Al HAJAR

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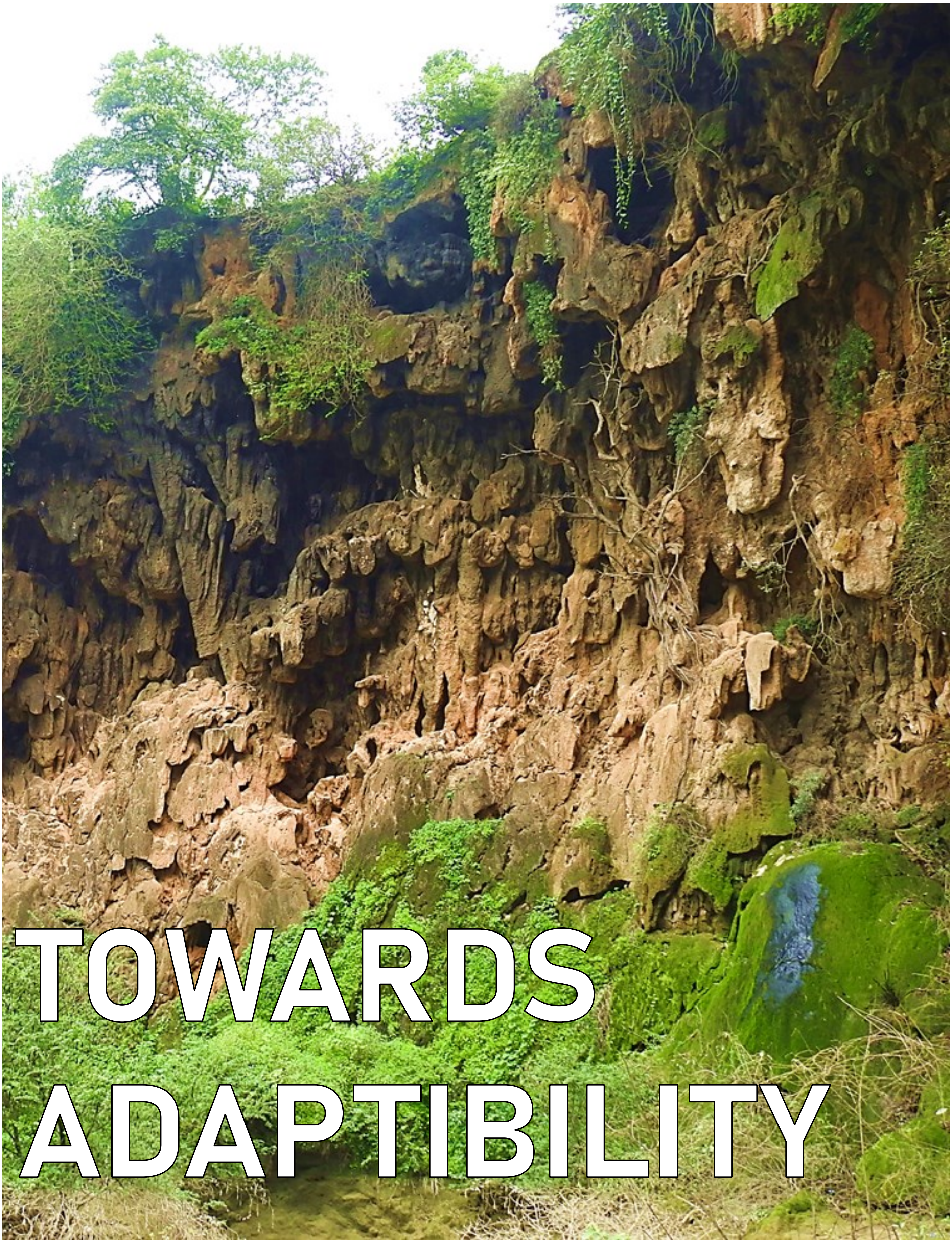

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ABOUT GSO

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

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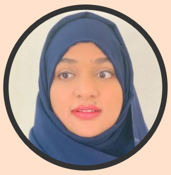
BY THE EDITOR

Dear GSO member,

Last year has brought us into sharp focus on the necessity of adaptability in which we had to be resilient to different challenges to our behaviors and way of working and living. Global events are not something unusual and they did happen before but the way to adopt to their aftereffects are the key to be better prepared for future events. We as geoscientists have the role to understand and analyze the past to be able to predict the future. Rocks and fossils in the geological records are the witness to past processes showing that different changes did take place and the Earth did adapt to the changes. Thus, I encourage you to be part of this global preparation of what are hidden in our future by exploring and learning with what our planet can reveal to us so we can be ready for any future events. I wish you an enjoyable read.

Husam Al Rawahi
GSO Editor
Petroleum Development of Oman

Al Hajar Editorial Team:



Naima Al Habsi
Petroleum Development of Oman

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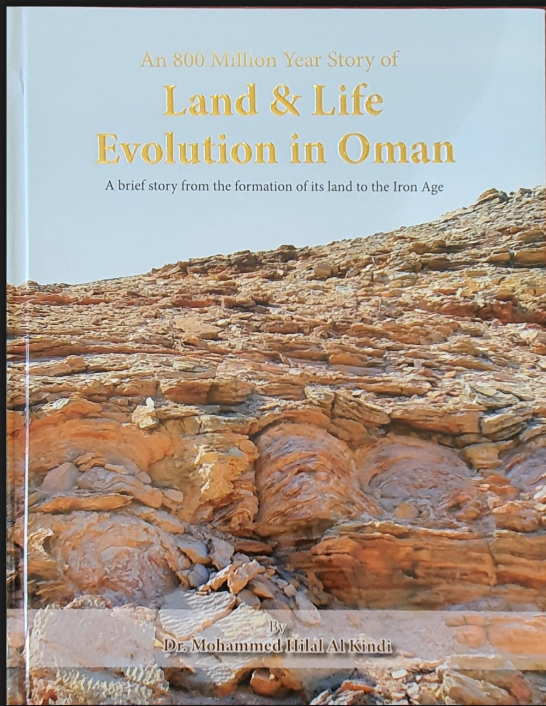
President Address

Dear Colleagues,

A year passes with tremendous events that slightly modified our programs and means of communications to adopt with health and safety precautions due to COVID-19 outbreak.
Late 2020; the Geological Society of Oman introduced "Omani Female Geoscientists" recognition series that focused on our Omani women who pose a career in geoscience within the oil and gas sector. This is a small token of appreciation and pride of our Omani women colleagues and gives the talent for younger generations to be motivated and to continue the success.
We have also continued with our technical programs and hosting geoscientists in live broadcast. Furthermore, GSO introduced its first workshops (i.e. online courses) designed for young professionals and researchers. We aim in future to extend it further to be undertaken by employees in oil and gas companies operating in Oman.
Dear members, we are looking forward to the year 2021 that will certainly carry more activities and programs to help and support the preservation of our wonderful geology in order to safeguard our marvelous geological outcrops and fossils in Oman.
I hope the year 2021 will be prosperous and brighter where the Geological Society of Oman can resume practicing its role via progressing technical programs and activities (i.e. field trips).

Elias Al Kharusi
President of the GSO

"WE WANT YOU TO TELL ABOUT GEOLOGY OF OMAN"



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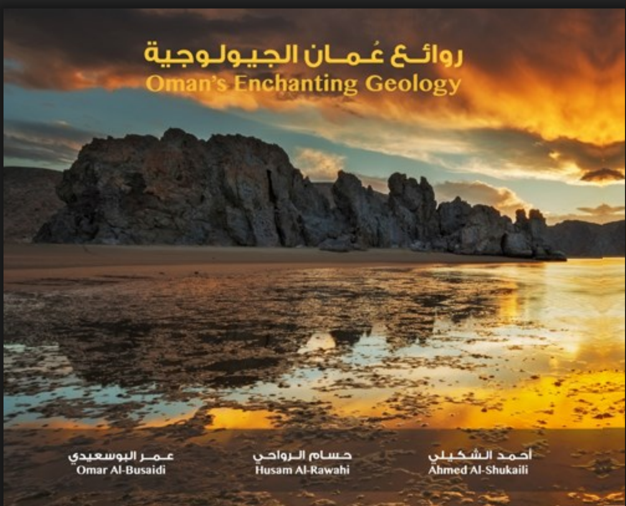

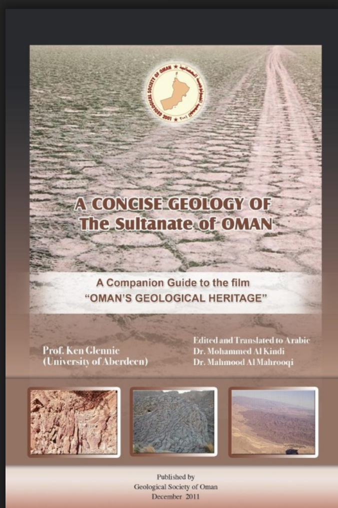

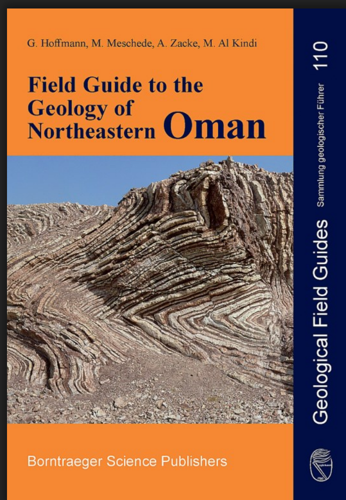

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EARLY PALEOPROTEROZOIC SEDIMENTATION ON THE SOUTHERN HAMERSLEY PROVINCE, PILBARA CRATON, WESTERN AUSTRALIA: A BRIEF OVERVIEW

