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THE FIRST RECORD OF CAMBRIAN CONODONTS FROM THE HUQF-HAUSHI OUTCROPS, OMAN, ARABIAN PENINSULA

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Abstract. Outcrops of Cambrian sediments of the uppermost Miqrat Formation, the Al Bashair Formation and the basal Barik Formation were sampled for conodont and palynomorph studies. The units are part of the Palaeozoic Haima Supergroup, exposed in the Huqf-Haushi area in central eastern Oman, Arabian Peninsula. Palynomorphs were absent but conodont samples yielded a small conodont fauna. The presence of *Muellerodus*? *erectus* allows the recognition of the *Muellerodus*? *erectus* Zone established for North China (late Paibian – early Jiangshanian), in accordance with previous reports on the trilobite fauna from the same interval.

Introduction

The Cambrian to lower Silurian Haima Supergroup is essentially composed of siliciclastic rocks. Part of the Haima Supergroup crops out in central eastern Oman, whereas the whole sedimentary succession of this supergroup is known from the subsurface of the Ghaba and Fahud salt basins and neighbouring areas (Milson et al. 1996; Droste 1997; Pollastro 1999) (Fig. 1A). The Haima Supergroup is composed of three groups and ten formations (Fig. 2A) and it unconformably overlies the Ediacaran-Cambrian carbonates and evaporites of the Ara Group and the clastics of the Nimr Group (Fig. 2A). The combination of detailed sedimentological studies of outcrops and subsurface data generated by the Petroleum Development Oman (PDO) makes the Haima Supergroup an important segment in the lower Palaeozoic succession on the Arabian Peninsula.

The base of the Supergroup is composed of Cambrian terrigenous sediments (Amin and Miqrat formations of the Mahattta Humaid Group) that upwards grade into the shallow marine Al Bashair Formation (Forbes et al. 2010). Above, several sequences of marine to fluvial/deltaic deposits define, from base to top, the Barik, Mabrouk, Barakat and Ghudun formations of the Cambrian – Ordovician Andam Group (Forbes et al. 2010, see Fig. 2A). The Haima Supergroup is mainly known from the subsurface of Oman, but sediments of the Amin to Barik formations interval are exposed in central eastern Oman (Fig. 1). In the Oman mountains, restricted tectonic windows expose the Amdeh Formation which is composed of sandstones, siltstones and shales. The Amdeh Formation is correlated with the Ordovician Ghudun Formation and Saih Nihayda Formation (Lovelock et al. 1981; G. Booth, pers. comm. 2014) known from the subsurface.

Hitherto, correlation between subsurface occurrences of the Al Bashair Formation and outcrops was based on lithostratigraphic comparisons. Tipically, the lower part of the formation contains more limestones and dolostones, while the upper part is more sandy with only a few carbonate beds.

The scope of the present work was to sample the outcropping section in the Huqf-Haushi area (Fig. 1) from the top of the Miqrat Formation, through the whole of the Al Bashair Formation to the basal part of the Barik Formation for palynology and conodont investigations. More precisely, the aim was to obtain two independent biostrati-

