AL HAJAR

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"Old Oman, New GeoParks" by Professor Mike Searle

"Ghaba-1: A little bit of Yorkshire in Oman" by Dr. Alan Heward

"Magma Mingling in the Oman ophiolite" by professor Hugh Rollinson

interview with professor **"Gösta Hoffmann"**

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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,

It brings me immense pleasure to extend a warm welcome to each of you. In the world of geology, where every rock holds a story and every mineral whispers secrets of Earth's history, our publication serves as a portal to exploration and discovery. In this issue of AL Hajar magazine, you will read about “Old Oman” written by Prof. Mike Searle. He reflects on Oman's geological and natural beauty, from its stunning mountains to pristine coastlines. These features have captivated visitors for decades, and despite the nation’s rapid development since the 1970s, Oman has prioritized the preservation of its unique geological heritage. “Ghaba-1: A little bit of Yorkshire in Oman” written by Dr. Alan Heward, explores the relationship between the Ghaba-1 rig derrick (a towering landmark visible from the road between Adam and Haima) and a Yorkshire Geological Society fieldtrip to the Cleveland Ironstone exposures at Skinningrove in the UK. “Cement Grade Limestone Deposit of Wantrag Anantnag Kashmir India” written by Mohsin Noor discusses a Late Triassic limestone belt situated between Mattan and Chak Ishwar Dass Wantrag Anantnag in Kashmir India. “Magma Mingling in the Oman ophiolite” written by professor Hugh Rollinson, explains plagiogranites which are located within the crustal section of the ophiolite and whose origin is closely associated with the mafic magmas of the ophiolite. We also share an interview with professor Gösta Hoffmann who has been a key member of the Oman geological community for many years.

As we embark on this journey together, I invite you to immerse yourself in the richness of our magazine and to engage with its content. Your support and enthusiasm are what drive us forward, and we are deeply grateful for the opportunity to share our passion with you.

Thank you for being a part of the GSO community. Together, let us continue to explore, discover, and marvel at the geological wonders that surround us.

Warm regards,

Laila AL Zeidi
GSO Content Editor

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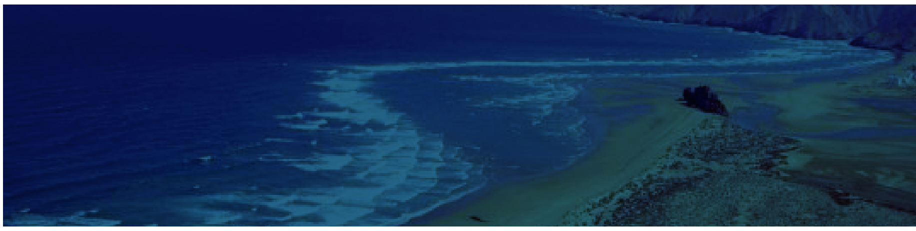
Old Oman,
New GeoParks



Mike Searle

Oman is blessed with an incredible array of geology and geological landforms. It has the most spectacular mountains in Arabia, a beautiful coastline and some World-class geological sites. I first came to Oman in 1967 as a 15-year-old schoolboy. My father worked for PDO and my mother worked in the Mission Hospital in Muttrah. In those days, Muscat was almost cut off from the outside world, surrounded by ophiolite mountains with watchtowers on hilltops (Fig. 1). The only road in Oman was a narrow concrete track between Muscat and Muttrah. Muttrah harbour was full of wooden dhows, and the fish catch was landed every morning on the beach.

Figure 1. (a) Muscat harbour, viewed from Fort Mirani, ca 1969. (b) Muttrah harbour with dhows, ca. 1974. (c) Semail Gap with Jebel Nakhl in distance and the ophiolite mountains in foreground, taken from the air, 1977. (d) Rustaq fort, ca 1975.

The Ruwi valley had one building, the old fort at Bait al Falaj, and a short airstrip where old Dakotas used to land. Flights from Dubai were the only way to travel to Muscat. The airstrip later moved out to Azaiba and then Seeb. The interior was extremely remote with only 4-wheel drive access to any major towns, like Nizwa, Ibri and Rustaq. The oil pipeline connecting newly discovered oil fields in Fahud, Natih and Al-Huwaisah with the offshore single buoy moorings feeding tankers offshore at Ras al Hamra (Saih al-Maleh), was constructed along the Semail Gap. The Batinah coast was an unbroken stretch of beach from Qurum to the Emirates border north of Sohar, with a few date palms and barasti palm frond houses in fishing villages scattered along the beach (Fig. 2). Before outboard motors arrived, fishermen landed their catch every morning on the beach with their small palm reed boats, shashas.

Figure 2. (a) Qurum beach, 1968, (b) Wadi Aday and Qurum beach, 1973. (c) Ras al-Hamra beach and Fahal Island beyond, 1968. (d) Al-Bustan beach, 1969.

Oil workers lived in the PDO camp at Ras al Hamra, a beautiful setting on hilltops overlooking white sand beaches. The rocky coastline to the east was dotted with a series of pristine beaches and coves from Sidap and Al Bustan to Bandar Jissah and beyond (Fig. 3).

One of the most beautiful beaches was the Yiti beach at the mouth of Wadi Mayh with its lagoon full of flamingos (Fig. 4). The lagoon was in-filled and the village moved for the new developments which are still ongoing. East of the capital area, the mountains dropped straight into the ocean with drowned fjord-like inlets at Bandar Jissah and Bandar Khuyran. Coral reefs offshore were pristine with any number of reef fishes, rays and black-tipped reef sharks. Occasionally we would see schools of dolphins, breaching sting rays and even whales. A magnificent stretch of deserted beach around the fishing village of As Sifah was surrounded by remote mountains with no roads or even tracks. For many of these villages the only access to Muscat, or the rest of Oman, was by sea. The eastern coastline from Quriat to Sur was almost completely deserted, with only a few small fishing villages at Ash Shab and Tiwi and herds of wild gazelle in the mountains.

Figure 3. (a) and (b) Yiti beach before and during recent developments. (c) Small cove near Ash Shab. (d) Old dhow beached at Muttrah.

Figure 4. (a) Bandar Jissah beach, 1972. (b) Bar al-Jissah beach, 1983. (c) Sidap village, 1973. (d) Fishing boats at Harambol village.

In July 1970 this all changed with the start of the Oman renaissance under Sultan Qaboos bin Said. The country underwent rapid development and within 10 years, new motorways connected all the major cities, new schools and hospitals sprang up, a new airport was built, and the people benefited greatly from this rapid development. Unlike the UAE, Qatar or Bahrain, where almost nothing old has been preserved, Oman set on a different and far more enlightened and more sensible course. Alongside development, the government determined to preserve Oman's unique natural heritage and culture. Old crumbling mud-brick forts were restored, and a series of National Parks, Sites of Special Scientific interest (SSSI), and Geo-Parks were outlined. Reserves were established to protect the endangered Arabian oryx at Yalooni, the rare Arabian tahr at Wadi Serin, turtle breeding beaches at Ras al-Jinz, and several coastal and marine sites were set aside for protection of the coral reefs, notably at the Daymaniat islands.

With increasing recent developments throughout the Sultanate, it has become more important than ever to preserve many of the unique and spectacular sites that are so important for geological, archaeological, and natural history studies. More than 50 geological sites were proposed as GeoPark sites for urgent preservation (Searle, 2014, 2019; Hoffmann et al., 2016). Three particular sites, the Semail ophiolite at Wadi Jizzi, Jebel al-Akhdar, and the Musandam peninsula, are so unique and special that it was proposed to preserve these areas as UNESCO World Heritage Site status. The Semail ophiolite along the Oman – UAE mountains is by far the largest, best exposed, and most extensively studied ophiolite complex anywhere in the World. Ophiolites are slices of oceanic crust and upper mantle that have been thrust and emplaced onto continental margins. The area around Wadi Jizzi, inland of Sohar was selected as the best and most complete ophiolite section. This area shows all units of the ophiolite including the famous Geotimes pillow lavas, the volcanic units around copper deposits at Lasail and Aarja, sheeted dykes that feed the pillow lavas, and the Moho – the transition between the basaltic oceanic crust and upper mantle composed entirely of peridotite.

Jebel Shams at 3009 meters is the highest peak in the Oman Mountains and is part of a single massive 60 km wavelength fold, the Jebel al-Akhdar – Jebel Nakhl anticline, one of the largest such structures anywhere in the World. This massif shows the complete Permian to Late Cretaceous shelf carbonate stratigraphy overlying pre-Permian basement rocks. These rocks in Jebel al-Akhdar, together with the two other exposures around Saih Hatat and the Musandam peninsula, are the only regions where geologists can examine outcrops of rocks that make up the important oil and gas reservoirs in the interior of Arabia. It is a scenically beautiful area with 1500 meter high cliffs, small villages and date palms tucked into the deeply incised wadis, perennial streams with waterfalls and wadi pools (Fig. 5).

Figure5. (a) Wajma village, Jebel al-Akhdar, 1977. (b) Terracing at Shariyah village, Saiq plateau, Jebel al-Akhdar, 1973.

It is also one of the most important rock climbing, canyoning and wild trekking areas in Arabia (Fig. 6).

Figure 6. (a) Grand Canyon of Wadi Nakhr, Jebel Shams. (b) Cliffs around Wadi Nakhr. (c) south face of Jebel Misht; note two climbers on skyline.

The Musandam peninsula is the wild and wonderful northern extension of the Oman Mountains ending at the Straits of Hormuz, the gateway to the Arabian Gulf. These mountains are also composed of Permian to Late Cretaceous shelf carbonates, but they also show uplift along the Miocene Hagab thrust, which is the earliest structure associated with the collision of the Arabian plate with central Iran. The entire peninsula has been uplifted, thrust towards the west, and tilted eastwards with the ongoing plate collision. The east coast shows a classic drowned coastline, with submerged wadis forming fjords, towering sea cliffs and small remote sandy beaches. The rugged mountains of Musandam are unique with very sparce habitation and incredible scenery. A few remote villages inhabited by the Shihu tribe have now been abandoned.
Oman has unparallel natural beauty in its landscape and geology. It has become world-famous for adventure sports, rock climbing, canyoning, trekking, and scuba diving, as well as having many World-class geological sites. It is up to us all, Omanis and foreigners alike, to make sure these sites remain secure and preserved for generations to come. The establishment of the National GeoParks would enable their protection from development and would benefit everyone, local people, tourists, scientists, and the world.

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Ghaba-1: A little bit of Yorkshire in Oman

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Some readers will know of the prominent ~ 35 m-high landmark of the Ghaba-1 rig derrick, visible to the east of the road when driving from Adam to Haima. What you may not know is that this is the derrick of the 1950s Ideal 100 rig which drilled Fahud-1 and which was then taken apart piece by piece and rebuilt at Wadi Gharb. Fahud-1 was completed on 28 May 1957 and Ghaba-1 spudded on 3 March 1958. 279 days for a rig move!

