Integrated Reservoir Modeling of the Natih E Member at a Salt-cored Carbonate Dome, Jebel Madar, Oman*

Johan S. Claringbould1,2, J Frederick Sarg1, Brittney B. Hyden1, and Bruce D. Trudgill1

Search and Discovery Article #110161 (2011)
Posted June 20, 2011

*Adapted from oral presentation at Session: Seismic Reservoir Characterization, at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

1Geology and Geological Engineering, Colorado School of Mines, Golden, CO
2Currently Columbia University, New York, NY (claringbould@ldeo.columbia.edu)

Abstract

The Upper 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 Upper 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-realistic LiDAR models, high-resolution Quickbird imagery, depth elevation models, and seismic and well-log data.

Analysis of the structural evolution of Jebel Madar shows 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 NNE 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, which 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.
Selected References


Integrated Reservoir Modeling of the Natih E Member at a Salt-cored Carbonate Dome, Jebel Madar, Oman

Johan S. Claringbould*, J. Frederick Sarg, Brittney B. Hyden, Terrance R. Birdsall

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

Jean-Christophe Embry, Giulio Casini, Stephane Homke, John B. Thurmond, David W. Hunt

Statoil ASA, Research Centre, Sandsliveien 90, Bergen, P.O. Box 7200, N-5020, Bergen, Norway

*present address: Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, New York, USA,
contact: claringbould@ldeo.columbia.edu

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT
Acknowledgements

• Statoil Research Centre in Bergen
• Colorado School of Mines – Dept. Geology and Geological Engineering
• Université Bordeaux 3: Carine Grélaud
• AAPG
Objectives

• Analogue reservoir model – calibrated to field
• Build three-dimensional integrated multi-layered reservoir model – generate workflow

• Fracture distribution analyses – 5 photo-realistic LiDAR Models and 21 fracture maps
• Lithofacies, porosity, permeability distribution analyses – 9 stratigraphic sections and SEM QEMSCAN® analyses of 200 samples
• Integrated geomodel – stratigraphic and structural field data, high resolution Quickbird imagery, and 30-meter ASTER DEM
Modified after Pollastro (1999) and Peters et al. (2003)

Presenter's notes: Dome dimensions--7 km across, 750 m high.
**Introduction**

Presenter’s notes: Late Cretaceous obduction; Miocene Alpine orogeny.

---

### Regional Geology - Stratigraphy

<table>
<thead>
<tr>
<th>Chronostratigraphy</th>
<th>Autochthonous Rock Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Ma)</td>
<td>Period/Epoch</td>
</tr>
<tr>
<td>0-1.6</td>
<td>Recent Pleistocene</td>
</tr>
<tr>
<td>3</td>
<td>Miocene</td>
</tr>
<tr>
<td>6</td>
<td>Oligocene</td>
</tr>
<tr>
<td>24</td>
<td>Eocene</td>
</tr>
<tr>
<td>63</td>
<td>Paleocene</td>
</tr>
<tr>
<td>93</td>
<td>Cretaceous</td>
</tr>
<tr>
<td>122</td>
<td>Turonian</td>
</tr>
<tr>
<td>145</td>
<td>Albian</td>
</tr>
<tr>
<td>157</td>
<td>Lower</td>
</tr>
<tr>
<td>176</td>
<td>Upper</td>
</tr>
<tr>
<td>205</td>
<td>Middle</td>
</tr>
<tr>
<td>251</td>
<td>Lower</td>
</tr>
<tr>
<td>270</td>
<td>Upper</td>
</tr>
<tr>
<td>290</td>
<td>Lower</td>
</tr>
</tbody>
</table>

Modified after Glennie (1995)

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Lithostratigraphy</th>
<th>Sequence stratigraphy</th>
<th>Sedimentary systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.6</td>
<td>Recent Pleistocene</td>
<td>Null Formation</td>
<td>carbonate ramp/inner shelf basin</td>
</tr>
<tr>
<td>3</td>
<td>Miocene</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>6</td>
<td>Oligocene</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>24</td>
<td>Eocene</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>63</td>
<td>Paleocene</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>93</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>122</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>145</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>157</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>176</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>205</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>251</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>270</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
<tr>
<td>290</td>
<td>Cretaceous</td>
<td>Cretaceous</td>
<td>mixed clastics/ carbonate ramp</td>
</tr>
</tbody>
</table>

