidium, NHMUK PI It 28337.
Figs 3–4. *Taihungshania* cf. *T. miqueli* (Bergeron, 1893). Rann Formation: Lower Member. (3) Latex cast of external mould of incomplete pygidium, NHMUK PI It 28338. (4) Latex cast of large incomplete pygidium with marginal spine. NHMUK PI It 28718.
Scale bar is 5 mm.
Interestingly El-Khayal and Romano (1988) reported the same *Cruziana* species from the top of the Saq Formation in Saudi Arabia, which they inferred was of “Arenig age”. However, no trilobite body fossils were found there, even though *Cruziana* traces are commonly considered to have been made by these animals. The Rann Formation occurrence adds support to the age inferred for the Saq Formation.

Fortey and Morris (1982) noted, when describing a younger occurrence of the genus from Saudi Arabia, that *Neseuretus* was a trilobite definitive of the Ordovician Gondwana palaeocontinent; the same is true of *Taihungshania*. When they occur in coarser clastic rocks *Cruziana* trace fossils of similar species are often found in adjacent strata. Together they constitute a shallow water faunal association widespread across the cratonic areas of Early Ordovician Gondwana, and unknown from contemporary strata in Baltica or Laurentia.

**Conodont Fauna (Plate 3; Appendix A for location)**

Limestone nodules weathered from a particularly carbonate-rich hyolithid shell bed were extracted for conodonts using 10% acetic acid and concentrated using a solution of sodium polytungstate at a specific gravity of 2.80. Many of the specimens recovered from this sample are over 1 mm in length and some are as large as 5 mm. Although the sample is dominated by coniforms a few platform elements are present and have tentatively been placed within *Baltoniodus* (Plate 3, figs 1–6). More elements, particularly better-preserved P elements are needed to make a more definitive identification. M elements present in the collection are similar to those figured by others as part of the apparatus of *Microzarkodina flabellum* (see Bednarczyk, 1998; Löfgren and Tolmacheva, 2008) or *Periodon flabellum* (see Löfgren, 1978, 1994). None of the more distinctive P elements have been found associated which perhaps indicates that they are more likely to be part of the *Baltoniodus triangulatus* apparatus (see Wang et al., 2005, fig. 4; Bergström and Löfgren, 2009, fig. 4t). However, one element (Plate 3, fig. 8) does have a denticulated upper margin to the base so could belong to a *Periodon/Microzarkodina* type apparatus. The assemblage is dominated by large coniforms such as *Drepanodus arcuatus*, *Drepanoistodus* and *Protopanderodus* (Plate 3, figs 7, 9, 11) and some small highly striated elements are present that resemble *Scolopodus* (Plate 3, fig. 10). The *Protopanderodus–Periodon* biofacies was recognised by Rasmussen and Stouge (1995) as covering outer-shelf to basin environments (Rasmussen, 1998). The large size of many of the specimens and the shell lag nature of deposition, would suggest mixing of shallow water and more offshore taxa and substantial sorting during transportation. Smaller elements may also be missing from this assemblage as a result. More material is needed to obtain a more definitive date for this sample. None of the coniform elements obtained contradict the Floian age suggested by the graptolites, palynomorphs and trilobites. 

*Baltoniodus* species have been found in the late Floian at the Global Stratotype (Wang et al., 2005, fig. 7). Further samples are currently being studied to obtain more definitive *Baltoniodus* material.

**Ayim Member: grey-red shales, bioclastic and nodular limestones, fossiliferous and notable for its orthoconic nautiloids (Figure 6)**

The orange-red colour, calcareous content and its abundant orthocones make this member distinctive, even in small outcrops. Its base is seen in some localities as a 0.15 cm orange coloured bed packed with elongate fossils, possibly hyolithids, resting irregularly on Rann quartzite rafts (e.g. 25°25’27.26”N, 56°4’19.48”E). Granules and small pebbles of phosphate and quartz, and lingulacean debris occur also. Robertson et al. (1990) reported fish scales, teeth and bones and well-rounded quartz grains from thin sections of this bed and interpreted it to represent a condensed horizon on an unconformity surface (they also described orthocones from this bed, but the elongate fossils lack septae and are the same fossils as the possible hyolithids of Figure 4c). The basal bed is overlain by orange-coloured sandstone with paired *Arenicolites* burrows on its upper surface.

