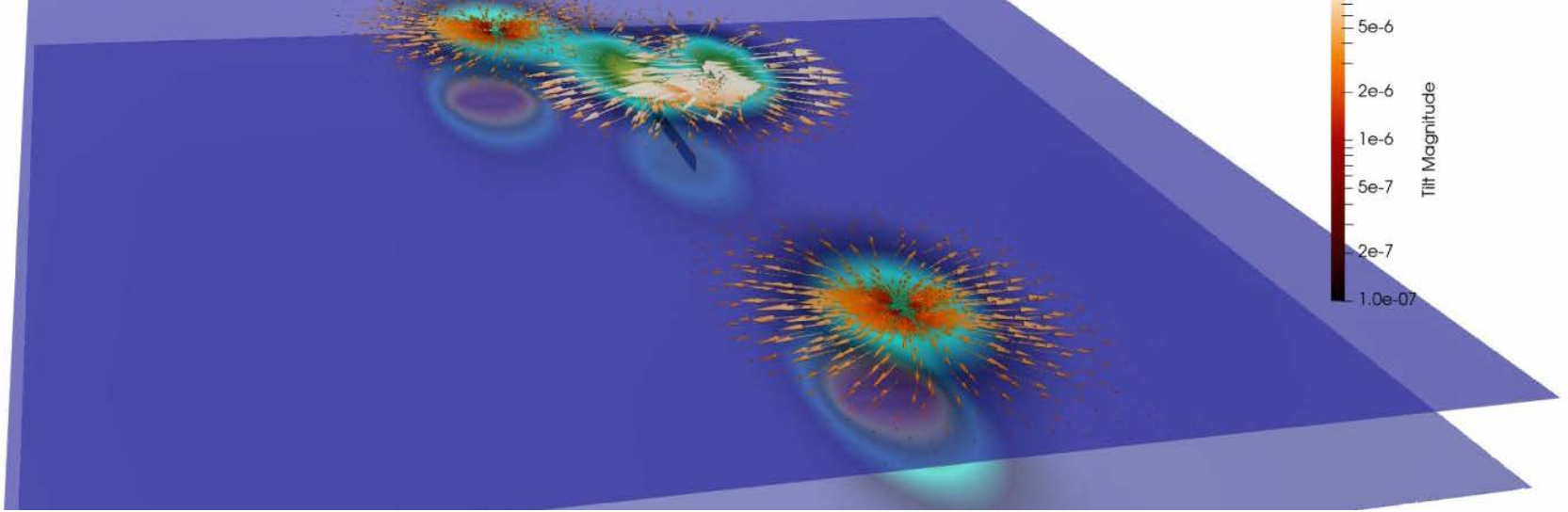
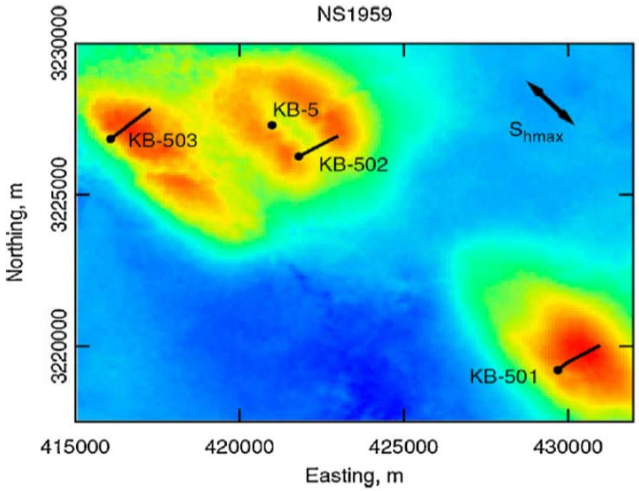


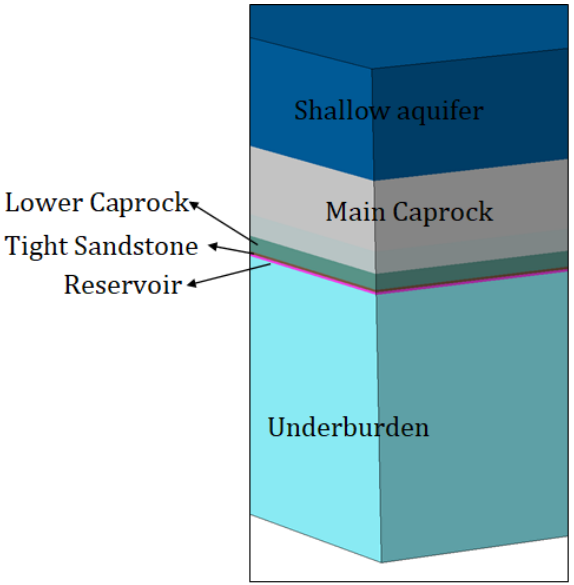
Surface Deformation Analysis of In Salah CO_2 Storage Site

Tiltmeter (inverse) analysis and Reservoir (forward) simulation

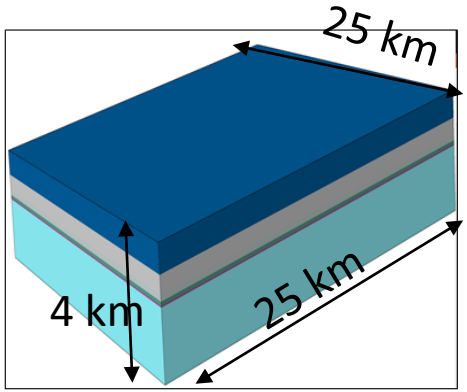
Saeed Salimzadeh, Elaheh Arjomand
29 Nov 2021

In Salah Finite Element Model

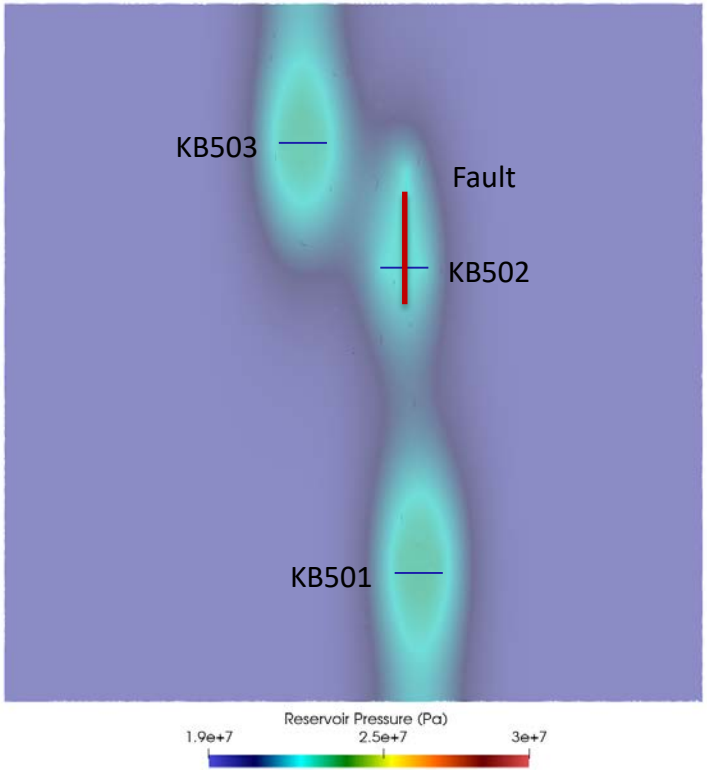


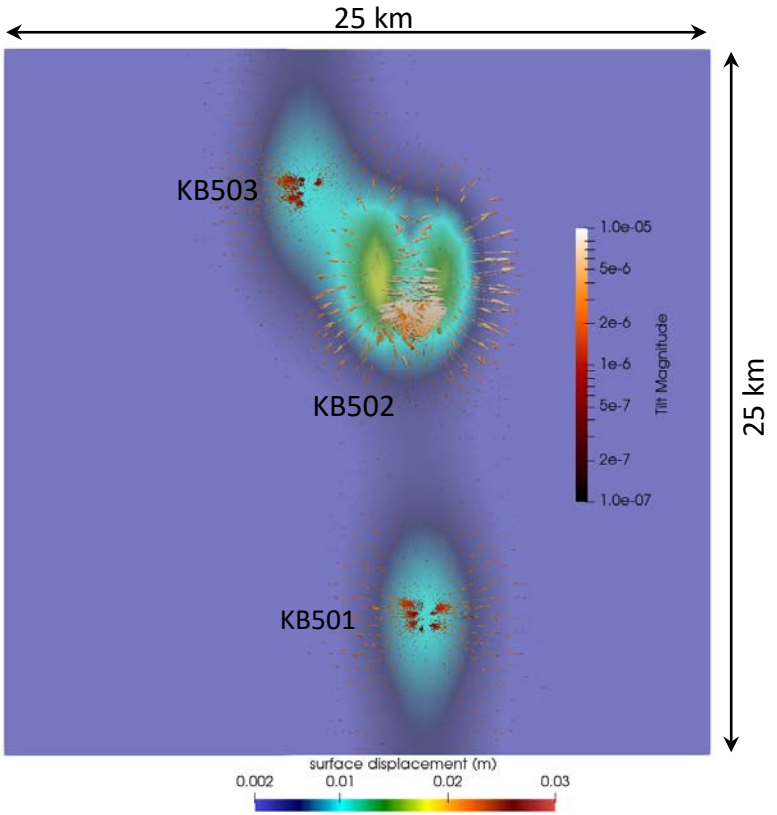


Shallow aquifer	0 – 900 m
Main caprock	900 – 1650 m
Lower caprock	1650 – 1780 m
Tight sandstone	1780 – 1800 m
Reservoir	1800 – 1820 m
Underburden	1820 – 4000 m

