[PS]An Outcrop Study of Fracturing, Stylolitisation and Mechanical Stratigraphy in the Carbonate Carapace of a Salt Dome (Lower Cretaceous Units of Jebel Madar, Oman): A Template for Subsurface Analysis*

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Abstract

Carbonate units in the Lower Cretaceous of Jebel Madar, Oman form part of the exposed carapace above a salt dome. They contain a fracture network that reflects burial and exhumation in addition to the impact of regional tectonics and the local salt intrusion. A study of the 3D geometry and control on the fracture system in these rocks could be used as a template when attempting to reconstruct the fracture systems in the carapace above sub-surface intrusions. The carbonate units are made up of several beds and each bed has its own fracture network, the geometry of which reflects the stress history and intrinsic properties of each layer. These intrinsic properties include the lithology, specifically grain size, cleanness of carbonates (amount of clay), porosity, and bed thickness. Furthermore, the diagenetic fluid flow history, which is reflected in the cements present in the matrix of the host rock and infilling part of the fractures, is also impacting the complex geometry of the fracture network within each unit. Consequently, the intrinsic properties and diagenetic history of several individual rock units have been investigated in order to determine the influence of the above parameters on fracturing. The aim is to use the results to predict flow properties of sub-surface analogues. It is possible to distinguish between the fractures generated during burial from those linked to the emplacement of the salt body. The early burial fractures, which are normal to bedding, are intimately related to the formation of bedding parallel stylolites, and together these structures can have a significant impact on the movement of fluids through the rocks. The synchronous formation of the extension fractures normal to bedding and bedding parallel stylolites is shown by their mutual crosscutting relationship. In addition, it is found that the specific lithology of individual beds and their thicknesses control both fracturing and the formation of stylolites. Two important components of the fracture network in these rocks are the bedding and the stylolites. Consequently, in addition to studying the relationship between the evolving stress regime, lithology and fracturing of the sequence, an attempt has been made to understand what controls the location, amplitude and lateral extent of the stylolites. This project is part of the Qatar Carbonates and Carbon Storage Research Centre, which is jointly funded by Qatar Petroleum, Shell, and the Qatar Science and Technology Park.

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Improving reservoir recovery and carbon storage potential

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An outcrop study of fracturing, stylolitization and mechanical stratigraphy in the carbonate carapace of a salt dome (Lower Cretaceous Units of Jebel Madar, Oman):

A template for subsurface analysis

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1. Aims

- **Deformation history** of the carbonate carapace of a **salt diapir** (Jebel Madar, Oman)

- **Fracture & stylolite network**
  - influenced by varying stress regimes (regional stress fields & local uprising of salt) and lithology of the rock
  - interplay between brittle deformation & pressure solution

Relevance to Reservoir Recovery and Carbon Storage Potential in Qatar:

- **Fracture & stylolite network** properties impact on **fluid flow (barriers, baffles, conduits)** in reservoirs

- **Subseismic fracture & stylolite network properties** through work at outcrops

- Template for **subsurface diapirs** in Qatar

2. Geological Setting

- **Jebel Madar:** salt dome south of the Oman Mountains (Fig. 2.1 & 2.2). The exposed stratigraphy comprises Triassic to Cretaceous units.

- **Late Cretaceous:** SW directed thrusting/obduction of Semail ophiolites (subduction of Arabia below the Eurasian plate) NE of Jebel Madar

- **Late Cretaceous-Earliest Paleocene:** obduction of Masirah ophiolites SE of Jebel Madar, transpressional stress regime with S_{hmax} NW orientated

- **Late Cenozoic:** NE-SW oriented S_{hmax}, opening of Red Sea, collision Arabian & Iranian Plate

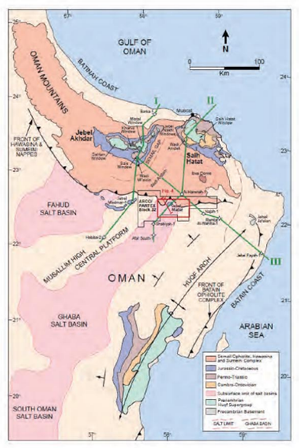

Fig. 2.1 Regional setting of NE Oman with Jebel Madar. Transect II (green line) is shown in Fig. 2.2 (modified after Mount et al. 1998; Gorin et al. 1982)

