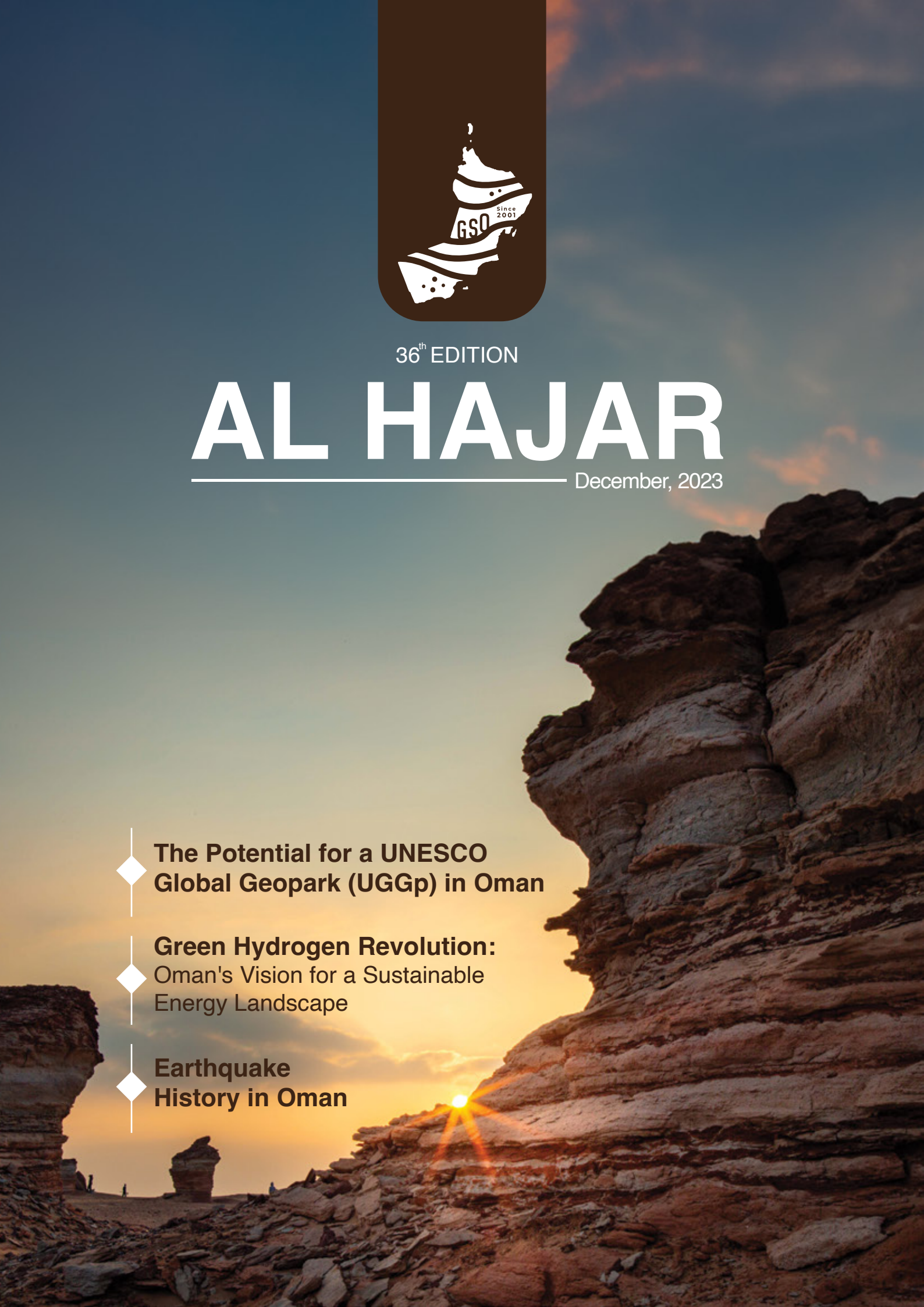

36th EDITION

AL HAJAR

December, 2023

The Potential for a UNESCO Global Geopark (UGGp) in Oman

Green Hydrogen Revolution: Oman's Vision for a Sustainable Energy Landscape

Earthquake History in Oman

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About GSO

The Geological Society of Oman (GSO) was established in April 2001 as a vocational non-profit organization which aims to advance the geological sciences in Oman, the development of its members and to promote Oman's unique geological heritage.

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Dear Readers,

Greetings from the editorial team of Al Hajar magazine! It is with immense pleasure and enthusiasm that I extend a warm welcome to each one of you. With each issue of Al Hajar magazine, we strive to build a bridge that connects the wonders of the Earth's past with the curiosities of the present. We explore the fascinating rock formations, the ancient tales preserved in the layers of stone, and the breathtaking landscapes that have been shaped by the forces of nature over millions of years.

Through the pages of Al Hajar, we aim to foster a community of geoscience researchers, students, and explorers. We strive to ignite curiosity, inspire exploration, and encourage the exchange of ideas and discoveries. The magazine is a canvas on which the vibrant colors of geological wonders are painted through articles, photographs, and insights.

I invite you to embark on this exciting geological journey with us. Let the pages of AL Hajar Magazine be a source of knowledge, wonder, and inspiration as we unravel the captivating mysteries of Oman's geology and the Earth's geological heritage.

Thank you for being an integral part of our community. Your continued support is what drives us to deliver the best geoscience content. Together, we can make positive contributions in the Earth sciences and develop a deeper understanding of our planet's history and future.

To access past issues of "Al Hajar," kindly visit our website. Feel free to explore the digital archive for a wealth of geological knowledge spanning several issues.

Warm regards,

Laila AL Zeidi
GSO Content Editor

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Huqf area,
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Honorary Membership Professor Sobhi Nasir

The Geoscience Society of Oman (GSO) is pleased to announce that Professor Sobhi Nasir has been awarded a lifetime Honorary GSO Membership. Professor Nasir holds a PhD in Mineralogy/Petrology from Wurzburg University-Germany. After his PhD studies he worked for 5 years at Yarmouk University in Jordan, 4 years at United Arab Emirates University, and 8 years at Qatar University. Prof. Nasir joined Sultan Qaboos University in Oman in 2004 as a department head and is now the UNESCO Chair for Ophiolite Studies as well as an Adjunct Professor at Western University, Canada.

Prof. Nasir relishes his continued involvement in teaching and research and contributes energetically to undergraduate and postgraduate teaching in various fields of Earth Sciences. He has published more than 250 papers in various journals, and has built an international reputation through his research. He serves on several editorial boards for international earth sciences journals and has received many national and international funding awards for his research. Dr, Nasir has also received many international awards including the ESESCO Prize for Sciences and Technology 2016.

Prof. Nasir continues to be highly involved in research with primary interests in ophiolite geology, volcanic rocks, carbonatite, kimberlite, and applied mineralogy. His research on upper mantle and lower crust mineralogy and chemistry has resulted in building a school

for Middle East petrology which has helped in interpreting large scale geological phenomena especially those related to the geodynamic evolution of the Arabian lithosphere and opening of the Gulf of Aden and the Red Sea.

The Geological Society of Oman awarded Professor Sobhi Nasir the Honorary Membership for his contributions, achievements and national initiatives in the field of geoscience. The Honorary Membership was given by his Excellency Mohsin bin Hamed Al Hadhrami, Undersecretary of Ministry of Energy and Minerals along with Husam bin Salim Al Rawahi GSO President, during the annual general meeting, 29th March 2023, attended by GSO members and other Honorary members.

The Potential for a UNESCO Global Geopark (UGGp) in Oman

Hoffmann, Gösta1; Decker, Valeska2
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When writing a text for the newsletter of the Geological Society of Oman, it seems unnecessary to emphasize that Oman is blessed with spectacular geology. However, in order to raise global awareness, it is worth doing so whenever possible. Therefore: Oman's geology is incredibly diverse and offers a fascinating glimpse into the Earth's history and geological processes. Exploring Oman's geology provides a remarkable journey through time and creates a deeper understanding of the planet's dynamic processes. In recent years, various books were published that describe the geological highlights of Oman (e.g. Hannah 1995, Guba 2002, Hoffmann et al. 2016, Al Kindi 2018, Searle 2019). The geotouristic potential of the country is evident (e.g. Dowling and Newsome 2010, Roepert et al. 2012, Nasir 2023). Further demonstrated by the fact that, for example, the German Geological Society has conducted fieldtrips in Oman for more than ten years (Kött 2023), both for senior scientists and also for young professionals and students for study visits (Djahansouzi et al. 2023). Usually, when planning a fieldtrip, you have to decide where to stop. In Oman it is the opposite: you have to decide where not to stop.