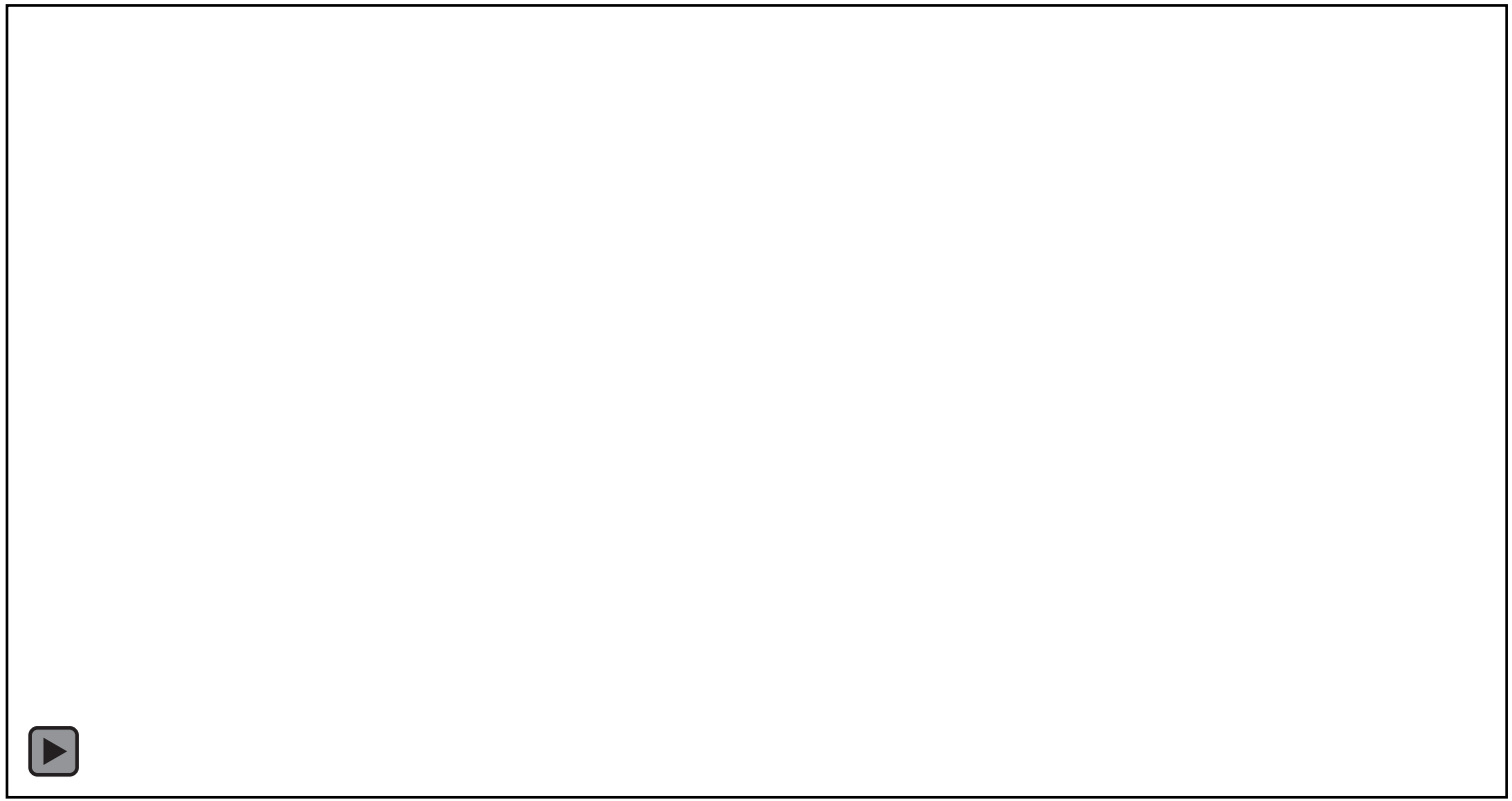


In Salah CO_2 Injection and Surface Deformation





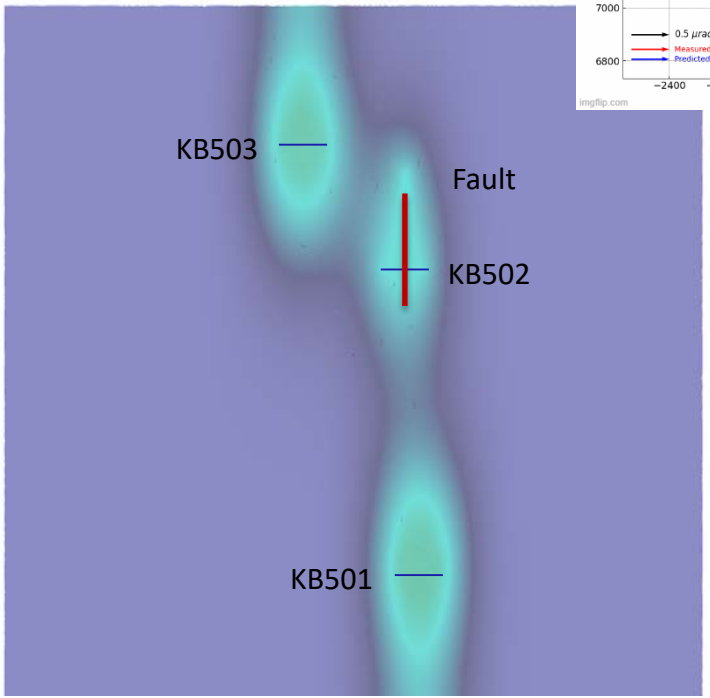
In Salah CO_2 Injection and Surface Deformation

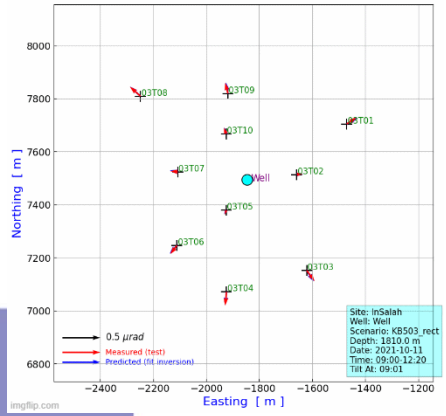


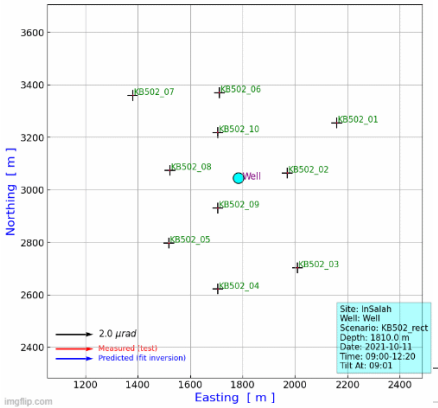
Tiltmeter Inverse Analysis (TAL)

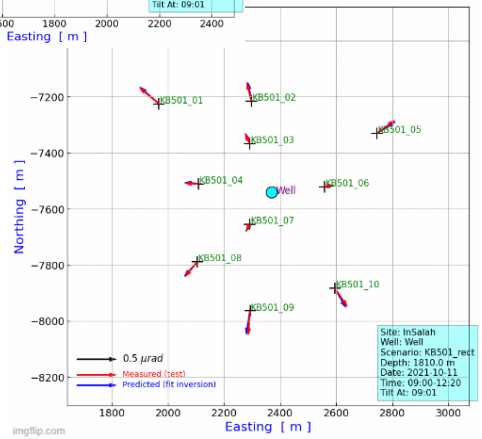
- An array of 10 tiltmeters are considered for each well
- The distribution pattern of tiltmeters around all wells are similar
- Tilt vectors of the surface (TOP) of the model are calculated from the deformation field in the forward modelling (CSMP) simulation
- The time-series of tilt vectors together with the coordinates of the tiltmeter units and injection points are fed into the TAL inverse modelling tool
- TAL performs a Bayesian inversion procedure for a given forward model
- The solution for a rectangular displacement discontinuity (DD) in a semi-infinite medium was used

