Three-Dimensional Structural Evolution of a Salt-Cored, Domed, Reactivated Fault Complex, Jebel Madar, Oman*

Johan S. Claringbould[1], J. Frederick Sarg[1], Brittney B. Hyden[1], and Bruce D. Trudgill[1]

Search and Discovery Article #30180 (2011)
Posted August 19, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011. Please see closely related article, "Integrated Reservoir Modelling of the Natih E Member at a Salt-Cored Carbonate Dome, Jebel Madar, Oman", Search and Discovery article #110161.

[1]Geology and Geological Engineering, Colorado School of Mines, Golden, CO (claringbould@ldeo.columbia.edu)

Abstract

The Late Cretaceous fractured carbonates of the Middle East contain some of the world's largest hydrocarbon reserves. Besides matrix permeability and porosity, reservoir quality is highly dependent on fracture distribution. The northern Oman region has a complex tectonic history, and multiple major tectonic events affected the area.

This study provides a three-dimensional structural evolution of the Late-Cretaceous outcrops of a salt-cored domed structure containing reactivated faults (Jebel Madar) that crop out in the Adam Foothills of Northern Oman. A multi-layered, integrated, three-dimensional, numerical structural model of the study area was built to determine the impact of multiple major tectonic events to the fault and fracture distribution in the study area. Data types and scales include: geologic field mapping, photo-realisitic LiDAR models, high-resolution Quickbird imagery, depth elevation models, and seismic and well-log data.

Analysis of the structural evolution of Jebel Madar show that three major tectonic events with different stress regimes resulted in a complex domed structure containing reactivated faults. NE-SW oriented graben- and half-graben structures formed as a result of initial local dome-formation, due to SW-verging compression of the Late-Cretaceous obduction of the Hawasina Complex and Semail Nappe to the N-NE of the study area. Seismic interpretation shows that the imbricates of the allochthonous Hawasina Complex were deposited across the study area, causing burial of approximately 1 km, and resulting in initial fluid release and calcite formation as fault infill. Early Paleocene obduction of the Masirah ophiolite, east of the study area and the opening of the Gulf of Aden, led to a NW-verging transtensional stress regime that caused E-W oriented oblique normal fault formation, cross-cutting pre-existing faults in the study area. Lastly, the Miocene Alpine orogeny resulted in growth of the Oman Mountains north of the study area and a foreland basin formation in the Adams Foothills that led to local dome-formation by reactivation of the pre-existing faults, and salt-diapirism as a result of differential loading. This event is marked by clear down-dip slickenlines on the fault surfaces, fault breccia containing a mix of calcite and blocks of older stratigraphy, and locally reactivated folding.

References

Glennie, K.W.,1995, Geology of the Oman Mountains: an outline of their origin: Scientific Press, Beaconsfield, Bucks, United Kingdom, 92 p.

Immenhauser, A., and G. Schreurs, 1999, West-Northwest directed obduction of the Batain group on the eastern Oman continental margin at the Cretaceous-Tertiary boundary: Tectonics, v. 18/1, p. 148-160.

Pollastro, R.M.,1999, Ghaba Salt Basin province and Fahud Salt Basin Province, Oman – Geological overview and total petroleum systems: US Geological Survey Bulletin, No. 2167, 45 p.

Shuster, M.W., M.J. Newall, J.B. Filbrandt, J.P. Grotzinger, J.M. Peters, and H.A. Al-Siyabi, 2003, Surface-piercing salt domes of interior north Oman, and their significance for the Ara carbonate “Stringer” hydrocarbon play: GeoArabia, v. 8/2, p. 231-270.

Three-dimensional Structural Evolution of a Salt-cored, Domed, Reactivated Fault Complex , Jebel Madar, Oman

Johan S. Claringbould*, J. Frederick Sarg, Brittney B. Hyden, Bruce D. Trudgill

Colorado School of Mines, Department of Geology and Geological Engineering, 1516 Illinois Street, Golden, Colorado, USA

*present address: Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, New York, USA,

contact: claringbould@ldeo.columbia.edu

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

Acknowledgements

- Statoil Research Centre in Bergen - funding, data
- Hunt Oil - data
- Colorado School of Mines – Dep. Geology and Geological Engineering
- Université Bordeaux 3: Carine Grélaud
- AAPG

Objectives

- Structural evolution analysis of Jebel Madar
  - Role of regional tectonics and salt diapirism on fault and fracture distribution pattern on dome complex

