Interpretation of Induced Surface Deformation over KB-502 at Krechba, Algeria

ERIC DAVIS
DIRECTOR OF TECHNICAL DEVELOPMENT - DIAGNOSTICS
CO₂ Sequestration at In Salah

- Injection began August 2004 (KB-502 April 2005)
- Approximately 3.6 million tons injected as of October 2010, 1 million tons in KB-502
- 15-20 m thick target zone at ~1850 m depth
- Three injectors – KB-501, KB-502, KB-503
Injection into KB-502 over time

MONTHLY CO2 INJECTION DATA

- Injected CO2
- KB-502 Injection

MMscf

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InSAR Measured Deformation at In Salah
Measured deformation over KB-502
NE-SW ‘Trough’ Deemed a Near-Surface Effect due to Wadi

Figure generated 09-Mar-2010. UTM 31N WGS-84 Coordinate System.

Well Trajectories

Max Movement (mm)

Min Movement (mm)

Well Trajectories

Max Movement (mm)

Min Movement (mm)

In Salah 29-Nov-2003 to 12-Jan-2008

Max Movement  (mm) 17.3

Min Movement (mm) -6.1

Max Movement (mm) 17.3

Min Movement (mm) -6.1

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Homogeneous model provides the fastest general solution

- Solution from Okada, 1992
- Dislocation has degrees of freedom in position (3), orientation (2), dimension (3) and slip (2)
- Forward model takes < 0.05 sec
- Quick forward model allows full search of solution space
- Only critical formation parameter is Poisson’s Ratio, which affects the magnitude, but not the pattern of deformation
Deformation due to horizontal dislocations at different depths, sized to produce similar uplift

- Depth = 1000 m, Volume = 142000 m$^3$, Aspect Ratio = 400000
- Depth = 1500 m, Volume = 152000 m$^3$, Aspect Ratio = 300000
- Depth = 2000 m, Volume = 163000 m$^3$, Aspect Ratio = 180000
- Depth = 2500 m, Volume = 176000 m$^3$, Aspect Ratio = 74000
- Depth = 3000 m, Volume = 190000 m$^3$, Aspect Ratio = 1000
Deformation due to vertical dislocations at different depths, sized to produce similar uplift

- Depth = 1000 m, Volume = 164000 m³, Aspect Ratio = 190
- Depth = 1500 m, Volume = 370000 m³, Aspect Ratio = 290
- Depth = 2000 m, Volume = 658000 m³, Aspect Ratio = 390
- Depth = 2500 m, Volume = 1040000 m³, Aspect Ratio = 660
- Depth = 3000 m, Volume = 1500000 m³, Aspect Ratio = 750
Significant modulus contrasts can affect the best fit solution.

Dislocation Depth = 3000m

- Constant Modulus
- Depth Range of Altered Modulus (1x, 2x and 4x)
- Vertical Deformation (mm)

Horizontal Distance (m) vs. Depth (m)

Distance from Dislocation Center (m) vs. Vertical Deformation (mm)
Significant modulus contrasts do exist at In Salah

Shear Modulus (GPa)

Depth (m)

- 6 Layer Model
- Cretaceous Superieur
- Cretaceous Continental Intercalaire
- Hercynian Unconformity
- C20 - Carboniferous Visean Mudstone
- C20.4 - Hot Shale
- C10 - Carboniferous Tournasian Sandstone
- C10.2 - Sandstone Main Reservoir
- C10.3 - Tight Sandstone/siltstone
- D70 - Devonian Sandstone

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Layered model accounts for the impact of modulus contrasts

- Solution from Wang et al., 2006
- Modifies the Okada solution using Green’s functions developed for each set of layers that integrate the wave-number spectra functions.
- Green’s functions are dependent only on formation properties (Modulus, Poisson’s Ratio, Density), so they are calculated only once.
- Forward model takes ~5 sec
Equal fracture systems modeled using homogeneous and layered models
Best Fit: Reservoir Constrained vs Unconstrained

Measured Deformation

Reservoir Constrained Solution

Unconstrained Solution

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Best Fit Fluid Distribution at KB-502
Best Fit Fluid Distribution at KB-502

Above Reservoir Vertical Dislocation (<20% of system volume)

Reservoir Level Vertical Dislocation (<30% of system volume)

Horizontal Dislocation/Poroelastic swelling (>50% of system volume)
Inversion Solution – 20% of fluid above the reservoir
Repeated runs with varying values of forced volume for the ‘above reservoir’ vertical dislocation. At each point, the dimension/volume parameters of the remaining dislocations was optimized. The results show that the best fit requires a vertical dislocation above the reservoir.
NW Linear Feature lines up with trough in surface deformation from 2009 3D Seismic (Top C20.1 shown)
NW Linear Feature Continues at least to the Hot Shale

Seismic image provided by Catherine Gibson-Poole/BP
Conclusions

• Solutions suggest that there is a deformation source located well into the C20 sealing layers at KB-502, comprising approximately 20% of the injected volume.

• Although the homogeneous model is best able to explore the full solution space in a reasonable amount of time, the layered model can have a measurable impact on the solution – in this case leading to a slightly deeper best-fit source.

• Deformation monitoring can’t distinguish which fluid is causing the deformation.

• Lateral heterogeneity is not accounted for in the current models.

• Other groups have advocated solutions that remain contained in or close to the main reservoir.

• Since injection into KB-502 was restarted, there has been no indication of similar surface uplift.
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2009 3D Seismic Results near KB-502
2009 3D Seismic Results near KB-502

1264 ms time slice
(textured by coherence)