Tilt Vectors

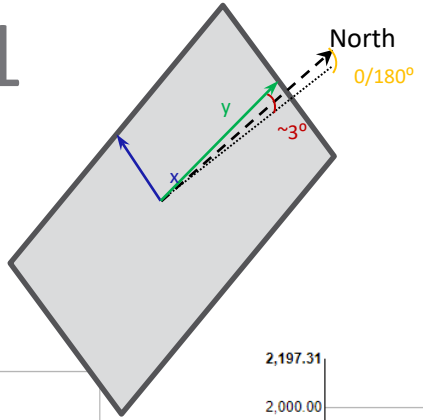


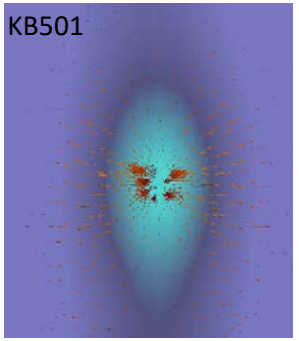


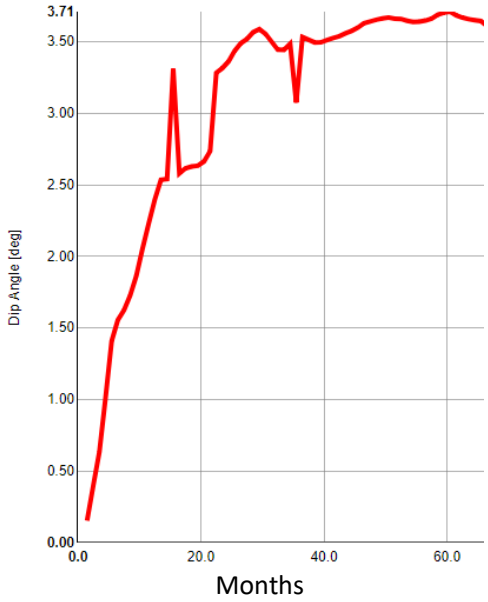


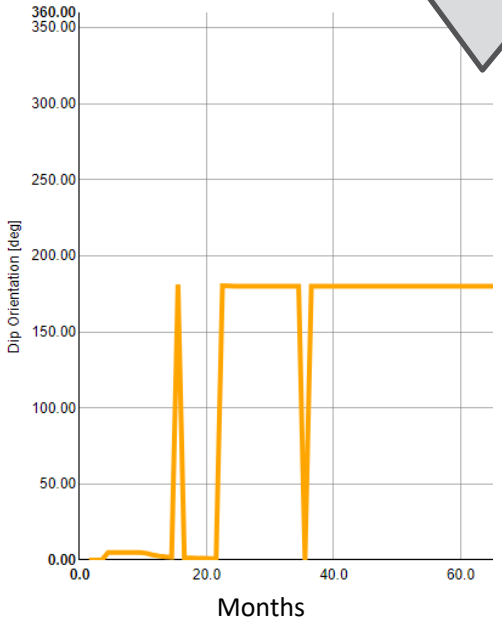


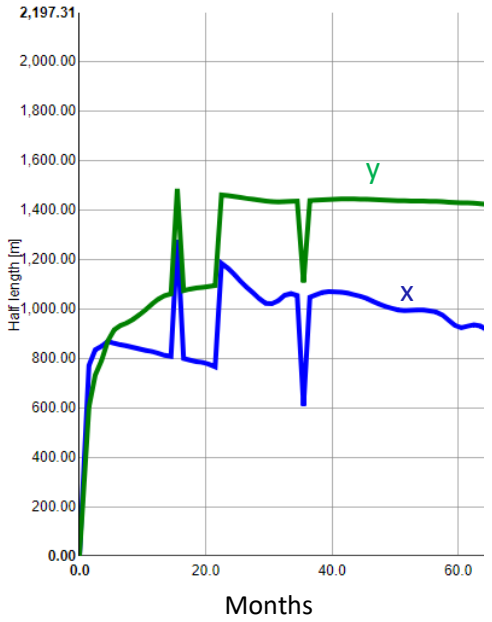
TAL Analysis - Well KB501



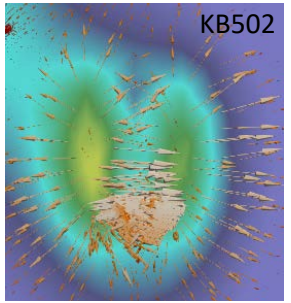


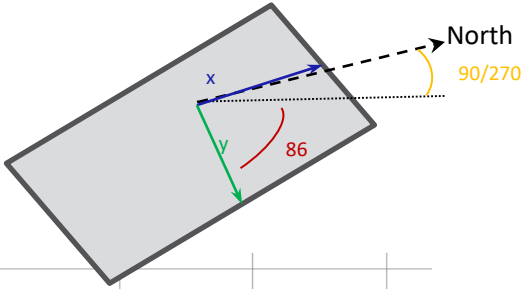


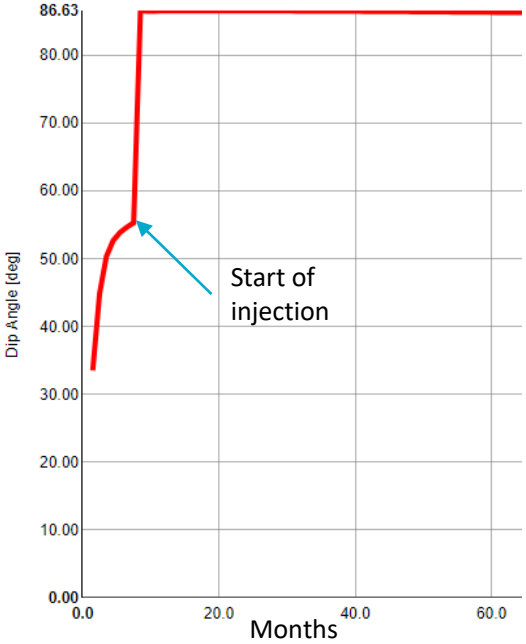


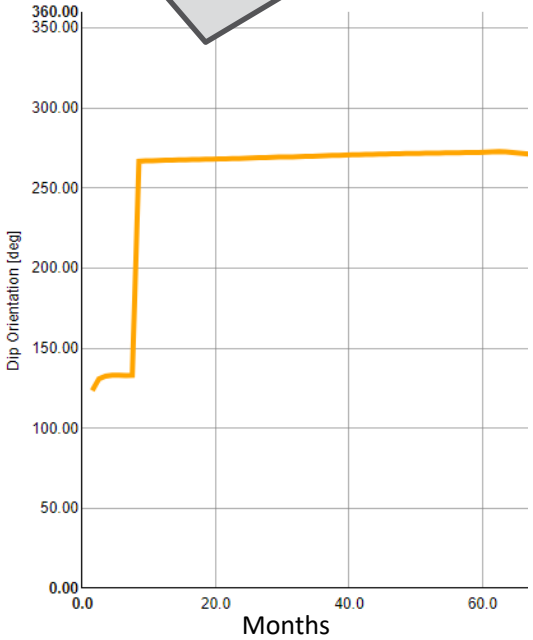


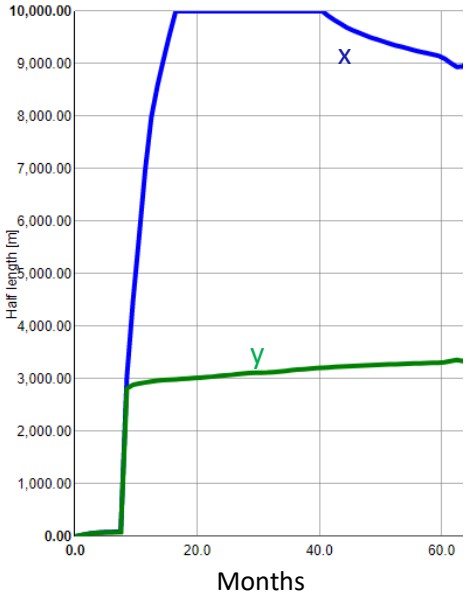