- Different data types and scales
- 1:5,000 scale geologic map
- Build three-dimensional integrated multi-layered geomodel

Presenter's notes:

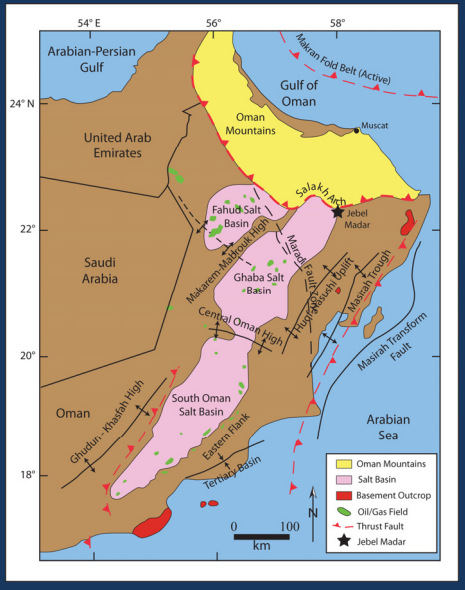
•Salt dome in compressional regime (like Zagros) unlike GOM, passive margin.

•1 tectonic dome forming event? Multiple events.

•Significant Middle Eastern fractured carbonate reservoirs

•Fault and fracture distribution of salt-cored dome

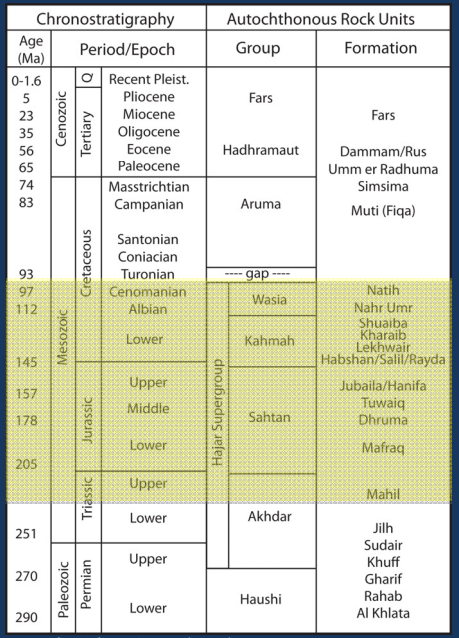
Study Area



Modified after Pollastro (1999) and Peters *et al.* (2003)

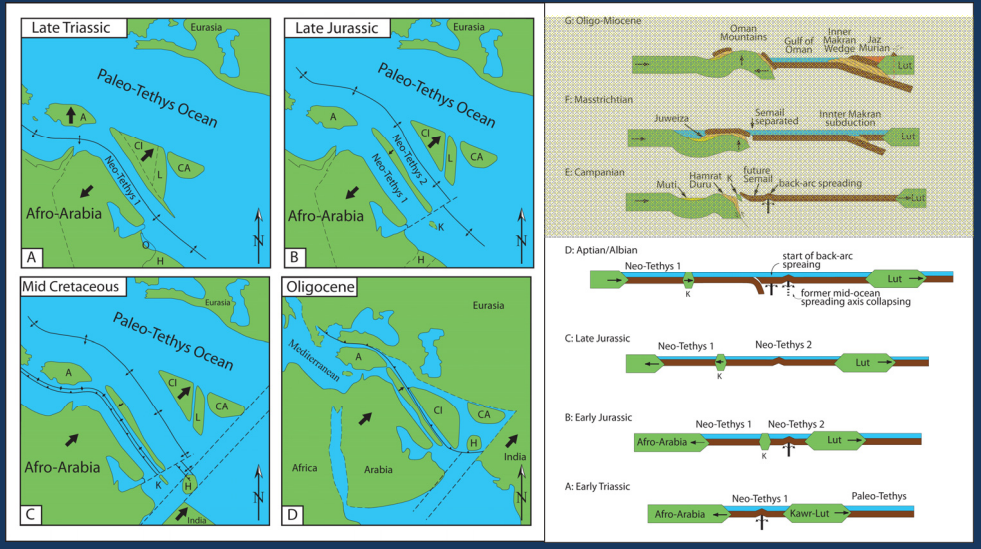
Presenter's notes: 7 km across, 750 meter high

Regional Geology - Stratigraphy



Modified after Glennie (1995)