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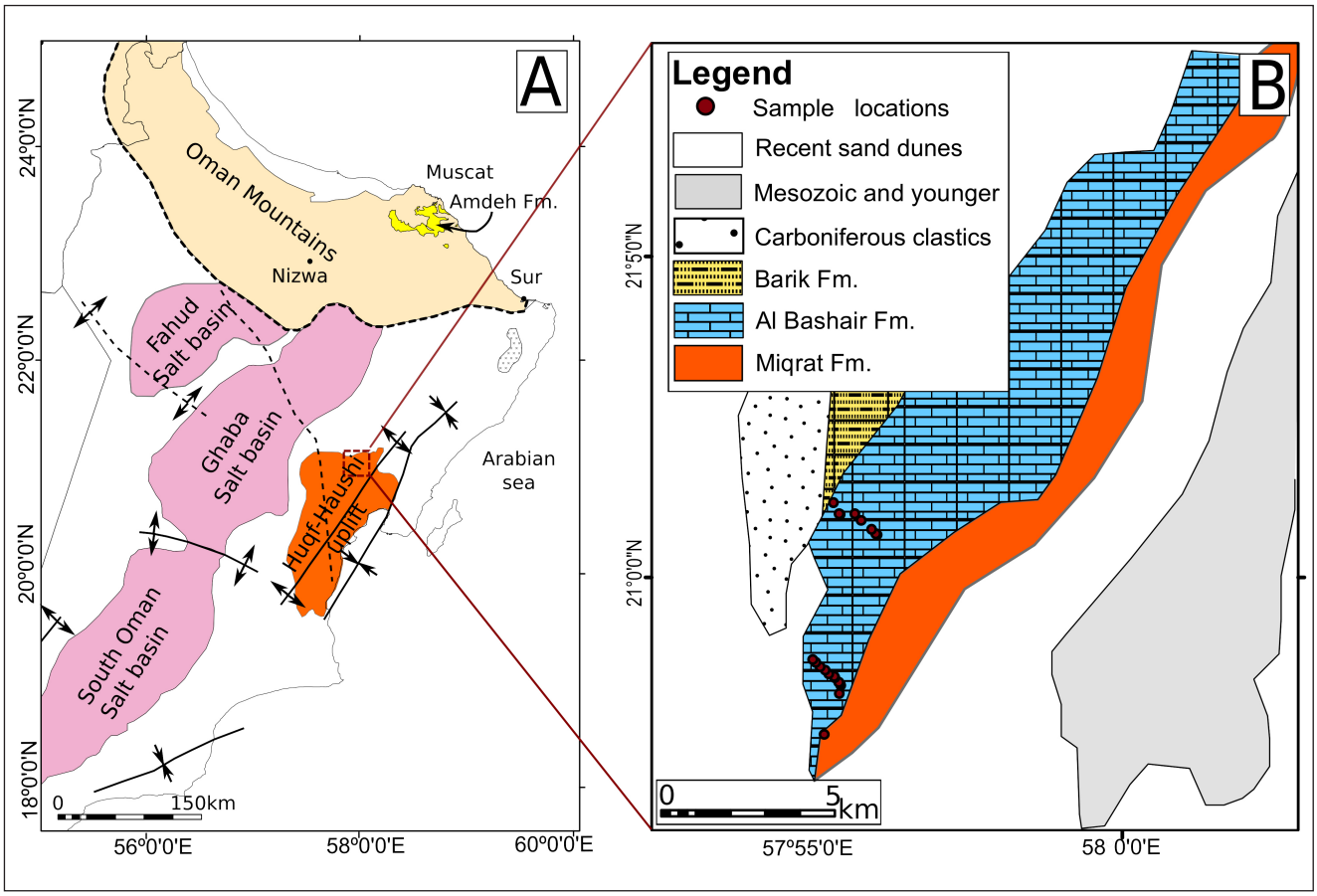


Fig. 1 - A) Geological sketch of Oman with emphasis on the Palaeozoic features (adapted from Droste 1977 and Lovelock et al. 1981); B) simplified geological map of the Huqf area (adapted from Millson et al. 1996) with sample locations.

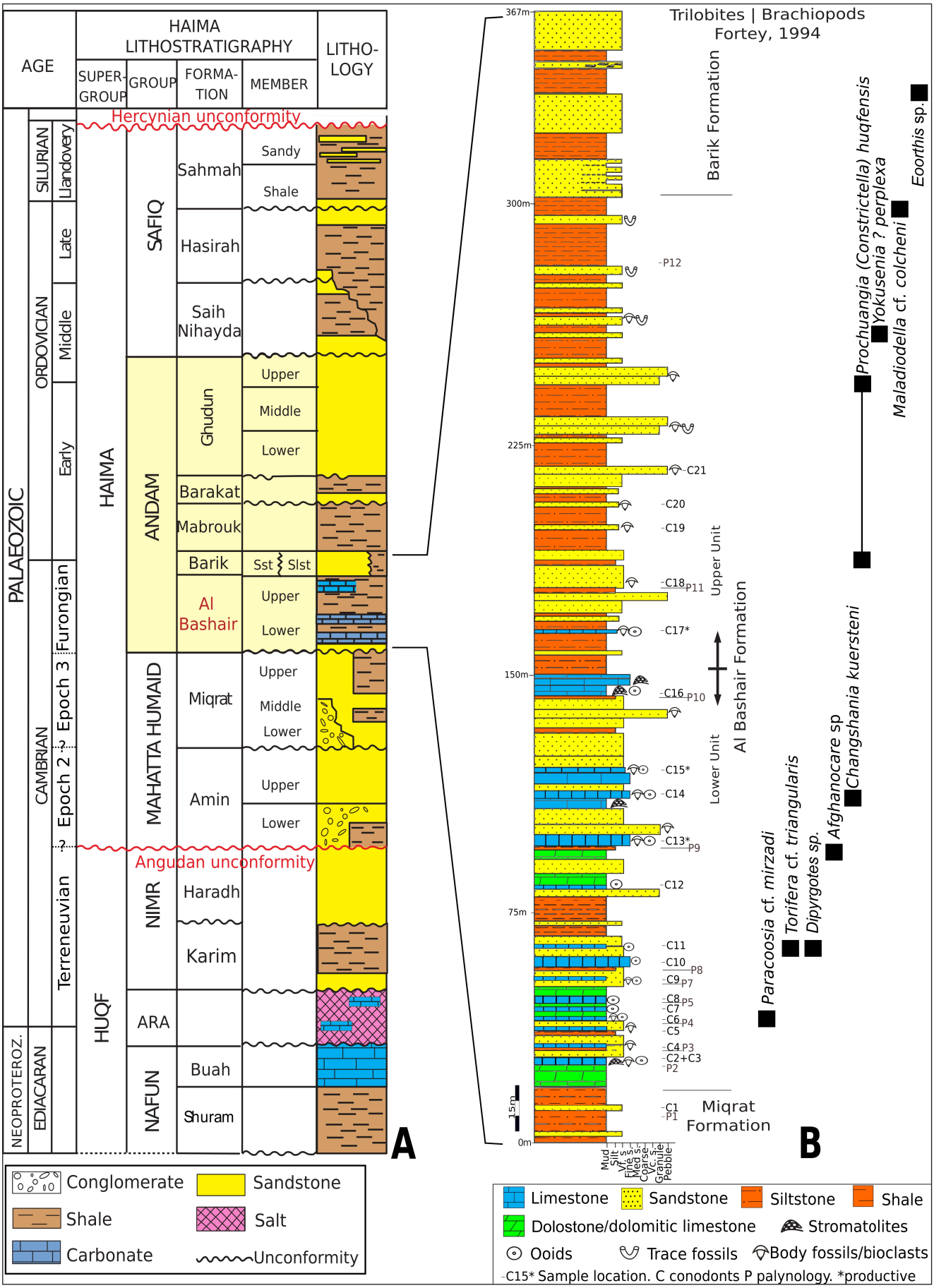
graphic data sets to improve correlation between outcrops and subsurface strata. Unfortunately, the palynological samples were barren, but a small conodont fauna was recorded.