TAL Analysis - Well KB502



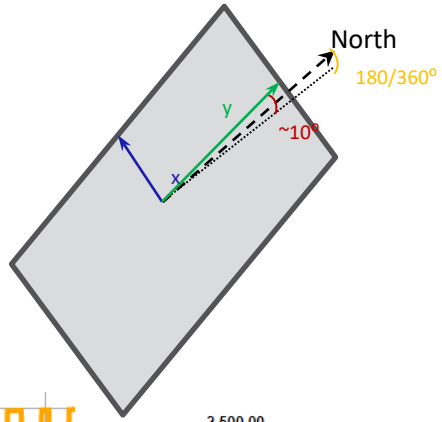


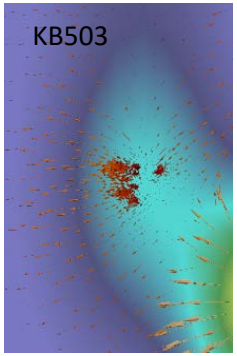


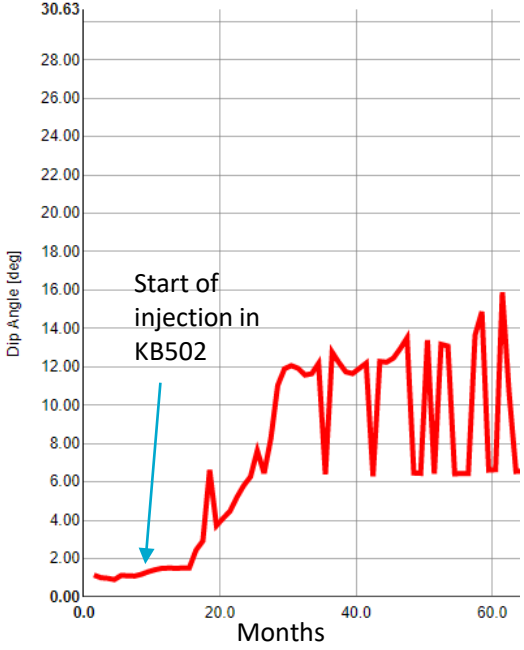


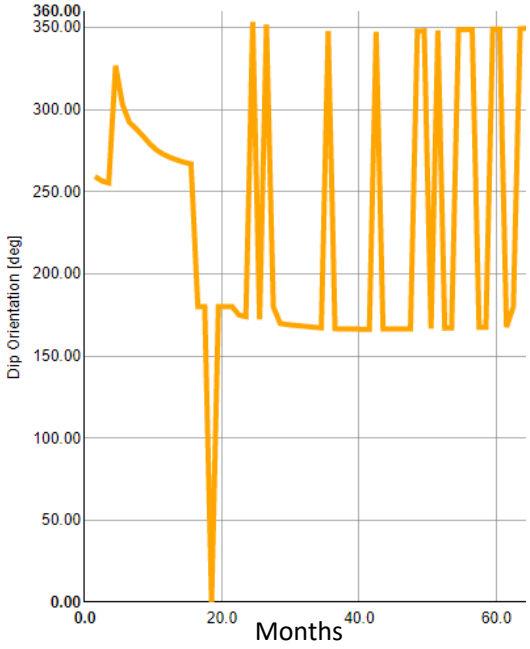


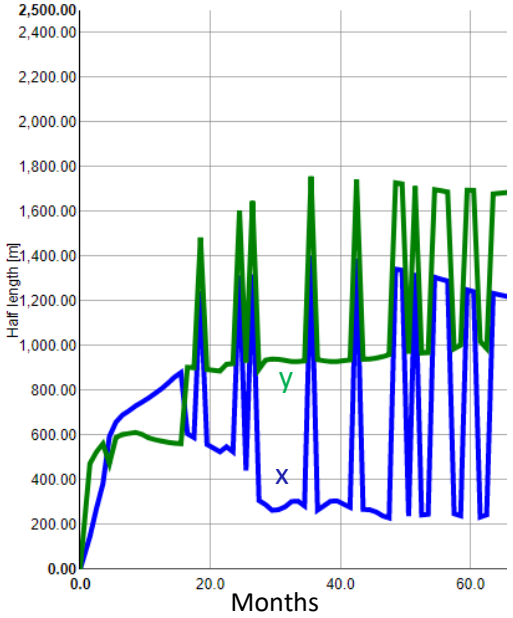
TAL Analysis - Well KB503



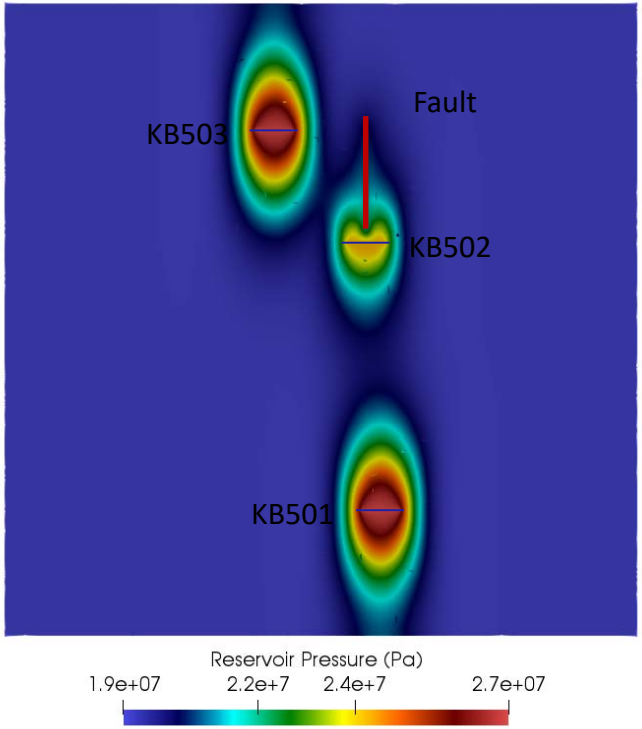


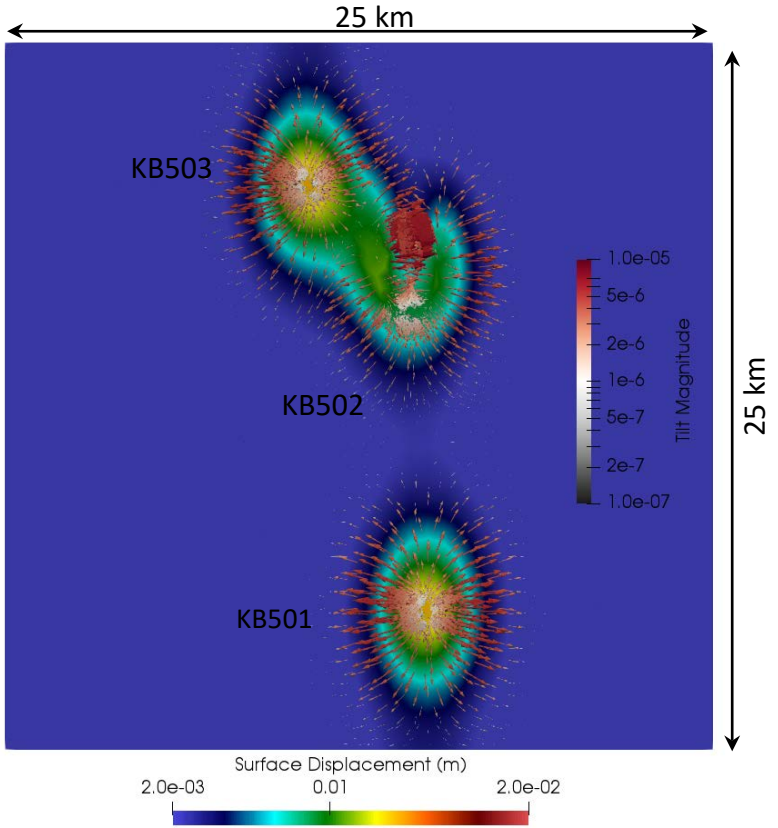




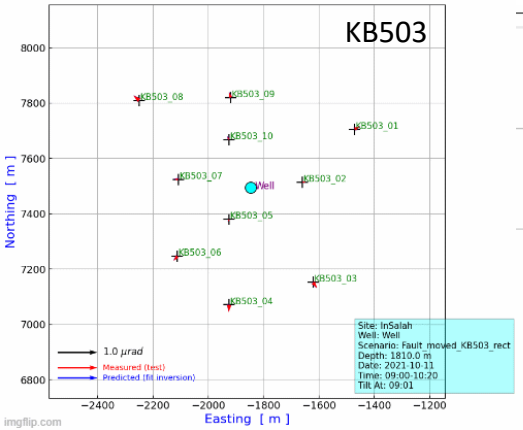


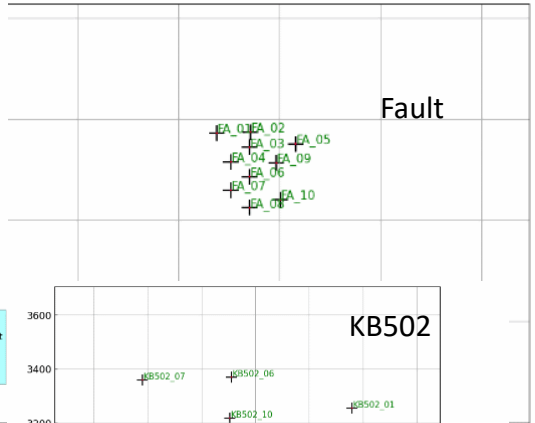
Scenario II: Fault not connected to the well

