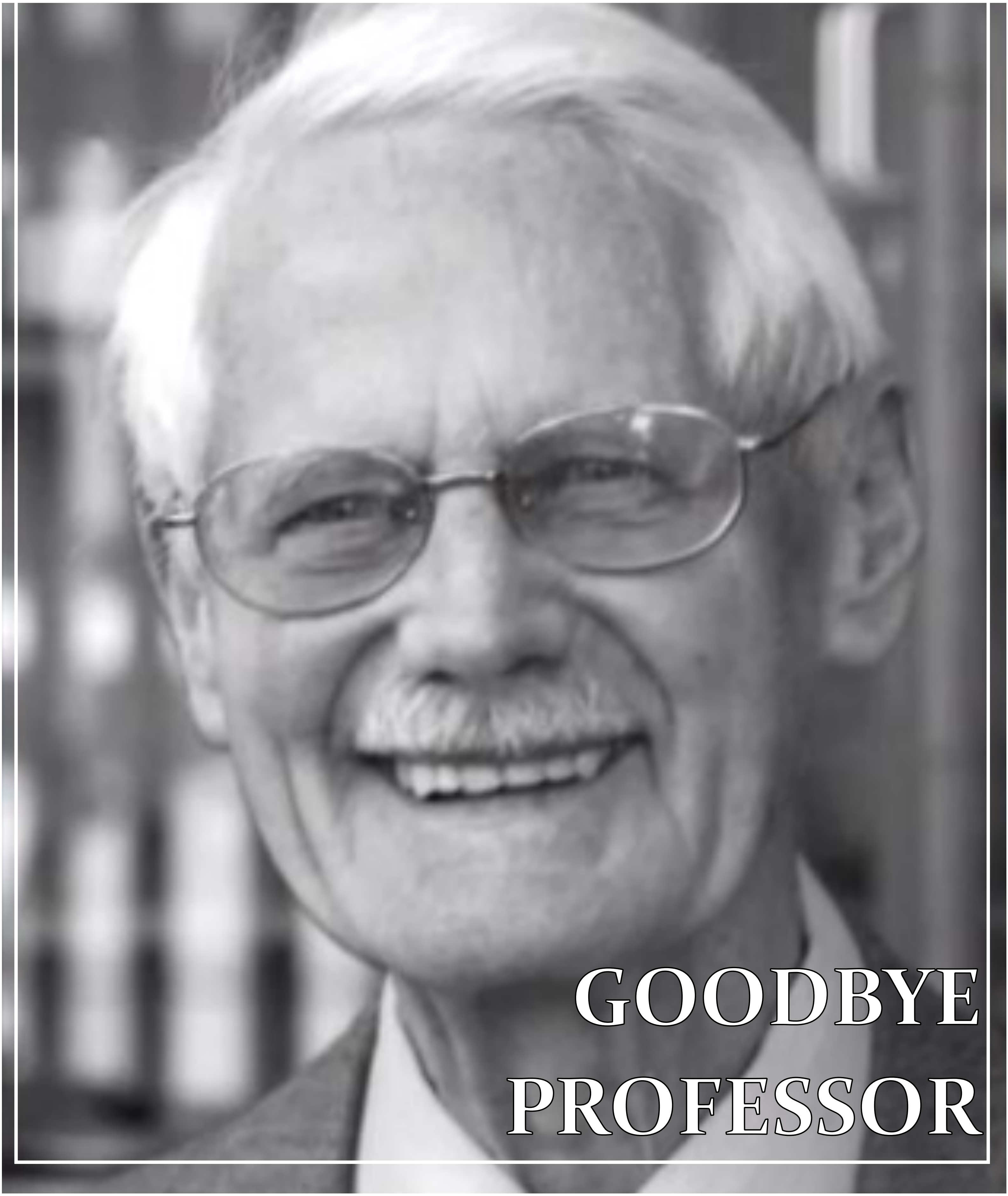
Al HAJAR

26th edition | December 2019



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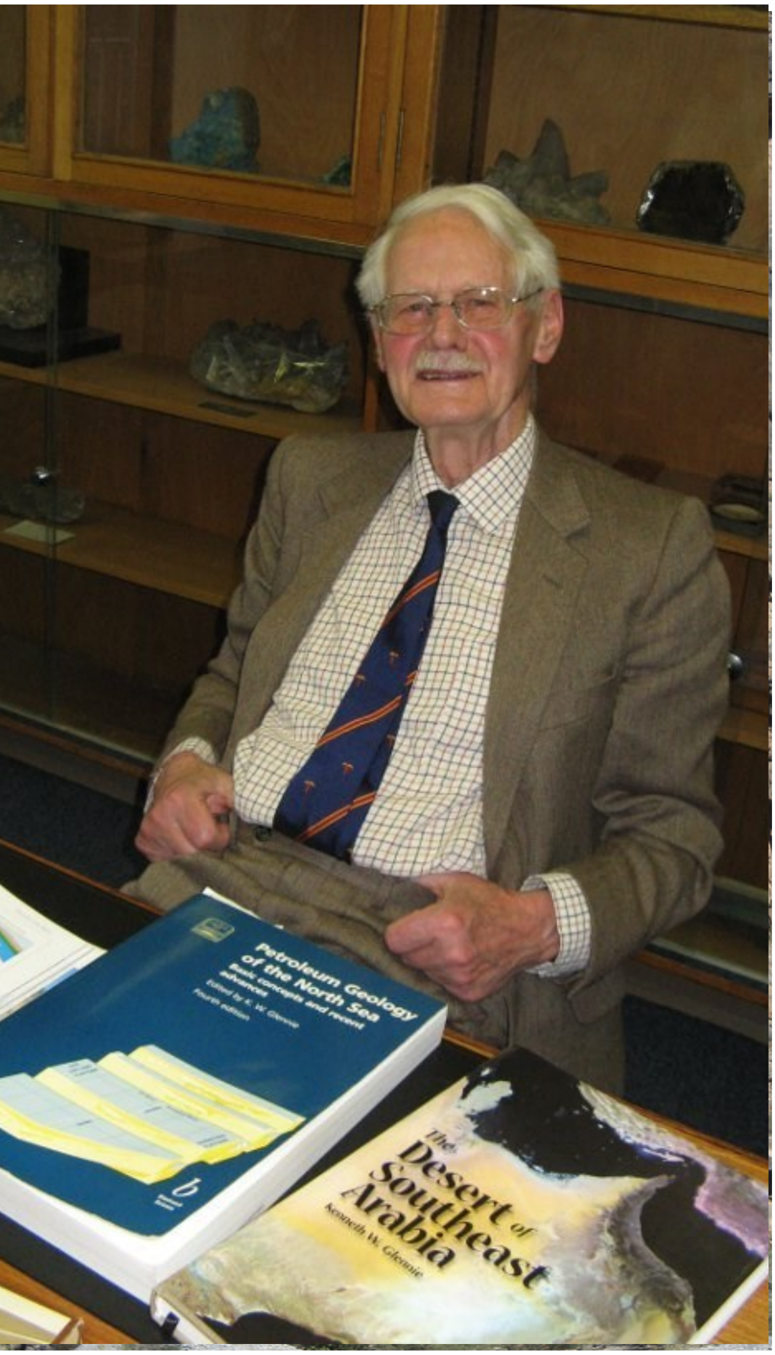

Photo of Professor Ken Glennie is an expert on desert environments, the Arabian Peninsula and the petroleum geology of the North Sea, and the proud recipient of many prestigious awards, medals and honours from the world's geological societies. (Source: Jane Whaley). From GeoExpro Vol. 6, No. 1 - 2014 issue.

FROM THE EDITOR

Dear All,

I don't think anyone will disagree to put the face of the father of geology of Oman at the first page of this issue. The news of Prof. Ken Glennie passing away was a sad news for many people not only for the geology community in Oman. Thank you Professor and goodbye. May your soul rest in peace. Myself and the editorial team would like also to thank those Geoscientists who unravelled Oman's geology and enriched our Geological society with information on our enchanting Geological Heritage. Those people created a platform from which many researches can be conducted, not only to explore for hydrocarbons and minerals but also to enable the appreciation of our geoheritage. Enjoy this issue of 26th of Al Hajar magazine and as we will enter a new year, I still encourage you to share your work with us and let us all enrich each other knowledge.

Husam Al Rawahi

Al Hajar Editor

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ABOUT GSO

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.

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GOODBYE PROFESSOR

KEN GLENNIE

Yes, Professor Glennie has gone but he certainly won the love of many geologists & researchers in Oman & the Middle East in general. Being an honorary member of the Geological Society of Oman since 2003; Ken devoted part of his life career studying and researching the geology of Oman in the past decades. His passions never stopped until his last visit to Oman mountains just in a couple years back. Close of his companions and family members think there is always something special attracted him to visiting Oman, its magical geology or simply the joy of walking the geology from past to present South to North; Mountains, Deserts and Wadis of Oman. We all witnessed the good will of Ken to pass the knowledge to our younger and passionate Omani geologists and helping them understand their own extraordinary and sometimes complex preserved geological sites. It was such an incredible TV programme named after his book ''Oman Geological Heritage'' giving the marvelous historical geological understanding in an easy and simple way. Ken will always be remembered as one of the great pillars in geology especially in Oman. As an honorary member of the geological society of Oman; Ken is regarded as the establisher & most enthusiast about Oman's geology for decades in his life. Goodbye Ken and may your soul rest in peace; you have won the heart of many geologists in Oman and the entire world.