The bulk of the ca. 25 m-thick Ayim Member lacks sand and consists of unfossiliferous grey-purple shales which pass upward into fossiliferous grey-red nodular bioclastic limestones and in turn into red, fossiliferous, nodular, shaley limestones. At least one bed near the top of the bioclastic limestone is capped by low-relief stromatolites in Jabal Ar Rann and in a tributary of Wadi Ayim, several kilometres distant. In thin section the nodular limestones are wackestones and packstones.
Plate 3: Conodonts from hyolithid limestone, Rann Formation, Lower Member.

Figs 1–6. *Baltoniodus* sp. (1) P₁ element, lateral, NHMUK PM X 3575. (2a-b) P₂ element, (2a) basal view, (2b) lateral view, NHMUK PM X 3576. (3) P₃ element, lateral view, NHMUK PM X 3577. (4) S₀ element, anterior view, NHMUK PM X 3578. (5–6) M elements, lateral views, (5) NHMUK PM X 3579. (6) NHMUK PM X 3580.

Fig. 7. *Drepanoistodus* sp. Sb element, NHMUK PM X 3581.

Fig. 8. Coniform element indet. NHMUK PM X 3582.

Fig. 9. *Protopanderodus* sp. NHMUK PM X 3583.

Fig. 10. *Scolopodus* sp. NHMUK PM X 3584.

Fig. 11. *Drepanodus arcuatus* Pander, 1856. NHMUK PM X 3585.

All scale bars are 200 µm.
with an abundant fauna of crinoid ossicles, dasycladacean algae, trilobite fragments, gastropods, indeterminate agglutinated foraminifera, ostracods and small bivalve fragments (Goodenough et al., 2006). Macroscopically, the most obvious fossils are orthoconic nautilods, some up to > 40 cm, planispiral gastropods, crinoid columnals and trilobite fragments. Often the largest orthocones are encrusted with barnacles. Sometimes the orthocones are oriented randomly, in other beds they have been aligned by current activity. Trace fossils are uncommon, except for within the nodular bioclastic limestone interval.

Niko et al. (1997) identified a diverse nautiloid and bactritoid cephalopod fauna from Ayim outcrops that formerly existed on the slopes of Jabal Qamar South (orthoceratids: *Michelinoceras* sp.1, *Michelinoceras* sp.2, *Temperoceras ayimense*, *Mooreoceras* sp.1, *Mooreoceras* sp.2, *Mitorthoceras* sp., *Spyroceratinae*, genus and species indeterminate; oncocerid: *Poterioceratidae*, genus and species indeterminate; and bactritid: *Bactrites cf. quadrilineatus*).

Gnoli and Serventi (2006) examined samples of nautiloid cephalopods collected by British Geological Survey geologists from an outcrop in Wadi Kub and identified *Vaginoceras, Endoceras, Michelinoceras* and *Geisonoceras* (Goodenough et al. 2006, appendix 7). They also noted one specimen with a *Balanus*-like epibiont barnacle.
Trilobite fragments collected by us are assigned to *Illaenus*, whilst fragments of spiny odontopleurid trilobites have been noted in the heavy fraction of conodont separations. Hamdan and Mustafa (2009) record *Nileus emiratus* from the lower beds of the Ayim. This genus has a range from Floian to Katian. Noticeably, there are no *Cruziana* present in this member, nor lingulacean shell debris, except in the basal condensed sand where fragments are probably reworked from below.

The depositional environment of the Ayim Member was probably low-energy shelfal, remote from any sandy input. There appears an unconformity at the base, a significant reduction in sand supply and an increase in water depth. The red nodular limestone parts are typical griotte facies, though it is predominantly bioclastic and lacks the cherts of some griottes. The presence of microbial stromatolitic features implies deposition within the photic zone, and the occurrence of *Thalassinoides* burrows and orientated orthocone shells, shallower, within storm wave-base, rather than deeper shelfal conditions (Wendt and Aigner, 1985; Tucker and Wright, 1990).

**Conodont Fauna (Plate 4; Appendix A for locations)**

Ferretti (in Gnoli and Serventi, 2006) proposed a Late Ordovician age for a conodont fauna extracted from cephalopod-rich limestone samples from Sha’biyyat Al Yaruf in Wadi Kub. The outcrops sampled by Goodenough et al. (2006) are no longer available due to house construction. Ferretti recognised *Scabbardella-Dapsilodus* and *Rhodesognathus* but was not able to constrain the age to anything more definite than Late Ordovician (Ferretti, pers comm.).