Do these facts qualify an area (or several areas) in Oman to become a UNESCO Global Geopark? The answer is: yes, partly. The UNESCO Global Geoparks initiative defines and supports unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education, and sustainable development. As outlined above, in a potential application to UNESCO it has to be unequivocally proven that sites and landscapes are of international significance, which could easily be demonstrated in Oman. However, geoparks are not Geology Parks as there is much more to a geopark besides outcrops of international significance.

Along with Biosphere Reserves and World Heritage Sites, Geoparks are one category of UNESCO-certified sites of worldwide special natural relevance. The establishment of a geopark follows a bottom-up approach that aims to combine conservation with sustainable development, while involving local communities. At present, there are 195 UNESCO Global Geoparks (UGGps) in 48 countries. None of them in Arabic countries.

One major goal of UGGps is the protection of geological heritage. A basic prerequisite and also their biggest strength is that they become model regions of sustainable development. UNESCO Global Geoparks promote sustainable local economic development and encourage local communities to use their geological heritage to create economic, social and ecological benefit for their home region. This can be achieved through geo-tourism but also by the creation and marketing of local products. The local communities are part of the management of the geopark. The overall goal is to achieve understanding for the geological heritage and how this is related to the biological diversity and to the cultural variety. Furthermore, UGGps have educational objectives. Schools and universities are involved in the activities of the geopark with a focus on education for sustainable development. In sum, a UNESCO Global Geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness and understanding of key issues facing society, such as using our earth's resources sustainably, mitigating the effects of climate change and reducing natural hazard-related risks. The successful establishment of a UNESCO Global Geopark requires active community participation and engagement. Oman has a strong tradition of community involvement and could leverage this to create a sense of ownership and responsibility among local communities, ensuring the sustainable management of the geopark.

Various regions were suggested for the establishment of geoparks in Oman (Searle 2014, Al-Ismaili et al. 2019). Out of these, one region seems very well suitable: the central part of the Hajar Mountains, including Jebel Shams, the Saiq Plateau, Nizwa, Al Hamra, Wadi

al Abyad, Nakhl and Rustaq. World class geological outcrops exist here. These include Wadi Ghul, the Permian unconformity (e.g. in Wadi Bani Kharus), the Neoproterozoic glacial deposits with cap carbonates, and the overlying tectonic nappes, including the Semail Ophiolite. Figure 1 gives an overview of the potential outline of a UGGp in Oman. Although this is rather a large area with roughly 30,000 km2 proposed, it is still feasible as no upper limit is defined by UNESCO.

Figure 1. Map of a potential UNESCO Global Geopark "Hajar Mountains" in Oman with several highlights illustrated.

People have been inhabiting this mountainous area already for thousands of years (e.g. Yule 2019). The mountain oases of the Hajar Mountains are unique. Various crops are grown here and very old cultural traditions still practiced, e.g. the production of rose-water. In a UNESCO Global Geopark, these traditions can be used for the economic benefit of the local communities and also demonstrated to visitors.

The Hajar Mountains are an area where the influence of climate change on the landscape and on society can be demonstrated. For example, the Falaj System is a sustainable way to use scarce water resources. The UNESCO World Heritage Committee recognized the cultural and technological significance of the Falaj System in Oman by inscribing five Falaj Systems on the World Heritage List in 2006. The Falaj System represents the ingenuity and engineering skills of Oman's ancient communities. It is an important part of the country's cultural heritage and has played a vital role in shaping the social and economic development of the region. The Falaj System reflects the close relationship between humans and water management in arid environments.

In conclusion: Based on its unique geological features, Oman's Hajar Mountains Geopark could become a model region for sustainable development, benefiting the local economy and serve as a major tourist attraction, promoting sustainable tourism. Once designated, the geopark must establish effective management and governance structures to ensure the conservation of geological, ecological, and cultural values. This includes developing a management plan, implementing sustainable tourism practices, fostering community involvement, and promoting education and research initiatives. Interpretation and visitor centres can easily be envisaged in the old castles of e.g. Nizwa, Bahla, Nakhl or Rustaq. Furthermore, parts of the historic city of al Hamra could also be included.

The acknowledgement of a region as UNESCO Global Geopark is not the end of a journey. On the contrary, the concession of UNESCO’s logo is the start of an enduring journey towards regional sustainable development. Following bottom up approaches, this journey can only be taken by enduring local engagement and regional initiatives as already initiated by the Geological Society of Oman. The procedure is outlined in detail in the document “Statutes of the international geoscience and geoparks programme“ published by UNESCO (2016) and may also be supported by the expertise of the German Commission for UNESCO which it gained by supporting the establishment of eight German UNESCO Global Geoparks.

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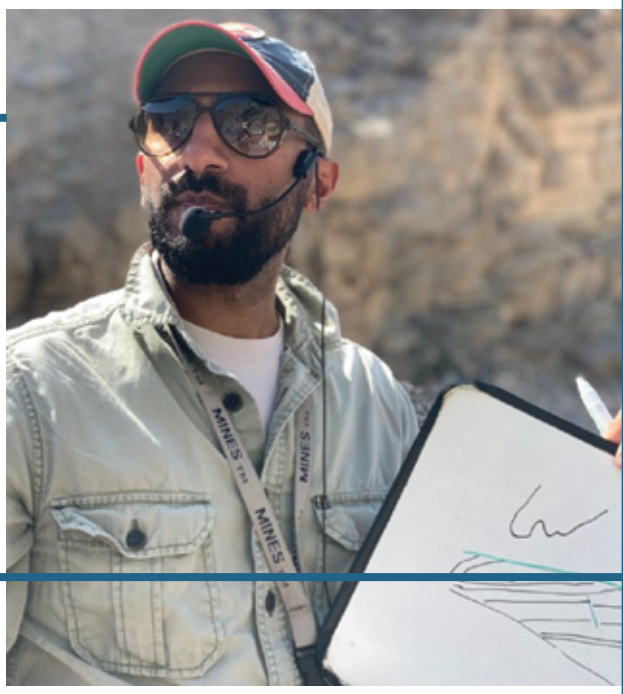
A Geological Tour Through The Geology Of The Jal Az Zor Escarpment, Kuwait

Mohammad H. Naqi, Ph.D.
Kuwait Geosciences Society, V. President
Kuwait University



Introduction

Kuwait is situated in the northeastern region of the Arabian Peninsula. Geologically, it forms part of the Arabian Plate, which was once a component of the ancient Proterozoic Gondwana Supercontinent and has shared its geological history and tectono-stratigraphy through much of the `Phanerozoic era.

While the surface geology of Kuwait appears modest, with most of the country covered by Quaternary deposits interspersed with a few exposed outcrops from the Oligo-Miocene to Pleistocene age, it is beneath the surface where the true uniqueness and fascination lie. The subsurface geology of Kuwait is characterized by remarkable and exceptional features (for further reading about the subsurface geology of Kuwait see, Al-Helal et al., 2023; Naqi & Amer, 2023). However, in this article will discuss only one of the major surface geological features of Kuwait, the Jal Az Zor escarpment.

A Brief History of the Geological Exploration of Kuwait

The geological exploration of Kuwait began in the early 20th century spurred by the pursuit of oil in the region which followed the discovery of oil in Iran in 1908. Initial geological investigations were conducted by British and American teams. In 1914, S. L. James, a British Admiralty commission holder, proposed drilling shallow wells based on oil seepages found in two locations near Bahrah (north of Kuwait Bay) and the Burgan area to the south.