Elias Al Kharusi

Geological Society of Oman President

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Brief on:

Kenneth W. Glennie

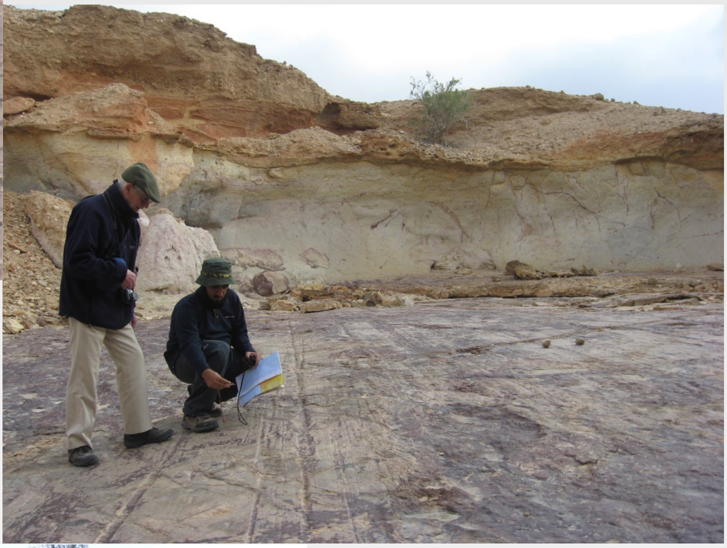
Kenneth William Glennie was born in the United Kingdom and started his life as an engineer when he left school but eventually studied geology at Edinburgh University after leaving the army to follow his interest and passion of understanding the process that make things happen in Earth. The passion ignited to understand the desert system was after his army assignment at the desert of Libya where he was stoked of the beauty of Libya sand seas. He joined Shell in 1954 and had many work assignments that enabled him to travel to many countries to study different geological system. In 1963, Shell assigned Ken to understand the aeolian sedimentary system. This lead Ken to travel to Libya (again), India, the United Arab Emirates and eventually Oman. When he came to Oman, he was fascinated of the Oman Mountain and the Semail Ophiolite. He was assigned to a project that aimed to map the North Oman mountains which lead to the creation of the first geological map of Oman mountain. Ken Glennie continued visiting Oman to run fieldtrips, lecturing and supervising PhD students and he became an ophiolite expert. All his work on Oman geology and the desert systems gave him the title that he truly deserve "The King of the Wahiba and Father of Oman Geology". Ken Glennie was the first honorary member of the Geological Society of Oman on which he was awarded in 2003 by Hisham Al Siyabi, the first president of the Geological Society of Oman. Ken is the author of several geological textbooks on Oman geology and aeolian depositional systems. He published a simple book on The Geology of the Oman Mountains (2nd edition 2005) and "Concise Geology of Oman" booklet in 2011 and contributed in the "Geological Heritage of Oman" movie.

We would like to thanks Hisham Al Siyabi (PDO) and Marcus Hollanders (PDO) for providing Ken Glennie stories to us. Also, some information was taken from a documented paper 2014 by Jane Whaley in GeoExPro magazine.

In 2003, Ken was made Honorary Member of the Geological Society of Oman, with Hisham Siyabi having the honor to present the awards ▶

Ken Glennie in 1967 with an Omani tribesman

Ken Glennie while filming the Geology of Oman movie . ▼



A visit from GSO members (Mohammed Al Kindy and Yousuf Al Sinani) to Ken's house.

Mining in Oman

Towards a Tangible Achievement in Mining

By | Yousuf Ali Al Darai

Geologist and project manager in the Earth Sciences Consultancy Centre

The mining sector is an important and promising sector in the Sultanate of Oman that contributes to the gross domestic product (GDP) of the country. The sector help to increase the exports and imports, as raw materials and manufactured products, as well as providing new job opportunities. Recently the Sultanate has worked very carefully on the success and development of the mining sector to achieve the highest levels of optimal exploitation of this vital sector.

Since ancient times, Oman was active in mining, as evidenced by the ancient archaeological discoveries around copper mineralization zones. These discoveries indicate that Omanis, since at least five thousand years ago, extracted copper ore from Wadi al-Jizzi in the Wilayat of Sohar as well as in various areas of the Wilayat of Yanqul in the Ad Dhahirah Governorate, in addition to some antiquities discovered in the Wilayat of al-Mudhaibi. The bright metals and gemstones also received great interest in the ancient Omani civilization and the Arab-Islamic civilization because of its importance in the ornaments and jewelry fields.

Mineral resources in Oman differ in various geological domains in Oman. The mining sector in Oman is divided into two main sections according to its chemical content: metals and non-metallic minerals. Metal minerals, which are typically malleable or ductile and shows a lustrous appearance, and conducts electricity and heat relatively well, such as copper, gold, iron and chromium, are found in abundant quantities within the ophiolitic belts and their associated weathering and recycled products. Production of these minerals is still ongoing.

The non-metallic minerals, which in contrary to the metallic minerals, tend to have a relatively low melting point, boiling point and density. Furthermore, non-metallic minerals usually have poor thermal conductivity and electrical conductivity. They are available in larger quantities in var-

Some types of mining commodities in Oman.

1974 Issued Royal Decree Act No. 42/74 of the oil and minerals law

1997 Issued Royal Decree Act No. 84/97 to change Ministry of Oil and Minerals to the Ministry of Oil and Gas, and transfer of the Directorate of Minerals and its competencies to the Ministry of Commerce and Industry

2003 Issued Royal Decree Act No. 27/2003 with the issuance of the mining law, and the cancellation of the previous oil and minerals law

2014 Issued Royal Decree Act No. 49/2014, with the establishment of the Public Authority for Mining

2019 Issued Royal Decree Act No. 19/2019, which issues a new mining law named as the Mineral Resources Law, and the cancellation of the previous mining law

Chronology of the mining sector in Oman.

ious domains in Oman. They include non-metallic rocks, such as limestone, marble, gabbro, gypsum and silica.

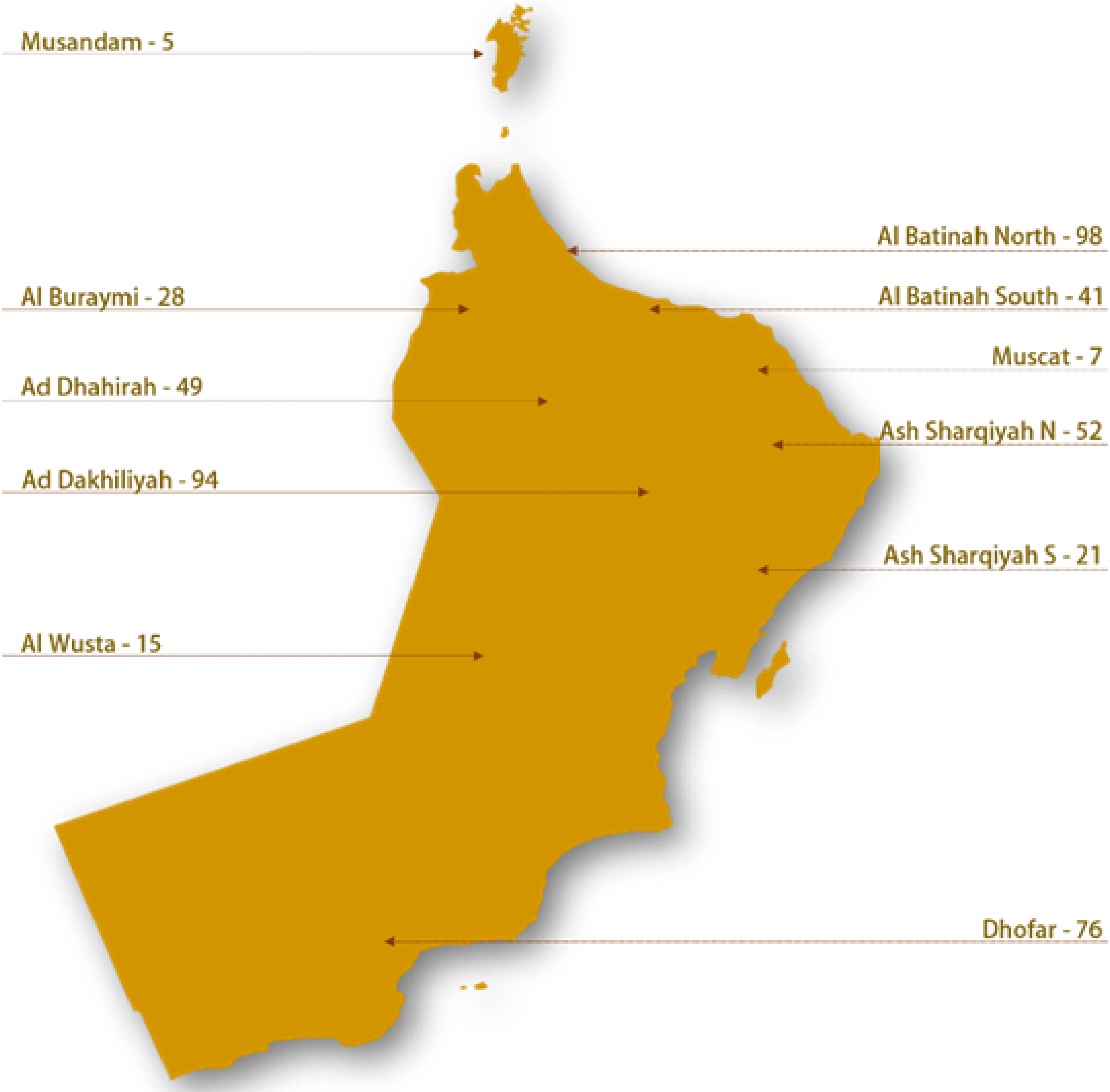
Since the beginning of Oman's renaissance in 1970, the government interest in the mining sector was always discussed. In the 1970s, a special directorate called Directorate General of Minerals for mining and quarries was established under the umbrella of the Ministry of Oil and Minerals at that time. Following is a review of the interest of the mining sector after the modern renaissance in Oman in 1970. In 1974, the Royal Decree Act No. 42/74 of the oil and minerals law was issued, regulating the exploration, extraction and exploitation of oil and mineral resources, as well as obtaining all appropriate permissions before taking advantage of the resources in the concession area. Later, in the last decade of the twentieth century, in 1997, a Royal Decree Act No. 84/97 was issued to change the names of some ministries, including the Ministry of Oil and Minerals to the Ministry of Oil and Gas, and transferring the Directorate General of Minerals and its competencies to the Ministry of Commerce and Industry.