By: Asma Al Badi, Rajat Mazumder and Wilfried Bauer

Introduction

The early Paleoproterozoic was marked by the onset of global glaciations, a substantial shift in terrestrial geochemistry and biology and led, ultimately, to the development and flourishing of eukaryotic life (Horodyski and Knauth, 1994; Kirschvink et al., 2000; Prave, 2002; Condie et al., 2009; Konhauser et al., 2011; Van Kranendonk and Mazumder, 2015; Van Kranendonk et al., 2015). An apparent minimum in the juvenile magmatic record between 2.4 and 2.2 Ga has been postulated as a consequence of shutdown of subduction (Condie et al., 2009). A critical synthesis of global geological record from about 2.3 to 2.2 Ga ago indicate an early Paleoproterozoic tectono-magmatic lull (Spencer et al., 2018 and references therein). It has been suggested that plate tectonics did not completely shut down but the Siderian Quiet Interval (Pehrsson et al. 2015)(Spencer et al., 2018).; represents an overall diminished tectonic activity (2.3-2.2 Ga; Spencer et al. 2018) . This episode of magmatic quiescence was terminated around 2.2 Ga. (Spencer et al., 2018).

In significant contrast to other cratonic blocks of the world (Eriksson and Condie, 2014), the Pilbara craton of Western Australia documents a near-continuous geological record of early Earth history across the rise of atmospheric oxygen (the Great Oxidation Event, GOE (Trendall and Blockley, 1970; Mazumder and Van Kranendonk, 2013; Van

Kranendonk and Mazumder, 2015; Fig. 1) and provides us a rare opportunity to gain valuable insights in to the extant geological processes. Herein we will briefly review the present state of knowledge on the sedimentology and stratigraphy of the Paleoproterozoic Turee Creek and the Lower Wyloo Groups of the southern Hamersley province, Pilbara craton. The present contribution is an initiative of the GUtech to undertake research on Paleoproterozoic successions of the Pilbara craton involving undergraduate students.

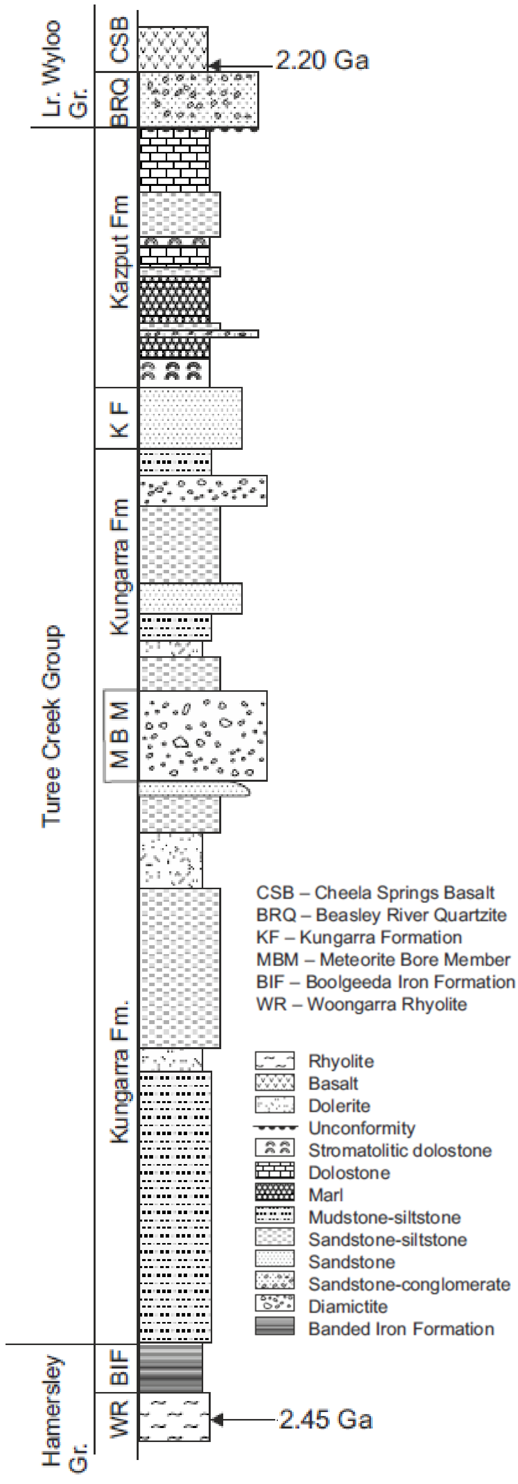


Figure 1. Early Paleoproterozoic stratigraphic sequence of the Pilbara craton (modified after Van Kranendonk and Mazumder, 2015).

Geological and geochronological background:

The early Paleoproterozoic stratigraphic record in the Pilbara craton is represented by the Turee Creek Group (TCG) and the Lower Wyloo Group (LWG) of rocks (Trendall, 1981; Martin et al., 2000; Van Kranendonk and Mazumder 2015). The TCG conformably overlies the Boolgeeda Iron Formation (Figs. 1-2). The 2449±3 Ma Woongarra Rhyolite lies conformably below the Boolgeeda Iron Formation (Fig. 1; Barley et al., 1997). The TCG is unconformably overlain by the LWG (Trendall, 1981; Martin et al., 2000; Mazumder and Van Kranendonk, 2013; Martin, 2020). The 2209±15 Ma Cheela Springs Basalt overlies the LWG (Fig. 1: Martin et al., 1998). A dolerite sill interpreted as coeval with eruption of the Cheela Springs Basalt and intruding the Kungarra Formation of the Turee Creek Group, has a 207Pb/206Pb baddelyite age of 2208±15 Ma (Müller et al., 2005). Interested reader may consult detrital zircon ages reported by Krapez et al. (2017) and Caquineau et al (2018) from the TCG and LWG successions. Martin (2020, his fig. 31) has reviewed the published geochronological and geological data from these successions.