Here, we present the first record of Cambrian conodonts from the Arabian Peninsula extracted from oolithic limestones of the Al Bashair Formation.

Location and lithostratigraphy

The Al Bashair Formation is ubiquitous in the subsurface of Central and North Oman, where it may reach 400 m in thickness (Forbes et al. 2010), and it reaches the surface in the Huqf-Haushi area in central eastern Oman (Fig. 1). It is an important regional hydrocarbon seal. The formation is composed of shales, siltstones, carbonates and sandstones deposited in a marine environment (Forbes et al. 2010; Marjibi et al. 2010; Marjibi 2011). The succession is typically arranged in metre-scale, generally coarsening upward, cycles (Fig. 3), where fine sandstones or silty dolomites and shales are capped by oolithic and stromatolithic limestones (Forbes 2010; Marjibi 2011). Towards the top of the formation, limestone beds become less common and the cycles are usually capped by bioclastic, carbonate-rich sandstones. The base of the cycles is dominated by red-brown mudstones in the upper part of the formation (Fig. 2B). The presence of limestone and dolostone beds is a characteristic feature of the Al Bashair Formation in an essentially siliciclastic Haima Supergroup. They represent the only upper Cambrian carbonate sedimentary rocks in the Arabian Peninsula.

Fig. 2 - A) General stratigraphy of the Haima Supergroup (adapted from Forbes et al. 2010); B) schematic lithological column of the Al Bashair Formation (adapted from Marjibi 2011) with trilobite and brachiopod occurrences from Fortey (1994).


AGE
HAIMA LITHOSTRATIGRAPHY
SUPER-GROUP
GROUP
FORMA-TION
MEMBER
LITHO-LOGY
Hercynian unconformity
PALAEOZOIC
SILURIAN
Llandovery
ORDOVICIAN
Late
Middle
Early
CAMBRIAN
Furongian
Epoch 3
Epoch 2
Terreneuvian
NEOPROTEROZ.
EDIACARAN
HAIMA
HUQF
SAFIQ
ANDAM
MAHATTA HUMAID
NIMR
ARA
NAFUN
Sandy
Shale
Sahmah
Hasirah
Saih Nihayda
Upper
Middle
Lower
Ghudun
Barakat
Mabrouk
Barik
Sst
Slst
Al Bashair
Upper
Lower
Miqrat
Upper
Middle
Lower
Amin
Upper
Lower
Angudan unconformity
Haradh
Karim
Buah
Shuram
A
Conglomerate
Sandstone
Shale
Salt
Carbonate
Unconformity
Trilobites | Brachiopods
Fortey, 1994
Barik Formation
Al Bashair Formation
Upper Unit
Lower Unit
Miqrat Formation
367m
300m
225m
150m
75m
0m
15m
P12
C21
C20
C19
C18
P11
C17*
C16
P10
C15*
C14
C13*
P9
C12
C11
C10
P8
C9
P7
C8
P5
C7
C6
P4
C5
C4
P3
C2+C3
P2
C1
P1
Mud
Silt
Vf. s.
Fine s.
Med. s.
Coarse
Vc. s.
Granule
Pebble
Prochuangia (Constrictella) huqfensis
Yokusenia ? perplexa
Maladiodella cf. colcheni
Eoorthis sp.
Changshania kuersteni
Afghanocare sp
Dipyrgotes sp.
Torifera cf. triangularis
Paracoosia cf. mirzadi
B
Limestone
Sandstone
Siltstone
Shale
Dolostone/dolomitic limestone
Stromatolites
Ooids
Trace fossils
Body fossils/bioclasts
-C15* Sample location. C conodonts P palynology. *productive