On a visit to Ghaba-1 in November 2007 we noticed that the beams were numbered to allow them to be assembled and re-assembled presumably to a plan, and some beams were stamped with the iron works where they were made (Figs 1 and 2; Al Hajar, 11th edition, February 2008, pp. 6-7). A noticeable name on some of the lower beams was Skinningrove, England. Skinningrove is a village on the coast of North Yorkshire, 25-30 km east of Middlesborough.

Figure 1. Derrick abandoned by the Iraq Petroleum Company at Ghaba-1 in 1959. The numbered beams to enable the derrick's re-assembly at each well location and one of the lower I-shaped beams being made at Skinningrove, England.

The derrick and rig equipment were manufactured by Oil Well Engineering Company (OWECo) in Stockport, Greater Manchester, under license from National Supply Company of the United States. The rig was powered by two portable Paxman diesel engines made in Colchester, Essex. European countries were short of foreign currency after WW2, particularly US dollars, and British-based oil companies sourced their equipment from within the sterling area. OWECo and Paxman were major suppliers of oilfield equipment to the operations of the Iraq, Anglo-Iranian and Shell Petroleum companies.

Figure 2. The camp and rig move from Fahud to Wadi Gharb. The photos were taken by George Laurance the chief mechanical engineer for PDO, 1956-60.

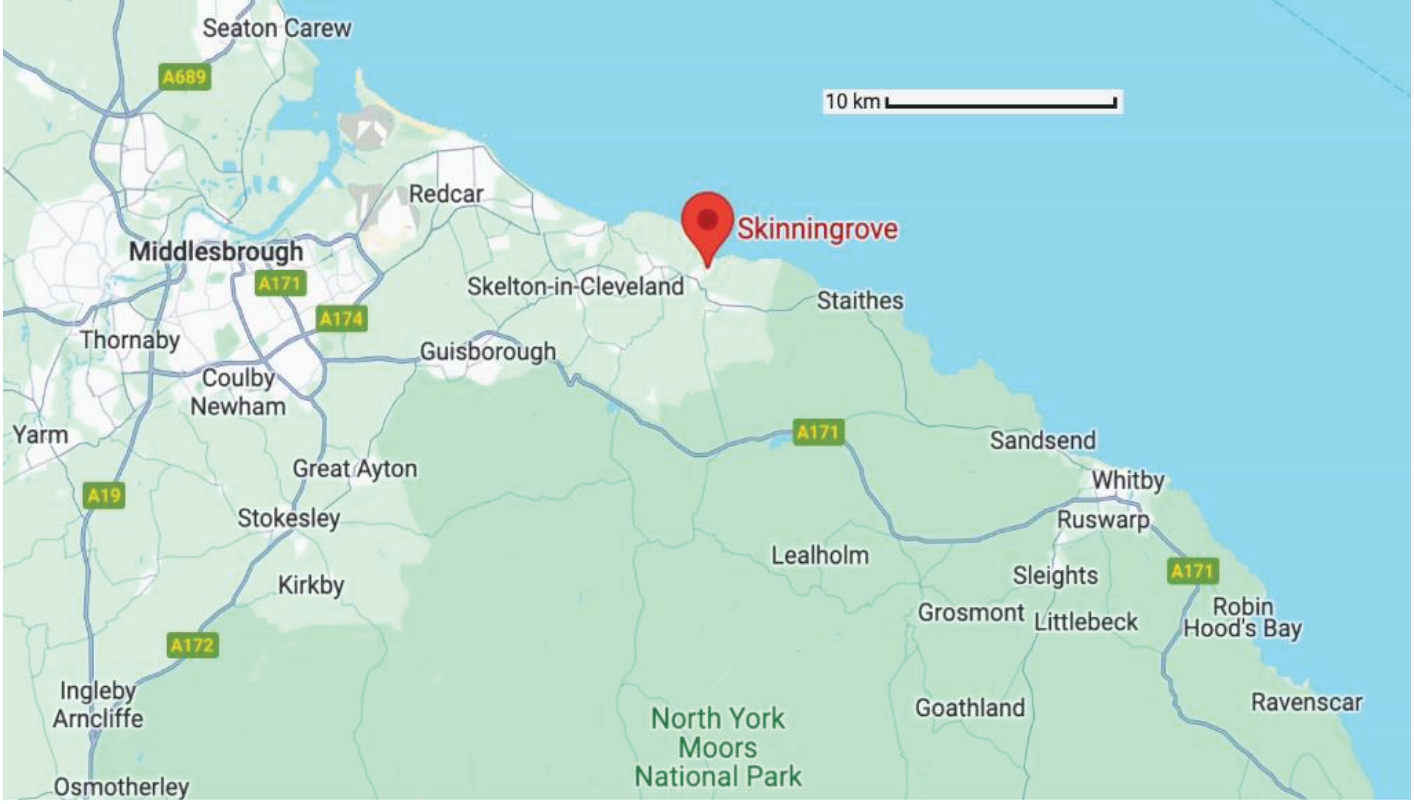
On 16 September, 2023, Steve Livera, a former Shell and PDO geologist led a Yorkshire Geological Society fieldtrip to the Cleveland Ironstone exposures at Skinningrove, on the North Yorkshire coast, with a visit to the 'Land of Iron Museum' in the afternoon when the tide was high (Fig. 3). The museum is situated between the Loftus mine, where the Jurassic Cleveland ironstone was worked, and the iron and steel works where some of the beams present in the Ghaba-1 derrick were smelted from iron ore and rolled to form girders. In 1950s when the beams at Ghaba were smelted and rolled, the blast-furnaces were using a mix of local Cleveland and Midlands ironstones and imported ores from Sweden, Morocco and Canada.

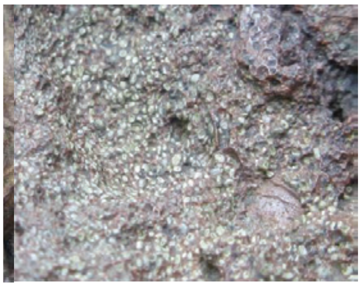
The early Jurassic ironstones are a widespread geological phenomena in Europe and consist primarily of the iron minerals siderite and berthierine. To form a commercially workable ore the seams have to have an iron content of more than 25% and be thick enough to mine. The Cleveland Ironstone Formation is up to 24 m thick and has several workable seams, the best being the combined Main and Pecten seams at the top of the Pleinsbachian-age formation. These iron-rich deposits are thought to have formed as condensed, shallow-marine deposits in areas where rivers drained extensive land areas with lateritic soils.

The Loftus mine at Skinningrove became uneconomic to continue working and was closed in 1958 and the last blast furnaces at the iron works, used for smelting the ore, ceased operation in 1971. The museum is housed in some of the former mine buildings.

The nearest equivalent of the Cleveland ironstone in Oman, is the lower part of the Mafraq Formation of Pleinsbachian-Toarcian age which contains beds of iron ooids but not thick- or rich-enough to be used commercially for making iron.

There is a further derrick left behind by the Iraq Petroleum Company in 1960, that being near the roadside south of the town of Haima. The company brought in a second derrick in 1959 to enable Haima-1 to spud only 82 days after Ghaba-1 was completed. The rig equipment, including the portable Paxman engines, and camp were still moved. The steel beams in that derrick were from a Scottish steelworks and do not appear to be numbered.





Left: Large ammonite fossil *Pleuroceras spinatum* typical of the Main seam.
Right: mm-sized ooids of berthierine in ground-mass of

Figure 3. Skinningrove on a Yorkshire Geological Society fieldtrip on a dull September day in 2023. Steve Livera pointing out the Main and Pecten seams of the Cleveland Ironstone in the cliffs. Photo of the iron and steel works taken from a board outside the museum and outcrops of the banded Pecten seam and ooidal ironstones of the Main seam preserved in the wave-cut platform. The camera case is 65 x 110 mm and the large ammonite > 100 mm.

Magma mingling in the Oman ophiolite

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Plagiogranites form a small but significant component of the Oman ophiolite. They are easily recognised by their light colour against a background of mostly dark rocks. There are two types which can be distinguished in the field on the basis of their position within the ophiolite stratigraphy. In the crustal section of the ophiolite (gabbros, dykes, pillow lavas) plagiogranites contain quartz and plagioclase feldspar +/- hornblende and biotite and are tonalites or trondhjemites. These plagiogranites are thought to be derived from a basaltic host and the product of processes operating within the ophiolite. In contrast, within the mantle section of the ophiolite, plagiogranite dykes tend to contain potassium feldspar and so are true granites. They are thought to reflect the input of a felsic component external to the ophiolite, probably by the partial melting of sediments and basalt within a subducting slab beneath the mantle section (Rollinson, 2015).

This article is about those plagiogranites which are located within the crustal section of the ophiolite and in origin are closely associated with the mafic magmas of the ophiolite. Their origin has been the subject of considerable discussion. Their association with a mafic host would suggest an origin either by the partial melting of that host, or by fractional crystallisation in a mafic magma chamber. In some localities the Oman plagiogranites display some very unusual textures which can be observed in the field in which dark basaltic 'blobs' are found within a light coloured plagiogranite host (Figure 1). These textures are found throughout the ophiolite in both Oman and the UAE, although the focus here is on a single locality in Oman. Many different terms have been used to describe these unusual textures in plagiogranites, but one which has been adopted in Oman is the term 'vinaigrette texture'. This term was introduced by the French team working in Oman in the 1990s and 2000s and uses the imagery of the immiscible relationship between olive oil and vinegar in a French salad dressing – vinaigrette.

Vinaigrette textures

The locality described here has been informally called Vinaigrette Valley. It is located in the Sumail block of the ophiolite southwest of Muscat, about 6 km north of the village of Somrah and 5 km west of the Ibra road near Wadi Uq. Vinaigrette valley is an unnamed wadi and has the UTM coordinates 0611665, 2559373.

Plagiogranites at this locality are hosted in massive hornblende gabbros and leucogabbros. The plagiogranites comprise for the most part sub-horizontal sheets between 30 cm and 2 m thick (Figure 1a). These light coloured sheets contain up to 50% of angular and rounded dark dolerite fragments taking many forms (Figure 1 b, c, d). There are sharp boundaries between the dolerite xenoliths and the plagiogranite although these boundaries are frequently irregular with a lobate form (Figure 1e) and show flame structures of plagiogranite penetrating the dolerite. Some dolerite fragments are dyke-like in form and up to 15 cm wide and 1 m long with rounded lobate terminations (Figure 1 d, e, f, g). These dolerite bodies may be located at the margin or the centre of the plagiogranite sheet. Some fragments are elliptical in shape and invaded by micro-veins of plagiogranite 10-50 cm long. Some dolerite xenoliths form patches of smaller elliptical inclusions typically 10-50 cm long and sometimes much smaller (Figure 1b, c, h). Occasionally the dolerite fragments are stretched out and show flow textures at the margin of plagiogranite sheets. There are also places where there are abundant mafic inclusion bands interspersed between narrower bands of trondhjemite, and over the space of about 1 m wide there may be as many as 8 irregular bands (Figure 1c). There is also evidence for multiple, composite plagiogranite-dolerite intrusive events where one composite dyke cuts an earlier one (Figure 1g).