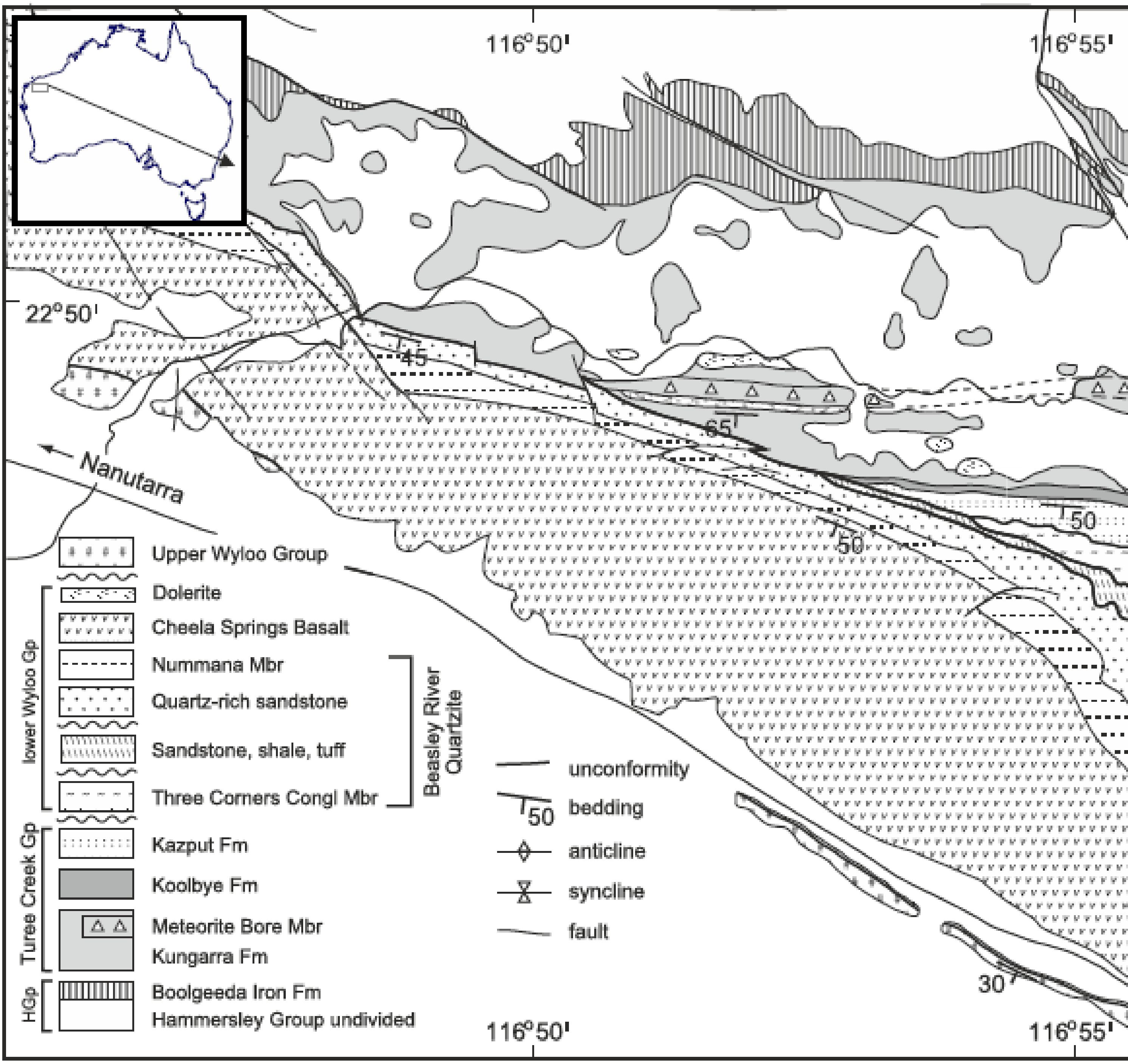
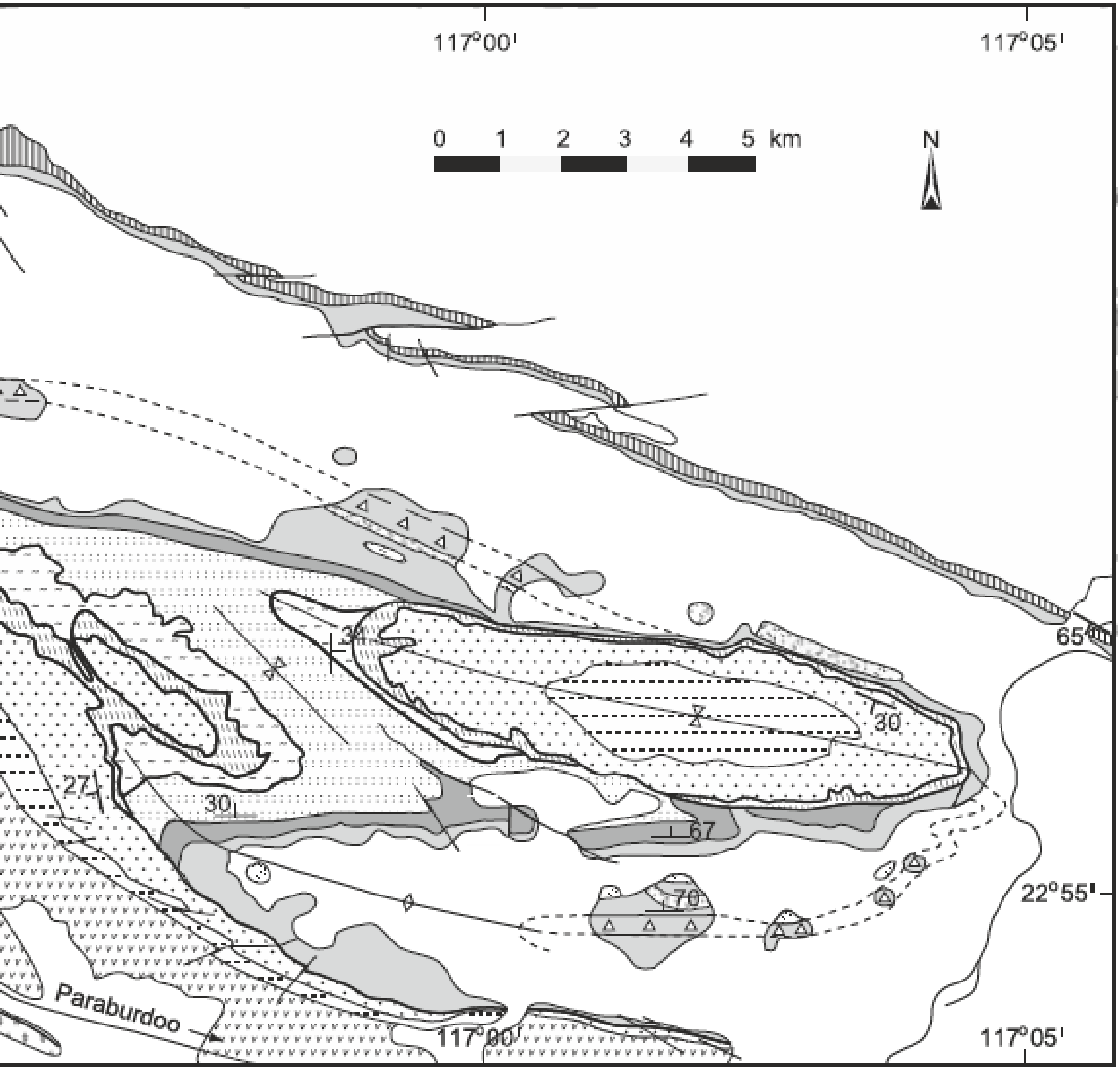


Figure 2. Geological map of Hardey Syncline, Western Australia (modified after Martin, 1999 and Van Kranendonk and Mazumder, 2015); map of Australia in inset

The early Paleoproterozoic sedimentation history on the southern Hamersley province

The Turee Creek Group (TCG)

The Turee Creek Group conformably overlies the Boolgeeda Iron Formation and is made up of lower Kungarra, middle Koolbye and upper Kazput Formations (Fig. 1; Trendall, 1981; Thorne and Tyler, 1996; Krapez, 1996; Martin et al., 2000; Van Kranendonk and Mazumder, 2015; Van Kranendonk et al., 2015). The Kungarra Formation is characterized by a shallowing upward entirely marine succession (sandstone-



siltstone-shale alternations with minor stromatolitic carbonate rocks) and preserves records of two Paleoproterozoic glaciation events (Figs. 3A-B; Van Kranendonk and Mazumder, 2015; Van Kranendonk et al., 2015). Sedimentary facies analysis reveals two distinct glacial cycles within the Kungarra Formation (Van Kranendonk and Mazumder, 2015). In the northern limb of the Hardy syncline area (Fig. 2), the Kungarra Formation is characterized by a lower offshore and an upper shoreface facies association (Van Kranendonk et al., 2015). The Kungarra Formation is conformably overlain by the Koolbye Formation (Fig. 1). The Koolbye Formation is characterized by a lower tidal flat, middle beach-coastal aeolian and an upper fluvial facies association (Martin et al., 2000; Eriksson and Condie, 2014; Mazumder et al., 2015). The Koolbye Formation is conformably overlain by the Kazput Formation (Fig. 1; Trendall, 1981; Martin et al., 2000; Martindale et al., 2015). In significant contrast to the Kungarra and Koolbye Formations, the Kazputs are characterized by ~350m thick predominantly stromatolitic carbonate rocks (with some clastics at the basal part) with microstromatolite and ooids (Martin, 1999) and formed in a shallow marine setting (Martin et al., 2000; Van Kranendonk, 2010; Eriksson and Condie, 2014; Martindale et al., 2015).

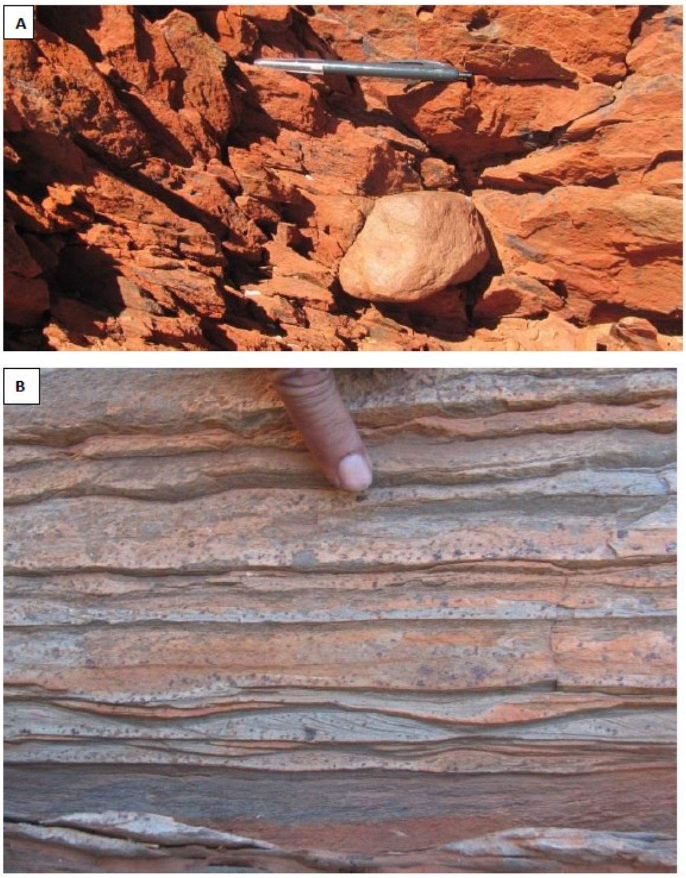


Figure 3. The Turee Creek Group; (A) Glacial diamictite from the Kungarra Formation (B) Wave ripples within the Kungarra Formation