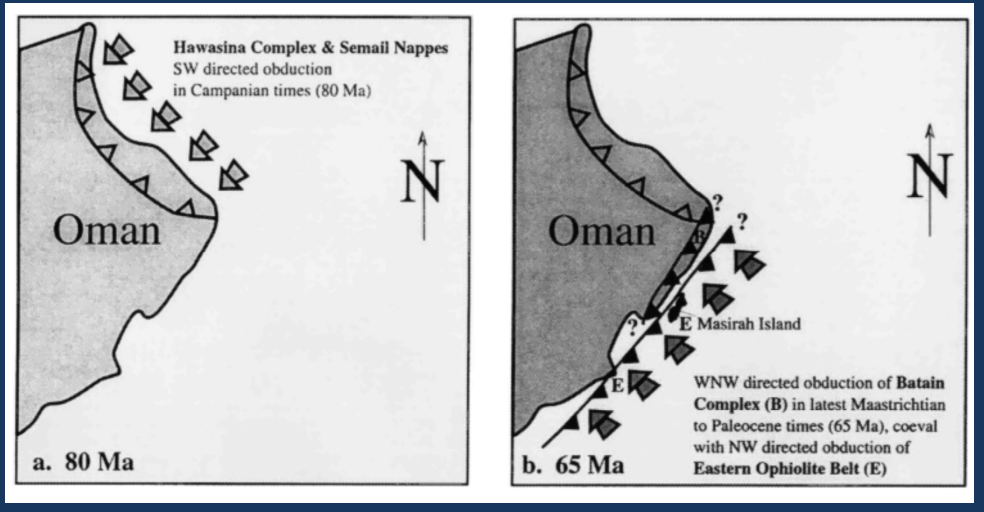
Regional Geology - Structure



Modified after Glennie (1995)

Presenter's notes: fault & frac pattern affected in the outcrop

Regional Geology - Structure



Modified after Schreurs and Immenhauser (1999)

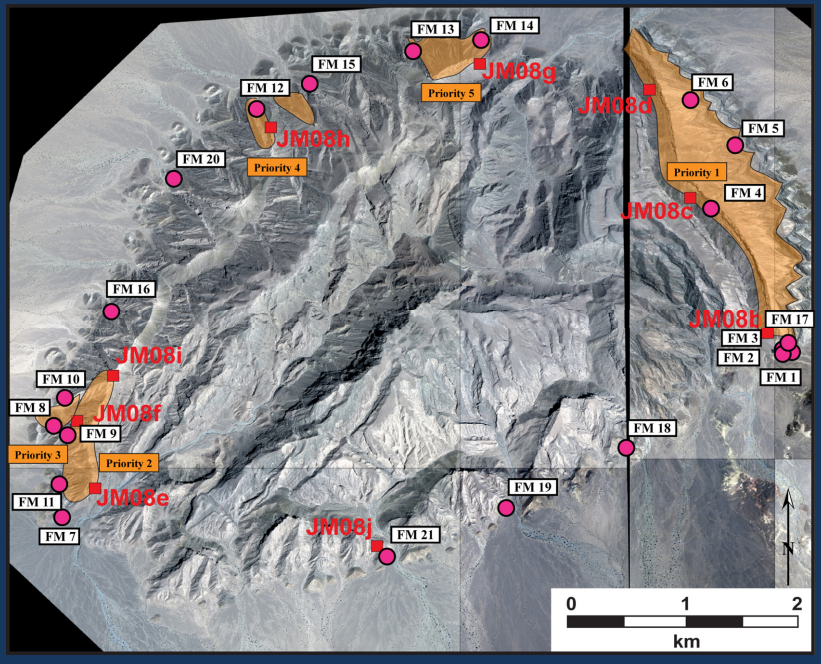
Presenter's notes: fault & frac pattern affected in the outcrop

Data and Processing

- Fracture distribution – 5 photo-realistic LiDAR models and 21 fracture maps
- Fault distribution and Structure – structural field data, 9 stratigraphic sections, high resolution Quickbird imagery, and 30-meter ASTER DEM
- Subsurface data – 5 seismic lines, 1 well log
- Integrated geomodel

Presenter's notes: Methodology to do the analyses.