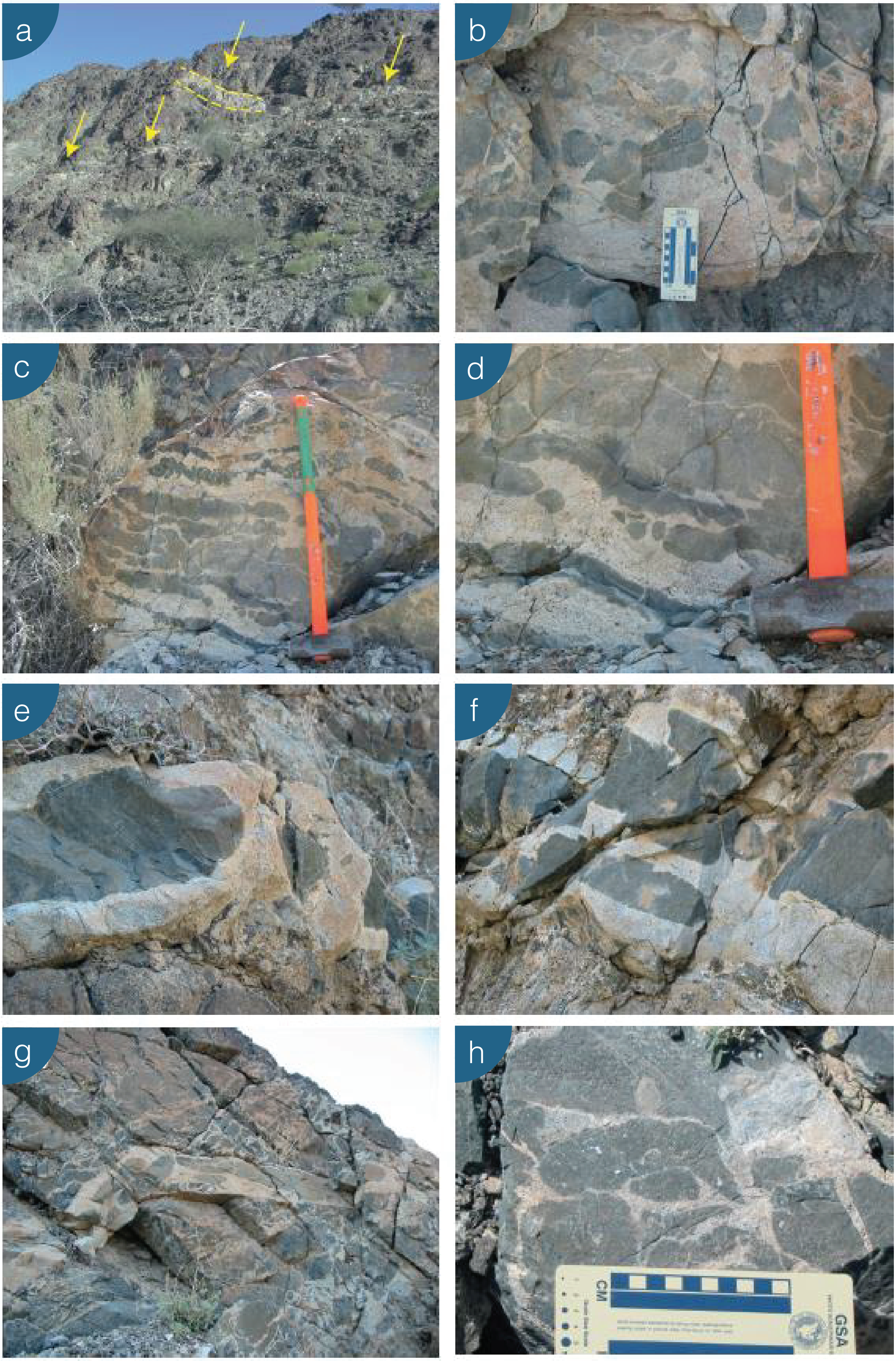

Figure 1. (a) Plagiogranite sheets (arrows) in gabbro, (b-h) examples of magma mingling at the Vinaigrette Valley locality. For details see the text.

What do the vinaigrette textures mean?

The field relationships described above and in Figure 1 demonstrate that:

- There are discrete blocks of mafic rock in a plagiogranite host with no obvious mixing of the two lithologies, nor macroscopic evidence of diffusion between the two.
- The majority of the mafic blocks have rounded margins.
- Some of the mafic blocks have margins characterised by embayments and flame textures (fingers of the mafic magma propagating towards the felsic host).
- The mafic blocks show no evidence of chilled margins.

These features suggest that the plagiogranite and doleritic/gabbroic melts coexisted as separate melts, with a similar rheology, and that their relationship represents one of 'mingling' rather than thorough mixing. The lack of angular fragments argues against their being part of the wall-rock and dragged from chilled margins by the plagiogranite magma.

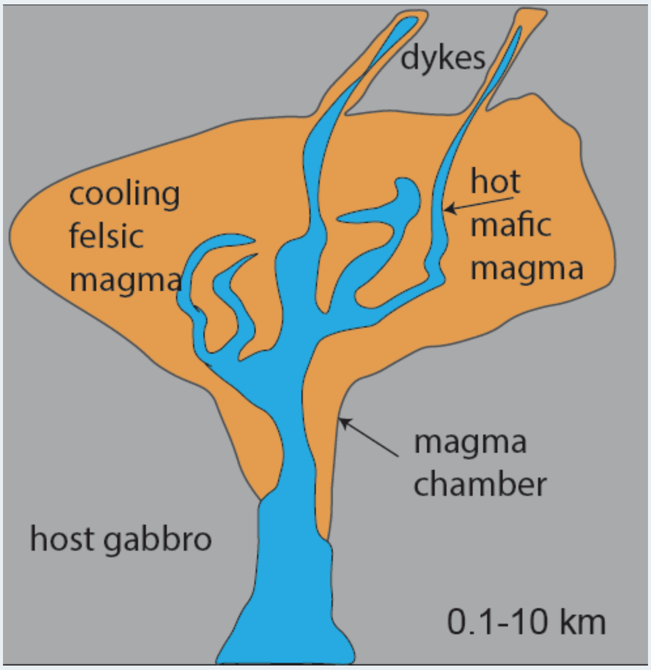

Figure 2. Sketch of a fractionating felsic magma chamber (orange) and associate dyke network, replenished with a pulse of mafic magma (blue) which rapidly cools and collapses within the felsic magma chamber (modified after Perugini and Poli, 2012).

If this interpretation of the field relationships is correct and these outcrops represent the mingling of two magmas, this means that they must have coexisted. It is proposed here that because of their close proximity in both time and space, the two magmas coexisted in the same magma chamber. If this is so, then the field relationships observed could represent the replenishment of a felsic magma chamber or dyke by a fresh influx of mafic magma during which some of the felsic magma is expelled into dykes and the hot mafic magma is quenched in the lower temperature environment of the felsic melt. Such a model has been previously described by Perugini and Poli (2012) from the Terra Nova Intrusive Complex (Northern Victoria Land, Antarctica). The rapidly cooled nature of the mafic component is consistent with its small grain size. There is no visible evidence of mixing and it is thought that the rapid cooling prevented this process taking place. The denser mafic melt may subsequently collapse under its own weight into rounded mafic blocks and smaller fragments (Weinberg et al., 2021). An additional effect may be the formation of rounded blocks of mafic rock due to the temperature contrast between the two melts in a manner analogous to the formation of pillow lavas during the eruption of hot lava into cold ocean water (Stakes and Taylor, 2003). A sketch illustrating the magma chamber model is given in Figure 2.

Does magma mingling have any wider significance?

There are two competing views for the origin of plagiogranites in the crustal section of ophiolites - either by the partial melting of their mafic host, or by fractional crystallisation from basalt to a felsic melt in a mafic magma chamber. The field evidence presented here for the coexistence of mafic and felsic magmas in the same magma chamber supports the fractional crystallisation model rather than the partial melting model. However, the observant reader will have noticed that although it is proposed that the plagiogranites are the product of fractional crystallisation from their associated mafic hosts the field evidence shows that the mafic magmas postdate the plagiogranites and so cannot be their exact parent. Thus, this model requires that there were multiple batches of near-identical mafic melts involved in plagiogranite genesis.

Wider implications of ophiolitic plagiogranite genesis

Although the evidence presented here strongly supports a fractional crystallisation origin for the plagiogranites in Vinaigrette Valley there is good evidence that in other places in the ophiolite a partial melting origin better explains the observations. Track back in time to the very early Earth, when it simply had a basaltic surface (similar to the Moon today), maybe the first felsic rocks on Earth, the precursors of the modern continental crust, were produced by very early partial melting processes from mafic rocks similar to those found in the Oman ophiolite (Rollinson, 2008).

Similarly, Gamal El-Dien et al. (2021) recently described the largest plagiogranite on Earth from the Wadi Ghadir ophiolite in Egypt which also contains up to 50% gabbro-diorite enclaves, indicating ‘extensive magmatic mixing’, similar to that reported in this study. They claim that these plagiogranites are partial melts of altered oceanic crust, although the results of this study would suggest a different model. Nevertheless, the production of large volumes of plagiogranite from a mafic precursor provides a further means of generating new felsic crust from the mantle, contributing to the formation of the Earth’s continental crust.