The Lower Wyloo Gropu (LWG)

The LWG unconformably overlies the TCG of rocks (Fig. 4A) and is unconformably overlain by the upper Wyloo Group. The lower Wyloo Group is made up of the Beasley River Quartzite (BRQ) and the Cheela Springs Basalt (Fig. 1). The lowermost polymictic Three Corner Conglomerate Member of the BRQ (Fig. 4A) represents alluvial fan-fluvial complex (Trendal, 1979; Mazumder and Van Kranendonk, 2013; Mazumder, 2017). The overlying medium to fine-grained sandstone of the BRQ with spectacular heavy mineral layering, dunes, low amplitude ripples, and pinstripe laminations, are beach deposits with aeolian reworking. The dominant, quartz rich sandstone member of the BRQ is largely fluvial, based on association of poorly sorted fining upward sandstone units, trough cross bedding, asymmetric ripples, and fluvial architectural elements (Mazumder and Van Kranendonk, 2013; Mazumder, 2017). The topmost fine-grained sandstone and siltstone unit of the BRQ (the Nummana Member; Fig. 2) is largely aeolian, based on the presence of large dune and interdune (adhesion features and translatent strata; Fig. 4B-C) facies (Mazumder, 2019). The nearshore to aeolian interpretation for the BRQ is compatible with the inferred subaerial eruption of the overlying Cheela Springs Basalt (Mazumder and Van Kranendonk 2013 and references therein).

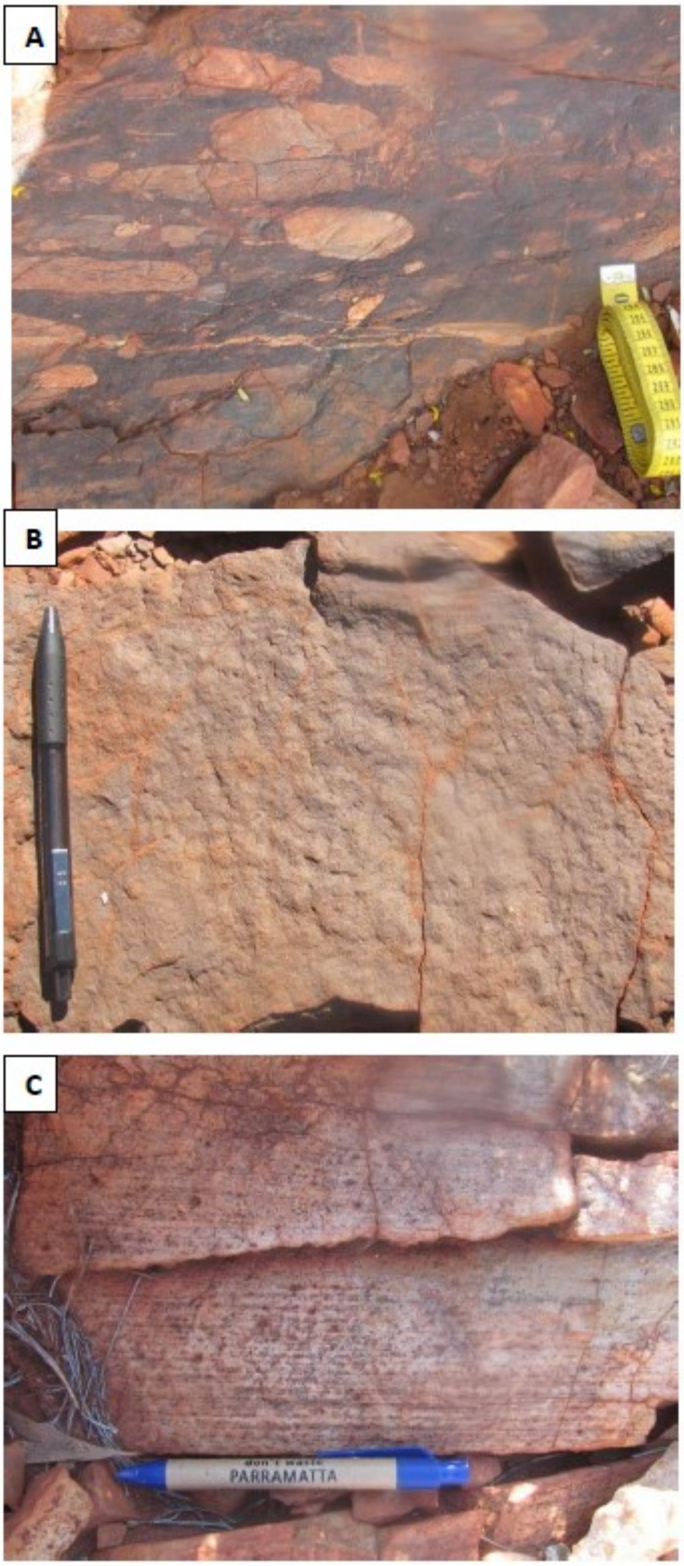


Figure 4. The Lower Wyloo Group; (A) The Three Corners Conglomerate (LWG) (B) Adhesion feature in the Nummana Member (LWG) (C) Pinstripe lamination in the Nummana Member (LWG); pen length 10cm

Sea level change

The Kungarra Formation of the TCG has a gradational, conformable lower contact with underlying banded iron-formation of the Hamersley Group (Figs. 1-2). The lower Kungarra offshore shale-sandstone facies association passes upward into shallow marine sandstone-siltstone-shale-stromatolitic carbonates of shoreface origin followed by the deposition of glacial diamictite (cf. Van Kranendonk and Mazumder, 2015; Van Kranendonk et al., 2015). Each of the two glacial cycles sharply commenced with a falling stage systems tract (Plint and Nummedal, 2000) and terminated with a transgressive systems tract, consistent with drawdown and subsequent release of large volumes of seawater from, and into, waxing and waning ice sheets, respectively (Van Kranendonk and Mazumder, 2015). The Kungarra Formation is conformably overlain by the Koolbye Formation (Figs. 1-2) The Koolbye Formation records a marine to fluvial transition (Mazumder et al., 2015) and the tidal flat to beach to aeolian-fluvial transition implies depositional regression (falling stage systems tract). The Koolbye-Kazput transition indicates marine transgression (cf. Martin et al., 2000; Eriksson and Condie, 2014; Mazumder, 2017).

In the Horseshoe Creek area (western part of the basin, see Fig. 2), the Kungarra Formation is unconformably overlain by the LWG (Fig. 3A) overrunning the Koolbye and Kazput Formations (Trendall, 1979; Mazumder and Van Kranendonk, 2013). A prolonged period of surficial exposure immediately after the deposition of the TCG and before the deposition of the LWG has been inferred (Morris 1980, 1985; Mazumder and Van Kranendonk, 2013; Mazumder, 2017). The TCG-LWG contact is an angular unconformity (Mazumder and Van Kranendonk, 2013). The Cheela Springs basalt is a typical flood basalt and is made of plagioclase feldspars and barroisitic hornblende with relict clinopyroxenes and secondary chlorite, epidote, titanite and leucoxene (alteration product of titanium bearing mineral phase). The chlorite grains are large and are characterized by anomalous bluish interference colour and are partially oxidized. The entire LWG represents a nearshore to terrestrial deposit (Mazumder, 2017, 2019).

The preservation of the LWG terrestrial succession has been interpreted as a consequence of rapid basin subsidence during rifting (Mazumder and Van Kranendonk, 2013). Such subsidence might have taken in intracontinental or continental margin rifts, or back-arc or transtensional setting. As there is no evidence of a contemporaneous arc, nor an orogen during LWG sedimentation, a continental rift setting for the LWG has been proposed (Mazumder and Van Kranendonk, 2013: Mazumder, 2017, 2019). The preservation of delicate aeolian features (Figs. 4B-C) supports rapid subsidence in a continental rift setting (cf. Mazumder and Van Kranendonk, 2013; Mazumder, 2019).

Geodynamic implications

Australia, India and South Africa constituted a Late Archaean southern supercontinent (Aspler and Chiarenzelli, 1998; Eriksson et al., 1999, 2006; Mazumder et al., 2000; Reddy and Evans, 2009; Mazumder et al., 2015). Paleoproterozoic glacial deposits are well known from Australia and South Africa (Bekker et al., 2001; Martin, 1999; Rasmussen et al., 2013; Eriksson and Condie, 2014; Van Kranendonk and Mazumder, 2015; Pehrsson et al., 2015) and Paleoproterozoic glacigenic rock has been described from the Sausar Group, Bastar craton of India (Mohanty et al., 2015).