Further studies followed in the subsequent years, with S. L. James and G. W. Halse conducting investigations in 1917, B. K. N. Wyllie and A. G. H. Mayhew in 1926, T. Dewhurst in 1931, and P. T. Cox in 1931-32 (Milton, 1967). Two shallow wells were drilled in 1931-32

at the proposed locations (Bahrah and Burgan) but they only penetrated the Miocene sands and hence they were dry (Milton, 1967). These efforts, along with a preliminary surface geology survey, led to the identification of a gentle anticline in the Miocene Formations at the Bahrah area.

In 1936, the first proposed well Bahra-1 was drilled in Bahra area (north of Kuwait Bay) based on a comprehensive geophysical survey that encompassed gravity, magnetic, and seismic surveys (Boots and McKee, 1946), however, it was dry. Another well was spudded in the south of Kuwait which revealed the huge Burgan oil field, which is the largest clastic reservoir worldwide. This discovery of commercial oil marked a turning point in the geological exploiation of Kuwait.

With the continued advancement of geophysical technology, more sophisticated and extensive surveys utilizing gravity, magnetics, and reflection seismology, helped unveil more of the complex geological history of Kuwait. These studies have since led to further significant oil and gas discoveries over the past several decades, establishing Kuwait as one of the world's major oil exporters.

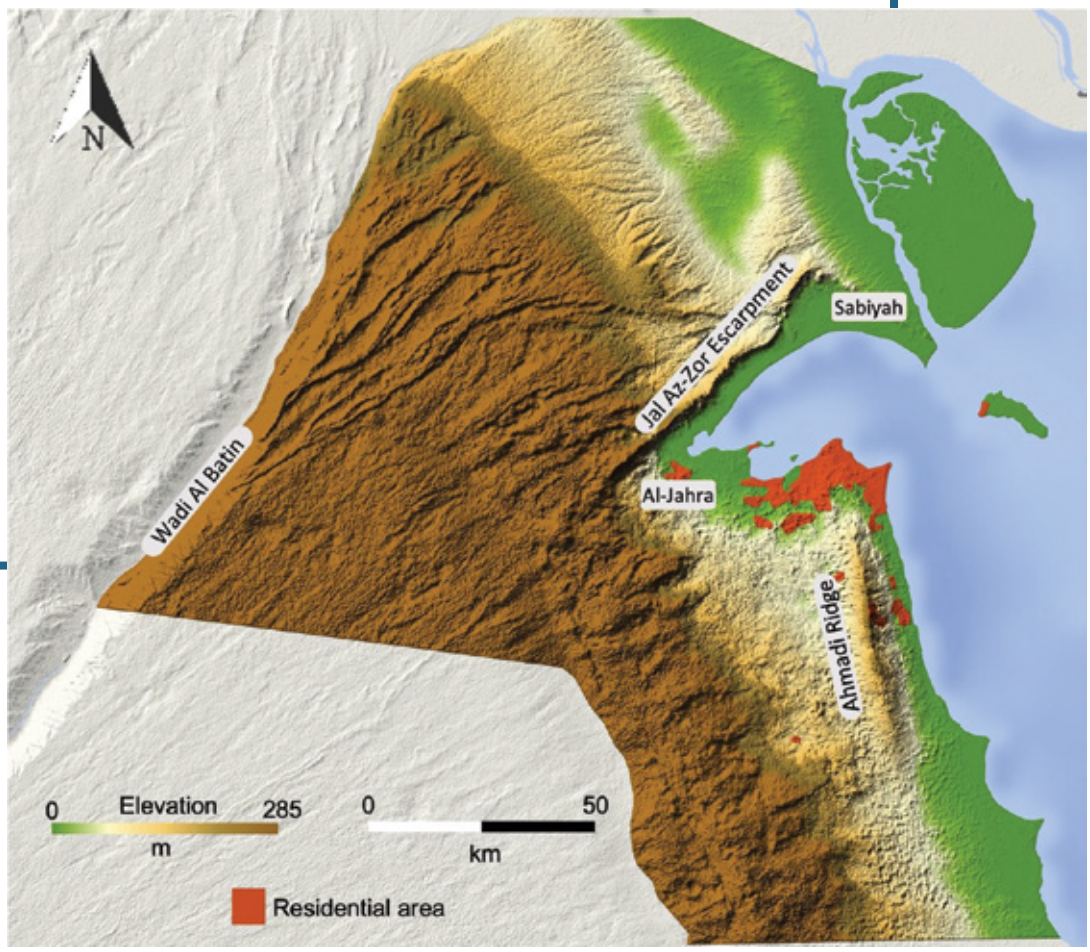


Figure 1. Topographic map of the State of Kuwait showing the main geomorphological features; Wadi Al Batin, Ahmadi Ridge and the Jal Az-Zor escarpment.

Jal Az Zor Escarpment

One of the profound geological features in Kuwait is the Jal Az Zor Escarpment which is parallel to the northern coast of Kuwait Bay (Figure 1). It extends about 60 km from north of Al-Jahra to the Sabiyah area and forms a cliff that reaches 36 m high (Figure 2).

Figure 2. Gully through the Jal Az Zor Escarpment cutting through Teriary rocks forming a cliff face of about 36 m from the escarpment base.

The origin of the Jal Az-Zor escarpment has been the subject of several geological investigations conducted by Salman (1979), Al-Sarawi (1982), Carmen (1996), and Amer & Al-Hajeri (2020), each proposing various scenarios. Al-Sarawi (1982) suggested, based on lithostratigraphic correlation between wells around the escarpment, that it resulted from the retreat of a major fault lineament located offshore in the center of Kuwait Bay during the Neogene, eventually reaching its current position through erosion. Bou-Rabee and Kleinkopf (1994), using free air and Bouguer gravity anomalies, proposed that the Jal Az-Zor escarpment is a surface expression of a basement strike-slip fault with minor displacement.

Al-Anzi (1995), based on a NW-SE 2D seismic section acquired in the 1960s, proposed the presence of a series of wrench faults without significant surface expression close to the Jal Az-Zor escarpment, although the interpretation was based on poor-quality seismic data.

Carman (1996) also placed the Jal Az-Zor fault in the center of Kuwait Bay. However, Amer & Al-Hajeri (2020) conducted a study utilizing reprocessed seismic data and were able to clearly identify faults and associated structures beneath the Jal Az-Zor escarpment. Through the interpretation of three seismic lines across the escarpment, they discovered the existence of detachment folds, recumbent folds, thrust faults, and fault propagation folds, forming a complex duplex system within the upper Dammam Formation below Jal Az-Zor. Their findings indicated that the present-day relief of Jal Az-Zor is a manifestation of fault kinematics and complex folding resulting from increased basal friction towards the south. Moreover, based on 2D structural restoration and balancing, along with GPS velocities and vectors for the Arabian Plate, Amer & Al-Hajeri (2020) estimated that the layers beneath the Jal Az-Zor escarpment accommodated approximately 6.25 km of shortening within the last 1 million years.

Stratigraphy of the Jal Az Zor Escarpment

The rock sequence exposed in the escarpment is part of the Kuwait Group which is composed predominantly of siliciclastic deposits (Al Refaei, et al., 2023). The Kuwait Group consists of three formations; the Ghar, Lower Fars and Dibdibah Formations from older to younger respectivly. However, the contacts between these formation were debated among geologists. Recent studies have proposed more accurate age constraints and more detailed stratigraphic descriptions for the exposed rocks (Amer & Al-Hajeri 2019, 2019a). The latter proposed an age of Late Eocene to Early Miocene for the rocks at the base of the Jal Az Zor escarpment.

According to Amer & Al-Hajeri (2019), the major occurance and distinctive facies exposed in Jal Az Zor is a calcareous sandstone facies. It is characterized by an amalgamated blocky pattern of poorly sorted calcareous sandstones to gravelly sandstones with an avarage thickness of 4 m. This unit is part of a larger estuary complex. The depositional environment of this unit is thought to be an estuary mouth bar\shoreface environment. This calcareous sandstone facies is bounded stratigraphically by thin beds of poorly to loosly cemented fine to medium sand size (Figure 3).