Further samples were collected from bioclastic limestones in the Jabal Ar Raan outcrops, from a tributary of Wadi Ayim and from a further outcrop in Wadi Kub. Both the red and the grey limestones yielded conodonts. The red limestones produced a greater number of age-diagnostic specimens while the grey limestones produced spiny trilobite fragments as mentioned above. P1 elements of *Complexodus cf. originalis* Chen and Zhang, 1984 have been recovered from the red limestone. The angular style of denticulation is more reminiscent of *C. originalis* than *C. pugionifer* (Drygant, 1974), which has

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Plate 4: Conodonts from the Ayim Member, Rann Formation. Figs 1a-b. *Complexodus cf. originalis* Chen and Zhang, 1984. (1a) lateral view, (1b) oral view, NHMUK PM X 3586.

Figs 2–5. *Eoplacognathus cf. protoramosus* (Chen, Chen and Zhang, 1983). (2) Dextral pastiniplanate element, oral view, NHMUK PM 3587. (3) Sinistral pastiniplanate element, oral view, NHMUK PM X 3588. (4) Dextral pastiniplanate element, oral view, NHMUK PM X 3589. (5) Dextral pastiniplanate element, oral view, NHMUK PM X 3590.

All scale bars are 200 µm.
denticles with widened tips (see Dzik, 1991 for comparison). It has been tentatively identified as C. cf. originalis as the row of denticles on the outer process is bent 90 degrees to the posterior which is not been previously been recorded for C. originalis, although the figures of the type specimen are unclear (Chen and Zhang, 1984, pl. 2, figs 11–12). Identifications of Complexodus suggest an age spanning the Middle-Upper Ordovician boundary as this taxon has been recovered from these levels in the Holy Cross Mountains, Poland (Dzik, 1978, 1991; Schätz et al., 2006), Estonia (Viira et al., 2001, 2006), Turkey (Sarmiento et al. 1999), Sweden (Bergström, 2007), the UK (Bergström 1983; Bergström and Orchard, 1985; Armstrong and Owen, 2002), Argentina (Ortega et al., 2008) and China (Chen and Zhang, 1984; Zhen et al., 2009). Complexodus has not been used widely in interregional correlations but does none the less have a narrow stratigraphic range in the areas where it has been found. Dzik (1999) attempted to show that the relationship between the angle of processes on P elements of Complexodus has changed through time in assemblages recovered from the Mojcza Limestone, Holy Cross Mountains. Applying the same criteria to the Ayim Member specimens shown here would suggest that these are older members of the lineage.

Other elements in the Ayim Member conodont fauna, particularly elements of Eoplacognathus, provide a better method for further constraining the age of the Ayim Member. Elements of this genus have been used as zonal indicators for Baltic successions (e.g. Zhang, 1999; Löfgren and Zhang, 2003; Löfgren, 2004) but the Ayim specimens are more closely related to Chinese forms, particularly Eoplacognathus protoramosus (Chen et al., 1983) (see Zhang, 1998b, fig. 5 and Zhang, 1998c) which is restricted to the late Pygodus serra Zone of China which equates to the E. lindstroemi subzone of Baltoscandia. In China E. protoramosus occurs with C. originalis at this level (Chen and Zhang, 1984, table 2). Other common elements in the assemblage such as Dapsilodus, Cornuodus and Panderodus are less useful for biostratigraphical zonation but suggest a similarity to a Darriwilian conodont fauna described from the Taurus Mountains in Turkey (Sarmiento et al., 1999). C. originalis has been recorded there as part of a fauna suggested as an equivalent to the Baltic Pygodus serra biozone. The combined occurrence of Complexodus and Eoplacognathus in the UAE suggests that the Ayim Member was deposited in the late Pygodus serra conodont Zone which is late Darriwilian, Middle Ordovician in age.

The conodont assemblage is consistent with a quiet shelf depositional environment and it is interesting that the more age diagnostic faunas occur in the red grittites rather than the grey bioclastic nodular carbonates. To investigate this, further sampling of the Ayim Member has been carried out and a more detailed description of the conodont fauna is in preparation (Miller, Ferretti and Heward, in prep).

**Upper Member: green-brown silts and sands, lacking bioturbation and with rare shell beds and faunas (Figure 7).**

This member occurs, confusingly, in an outcrop at the base of the section at Jabal Ar Raan (D in Figure 2) and also higher up the slope above the Ayim. The lower outcrops comprise beds of green-brown, fine-grained, silty sandstones 5 cm to 1 m thick. At a number of horizons over an interval of about 5 m they contain scattered decalcified fragments of trilobites, small brachiopods and crinoid columnals. Fossil fragments were first noticed in scree derived from the knoll due to the distinctive brown staining of the decalcified moulds (Figure 7d). The sands are horizontally laminated and swaley cross-stratified. Trace fossils are uncommon, and where they do occur are small simple burrows on bedding surfaces.