Modified after Razin et al. (2007)
Presenter's notes: Quickbird imagery and ASTER DEM model; geo- and ortho-rectified combined Quickbird images; 30-meter ASTER DEM.
**Presenter's notes:** Six lithofacies in three facies associations in Natih E Member; Mid-ramp position, patchy inactive to active back-shoal.
Presenter's notes: Three depositional cycle tops correlated in Natih E Member, aggrading shoaling upward fourth order cycles.
Porosity and Permeability

- Dominant micro-rhombic low-Mg lime mud, interconnected mudstone microporosity
- Grainstones: moldic microporosity
- Low average porosity (0.3 – 4.8 %)
- Low average permeability (0.002 – 0.028 mD)
Presenter's notes: 8x8 m fracture maps--radial and concentric fractures superimposing earlier fracture sets.
Fracture Distribution – Field

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

- Photo-realistic LiDAR
  - 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

**Presenter’s notes:** Dominant radial and concentric fractures; high-angle dips (~75 – 90 degrees).
Integrated Geomodeling

Integrated Geomodel

- Digitized Data Projection
  (Statoil Digitizer)

- Structural Model
  (GoCAD)

- Three-dimensional Grid
  (Petrel)

- Lithofacies Distribution Model
  (Petrel)

- Porosity Distribution Model
  (Petrel)

- Permeability Distribution Model
  (Petrel)

- Fracture Distribution Model
  (Petrel)
Digitized Data Projection

Integrated Geomodel
- Digitized Data Model
  - Statoil
- Structural Model
  - (Not visible)
- Three-dimensional Grid
  - (Not visible)

- Lithofacies Distribution Model (Pixel)
- Porosity Distribution Model (Pixel)
- Permeability Distribution Model (Pixel)
- Faults Distribution Model (Pixel)

a) ~100 m
b) ~200 m

Statoil
Structural Model
Structural Model

Presenter’s notes: Curvature/dips based on field measurements.
Three-dimensional Grid

**Presenter's notes:** 50 x 50 meter cells – over 3 million cells.
Lithofacies Distribution Model

- Distal Shoal Margin
- Proximal Shoal Margin
- Proximal Shoal Margin to Shoal
- High Energy Back-shoal
- Low Energy Back-shoal
- Moderate Energy Back-shoal
**Presenter's notes:** Sections used as pseudo-wells. Combination of two different distribution algorithms (Trial and Error): “Truncated Gaussian Simulation with trends” and “Object Modelling” algorithms. Ellipsoidal form of 1000 m in the major direction, 1000 m in the minor direction, 8 m in the vertical direction, a dip of 0 degrees, and a vertical variance of 0.8. The vertical geometry of the distribution had a trend with an azimuth of 218, with a line source and progradational distribution. Distal lithofacies – trending 218 and always bound in order. Back-shoal lithofacies – trending 218, not bound in order; are more patchy. Trial and error--calibrated to field data.
Lithofacies Distribution Model

Presenter's notes: Results based on field observations, not on algorithm.
**Presenter's notes:** Based on lithofacies distribution. Variable but low average porosity (0-5%). No clear distribution trend. Not dependent on lithofacies or sample location. Reservoir quality of Natih E Member is highly dependent on fracture network.
Permeability Distribution Model

Presenter's notes: 0.001 mD – 1 mD (around 0.01 mD).
Presenter's notes: No clear fracture distribution within lithofacies or location. Orientation all around, but abundant radial and concentric. Fractures heights – variable. Fracture density – consistent. Distribution – through whole grid: no density of preferred orientation change. Concentric/Radial fractures considered to have biggest impact on reservoir quality as they are larger (vertically and laterally). They are more likely to be open or partially cemented than regional ones.
Integrated Geomodeling

• Limitations:
  – Quality of field area and resolution of data models
  – Quality and quantity of data in field and models
  – Limitations of workflow and software

• However, since richness and quality of the data are high, biases are minimized.
**Conclusions**

- Stratigraphic framework of Natih E Member: three shoaling-upward fourth-order depositional cycles, six lithofacies
- Facies occupy mid-ramp position: quiet subtidal shelf environment with inactive to active shoal
- Porosity and permeability: low, no clear distribution
- Dominant fracture orientations: concentric and radial – superimposed to reactivated

*Presenter's notes:* Field data—shoaling upward, within framework of SW-basinward direction.
### Conclusions

- **Integrated geomodel**
  - Component models: structural, 3D grid, lithofacies, porosity, permeability, and fracture
  - Based on different data types and scales
  - Calibrated to the field
  - Workflow is simple, but with limitations

*Presenter’s notes:* "All models are wrong; some of them are useful."