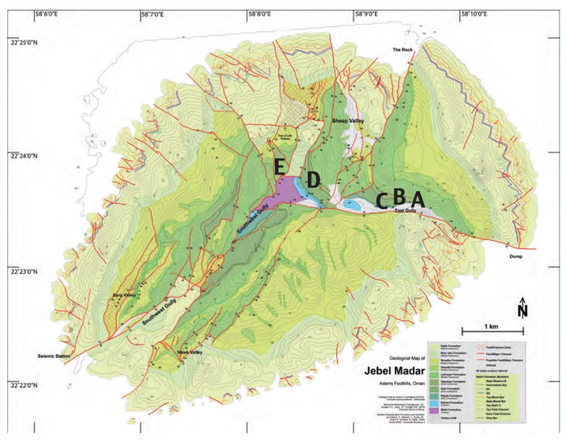

Fig. 2.3 Geological map of Jebel Madar salt dome structure. A-E are locations where fracture analyses were carried out. Modified from Claringbould (2010).

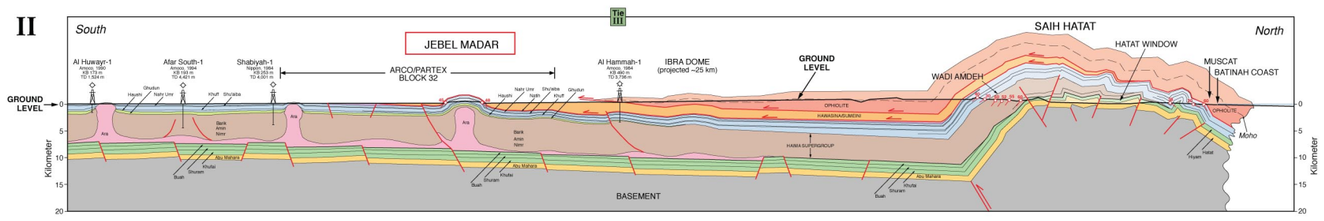

Fig. 2.2 Structural transect II (transect shown in Fig.2.1). Uprising salt at Jebel Madar caused the stratigraphy to rise 500 m above the surrounding plain (modified after Mount et al. 1998).

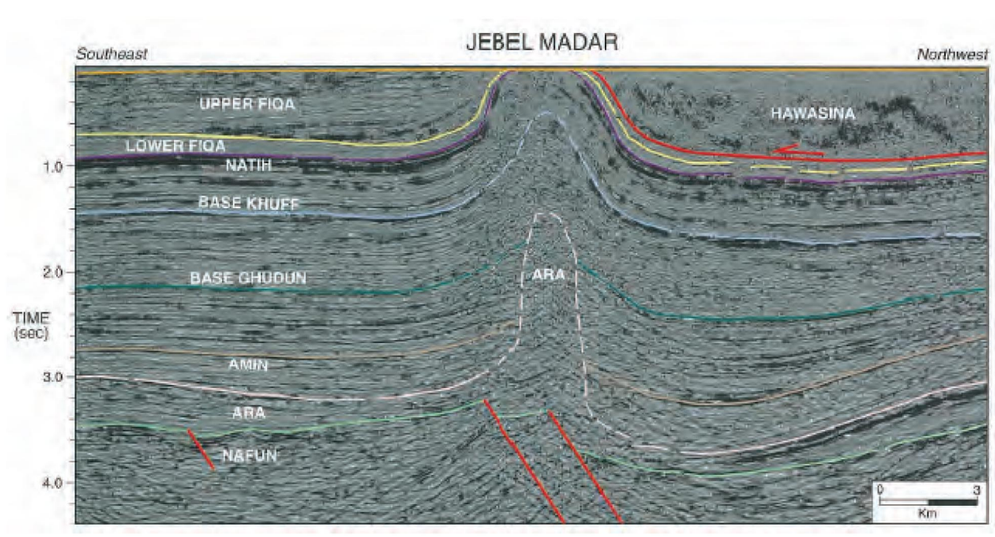

Fig. 2.4 Seismic located along transect II (Fig.2.2) in the Arco/Partex concession showing Jebel Madar (Mount et al. 1998).

3. Methodology

Fig. 3.1 Plan view of beds of the Rayda formation where fracture analysis and vein sampling were carried out. Different fracture sets are present. Close-up shows intersection of two veins. Note variable intensity of fracturing in different beds.