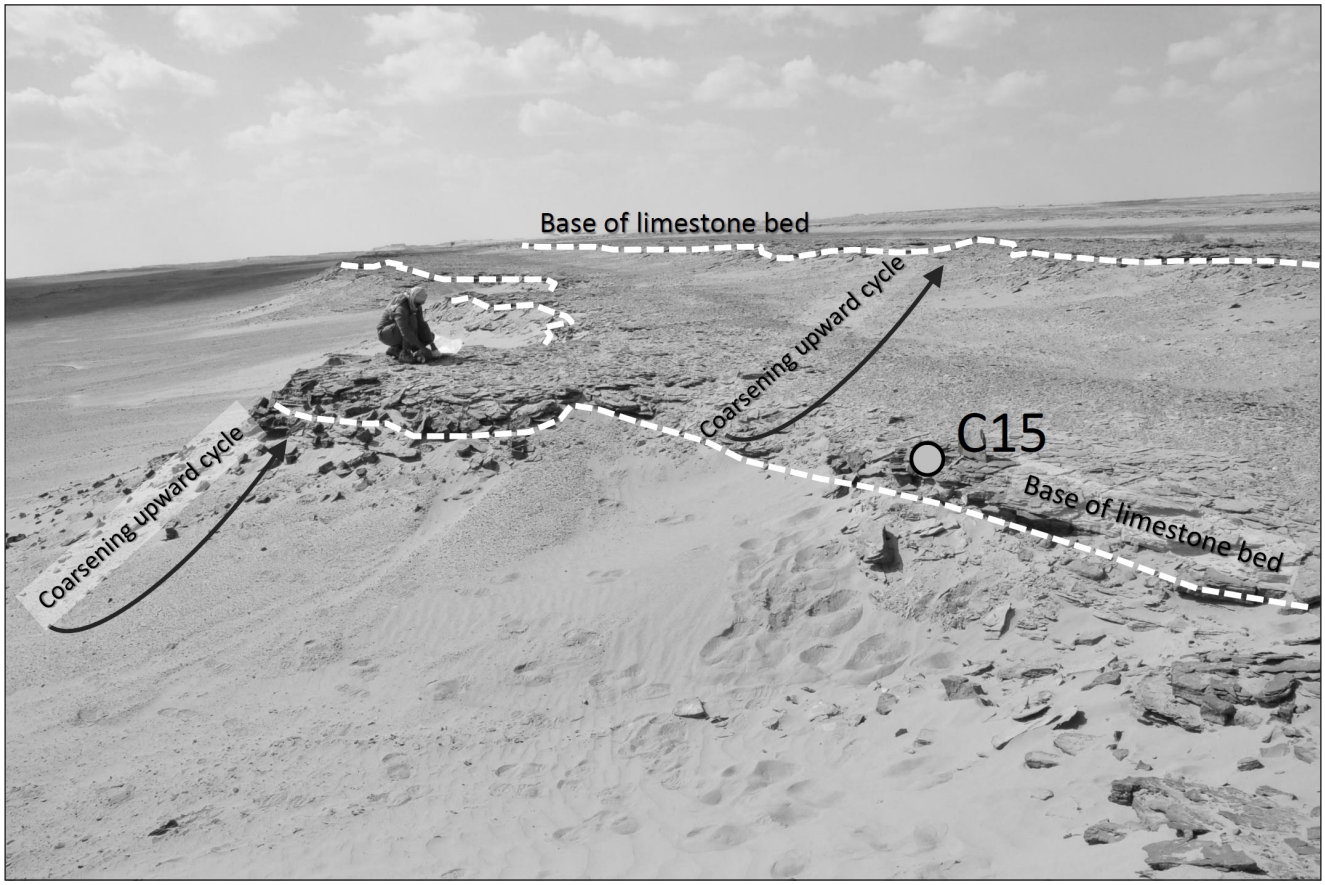


Fig. 3 - Exposure of the Al Bashair Formation showing coarsening upward cycles and position of sample C15.