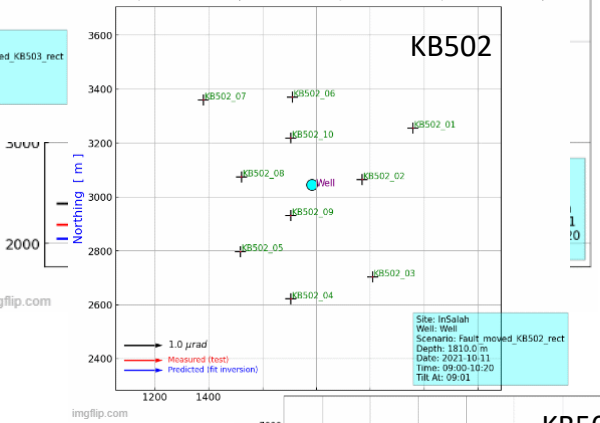


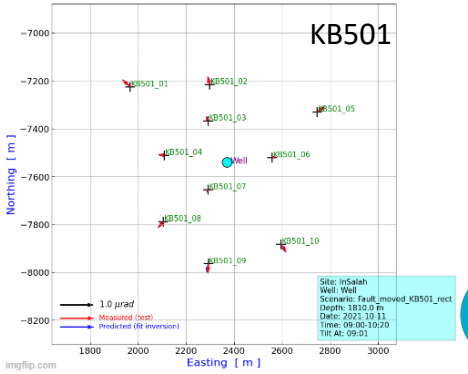


Tilt Vectors



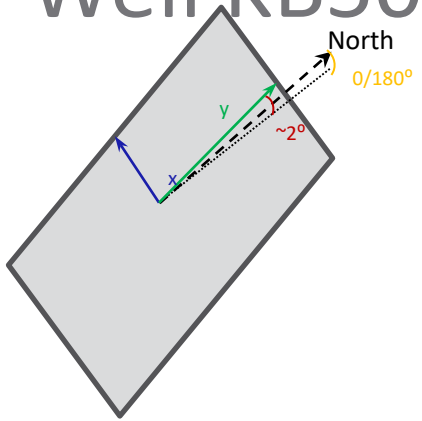


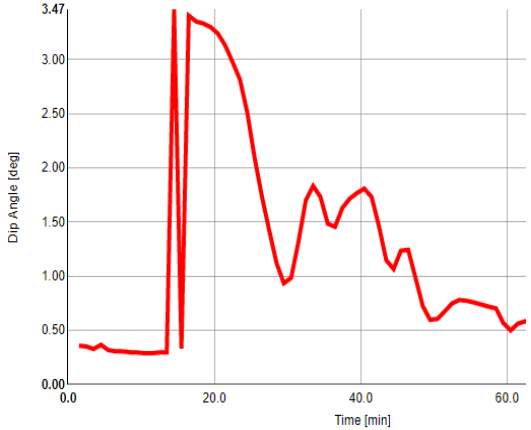


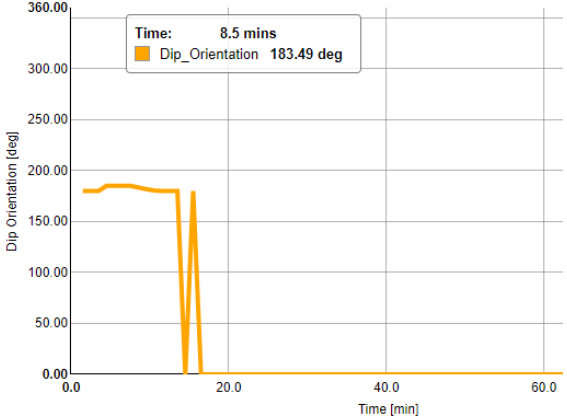


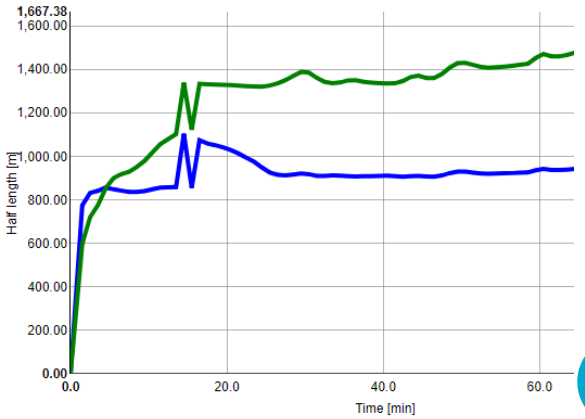
- Good match between measured and predicted tilt vectors in KB501 and KB503
- Good match in KB502 prior to pressurization of the fault
- The onset of fault pressurization can be determined from the tilt vectors
- Noticeable change in direction of tilt vectors at KB502 and the fault after fault pressurization
- Tiltmeters closer to the fault (KB501_01 and KB502_07) indicate a significant change in the direction of tilt vectors, but mainly affected by the deformation of the fault
- Tiltmeters away from the fault (KB502_03 and KB502_05) represent the mixed deformation due to both pressurization of the layer and the fault

