Al HAJAR

25th edition | August 2019

Explore Your Surroundings

INSIDE THIS ISSUE

FROM THE EDITOR

Dear All,

Since the first issue of Al Hajar magazine was published, many articles and papers were written to share the geoscientific knowledge with GSO members and other geo enthusiasts. Here I am taking the role of Geological Society of Oman's Editor as an opportunity to create the common platform where GSO geoscientists may share their inspiring stories, scientific breakthrough and adventures. Together with the editorial board, a creative team was formed that have done an amazing work to deliver this issue in the best format possible. In this issue, five articles were selected from those who took the extra mile to explore their surroundings, to learn about our planet, and to make us aware of our geological heritage so we can conserve it. I hope you enjoy this issue. As the new Editor for Al Hajar magazine, I am aiming to connect the dots across the geoscience community and I look forward to receive your scientific contributions about all amazing projects that you are working on.

Husam Al Rawahi

The Geological Society of Oman GSO was established in April 2001 as a vocational non profitable organizations which aims to advance the geological science in Oman, the development of its members and to promote Oman's unique geological heritage.

PRESIDENT ADDRESS

Dear members of the Geological Society of Oman,

Allow me to welcome on board the new executive committee of the Geological Society of Oman (GSO). It is a continual success taking over from the previous committees along the years who managed to put our society in front line and closer to the geoscience community in Oman and in the region. In April 2019 the GSO completed 18 years from its establishment back in 2001; started with few members and now this figure increased dramatically. Our goal is to continue this success and strengthen the communication with all geoscientists & petroleum engineers in Oman and the region, also, to cater for whomever interested to add a value in this society and get the benefit of accessing extraordinary events, technical talks, field trips across Oman, and many other activities of knowledge sharing.

In 2019, we are looking forward to provide a rich technical program from hosting topics related to geoscience, geo-tourism, mining, petroleum engineering, and petroleum economics; to field trips across Oman to serve the need of our young geologist as well as the professionals who are conducting researches related to the geological history of Oman.

The Geological Society of Oman is moving forward on controlled bases and solid grounding. It is now flourishing in terms of sitting up researches and supporting government firms in their development plans in in various sectors in Oman including Geo-Tourism and Mining where the society is proud to provide consultations and steer in some of the business related to geology & petroleum Geology projects to private sectors. We are proud of our Omanis professionals in many areas who offered to stand in hand with the society enriching its quality work and marking our name among other technical firms and trusted regime as a hub for establishing technical achievements and publishing technical books to reach all levels whom are interested in geoscience and petroleum engineering.

Our students, on the other hand, has a special value in the society as they are regarded the next generation who will take over the oil and gas sectors forward; learning from present and past superiors and professional communities.

With that I conclude that the GSO will introduce an enrich technical program for this year and the interesting field trips that should have an added value to our members and young professionals all the time. and I hope it can open the channel to enrich our understanding and commuting new studies progressed in Oman

Thank you,

Elias Suleiman Al-Kharusi

President of the Geological Society of Oman

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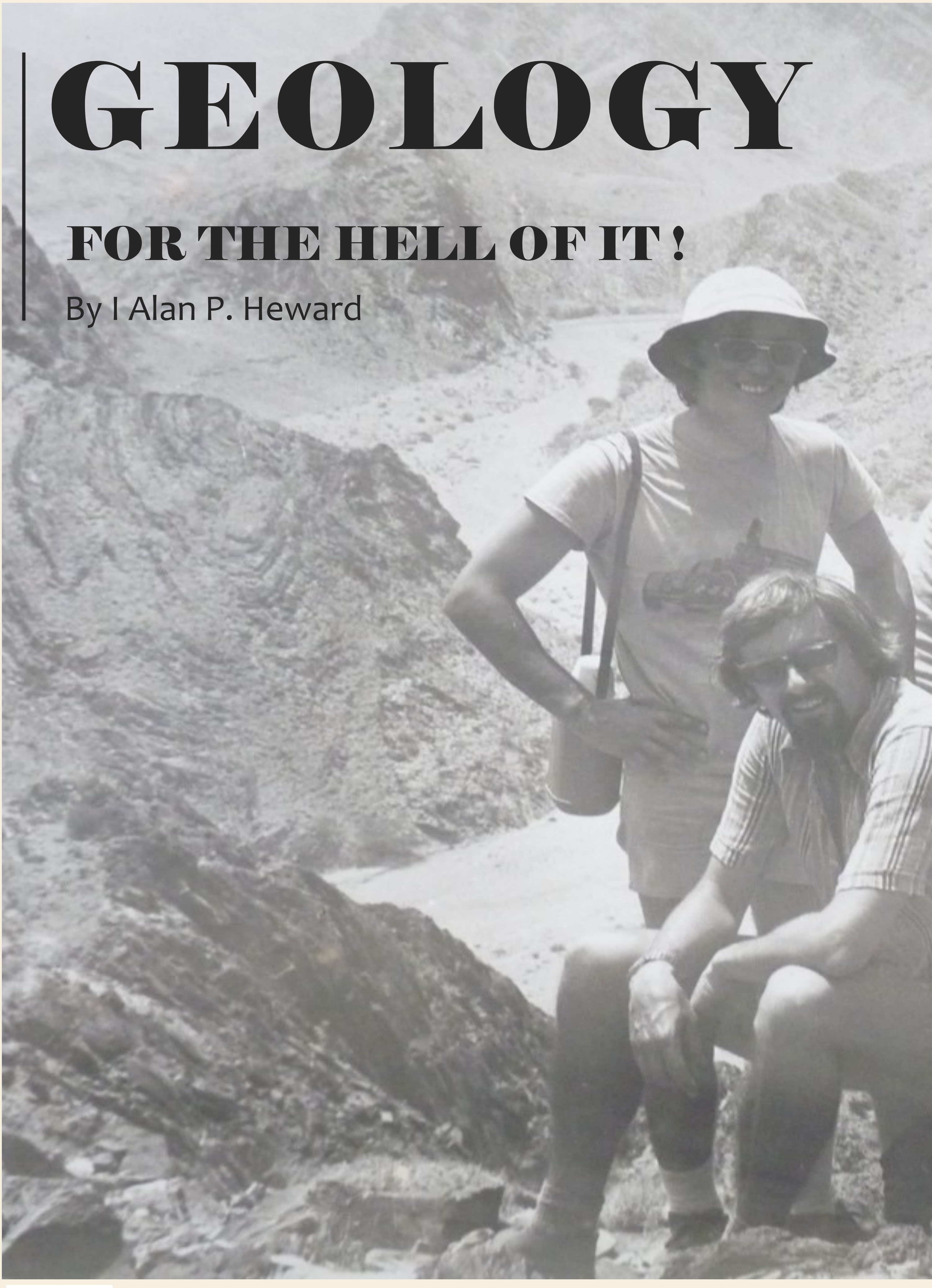
Thank you members

Without your commitment and contribution to the Geological Society of Oman, we wouldn't be able to achieve our goals to spread the knowledge of Oman Geo-science or help prepare the next generation of geoscientist in Oman

Thank you for your time, talent and expertise that you contribute to the GSO. Lets keep this momentum and lets connect the dots among us to protect and illuminate our geology to the world.


سلطنة



GEOLOGY

FOR THE HELL OF IT !

By I Alan P. Heward

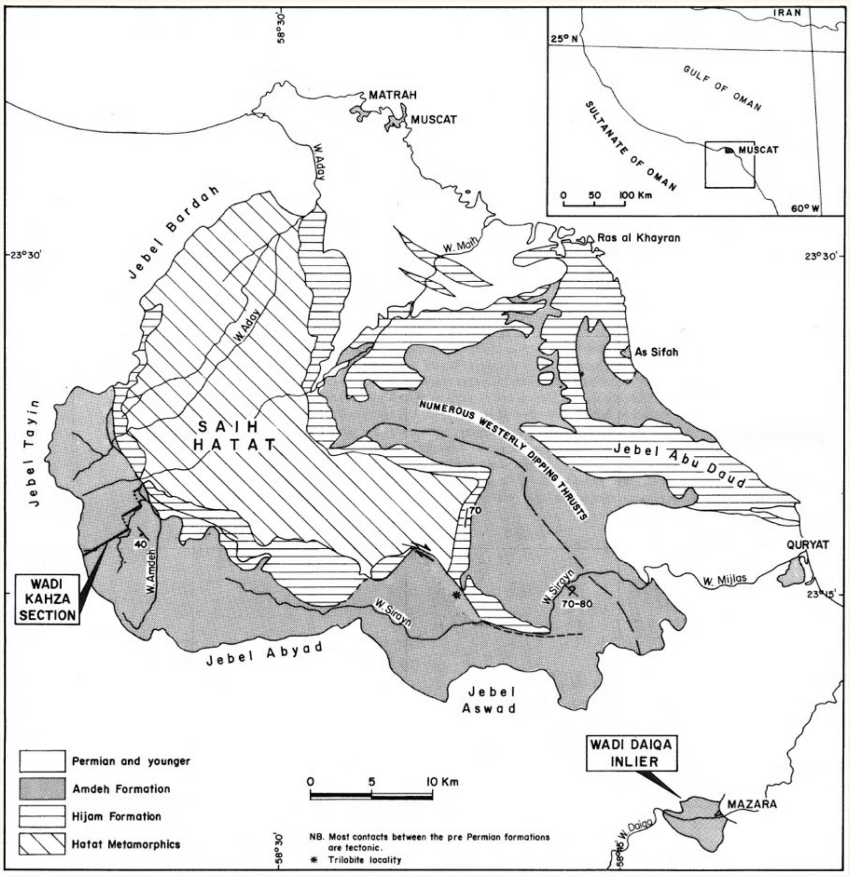
The Amdeh Formation was first formally defined by Ken Glennie and colleagues in their mapping of the Oman Mountains[1]. Several years later, a group of geologists from Petroleum Development Oman (PDO) logged a type section of 3400 m through the formation during their weekends. Not only did they log and sample the section, they drew up their log at 1:1000 scale and published their findings in *Geologie en Mijnbouw* (Lovelock et al. 1981). During discussions on a Geological Society of Oman field trip in February 2016, we wondered at the motivation for undertaking this significant undertaking through an apparently unpromising pile of Armorican-type quartzite and cleaved shales.

In 1978, the age of the Amdeh Formation was not known and considered possibly Late Precambrian-Early Paleozoic[1,3,4]. The formation was thought to overlie the Hatat Schists[3] or be the proximal equivalent of them[1,4]. Outcrops with Ordovician fossils were known from the Northern Oman Mountains[5] and from Qarn Mahatta Humaid (QMH) in Central Oman [4]. In the mid 1970s, PDO, having acquired the Dhofar concession, was busy appraising the Marmul and Amal discoveries, exploring elsewhere in South Oman and recognising that some of the reservoirs were Palaeozoic Clastics of the Haima Group. In Central Oman, a sequence of un-named and apparently un-prospective pre-Carboniferous Palaeozoic Clastics was known from the TD sections of numerous wells.