Data and Processing

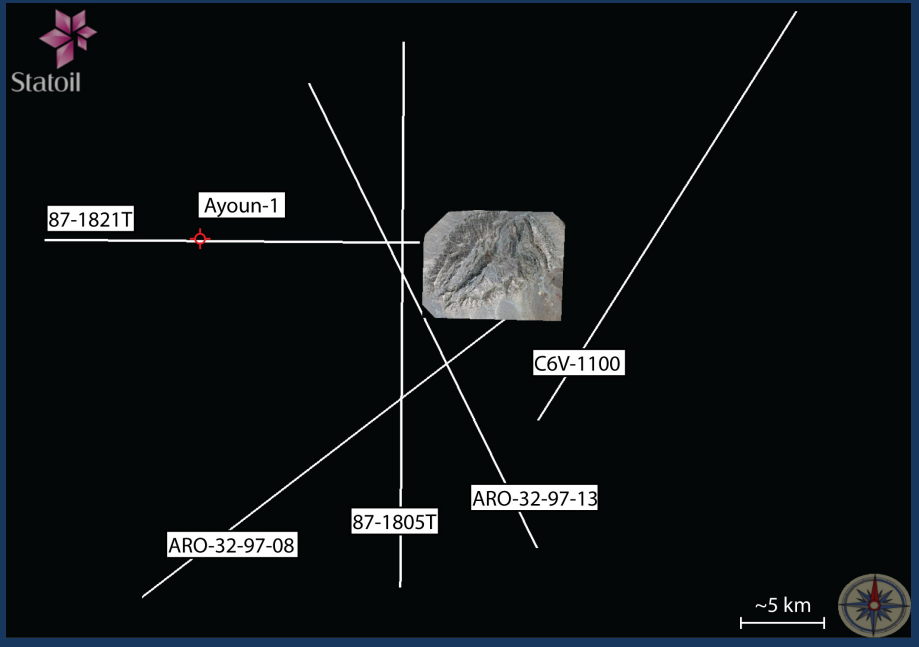


Presenter's notes: Quickbird imagery and ASTER DEM model

Geo- and ortho-rectified combined Quickbird images

30-meter ASTER DEM

Data and Processing

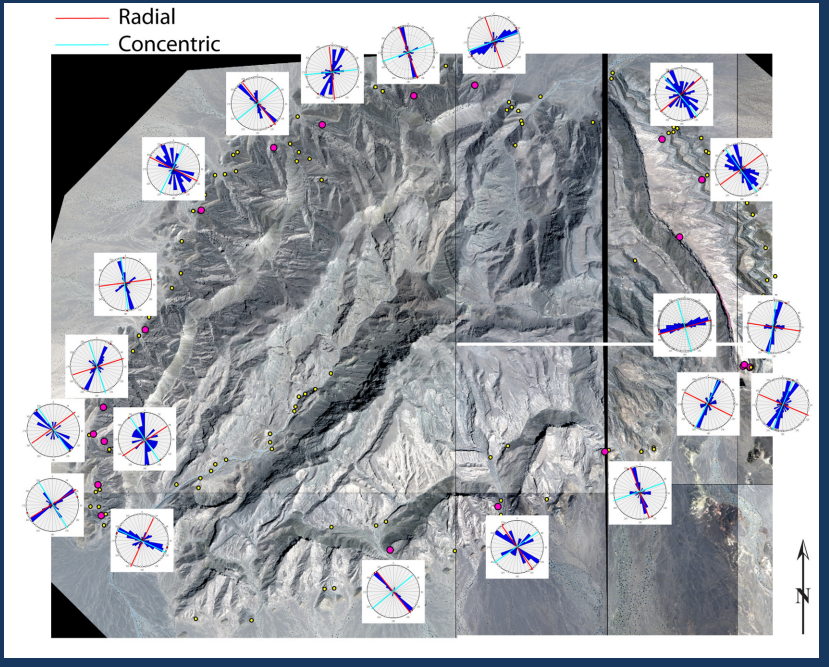


Presenter's notes: Quickbird imagery and ASTER DEM model

Geo- and ortho-rectified combined Quickbird images

30-meter ASTER DEM

Fracture Maps



Fracture Maps

- Primary trend: NNW – SSE and NNE – SSW
- Secondary trend: NW – SE and ENE – WSW
- Dominant superimposed reactivated concentric and radial fractures
- High angle dip (~80 – 90 degrees)
- Fracture swarms near major faults