Figure 3. The stiff calcareous sandstone (light color unit) overlain by a more soft unit of poorly cemented sandstone (darker color unit).

The Jal Az Zor Joint System

The rocks exposed in the Jal Az Zor escarpment exhibit a structural joint system with two major trends, NE-SW and NW-SE (Figure 4).

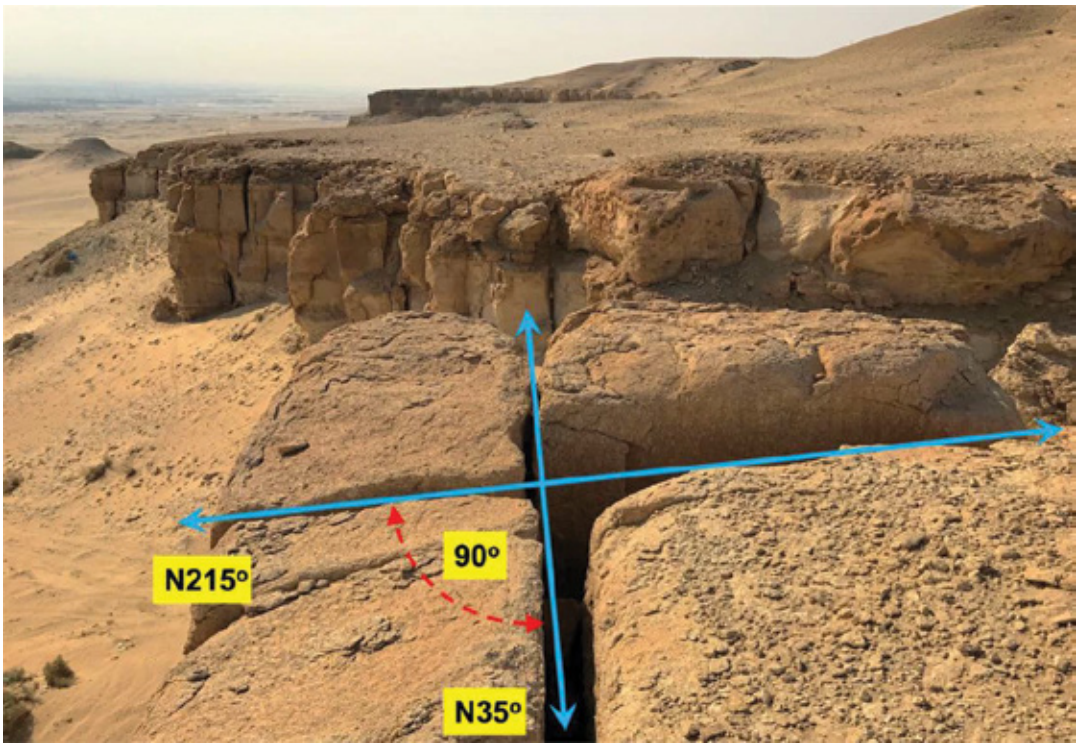


Figure 4. Two sets of orthogonally intersected joints cutting through the cliff forming calcareous sandstone unit.

Figure 5. One single joint cutting through both stiff and softer units. Notice the majority of the joints are constrained only within the stiff (light color) unit.

From outcrop exposures, the joint system seems to be present within the stiff calcereous sandstone beds and do not penetrate the over- and under-lying softer beds. However, some exceptions appear when the interbedded softer layers are relatively thin (Figure 5).

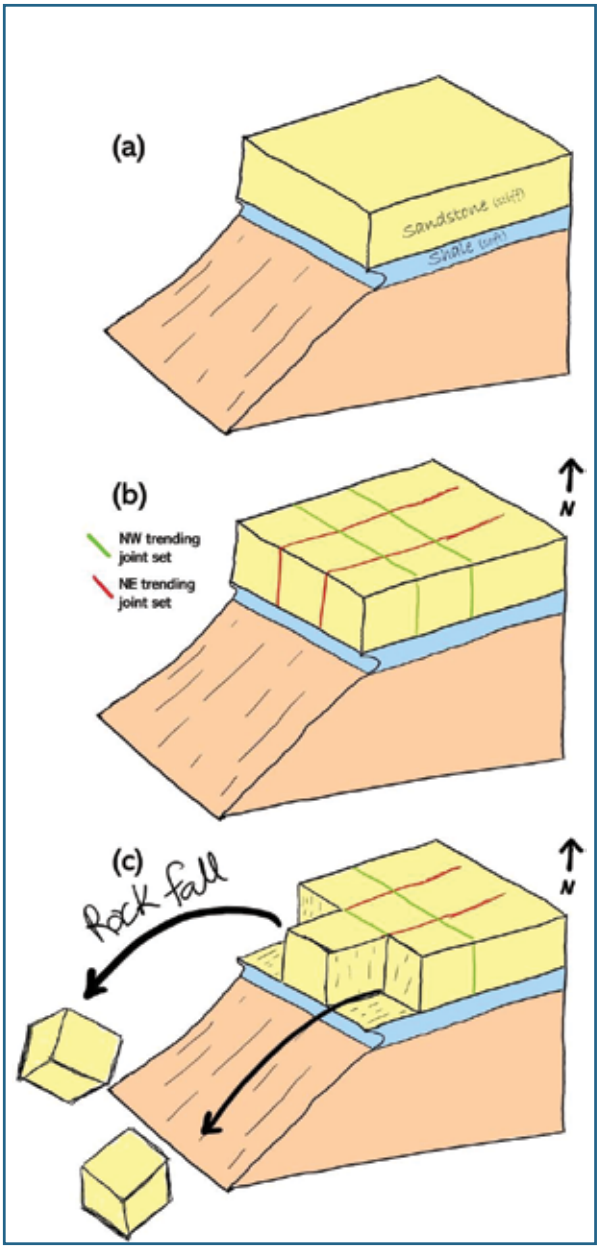


Figure 6. Conceptual model illustrating the role of the joint system in the development of the Jal Az Zor Escarpment.

The two joint sets are perpendicular to the bedding planes and intersect orthogonaly with each other forming cubical block masses. In addition, weathering and erosional forces along with gravity rock fall is causing mass wasting to occur. This mass wasting process is very active today and is probably responsible for the formation of the present day Jal Az Zor cliff (Figure 6).

The trend of the two joint sets coincide with present day in-situ stress. This stress in Kuwait is oriented NE-SW consistent with the current tectonic setting of the region due to the collision of the Arabian Plate with the Eurasia Plate since the Oligocene (Naqi & Amer, 2023). The NE-SW joint set is parallel to the maximum in-situ stress where as the NW-SE joint set is perpendicular. It is very common in foreland areas to observe a joint set parallel to the reigonal compressional direction. However, in the Jal Az Zor structure, the formation of orthogonal cross joints also requires a local principal stress rotation of 90. °This stress rotation can be atributed to numerous local and reigonal mechanisms (Bai et al., 2002), but the exact source of the stress responsible for the NW-SE jointing is not well understood. Given the age constraints of the Jal Az Zor rocks, the formation of these joint sets is probaly post-Pliocene.

The Kuwait Oil Company (K.O.C) is targeting the lateral continuation of the exposed Jal Az Zor rocks in the north of Kuwait for heavy oil exploration and production. The Lower Fars Formation in north Kuwait hosts a huge amount of heavy oil, hence rock exposure in Jal Az Zor offers a great oppurtinity for geologists to better understand the heterogeneity in those reservoirs of northern Kuwait.

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Green Hydrogen Revolution: Oman's Vision for a Sustainable Energy Landscape

Written by: Abdulhadi Al Saadi, Muzna Al Jufaili

Introduction

As we stand on the precipice of a new energy era, the most abundant element in the universe, hydrogen, makes a compelling case for why it should be part of a sustainable energy future. When combined with oxygen to release energy, hydrogen's only byproduct is water, thus making it seem to be an ideal green energy fuel. However, the environmental footprint of hydrogen hinges on its production method, which leads us to the concept of "green hydrogen."