TAL Analysis - Well KB501

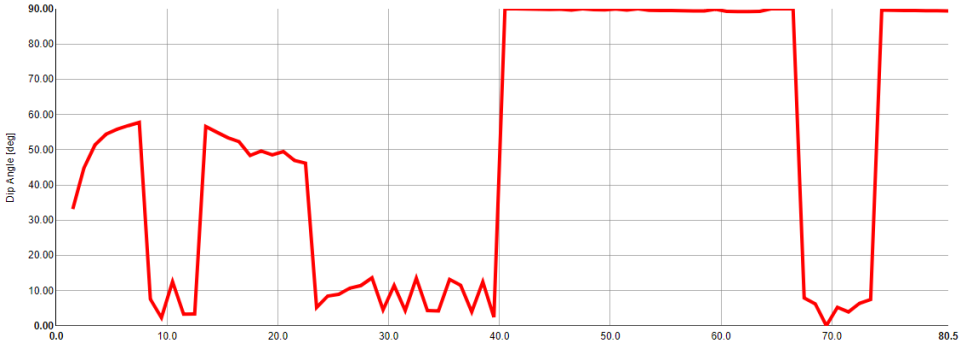


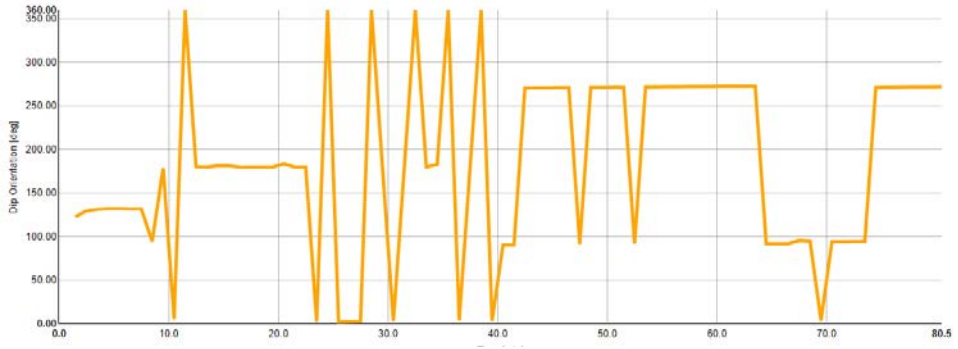


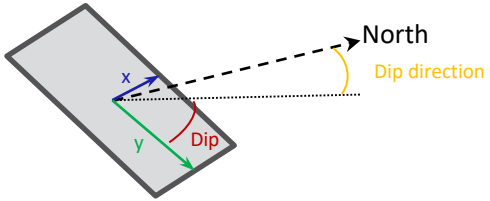


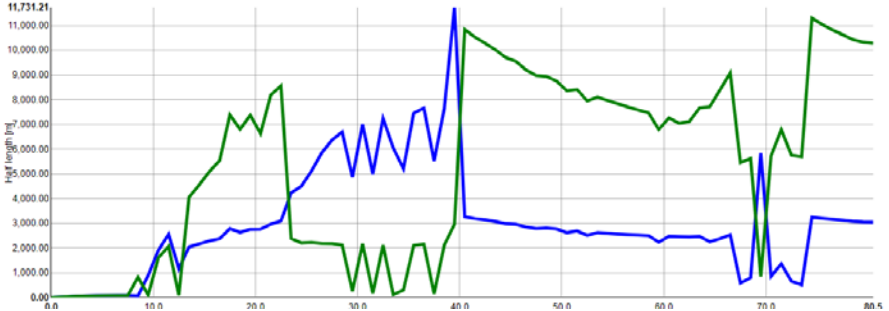


TAL Analysis - Well KB502

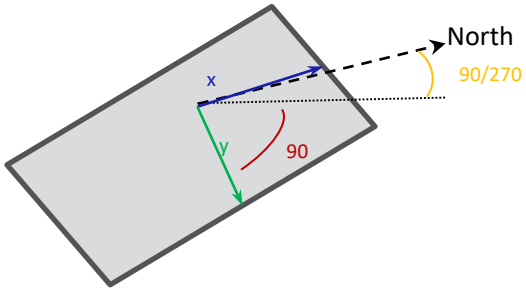


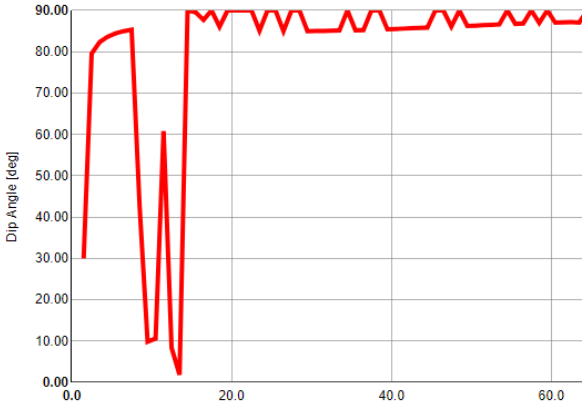


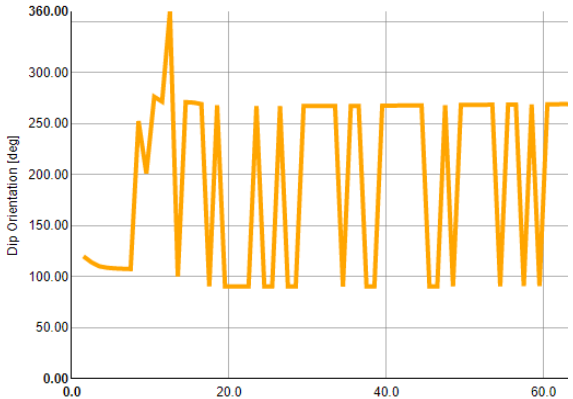


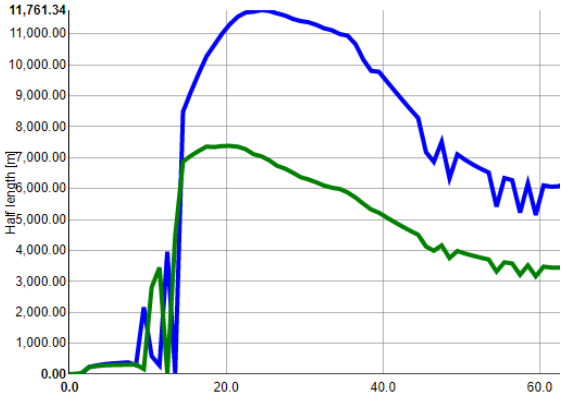


TAL Analysis - Fault KB502

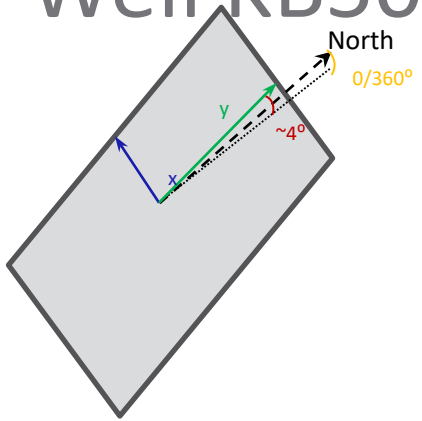


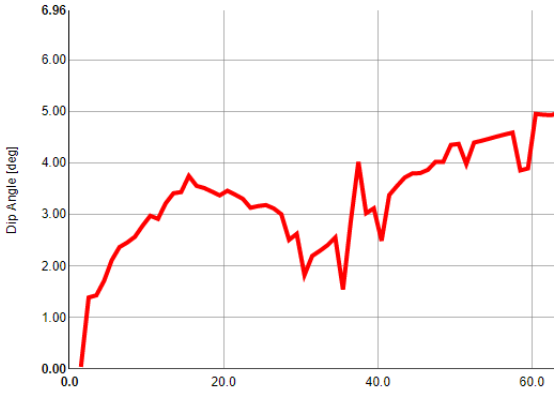


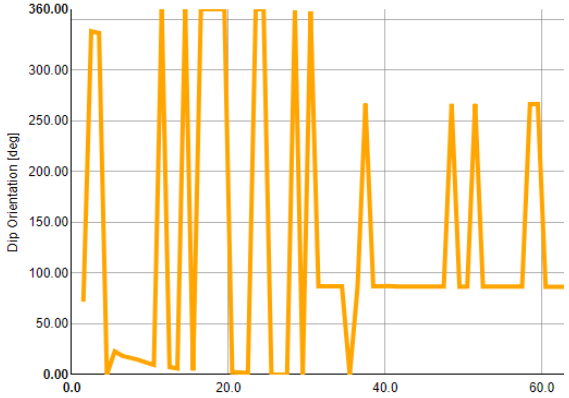


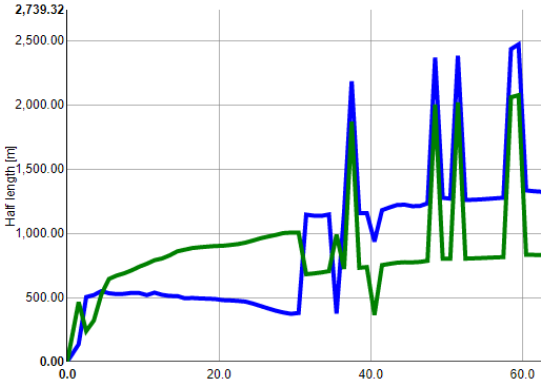


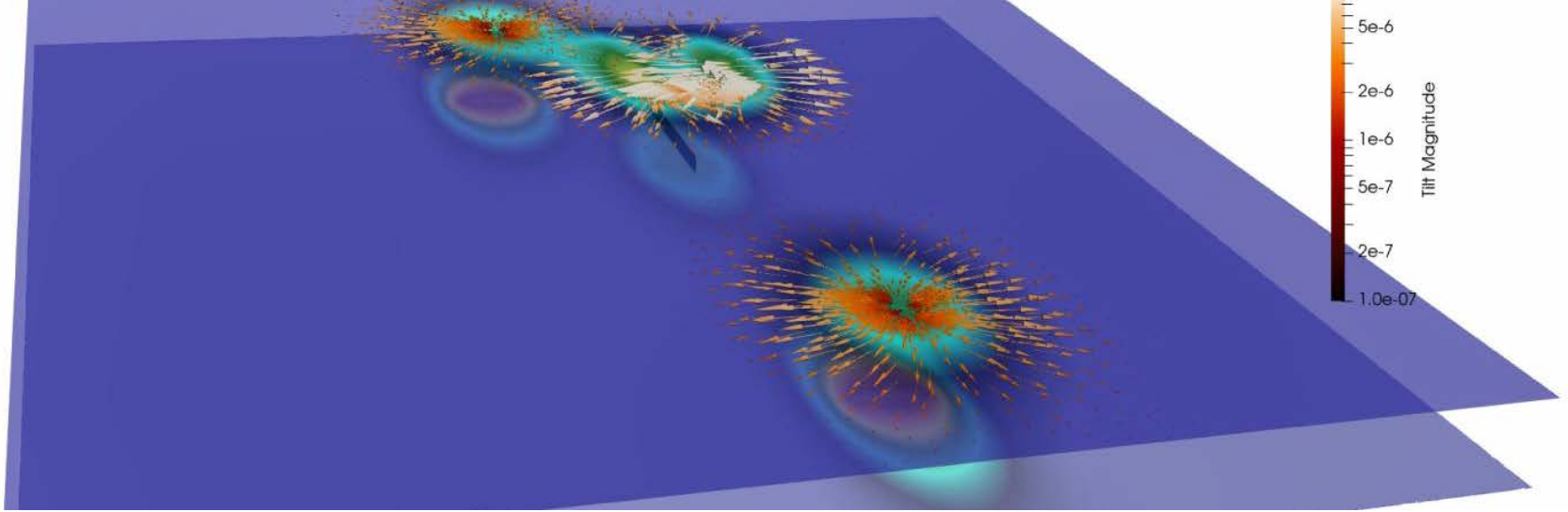
TAL Analysis - Well KB503