Rare, distinctively reddish-brown coloured, coarser-grained, partly decalcified shell beds also occur. They contain gastropods, orthoconic nautiloids and trilobite fragments (Figure 7c). The beds can be strongly erosively based, massive to swaley cross-stratified, harder than the surrounding silty sandstones and in places are boudinaged during deformation making them difficult to trace laterally. Omatsola et al. (1981) photographed and described a loose block of one such bed containing trinucleid trilobites.

Outcrops towards the top of the section at Jabal Ar Raan share many of the same attributes as above, but are siltier and generally thinner bedded. They are characterised by negatives, compared with the deposits of the Lower Rann Member, a lack of bioturbation and Cruziana, a lack of shell beds.
Figure 7: Facies of the Upper Member, Jabal Ar Rann, all photos from the vicinity of the described trilobite fauna.
(a) Outcrop, middle distance, of green-brown silty sands.
(b) Rare, red coloured, more calcareous, sandy shell bed forming a protruding ledge. Horizontally laminated and low-angle swaley cross-stratified silty fine sandstones above and below. Lens cap (circled) is 5 cm.
(c) Faunal remains occurring as moulds in the shell bed of (b), gastropods, orthoconic nautiloids and fragments of the pitted fringes of trinucleid trilobites. Lens cap is 5 cm.
(d) Silty sandstone, from above the shell bed, with brown stained moulds of brachiopods and trilobites. Coin is 2 cm in diameter.

and a lack of lingulacean debris. Only in one scrappy locality, largely obscured by blocks of Permian-Triassic carbonate scree, has a shell bed with a gastropod, orthocone and trinucleid trilobite fauna been observed thus far. No other outcrops of this member have been identified convincingly, though there is a candidate sequence with many of the same negative attributes in the tributary of Wadi Ayim (opposite the good Ayim outcrops of Figure 6, b–e).

These are also shallow-marine shelfal deposits, representing a return of sand supply and storm conditions where beds are deposited rapidly and shell fragments are generally not concentrated in shell beds or lag. The lack of Cruziana and bioturbation suggests bottom conditions that were anoxic or too high energy. The latter seems improbable given the fine silt-sand grain size. It seems likely that the fauna present locally, was washed in.

Trilobite Fauna (Plates 5–7; Appendix A for location)
This fauna is rather better preserved than the Lower Ordovician one, but again occurs mostly as moulds in sandstones. Three trilobite species are found therein, and all are indicative of an Upper Ordovician age at generic level. The trinculeid Deanaspis is widespread in Caradocian age strata throughout Europe, North Africa and the Middle East (Fortey and Cocks, 2003). A close comparison is drawn with specimens of late Caradocian age in Bohemia. The occurrence of the unusual calymenid Vietnamia is of particular interest since its previous occurrences are mostly further to the east than...
the Arabian Peninsula, where it extends into the Ashgillian (Turvey, 2005). The closest comparison is with a species originally described under a different generic name from Sardinia from the Punta Serpeddi Formation (Hammann and Leone, 1997); this formation is described as Caradocian, but not more precisely correlated. The third trilobite is compared with Spanish material described by Hammann (1974) and identified with *Dreyfussina taouzensis* (Destombes) from Morocco. Again, Hammann does not discriminate which part of the Caradocian his material comes from. The original material of Destombes (1972) is from the “caradocien inférieur”. Since our material compares more closely with Hammann’s than with the Moroccan types it seems possible that it is younger than that; Hammann (1974, p. 15) indicated that it is the youngest Caradoc trilobite from the Valencia de Alcantara section. The new material is also closely similar to two species from the Upper Caradocian of Sardinia (Hammann and Leone, 2007) as discussed below. In summary, the younger fauna is certainly Caradocian, and the trinucleid, and probably the acastid, suggests that it is more likely late in that stage (early Katian rather than Sandbian in international terms), but the evidence is not entirely unequivocal. However, an upper Caradocian (Katian) age is supported from chitinozoan evidence (see below). As with the earlier fauna, the genera present carry a definite Gondwana signature, especially if it is correct to regard the phacopoid as *Dreyfussina* as suggested herein.

El-Khayal and Romano (1988, p. 161) noted Caradoc age fossils from the type locality of the Ra’an Shale of the Qasim Formation (Figure 3). Trilobites were determined by the late Dr. D. Price as a trinucleid (*Onnia*) and a dalmantitid (*Kloucekia*), neither of them congeneric with the Rann fauna. It
is worth noting that Destombes (1972) originally placed Dreyfussina taouzensis into Kloucekia, and it remains possible that the same species as that from the Rann Formation is present in Saudi Arabia.