Mining laws and regulations have been constantly changing with time. Another Royal Decree Act No. 27/2003 was issued, with the cancellation of the previous oil and minerals law. This law was more comprehensive and regulated than the previous one. With time, mining concepts and their uses evolve globally day over day, and the government aimed to coupe with this.

With time, it became urgent to establish a special authority dealing with mining, because of the increasing and complexity of mining in the country. In 2014, his Majesty Sultan Qaboos bin Said issued Royal Decree Act No. 49/2014, where the Public Authority for Mining (PAM) was established. PAM deals with all mining matters and organizes and supervises quarries. Also, the authority is responsible for issuing mining licenses for sites after study them in details. The authority currently has five branches across the governorates of Sultanate. In 2019, a Royal Decree Act No. 19/2019 was issued. This decree includes the issuance of a new mining law. The law is known as the Mineral Resources Law. It includes the cancellation of the previous mining law, which was issued in 2003. The new law was more regulatory, so as not to conflict with other laws applicable in the Sultanate.

The Public Authority for Mining (PAM) works with investors to follow up and issue mining licenses and related studies according to certain regulations. There are different phases are important for a detailed assessment of mining concessions.

In the first phase, a preliminary exploratory study is provided for the site where the mining is intended. These include determining the type of the ore resources and the estimated amounts to be managed by the site. During the preliminarily evaluation, PAM communicates with about 8 government authorities to check the availability of the mining site, and make sure this site is not in conflict with government and public interests. Then, after confirming the validity of the investment in the site, the client starts to

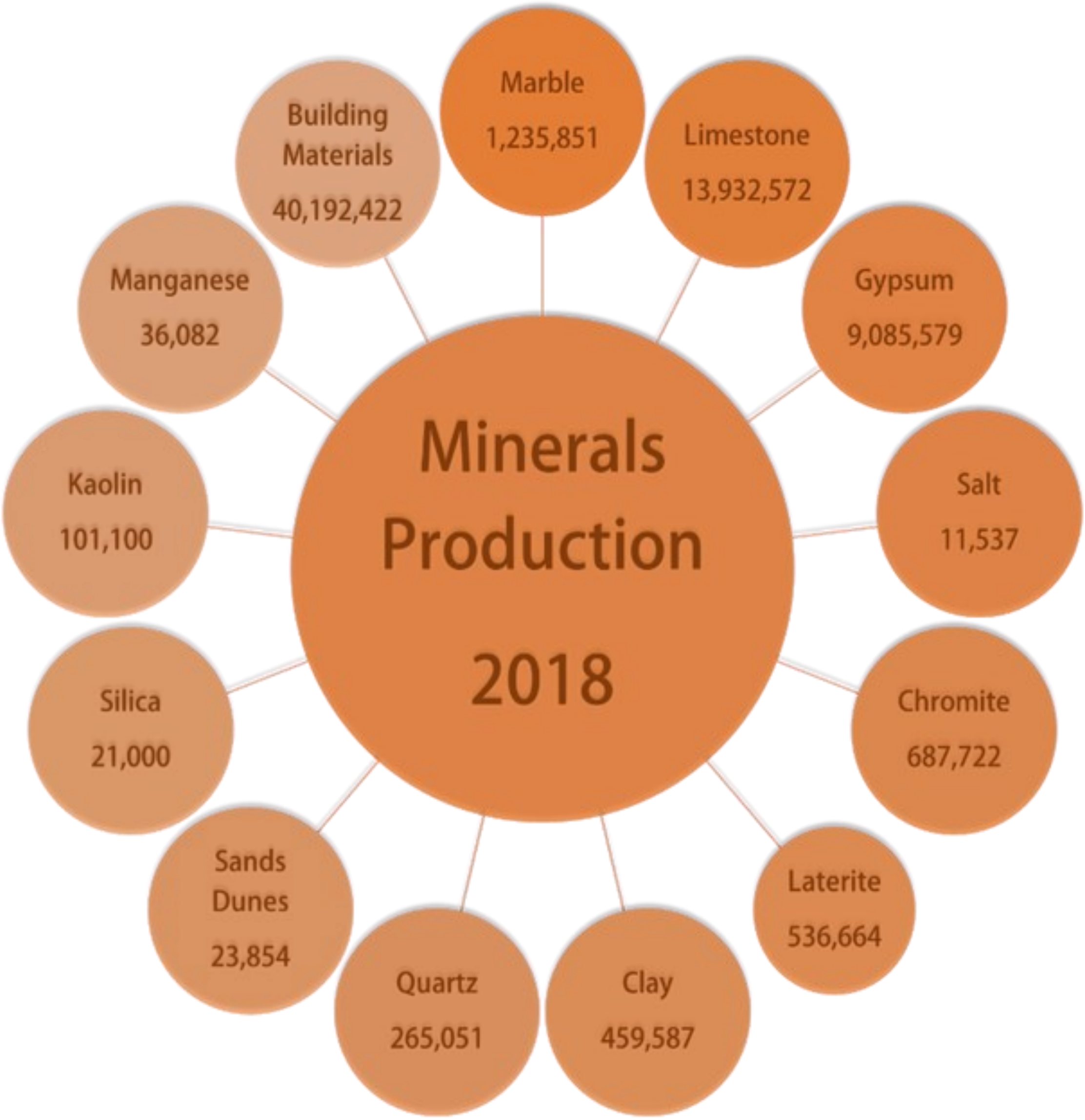


Number of mining licenses until the end of 2018 are reached 486 licenses. (Reference: Public Authority for Mining)

apply exploration program for the site, including geological survey, topography survey, chemical assessment of the site and geophysical survey, if required, as well as providing the coring and drilling programs for most commodities. These initial surveys get submitted to PAM for assessment and give the client the permission to start the second phase of exploration.

In the second phase, the applicants and their mining consultants study the area more in details, to estimate the quality and quantity of the reserve in the concession area. They submit a comprehensive mining geological study with 3D modelling of the site and its mining resources. In addition, they conduct appropriate economic feasibility studies for the mining in the concession for five or ten years. These include items like capital investment, number of manpower and machineries, and estimate the production rate and asses the market options. Moreover, the final study provides a mining plan, which includes mining and quarrying plans, and the necessary machinery and equipment to extract the ore from the mining concessions over time. According to the statistics of the Public Authority for Mining, the number of mining licenses until the end of 2018 have reached about 486 licenses.

The main vision for the Public Authority for Mining is to develop the mining sector so that it contributes to around 300 million Omani Riyals in the GDP by 2030 shows the statistics of production of minerals at 2018.



Statistics of production of minerals at 2018. (Reference: Public Authority for Mining

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OMAN GEOPARKS AND GEOTOURISM

A recent study done by GSO for the Ministry of Tourism initiative to build the concept of geotourism In Oman

By | Ibrahim Al Ismaili (Geoscience consultant for Vision Advances Petroleum Services)

Oman with its diverse geological heritage, complemented by rich cultural heritage and biodiversity, can offer wide range of sustainable tourism. More specifically Oman with its unique and enchanting Geology can offer Geoparks and sustainable geotourism. This is a knowledge-based tourism that offers an integrated tourism of the geographic, geological, environmental and cultural heritage. Another definition of geotourism, offered by National Geographic, is tourism that sustains or enhances the distinctive geographical character of a place—its environment, heritage, aesthetics, culture, and the well-being of its residents.

Geoparks are areas with unique geology that offers geotourism while ensuring conservation and education. Since mid 1990s different countries started offering such experience. By 2015 UNESCO adopted this notion and offered to enlist areas adhering to a set criterion as part of UNESCO Global Geoparks. Presently (in 2019), there are 147 UNESCO Global Geoparks in 41 countries. UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development.