The Green Hydrogen Revolution

Green hydrogen is the product of renewable energy sources powering a process known as electrolysis. During electrolysis, electricity — sourced from wind, solar, or hydro power — is used to separate water into its constituent elements, hydrogen, and oxygen. If the electricity is harnessed from renewable sources, the entire process results in minimal carbon emissions, hence the term "green."

The Role of Green Hydrogen in Achieving Net Zero

The global march towards a net-zero carbon future necessitates a 'seismic shift' in our energy landscape. Green hydrogen is poised to be a key player in this transition through the following:

- Tackling Hard-to-Abate Sectors: Industries such as steel and cement production are notoriously difficult to decarbonize. Green hydrogen can step in as a clean fuel or reducing agent in these processes.
- Storing Renewable Energy: The intermittent nature of renewable energy sources poses a challenge. Green hydrogen can act as an energy storage medium, holding excess renewable energy and releasing it when needed.
- Fueling Transportation: While electric vehicles are gaining traction for personal use, long-haul trucking, shipping, and aviation remain hurdles. Green hydrogen can provide a zero-emission fuel solution for these sectors.

The journey to net-zero emissions will require a diverse portfolio of solutions, and green hydrogen offers a versatile and scalable option to complement other renewable technologies.

The Geological Connection: Unearthing the Role of Earth Sciences

Readers with a keen interest in geology may be pleased to know that the Earth sciences play a significant role in the green hydrogen narrative. Examples of such include:

- Underground Storage: Post-production, hydrogen needs a home. Geological formations, such as salt caverns and depleted gas reservoirs can provide safe, large-scale underground storage for hydrogen.
- Natural Electrolytes: Some geological formations harbor brines that can serve as natural electrolytes in the electrolysis process, potentially driving down costs.
- Harnessing Geothermal Energy: Geothermal energy, derived from the Earth's internal heat, can be used to power the electrolysis process, further bolstering the sustainability of green hydrogen production.
- Carbon Capture and Storage (CCS): While green hydrogen is the ultimate goal, blue hydrogen (produced from natural gas with carbon capture and storage) can be a stepping stone. Geology is integral to CCS, as carbon dioxide is stored in deep geological formations.

As we delve deeper into the potential of green hydrogen, it's clear that it represents a promising pathway towards a net-zero carbon future. Its adaptability as an energy carrier can help decarbonize sectors that have long been considered challenging to electrify. The role of geology in this narrative, from offering storage solutions to facilitating sustainable production methods, highlights the intricate interplay of our energy and environmental challenges. As we forge ahead, the symbiosis between green hydrogen and geology will be instrumental in shaping a sustainable energy landscape.

Green Hydrogen Solution

In the quest for a greener and more sustainable future, visionary companies have emerged and are driving industrial innovations that can reshape our world. Among these trailblazers is Green Hydrogen Solution "GHS," an Oman-based company committed to advancing the green hydrogen sector through reliable scientific research and through fostering the potential of young minds. Founded with passion and a strong belief in the power of youth, GHS intends on being a driving force behind Oman's Vision 2040 which encourages reducing dependence on fossil fuels, diversifying the state’s sources of income, and creating new job opportunities for citizens.

The company, which started in 2021, has quickly emerged as an important player in the green hydrogen and alternative energy sector. Despite being a relatively new company, the GHS team is comprised of seven exceptionally passionate and talented young members who are all deeply committed to advancing sustainability. The dynamic blend of youthful energy, innovative ideas, and a strong sense of purpose has been instrumental in propelling GHS forward on its journey to create a greener future for Oman.

Each team member brings unique expertise and enthusiasm to the table, bolstering the company's scientific research efforts as it endeavors to develop green hydrogen technology. Dedication to this sector stems not only from their professional aspirations, but also from a genuine concern for the environment and a desire to make a meaningful impact on society.

Fostering a Fertile Environment for Young Talents

In a powerful and passionate endeavor to pave the way for a sustainable future, GHS has joined forces with several esteemed organizations to create fertile ground for the learning and exploration of green hydrogen and renewable energy.

One such initiative, the "Green Hydrogen Challenge Program," is a collaboration with NYP (National young professionals committee) Oman. This transformative 4-week online training program targets 50 exceptional engineering graduates, nurturing their potential as future leaders in the green energy sector.

Through intensive discussions and workshops, participants dive deep into the complexities of the hydrogen sector, addressing critical challenges head-on. From unraveling the secrets of economical production to devising safe storage and efficient transportation solutions for green hydrogen within Oman's borders, this program ignites an innovation and determination in the participants.

Another remarkable project that demonstrates GHS' commitment to nurturing the future, is the "Future Pioneers Program." This visionary project was born out of a powerful collaboration with Salcon, a teaching initiative dedicated to enriching the knowledge of middle school students.

With a primary focus on renewable energy, the "Future Pioneers Program" provided 120 bright young minds from various Sur area schools with a foundational understanding of renewable energy and an in-depth exploration of solar energy utilization in Oman. The students' enthusiasm for the renewable energy sector and their remarkable capacity to rapidly learn new concepts was truly impressive.

Figure 1: Participants in Future Pioneers Program

Figure 2: Future Pioneers program

Another joint effort with Salcon, was the “Future Makers Program" in which 80 Al Duqm students participated and learned about the wonders of alternative energy. Through captivating sessions and interactive tasks, they developed an understanding of renewable solutions in the battle against climate change. The success of this program encourages further commitment toward making a positive impact on the environment and the community through similar future educational initiatives.

Figure 3. Participants in Future Makers Program

Figure 4. Future Makers Program

One of the proudest achievements for GHS was the "Future Energy Leaders Competition" held during the Oman Green Hydrogen Summit in December 2022. This visionary project was aimed at identifying and promoting young talents in the dynamic field of hydrogen energy, and it received global participation from over 400 universities across 35 countries. In the competition, participants had the opportunity to present their cutting-edge research on various aspects of green hydrogen energy. The event drew the attention of experts from the energy sector, investors, and policymakers, creating an exceptional platform for participants to showcase their findings and engage with industry leaders.

Figure 5. One of the participants presenting her research.

The response to the competition was nothing short of overwhelming, as students and researchers from around the world eagerly submitted hundreds of entries. The exceptional quality of the submissions reflected the dedication and ingenuity of the participants, who presented groundbreaking research across multiple facets of hydrogen energy, encompassing production, storage, and utilization.

The winning team was a group of three girls from the German University of Technology. a Their research promoted green hydrogen production from effluent treated water from a sewage treatment plant. As first-place winners, they received a monetary prize of 1000 OMR. We are elated with the impact of this competition, which not only recognized outstanding young talents but also fostered a community of future energy leaders devoted to driving the transformation towards a sustainable and hydrogen-powered future.

Figure 6. Participants in the future energy leaders compitition.

Company Aspiration

In the pursuit of a commitment to a greener future, GHS aims not only to advance the green hydrogen sector but also to create a positive impact on society. This includes a core objective to increase job opportunities for young people within this burgeoning sector. Fostering a knowledgeable and skilled workforce will not only propel Oman's Vision 2040 forward, but will also contribute to sustainable economic growth and social development.

With the global call to reduce carbon emissions and combat climate change, GHS aspires to play a crucial role in reducing dependence on fossil fuels. By investing in green hydrogen technology and promoting the adoption of cleaner energies, they are paving the way forward toward a more sustainable and environmentally friendly energy landscape. Through dedication to reliable scientific research and technological innovation, GHS seeks to accelerate the transition towards renewable energy sources, thereby aligning with Oman's broader sustainable development goals.

Earthquake History in Oman

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1- General Introduction to Earthquakes

Earthquakes are natural phenomena that significantly impact specific regions on Earth's surface. They are defined as vibrations in the Earth's crust resulting from the release of stored energy in the form of seismic waves, caused by fractures in the Earth's rock layers. Earthquakes vary in magnitude, from weak tremors that are imperceptible, to violent quakes that are strongly felt and accompanied by significant destructive effects. The term "earthquake" is used to describe any seismic event that generates seismic waves, whether natural or induced by human activities.