**Chitinozoan Fauna**

Omatsola et al. (1981) recorded an assemblage of poorly preserved dark brown chitinozoans from a shale sample taken near the base of the succession (in the vicinity of where they had noted trinucleids in a sandstone). The chitinozoans from 1981 have been re-examined by Florentin Paris who recognised specimens of Tanuchitina fistulosa (= Hyalochitina fistulosa) of mid-Katian, Late Ordovician age. Shalier lithologies from outcrop D (Figure 2) have been resampled twice during the current work, but without further recovery of microfossils.
DISCUSSION

The Ordovician Rann outcrops in the Dibba Zone are unique older Palaeozoic exotics in the Haybi Complex of the Oman Mountains. Such exotics have been interpreted as forming on horsts of thinned continental crust close to the Arabian Plate margin, on Neotethyan seamounts, or as detached blocks along a Triassic fault scarp (Glennie et al., 1974; Searle and Graham, 1982; Robertson et al., 1990; Pillevuit et al., 1997; Searle and Cox, 2002).

The new sedimentological and faunal observations in this paper provide few insights into the ‘bigger picture’ of the origins of the Rann outcrops in the Dibba Zone, though a fault scarp origin seems unlikely given the areal spread of the outcrops, the style of deformation and the likelihood that Rann clastic and carbonate lithologies formed some of the protoliths for metamorphic rocks in the Asimah-Masafi and Wadi Bani Hamid areas. Shallow water oxygenated shelfal conditions prevailed during the deposition of the Lower Rann. There was plenty of quartzose sand available and periodic storms transported the sand and winnowed the shell beds. It seems unlikely that deposition was on horsts, at this stage, as there was ready access to shelfal sand. There was limited accommodation space, resulting in a relatively thin succession compared to subsiding basinal areas. For some reason, probably falling sea level (Rickards et al., 2010), accumulation of sediment ceased and the deposits of the next sea-level highstand were the sand starved, shallowish-water shales and red nodular carbonate griottes of the Ayim. Later Upper Rann deposits represent a return to clastic shelfal conditions during the next sea-level highstand but now poorly oxygenated, with more restricted sand supply and with faunas washed in. No younger Ordovician or basal Silurian rocks have yet been identified in the Dibba Zone, though they are known from offshore Abu Dhabi, from the Fars Province of Iran (Sarchahan Formation), the wider Gulf area, Saudi Arabia and the subsurface of Oman (Figure 3). Younger Silurian black shales are rumoured to have been encountered in an exploration well drilled recently near Ras Al Khaimah city.
The trilobite faunas occurring in the Rann have distinct Gondwanan affinities, whereas the conodont faunas are more cosmopolitan (Baltic, Avalonian, Gondwanan and South Chinese affinities) reflecting the different life habits of these two groups of animals. This may show a greater dispersal potential for the conodonts, particularly those from the pandemic Protopanderodus-Periodon biofacies (Rasmussen, 1998). Bergström et al. (2009) noted that conodonts are absent and shelly faunas are largely endemic in North Gondwana (in the general area that includes the Arabian Peninsula) and suggested there are serious issues with correlating these areas. This study suggests that the Rann conodonts are typical of the traditional Atlantic Faunal Realm as opposed to the North American Mid-Continent Province (see for example Zhang 1998a). This twofold palaeogeographic division has recently been challenged and subdivided by Tropical, Temperate and Cold domains (Zhen and Percival, 2003). The Arabian Peninsula is not included in this division, but the conodonts described here suggest a mix of Open-Sea and Shallow-Sea faunas in the Temperate and Cold domains. Further work on the conodonts from this area could therefore prove useful for both biostratigraphy and palaeogeography.

The lack of metamorphism (< 100°C from CAI) and cleavage development in the Rann outcrops is remarkable given their quite extensive deformation, the proximity of the Semail Ophiolite on the other side of Wadi Ayim and the nearby ophiolite sole metamorphics of the Asimah-Masafi and the Wadi Bani Hamid (800–860°C and 20–30 km depth, Searle and Cox, 2002; Figure 1). The deformation appears tectonic, possibly related to a short period of subduction during ophiolite emplacement. The Rann deposits have been buried to 2–3 km, at most.

NOTES ON THE TRILOBITES

All figured specimens in this paper (trilobites, conodonts) are held in the Department of Palaeontology at the Natural History Museum, London. The earlier and later trilobite faunas are treated separately in the account below.