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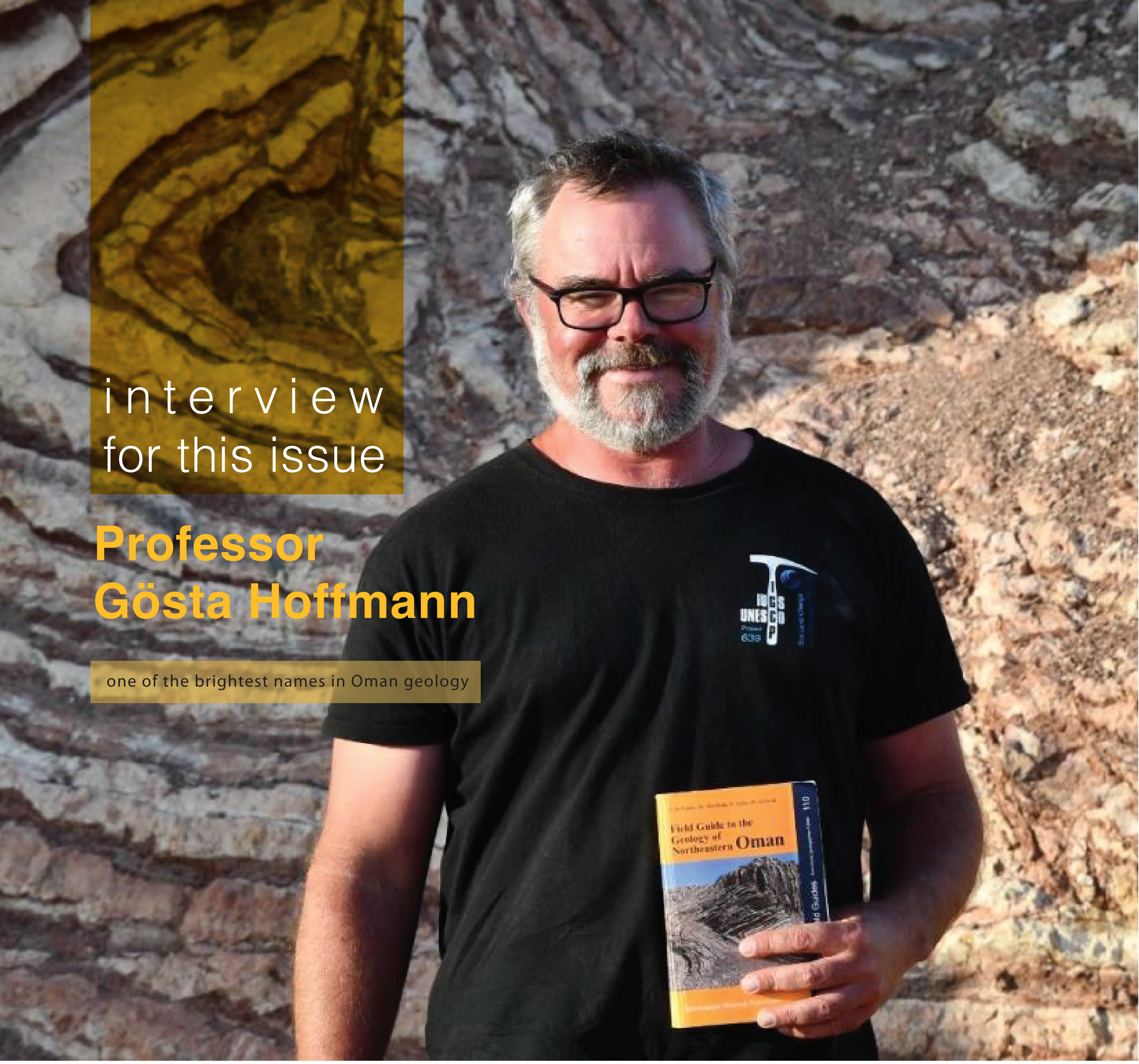
Hugh Rollinson is Emeritus Professor of Earth Sciences at the University of Derby, UK and was Professor of Earth Sciences at SQU from 2002-2008. This article is a shortened version of a paper describing the geochemistry of vinaigrette samples from Oman and the UAE to be published in the geochemical literature.



interview
for this issue

Professor Gösta Hoffmann

one of the brightest names in Oman geology

"Dr. Hoffmann, please tell us more about yourself"

I am a German geologist currently working with the German Commission for UNESCO and responsible for coordination of the German UNESCO Global Geoparks. I lived in Oman for eight years when I was working for the German University of Technology. However, although based in Germany now, I return to Oman several times a year. Usually I do not come alone, but bring some 20-30 geologists with me. They are either geology students or members of the German Geological association. We then conduct fieldtrips in Oman. Wonderful thing to do, because you have very happy people around you for 14 days.

"Can you share your educational background and how it led you to specialize in geology?"

Geography was one of the subjects I liked most in school. They did not teach geology though. But I became very much interested in the processes that make this planet so dynamic and therefore so special. So, I studied geology and found it so fascinating that I directly continued with my PhD.

"What motivated you to pursue a career in academia, specifically as a geology lecturer?"

As a geologist you are able to read stories from rock, a fascinating skill. Most other people are able to read stories from books. So, becoming a geology lecturer you have the task to teach reading, once the students understand the concept, they love it. And the good thing is that you do not have to do all the lectures in boring classrooms. You can go outside and study the rocks in the field.

“Can you discuss your experience with geological mapping in the Oman region and highlight any significant findings or challenges you encountered?”

Most of my research concentrated on coastal processes. So we mapped the entire coastline of Oman searching for evidence of past tsunamis. This was basically fun. We also spent ages mapping the coastal terraces between Quriat and Qualhat. These terraces are interesting because they allow us to quantify Pleistocene sea-level changes as well as tectonic uplift. However, besides some other data you need the precise elevation of the terrace scarps and beach deposits associated with them. Which means you have to climb up all the terraces – and they reach up several hundred meters from the beach. The older they are, the higher and the more eroded. It was hundreds of kilometers of walking. Luckily it almost never rains in Oman.

“Can you discuss the geological features specific to Oman and how they contribute to the country's unique geology?”

There are several features that are outstanding. For example, Oman is lucky to have a sequence of rocks that illustrates the evolution of the Neotethys Ocean. In principal the autochthonous Permian-Mesozoic sequence in the Hajar Mountains. The fact that the rocks form mountains and that the layers are tilted is interesting but there is another very special feature: the erosion. The Hajar Mountains are basically a ruin of a mountain, where a lot of rocks are already weathered and eroded. But this allows us now to look into the sequences as everything is exposed. If you drive through Wadi Mistal for example, it is like drilling a core into the earth, traveling down in time. And then you reach the Gubbrah Bowl and all of a sudden you are located in this magnificent open amphitheater of geology. To be honest I cannot even say what the single highlight of Oman´s geology would be: the ophiolite, the megafolds in Wadi al May, the Mother of al Outcrops, Pillow lavas of Wadi Jizzi?

“Can you share a memorable field experience or geological discovery that had a significant impact on your perspective as a geologist?”

I think the moment where a student pointed out a method to date tsunami deposits. It was very simple, but we had overlooked this possibility for years. He argued that sessile marine organism attached to tsunami boulders can be used for dating as they probably died the moment the tsunami moved the boulder. He was absolutely correct and we were award with the research award by The Research Council later.

"In your opinion, what role does geology play in environmental management and sustainability?"

Geology provides essential knowledge and tools for effective environmental management and sustainability by informing resource utilization, land use planning, hazard assessment, climate change research, ecosystem management, and waste management efforts. Integrating geological principles into decision-making processes is essential for achieving long-term environmental sustainability and resilience.

"Geology often involves interpreting the Earth's history. What techniques or methods do you find most effective in unraveling the geological history of a particular area?"

I think the most efficient way is by employing a multidisciplinary approach. If you combine traditional mapping with geophysics, paleontology and other disciplines you will achieve best results.

"How do you navigate the balance between theoretical knowledge gained in academic settings and practical challenges encountered during fieldwork?"

You need to remain adaptable and flexible during fieldwork, as unexpected challenges and variations in geological conditions may arise.

"What is your advice for the geoscientists?"

Rock on!

Cement Grade Limestone Deposit of Wantrag Anantnag Kashmir India

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Abstract

The Department of Geology and Mining, Srinagar carried out surface geological mapping during the 1984-1985 field season over a Late Triassic limestone belt situated between Mattan and Chak Ishwar Dass Wantrag Anantnag, Kashmir India. The survey revealed the presence of an estimated 3.88 million tons of cement grade limestone. Recently, an adjacent area that was not part of the original mapping, which covers 5.36 hectares and is situated on the north-eastern side of Chak Ishwar Dass ridge, was evaluated by the current author from 2022-2023. Exploratory drilling resulted in three boreholes that were drilled to depths of approximately 50 meters. The chemical analysis of core samples from the boreholes revealed that some of the limestone is of cement grade with an average CaO of 42.42 weight percentage (wt. %). The block consists of 1.39 million tons of proven reserves. Based on the average depth of borehole logs, the limestone's specific gravity, and mining potential of the block, it is concluded that the Wantrag limestone block is feasible for exploitation using an open cast mining (OCM) method.

Introduction

The area of investigation is locally called Kawnaar and is situated between Check Ishwar Dass in the east and Mattan in the west and about one kilometer northwest of Wantrag Village. The area falls within the survey of India topographic map bearing reference no. 43 0/1. Most of the area under investigation is a barren mountainous belt. The Limestone block is bounded by the geographic coordinates provided in the table below:

Station	Geographic Coordinates	
A	N 33^{0} $45^{/}$ $19.67^{//}$	E 75^{0} $14^{/}$ $51.09^{//}$
B	N 33^{0} $45^{/}$ $19.57^{//}$	E 75^{0} $14^{/}$ $45.11^{//}$
C	N $33^{0}45^{/}$ $30.27^{//}$	E 75^{0} $14^{/}$ $45.26^{//}$
D	N $33^{0}45^{/}$ $31.57^{//}$	E 75^{0} $14^{/}$ $50.76^{//}$

Purpose of the mineral investigation

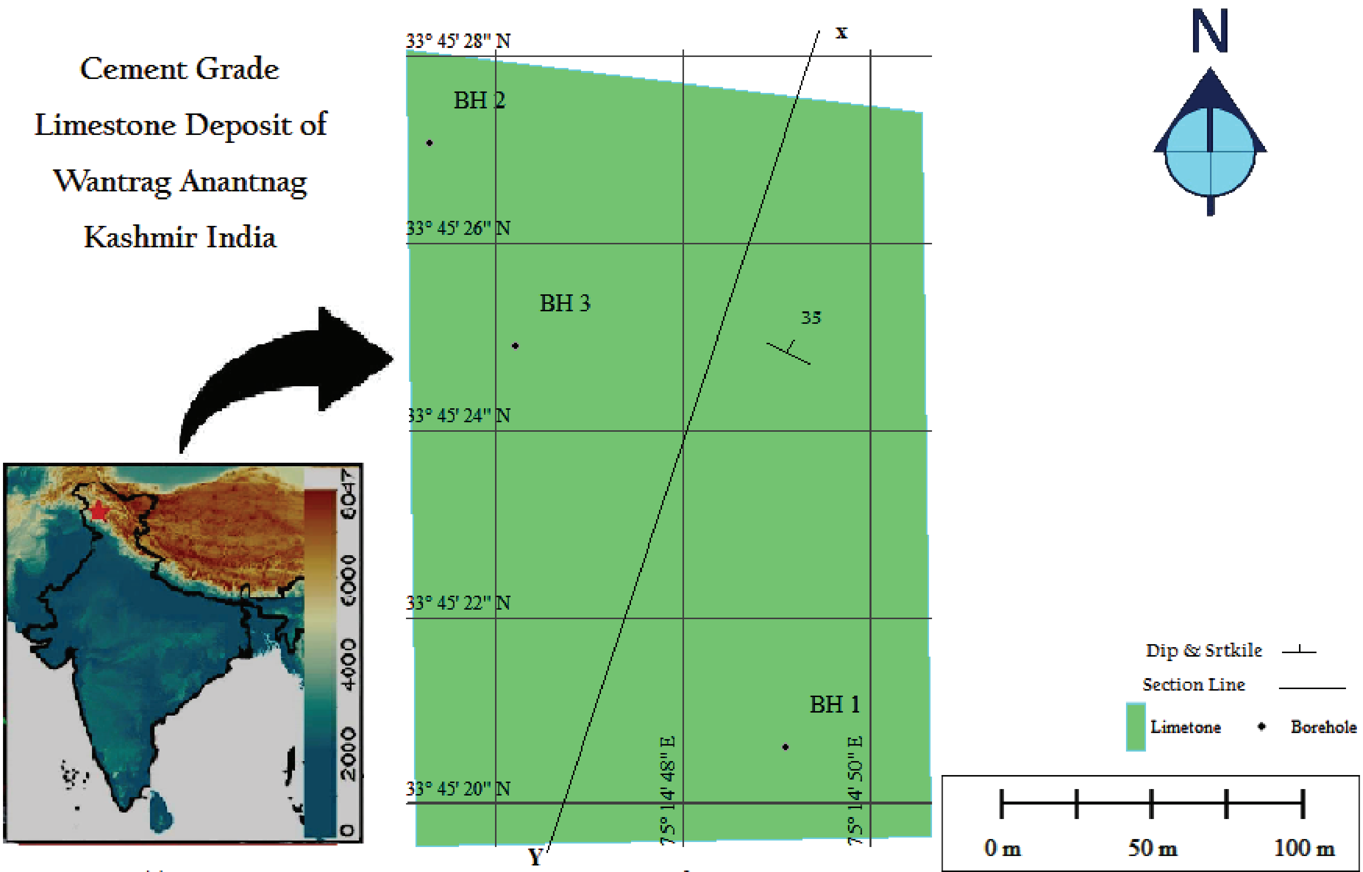
There is a need to locate and define more industrial mineral deposits. The purpose of this investigation was to collect data about the quality and quantity of limestone reserves in an area nearby an already known cement–grade limestone deposit near Wantrag village at Kawnaar. This work consisted of:

- Exploratory drilling
- Core sampling
- Estimation of reserves

The exploration location is relatively barren and isolated. The area is likely suitable for manufacture of cement as damage to the environment and ecology will be minimal.

Geology of the Wantrag Block

The study area is comprised of Cambrio-Sillurian aged Panjal Traps and sedimentary rock units ranging from Cambrian to Triassic in age. The sedimentary formations have been folded with the fold axis running through the Kuthiar Valley and is considered to be a part of Lidder valley anticline. This structure is tightly folded and all formations on the southern limb are inverted. The Wantrag limestone block is bounded to the north by steep mountain escarpments that trend southwest-northeast and bounded to the south by recent alluvial material that supports agricultural/horticultural activity. Ridges to the north and northeast are mostly forested. The area consists of rugged and mountainous topography. The upper reaches are surrounded by snow-fed mountains which form dendritic drainage patterns. The area has moderate to steep relief with an elevation range from 1870 to 2040 meters.



(a)
Location map of Study Area w. r. t. India

(b)
Location Map of Study Area

New exploratory drilling

During a recent field season (2022-2023), three exploratory boreholes were planned within the Wantrag limestone mineral block (Figure 1).

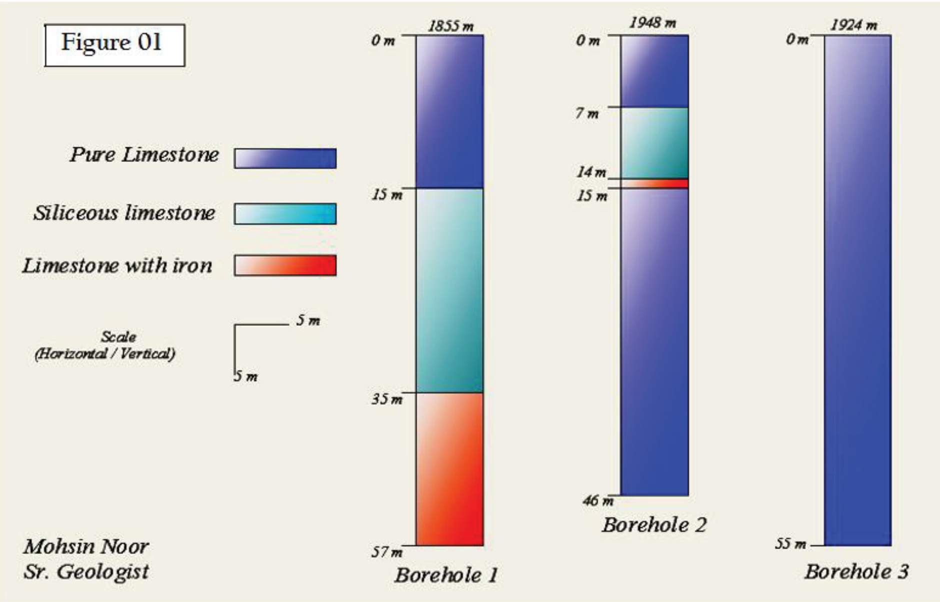


Figure 1. Details of each Borehole and chemical analysis report furnished by the departmental laboratory

The three boreholes were strategically placed at locations along the slope of the block where drilling across all the limestone bedding planes at various angles and down to targeted depths would help to define the maximum thickness of the block.

The exploratory wells utilized diamond core drilling with a casing size of NX (**Casing tubes size of 88.9 mm**) to achieve the target depths which totaled 158 meters (Picture 1).

Picture 1:- Borehole (BH 3) at Limestone Block Wantrag Anantnag

Borehole -1 was vertically drilled to a depth of 57 meters. Borehole -2 was vertically drilled to a depth of 46 meters. Borehole-3 was drilled to a depth of 55 meters but at an angle of 45 degrees relative to the surface. The angle, distance and coordinates of the three boreholes is provided in the table below:

Borehole	Coordinate with Elevation	Angle and Depth	Strike Direction	Dip Direction and Amount
BH-1	N 33°45′ 20.5″ E 75° 14′49.2″ 1855m	Vertical 57 meters	N70°W S70°E	NE/45°
BH-2	N 33°45′ 27.4″ E 75° 14′ 45.4″ 1948m	Vertical 46 meters	N40°W S40°E	NE/33°
BH-3	N 33°45′ 24.9″ E 75° 14′ 46.1″ 1924m	45 ° 55 meters	N50°W S50°E	NE/45°

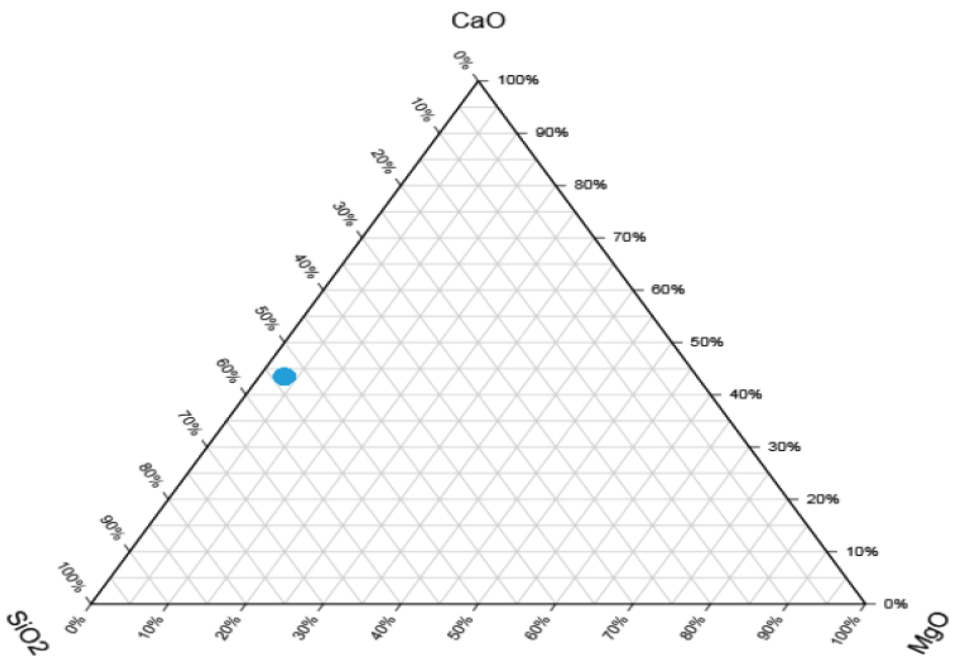
Geochemical survey

A total of 99 core log samples were collected for geochemical analysis from all three boreholes. The recovered core samples were split lengthwise in two halves for geochemical analysis of the weight percentage of different elements (Picture 2).

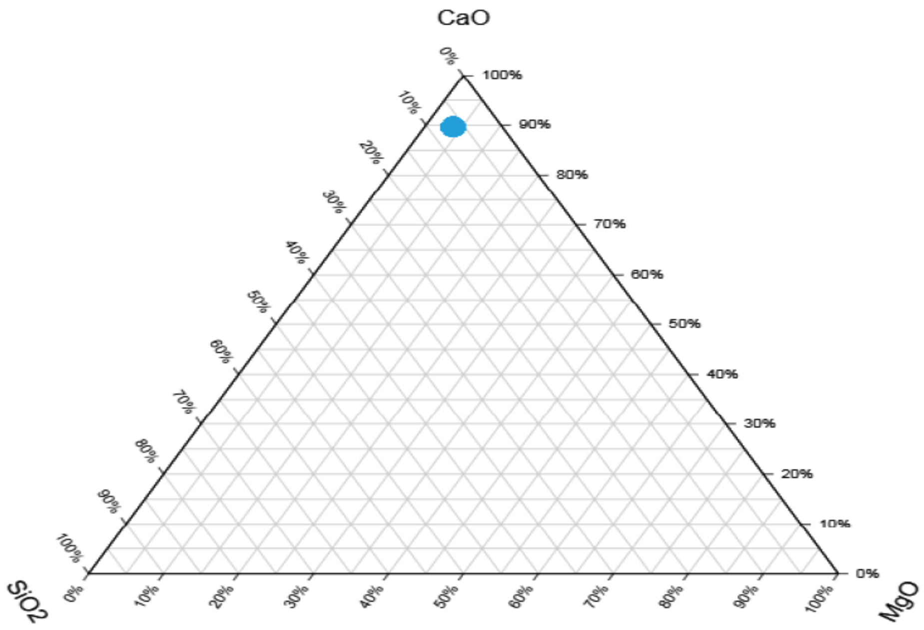
Picture 2:- Core logging and sampling

This is required by the Bureau of Indian Standards, New Delhi and by the National Council for Cement and Building Material, New Delhi to determine whether the chemical specifications qualify the rock as cement-grade limestone. The cores were properly marked as per the run and were boxed. One set of marked core boxes were placed in the custody of the Departmental Geoscience Museum, located at Budgam Kashmir. These will be retained as a reference record for future studies. The other set were sent to the Departmental Laboratory located at Budgam for analysis.