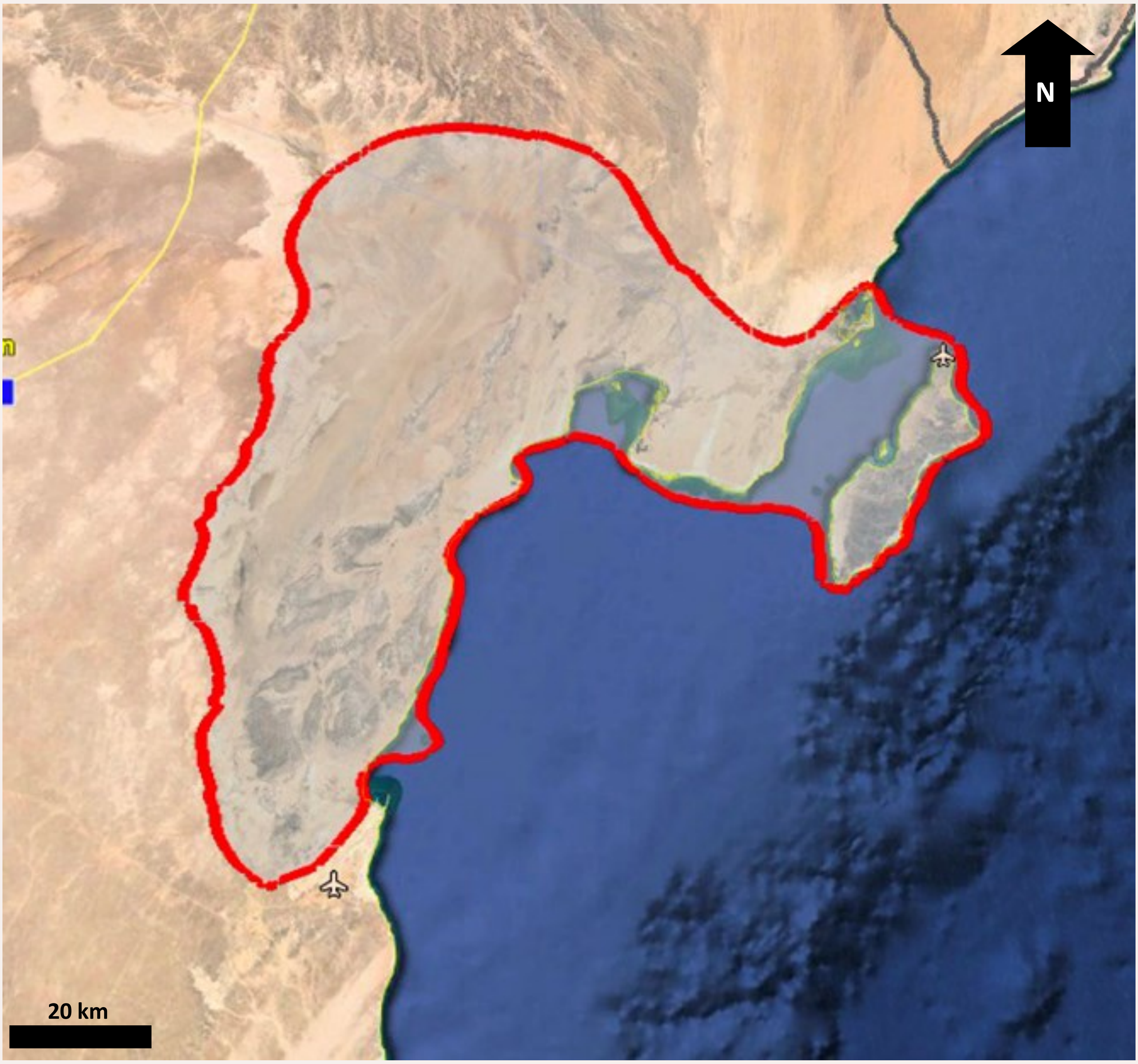
In 2019, the Geological Society of Oman (GSO) was invited by the ministry of Tourism to conduct a feasibility study for sustainable development of geoparks in the Sultanate of Oman (Ref. 1). The study was delivered in September 2019, it evaluated and ranked seven potential geoparks and concluded that Oman has great potential towards geotourism and suggested two areas for immediate development as Geoparks with prospect to add further areas in future. Through effective management and development including education, many areas in Oman have great potential to become Geoparks. Sites within a Geopark must have management and interpretation plans to protect resources and make geology and other heritage sites accessible to the public. The government shows huge interest towards such developments where Oman's character is preserved, and sustainable development enables and adds value to local communities.

Examples of Oman's Geological Areas

The following are few fascinating examples of Oman's geological areas and hence potential Geoparks, these are adopted from the study conducted by GSO in 2019.

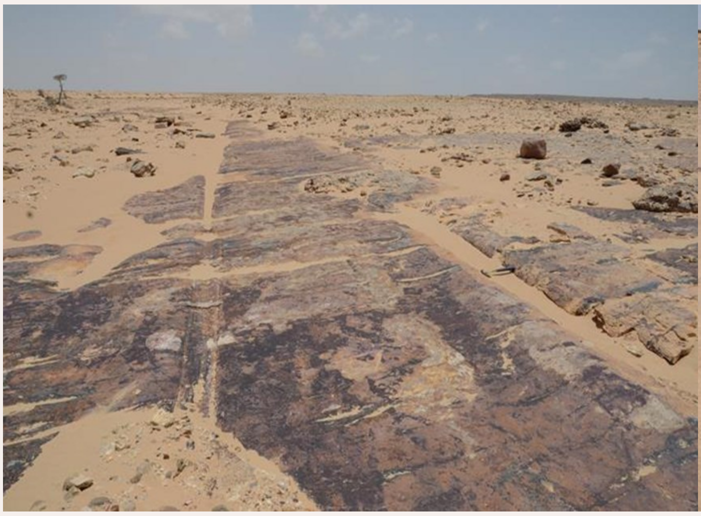
Al Huqf Area- Central Oman

Al Huqf area extends from the Mahout towards Haima and to the northern part of Al Duqm for a total length of about 200 km and a width of 75 km. This area is covered by small escarpments and hills that reach a height of more than 150m in the southern part (e.g. the Khufai Dome in Al Duqm). In general, this variation in rock composition (including igneous, sandstone and limestone rocks) makes this area one of the most colourful parts of Oman from Space. The majority of this area is a topographical depression (with an average height of 50m above sea level), covered by flat muddy salt plains (sabkha's). Although the topography of the area is low, the underlying rocks define a 'high', with very old rock in its core (granodiorites at Al Jobah, with an age of more than 720 million years). Sedimentary rocks of sandstone and carbonates that home Oman's northern oil and gas fields in basins further to the west, are present in different parts of Al Huqf. This area is of great scientific interest, has many fascinating geology (see images), home to the Arabian Oryx and Gazelles, and have many archeological sites.



Satellite image of the Huqf Area. The area is in close proximity to Bar Al Hakman and Musairah Island which enrich a potential Geopark as illustrated in red boundary. ▲

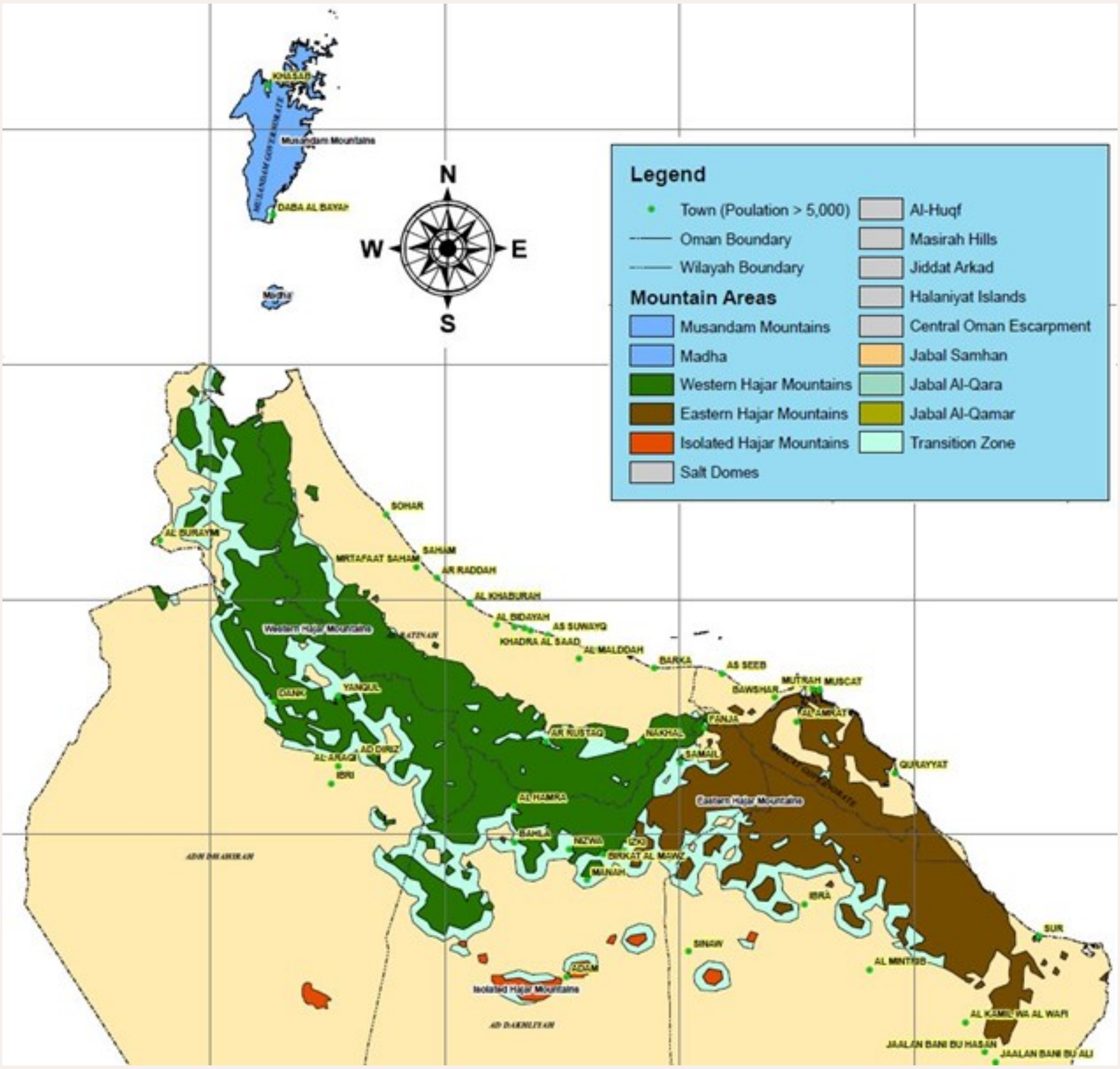
The low-elevated hills of the rudist and other shallow-marine Cretaceous fossils in the northern side of Al huqf are among the best fossils sites in Oman and the world for this type of organisms. ▲