Preventing or stopping earthquakes is difficult, and they are rarely accurately predictable. They can lead to extensive losses that societies cannot easily bear, requiring long-term efforts to mitigate their physical and psychological impacts. Therefore, studying and understanding the causes of earthquakes, their mechanisms, and how to reduce their risks are essential to avoid massive losses. Seismic monitoring centers worldwide strive to establish and develop extensive earthquake monitoring networks and attempt to predict seismic events. However, the world still faces numerous disasters and natural phenomena annually, resulting in building destruction and loss of human lives. An example of one of the most powerful devastating earthquakes globally in the last century is the 1960 Valdivia earthquake in Chile, with a magnitude of 9.5 on the Richter scale. It caused severe losses, including destructive tsunamis that wiped out entire villages.

2- Types of Earthquakes and Their Effects

Earthquakes are classified based on their energy sources into natural and anthropogenic (human-induced).

- **Natural Earthquakes:**

These earthquakes are further classified according to whether their energy sources are tectonic or volcanic in origin. Tectonic earthquakes occur in areas of the Earth's surface known as seismic belts or seismic zones. They are classified based on their formation stages and on the geological forces within rocks and neighboring tectonic plates. Tectonic

earthquakes result from crustal movements along plate boundaries, causing the Earth's crust to fracture. Tectonic earthquakes are the most destructive and challenging to predict. Volcanic earthquakes, on the other hand, result from volcanic activity as molten rock materials move from the Earth's interior to the surface. They pose various risks, including ground ruptures and deformations.

- **Anthropogenic (Human-Induced) Earthquakes:**

These earthquakes result from human activities that disturb rock layers, such as burying nuclear waste in deep repositories, building large dams and reservoirs, water and oil extraction, wastewater disposal subsurface mining, and rock blasting.

All types of earthquakes can have a disastrous effect on humans and their surrounding environment, often occurring suddenly and without prior warning. Thus, at-risk communities must be fully prepared for earthquakes, taking necessary precautions to minimize the damages caused by earthquakes. These risks include ground shaking leading to building collapses, changes in the Earth's surface level, ground ruptures and fissures, fires, floods, material damages, and psychological effects.

3- Earthquakes in the Sultanate of Oman

Earthquake research in the Sultanate of Oman is of great importance for monitoring seismic activity both historically and in modern times. Oman established a seismic monitoring center at Sultan Qaboos University, one of the oldest and most significant research centers in the country. This center oversees the Oman Seismic Monitoring Network's continuous monitoring and development, reporting seismic events within and outside the country, and disseminating data to relevant authorities.

The Oman Seismic Monitoring Center has established twenty seismic monitoring stations distributed across different regions throughout the Sultanate. It continuously assesses seismic hazards by determining earthquake locations and measuring their magnitudes. The center prepares seismic studies, reports, and necessary maps for earthquake-prone areas within Oman and its neighboring regions. Moreover, the center promotes awareness, emergency planning, and updates building codes to reduce earthquake losses, ensuring the safety, stability, and resilience of structures and facilities. The center employs modern technology to display earthquake maps, helping decision-makers and rescue teams identify high-risk areas and provide necessary services.

4- Historical Earthquakes in the Sultanate of Oman

The Sultanate of Oman is situated in the southeastern part of the Arabian Plate, encompassing the Arabian Peninsula along with the surrounding seas, including the Red Sea, Arabian Sea, Gulf of Aden, and the Sea of Oman. Oman is affected by three major tectonic movements: the northeastern margin, the Zagros collision zone, and the Owen Transform Fault. These movements give rise to various seismic activities and structures in the region. As the Arabian Plate moves northeastward, differential deformation occurs in its various parts, leading to earthquakes within the plate. Seismic activity is more concentrated along the Arabian Plate's boundaries, particularly the Zagros collision zone, which exhibits intense seismic activity. However, Oman is relatively stable tectonically, and its seismic activity is limited despite being affected by seismic faults from various directions, such as the Sea of Oman, Arabian Sea, and the northern Oman Mountains.

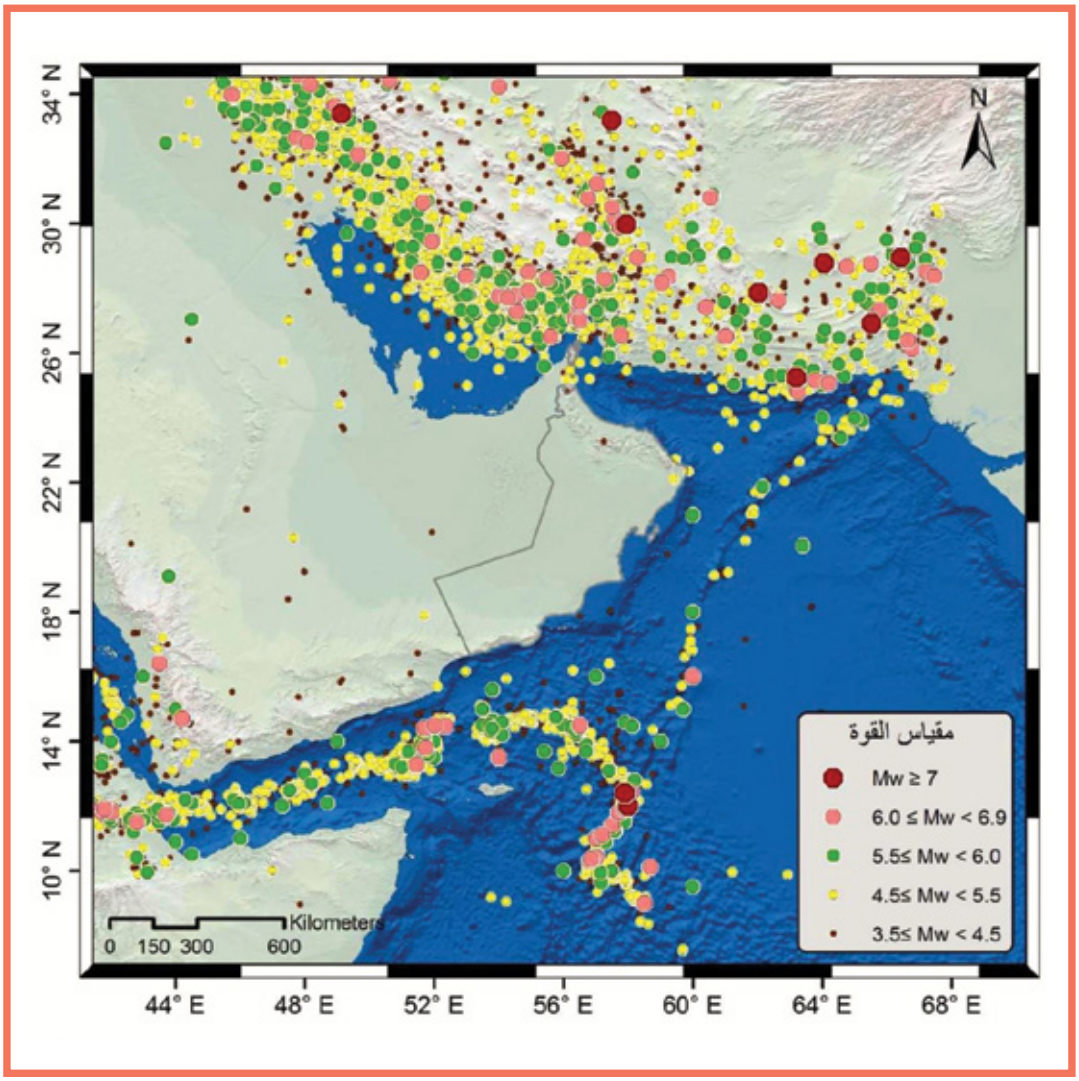

Figure 1. Recorded seismic activity within and around the Sultanate of Oman from 1900 to 2015, illustrating that the boundaries of the Arabian Plate exhibit higher activity compared to its interior. (Source: Sultan Qaboos University Seismic Monitoring Center, 20th Seismic Bulletin).

Historical earthquakes, tectonic activities, and geological data, including surface faulting zones, are among the crucial factors that can be utilized and detailed to understand the tectonic seismicity of the Sultanate of Oman and its surrounding areas. Reports and historical records indicate the occurrence of perceptible earthquakes in Oman between the years 977 and 1999 CE. These reports and data were documented in ancient manuscripts, some of which were compiled from elderly individuals recounting past events. Some of these data are not highly reliable due to their reliance on human memory.