Previous work

The available paleontological data for the Al Bashair Formation are restricted, but include trilobites from the outcrops and palynomorphs from subsurface sediments.

Fortey (1994) investigated trilobites from the Al Bashair and basal Barik formations in outcrops and recognized three different faunas comparable to the trilobite assemblage succession from North China and other paleo-tropical Gondwana regions. The trilobite faunas indicate a Furongian (late Cambrian) age (Fig. 2B).

Forbes et al. (2010) and Molyneux et al. (2006) investigated the palynostratigraphy of the Al Bashair Formation from subsurface sediments. They erected biozone 1108A for this unit, indicating a Furongian age (late Cambrian). They observed typical Cambrian palynomorphs including *Ninadiacrodium dumontii* (Vanguestaine, 1973), *Vulcanisphaera* spp. and *Cristallinium cambriense* (Slavíková, 1968) among others.

Material and methods

Twelve shale and siltstone samples for palynology from the Al Bashair and uppermost Miqrat formations outcropping in the Huqf-Haushi area were collected (Fig. 1B, Fig. 2). Green and grey shales and siltstones were preferably sampled, occurring just below the limestone or carbonate-rich beds at the top of each metre-scale cycle. Occasionally, trace fossils that are considered indicative of marine sedimentation, are present. In addition, these intervals are frequently the less weathered and best exposed of the cycles. Samples were taken several decimetres below the surface to avoid the weathered part of the outcrop. Palynology samples, approximately 100 g each, were processed at Petroleum Development of Oman, by use of standard methods.

Twenty-one limestone and carbonate-rich sandstone samples were collected for conodonts from the uppermost part of Miqrat Formation and the Al Bashair Formation. The uppermost part of the latter formation did not have a suitable carbonate lithology for extraction of conodonts (Fig. 1B, Fig. 2B). Five of these samples were also processed for palynology. Conodont samples (about 2 to 3 kg each) were processed at the Department of Earth Sciences, Pisa University, by use of standard techniques. No heavy liquid separation was done.

The sampled interval is approximately 300 m thick. Coordinates in WGS84 of the position of the three productive samples, C13, C15 and C17, are 20.97878N and 57.91972E, 21.01147N, and 57.93610E, 21.01488N and 57.93227E respectively.

Figured specimens are deposited in the Department of Earth Science, University of Milan, Italy (MPUM 7200).

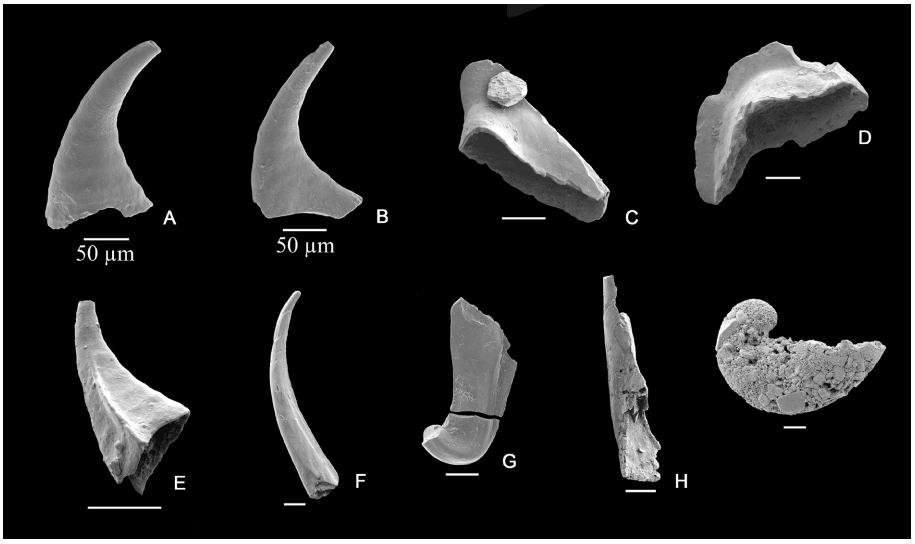


Fig. 4 - SEM pictures of specimens from the Huqf-Haushi section, sample C15. A-B) *Prooneotodus gallatini* (Müller, 1959), lateral view; C-D) *Nogamiconus* sp., lateral view; E) *Muellerodus*? *erectus* Xiang, 1983, lateral view; F) *Phakelodus elongatus* (Zhang, 1983), lateral view; G) *Westergaardodina* sp. posterior view; H) *Furnishina* sp., posterior view; I) mould of a monoplacophoran mollusc.
Scale bar = 100 µm if not specified.