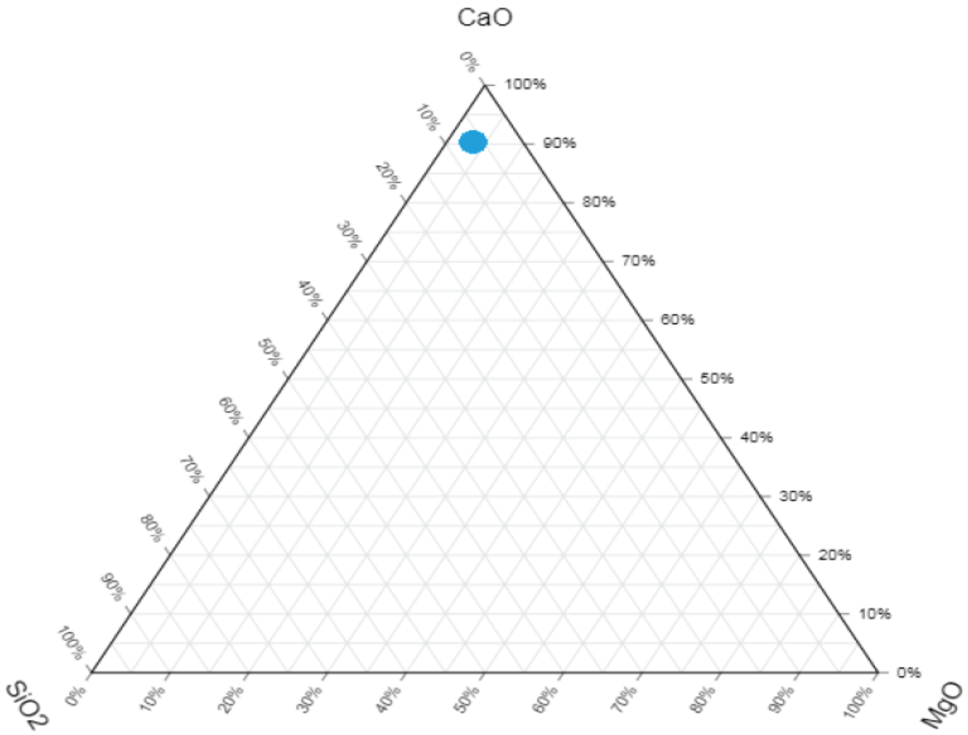
The details of each Borehole and the chemical analysis report furnished by the departmental laboratory are shown in Figure 1, Table 1A, Table 1B and Table 1C. The average grade of lime-stone is cement-grade i.e., Cao 42.42%, however the limestone is generally higher grade within the first 10 meters below the surface. The average chemical analyses of the bed rock samples received from the Departmental Chemical and Mineralogical laboratory, Srinagar is represented by Ternary diagrams (Figure 02) showing the average wt. % of the major oxides Cao, MgO and SiO2. A high Iron oxide (FeO) content also is found in some of the limestone layers. The high SiO2 and high FeO content of some limestone layers means that not all of the limestone block is considered to be cement-grade.



Borehole 1



Borehole 2



Borehole 3

Figure 02: Ternary diagram plot of CaO-MgO-SiO2
of Wantrag limestone

Reserves

The calculation of cement-grade limestone reserves is based on the mappable surface extent of the limestone block, the average depth or thickness of the limestone with a CaO content > 42%, and the specific gravity of the limestone. The reserve was calculated to a minimum depth of 10 meters below the surface as per the UNFC Classification. The limestone reserve calculation is tabulated as follows with 1.39 million tons in the proven category:

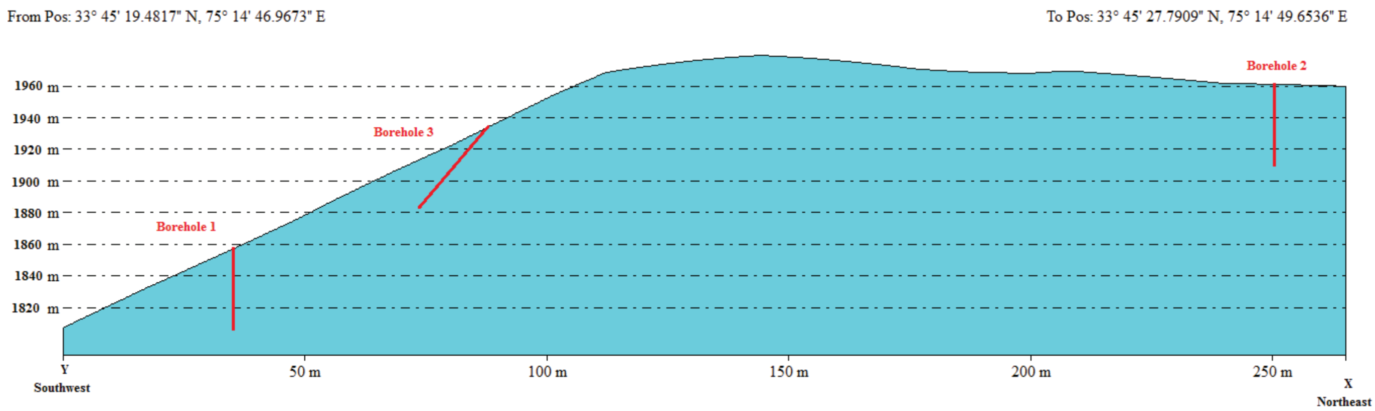
Borehole	Average Depth (meters)	Sectional Area (meters)	S.P Gravity/ Density	Reserves (million Tons)
BH1 , BH2 and BH3	10	53600	2.60	1.39

Mining feasibility of the Wantrag limestone block:

A mining feasibility study is an evaluation of a proposed mining project to determine whether the mineral resources can be mined economically and safely under the Provisions of the Mines Act, MM (D&R) 1957 and the rules and regulations made thereunder. Getting resources out of the ground requires a significant amount of money and investors will not risk their capital on projects without a reasonable prospect of return on investment. As such, mining feasibility is an important parameter to define before proceeding with the exploitation of target minerals.

Observations:

a. The Wantrag limestone block is located on a hill, the height of which ranges from 90 to 120 meters and the dip of the limestone block is 30 0 to 40 0 towards SW direction.
b. The top portion of the hillock shows exposure of the limestone material.
c. A dirt road passes towards Kawnaar Chak Ishwar Dass village at the base of the block which could be developed on a gentle gradient and utilized as a haul road for the transportation purposes. The road can be extended to the top of the limestone block making it more accessible for limestone extraction.
d. The limestone block is devoid of any vegetation and away from local populations.
e. The Wantrag limestone block consists of substantial amounts of mineral reserves that are easily, economically, and safely accessible through the open cast method of mining under the provision of the Metalliferous Mines Regulations 1961.



Geological cross-section of Wantrag limestone block Anantnag

Depth (Metres)	Lithology	Sp. Gravi	SiO_2 %	Fe_2O_3%	Al_2O_3%	CaO%	MgO	L.O.I%	Casing Details NX
0.00-3.00	Limestone with ferrogeous quartzite	2.65	5.31	1.78	1.82	48.88	0.92	40.81	
3.00-6.00	Iron rich Limestone	2.71	2.48	0.68	0.72	51.52	1.60	42.50	
6.00-9.00	Limestone	2.62	5.8	1.82	1.98	49.16	0.84	39.91	
9.00-12.00	Pure Limestone	2.62	5.8	1.82	1.98	49.16	0.84	39.91	
12.00-15.00	Limestone with quartz tints	2.62	5.8	1.82	1.98	49.16	0.84	39.91	
15.00-18.00	Silliceous Limestone	2.66	35.87	5.40	2.17	28.56	2.40	25.10	
18.00-21.00	Silliceous Limestone	2.65	46.58	3.80	9.15	19.42	2.40	18.15	
21.00-24.00	Silliceous Limestone	2.64	51.14	1.04	2.09	23.52	1.50	20.21	
24.00-27.00	Limestone	2.68	38.54	9.40	7.11	22.40	2.00	20.05	
27.00-30.00	Iron rich Limestone	2.58	2.34	1.06	1.37	50.95	1.78	42.00	
30.00-33.00	Fractured Limestone	2.51	19.40	2.32	6.68	34.16	4.78	32.15	
33.00-36.00	Impure Limestone rich in silica	2.60	4.92	0.96	1.12	51.28	0.44	40.78	
36.00-39.00	Silliceous Limestone	2.65	51.62	8.78	21.02	6.24	3.17	8.67	
39.00-42.00	Ferrogenous Limestone	2.22	83.68	7.19	3.01	2.12	0.71	2.79	
42.00-45.00	Ferrogenoues Quartzite with limestone in lower part	2.26	67.38	15.17	11.95	1.75	0.80	2.45	
45.00-48.00	Ferrogenous Quartzite	3.02	37.08	22.40	17.32	8.78	2.98	10.94	
48.00-51.00	Ferrogenous Limestone	2.63	69.72	9.60	11.28	2.58	1.98	4.34	
51.00-54.00	Ferrogenous Limestone with Sand	2.47	76.80	5.98	2.32	6.24	1.32	6.86	
54.00-57.00	Sand	1.18	53.95	17.02	13.93	5.82	1.98	6.80	