The Paleoproterozoic basins of India are essentially intracratonic depositories (Mazumder and Eriksson, 2015); the ~2.5-2.1 Ga Dongargarh (Bastar craton, India) basin-fill suggests post-orogenic collapse and concomitant rift basin formation followed by stable shelf development and glacigenic deposits (Mohanty et al., 2015; Mazumder and Eriksson, 2015). The ~2.6-1.6 Ga supracrustal successions of the Singhbhum craton, India formed in an intracontinental rift setting and records a transition from alluvial fan-fluvial (the Dhanjori Formation) to deep to shallow marine (the Chaibasa Formation) and then fluvial-aeolian (the Dhalbhum Formation) (Mazumder et al., 2019). Other Precambrian basins of India lacks early Paleoproterozoic successions or contains late Paleoproterozoic to Neoproterozoic successions or are entirely Archaean (Saha and Mazumder, 2012; De et al., 2016; Mazumder et al., 2019).

The Transvaal Supergroup (2.66-2.05 Ga) represents the late Archean-early Paleoproterozoic transition in South Africa (Eriksson et al., 2006). The Transvaal Supergroup succeeded the relatively short-lived Ventersdorp plume event (Eriksson et al., 1999, 2006; Mazumder et al., 2012). The lower part of the Transvaal succession represents alluvial braid plain facies association grading to transgressive shallow-marine and braid-delta facies association (Eriksson et al., 2006; Mazumder et al., 2012). The Malmani Subgroup of the overlying Chuniespoort Group is represented by transgressive black shale deposits followed upward by the carbonate platform deposits. The overlying Penge Formation and Duitschland Formation are characterized by banded iron formation and lacustrine deposits, respectively (Mazumder et al., 2012). The overlying Pretoria Group represent largely alluvial fan-braided stream-epeiric sea and shallow lacustrine deposits (Eriksson et al. 2006; Mazumder et al., 2012).

The TCG lacks juvenile zircons from accreted and uplifted arc rocks but contains recycled zircons from older Hamersley succession (e.g., Martin et al., 2008; Martin, 2020 and references therein) and is inconsistent with the foredeep setting as it was previously interpreted (Martin et al., 2000 and references therein; Young 2013). Neither there is evidence of early Paleoproterozoic (2.45-2.22 Ga) orogen nor arc in the Pilbara craton (Mazumder and Van Kranendonk, 2013; Van Kranendonk et al., 2015). The sedimentological analysis clearly reveals that the TCG as well as the LWG deposited in an intercontinental rift setting (Mazumder and Van Kranendonk, 2013; Van Kranendonk et al., 2015; Mazumder, 2017) broadly similar to the Huronian succession of Canada (Young, 2013). The unconformity between the TCG and the LWG indicate prolonged emergence and stable tectonic environment (Mazumder and Van Kranendonk, 2013) which may be a consequence of global magmatic shutdown (cf. Condie et al. 2009) or Siderian Quiet Interval (Pehrsson et al., 2015). More geochronological data from the TCG and overlying LWG and global chronostratigraphic correlation with other Siderian successions of the world is essential to resolve this.

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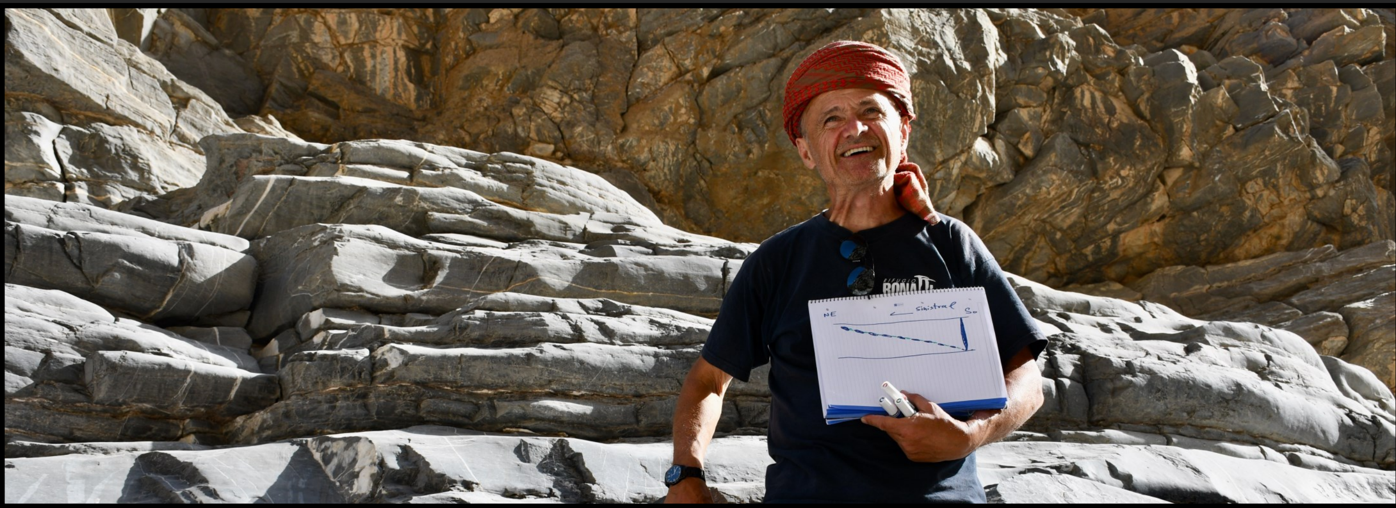

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STRUCTURAL AND HYDRO-GEOLOGICAL ANALYSIS OF OMAN DRILLING PROJECT BA-SITE

By: Anwaar Al-Hajri A., Ivan Callegari and Ekkehard Holzbecher

Introduction:

The study area is located in the north-east section of Oman, south of the south-eastern section of the Hajar mountains (Figure 1). The area is constrained around the BA-Borehole sites drilled by the Oman drilling project (ODP). The focus of the study is to characterize the brittle structures currently being studied as the Issmaiya Lineament Swarm (ILS). ILS is a north-west subvertical fault zone with strike-slip movement. This fault zone extends from the Mesozoic autochthonous unit B to the NW and the Paleogene basin to the SE. The study area is located in the area where the fault affects the allochthonous Samail unit, and the lithology is mainly serpentinized Harzburgite and Dunite. The Ibra basin to the SE is part of the Cenozoic autochthonous unit. The wadi is covered by Quaternary alluvial deposits (Peters et. al., 1986).

The lineaments in this area are currently studied under the name of 'Ismaiya Lineament swarm' in a collaborative effort between GUtech and University of Oslo.

Methodology:

To identify the connectivity and the nature of the fractures different methods were used:

- Field structural analysis: different outcrops nearby the wells were chosen and three different types