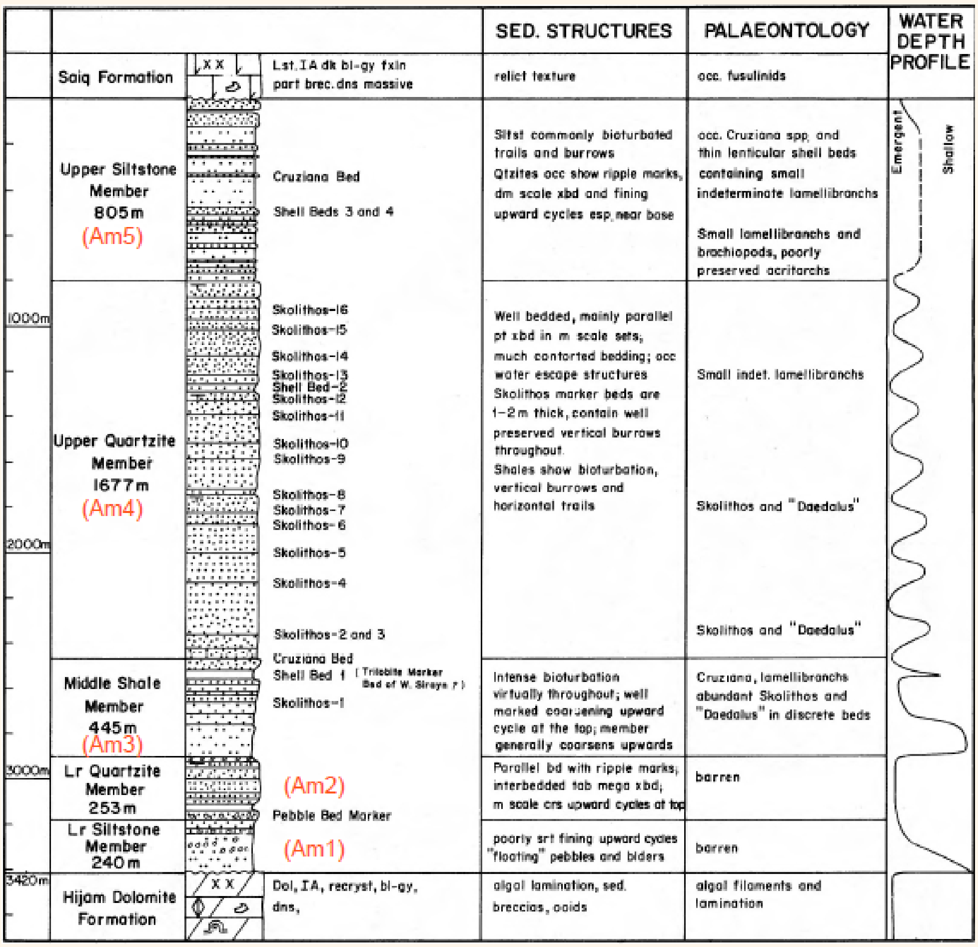
The story of the logging of the Amdeh section is best told by those involved, whom we contacted in 2016. Sadly, two of the main contributors to the fieldwork and paper are no longer with us, Phil Lovelock having passed away in 2008[6] and Brack Walsworth-Bell in 2011. Pete Jeans (PJFJ), Maarten Wiemer (WMW) and Tim Potter (TLP) have kindly provided their recollections.PJFJ- ‘In 1977-78, I recognised that the presence of the Rann Quartzite in the Northern Oman Mountains implied that there was no reason why Palaeozoic Clastics might not be present in the Saih Hatat (I thought that the Jebel Akhdar was well enough known and knew that no candidate section was present below the Base Khuff unconformity (only the Huqf-equivalent sequence)). However, in Saih Hatat there was a thick section of undated clastics below the Base Khuff unconformity, with little or no carbonate, which at the time was thought to be Cambrian or Infra-Cambrian. So, one weekend, Brack, Phil, myself, and Tim (I can't remember whether Maarten was present) drove out to the outcrop (with our kids) and proceeded to browse up and down the sequence. Brack it was who found the first *Cruziana* trail - the evidence that the sequence was, at least in part, Lower Palaeozoic. I left Oman in early 1979 and so played little part in the actual mapping/logging of the outcrops which led to the publication.’

Pete was present on the first day of logging on 2nd December 1978 according to the detail recorded on the 1:1000 log.

WMW- ‘Most of the 3400 m was logged by Brack and I, with Phil participating when he could. Tim was focused on the biostratigraphy. Phil essentially wrote the publication. Once we started measur-



Location map from Lovelock et al. (1981) ▶



The summary type-section of the Amdeh Formation measured in Wadi Khaza (Lovelock et al. 1981). The names of the members were abbreviated to Am1-Am5 by geologists of BRGM when re-mapping the area in the mid 1980s.

ing it also became a challenge to finish it. The motivation, I don't remember that well, other than that Phil, Brack and I liked to go out and "do" geology. At least I was certainly intrigued by the variety of beautiful sedimentary structures and trace fossils. I don't think there was a lot of company support at the time. I worked on the Haima Group stratigraphy, focused on South Oman, even to the extent of doing a heavy mineral study.'

PJFJ- 'In 1978 there was certainly no 'corporate' interest in what we were doing: it was just fun geology and the excitement of finding something new. At the time, the interest in South Oman was in its very early days, whilst in Central Oman the main play was for the Permo-Caboniferous Haushi Group (Gharif and topmost Al Khlata). Below the Haushi Group was an undated section in which most of the wells TD'd called 'Un-named Clastics'. I don't think we had any penetration at the time in Central Oman which proved the Un-named Clastics to be underlain by Huqf/Salt and hence provide an age bracket. In the late-70s South Oman started to take off and hence PDO became very interested in the Haima Group (as Maarten and Tim describe) but this post-dated our 'geology for the hell of it' efforts.'

TLP- 'The Lab was probably less in the loop than team geologists/seismologists so Pete and Maarten probably have a better view on the exploration objectives of the day. It is a great shame that Phil and Brack are no longer with us to help. Certainly, there was beginning to be a focus in PDO on the subsurface Palaeozoic and this supported a couple (at least) of 'working time' field trips to the south and one to Ras Al Khaimah to look at surface expression and find fossil evidence for the ages (those were the days!). I recall the main motivation for me was the excitement of searching for age-significant fossils in a 'challenging' rock succession, in the company of a great bunch of enthusiastic geologists and in an amazingly beautiful environment. I have a photo of the four of us looking surprisingly happy at well over 40°C in the mountains. It was just an excellent way to spend some time at the weekends away from the 'camp', although I'm not sure the respective families would have agreed!'

The 1:1000 log shows that the section was logged in 14 weekend days between 2 December 1978 and 14 September 1979 (either on Thursdays or Fridays). 200-300 m was typically logged in a day by two or three members of the group. Several colleagues also visited the outcrops in Wadi Daiqa in May 1979 and sampled shales that yielded age-indicative microfossils (acritarchs and chitinozoans). Following the visit to Wadi Daiqa, there was a suggestion to measure a section there and attempt to correlate it to Wadi Kahza and with Central Oman wells. This was never followed through. Moulds of bivalve, trilobite and brachiopod shells were collected from shell beds in Wadi Sirayn (Sareen) and identified by various experts at Cambridge and Birmingham Universities. Photographs of trace fossils were sent to Peter Crimes of Liverpool University who commented 'the material you have seen is certainly good stuff' and identified *Cruziana furcifera*, *Cruziana rugosa*, *Phycodes circinatum* and *Daedallus*. The microfossils, fossils and trace fossils were interpreted to indicate an Early to Middle Ordovician age. A field guide to Wadi Kahza was produced in April 1980 which formed a basis for many subsequent PDO field trips[7]. The outcrops of the Rann Formation in Ras Al Khaimah were visited in July 1981, in the context of PDO's growing interest in Cambro-Ordovician sediments in Oman.

Surprisingly little work was carried out on the outcrops of the Amdeh Formation for the next 25 years, despite the closeness of the outcrops to Muscat and the increased significance of Haima reservoirs and seals following the discovery of deep gas and condensate in Central and Northern Oman in the period 1989-present. Recent studies have confirmed the age-equivalence of two of the shaly members of the Amdeh Formation (Am5 and Am3) to Middle and Early Ordovician formations in the subsurface[8,9]. The latter study also explains why acritarchs are only rarely preserved in the formation in Wadi Khaza, due to the temperatures to which the sediments have been exposed during burial (>200°C).

The pioneering efforts of the 'Amdeh colleagues' continue to provide an inspiration for those who have followed in their footsteps.

References:

[1] Glennie, K.W., Boeuf, M.G.A., Hughes Clarke, M.W., Moody-Stuart, M., Pilaar, W.F.H. & Reinhardt, B.M., 1974. *Verhandelingen van het Koninklijke Nederlands geologisch mijnbouwkundig Genootschap* **31**, 423p.

[2] Lovelock, P.E.R., Potter, T.L., Walsworth-Bell, E.B. & Wiemer, W.M., 1981. Ordovician rocks in the Oman Mountains: The Amdeh Formation. *Geologie en Mijnbouw* **60**, 487-95.

[3] Lees, G.M., 1928 The geology and tectonics of Oman and parts of south-eastern Arabia. *Quarterly Journal of the Geological Society of London* **84**, 585-670.

[4] Morton, D.M., 1959. The geology of Oman. *Proceedings 5th World Petroleum Congress* **1**, 277-94.

[5] Hudson, R.G.S., Browne, R.V. & Chatton. M., 1954. The structure and stratigraphy of the Jebel Qamar area, Oman. *Proceedings of the Geological Society of London* **1513**, xcix-civ.

[6] https://www.geolsoc.org.uk/en/About/History/Obituaries%202001%20onwards/Obituaries%202008/Philip%20Edward%20Richter%20Lovelock%201941-2008

[7] Lovelock, P.E.R., Potter, T.L., Walsworth-Bell, E.B. & Wiemer, W.M., 1980. Wadi Khaza Fieldtrip, Saih Hatat-Oman Mountains: The Amdeh Formation, Lower Ordovician. April, 1980.

[8] Heward, A.P., Booth, G.A., Fortey, R.A., Miller, C.G. & Sansom, I.J., 2018. Darriwilian shallow-marine deposits from the Sultanate of Oman, a poorly known portion of the Arabian margin of Gondwana. *Geological Magazine* **155**, 1, 59-84.

[8] Heward, A.P., Miller, C.G. & Booth, G.A., In press. The early Ordovician Middle Shale Member of the Amdeh Formation (Am3) and further evidence of conodont faunas from the Sultanate of Oman. *Geological Magazine*

NATIONAL YOUNG PROFESSIONALS (NYP) COMMITTEE IS A NON-PROFIT ORGANISATION ESTABLISHED IN MAY 2018 UNDER SUPERVISION OF MINISTRY OF OIL AND GAS. THE COMMITTEE WAS OFFICIALLY LAUNCHED ON 18TH OF OCT 2018 UNDER PATRONAGE OF H.E. ENG. SALIM AL AUFI, UNDERSECRETARY OF MINISTRY OF OIL AND GAS.

VISION

SHAPING THE GLOBAL ENERGY FUTURE BY BRINGING TOGETHER THE PASSION AND TALENTS OF INDUSTRY STUDENTS, YOUNG PROFESSIONALS AND EMERGING LEADERS.

MISSION

NYP AIMS TO CHAMPION NEW IDEAS THAT WILL LEAD THE CHANGE, BRIDGNING THE GAP BETWEEN GENERATIONS AND BUILDING REALISTIC PICTURE OF PETROLEUM INDUSTRY WITH ITS CHALLENGES AND OPPORTUNITIES.

VALUES

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- SUSTAINABILITY
- TRANSPARENCY
- PARTICIPATION
- EXCELLENCE

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SEP 2018
NYP PARTICIPATION IN THIRD TOMORROW'S LEADERS SYMPOSIUM IN BELGRADE, SERBIA

APR 2019
PETRO OLYMPICS CONTEST FOR OIL AND GAS COMPANIES

OCT 2018
NYP COMMITTEE LAUNCH EVENT

JAN 2019
SEMINAR OF THE IMPACT OF DIGITAL TRANSFORMATION ON OIL AND GAS INDUSTRY.