Results

Palynology

The palynology samples provided very little organic residue larger than 15 µm and were barren in terms of palynomorphs. Most samples contained inertinite particles and rare amorphous organic matter. Most likely, the highly oxidative rock weathering that prevails in a desertic, essentially flat area such as the Huqf, destroys organic matter in rocks or leaves inertinite particles as the ones observed.

Conodont fauna

Only samples C13, C15 and C17, which were collected from bioclastic and oolitic limestones from the middle part of the Al Bashair Formation, yielded conodonts. It is worth noting that similar lithologies collected at the base of the formation did not dissolve, possibly due to dolomitization. Samples C18, C20 and C21 did not dissolve. The carbonate-rich sandstones, even though bioclastic, did not prove suitable for conodont extraction. The interval from sample C10 to C15 produced fossiliferous residues containing brachiopod fragments and moulds of monoplacophoran molluscs. Sample C13 contained moulds of trilobite fragments.

The Furongian conodont fauna recorded from samples C13, C15 and C17 includes protoconodonts and paraconodonts (Tab. 1). Samples C13 and C17 yielded only few protoconodonts represented by *Phakelodus elongatus* (Zhang in An et al., 1983). Sample C15 includes several specimens of *Phakelodus elongatus* and a small number of paraconodonts (Fig. 4). The specimens are translucent and white to amber in colour.

The paraconodonts include two specimens of *Prooneotodus gallatini* (Müller, 1959), one specimen of *Muellerodus*? *erectus* Xiang in An et al., 1983 and two specimens of *Nogamiconus* sp. In addition, one fragmentary specimen of *Westergaardodina* sp. and one of *Furnishina* sp. are present (Fig. 4).

Furongian conodonts from the interval below the lowest occurrence of the euconodont *Proconodontus* in Gondwana regions are mostly known from North China (An 1982; An et al. 1983; Bagnoli et al. 2014) and South China (Dong & Bergström 2001; Dong et al. 2004; Qi et al. 2006), where conodont biostratigraphy was established and correlation with trilobite biozones was produced (Fig. 5). Little is known about conodonts from this interval outside China. Lee (2014) introduced the *Prooneotodus rotundatus* Zone for an interval below the first appearance of *Proconodontus* in the Taebaeksan Basin, Korea, but the lack of index conodont taxa (Lee, 2014, p. 40) prevents a precise correlation with the chinese biozones. The only other reports of conodonts from Gondwana from the same

Conodont taxa \ Samples	C13	C15	C17
Furnishina sp.		1	
Muellerodus ? *erectus*		1	
Nogamiconus sp.		2	
Phakelodus elongatus	1	93	6
Prooneotodus gallatini		2	
Westergaardodina sp.		1	
Total	1	100	6

Tab. 1 - Occurrence of conodonts in the Huqf-Haushi section.

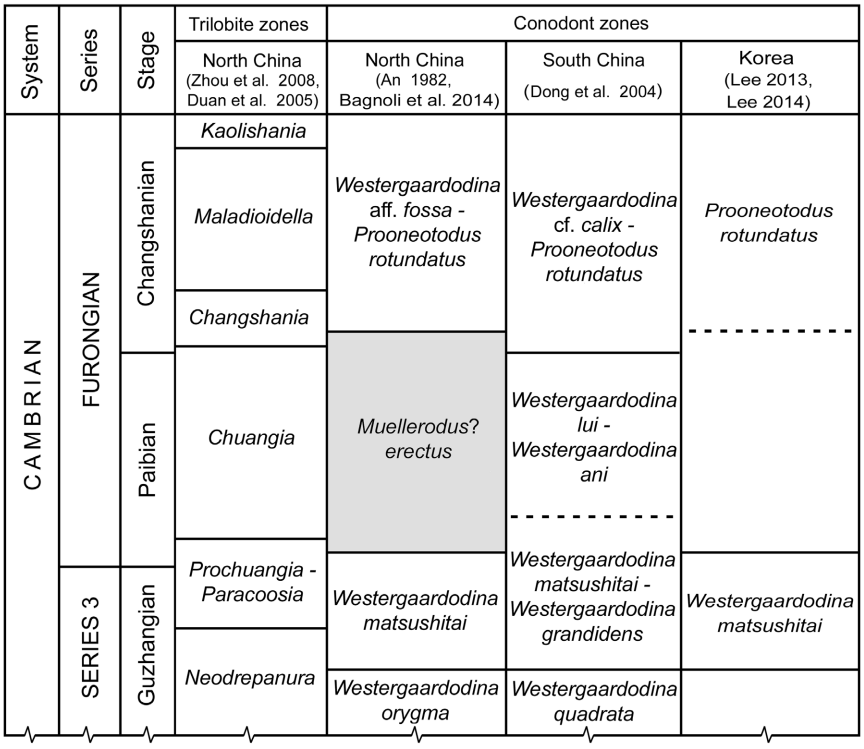


Fig. 5 - Correlation of Furongian (part) conodont zones in North China, South China and Korea with trilobites biozones in North China.

interval are those of Müller (1973) from northern Iran and Ghaderi et al. (2008) from central Iran. Assemblage zones 1 and 2 introduced by Müller (1973) and the *Furnishina-Westergaardodina* Assemblage zone introduced by Ghaderi et al. (2008) include long ranging conodont taxa, thus preventing a precise biostratigraphic assignement.