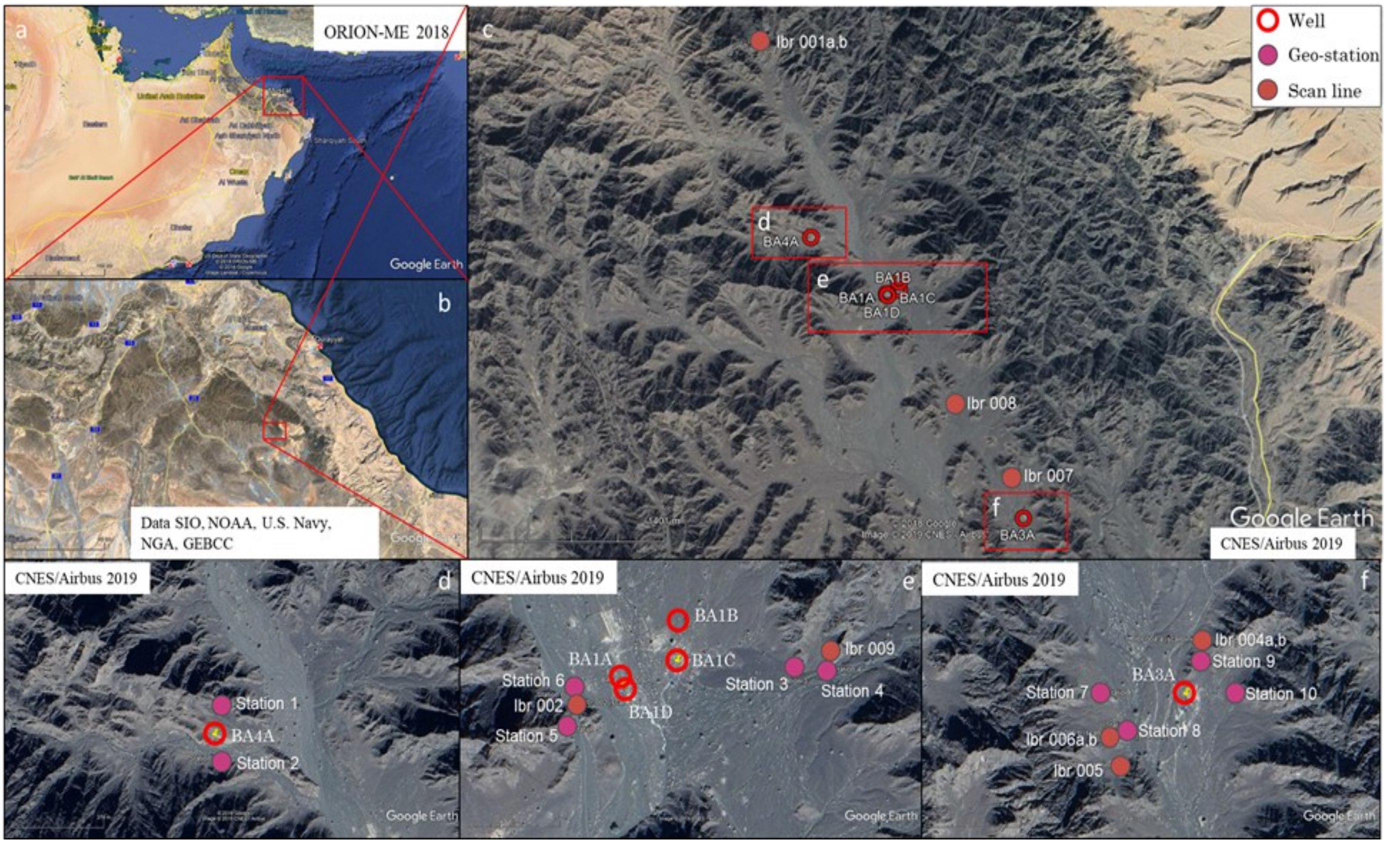


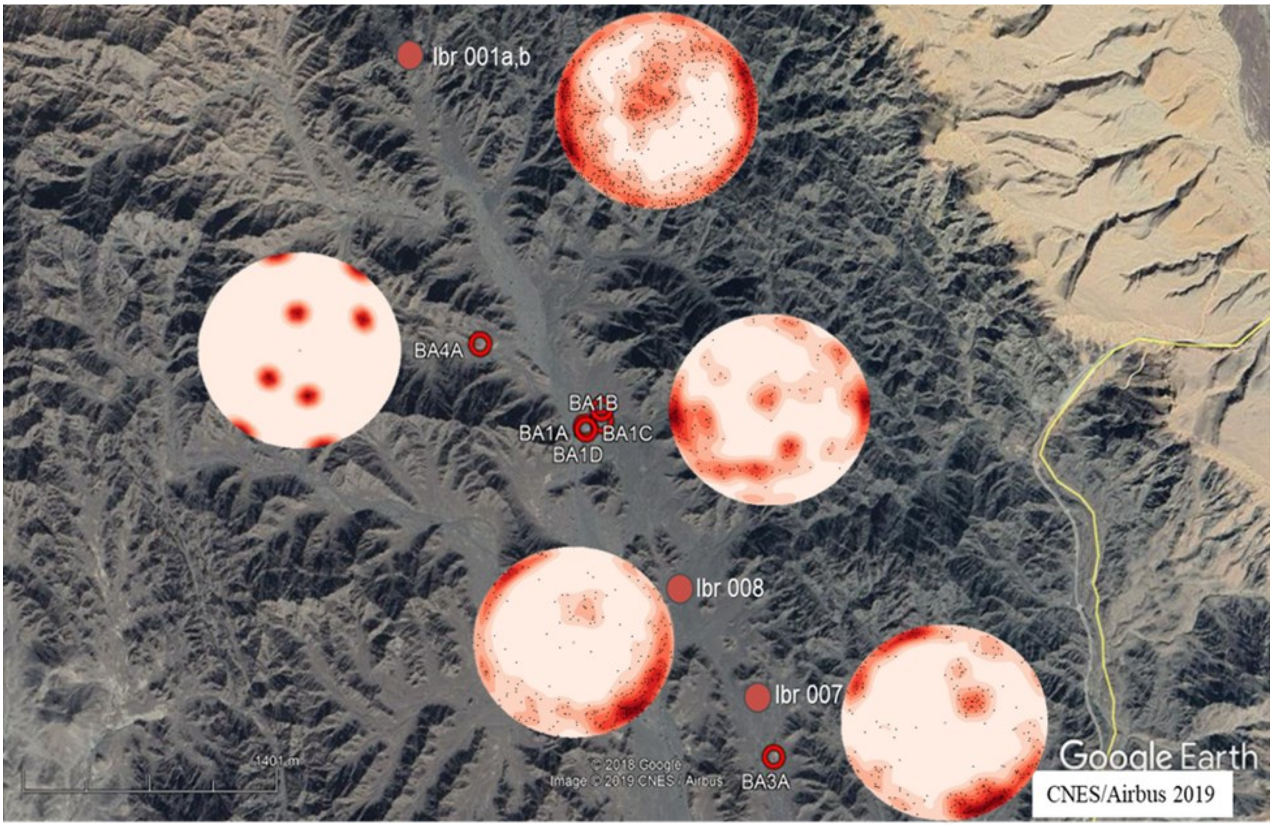
Figure 1. Location maps of the study area.

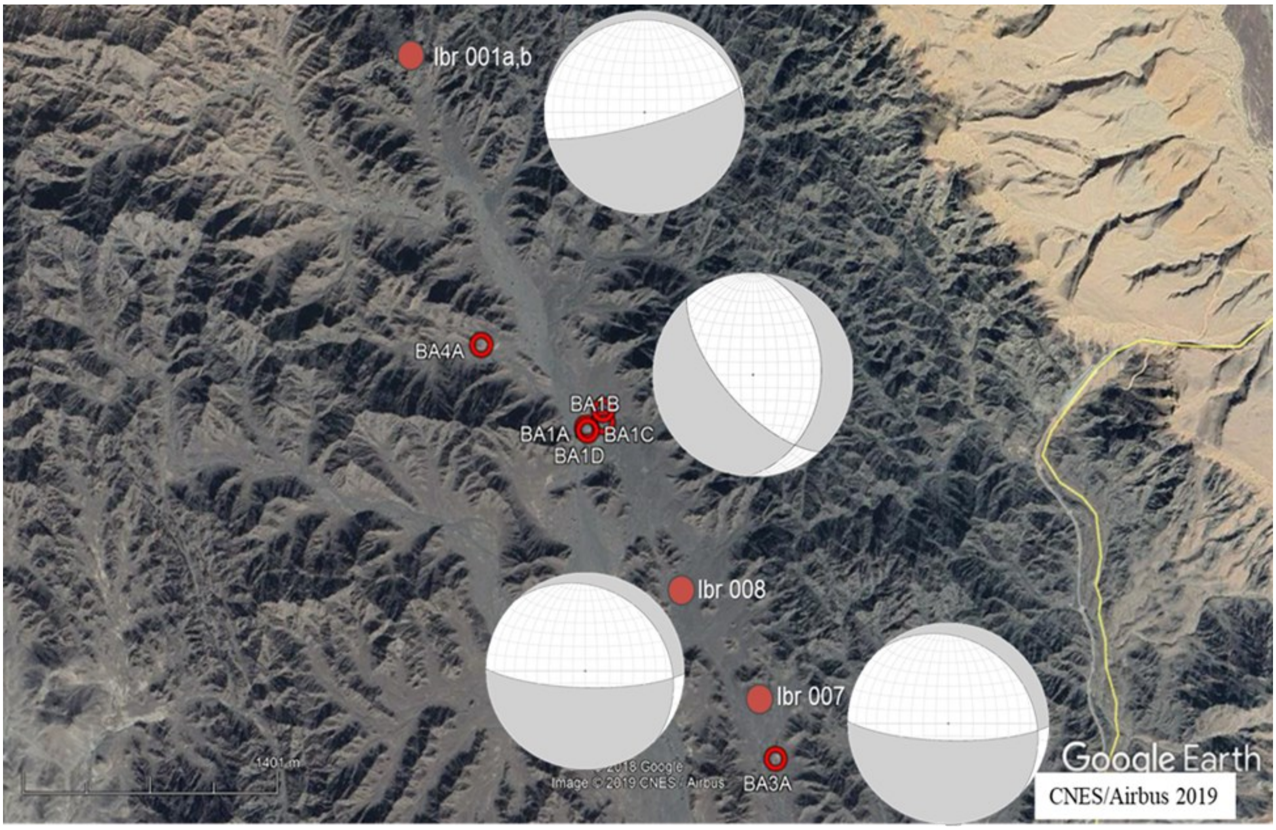
of measurements were taken: fault plane slicken-slides and slicken-lines, scan lines where the frequencies of fractures were tallied per meter, and finally stations which are meter-long outcrops where the orientation and frequency of the different families of fractures near the wells to help correlate fractures interpreted from the acoustic borehole image logs.

- Pumping test evaluation: pumping tests were carried out through packer tests and produced drawdown values using a pressure sensor. The pressure data were changed into head values. These values were plotted against time using different models in Hytool (Renard 2017) (Matlab) to calculate transmissivity values for different intervals.
- Acoustic borehole image logs analysis: The borehole image logs consist of travel-time image logs and Amplitude logs. The fractures were interpreted and logged using WellCad: Image and structure interpretation model. The optical image logs were also used to log fractures displacing veins and fractures with large openings.
- Hydrogeochemical log analysis: the hydrogeochemical logs of pH, temperature, Eh, conductivity, and pressure were used to identify anomalies to correlate with fractures nearby.
- Flowmeter logs: these logs identify zones of fluid exchange in the wellbore and is used to help identify the changes in the other hydrogeochemical logs and pumping test values.