JAN 2019
NYP PARTICIPATION IN FOURTH GATHERING OF IRAN OIL INDUSTRY YOUNG PROFESSIONALS

NOV 2018
SEMINAR OF DIRECTIONAL DRILLING AND DRILLING ENGINEERING

COMMITTEE STRUCTURE

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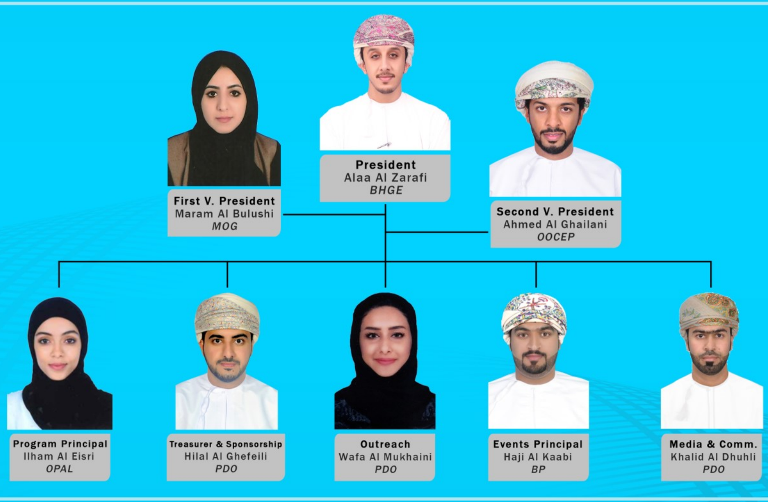

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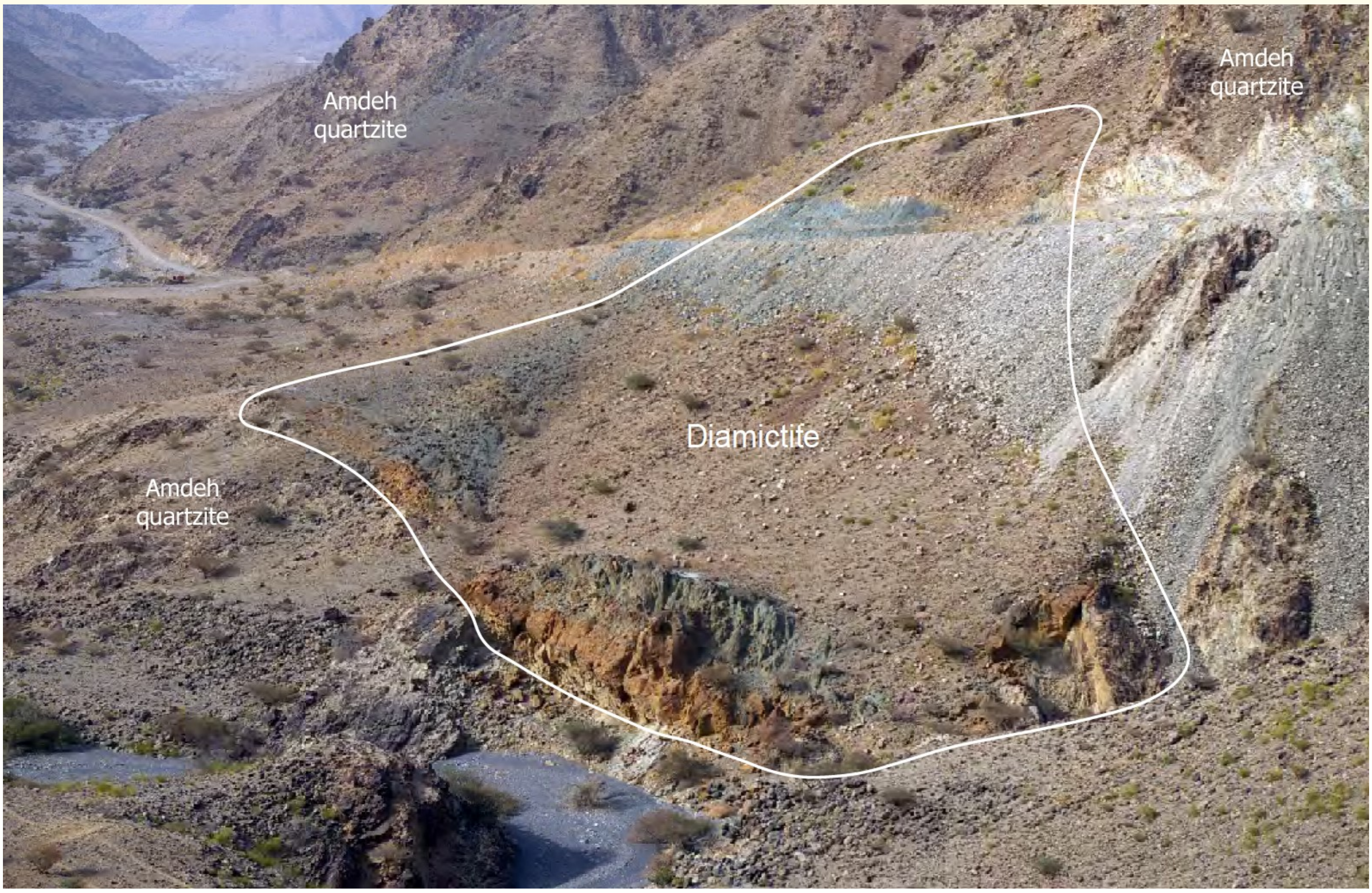
FURTHER OUTCROPS OF DIAMICTITE IN WADI AMDEH:AL KHLATA, MESOZOIC OR CENOZOIC SLOPE DEPOSITS?

By I Alan P. Heward

Two further outcrops of diamictite were found in the headwaters of Wadi Amdeh when examining exposures of the Amdeh Formation in February 2015. The new outcrops occur on the opposite side of the wadi and within a few hundred metres of the main diamictite outcrop that was described by Al-Hajri (2009) and Heward and Penney (2014). The new outcrops occur in depressions on the flank of, and at the crest of, a ridge of Amdeh quartzites. Both outcrops are orange in colour and clast-supported, like the margin of the larger main deposit. Strictly, these are conglomerates, rather than diamictites, but because of the alteration and staining of carbonate clasts they appear to have more matrix than they have. These new deposits have not been examined in detail, just in passing, on the back of looking at the Amdeh Members 4 and 5.

New outcrop 1 is a linear fissure-fill trending 80° and more than 5 m wide . Locally, the conglomerate can be seen to fill open joints and cracks in the underlying quartzite, as occurs around the margins of the main outcrop. The fissure-filling diamictite is overlain by a remnant of bedded alluvial fan conglomerates. New outcrop 2 occurs in a col at the crest of a ridge and it is more than 4 m wide. Blocks of the distinctively coloured diamictite were also seen on the wadi floor beyond, possibly from this outcrop or another undocumented occurrence.



▲ New diamictite outcrop 1 (58°22’57.9” E, 23°14’4.0” N) showing a linear fissure-fill within Amdeh quartzites and apparently overlain by bedded alluvial fan or wadi conglomerates. View to southwest.

Clasts within the diamictite of the new outcrops are less than 50 cm in size, angular to sub-rounded and consist mainly of quartzite and carbonate, with a few rare pebbles of vein quartz. There are no more exotic clasts like granites or volcanics that are typical of the Al Khlata. The quartzite clasts are angular and the carbonate clasts are more rounded. There is no evidence of clast fabric or of bedding. Most of the carbonate clasts are altered to an orange brown mineral assumed to be iron-stained dolomite. The alteration leads to the impression of matrix support for these clasts within the diamictite. A few clasts are rimmed or replaced by what appears to be copper carbonate, probably malachite. Some clasts are fossiliferous or fossils form clasts, like the coral cobble and the fusulinid foraminifera .

As there are palynologically-dated Al Khlata P9 deposits in Wadi Daiqa, it was concluded by Heward and Penney (2014) that the main outcrop in Wadi Amdeh might also be Al Khlata. But the evidence was slim and the location of the deposits within the Amdeh Formation , and not at the top of the sequence between the Amdeh Formation and the Saiq Formation, was a problem.

Annotated Google earth image of the currently known diamictite localities in the headwaters of Wadi Amdeh. Note the linear depression filled by new deposit 1. The image is rotated and north is to the right.

No spores or pollen either could be extracted from the grey matrix of the diamictite in Wadi Amdeh, despite several attempts, and no conodonts were recovered from the fossiliferous carbonate clasts that were sampled. A fusulinid from the matrix discovered by Al Hajri (2009) was identified as probably of the genus *Sphaerulina* of Permian age (Ernst Leven, pers. comm. 2012). No marine fossils have been found in Al Khlata diamictites and fusulinid foraminifera are typical of warm water tropical environments in the Carboniferous and Permian, not of colder high latitudes. Large bivalve-like fossils present in some clasts of the main outcrop resemble megalodontid or *Lithiotis* bivalves that occur in Triassic and Early Jurassic rocks in Oman.

Lithiotis is reported in the lower part of the Sahtan Group that is mapped to occur in high ground within a kilometre or so from the diamictite deposits (Villey et al. 1986).

The form and location of the new outcrops, and the presence again of fusulinids and blocks of coral in the matrix, convince the author that this cluster of diamictite outcrops are almost certainly not Al Khlata glacial deposits. It seems likely that they are some form of terrestrial slope accumulation of Mesozoic, or possibly Cenozoic, age infilling low areas and joints and derived from nearby Amdeh Formation Saiq Formation and younger carbonates. The mineral chlorite was detected in analyses of samples from the main outcrop by Al-Hajri (2009) and may have formed during regional greenschist-facies metamorphism in the Late Cretaceous. Zircon fission-track results indicate palaeo-temperatures exceeding 200°C during the Late Cretaceous in a sample from the Amdeh Member 5 close-by (RH29, Hansman et al., 2017). Alternatively, the chlorite might be detrital derived from metamorphosed Amdeh Formation shales.

The slope deposits are older than bedded alluvial fan conglomerates that probably accumulated and were dissected during wetter periods in the past few hundred thousand years (Blechschmidt et al. 2009).

There are many open questions regarding the origin, age, metamorphism, dolomitisation and minor copper mineralisation of these slope deposits. There are possible implications for the multi-phase uplift of the Saih Hatat dome (Hansman et al., 2017). Do these patches of conglomerate and fissure fills contain terrestrial vertebrate faunas as some fills in the U.K.? (e.g. Whiteside et al., 2016)?. Other localised conglomeratic accumulations, of unknown age, have been mapped in the mountains near Wadi Aday (Mike Searle, pers. comm. 2018) and further study is required.

▲ New diamictite outcrop 2 (58°22’49.7” E, 23°14’4.1” N), a shallow depression in a col on the ridge of Amdeh quartzites. View to northwest. Hammer handle is 28 cm long.

▲ Not strictly a diamictite but a clast-supported conglomerate. The alteration of many of the carbonate clasts to dolomite gives the impression of matrix support. A large fusulinid is circled, as is also a small clast that is mineralised by copper. Coral head inset, a loose cobble-sized clast weathered from the diamictite.

References

Al-Hajri, A.A. 2009. Characterisation of diamictite of Al-Khlata Fm. and Am4 of Amdeh Fm. in Saih Hatat window. *B.Sc. thesis, Sultan Qaboos University* (unpublished).

Blechschmidt, I., A. Matter, F. Preusser and D. Rieke-Zapp 2009. Monsoon triggered formation of Quaternary alluvial megafans in the interior of Oman. Geomorphology **110**, 128-139.

Hansman, R.J., Ring, U., Thompson, S.N., den Brok, B. and Stübner, K. 2017. Late Eocene uplift of the Al Hajar Mountains, Oman, supported by stratigraphy and low-temperature thermochronology. *Tectonics* **36**, 12, 3081-3109.

Heward, A.P. and R.A. Penney 2014. Al Khlata glacial deposits in the Oman Mountains and their implications. In H.R. Rollinson, M.P. Searle, I.A. Abbasi, A. Al-Lazki and M.H. Al Kindi (Eds.) Tectonic Evolution of the Oman Mountains, Geological Society Special Publication No. **392**, 279-301.

Villey, M., Le Métour, J. & De Gramont, X. 1986. *Geological Map of Fanjah, Sheet NF 40-3F, Scale 1:100,000. Explanatory Notes* - Directorate General of Minerals, Oman Ministry of Petroleum and Minerals, 68pp.

Whiteside, D.I., Duffin, C.J., Gill, P.G., Marshall, J.E.A. and Benton, M.J. 2016. The Late Triassic and Early Jurassic fissure faunas from Bristol and South Wales: Stratigraphy and setting. Palaeontologia Polonica **67**, 257–287.