LOWER ORDOVICIAN FAUNA

Genus Taihungshania Sun, 1931
Type species. Taihungshania shui Sun 1931
Taihungshania cf. T. miqueli (Bergeron, 1893)
(Plate 2, Figs 3 and 4)

Occurrence: Rann Formation, Lower Member

Material: External moulds of two large, fragmentary pygidia, NHMUK PI It 28718, 28338.

Remarks: The pygidium of Taihungshania is unmistakeable so that even fragmentary specimens can be assigned to the genus with confidence. Furthermore, most of the differences recognised between species relate to the pygidium. However, neither of pygidia from the UAE is complete, which is unfortunate as we cannot be absolutely certain of the total number of pleural ribs. The specimen preserving the marginal spine shows ten ribs (as does the less complete one) and judging by the position of the lateral spine by comparison with other species it is probable that the pleural field is nearly complete – an 11th or 12th rib is a possibility. Dean (1966, p. 332) noticed that T. miqueli had 12–13 ribs and that the slightly younger T. landeyranensis (called T. shui landeyranensis by Courtessole et al. 1981) no more than eight, an observation with which Berard (1986) concurred, and according to Courtessole et al. (1981) the cephalic shields of these two taxa are identical. Our material therefore invites comparison with T. miqueli, but is probably larger than much material of that species illustrated previously. This may account for the narrowness (tr.) of the pygidial pleural field. One of the specimens in the type series of Bergeron (1893, pl. 7 fig. 2) is comparable. However, Courtessole et al. (1985) named Taihungshania ogivalis from incomplete pygidia, which appear to be identical to the material from UAE, notably in the rapid backward slope of the pleural furrows. They occur above the range of T. miqueli and within the range of T. landeyranensis but still within the “lower Arenigian.” Lu (1975)
Fortey et al.

redescribed the type species from China, which had been considered as a possible junior synonym of \textit{T. miqueli}. Their pygidia are certainly very similar. The Chinese species is also Floian ( Arenig) in age, but appears to be a little younger than \textit{T. miqueli}, and possibly approximately the same age as \textit{T. landeyranensis}, which Courtessole et al. (1981) regarded as a subspecies of \textit{T. shui}. Since the UAE specimens are incomplete, it seems best to be cautious about assigning a species name to them, while noting that they are strikingly similar to specimens from southern France (Montagne Noire). Since \textit{T. miqueli} is the senior name, the new material is compared with that species.

**Genus \textit{Neseuretus} Hicks, 1873**

*Type species. \textit{Neseuretus ramseyensis} Hicks, 1873*

\textit{Neseuretus cf. N. arenosus} (Dean, 1966) (Plate 1, Figs 1 to 4, Plate 2, Figs 1 and 2)

**Occurrence:** Rann Formation, Lower Member

**Material:** Four fragmentary cranidia, NHMUK PI It 28743, 28745, 28336, 28337; incomplete thorax, NHMUK PI It 28744; fragmentary pygidium, NHMUK PI It 28746.

**Remarks:** The fragmentary sclerites do not allow a full description. Nonetheless the gently tapering glabella truncated at the front is typical of \textit{Neseuretus}. Four specimens show the position of the palpebral lobe mostly anterior to glabellar furrow S2. This distinguishes the UAE species from stratigraphically early Arenigian (Arenig) species from Wales revised by Fortey and Owens (1987), which have more posteriorly positioned eyes. Dean (1966) proposed \textit{N. arenosus} from the early Arenigian \textit{Schists a lingules} of the Montagne Noire, and refigured \textit{N. attenuatus} (Gigout, 1951) from Morocco; additional material of the former was subsequently illustrated by Courtessole et al. (1983). \textit{N. attenuatus} has a more tapering glabella and stronger S3 than \textit{N. arenosus}. The cranidia of the species from UAE cannot be distinguished from some of those attributed to \textit{N. arenosus} and compare most closely with specimens in which the basal glabellar lobes are slightly inflated and S1 gently curved (e.g. Courtessole et al., 1983, pl. 1 fig. 2). However, those of our specimens that preserve the anterior border appear to show a wider preglabellar field behind it than is the case in some specimens from the Montagne Noire (e.g. Courtessole et al., 1983, pl. 6, fig. 1), and the frontal area is longer as a whole. By contrast, some specimens in Courtessole et al. (1983, pl. 1 fig. 1) are very similar to the new material in these features. Caution dictates that the identification given here should be qualified. An incomplete thorax and pygidium does not help resolve the issue.