Table 1A: Chemical Analysis of Borehole 1

Depth in Mts	Lithology	Chemical Characteristics									Casing Details		
		Name of	Sp. Grav	SiO_2 %	Fe_2O_3%	Al_2O_3%	CaO%	MgO	L.O.I	FeO	NX	BX	AX
0.00-3.00	Limestone	WL-1	2.68	0.98	0.42	0.52	52.49	1.87	43.22	0.37			
3.00-4.50	Limestone with thin bands of sand	WL-2	2.61	1.06	0.37	0.63	52.36	1.98	43.12	0.33			
4.50-6.00	Limestone	WL-3	2.65	8.68	1.90	2.92	45.33	2.40	38.27	1.71			
6.00-7.50	Limestone with fractures	WL-4	2.55	0.78	0.84	1.16	51.21	2.51	43.00	0.76			
7.50-9.00	Limestone	WL-5	2.62	7.11	1.44	2.53	48.62	0.80	39.00	1.29			
9.00-10.50	Limestone	WL-6	2.64	11.76	2.51	3.12	44.59	1.20	36.32	2.25			
10.50-12.00	Limestone	WL-7	2.65	13.13	1.91	2.44	44.53	1.20	36.30	1.71			
12.00-13.50	Limestone	WL-8	2.67	10.18	3.68	6.40	43.49	0.80	35.00	3.31			
13.50-15.00	Limestone with ferrogeous quartzite	WL-9	2.67	0.68	0.27	0.47	52.52	2.02	43.54	0.24			
15.00-16.50	Limestone	WL-10	2.63	36.50	6.16	3.67	28.78	0.80	23.61	5.54			
16.50-18.00	Limestone	WL-11	2.69	0.85	0.30	0.55	53.26	1.32	43.25	0.27			
18.00-19.50	Limestone	WL-12	2.69	0.81	0.28	0.57	53.02	1.60	43.25	0.25			
19.50-21.00	Limestone	WL-13	2.69	0.27	0.11	0.14	53.18	2.02	43.80	0.09			
21.00-22.50	Limestone	WL-14	2.63	0.72	0.34	0.46	53.12	1.58	43.28	0.30			
22.50-24.00	Limestone with Quartzite veins	WL-15	2.67	0.14	0.13	0.15	53.82	1.50	43.76	0.11			
24.00-25.50	Limestone	WL-16	2.48	0.47	0.14	0.26	52.01	2.98	43.64	0.12			
25.50-27.00	Limestone	WL-17	2.71	0.51	0.14	0.23	40.88	12.04	45.70	0.12			
27.00-28.50	Limestone	WL-18	2.68	0.72	0.32	0.48	52.44	2.10	43.44	0.28			
28.50-30.00	Limestone	WL-19	2.69	0.37	0.16	0.21	52.92	2.06	43.80	0.14			
30.00-31.50	Limestone	WL-20	2.65	1.94	0.56	0.64	45.36	7.29	43.73	0.44			
31.50-33.00	Limestone	WL-21	2.64	2.29	0.32	0.58	49.84	3.46	43.03	0.28			
33.00-34.50	Limestone	WL-22	2.67	0.97	0.23	0.36	52.26	2.24	43.49	0.20			
34.50-36.00	Limestone	WL-23	2.63	0.49	0.20	0.29	53.06	1.82	43.65	0.18			
36.00-37.50	Limestone	WL-24	2.64	1.19	0.41	0.53	52.57	1.70	43.10	0.28			
37.50-39.00	Limestone	WL-25	2.66	0.28	0.14	0.16	53.12	2.02	43.80	0.12			
39.00-42.00	Limestone	WL-26	2.64	0.98	0.58	0.65	52.02	2.12	43.15	0.52			
42.00-45.00	Limestone	WL-27	2.64	3.96	1.96	1.98	50.32	0.88	40.40	1.76			
45.00-48.00	Limestone	WL-28	2.68	1.92	0.78	1.05	52.32	1.24	42.21	0.70			
48.00-51.00	Limestone	WL-29	2.67	0.28	0.42	0.52	53.26	1.54	43.50	0.38			
51.00-54.00	Limestone	WL-30	2.67	2.98	1.28	1.72	50.12	2.04	41.38	1.15			

Table 1B: Chemical Analysis of Borehole 2

Depth in Metres	Lithology	Chemical Characteristics								Casing Details		
		Name of Sample	Sp. Grav	SiO_2 %	Fe_2O_3%	Al_2O_3%	CaO%	MgO	L.O.I	NX	BX	AX
0.00-1.50	Fine grained, dark colored Limestone	BH3/Wantrag/0-5	2.38	2.43	0.79	1.30	51.24	1.60	42.10			
1.50-3.00	Fine grained, dark colored Limestone	BH3/Wantrag/5-10	2.59	2.71	0.79	0.67	52.08	1.20	42.05			
3.00-4.50	Fine grained, dark colored Limestone	BH3/Wantrag/10-15	2.80	3.16	0.38	0.62	51.59	1.60	42.15			
4.50-6.00	Fine grained, dark colored Limestone	BH3/Wantrag/15-20	2.68	2.00	0.20	0.47	52.43	1.60	42.80			
6.00-7.50	Light grey colored, fine grained Limestone	BH3/Wantrag/20-25	2.67	2.11	0.18	0.23	52.98	1.20	42.80			
7.50-9.00	Dark grey, fine grained Limestone, silliceous	BH3/Wantrag/25-30	2.70	2.49	0.11	0.19	52.36	1.60	42.75			
9.00-10.50	Dark grey, fine grained Limestone.	BH3/Wantrag/30-35	2.70	2.54	0.19	0.43	52.64	1.20	42.50			
10.50-12.00	Dark grey, fine grained Limestone.	BH3/Wantrag/35-40	2.68	2.55	0.25	0.46	52.64	1.20	42.40			
12.00-13.50	Dark greenish fine grained color Limestone	BH3/Wantrag/40-45	2.67	2.70	0.25	0.51	51.54	2.00	42.50			
13.50-15.00	Dark grey colored fine grained Limestone with Iron partings	BH3/Wantrag/45-50	2.71	11.27	0.86	1.14	46.52	1.56	38.15			
15.00-16.50	Fine grained chocolate coloured Limestone with iron partings	BH3/Wantrag/50-55	2.71	2.86	0.31	0.49	52.34	1.20	42.30			
16.50-18.00	Fine grained Light grey Limestone	BH3/Wantrag/55-60	2.66	3.28	0.46	0.72	51.89	1.25	41.90			
18.00-19.50	Fine grained Light grey Limestone	BH3/Wantrag/60-65	2.67	3.40	0.16	0.27	52.72	0.80	42.15			
19.50-21.00	Fine grained Light grey Limestone	BH3/Wantrag/65-70	2.67	2.76	0.37	0.53	52.84	0.80	42.20			
21.00-22.50	Fine grained Light grey Limestone	BH3/Wantrag/70-75	2.71	4.10	0.40	1.13	51.52	0.80	41.55			
22.50-24.00	Fine grained, dark grey coloured Limestone	BH3/Wantrag/75-80	2.69	5.39	0.96	1.48	49.84	1.20	40.65			
24.00-25.50	Medium to fine grained light green coloured Limestone	BH3/Wantrag/80-85	2.64	5.65	0.40	0.95	50.40	1.20	40.90			
25.50-27.00	Medium to fine grained light green coloured Limestone	BH3/Wantrag/85-90	2.65	5.90	1.68	2.37	47.60	2.00	39.95			
27.00-28.50	Medium to fine grained light green coloured Limestone	BH3/Wantrag/90-95	2.70	0.81	0.32	0.77	53.20	1.20	43.20			
28.50-30.00	Medium to fine grained light green coloured Limestone	BH3/Wantrag/95-100	2.67	1.78	0.72	1.27	52.08	1.20	42.45			
30.00-31.50	Medium to fine grained light green coloured Limestone	BH3/Wantrag/100-105	2.66	6.84	1.04	2.04	49.84	0.40	39.63			
31.50-33.00	Fine grained, Light grey coloured Limestone with iron partings	BH3/Wantrag/105-110	2.70	4.62	0.56	0.99	50.96	1.20	41.18			
33.00-34.50	Fine grained, Light grey coloured Limestone with iron partings	BH3/Wantrag/110-115	2.65	5.05	1.04	1.85	49.84	1.20	40.55			
34.50-36.00	Dark grey coloured fine grained limstone	BH3/Wantrag/115-120	2.66	3.98	0.72	1.42	50.96	1.20	41.22			
36.00-37.50	Dark grey coloured fine grained limstone with iron strings	BH3/Wantrag/120-125	2.59	6.29	0.64	1.39	49.28	1.60	40.30			
37.50-39.00	Dark grey coloured fine grained limstone with iron strings	BH3/Wantrag/125-130	2.70	4.21	0.51	1.38	51.00	1.20	41.20			
39.00-40.50	Dark grey coloured fine grained limstone.	BH3/Wantrag/130-135	2.67	3.71	0.64	1.36	51.19	1.20	41.40			
40.50-42.00	Dark grey coloured fine grained limstone.	BH3/Wantrag/135-140	2.65	2.69	0.54	1.48	49.68	2.97	42.14			
42.00-43.50	Dark grey coloured fine grained limstone.	BH3/Wantrag/140-145	2.73	4.82	0.87	1.22	47.88	3.41	41.30			
43.50-45.00	Dark grey coloured fine grained limstone.	BH3/Wantrag/145-150	2.72	5.88	0.69	1.31	49..61	2.00	40.01			
45.00-48.00	Dark grey coloured fine grained limstone.	BH3/Wantrag/150-160 (1 0f 3)	2.66	5.39	0.76	1.24	49.28	1.97	40.86			
(2 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/150-160 (2 0f 3)	2.70	2.65	0.33	0.51	52.41	1.20	42.40			
(3 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/150-160 (3 0f 3)	2.69	2.00	0.13	0.19	51.52	2.56	43.10			
48.00-51.00	Dark grey coloured fine grained limstone.	BH3/Wantrag/160-170 (1 of 3)	2.76	1.19	0.48	0.99	49.84	3.60	43.40			
(2 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/160-170 (2 of 3)	2.66	2.64	0.72	1.16	52.64	0.40	41.94			
(3 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/160-170 (3 of 3)	2.69	2.18	0.24	0.41	53.20	0.80	42.67			
51.00-55.00	Dark grey coloured fine grained limstone.	BH3/Wantrag/170-180 (1 0f 3)	2.72	0.94	0.32	0.45	53.76	0.80	43.23			
(2 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/170-180 (2 0f 3)	2.72	2.75	0.32	0.54	47.04	5.60	43.25			
(3 of 3)	Dark grey coloured fine grained limstone.	BH3/Wantrag/170-180 (3 0f 3)	2.75	3.43	0.64	1.21	40.32	10.40	43.50			

Table 1C: Chemical Analysis of Borehole 3

Conclusions

The quality-based reserve estimation of the Wantrag limestone block is 1.39 million tons of limestone in the proven category down to at least 10 meters depth from the surface. It is feasible that the mineral reserve can be economically exploited through the open cast method of mining.

Acknowledgement

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Under the microscope!