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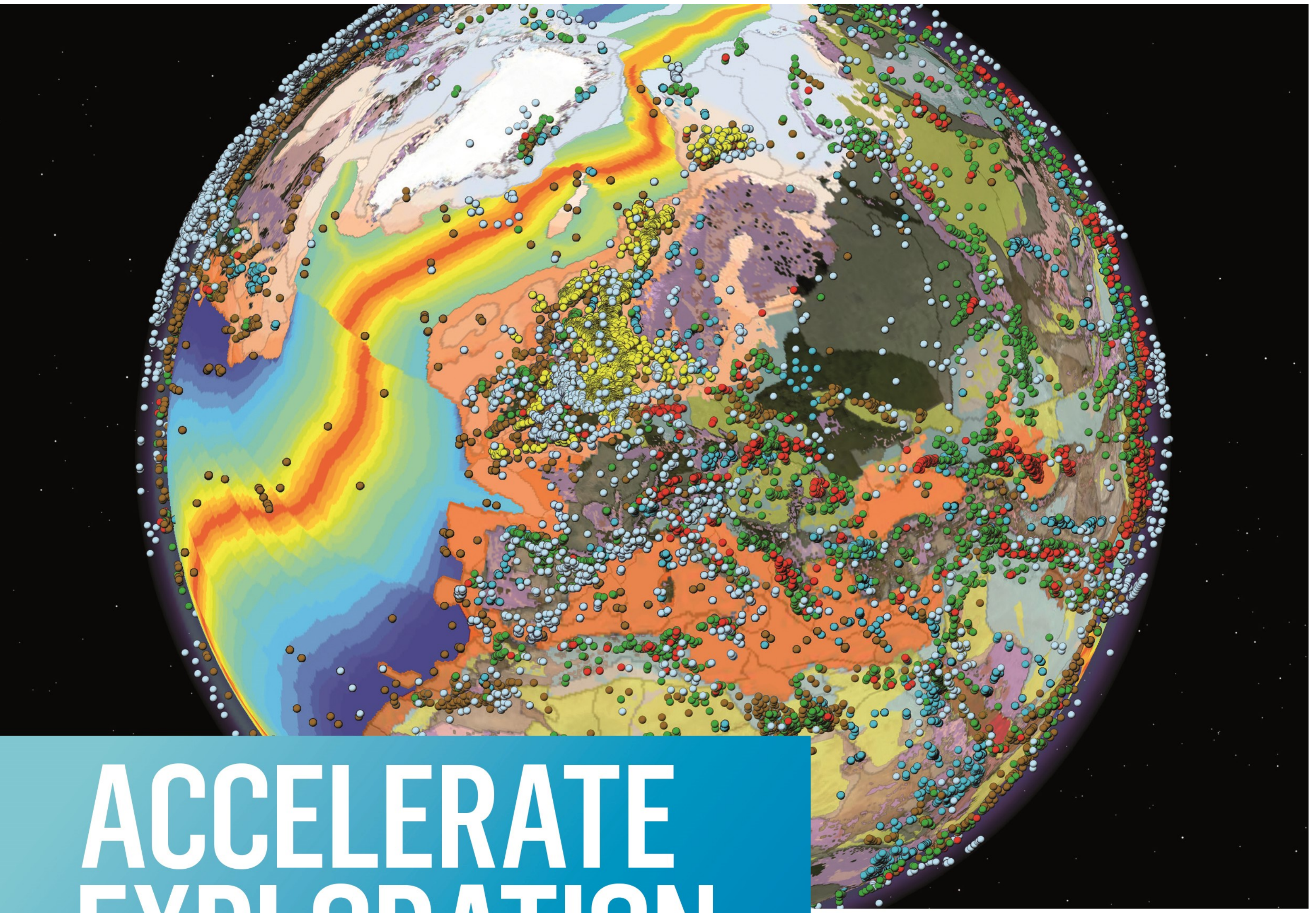


Kittat Al Suwairat Cave in the Wilayat of Al Hamra

By | Mohammed Al Kindi

The Speleological Team of Oman (known previously as the Oman Team for Cave Exploration or OTCE) surveyed yet another major addition to the Oman's geological and natural masterpieces. The Kittat Al Suwairat Cave is located in the Wilayat of Al Hamra. The cave enables long-term researchers to study the properties of rocks and groundwater in the area, in addition to being a destination for potential tourist adventure in Oman.

The exploring and surveying team included the following people: Mohammed Al Kindi, Nasser Al Riyami, Nabeel Al Saqi, Nabeel Al Zakwani, Salim Al Saqri, Mohammed Al Riyami, Khalifa Al Jamoudi, Mohammed Al Jamoudi, Tariq Al Riyami and Said Al Riyami. The team explored and surveyed the cave in two different visits; in Nov 2017 and in Jan 2018. The upper entrance of the cave was accessed previously by two Omani cavers; however, apparently the following drops of the cave and its main path have never been accessed before.

The cave is located about 15 kilometers west of the Al Hota Cave, in the southern flanks of Jabal Shams. The cave's paths run southward parallel to the inclination or dip of the rock units at the foot of the mountain, at a dip angle of about 20 degrees to the south.

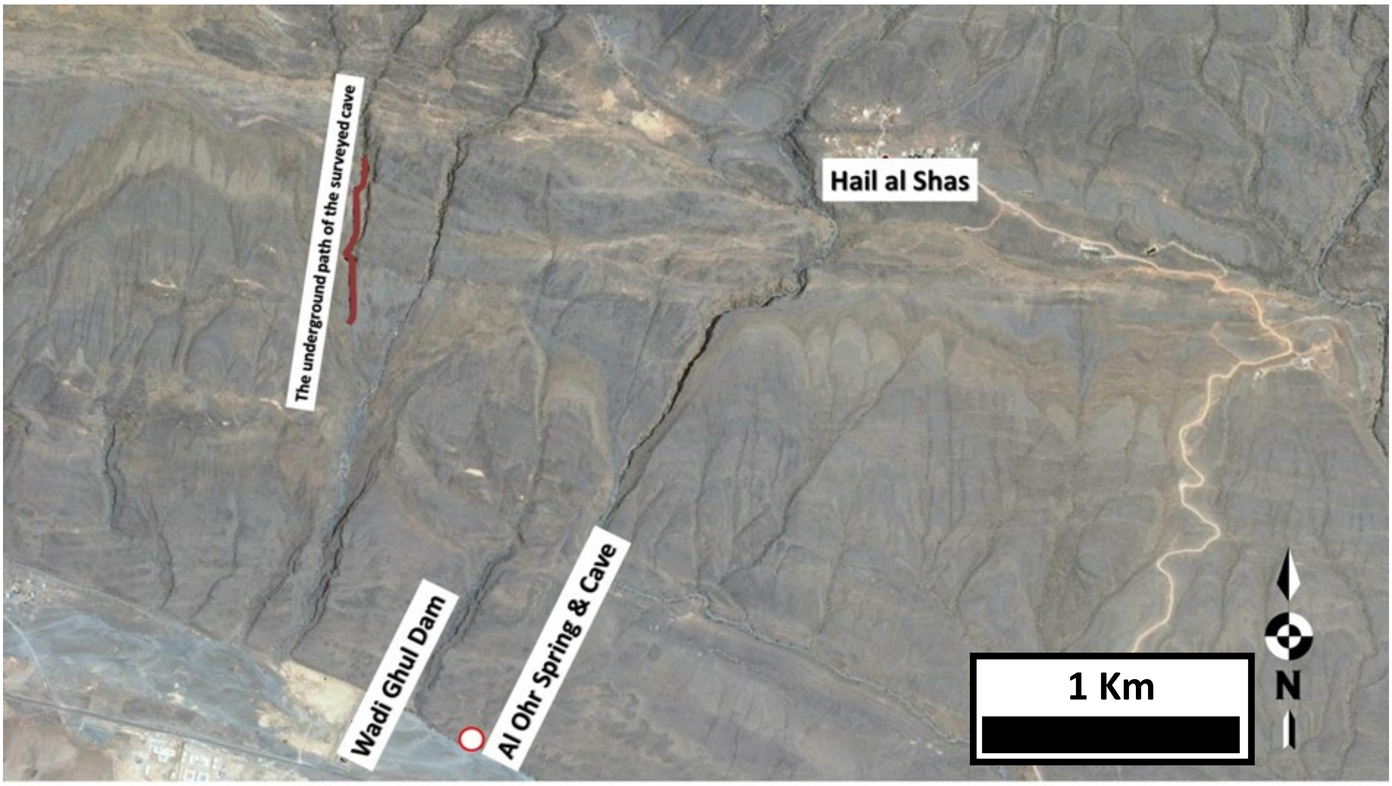
The rocks in the cave are of Cretaceous age. They form the upper thickly bedded sequence of the Natih Formation, which in turn is part of the Mesozoic Carbonate Platform that forms the flank of the Jebel Akhdar Massif.

In general, and particularly in the Jebel Shams area, these shallow marine carbonates are heavily fractured and faulted. Numerous numbers of NW-SE and NE-SW faults and fractures, formed respectively during the Cretaceous and Tertiary times, could be mapped from Satellite images around the area. These structures have clearly supported the formation of many caves in the area. They also in many cases controlled the underground orientations of these cave systems.

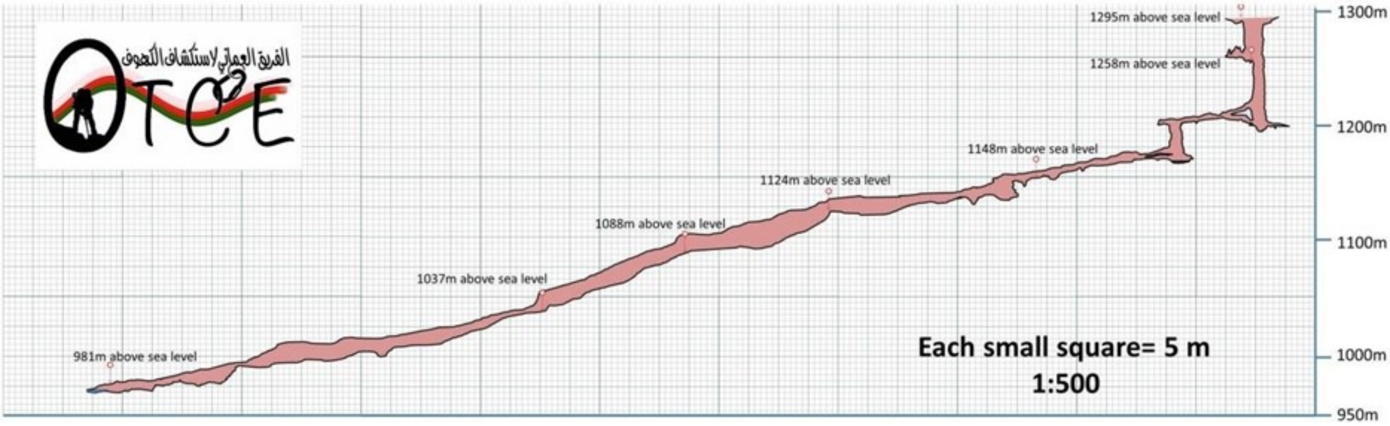
The Speleological Team of Oman has surveyed Al Suwairat Cave since its first descent on the 3rd of November 2017. The survey was completed on the 25th of January 2018. The team waited for this period to complete the survey due to the heavy rainfall in the area in the months of November and December and the runoff of the valley, where the cave is located. During the geological survey, the team developed a series of cross sections of the cave, in different orientations, as well as a complete map of the continuous part of the cave, before the final water pond. The cave ends with a large water pond about 1 km from the beginning of the cave. The cave's ceiling is in continuous contact with the pond and there is no clear outlet through the roof. The team seeks to dive into this pool using special equipment to complete the cave survey after the pool.

There are three main areas in the cave that require the use of ropes. The first is located at the beginning of the cave and is about 80 meters deep. The second is located immediately after the first and is about 30 meters deep. The third is located about 200 meters inside the cave, after the second drop, and it is 12 meters deep.