Surface Deformation Analysis of In Salah CO_2 Storage Site

Tiltmeter (inverse) analysis, **Reservoir (forward) simulation**

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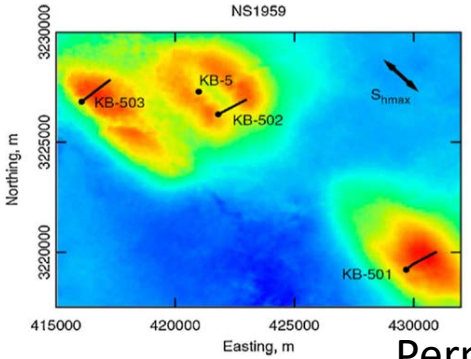
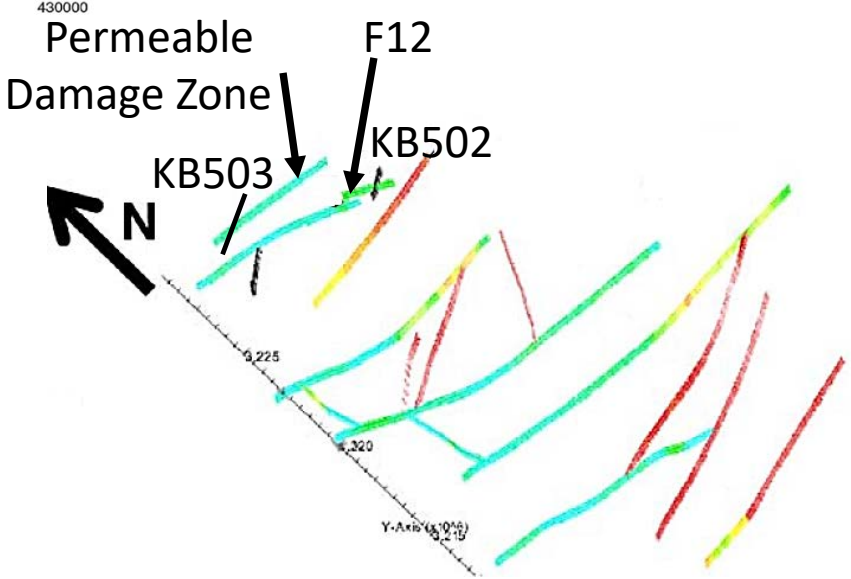
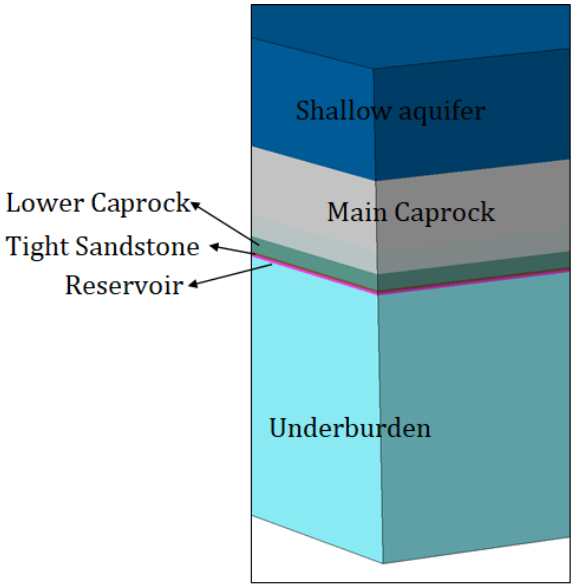
29 Nov 2021

Reservoir Geological Structures – KB503



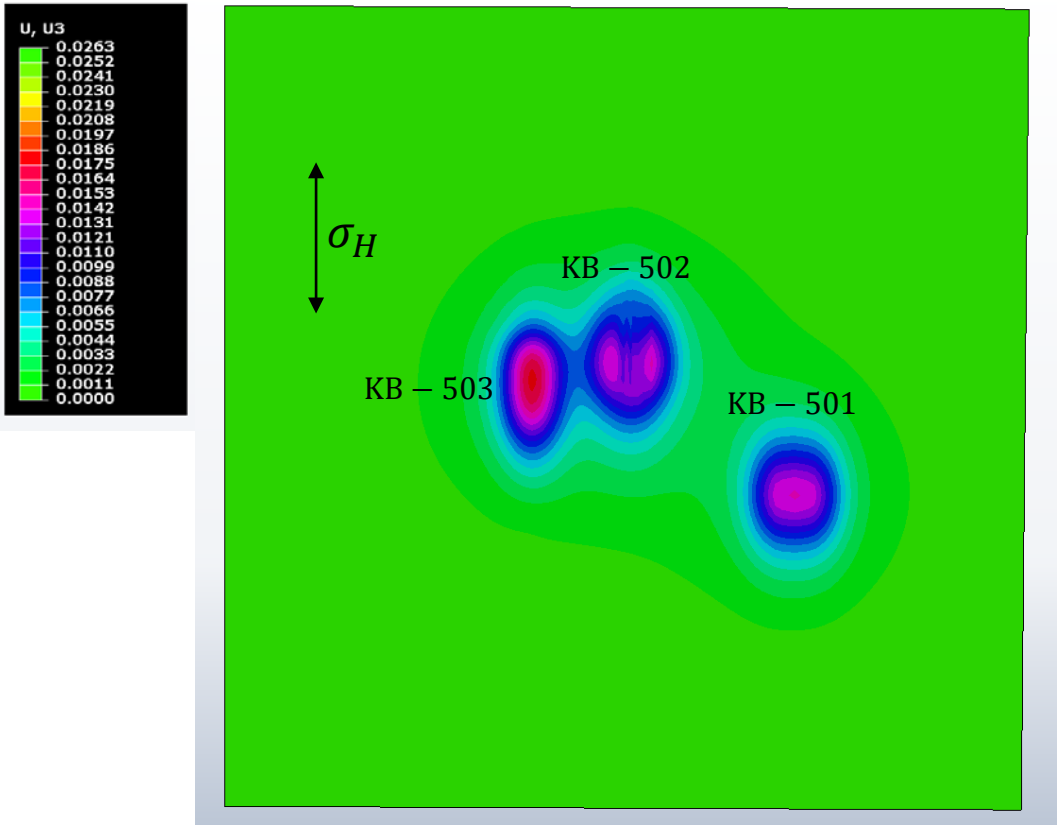
The seismic surveys supports the notion of two vertical north–west trending damage zones intersecting the wells KB-502 and KB-503 (Gibson-Poole & Raikes 2010).





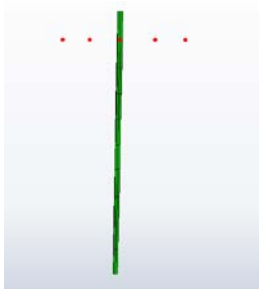
(Morris et al., 2011b; Rucci et al., 2013)