The glacial striated pavements from the Carboniferous (left) and the petrified wood from the Permian (right) are among the most astonishing wonders in Al Huqf, near the South Pole, northwards to more tropical climates, at the end of the Palaeozoic, around 300 million years ago. ▲

Samail Ophiolite

The Oman ophiolite, known as Samail Ophiolites, are the most spectacular exposed oceanic lithosphesre (crust and upper mantle sequence) in the world. The Samail Geopark includes several rock unites; Pre-Nappes unit, Mantle Sequence, The Moho, The Moho Transition Zone (MTZ) , Crustal Sequence, Gabbro Plagiogranite, Sheeted dykes Pillow Lavas, Hawasina Nappes, The Sumeini Nappes, Oman Exotics (Ex), The metamorphic sole, The post-nappes Units, Quaternary deposits.



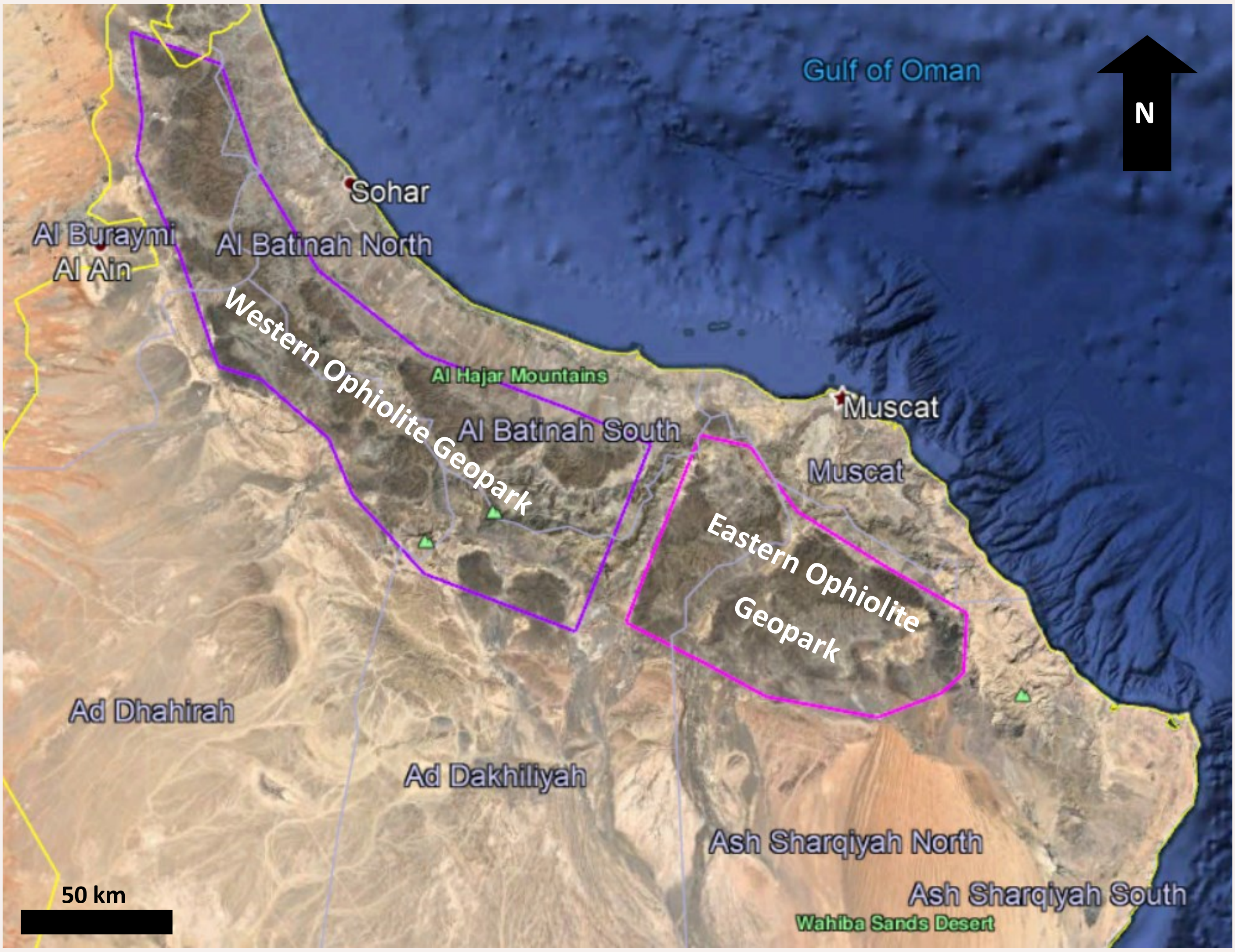
Simplified geological map of the Samail Ophiolite ▲

For the purpose of comparison, the Ophiolite exposures in Oman have been divided to two main parts as described below:

Eastern Ophiolite Geopark area: The Eastern Hajar Mountains occupy a domain extending about 300 km between the Samail Gap and Ra’s al Had and represented by Samail and Wadi Tayin-Ibra blocks.

Western Geopark area: The Western Hajar Mountains form an arcuate structure extending over 270 km, between WadI Hatta and the Samail Gap. The mountain is composed of parallel ranges having their own lithology.

Samail Ophiolite is recognized worldwide by the international scientific community. Rightly so, as the ob-ducted oceanic lithosphere (ophiolite) appear stratigraphically undisturbed and hence complete sections of ophiolite is in display. above sea level is striking.



Satellite image showing the East and West blocks of the Samail Ophiolite ▲

▲

The pillow lava (left) and the associated mineralized zones (right) that formed in the magma chambers of mid oceanic ridges are exceptional geological wonders and should be prompted as World Heritage Sites.

Al Jebel Al Akhdar - North Oman

Jebel Akhdar (Green Mountain) forms the central and most prominent feature in North Oman Mountains, reaching height of just over 3 km above sea level in Jebel Shams Summit. It is certainly one of the most spectacular areas of Oman. The most habitable part of this mountain range is Saiq Plateau, which stands over 2km above sea level, is famous for its traditional rose water extraction and agricultural products including pomegranate, apricot, peach and walnut.

The overview from the Saiq gives a unique opportunity to see the Precambrian, Late Palaeozoic and Mesozoic rocks. The weathering profile and rock colours can be used to distinguish between three rock types present from this view point. The Precambrian rocks were deposited between 700-542 Myr ago, whereas the travertine traces (carbonate minerals precipitated by springs) are probably deposited during the last million year when the climate was more wet. The springs that formed the travertine deposits possibly emerged in the contact between the porous Permian and tight Precambrian rocks. As the rain falls (nowadays the area only receives around 300mm of rainfall), it passes through the porous Permian carbonate rocks and exclude carbonate minerals from the rocks. It then re-precipitates these minerals in the spring area. The layering of the travertine suggests presence of big waterfalls in the area, which might have been very attractive for living particularly in the wet periods of the Pleistocene and Holocene.

An angular unconformity with 350+ time gap (hiatus) can be well seen separating the Permian carbonates of Khuff Formation (here known as Saiq) and the Precambrian glacial and clastics deposits of Nafun Group. The tectonic deformation that affect the Pre-Permian rocks and predates the Khuff Formation is either a result of a Hercynian orogeny (around 320 Myr ago) that was caused by the collision between the Euramerica (Laurussia) and Gondwana to form the supercontinent Pangaea or related to a Precambrian compression that also resulted in the formation of Oman Salt Basin flexural depression. The Haima and Haushi rocks (deposited between Cambrian to mid Permian) that are present south of Jebel Akhdar area have been have been either eroded because of the Hercynian deformation or not deposited as a result of the uplift caused by the Precambrian uplift.