The passage of the underground cave follows a path similar to the valleys and the shafts above, and its path descends from an altitude of approximately 1,300 meters above sea level to the south. At the bottom of the first vertical hole, there is a small cave room, followed by a series of vertical tunnels. Beyond the vertical shafts, a wide and long cave tunnel extends to hundreds of meters and features wonderful cave deposits, isolated cave rooms and shallow water lakes, which represent the main part of the cave. Although the passage generally does not require the use of ropes and climbing equipment, walking through it requires attention because the floor and boulders here are generally wet in many places. The adventurers may be exposed to slide or fall. The cave ends with a lake in direct con-



▲ Location of Kittat Al Suwairat Cave and Al Ohr Spring and Cave

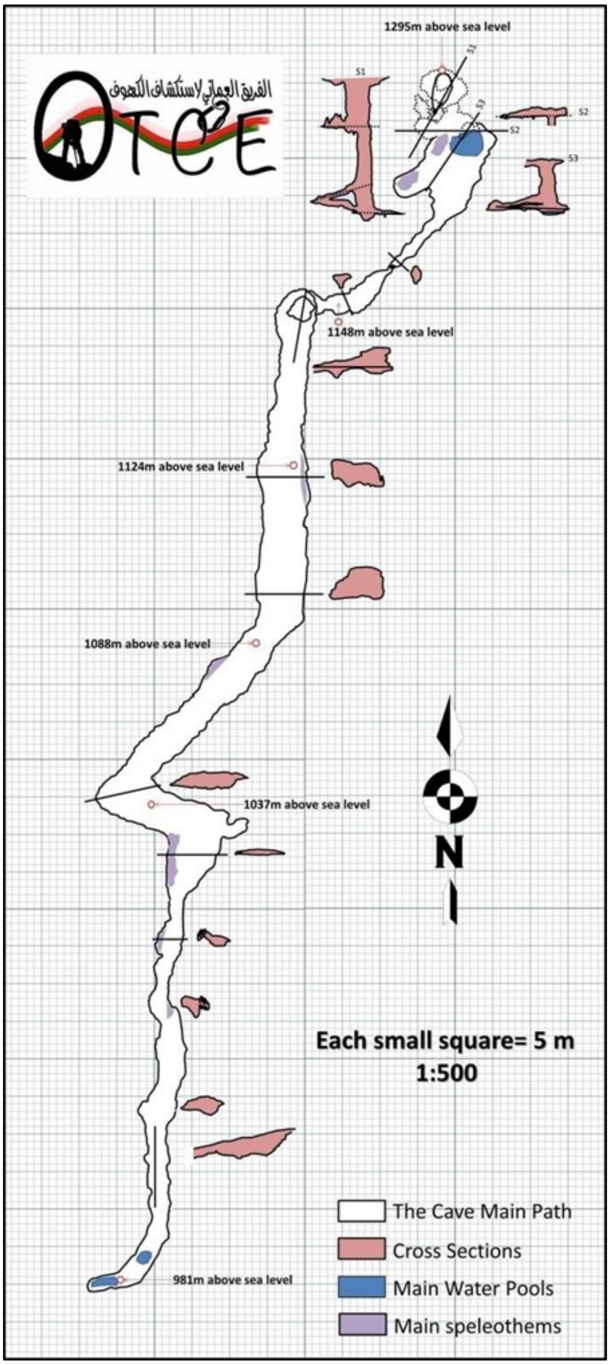


▲ Cross Section of the cave

tact to the ceiling of the cave. The trend of the cave suggests that it is still continues for hundreds of meters beyond the lake.

It is worth mentioning that the Speleological Team of Oman has completed the survey of the cave path that precedes the last water pond. This map was superimposed on the mountain's surface to predict the effect of various geological features obvious from the surface to the cave geometry.

During the heavy rain of July 2017, water was gushing from Al Ohr Spring, near the Wadi Ghul Dam in Al Hamra. The entrance of this spring is about 50m up wadi gravels at 524804, 2558896 UTM 40Q. The entrance leads into a cave, at the back of which lies a big sump pool. The cave is relatively easy to reach and also to take the caving and diving gears to. This cave was first surveyed by the Oman Cave Diving Group (OCDG) in the mid-1990s. In an effort to complete the geological survey at the Kittat Al-Suwairat Cave, and with the help of Simon Cahill, the OTCE team coordinated with three cave-diving experts to visit the opening of the lower cave at Al Ohr Spring, and attempted to connect it to the upper path of the Kittat Al-Suwairat Cave, and the operations resulted in a preliminary survey confirms the results of the previous extension of the cave and shows



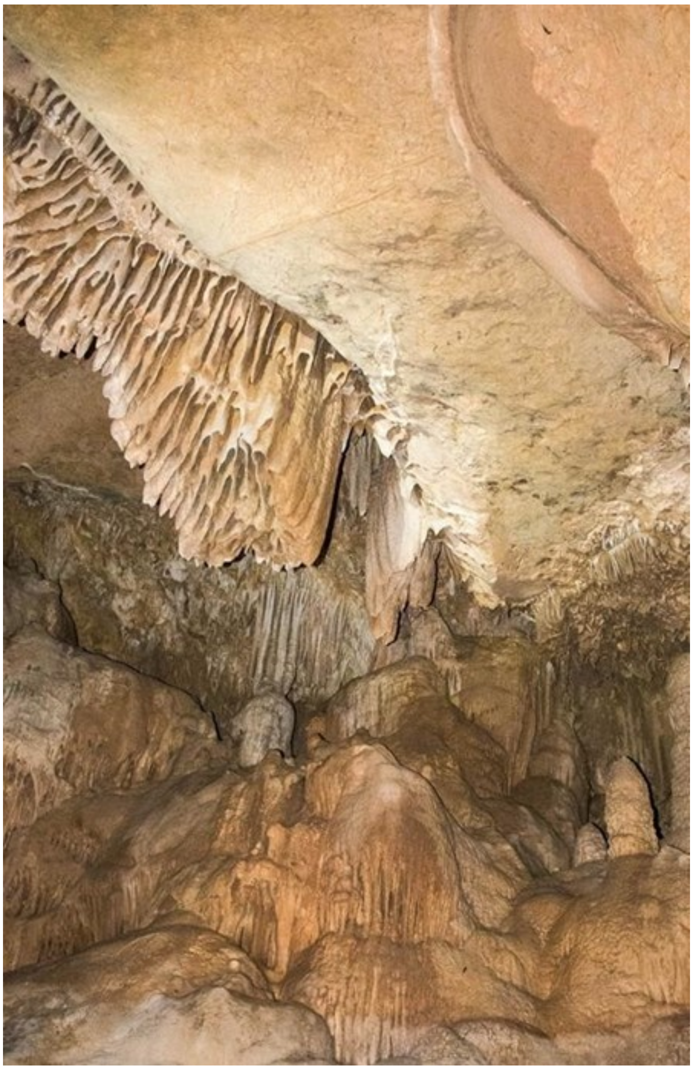
▲ Map of the cave

some of its lower structures. The predicted complete trajectory of the cave, including Kittat Al Suwairat, Al Ohr Spring Cave and the un-accessed path between these two, is about 3 kilometres long. The OTCE team, with the help of other international cavers and divers, will attempt to dive the un-accessed part of this cave to connect the whole trajectory.

▲ Preparing to go to the cave entrance, carrying the cave gear and food by donkeys. The hike is about 30 minutes from the village of Hail al Shas.

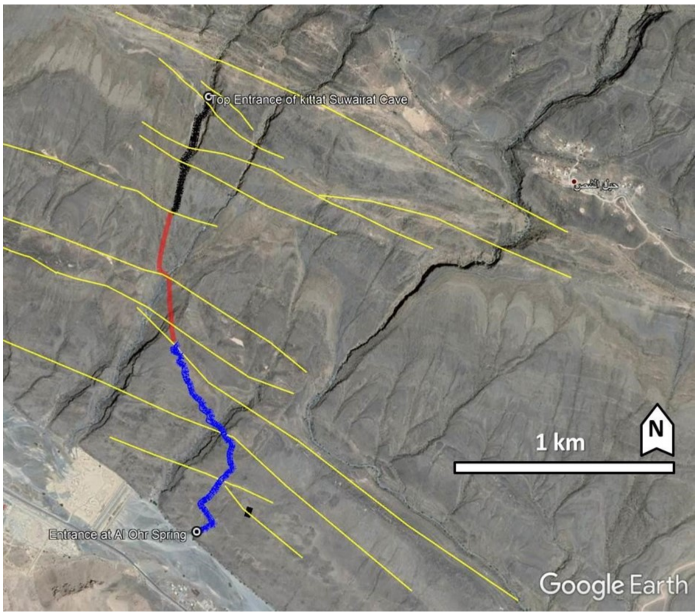
▲ Top Entrance of the cave (about 80m drop), note the abseiling person for a scale

▲ The main sump at the end of the surveyed path of the cave. The OTCE attempted to dive in this lake but couldn't progress significantly as the appropriate caving gear was not available.



Beautiful cave deposits near the crystal room ▲

◀ Attempting to dive Al Ohr spring again early in 2018 with a number of international divers (Jarrod Jablonski, Xavier Vridag, and then Christopher Pike). In the background of the pictures are: Simon Cahill, who is currently arranging the collaboration and communication between the OTCE and the international divers) and Nasser Al Riyami from the OTCE. The OTCE team with the help of other international cavers and divers will attempt in the near future to dive the un-accessed part of this cave to connect the whole trajectory.



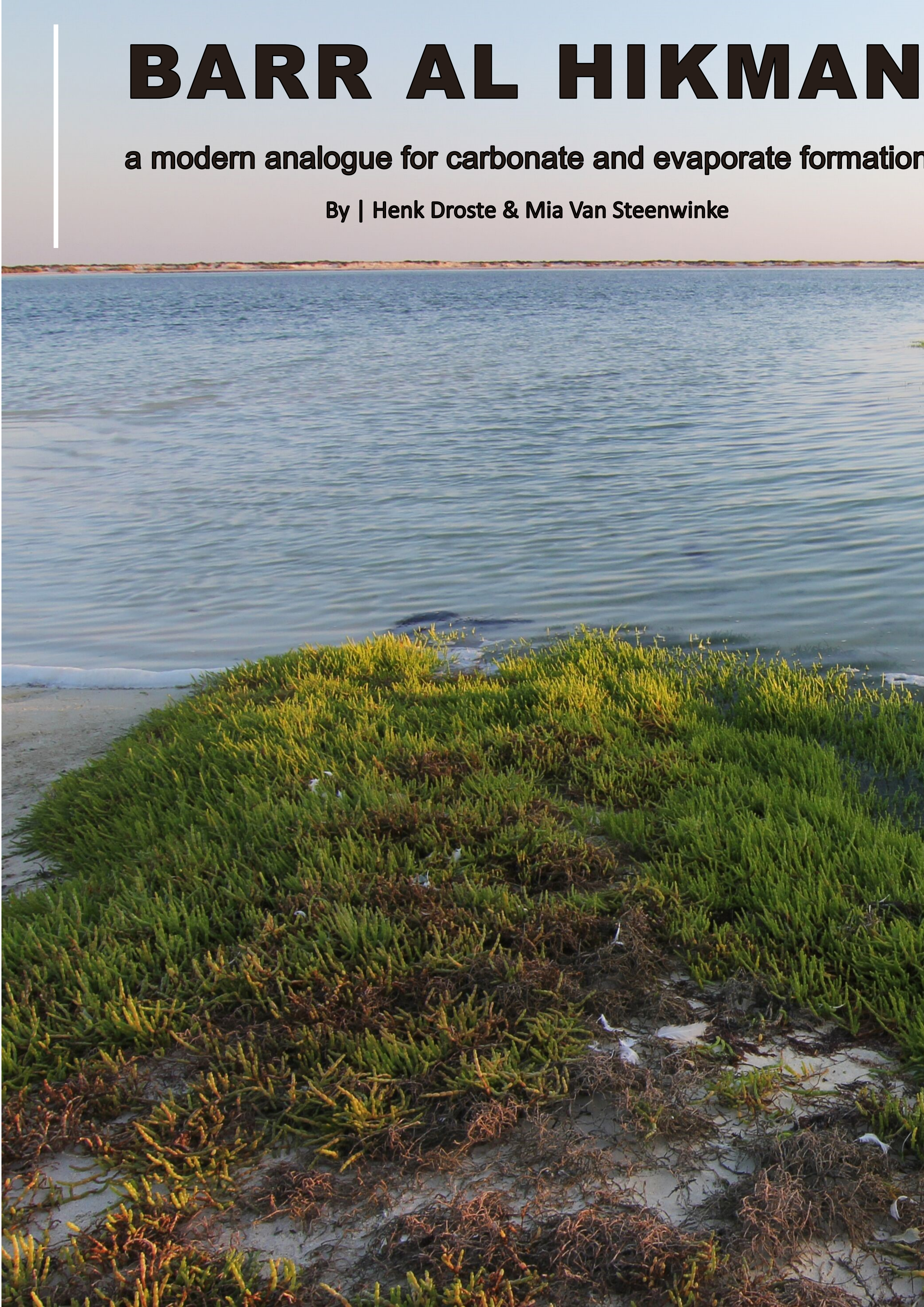
▲ An attempt to link with the surveyed path of Kittat Al S wairat done by the OTCE (black line) with the previously surveyed path by the OCDG (blue line) to understand the possible link between the two cave systems (red line), made in collaboration with Simon Cahill. The length of the red line, which is not yet accessed by anyone, is estimated to be about 900m. Note how the path of the cave changes in response to the surface fault escarpments (yellow lines) as traced from the Google-Earth satellite image. Apparently, the faults also control the position of the main lakes in this cave system.