Results:

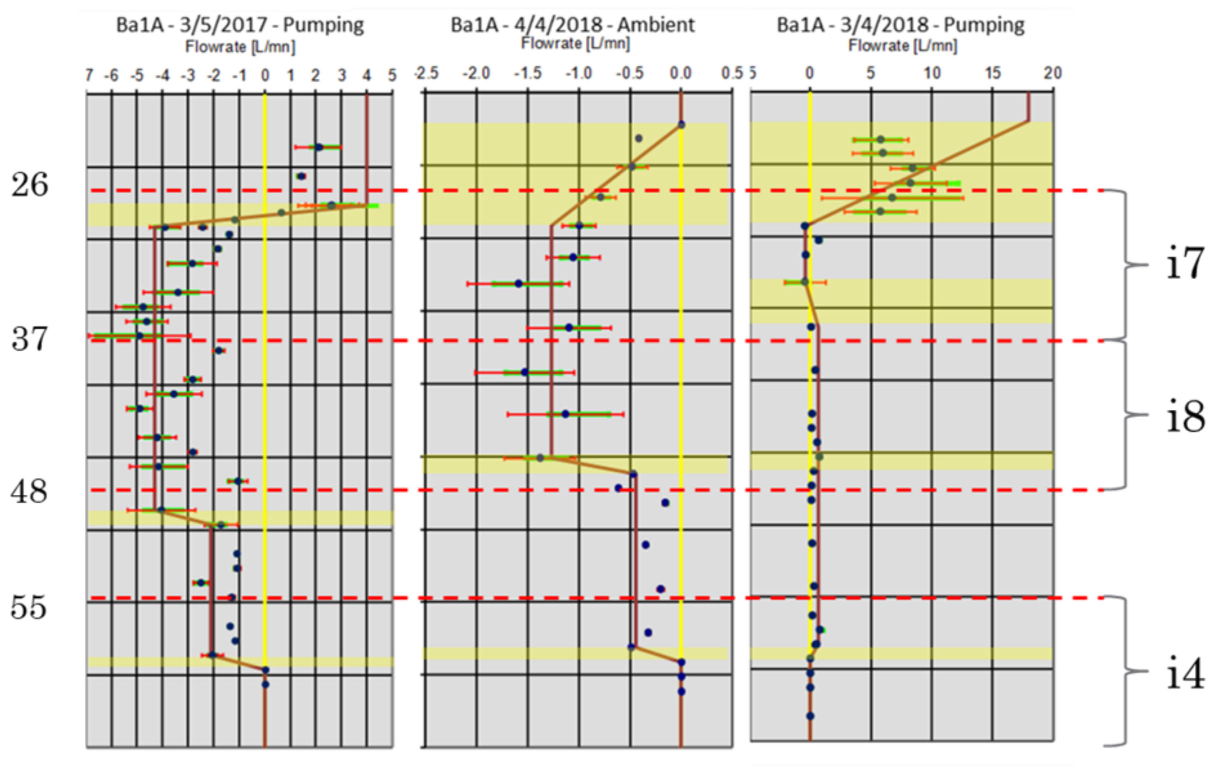
The fractures were grouped into 5 different groups along the wadi to show changes in orientation. The fractures upstream of the wells are mostly oriented NW-SE, while downstream of the wells they are oriented NE-SW.