A number of fossil coral gardens are present where the fauna-rich Lower Saiq beds are exposed in Al Jebel Akhdar. The gardens are situated within very attractive areas that tourists frequently visit to enjoy the scenic viewpoints of the garden terraces and mountain villages in Jebel Akhdar. The combination between scenery and science in this area is a perfect attraction. The fact that a high variety of well-preserved sea-creature fossils can also be seen today at an elevation of more than 2000m above sea level is striking.

In the last few years, the efforts of members of the Speleological Society of Oman have led to the discovery of several new cave systems in the al Jebel al Akhdar, where at least 10 new caves have been mapped and documented. These revealed a new aspect of enchanting attractions in the area that could be developed into geo sites. Caves often allow access to wide exposures of underground rocks and cave deposits; hence they contain significant information about the paleoclimate and the history of rainfalls, while enjoying the beautiful deposits that formed through thousands of years. The cave deposits in al Jebel al Akhdar indicate the presence of high rain-fall episodes, most likely in the last thousands of years.

Satellite image showing Al Jebel Al Akhdar Potential Geopark site

◀

The Permian coral gardens in Al Jabal Al Akhdar with their various types of corals and amazing preservation of fossils are certainly among the most attractive geological wonders in Oman and the region.

Oman Geoheritage and Conservation:

A good knowledge of geological heritage and tourism is an important factor in the holistic approach for sustainable development in the Sultanate of Oman. Geopark tourism may offer a whole new range of economic development potential if included within sustainable tourism-schemes. With spectacular landscapes and scenic vistas throughout the country, Oman is committed to expanding its reputation as a world-class tourist destination that is without equal in the region.

The tourism strategy for the country is heavily reliant on the beauty and diversity of Oman's landscapes such as the spectacular mountains features, which are located throughout the country. The geoheritage of the Sultanate of Oman presents a basis for geo conservation and geotourism activities. The relatively long tradition and currently satisfactory conditions of the protection of the geological and geomorphological heritage in Oman can be considered as a good starting point for the future of Geopark activities as some geotourism products were established.

The rocks of the Hajar Mountains and Al Huqf areas present a precious testimony of the history of the Earth. The combination of wonderfully colored rocks, spectacular droplets, uniquely shaped caps and monuments and huge dimensions is unmatched anywhere else in the world. Numerous areas in the Oman Hajar Mountains and Al Huqf desert areas offer immediate opportunities to develop a Geopark because of the presence of a diverse range of geological phenomena and outcrops including, amongst many, landforms, structures, minerals and fossils.

The record of the Earth's history in Al Hajar Mountains and Al Huqf areas is unique. They have a globally significant natural diversity, including sites of great importance for geo- diversity. The two areas comprise many geological heritage and geotourist sites of special scientific importance, rarity and beauty, and may not be solely of geological significance but also of archaeological, ecological, historical and cultural value.

The sites of these two areas could be linked to one another and safeguarded in a formally managed Geopark-type situation. For many tourists and geotourists, the charm of Oman lies in its mountain ranges and spectacular scenery and geology. However, much of the record of the geological history in Oman is fragile. It must be conserved so that future generations can enjoy it and seek a greater understanding of it for their benefit. Many elements of geology are irreplaceable if degraded. Common causes for the degradation of geological sites include; mining, commercialization, overuse, weathering, natural processes and tourism.

The development and planning for a tourism product is central to any touristic site development. Theoretically, tourism studies and scholars place geotourism products, activities, and experiences within the paradigm of Ecotourism. It is important to clearly articulate the main principles that any ecotourism products planners and developers, including geotourism, are required to consider. Many studies agree that geotourism products should:

- ⇒ Minimally impact its environments
- ⇒ Geotourism products should include education and learning components
- ⇒ Geotourism needs to contribute toward conservation of the park; and
- ⇒ Provide economic and social benefits to its community.

Acknowledgment:

Thanks to Ministry of Tourism who tasked GSO to conduct the feasibility study of Geopark in Oman in 2019 (Ref. 1) and for their agreement to share this article based on that study.

References:

Ibrahim Al-Ismaili, Mohammed Al-Kindi, Sobhi Nasr, Falah Al-Sukaiti; 2019; Feasibility study for sustainable development of geoparks in the Sultanate of Oman; Ministry of Tourism

إنجـاز 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.

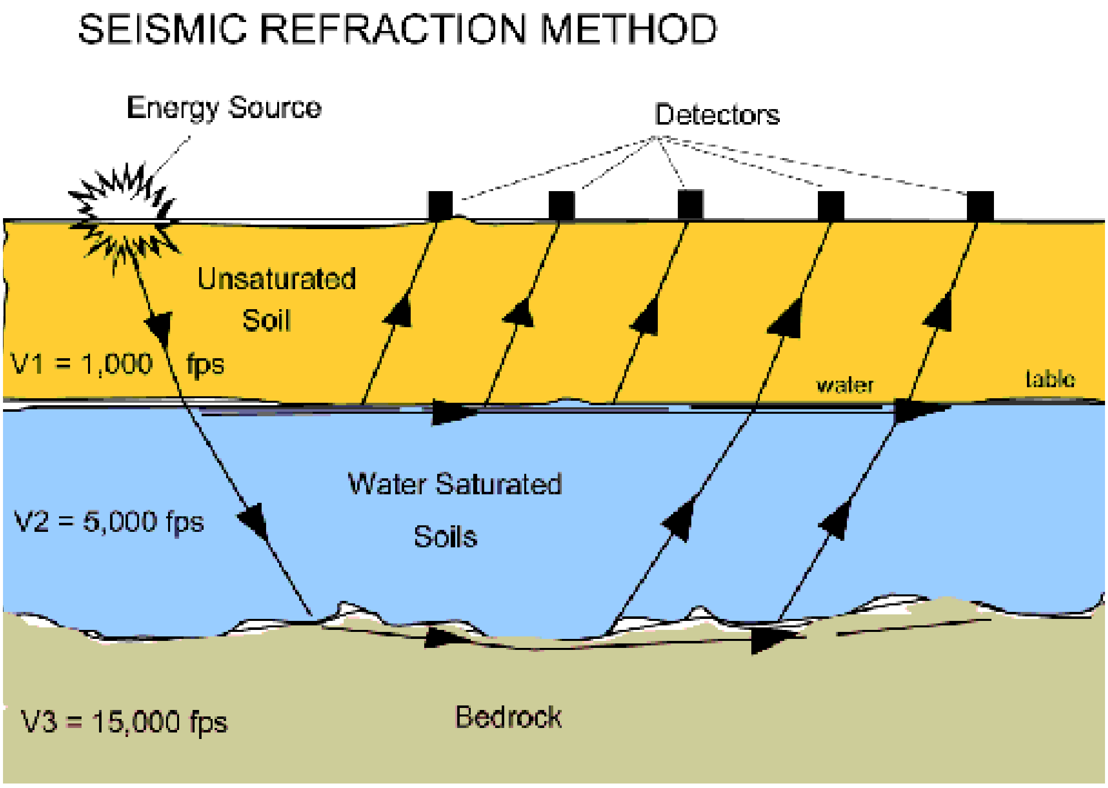
INJAZ UPS vision is to establish a local Omani community of geosteerers where the accumulated experience from geosteering in different fields will be retained and kept in the country and transferred to the subsequent junior geosteerers. With the expertise we will develop we have the vision to support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

Searching the Underground with Geophysics

By | Ahmed Al Yaqoobi

(Seismic interpreter at Petroleum Development of Oman)

Geophysics is the science of utilizing physical phenomena to understand the geology of the Earth subsurface. The geophysical methods are used to image the subsurface physical properties and geological structures. Such methods may broadly be sub-categorized to reflection and non-reflection types. Their practical applications span from exploration for hydrocarbons, mineral exploration, water supply, pollution monitoring, archaeological studies, geotechnical and forensic investigation, to construction of roads and buildings.



▲ *Seismic Refraction method layout*

The main geophysical reflection measurement known is the seismic method. This is the preferred method used by industry worldwide to explore for oil and gas. However, this article sheds the light rather on the non-reflection geophysical methods and their applications. Non-reflection methods are also known as near-surface methods due to their general limitation of measuring changes in the near-surface physical properties in order to construct a geophysical model of the Earth ground which could be used to interpret geological features and the different lithologies. The physical properties measured by near-surface methods include, but not limited to, seismic velocity, density, magnetic properties, resistivity, natural potential, etc. In all cases for such methods to work properly, the target body in the subsurface must have sufficiently different physical properties to its surrounding.

Seismic refraction method

The first geophysical type of measurement to tackle in this article is the seismic refraction method. Being the closest to seismic reflection method, seismic refraction is used to measure subsurface velocities by generating seismic waves using "sources" at the surface and record their travel times at the "receivers". The source for refraction method could be as simple as a hummer and a plate, and the receivers as geophones in a simple one-line layout. Those travel times are then used to construct a velocity model of the subsurface. Refraction methods are used to study the near surface layer – weathering layer – that could cause velocity uncertainties. The results are used to correct for statics especially in land surveys in order to correct to a datum. The limitation of these methods is in the depth of penetration.