▲ Water coming out from the Al Ohr spring near Wadi Ghul Dam during the heavy rain in July 2017 supports the linkage between Al Ohr cave and Kittat Al-Suwairat Cave. This aerial photo is taken by Yousuf Al Abri.

BARR AL HIKMAN

a modern analogue for carbonate and evaporate formation

By | Henk Droste & Mia Van Steenwinke

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Barr Al Hikman is a 30 km wide peninsula along the central east coast of Oman, just west of Masirah Island, protruding some 40 km to the south into the Masirah Bay. The landscape is remarkably flat, with a few scattered low-relief, rocky outcrops sticking out of the deflated soft-sediment surface. The peninsula is lined along its coasts with beaches and lagoons, forming one of the last large pristine wetlands preserved in the Middle East. It is a major nursery and feeding area for shrimps, fishes, crabs and green turtles and mostly known for its abundant birdlife (www.omanbarralhikman.org; Eriksen and Eriksen, 1999; Eriksen et al., 2001). The area is also known for its mangrove forests (in embayments to the est of the peninsula), for its turtle habitat, the passage of whales and dolphins in the Masirah channel between the peninsula and Masirah Island, and for the unique monospecific Montipora corals off the southern coast (Claereboudt, 2006; Homewood et al., 2007). Due to its uniqueness and importance, the area has been proposed as a World Heritage Site (Pilcher, 2002; Mettraux et al., 2011).

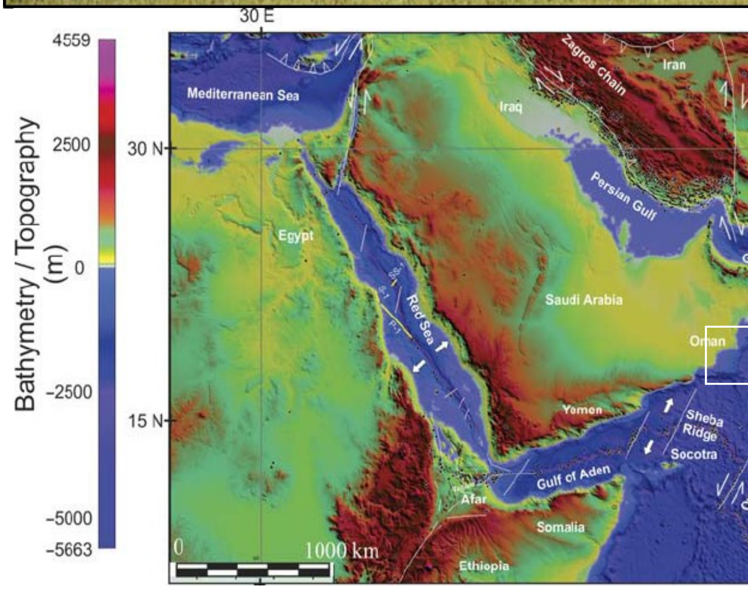
Barr Al Hikman also attracts the attention and enthusiasm of geologists as a modern analogue for carbonate and evaporite formations (Homewood et al., 2005; 2007, Mettraux et al., 2011). It offers the opportunity to view how carbonates are being formed, to witness depositional processes, to perceive scales, geometries, the distribution of sedimentary facies and how they shift through time. These real-life experiences are of enormous learning value for understanding carbonate reservoirs in the subsurface of Oman and elsewhere.

Tectonic setting

The geology of the Barr Al Hikman peninsula is strongly influenced by its location along the NNE-SSW trending Masirah transform fault zone.

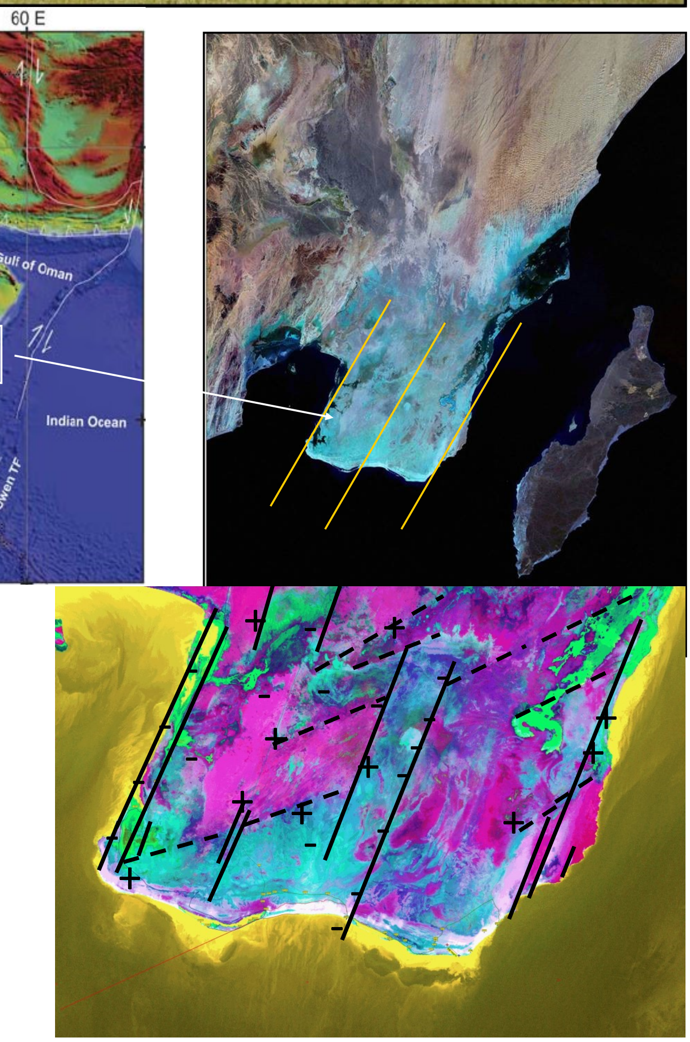
This fault system separates the Indian and the Arabian Plate and has been active since Late-Cretaceous times. A period of very rapid northward movement of the Indian Plate led to the NE directed thrusting of oceanic crust onto the eastern margin of Arabia during the Latest Cretaceous to Early Tertiary (see Immenhauser et al., 2000 and Peters, 2000). This oceanic crust forms the ophiolite outcrops on Masirah Island, located some 15 km kilometres east

Barr Al Hikman is a precious place for bird watchers.



▲

The Barr Al Hikman Peninsula is located along the transform margin of the Arabian Plate, fault lineaments visible on satellite maps suggest active tectonism.

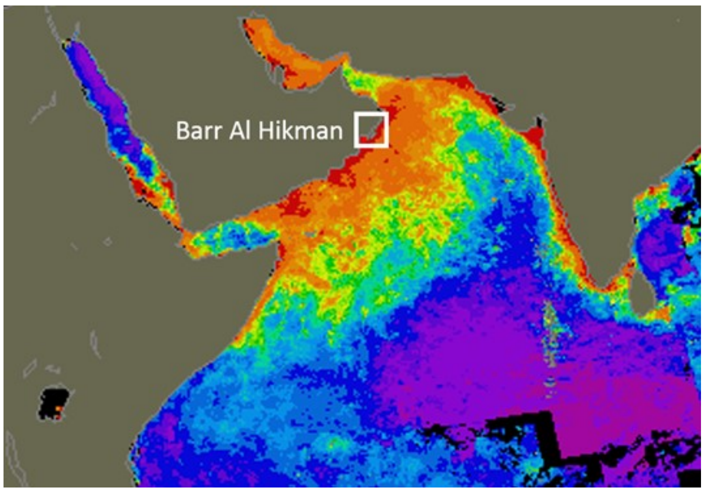


of the Barr Al Hikman. The frontal section of the Masirah Melange, a pile of deep-water sediments pushed up in front of the ophiolite, is outcropping along the eastern coast of Barr Al Hikman and has been encountered in a shallow core hole on the eastern part of the peninsula. Both the western and eastern margin of the peninsula are fault bounded. Deep subsurface data shows that the peninsula is also underlain by a complex of uplifted fault blocks.

The faulted topography has been draped by deposition of Pleistocene and Holocene fluvial to aeolian sands and a carbonate cover in the south, all of which has been smoothened by recent wind deflation, with just a few patches of remaining low-relief outcrops of Miocene /Pliocene carbonates. Satellite photographs and surface observations show some faint lineaments, which are faults penetrating the surface (Homewood et al., 2005; Mettraux et al., 2011). This suggests that there is still tectonic activity going on today. Sub-recent tectonic activity is also suggested by uplifted Pliocene to Pleistocene reefs along the eastern coast and by elevated Holocene lagoonal sediments some 10 m above present -day sea level (Homewood et al., 2007).

Upwelling

Barr Al Hikman lies within one of the five large upwelling systems of the world (www.omanbarralhikman.org). Upwellings are



▲ *Upwelling-related, high* chlorophyll concentration (high in red) in the Arabian Sea in the summer.

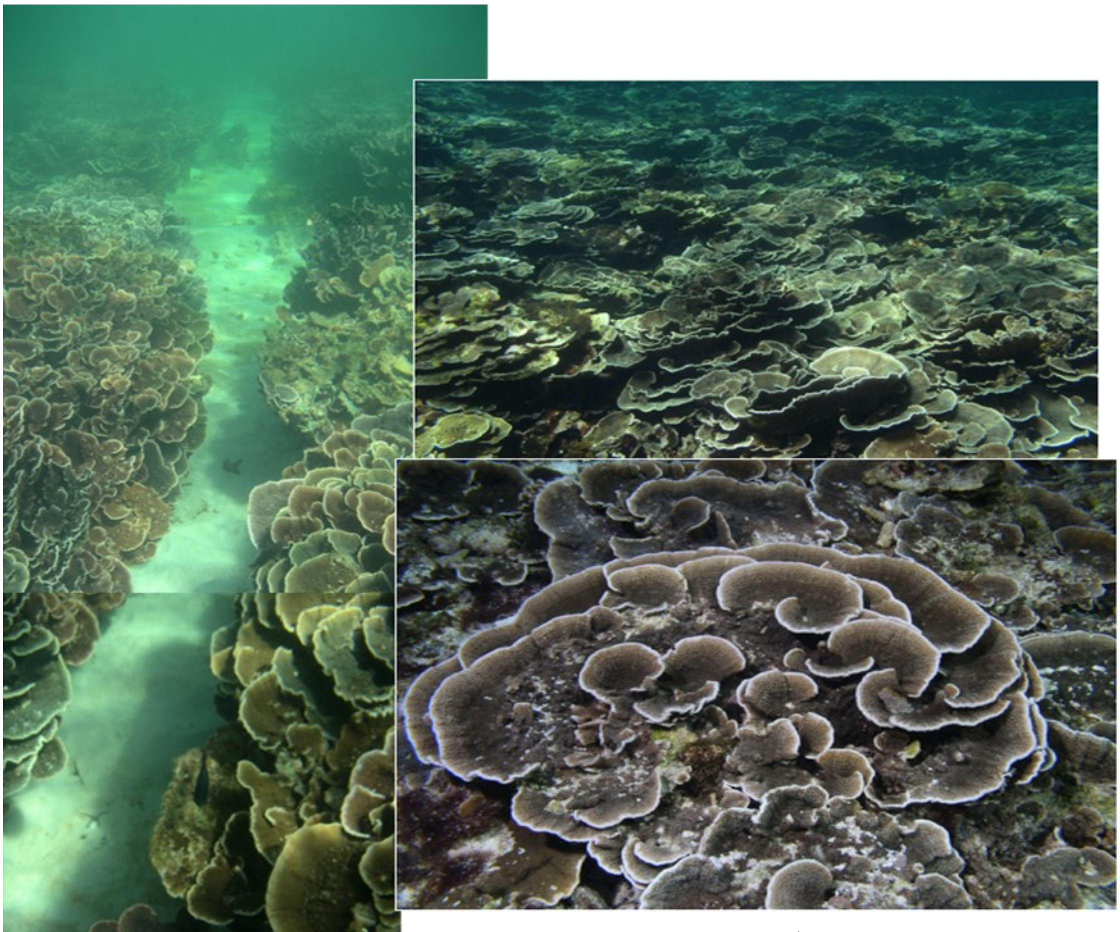
wind-driven motions of the sea water by which cool, nutrient-rich water comes to the surface. In Oman, the upwelling is driven by the yearly monsoon, which generally occurs between June and October. Typically, areas bordering an upwelling have enormous input of nutrients which can be a catalyser for phytoplankton blooms and rapid growth of large benthic, brown macro-algae (seaweed). Algae and seagrasses are thought to form the foundation of the Barr Al Hikman ecosystem, being critical nursery grounds for animals such as crabs and benthic animals and the main reason for the enormous richness in fish in the area. Occasionally, the macro-algae are detached from the substrate by storms and vast floating mats of seaweed wash up onto the beaches, filling the air with the stench of rotting eggs.