Photo-realistic LiDAR

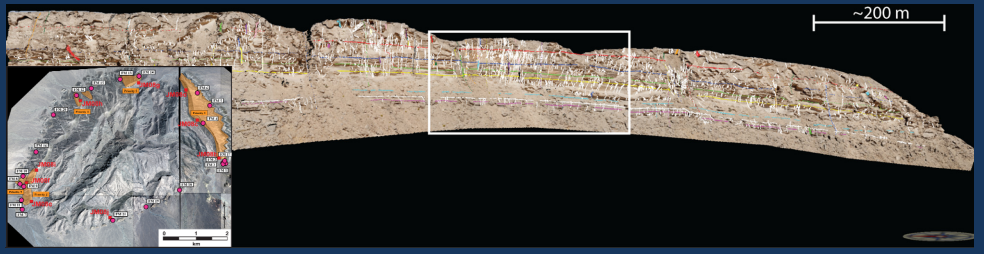


Photo-realistic LiDAR

Statoil

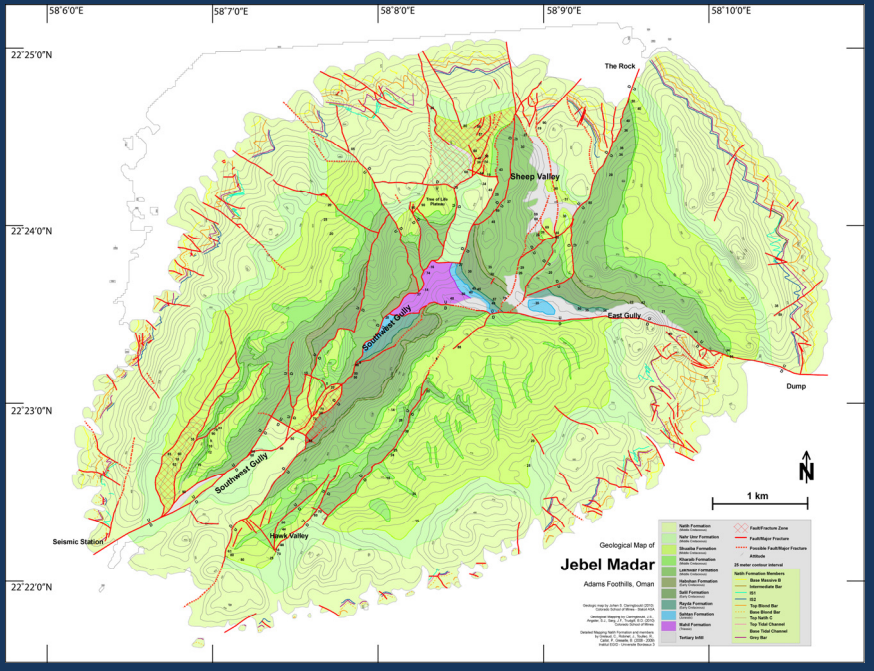
Photo-realistic LiDAR

Statoil

Photo-realistic LiDAR

- Dominant radial and concentric fractures
- High angle dips (~75 – 90 degrees)
- Concentric fractures (av. FH: 14.3 m, av. FD: 0.09 frac/m)
- Radial fractures (av. FH: 23 m, av. FD: 0.08 frac/m)
- No consistent fracture swarm distribution

Fault Distribution



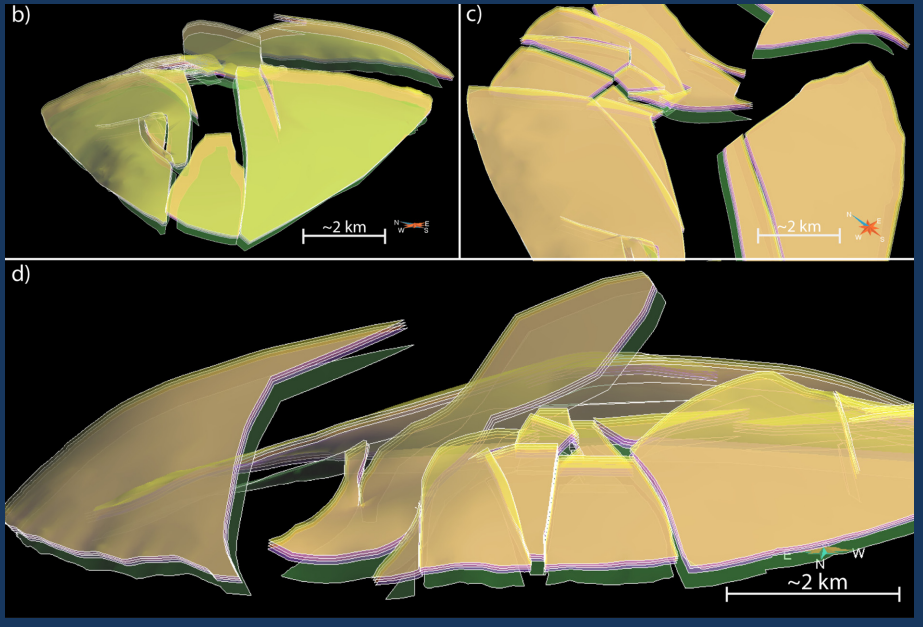
Presenter's notes: Green – Cretaceous, little Jurasic and Triassic in centre.