Ground Penetrating Radar (GPR)

This method is very useful in detecting near surface metals, and therefore used in roads construction. The method measures changes in subsurface electrical and magnetic properties. GPR surveys use electromagnetic waves that are generated at surface, travel down through the subsurface and reflect back to surface when there is a change in velocity due to the electrical properties of the rocks. The arriving waves are plotted as a function of travel-time, and hence the similarity of GPR to

▶ *One layout of a refraction survey with 4 m spacing. (Courtesy of A. Yaqoobi, 2005).*

seismic reflection and seismic refraction methods. Real applications of GPR include identifying areas of damage in roads and bridges, forensic application, and locating graves and buried bodies. GPR methods are limited in depth of penetration and could be affected by rain.

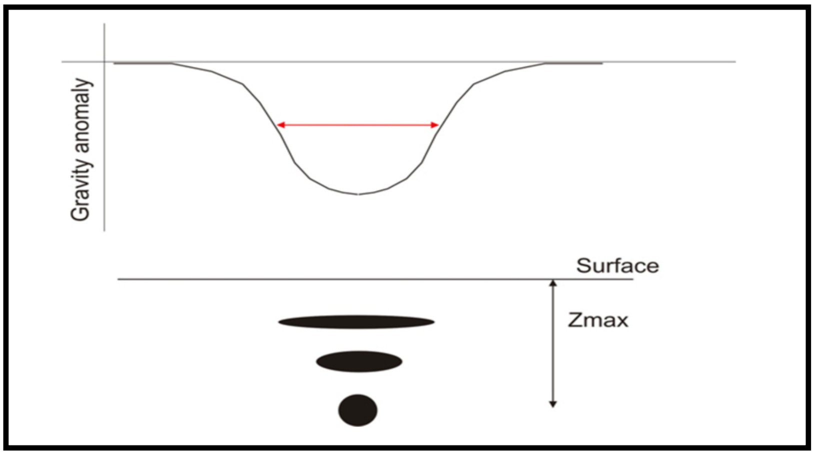
GPR method is used to identify bridge and road damages (photo from Infrastructure Preservation Corporation website)

Gravity method

The gravity method reflects the changes in near-surface density caused by the substantial difference in density of the target body compared to the surrounding. In addition to measuring density, the gravity readings could vary based on elevation, latitude, topography, tides, and instrument drift.

Therefore, a number of corrections are done to the gravity anomaly in order to account for other effects and reflects only the near-surface density. In general, salt bodies and sedimentary basins have relatively low gravity readings compared to ore bodies and anticlines. The main difficulty of conducting gravity surveys is the turn-around time, which means accurate gravity surveying is slow. As with many geophysical methods, the gravity survey has the main problem of non-uniqueness, i.e. a sized target body could give similar gravity response to bodies that are placed at shallower levels. Gravity surveys are commonly used in search for metalliferous bodies. Gravity data could also be used as constraints for mapping fault, and geological outcrops.

The same gravity response could be obtained from bodies with different sizes at different depths. ▶



Resistivity method

In order to detect discrepancies in fluid properties, resistivity method provides a good tool to achieve ▲ such a goal. Resistivity of rocks is a measure of how resistance the rocks are to current flow (electrical flow). The resistivity decreases in general with increasing area and increases with increasing distance (length). Resistivity is one of the most variable of physical properties. Certain minerals such as native metals and graphite conduct electricity via the passage of electrons. Most rock-forming minerals are, however, insulators, and electrical current is carried through a rock mainly by the passage of ions in pore waters. It follows that porosity is the major control of the resistivity of rocks, and that resistivity generally increases as porosity decreases. Dry rocks usually have high resistivities where as fluid inside the pores helps to flow the electric current (i.e. has high conductivity). Fresh water, gas and oil have a higher resistivity than saline water. The resistivity method is conducted by putting metal rods (called electrodes) into the ground. An electrical current is then sent through the electrodes and voltage drop is measured between two potential electrodes. The limitation of the resistivity method lays in the depth of penetration of the electrical field. In addition, thin beds may not be detectable with resistivity methods. Resistivity method is used a lot in wireline logging in a borehole. However, the ways of conducting resistivity in wireline logging differs from the surface resistivity surveys.

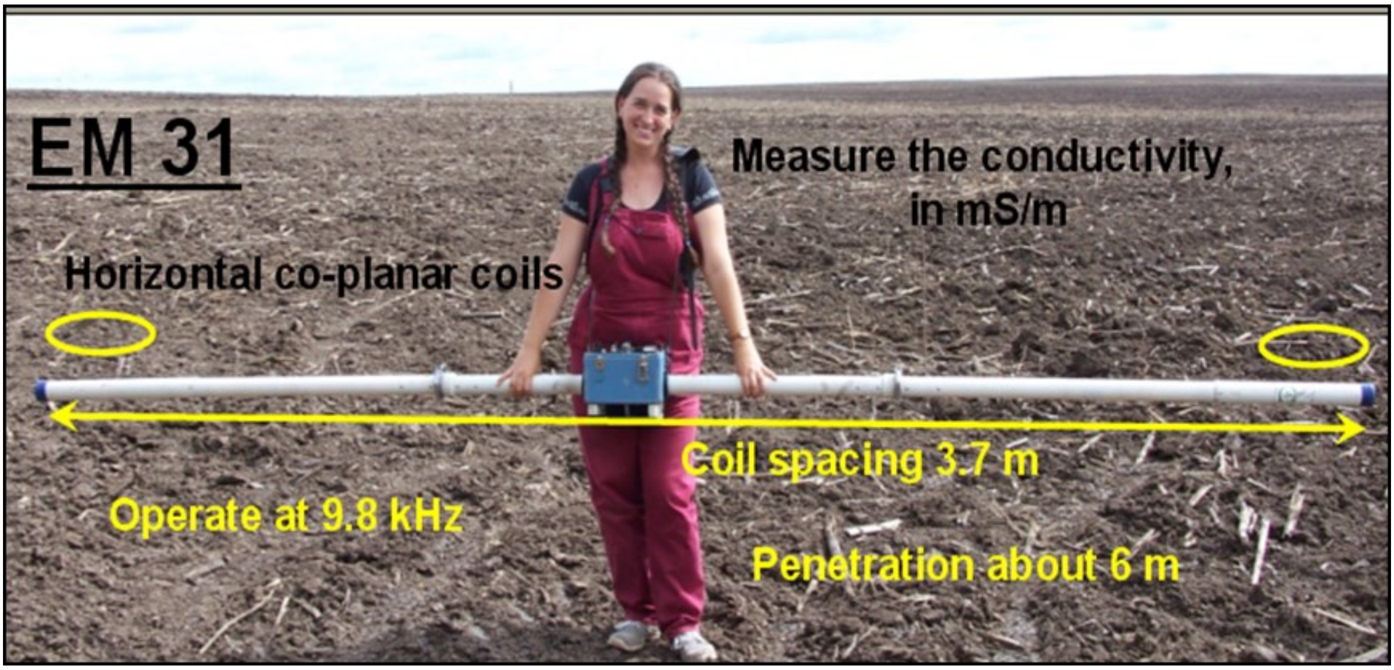
Other types

There are other types of non-reflection methods, including magnetic methods that measure changes in Earth's magnetic field. Such methods could be a good indicator of rock types. Another type is the self-potential (SP) method. SP is a measure of natural potential differences due to electrochemical reactions or flowing water. The method is also used in wireline logging in order to measure the clean sand (minimum SP) and shale (maximum SP) values. Electromagnetic (EM) surveying methods make use of the response of the ground to the propagation of electromagnetic fields, which are composed of an alternating electric intensity and magnetizing force. Primary electromagnetic fields may be generated by passing alternating current through a small coil made up of many turns of wire or through a large loop of wire. The response

▲ Layout of a resistivity survey. The survey could be 2D or 3D depending on the number of electrodes used in the layout (Courtesy of the State University of New York).

of the ground is the generation of secondary electromagnetic fields and the resultant fields may be detected by the alternating currents that they induce to flow in a receiver coil by the process of electromagnetic induction. A good example of EM tools is the GPR which is described above. Another example of EM tool is the hand-held portable transmitter and receiver EM-31 rode.

In conclusion, there are many useful applications for near-surface non-reflection geophysical methods depending on the purposes of survey and the objectives facing the conduction of such surveys. Those methods are limited in their depth of imaging and the target depth. Therefore, in a large-scale oil and gas exploration, the wide-azimuth seismic reflection surveys are the preferred methods.