Fractures & Veins

- **fracture analysis**: identification of suitable beds (top view/ pavements of beds is necessary) in lithologically different formation at different locations across Jebel Madar: occurrence, length, density, orientation of fractures along a ~10 m scanline have been recorded (Fig. 3.1).

- **samples of vein infilling cements** taken from veins in the beds where fracture analysis was carried out. Geochemical methods (stable isotopes) are going to be applied to help distinguish between different fracture sets and to make implications for the origin of the fluids (Fig. 3.1)

Lithology

- Logging and sampling of stratigraphic sections in the Lower Cretaceous in the context of stylolite mapping and fracture analysis has been carried out to determine **lithologic impact on fracturing and stylolitization**.

Stylolites

- **bed parallel stylolites** are being mapped in sections in the same stratigraphic positions across Jebel Madar to determine **lateral continuity**.

References

Claringbould, J. S., 2010, Structural evolution and integrated geomodelling of a saltcored carbonate dome, Jebel Madar, Oman [Master Thesis]: Colorado School of Mines, 223 p.
Gorin, G.E., L.G. Racz and M.R. Walter 1982. Late Precambrian-Cambrian Sediments of Huqf Group, Sultanate of Oman. American Association of Petroleum Geologists Bulletin, v. 66, p. 2609-2627.
Mount Van S., R. I. S. Crawford, S. C. Bergman; 1998: Regional structural style of the Central and Southern Oman Mountains: Jebel Akhdar, Saih Hatat, and the Northern Ghaba Basin. GeoArabia, Vol. 3, No. 4.