**UPPER ORDOVICIAN FAUNA**

**Genus \textit{Vietnamia} Kobayashi, 1960**

*Type species. \textit{Calymene douvillei} Mansuy, 1908*

**Vietnamia teichmuelleri** (Hammann and Leone, 1997) (Plate 5, Figs 1–4)

**Occurrence:** Rann Formation, Upper Member

**Material:** Two cranidia, NHMUK PI It 28719, 28720; two pygidia, NHMUK PI It 28721, 28722.

**Remarks:** Turvey (2005) in his revision of \textit{Vietnamia} emphasised the characteristic prominent inflated post-axial ridge on the pygidium as a feature of the genus, which is clearly shown on the new material; a strongly tapering glabella is also typical. However, the glabella of the type species is exceptionally...
wide (tr.) at the level of the basal lobes of the glabella, which greatly exceeds the glabellar length, and the first glabellar furrow is forked at its inner end. These features are less developed in the stratigraphically earlier species of the genus, including *V. teichmuelleri* (Hammann and Leone, 1997), *V. nivalis* (Salter, 1865) (revised by Turvey, 2005) and *V. abnormis* (Li, 1988), all of which have the glabellar width across the basal lobes equal to, or only slightly more than the sagittal glabellar length, and a less drastic forward taper on the glabella. The latter two species are from the Himalayas. *V. nivalis* has a longer border compared with our new material, and the first glabellar furrow appears to be forked at its inner end. *V. abnormis* appears to be similar, but the material is not good. The Rann Formation material compares closely with *V. teichmuelleri* from the Caradoc Punta Serpeddi Formation of Sardinia, notably in having a relatively gently tapering glabella, simple, unforked glabellar furrows and cranidial border about one-third the length of the glabellar behind. Eye position is similar, and there is a small median dimple in the front of the glabella which can be matched in the Sardinian and Rann material. The Sardinian material is somewhat distorted, particularly the pygidia, and this may partly account for a small difference from the Rann material. There is clearly a fifth pair of pygidial pleural ribs in the latter, but the specimens illustrated by Hammann and Leone apparently show no more than four well-developed pygidial pleural ribs; however their specimen (ibid. 1997, pl. 29, fig. 6) shows a weakly developed fifth pair and it seems unwise to make much of this distinction. Eight, possibly nine axial rings are developed on the funnel shaped pygidial axes of both collections. The similarities between the Rann and Sardinian material are considered significant enough to recognise the same species.

**Genus Deanaspis Hughes et al., 1975**

**Type species.** *Cryptolithus? bedinanensis* Dean, 1967

*Deanaspis goldfussii seftenbergii* (Hawle and Corda, 1847) (Plate 6, Figs 1–5)

**Occurrence:** Rann Formation, Upper Member

**Material:** Cranidia, NHMUK PI It 28723, 28725, 28727; lower lamellae, NHMUK PI It 28724; pygidium, NHMUK PI It 28726.

**Remarks:** The type species of this trinucleid genus was refigured by Hughes et al. (1975, figs 100–101). Although generally similar to the species from the Rann Formation it differs in three respects: 1. It lacks a very prominent inflated girder list that is a notable feature of the present material, 2. It lacks an occipital spine, and 3. On the lower lamella it has fewer extra pits inside the fourth arc. These assuredly add up to a specific difference. Shaw (1995) revised trinucleid species from the Upper Ordovician of the Czech Republic, including *Deanaspis goldfussii* (Barrande, 1846), the senior name in the genus. *D. goldfussii* is very like our new material, and one specimen figured by Shaw (his fig. 13.5) has an extremely prominent girder list. This particular specimen is the holotype of *Trinculeus seftenbergii* Hawle and Corda, 1847 from the Vinice Formation of upper Caradocian age. Like the Rann material it has 23–24 pits in the I1 arc, and the right hand side of the specimen figured shows a similar number of additional pits on the inner part of the upper lamella. However, Shaw (1995) synonymised this and other previously named species with *D. goldfussii* taking a broad view of that species and thereby extending its stratigraphic range throughout the Caradocian. Hammann and Leone (1997) subsequently described *D. goldfussii fluminensis* from Sardinia, and one of their specimens (their pl. 25 fig. 10) has a similar fringe with inflated girder list to the Rann specimens. They also attributed a pygidium to this subspecies that shows subdued dorsal furrows like our material. Since the new material from the Rann Formation seems to be so similar to the type of *seftenbergii* we have adopted the approach of Hammann and Leone and recognised it here as a subspecies of *A. goldfussii*, since this is a senior name to *fluminensis*. Both also have occipital spines. Shaw (1995) did not illustrate a lower lamella of *D. goldfussii* (sensu lato) from the Vinice Formation, and the lower lamella from the Letná Formation that he used to illustrate this feature (his fig. 13.8) does not have an inflated girder like the Rann specimen herein. Further research may show either that these features are variable, or that they indeed merit taxonomic recognition.
Genus *Dreyfussina* Hupé in Choubert et al., 1956  
*Type species.* *Dalmania exophtalma*, Dreyfuss, 1948  
*Dreyfussina cf. D. taouzensis* (Destombes, 1972)  
(Plate 7, Figs 1–6)