NE-SW Grabens – synthetic faults, E-W faults, domal shape (dips increase from top)

3D Structural Model

Presenter's notes: Top view Natih A Member

3D Structural Model



Presenter's notes: Side views, no faults, dips based on field measurements

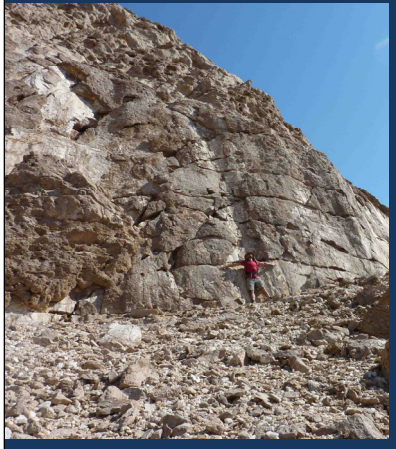
Field observations

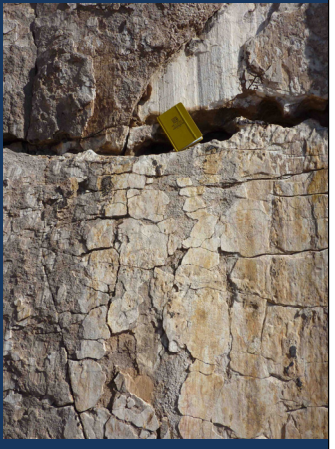
Presenter's notes: Slickenlines, downdip

Fault breccia with calcite in place

Calcite fault fill only in NE-SW oriented faults.