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4. Preliminary Data

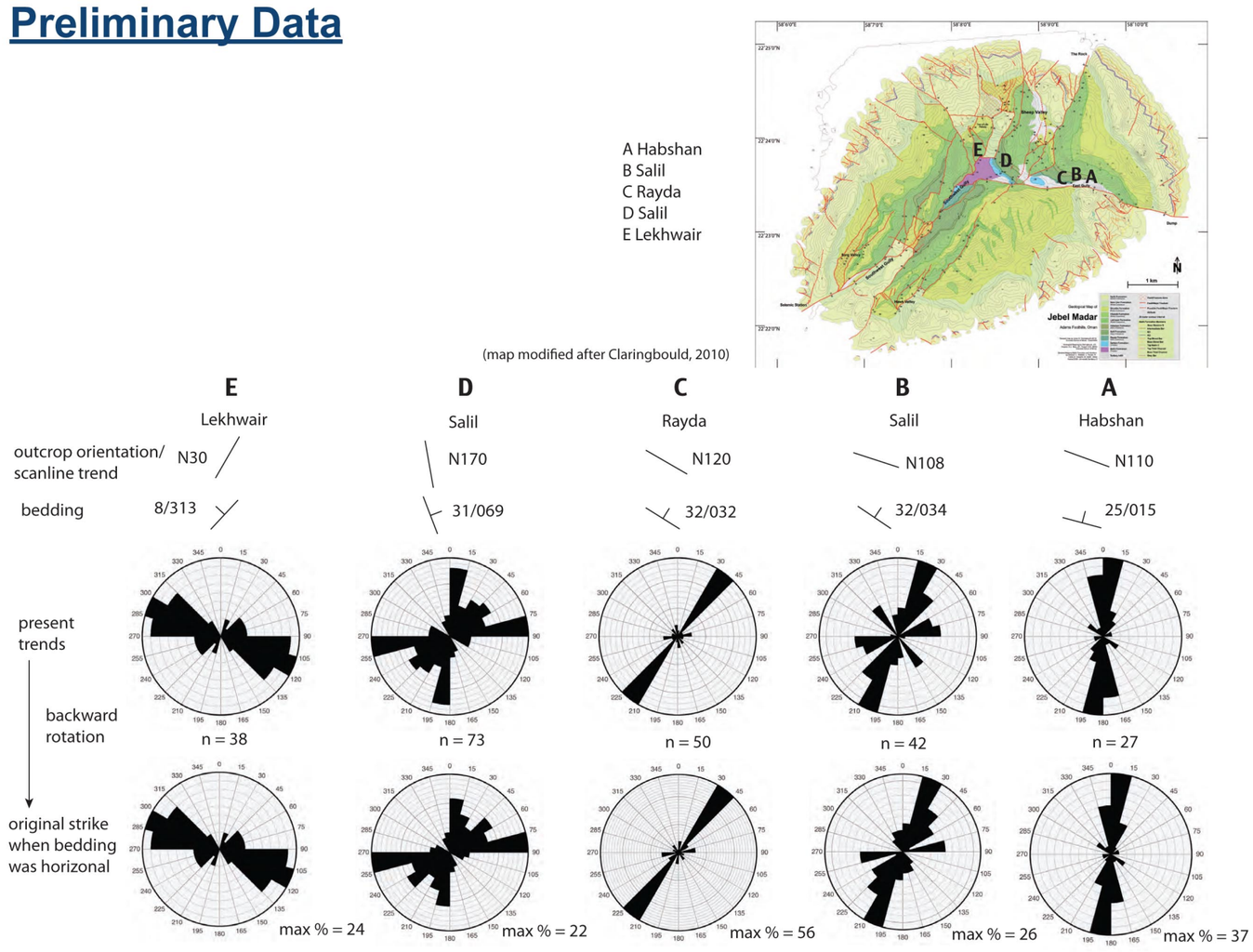
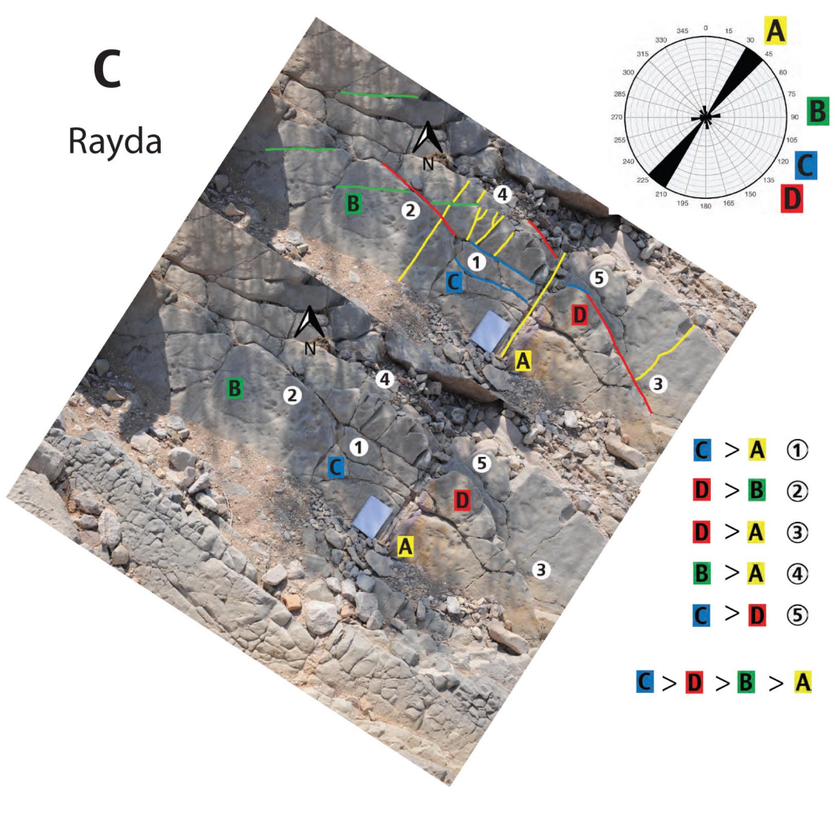


Fig. 4.1 Map shows locations of fracture analyses within the three uplifted and rotated slabs of the salt dome. Upper row of rose diagrams shows present fracture trends as measured in the field. Below previous fracture strikes when bedding was horizontal are shown. Locations A-D have fracture sets trending NNE-NE and NEE in common. Location E, which lies on a differently orientated slab indicated by a the bedding orientation, does not show these trends in the same intensity. Since fractures have been measured along one scanline only fractures parallel and subparallel to the orientation of the scanline are expected to be underestimated. An additional analysis using box counting methodology of the fracture orientation in plan view is suggested due to this bias of the data.