Hand-held EM-31 tool used to conduct EM surveys (Courtesy of Yaqoobi A., 2007). ▲

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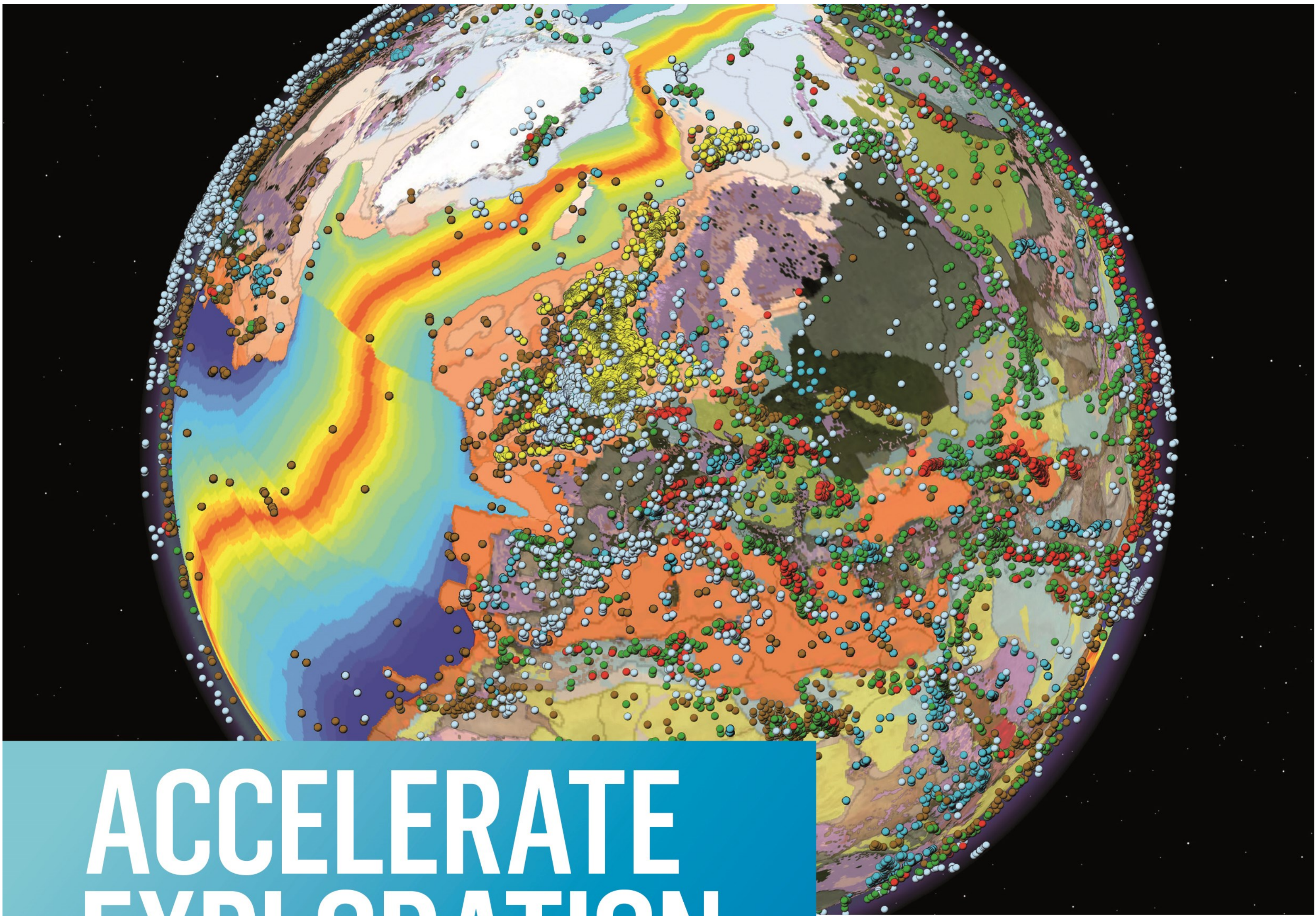


COMMENT ON:

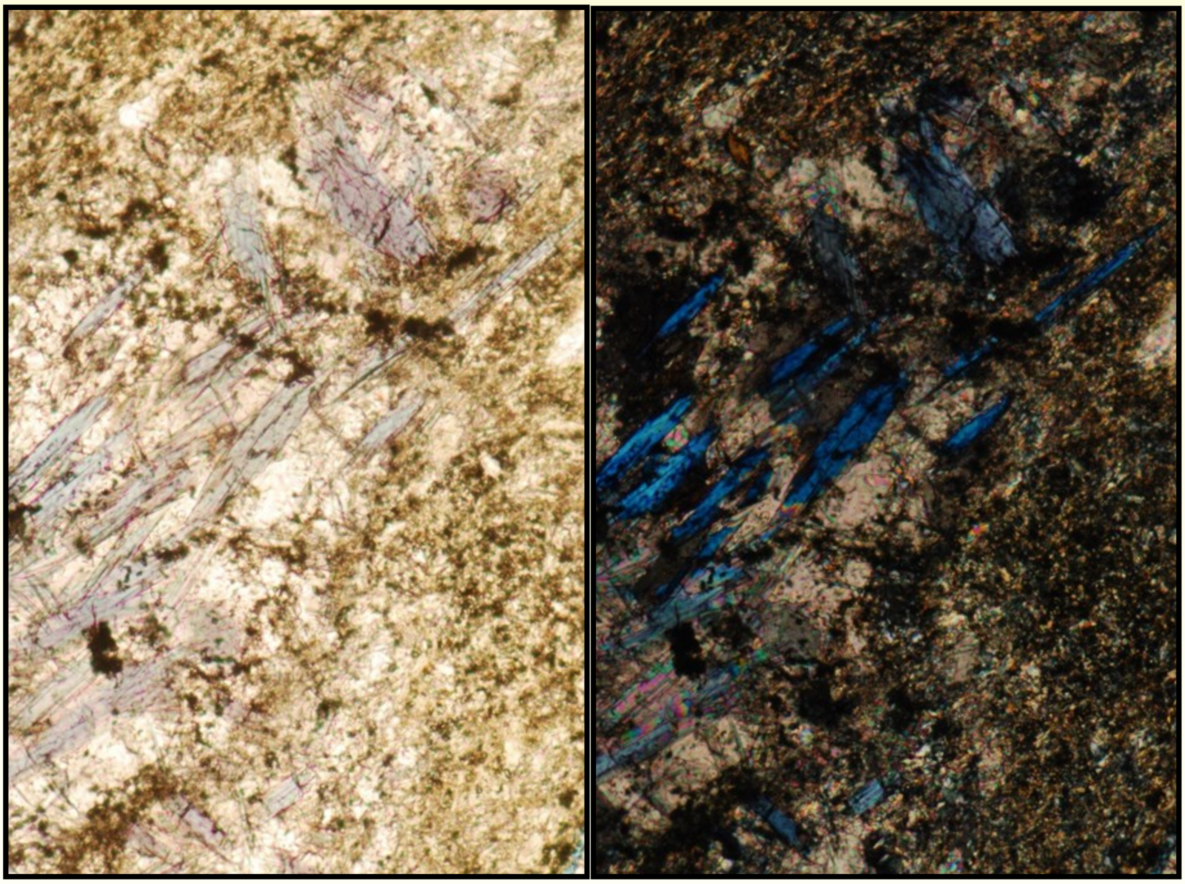
"ALAN P. HEWARD: FURTHER OUTCROPS OF DIAMICTITE IN WADI AMDEH: AL KHLATA, MESOZOIC OR CENOZOIC SLOPE DEPOSITS?"

By I Wilfried Bauer (Professor at German University of Technology Oman)

I read with great interest Alan Heward's article in the August 2019 issue of Al Hajar about his new interpretation of the diamictite outcrops in Wadi Amdeh which were originally interpreted as Al Khlata Formation by Heward and Penney (2014). In 2016, a student project at the German University of Technology in Oman focused on the petrography of pebbles and matrix of the supposed diamictite in Wadi Amdeh. Along a 15 m long profile in the main outcrop (which is shown on Heward's Fig. 1 on page 14 and not the new outcrop as stated in the description of figure 1) every 50 cm a pebble was collected to get a representative sample. The 30 pebbles are poorly to moderately rounded with diameters between 3 and 17 cm, and 13 pure quartzites, 5 dolomites and 8 limestones were identified. Four pebbles are rather dark, impure quartzitic rocks which may represent Amdeh 5 components. The lack of components of igneous origin and the discovery of fossiliferous limestone pebbles make an Al Khlata age very unlikely.

◀ Fragment of a large pebble from the Wadi Amdeh "diamictite" with a poorly preserved gastropod

The fine-grained matrix is composed of quartz, plagioclase (probably albite), white mica, chlorite (with anomalous leather brown interference colours) and glaucophane with a blue to brownish purple pleochroism. The needle shaped glaucophane crystals are obviously not detrital but most individuals are clearly oriented with their long axis parallel, concentrated in nematoblastic textures, indicating that the "diamictite" underwent blueschist facies metamorphic conditions. The only high-pressure metamorphism known to the Saih Hatat is related to the subduction of the edge of the Arabian plate prior to the obduction of the Semail Ophiolite. Peak low-tem-perature/high-pressure metamorphism of the As Sifah eclogite was dated as 78.95 ± 0.13 Ma (Warren et al. 2003), therefore a pre-Campanian depositional age of the "diamictite" in Wadi Amdeh is most likely. Considering the composition and the metamorphic overprint, the rock should be named a meta-conglomerate. Further research is necessary because a better understanding of the pre-obduction geomorphology are to be expected.



▲ Thin section of the matrix of the Wadi Amdeh "diamictite". Left plane polarized light, right crossed polars. Elongate blueish to purplish glaucophane with deep blue interference color, surrounded by calcite, mica, fine-grained quartz and chlorite. Width of view approx.. 0.28 mm.

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