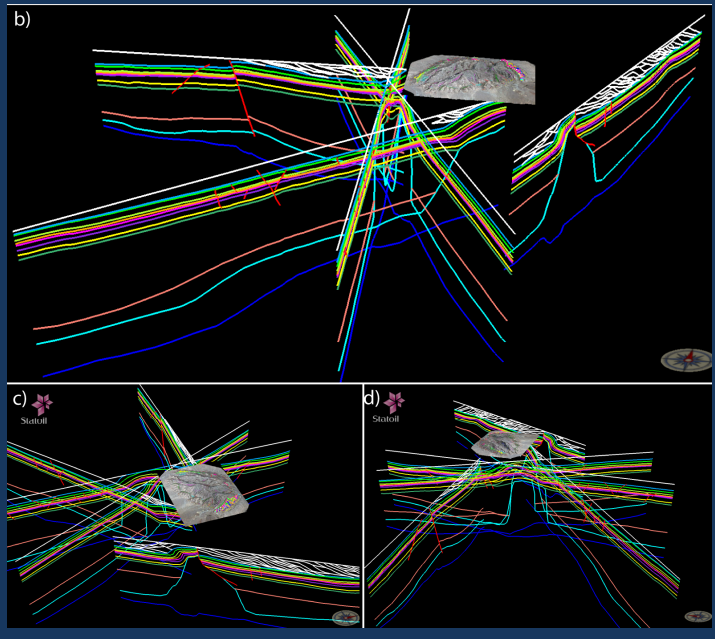
Field observations





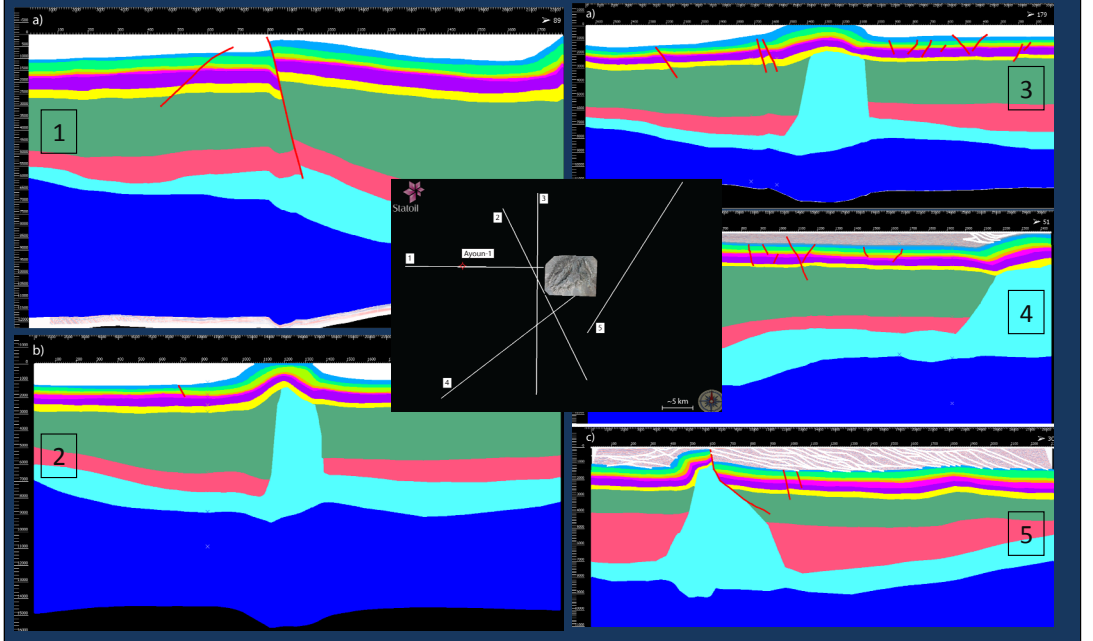
Presenter's notes: Multiple stage of movement, slicken lines on the fault surface