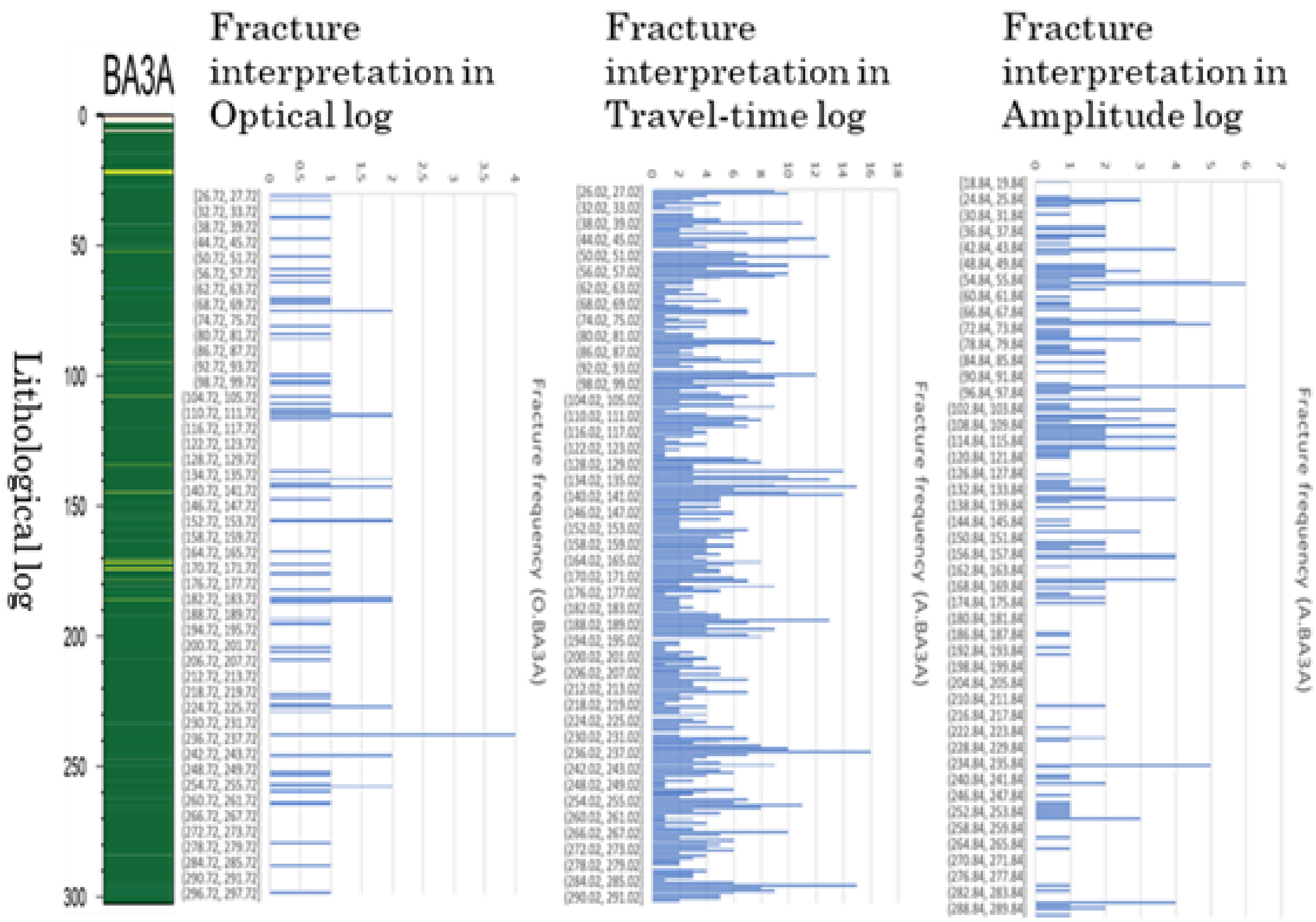


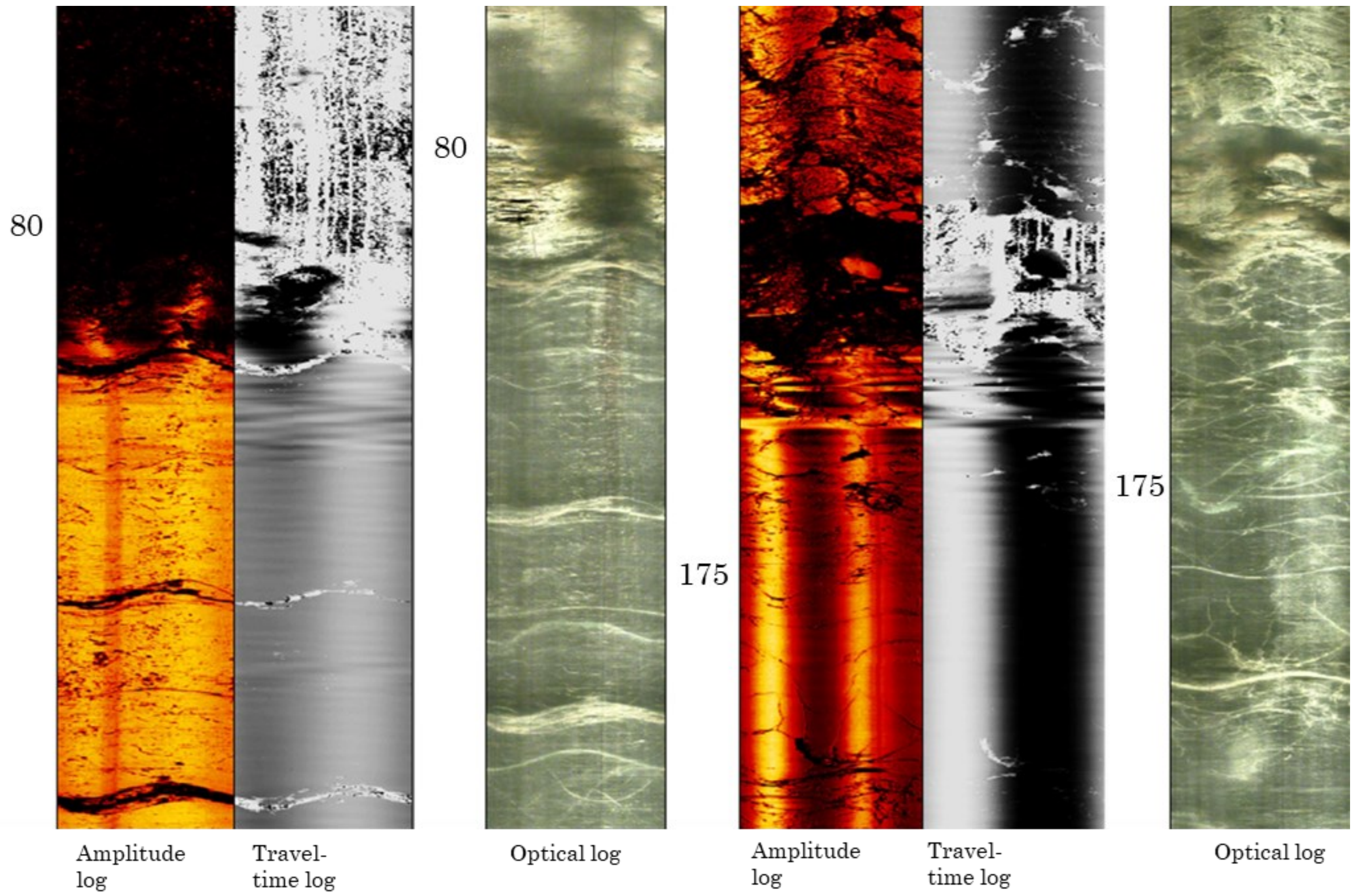
The transmissivity values correlate well with the flowmeter logs, where zones with calculated high transmissivities are also seen in the flowmeter log to show exchange in fluids in the same zone. The Hydrogeochemical logs also show anomalies within the same zones.

	Pumping		Recovery		Complete	
i7 (26-37mbgl)	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity
	4.50E-03	0			4.50E-03	0
	Pumping		**Recovery**		**Complete**	
i8 (37-48mbgl)	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity
	9.60E-06	0	7.72E-07	4.04E-05	9.60E-06	0
	Pumping		**Recovery**		**Complete**	
i4 (55-66mbgl)	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity
	1.93E-05	9.55E-01	8.64E-05	5.40E-02	2.00E-05	8.60E-01
	Pumping		**Recovery**		**Complete**	
i15 (111-400mbgl)	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity	Transmissivity (m^2/s)	Storativity
	1.70E-06	6.90E-04			2.30E-06	8.70E-05



Three high aperture fractures were interpreted in the borehole image logs of well BA3A. Those fractures with high frequency of fractures along the borehole in the well and shattered outcrop close to the well may be explained by the well being positioned close to two fault plane intersections.


BA3A
Lithological log
0
50
100
150
200
250
300
Fracture interpretation in Optical log
Fracture frequency (O.BA3A)
Fracture interpretation in Travel-time log
Fracture frequency (A.BA3A)
Fracture interpretation in Amplitude log
Fracture frequency (A.BA3A)


80
80
175
175
Amplitude log
Travel-time log
Optical log
Amplitude log
Travel-time log
Optical log

Conclusion:

The results show that the study area is affected by two systems of fractures formed by two main fault orientations. These fracture systems caused complex groundwater flow systems in response to the structural changes. The fractures frequency lowers with depth as expected due to the affects of weathering. The conditions around borehole are unique which makes linking the fracture systems to the those in the nearby outcrops difficult.

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OMAN: OUTDOOR DIAGENESIS MUESUM

By: Aisha Al Hajri

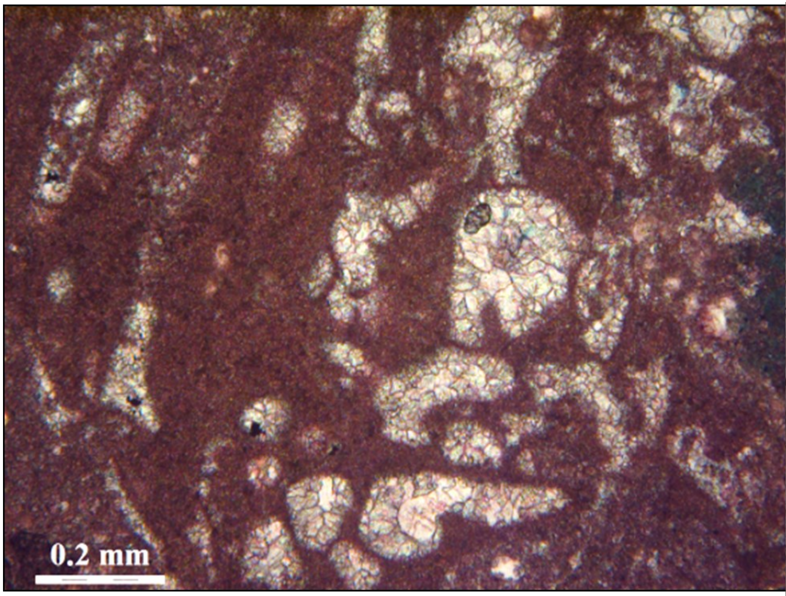
Digenesis is a very common yet complex chemical and physical alteration process that affects rocks throughout the geological time. Diagenetic processes may include dissolution of rocks, precipitation of cements within the rocks, and compaction and fracturing because of an applied stress. There are different parameters involved in any diagenetic process, including the chemistry of reactive fluids within the pore system, burial depth, and temperatures at which alteration occurs. Therefore, detailed study of rocks diagenesis can provide a geological record of different processes that helped reshaping an area or a basin in the context of the, climatic, burial and tectonic evolution of that area or basin. In this article, I would like to focus on diagenesis in sedimentary rocks, particularly the carbonate rocks that I have worked on extensively for the last 10 years.

In sedimentary rocks, which are the main reservoirs of the most important fluid for the creatures on Earth (i.e. the water of course), diagenesis plays a very important role in modifying the rocks' properties; how porous and well connected (via dissolution and fracturing) or tight and poorly connected (via cementation and compaction) these rocks are to allow good storage, mobility, and discharge of water from them. In petroleum industry, the role of diagenesis in sedimentary rocks is equally important, because it can also contribute to the generation (via compaction of the rocks containing organic matter) and distribution (via fracturing and faulting of rocks) of other commercially important fluids and these are the oil and the gas. In mining industry, the diagenesis of the sedimentary rocks can also generate some products that are of a very high commercial value in the market. Examples of these products are gypsum, barite, and travertine.

What makes digenetic products very interesting is that they can be seen at many scales; some of them can be seen from a distance of 100s of meters; while others can only be seen under the microscope. While working on diagenesis of carbonate rocks, I enjoyed looking, capturing, and documenting many, beautifully looking diagenetic products that never stopped surprising me how different elements can be linked to each other to tell you an interesting piece of the Earth evolving story. Therefore, I thought of sharing some pictures that illustrate some of the wonders of diagenesis with you. I hope you will enjoy them.

Aisha Al Hajri

A very active Geologist and the Vice President of GSO. She is working as a carbonate Geologist at Petroleum Development Oman. Her field of interest is carbonate sedimentology, stratigraphy, diagenesis, and petrophysical evaluation



▲ Microscopic photograph showing *Bacinella* algae-rich boundstone with strong calcite cement (white crystals inside the algae chambers). Subsurface sample from the Shuaiba Formation.

▲ Hexagonal shaped calcite cement deposited in Tertiary carbonates, Masirah Island.

▲ Hydrothermal dolomitization (brown areas) confined to area around fracture, Khufai Formation (Snake Gorge, Wadi Bimah)

Vugs within Tertiary carbonates generated after dissolution by meteoric water, Abandoned mine in Salalah ▲

▼ Big circular sinkhole generated by dissolution and collapse of carbonate rocks , Taiq Cave Salalah

PHOTOS FROM GSO MEMBERS

WHO:
Ali Al Hajri, a geologist from Oman

WHERE:
Mahoot, Al Wusta

WHAT:
IPhone 6 camera

In one of Oman outcrops of the Cambrian Miqrat Formation in the Al Huqf area, eye-catching syneresis cracks can be observed and examined. Such structures form due to shrinkage that form under water in clayey sediments. The curved tapering nature of the cracks and the color contrast in the outcrops makes it a text-book example.

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