These photos are of the Barzaman Formation. The selected lithofacies is a pebbly sandstone and is classified as a litharenite. It is characterized by a brownish color and small grain size from 1 mm to 20 mm. The following figures highlight important features of this rock and include thin section images shown in both plane-polarized light (PPL) and cross-polarized light (XPL).

pebbly sandstone lithofacies:

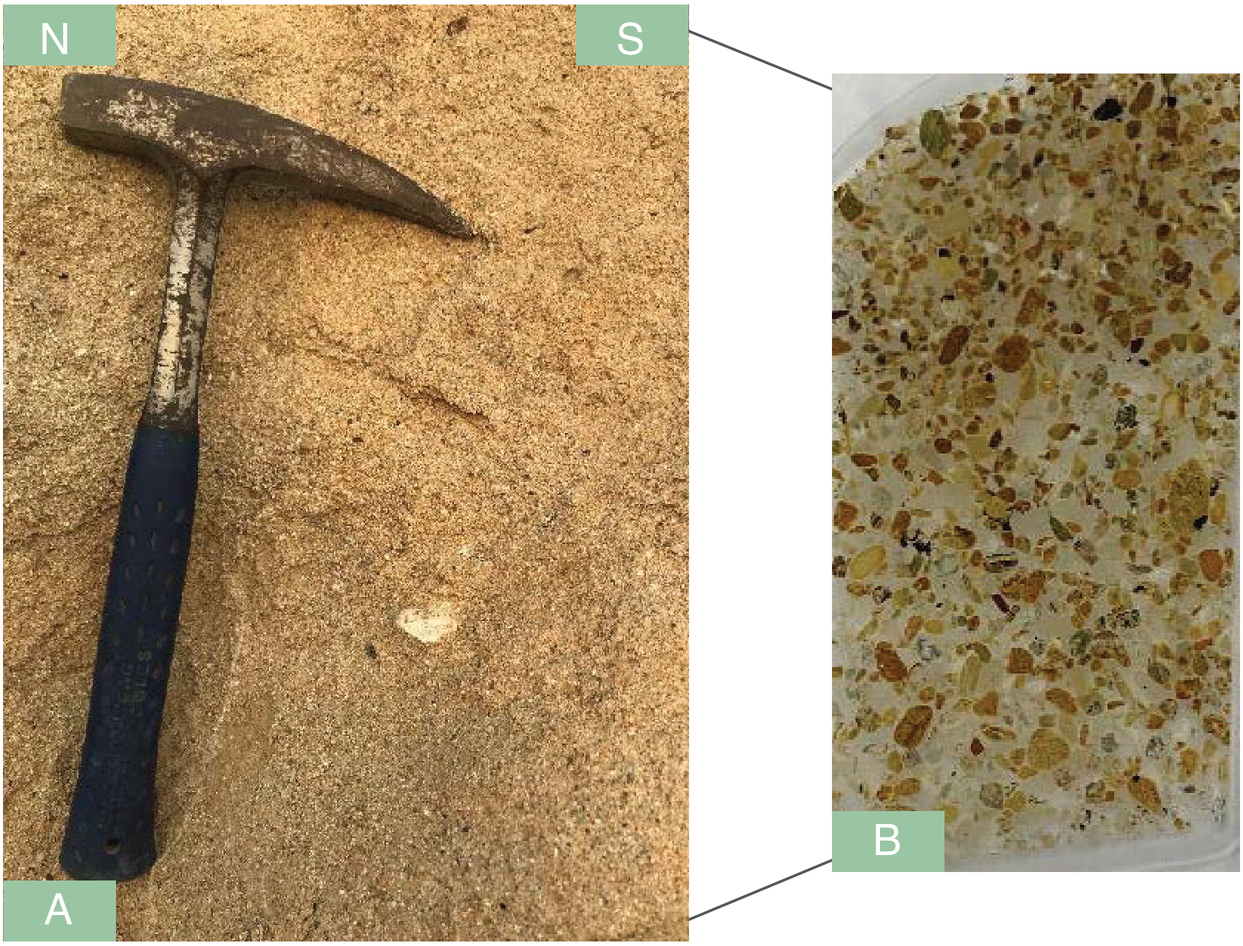

Figure 1. A. Field photo of the sandstone, B. Digital scan of a thin section from the sandstone.

pebbly sandstone lithofacies under microscope (Figure 2&3):

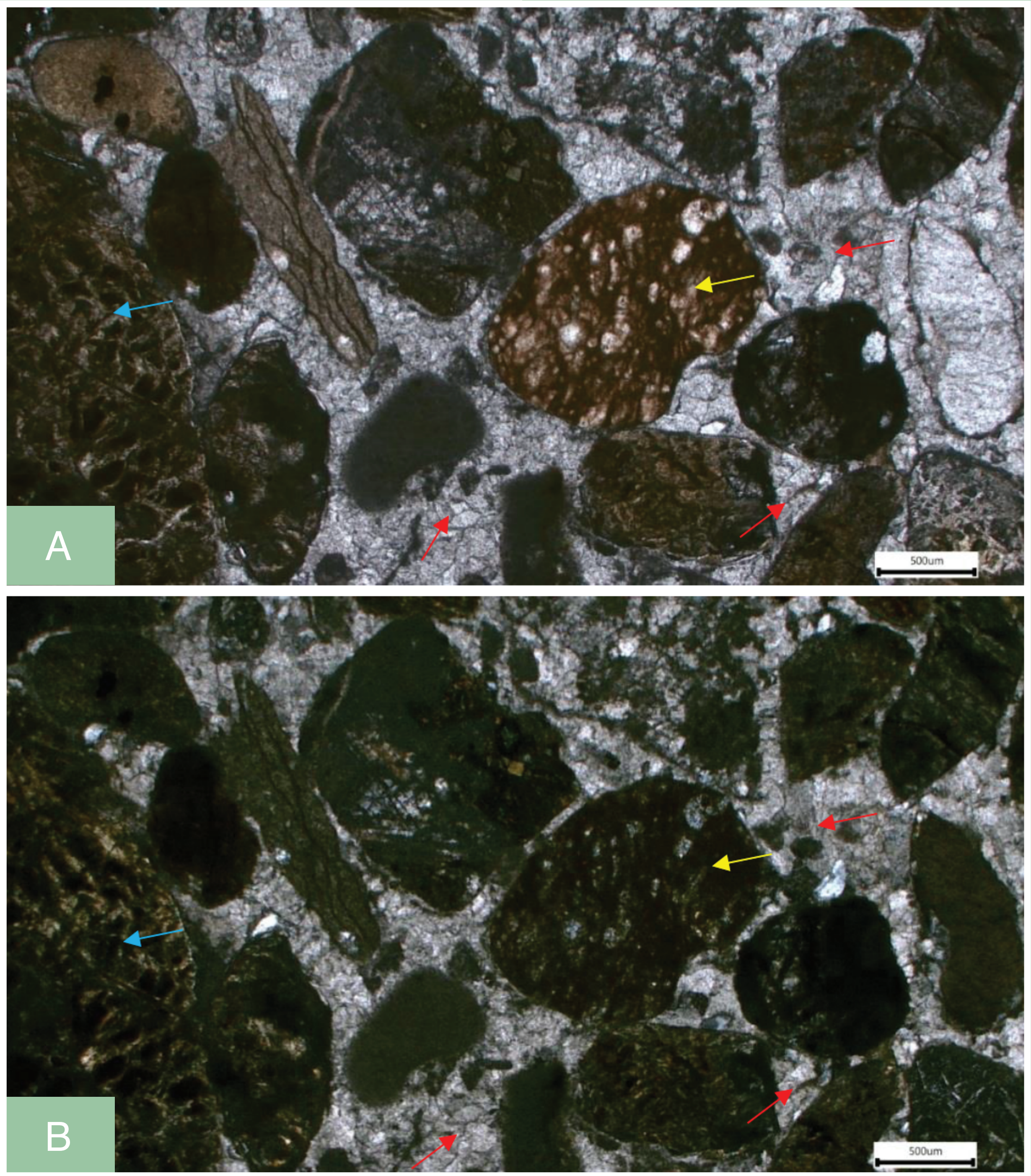

Figure 2. A. Thin section under PPL, the grains are subrounded to rounded, poorly sorted and cemented by blocky calcite cement (red arrows). The grains that can be recognized are radiolarian chert (yellow arrows) and serpentine (blue arrows). B. Thin section under XPL, indicate same things as in A.

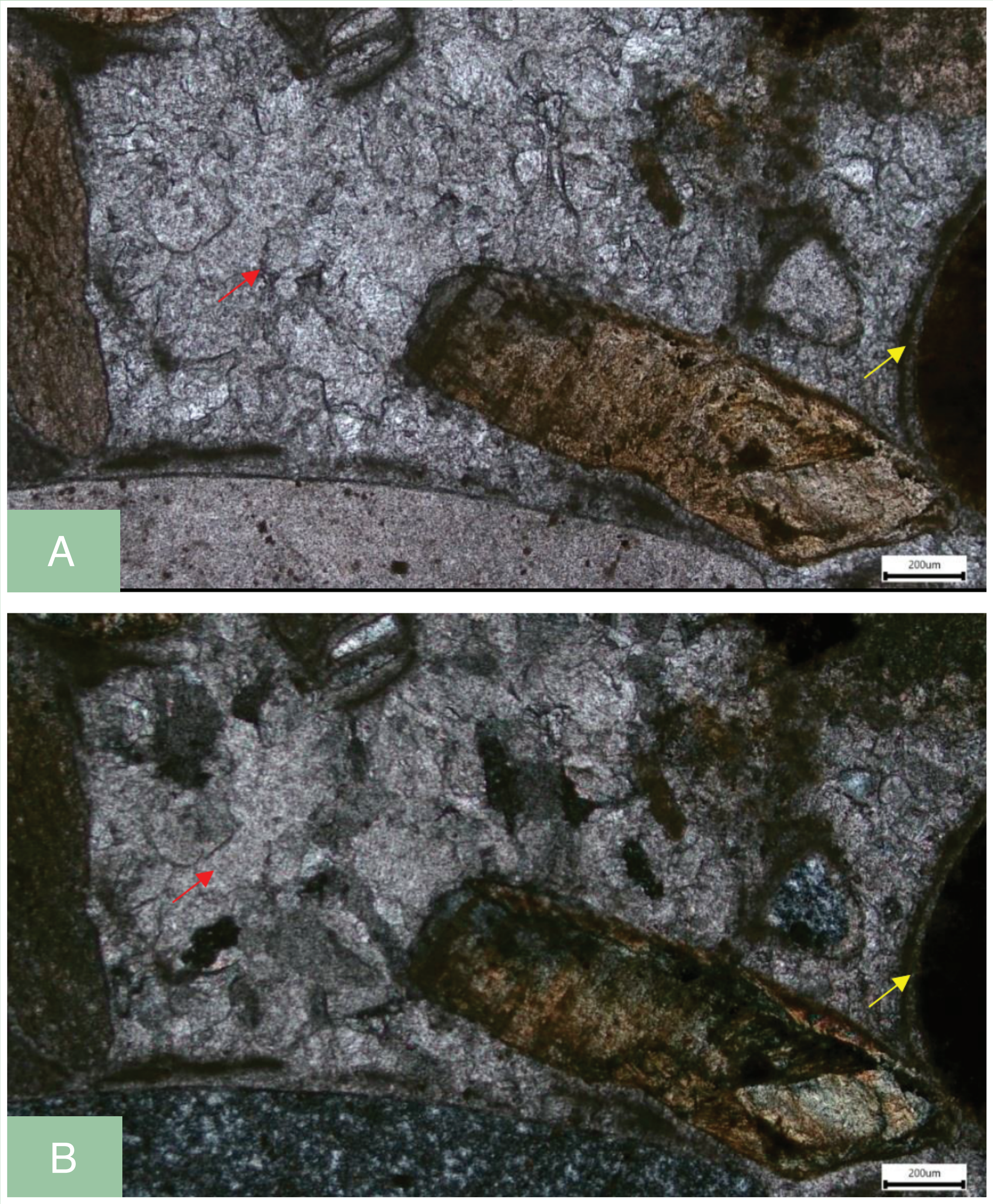

Figure 3. A. Thin section under PPL, there are two cement generation, the first is isopachous bladed calcite cement (yellow arrow) and the second generation is blocky calcite cement (red arrow). B. Thin section under XPL, indicate same things as in A.

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