Seismic Sections



Presenter's notes: Salt diapir under Madar

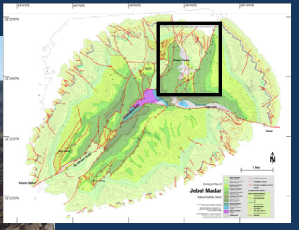
Seismic Sections

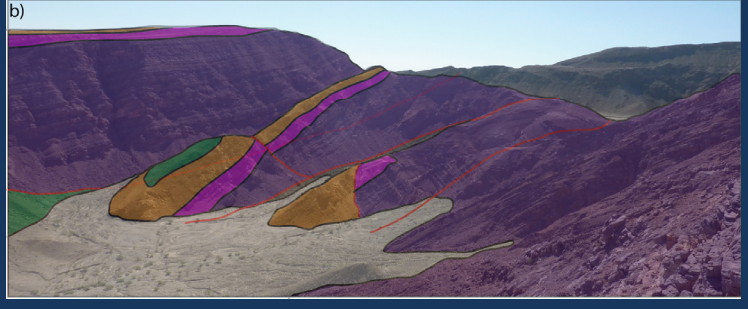


Presenter's notes: Thrust fault on 1,

Imbricates on 5, over madar

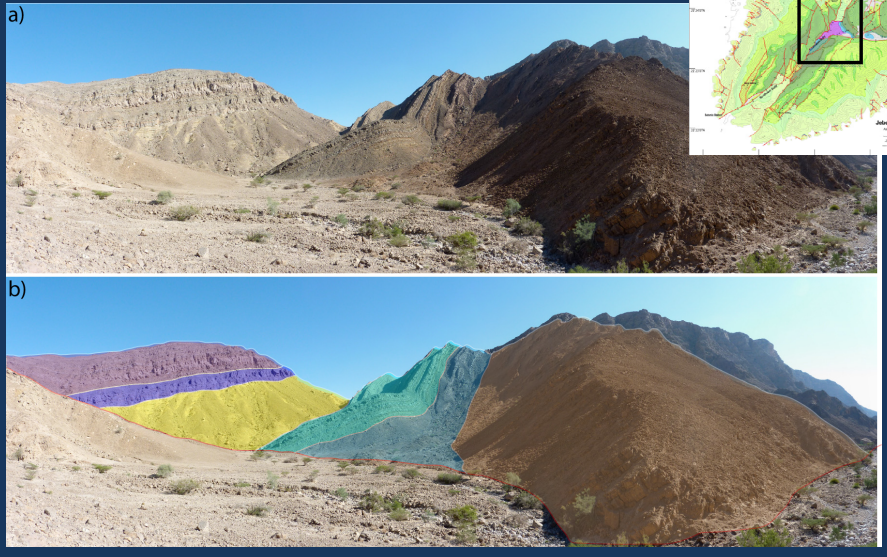
Sheep Valley – Half Graben





Presenter's notes: Half graben structure, calcite in breccia

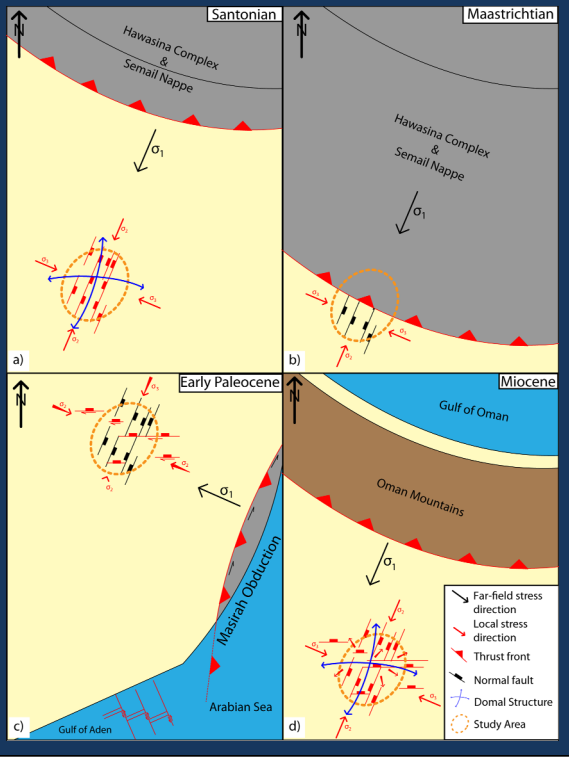
Centre Dome



Presenter's notes: Centre "teared open"

Structural Evolution

1. Obduction (N-NE) – Fractures, grabens
2. Burial – Calcite growth
3. Obduction (W-SW) – Oblique faulting
4. Compression (N-NE) – Doming and salt diapirism



Presenter's notes: Orange marks field area (not to scale)

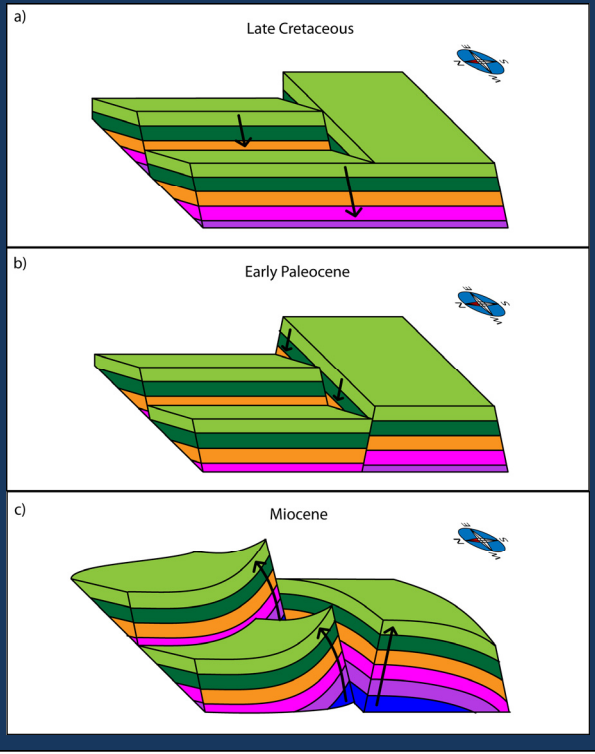
Mode 1 opening fractures, Initial doming with grabens (Withjack and Scheiner -1982)

Burial calcite growth, fluid release

Pre-existing weakness under dome, salt diapir responsible for geometry.

Centre Dome

1. Grabens
2. Oblique faulting
3. Reactivating, doming and salt diapirism



Conclusions

- Three different structures:
  1. NE-SW oriented grabens
  2. Cross-cutting E-W oblique normal faults
  3. Domal structure with superimposed reactivated concentric and radial fractures
- Three major tectonic events:
  1. SW-verging compressional event (Mid Cretaceous)
  2. NW-verging compressional event (Early Paleocene)
  3. SW-verging compressional event (Miocene)

Presenter's notes: Caution required with interpretation of fault patterns on salt-cored domes.