In spite of the low number of recovered specimens, it is possible to assign the productive interval from the Al Bashair Formation to the *M.*? *erectus* Zone of North China (An 1982), owing to the presence of the eponymous taxon. According to An (1982), the *M.*? *erectus* Zone is defined at the base by the last occurrence of *Westergaardodina matsushitai* Nogami, 1966 and at the top by the last occurrence of *M.*? *erectus*. *Prooneotodus gallatini* first occurs within this zone.

Bagnoli et al. (2014) investigated the Cambrian conodont succession from the Tangwangzhai section in the Shandong Province, North China, and demonstrated that the *M.*? *erectus* conodont Zone correlates with the *Chuangia* and lowermost part of the *Changshania* trilobite zones. In China the *M.*? *erectus* Zone extends from the upper part of the Paibian Stage to the lowermost part of the Jiangshanian Stage (Fig. 5). In the Tangwangzhai section the first occurrence of *Changshania* is just before the last occurrence of *M.*? *erectus*, at a level close to the demise of the SPICE (Steptoan Positive Carbon Isotope Excursion) event (Glumac & Walker 1998; Saltzman et al. 1998). In the Huqf-Haushi outcrop, *Changshania* was reported (Fortey 1994) few meters below sample C15 with *M.? erectus*, thus indicating a latest Paibian – earliest Jiangshanian age (Fig. 2B).

Concluding remarks

The scope of this work was to sample the section from the top of the Miqrat Formation, through the Al Bashair Formation and to the basal part of the Barik Formation for palynomorphs and conodonts to improve the correlation between outcrops and subsurface strata. Unfortunately the negative results from the palynology samples and the limited conodont recovery preclude broader conclusions.

The newly obtained results point to a latest Paibian – earliest Jiangshanian Age of the Furongian Epoch (*Muellerodus*? *erectus* Zone) for the middle part of the Al Bashair Formation. Cambrian conodonts are here reported for the first time from the Arabian Peninsula.

Further investigations on the Al Bashair Formation biostratigraphy and the correlation of outcrop and subsurface sequences are dependent on the availability of suitable lithologies for both palynology and conodonts, and especially non-weathered samples. For this purpose, shallow cores in the Huqf-Haushi outcrop area seem a reasonable option.

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References

An T.X. (1982) - Study of the Cambrian conodonts from north and northeastern China. *Sci. Rep. Inst. Geosci., Univ. Tsukuba,* Set. B, 3: 113-159.

An T.X., Zhang F., Xiang W.D. Zhang, Y.Q. Xu W.H., Zhang H.J., Jiang D.B., Yang C.S., Lin L.D., Cui Z.T. & Yang X.C. (1983) - The Conodonts of North China and adjacent regions. Science Press, Beijing, 223 pp. [in Chinese, with English abstract].

Bagnoli G., Qi Y.P., Zuo J.X., Du S.X., Liu S.C. & Zhang Z.Q. (2014) - Integrated biostratigraphy and carbon isotopes from the Cambrian Tangwangzhai section, North China. *Palaeoworld*, 23: 112-124.

Dong X.P. & Bergström S.M. (2001) - Middle and Upper Cambrian protoconodonts and paraconodonts from Hunan, South China. *Palaeontology*, 44: 949-985.

Dong X.P., Repetski J.E. & Bergström S.M. (2004) - Conodont biostratigraphy of the Middle Cambrian through Lowermost Ordovician in Hunan, South China. *Acta geol. Sinica*, 78: 1185-1206.

Droste H.H.J. (1997) - Stratigraphy of the Lower Paleozoic Haima Supergroup of Oman: *GeoArabia*, 2: 419-492.

Duan J.Y., An S.L., Liu P.J., Peng X.D. & Zhang L.Q. (2005) - The Cambrian Stratigraphy, Fauna and Palaeogeography in Eastern part of North China Plate. Yayuan Publishing Company, Hong Kong, 255 pp. [in Chinese, with English abstract].