A Present-Day Carbonate Factory

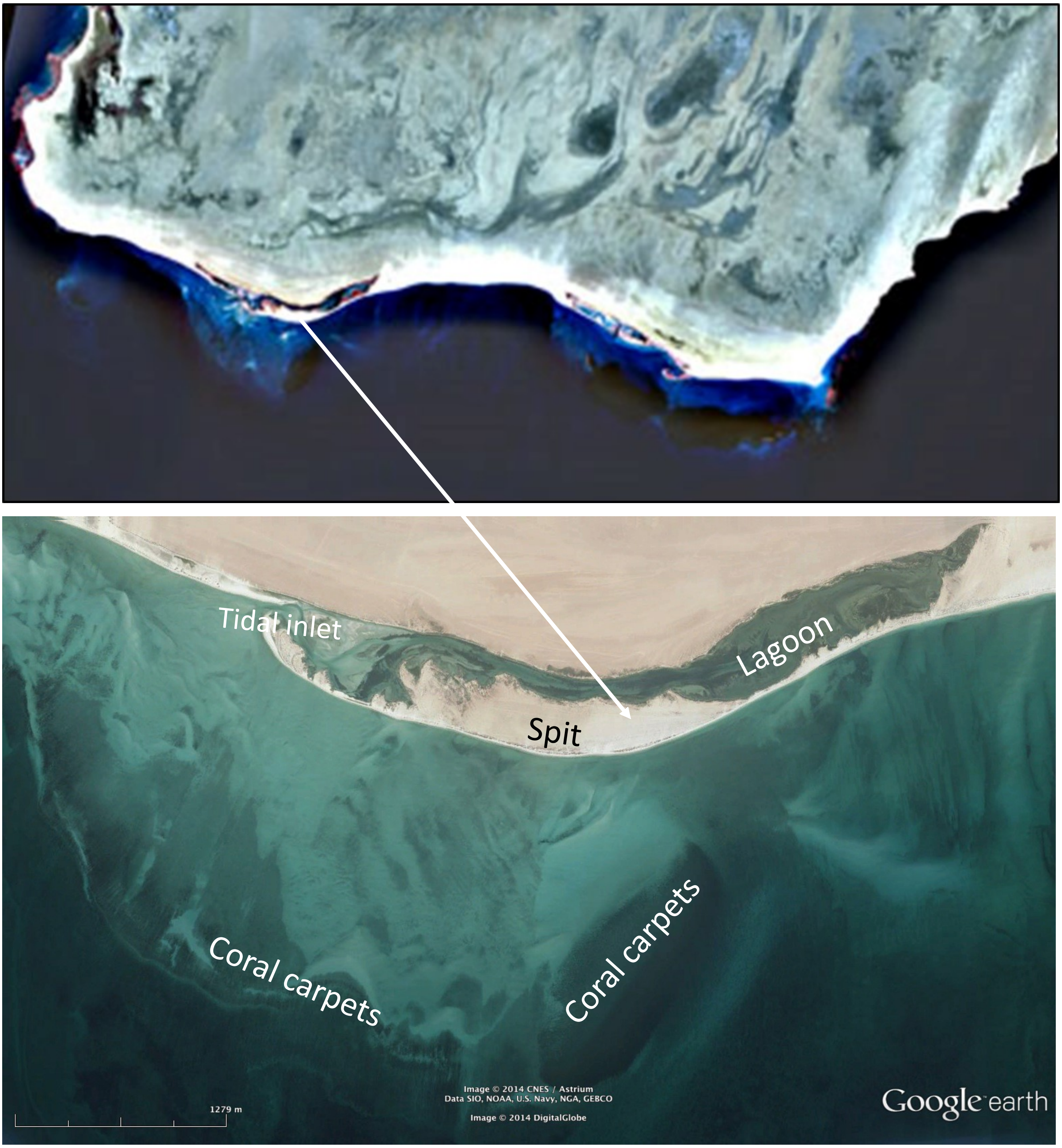
The Barr Al Hikman/Masirah area is one of only four areas along Oman's coastline that support coral growth (the other areas are Musandam, Muscat and Dhofar areas; Salm, 1993). Several patches with corals have been recognised around the peninsula (Homewood et al., 2005; 2007). The underlying geology caused subtle lateral variations in uplift and submarine topography, which led to preferential growth of corals. Along the southern margin, corals grow on subsurface structural highs and uplifted ridges along fault zones.

When you are used to scuba dive in other tropical areas, you will find corals growth in Barr Al Hikman to be clearly less prolific though. Upwelling-related, relatively low seawater temperatures, very high nutrient concentrations and turbid waters are limiting factors for corals growth and reef development (Homewood et al., 2007; Burt, 2018). Instead, algal growth prevails, which competes with the corals.

However, some of the corals accumulations in the South are quite spectacular, almost exclusively consisting of cabbage corals (Montipora). These; however, do not form reefal frameworks, but cover the surface like a "carpet" (Homewood et al., 2007). Coral patches occur 1-2 km offshore, in the upper 5 m water depth and are some 10 km wide (Homewood et l., 2007). They are of remarkable

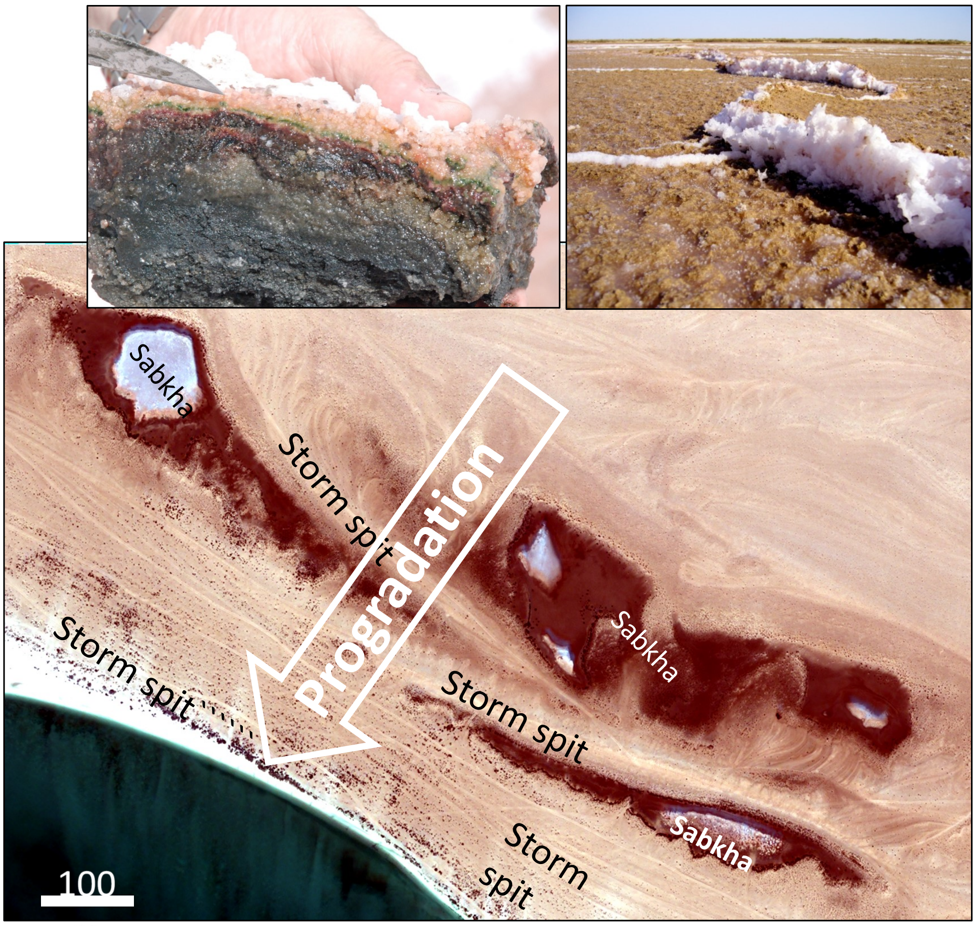


Montipora coral carpets ▲



▲ *Different carbonate environments along the southern margin of Barr Al Hikman, sediments derived from the coral carpets are redeposited by currents into a beach barrier system with lagoons and spits (*Homewood et al., 2005).

Satellite map (Homewood et al., 2007, Modified) *showing* salt pans in barred and abandoned back-barrier lagoons (now sabkhas), each one used to be protected from the open sea by a storm spit in previous times. Sabkha-storm spit facies belts are prograding out to the SSW since the last 6000 y (Homewood et al., 2007). *Inset upper left: Organic matter produced by algae and bacteria, is preserved due to anoxic conditions under the salt.*



interest as an analogue for Cretaceous carbonates rocks in the subsurface.

The corals are the main source of the carbonate sediments found in the Barr Al Hikman area. Other sediment components are bivalves, gastropods, red algae and foraminifera (Homewood et al. 2007). Coral debris and sand are transported to the coast during the monsoon summer storms and redistributed by longshore currents into a beach barrier spit system. Oolites and benthic green algae, common elements of tropical carbonate factories, are missing. The absence of green algae may explain the very low percentage of carbonate mud in the Bar Al Hikman carbonates. Even the sediments in the narrow lagoons behind the beach spit are sandy; in more saline restricted ponds they are covered by algal microbial mats (Mettraux 2011). During the strong summer monsoon winds, most of the finer sand and silt-sized carbonate grains are transported from the beach ridges further inland, where they form patches of aeolian sand dunes.

Sabkhas

Sabkhas developed, due to the extremely arid climate, within depressions along the coastline and within exposed soft sediments of the interior part of the peninsula.

Two different types have been recognised by Mettraux et al. (2011): 1) Lower lying (0-5 m) coastal sabkhas, often formed by isolated remnants of older lagoons, which are for a large part fed by marine waters (episodic flooding during high tides or storms). They are characterised by halite deposits forming salt pans. Underneath the salt, organic matter produced by algae and bacteria is preserved due to anoxic conditions. 2) Slightly elevated (5-15 m) continental sabkhas within the interior of the peninsula, which are fed by continental groundwater derived from the Oman mountains. The latter are characterised by layers of gypsum crystals growing within the sediment.

Changes through time

Due to a relative fall in sea level the carbonate system has been prograding towards the South over the last few thousand years. This progradation can clearly be seen on satellite photos and in the field: a 2 km wide band of arcuate storm spits, linear beach ridges (storm spits) and abandoned lagoons can be observed inland of the coastline, Homewood et al, 2007). These sediments are now a few meters above sea level, indicating the progradation was forced by a relative sea level fall ("forced regression"). The upper part of the sediment has been removed by wind erosion and the deflated surface shows a subcrop of the carbonate platform below an erosion surface.