Prominent examples of historical earthquakes include occurrences in Masqat in the years 977, 1184, and 1483 CE. Another notable earthquake occurred in Qalhat in 1491 CE, which led to the destruction of the Qalhat region. This is considered one of the largest ancient earthquakes to hit the Sultanate. In 1883 CE, tremors struck Nizwa and its vicinity, resulting in the destruction of nine villages. An earthquake also occurred in Muscat in 1929 CE, but caused no significant damage. In 1945 CE, an earthquake with a magnitude of 8.1 on the Richter scale struck the Arabian Sea near the Balochistan region in Pakistan, generating a tsunami that affected the coasts of Oman along the Arabian Sea and the Sea of Oman.

In the Al Kamil area, a 5.1 magnitude earthquake on the Richter scale occurred in 1971. In 1982, an earthquake with a Richter magnitude of 5.7 hit Yemen, and was felt by the residents of Salalah. Similarly, in 1983, multi-story buildings in Muscat experienced a 6.5 magnitude earthquake, which occurred in Balochistan about 590 km away from Muscat.

Additionally, three earthquakes were detected in the Rustaq region in 1998, and their seismic waves were recorded. The following table documents some of the destructive earthquakes and tremors that were felt within the Sultanate of Oman:

Table 1. Historical Earthquakes Perceived in Oman.

Number	Location	years of occurrence of seismic events or earthquakes (AD)
1	Sohar	968
2	Musandam	977, 1184, 1483 (and others)
3	Qalhat	1491
4	Nizwa	1883, 1931
5	Muscat	1929, 1958, 1960, 1965, 1967, 1969, 1983
6	Al Qabil	1934, 1968, 1971
7	Shinas	1945, 1955, 1965
8	Al Kamil and Al Wafi	1949, 1955, 1971
9	Saham	1944, 1945
10	Sinaw	1945
11	Al Buraimi	1965, 1983
12	Nakhil	1965, 1996
13	Qurayyat	1965, 1967
14	Masirah	1965, 1967
15	Liwa	1969
16	Ja'alan Bani Bu Hassan	1969
17	Salalah	1982, 1995
18	Al Halaniyat Islands	1995
19	Al Rustaq	1998, 1999

These events highlight the historical seismic activity within the Sultanate of Oman and underscore the importance of studying past earthquakes for assessing seismic risks and enhancing preparedness measures.

Previously, very few earthquakes were recorded in Oman due to the absence of local seismic monitoring stations. However, with the advancement of technology and collaborative

research efforts with other countries, Oman has undertaken significant efforts to establish seismic monitoring networks and stations in various locations. This focus on studying seismic activities and determining their levels contributes to creating a detailed database for conducting research studies.

By investing in seismic monitoring infrastructure and conducting studies on seismic activities, Oman aims to enhance its understanding of earthquake occurrences, their patterns, and potential impacts. These efforts not only improve the scientific knowledge about earthquakes in the region but also contribute to the overall preparedness and mitigation strategies to minimize the potential damage caused by future earthquakes.

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Interview with Lukman Al Hooti,
Explorer and Gemstone Collector

1- Please tell us about yourself

I am an Omani researcher and explorer with a keen interest in the gemstones, minerals, and fossils found in the Sultanate of Oman. I diligently work on exploring and studying these precious gemstones, minerals, and rare fossils in various regions of the country. Additionally, I have a great passion for crafting and designing exquisite jewelry using these precious gemstones and metals, and I strive to create unique and captivating designs that reflect the culture and beauty of Omani gemstones.

2- How did you start your journey in collecting gemstones?

The journey began with a series of questions during my frequent travels through the mountains and valleys in different parts of the Sultanate. While driving amidst the mountains, I observed the diverse landscapes and rock formations in each area. It was on one such day that I pondered why there was little mention of Omani gemstones. This sparked my curiosity, leading me to embark on extensive research through the internet and other various sources. However, I could only find brief references to certain types of stones. From that moment on, a deep passion for exploring and studying gemstones within the rocks of the Sultanate was ignited within me

3- How did gemology catch your interest in the first place, and what motivated you to search for gemstones?

People often assume that I started with a degree in geology. In reality, my university studies were in the field of business administration, and all my knowledge of geology was

self-taught. As I began to explore for and find different types of rocks and gemstones, I attempted to identify their scientific names through various sources such as books and specialized laboratories, I realized that there is a vast array of gemstone classification and that gemology is a dedicated scientific field. This inspired me to purchase more books and to dedicate hours each day to reading and also to participating in online courses taught by specialized instructors for a fee. These introduced me to gemstones, their examination methods, and classifications. After gathering relevant information through study and research, I then applied that knowledge in the field toward the investigation of many kilometers of rock outcrops. Whenever this research and exploration led me to find gemstones, I felt proud and satisfied and considered it an achievement or a goal accomplished. This further motivated me to search for other types of gemstones.

4- What does your hunt for gemstones look like nowadays? Tell us the techniques you use to search for and extract gemstones.

I continuously document all my gemstone exploration trips, which I share on my Instagram page (alhooti__). These posts have gained appreciation and interest from many enthusiasts both within and outside the Sultanate. The tools I use in my search are simple: knowledge, a hammer, and a chisel. As for discovering gemstone locations, this is done by first understanding the locations of different rock types in Oman. Rocks serve as the host for gemstones, and each gemstone forms in a specific type of rock. For example, when I want to search for agate, I explore sedimentary rock sites. It wouldn't make sense to search for agate in granite rocks due to the differences in minerals and formation conditions between them, and this applies as well to all other types of gemstones.

5- Where do you see yourself going with your talent? What's next for you in collecting gemstones?

I document and photograph all the gemstones I find, along with the methods used to discover them, noting everything in my journals. I hope to organize and document them further in a dedicated book about Omani gemstones.

6- What are the types of gemstones you collect, and how many do you have currently? Please tell us about your favorite one.

The gemstones I have collected include black and green tourmalines, aquamarine, green garnet (tsavorite), demantoid garnet, and various quartz crystal types such as high-purity amethyst, citrine, smoky quartz, and large, well-formed crystals of Herkimer quartz, weighing up to 2.7 kilograms per crystal. Additionally, I have turquoise, two types of opals - dendritic opal and fire opal - with distinctive colors, as well as fluorite, and various agate types in different colors and forms. My personal favorites are aquamarine, tourmaline, and green agate, which is considered rare among agate varieties as the unique green color is found only in Oman. The Omani gemstones I have collected amount to over 400 kilograms, and while there are many more in nature, I content myself with taking small and distinctive samples of each type.

7-How do you benefit from collecting gemstone?

I have utilized my collection by creating a mini-exhibit of various Omani gemstones, which I keep at home and display in a gallery. Visitors to the exhibit are introduced to Omani gemstones, and I am supported by a company called Ooredoo. Interested readers can visit my gallery by contacting me through the provided Instagram. I also cut and polish these gemstones and transform them into gems used in making jewelry. There is a large demand for these gems, which has led me to establish a specialized workshop for jewelry production, thereby turning this hobby into a source of income.

8- What are the challenges you face in collecting gemstones?

In the beginning, the challenges were the scarcity of specialized information on Omani gemstones and mining sciences. Additionally, people found it difficult to accept the idea that gemstones occur in Oman. This led some to doubt the credibility of the information and the stones that I photographed and shared. However, with time, the reputation of Omani gemstones became better understood, and the demand for them has increased. It has become a hobby that fascinates young people who are interested in exploring and benefiting from gemstones by selling them. I haven't faced any problems because I avoid entering restricted areas and private properties. I focus my research in remote areas far from populated areas.

9- What is your advice for people who want to search for gemstones?