**Occurrence:** Rann Formation, Upper Member

**Material:** Cranidia, NHMUK PI It 28728, 28729, 28730, 28731; pygidia, NHMUK PI It 28732, 28733.

**Remarks:** None of our material preserves the dorsal surface well. Important features of the species illustrated here are the complete effacement of the glabellar furrows anterior to S1 and the somewhat triangular pygidium with an indistinct border. Destombes (1972) placed the species with which our material is compared in *Klouckéka*. Hammann (1974) attributed material from Spain to the same species but placed it with question in the Scoto-American genus *Scotiella*. This seems improbable since there are no other genera in common between Morocco and Laurentian faunas, which were at very different palaeolatitudes in the Ordovician, we prefer to regard the species as belonging to *Dreyfussina*, some species of which have a similarly effaced glabella, in spite of the development of a well-defined pygidial border in some species which have been attributed to that genus. Specimens from the Rann Formation have slightly larger basal glabellar lobes compared with Destombes’ type specimens, but some illustrated by Hammann (1974, fig. 135) are more similar in this regard. On the other hand, the longer glabella of the most complete new cranidium is more like the type and less like Hammann’s attributed material. The type material also has a more tapering pygidial axis than our specimens; however Hammann’s (1974, fig. 141) looks very similar to our material. If Hammann (1974) is correct in identifying the Spanish material with the Moroccan *D. taouzensis* then we can apply the same name to our material. However, the Spanish material shows up to four axial rings on the pygidium, whereas two only are preserved on our material; it is possible that the internal mould preservation could well account for this. Two species described from late Caradocian strata from Sardinia by Hammann and Leone (2007) invite comparison with the material from the UAE. Specimens they attributed to the type species of *Dreyfussina, D. exophtalma*, include pygidia identical with ours (their plate 39, fig. 6e) in having only two deeply defined pleural ribs, but the glabella of the Sardinian material appears to have narrower (exsag.) basal lobes. A species Hammann and Leone (2007) named *Klouckéka cf. phillipsi* (Barrande) is also very similar to our material, although its fixed cheeks are apparently narrower (tr.) and its pygidium has fewer pleural furrows. Given the differences in preservation between all the species mentioned here it is difficult to be particularly confident in the delimitations of the species. In sum, it seems best to maintain an element of caution in naming the species herein.

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### Appendix A: List of locations

| Occurrence                      | Horizon | Latitude     | Longitude     | Location                          |
|--------------------------------|---------|--------------|---------------|-----------------------------------|
| Fauna up slope                 | Rann    | 25°25'28.36"| 56°4'2.82"    | Jabal Ar Rann                     |
| Upper trilobite fauna          | Rann    | 25°25'32.75"| 56°4'8.15"    | D. Jabal Ar Rann                  |
| Chitinozoan fauna              | Rann    | 25°25'32.75"| 56°4'8.15"    | Probable location, Jebel Ar Rann  |
| Conodont fauna                 | Ayim    | 25°25'27.90"| 56°4'10.35"   | C. Jabal Ar Rann                  |
| Conodont fauna                 | Ayim    | 25°25'59.35"| 56°3'58.75"   | Tributary Wadi Ayim               |
| Conodont fauna                 | Ayim    | 25°27'59.69"| 56°6'35.88"   | Wadi Kub                         |
| Conodont fauna                 | Ayim    | 25°28'56.84"| 56°8'13.92"   | Sha’biyyat Al Yaruf, Goodenough et al. (2006) |
| Top L Rann bed                 | Rann    | 25°25'27.26"| 56°4'19.48"   | Jabal Ar Rann                     |
| Conodont fauna                 | Rann    | 25°25'30.50"| 56°4'5.15"    | Jabal Ar Rann                     |
| Lower trilobite fauna          | Rann    | 25°25'30.95"| 56°4'4.00"    | B. Jabal Ar Rann                  |
| Graptolite, acritarch assemblage | Rann | 25°25'33.35"| 56°3'55.25"   | A. Quarry in shales, Rickards et al. (2010) |

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