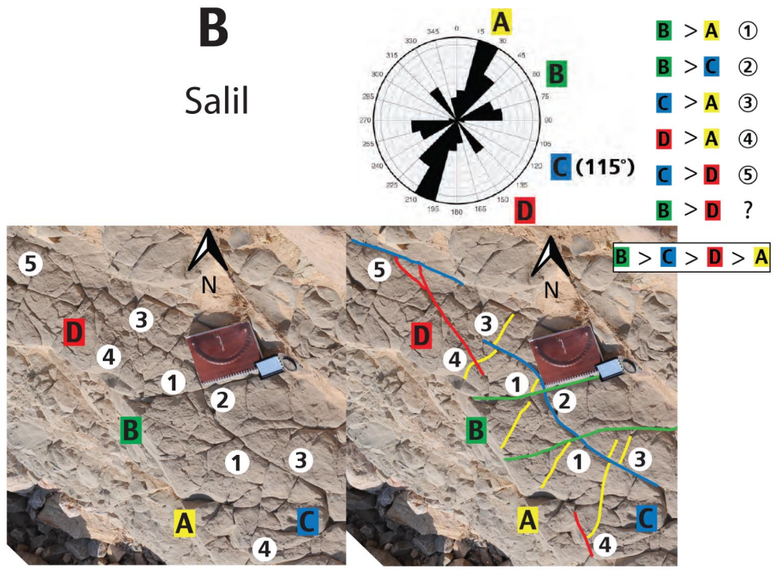


Fig. 4.2 Relative age analyses at locations C and B based on abutting relationships of fractures. Preliminary analysis implies that fracture set A is the youngest.

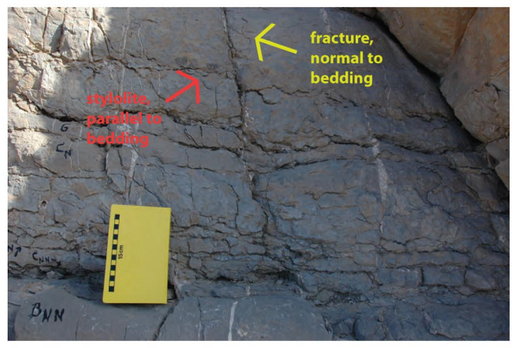


Fig. 4.3 Fractures normal to bedding and bedding parallel stylolites in the Habshan formation at a stylolite log in the South-west Gully.

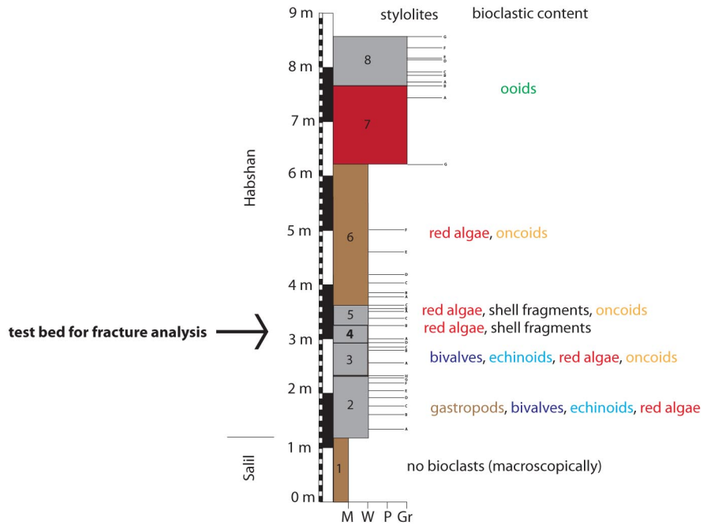


Fig. 4.4 Stylolite log in the Habshan formation in the East Gully at location A. Stratigraphic positions of stylolites are noted as lines.

5. Future Work

- Finalise current fracture study (**orientation & chronology of fracture sets**)
- **Correlation of stylolite logs**
- Determine **lithology of beds** where fracture analyses have been carried out (thin sections)
- **Geochemical signature of vein/cement samples** to help distinguish between fracture sets and implications for the origin of the fluids
- Further fieldwork: **texture and geochemistry** in infilled **large- scale structures of Jebel Madar** (SW-Gully, NNE-trending fault in the Northeast of Jebel Madar)

6. Conclusions

- Majority of **fractures perpendicular to bedding** & **stylolites bedding parallel**: implies relation to **burial and/or salt doming**
- **Stylolites with higher amplitudes continuous** over distance up to 5 km
- Fracture analyses in **East Gully** imply: **dominant fracture set trending NNE to NE** seems to be the **youngest**