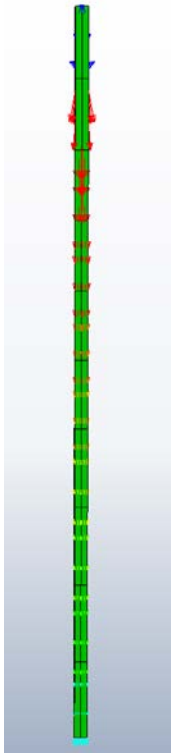
Numerical Simulations Results

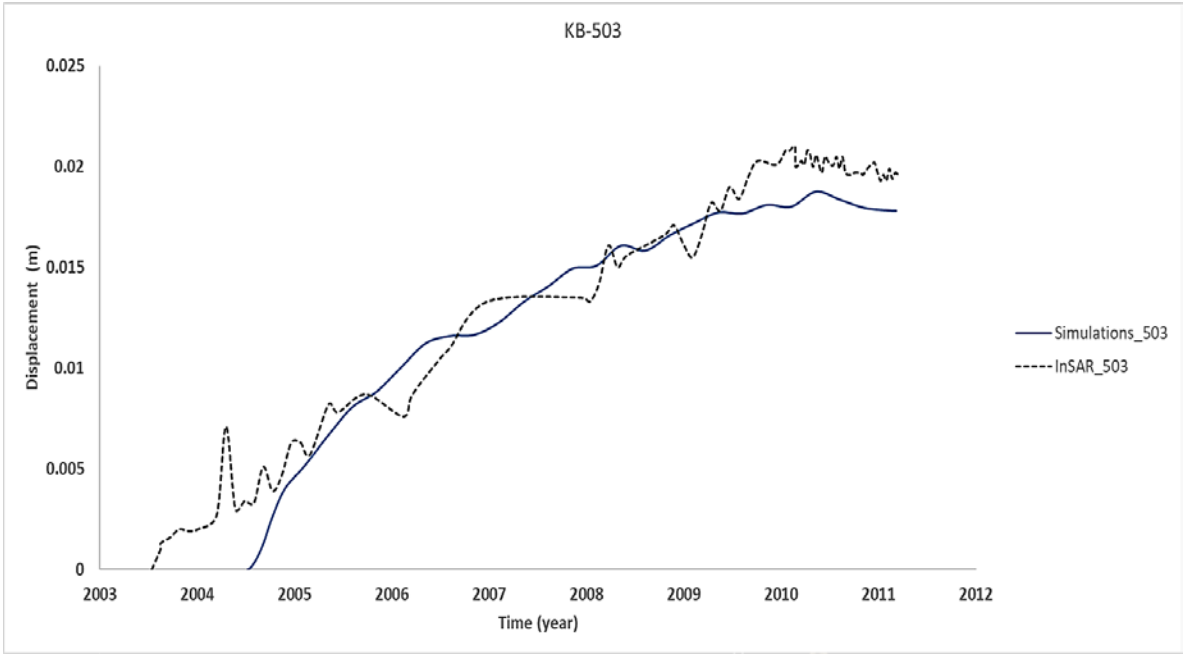


KB-503

Fault intersecting KB503





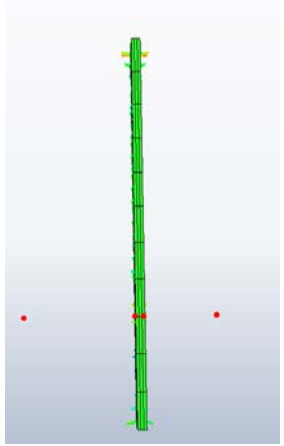


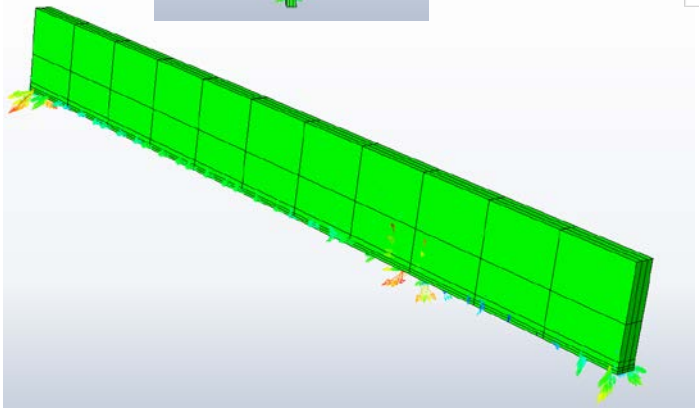
Fault Properties:

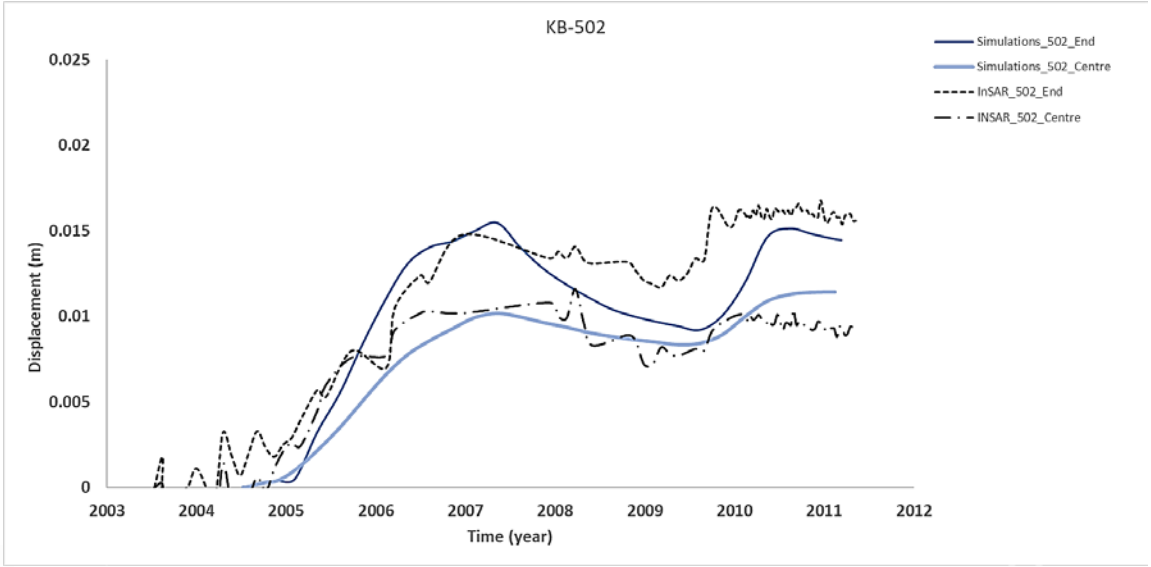
$$\begin{cases} \text{Mechanical :Orthotropic Material} \\ E_x = 6\text{GPa} > E_z = 3\text{GPa} > E_y = 1.8\text{GPa} \\ \vartheta_{xy} = \vartheta_{xz} = 0.18, \vartheta_{yz} = 0.25 \\ \mathrm{G_{xy}} = \mathrm{G_{xz}} = \mathrm{G_{yz}} = 1\ \text{GPa} \\ \text{Permeability: 1 Darcy} \\ \text{Height} = 20\ \text{m} \\ \text{Length} = 4000\ \text{m} \\ \text{width} = 60\ \text{m} \end{cases}$$

KB-502

Fault intersecting KB502



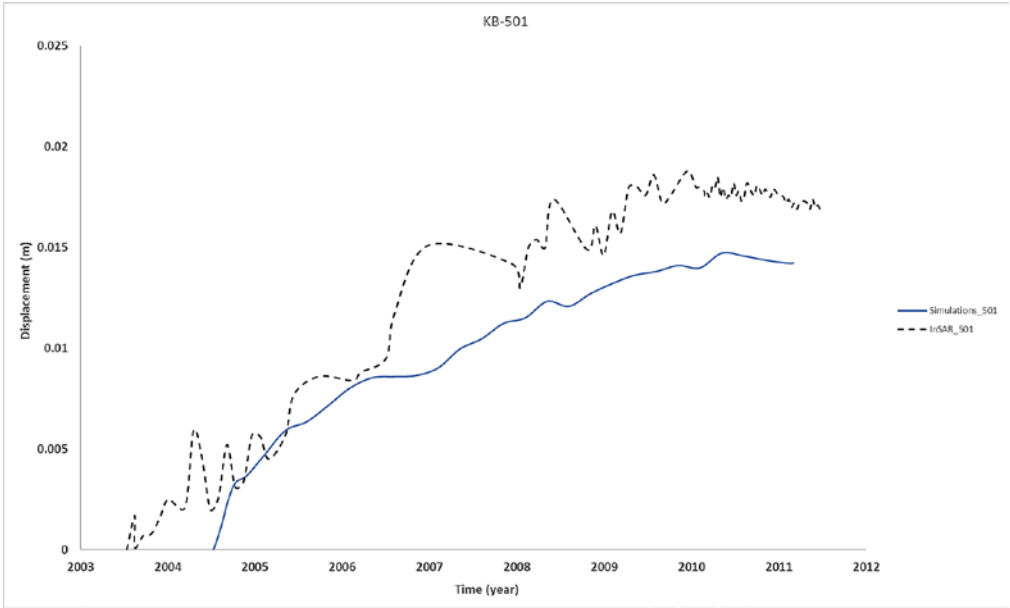




Fault Properties:

$$
\begin{cases}
\text{Mechanical :Orthotropic Material} \\
E_x = 0.5\ \text{GPa} < E_y = 1.2\text{GPa} < E_z = 6\text{GPa} \\
\vartheta_{xy} = \vartheta_{xz} = 0.18, \vartheta_{yz} = 0.25 \\
G_{xy} = G_{xz} = G_{yz} = 1\ \text{GPa} \\
\text{Permeability: } 0.1\ \text{Darcy} \\
\text{Height} = 400\ \text{m} \\
\text{Length} = 3500\text{m} \\
\text{Width} = 60\ \text{m}
\end{cases}
$$

KB-501


KB-501
0.025
0.02
0.015
0.01
0.005
0
Displacement (m)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Time (year)
Simulations_501
InSAR_501

Thank you

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