Forbes G.A., Jansen H.S.M. & Schreurs J. (2010) - Lexicon of Oman subsurface stratigraphy. *GeoArabia* Spec. Publ., 5: 371 pp., Gulf PetroLink, Bahrain.

Fortey R. (1994) - Late Cambrian Trilobites from the Sultanate of Oman. *N. Jb. Geol. Paläont. Abh.*, 194: 25-53.

Ghaderi A., Aghanabati A., Hamdi B. & Miller J.F. (2008) - Biostratigraphy of the First and Second Members of the Type Section of the Shirgesht Formation in North of Tabas with Special Emphasis on Conodonts. *Geosciences*, 17: 150-163 [in Persian, with English abstract].

Glumac B. & Walker K.R. (1998) - A late Cambrian positive carbon excursion in southern Appalachians: relation to biostratigraphy, sequence stratigraphy, environment of deposition and diagenesis. *J. Sediment. Res.*, 88: 1212-1222.

Lee B.-S. (2013) - Middle Cambrian (Upper Series 3) Protoconodonts and Paraconodonts from the Machari Formation at Eodungol Section, Yeongwol, Korea. *J. Earth Sci.*, 24: 157-169.

Lee B.-S. (2014) - Conodonts from the Sesong Slate and Hwajeol Formation (Guzhangian to Furongian) in the Taebaeksan Basin, Korea. *Acta geol. Sinica*, 88: 35-45.

Lovelock P.E.R., Potter T.L., Walsworth-Bell E.B. & Weimer W.M. (1981) - Ordovician rocks in the Oman Mountains: the Amdeh Formation. *Geol. en Mijnb.*, 60: 487-495.

Marjibi S., North C.P. & Neilson J. E. (2010) - "Intra-Al Bashair Boundary" (Late Cambrian, Oman): is it a Maximum Flooding Surface or a Sequence Boundary? 9th Middle East Geosciences Conference, GEO 2010. Manama, Bahrain. *GeoArabia,* Abs. part 1, 16 (1)1: 155-156.

Marjibi S. (2011) - Unravelling the depositional environments within the lower Andam Formation (Al Bashair Member, Late Cambrian) of north-central Oman. Unpublished PhD thesis, University of Aberdeen, United Kingdom, 385 pp.

Millson J.A., Mercadier C.G.L., Livera S.E. & Peters J.M. (1996) - The Lower Palaeozoic of Oman and its context in the evolution of a Gondwanan continental margin. *J. Geol. Soc.*, 153: 213-230.

Molyneux S.G., Osterloff P., Penney R. & Spaak P. (2006) - Biostratigraphy of the lower Paleozoic Haima Supergroup, Oman; its application in sequence stratigraphy and hydrocarbon exploration. *GeoArabia*, 11: 17-48.

Müller K.J. (1959) - Kambrische Conodonten. *Z. deutsch. geol. Ges.*, 111: 434-485.

Müller K.J. (1973) - Late Cambrian and Early Ordovician Conodonts from Northern Iran. *Geol. Surv. Iran Rep.,* 30: 1-77.

Nogami Y. (1966) - Kambrische conodonten von China. Teil 1. Conodonten aus den oberkambrischen Kushan-Schichten. *Mem. College Sci., Univ, Kyoto,* Ser. B, 32: 351-367.

Pollastro R.M. (1999) - Ghaba Salt Basin Province and Fahud Salt Basin Province, Oman - Geological Overview and Total Petroleum Systems. *U.S. geol. Surv. Bull.,* 2167: 41 pp.

Saltzman M.R., Runnegar B. & Lohmann K.C. (1998) - Carbon isotope stratigraphy of Upper Cambrian (Steptoan Stage) sequences of the eastern Great Basin: record of a global oceanographic event. *Bull. geol. Soc. Amer.*, 110: 285-297.

Qi Y.P., Bagnoli G. & Wang Z.H. (2006) - Cambrian conodonts across the pre-Furongian to Furongian interval in the GSSP section at Paibi, Hunan, South China. *Riv. It. Paleont. Strat.*, 112: 177-190.

Slavíková K. (1968) - New finds of acritarchs in the Middle Cambrian of the Barrandian (Czechoslovakia). V*estn. ústred. Ústavu geol.*, 43: 199-205.

Vanguestaine M. (1973) - New acritarchs from the Upper Cambrian of Belgium. Proceedings of the Third International Palynological Conference, Novosibirsk, 1971: 28-31. Akademiya Nauk, SSSR, Geologicheskii Institut, Moscow.

Zhou Z.Y., Zhen Y.Y., Peng S.C. & Zhu X.J. (2008) - Notes on Cambrian trilobite biogeography of China. *Acta palaeont. Sinica,* 47: 385-392 [in Chinese, with English abstract].