A Precious Analogue for the Subsurface

The recent "carbonate factory" in Barr Al Hikman are of special interest to petroleum geologists and engineers and provide very valuable insights for some of the carbonate reservoirs in the subsurface of Oman. It consists of organisms predominantly forming layer-shaped "carpets" on the sea bottom, without a cohesive framework, which are reworked during storms into coarse-grained carbonate sands of a beach barrier system. These features are in many ways like what can be observed in the Cretaceous subsurface Shu'aiba and Natih fields (Homewood et al., 2007). Hence, Barr Al Hikman may be a better analogue for some of the carbonate reservoirs in the Oman subsurface than the classical tropical carbonate examples.

Driving and walking over the peninsula give a good impression, not only about the facies variety and lateral heterogeneities, but also about the scales of different geomorphologic units (Homewood et al., 2007). Physically walking out these units on the surface enables geoscientists and petroleum engineers to get a realistic feeling for the scale of permeability heterogeneities. This is of tremendous value as an analogue for and the appreciation of the characteristics and dimensions of different flow units in carbonate reservoirs. The geomorphologic units visible on the Barr Al Hikman satellite photographs can be used as a guide for the interpretation of seismic attribute maps over the reservoirs in the subsurface.

The observed scale of lateral facies variations also can help to address upscaling issues for static reservoir models. It gives an idea of how much detail is lost with each upscaling and how much detail still can be deterministically correlated over larger distances.

Another real-life learning from Barr Al Hikman is how carbonates prograde. The accumulation of carbonates along the southern edge of Barr Al Hikman took place during a falling sea level. The observed seaward progradation is an example of a lowstand systems tract with offlapping wedges. The top surface is an erosional surface on the peninsula and illustrates how the subcrop of an ex-

posed carbonate platform would look like. All these features are comparable to what is happening in the upper part of the Shu'aiba in the subsurface of Oman and can give valuable insights into both the regional stratigraphy and reservoir development of this interval and other similar carbonates.

Modern Hazards

It brings tears to the eye, however, to see how the beauty of this place is overshadowed by gigantic amounts of plastic and other waste, swept ashore and/or carelessly left behind, covering the beautiful beaches. Several biogeographic, wildlife, marine and socio-economic aspects have been investigated in the past (Weidle, 1991; Anon, 1992), pointing out how man is about to irreversibly destroy his own habitat, how natural features in these areas are of unique significance and value and should be subject to conservation (Weidle, 1991; Anon, 1992; Pilcher, 2002).

And so…

It's always a blessing to bring groups of geoscientists and petroleum engineers to this open-air, real-scale-, real-time geological laboratory, where people learn by experiencing the dynamic processes that build their reservoirs.

nshallah together we will find solutions to preserve this Pearl of Nature, so that we can keep learning from it and enjoy its beauty for many generations to come.

References

Anon (1992) Study for Wildlife and Conservation Areas – Master Plan for the Coastal Areas of Barr Al Hikman and Masirah Island. Weidleplan Consulting GmbH.

Burt, J.A., S. Coles, H. van Lavieren, O. Taylor, E. Looker and K. Samini-Namin 2016. Oman's coral reefs: A unique ecosystem challenged by natural and man-related stresses and in need of conservation. Marine Pollution Bulletin 105 (2016) 498–506.

Claereboudt, M.R. (2006) Reef Corals and Coral Reefs of the Gulf of Oman. The Historical Association of Oman, Al Roya press and Publishing House, 344 pp.

Eriksen, H. and Eriksen, J. (1999) Bird Life in-Oman. Al Roya Publishing, Muscat.

Eriksen, H., Eriksen, J., Sargeant P., and Sargeant, D. E. (2001) Bird Watching Guide to Oman. Al Roya Publishing, Muscat. 256 pp.

Homewood, P., A. Kwarteng, and M. Mettraux, 2005. Bar Al Hikman. Modern and Pleistocene carbonate/evaporite depositional system. Field guide, January 2005. IAS 24th Regional Meeting, Muscat, 70 pp.

Homewood, P.W., V. Vahrenkamp, M. Mettraux, J. Mattner, B. Vlaswinkel, H. Droste and A.Y. Kwarteng, 2007. Barr al Hikman: a Modern Carbonate and Outcrop Analogue in Oman for Middle East Cretaceous Fields. First Break, 25, 55–61.

Immenhauser, A., G. Schreurs, E. Gnos, H. Oterdoom and B. Hartmann 2000. Late Palaeozoic to Neogene geodynamic evolution of the northeastern Oman margin. Geol. Mag. V. 137, p. 1-18.

Mettraux, M., P.W. Homewood, A. Y. Kwarteng and J. Mattner 2011. Coastal and continental sabkhas of Barr Al Hikman, Sultanate of Oman. Int. Assic. Sedimentol. Spec. Publ. 43, p. 183-204.

Peters, T. 2000. Formation and evolution of the western Indian Ocean as evidence by the Masirah Ophiolite: A review GSA Special Papers 2000, v. 349, p. 525-536.

Pilcher, N.J., (2002) Potential Tropical Coastal, Marine and Small Island World Heritage Sites in the Middle East Region. Report to IUCN/UNESCO/NOAA. World Heritage Biodiversity: Filling Critical Gaps and Promoting Multi-Site Approaches to New Nominations of Tropical Coastal, Marine and Small Island Ecosystems. Hanoi, Vietnam, 18 pp.

Salm, R., 1993. Coral reefs of the Sultanate of Oman. Atoll Res. Bull. 380, 1–85.

Weidle, A. (1991) Study for Wildlife and Conservation Areas Master Plan for the Coastal Areas of the Barr Al Hikman and Masirah Island. Ministry of Regional Municipalities and Environment, Muscat, Oman.

إنجاز المتحدة

INJAZ UNITED

Inspired by **His Majesty words of wisdom** to support local Omani SMEs and creating job opportunities, INJAZ UNITED PETROLEUM SERVICES LLC (INJAZ UPS) was established in the midst of the economic downturn in 2016 with the objective of providing **a very cost effective independent geosteering services.**

With our approach using a computationally powerful geosteering software with advanced capability of data integration a considerable **cost saving is guaranteed for our clients by eliminating**, at least by 40%, the need for lowering the super-expensive downhole resistivity tools.

INJAZ UPS vision is to establish a local Omani community of geosteerers where the accumulated experience from geosteering in different fields will be retained and kept in the country and transferred to the subsequent junior geosteerers. With the expertise we will develop we have the vision to support PDO to establish their own **Realtime Geosteering Centre.**

THE BAUSHER SAND DUNES

LIVING RELICS OF THE LAST ICE AGE

By I Carlonie Hern

The Bausher Dunes are renown to those who live, and have lived, in the Muscat area. The majesty of their gently rolling carapace, bathed in the liquid evening sun is a memory I will treasure.

Why are the Bausher dunes important? First, a little background…

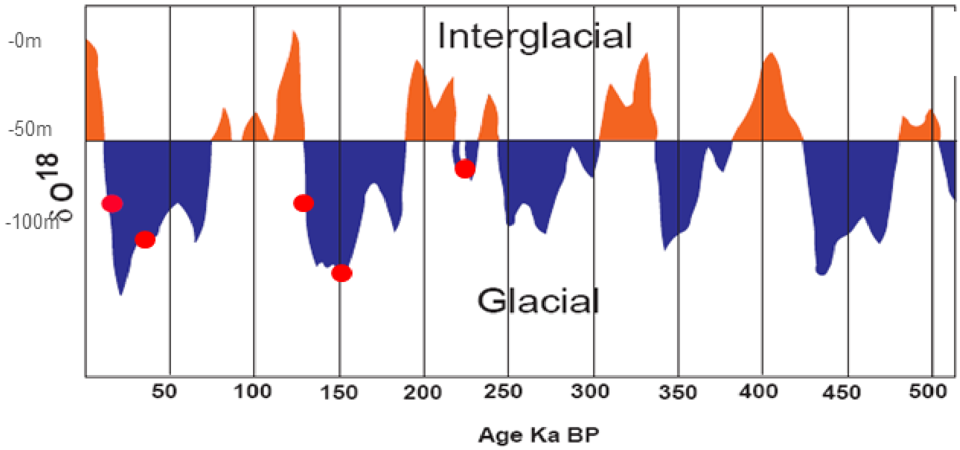
The Bausher dunes formed during the Pleistocene – a time of glacial activity. This timing places the dunes' formation in the same geological interval as that of the Wahiba Sands .

Extensive desertification & dune formation often occurs during glacial periods, because winds are thought to be stronger in glacial periods than during interglacials due to the compression of latitudinal cells by the extensive high pressure systems resulting from the polar ice caps.

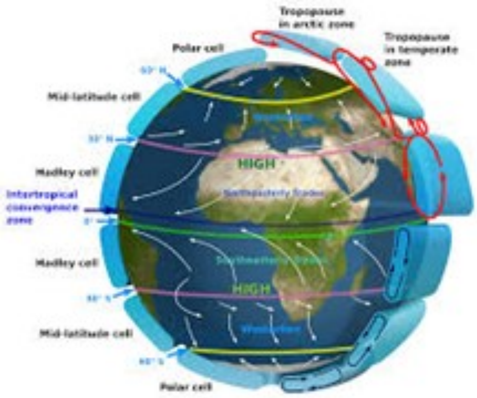
The dunes are not only a thing of beauty, but they also hold real scientific value. Why is this? Globally, there are very few examples where the resultant architecture is exposed in 3D allowing us to link the internal geometry to the dune shape .This internal architecture shows sweeping cross-bedding separated into packages by discordant surfaces – or bounding surfaces. The facies composition of each package controls the reservoir quality assuming the depositional character is preserved on burial). The surfaces between packages are significant permeability baffles and may even be barriers. Knowing the spatial distribution of these surfaces and the package character helps us to more accurately predict how fluid will move through these rocks.

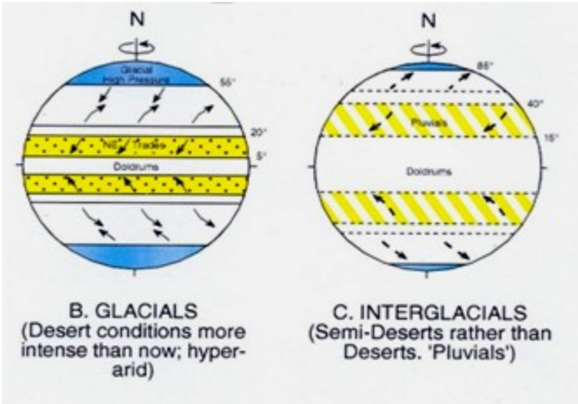
The internal geometry of the dune may be linked to the contemporary dune shape. Note already, how construction is impinging on the outcrop. ▲

Glacial cyclicity over the last 500Ka. Red dots are some key Wahiba age dates. Note the asymmetric shape of glacials; slow build up and sharp breakdown ▶



Contemporary atmospheric circulation cells and changes in size during glacials & interglacials. ▼





Why could this be important? In our subsurface reservoirs that were deposited by aeolian dunes, fluids (oil & water) must pass through architecture like that exposed on the flanks of the Bausher dunes. Without good outcrop analogs, it is much more difficult to properly model such architecture. With access to such outcrops, carefully recorded dips and dimensions can be used to construct deterministic models so that the precise impact of such arrangements can be assessed. Learnings can then be carried forward to the subsurface which enables optimization of field development planning to ensure we are fully utilizing resources.

Now however, the relentless growth in construction threatens to destroy the dunes through the combined assault of sand removal for use as a building material, by the physical invasion of roads and buildings into the dune area and also through unregulated use of all-terrain vehicles (ATVs), 4x4 and sand-boarders which destroys the fabric of the sand making it more susceptible to erosion.

These dunes are living relics of the last ice age, allowing us a window on processes and products from a different geological age. They form a unique ecosystem for both plants and animals that, being so close to Muscat offers easy access for tourists and students to learn about desert ecology along with the scientific application to Oman's hydrocarbon industry.

Previous articles, such as published in the Muscat Daily (https://www.muscatdaily.com/Archive/Opinion/Muscat-s-disappearing-mountains-and-sand-dunes-50d5) convey the level of support for protection of the dunes. I can only add my sincerely support for such preservation.

And on a final note, it does us well to remember that 'a thing of beauty is a joy forever (Anon.)', and once gone, it is gone forever.

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