My advice to those interested in gemstone prospecting is to obtain information from reliable sources. There is an abundance of false information circulating on social media that can hinder proper understanding of the prospecting process. It's crucial to learn about geology, distinguish between types of rocks and minerals before embarking on the search for gemstones. Also, prospectors should be humble, taking only necessary samples and leaving the rest for future generations while preserving the discovered sites for researchers and specialists to benefit from. These are some sources that I used:

https://www.gemstones.com/gemopedia/topaz#Alternate-Names

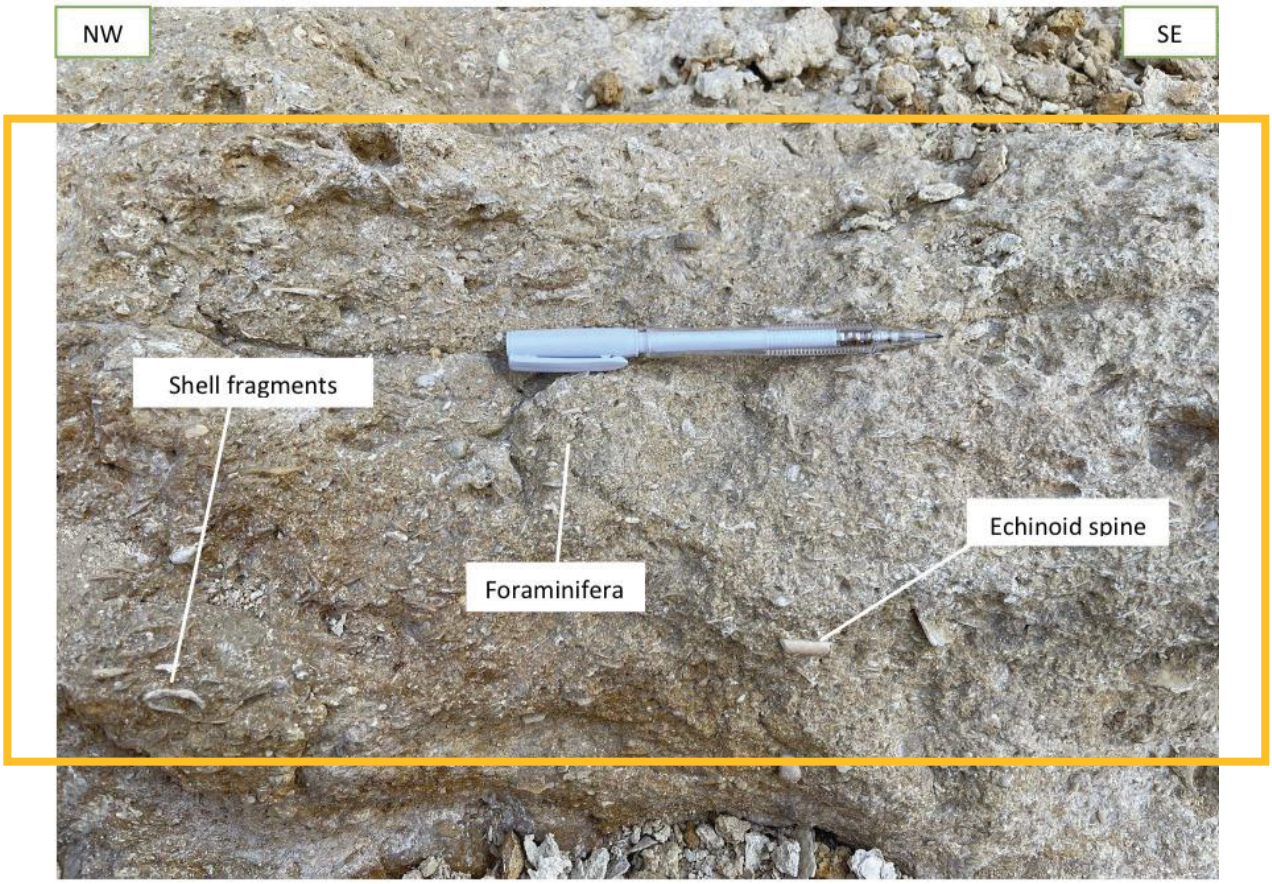
https://www.opalauctions.com/learn/did-you-know/difference-between-precious-and-common-opal

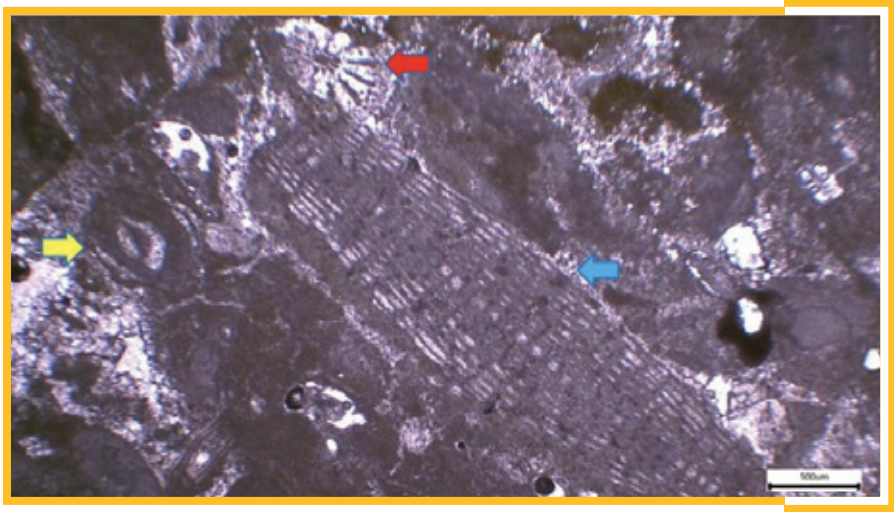
https://youtu.be/xEuMlXMth_M

https://youtu.be/9xolSxRfblc

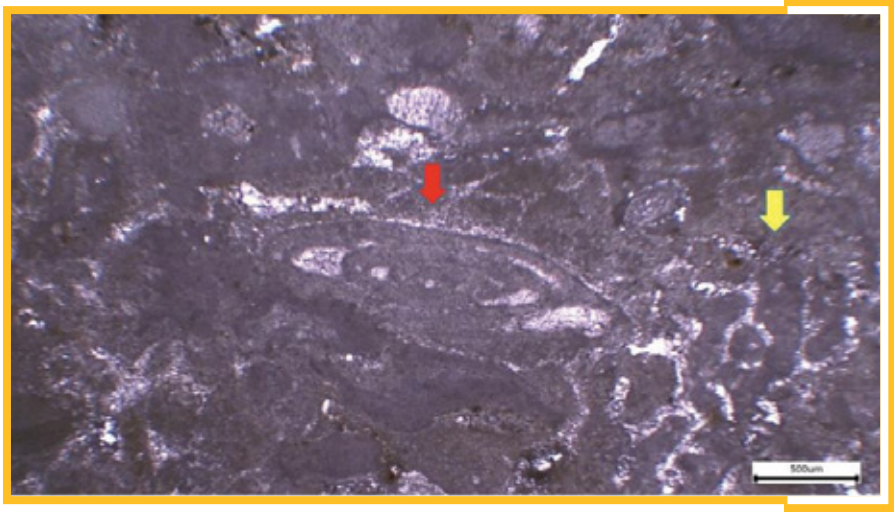
Microfacies of the Ma'ahm Reef Formation

This photo is of the Middle Ma'ahm Reef Formation which located in south Mawaleh, Muscat. The bed is a brown color fossiliferous limestone which measures 50 cm thick. It is described as a packstone and comprises diverse types of bioclasts such as echinoid spines, corals (not oriented in their original direction of growth) and shell fragments, but it is predominated by the presence of benthic foraminifera.





These photos are of samples taken from the packstone bed and shown under microscope. The red arrow in the photo at the top points to an echinoid spine in a slightly oblique orientation. The yellow arrow points to a Miliolid foram. The blue arrow points to large Sprioclypeus foram species with well-preserved calcitic walls. This sample is classified as a biomicritic packstone. The red arrow in the photo at the bottom points to an oblique section of a coiling benthic foraminifer. The yellow arrow points to a poritid coral whose septae are neomorphosed. This sample is also classified as a biomicritic wackstone.



Taken by: Fatima AL Mahrouqi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