AVO Sensitivity to Shale Reservoirs

Hamad Alghenaim - NTNU

Outline

- Objectives
- Laboratory Experiment
- Data and Model
- Results
- Conclusion
- Next
- Acknowledgment

Objectives

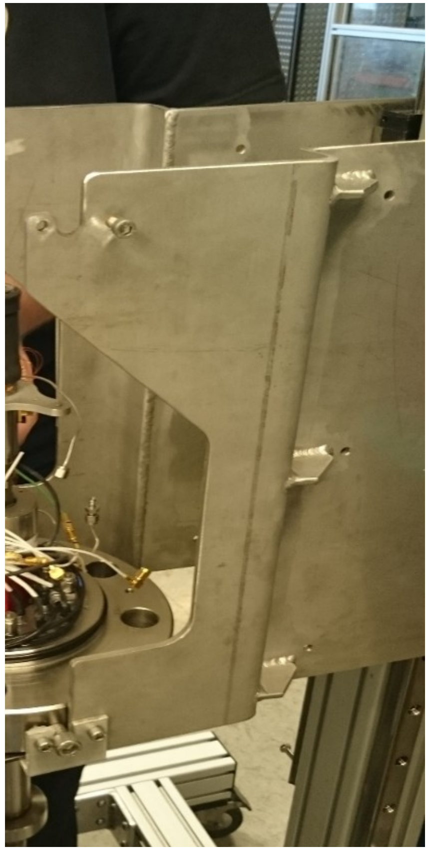
- Examine unconventional shale reservoir sensitivity to:
  - Saturation
  - Stress
  - Frequency
  - Anisotropy
  - Cracks

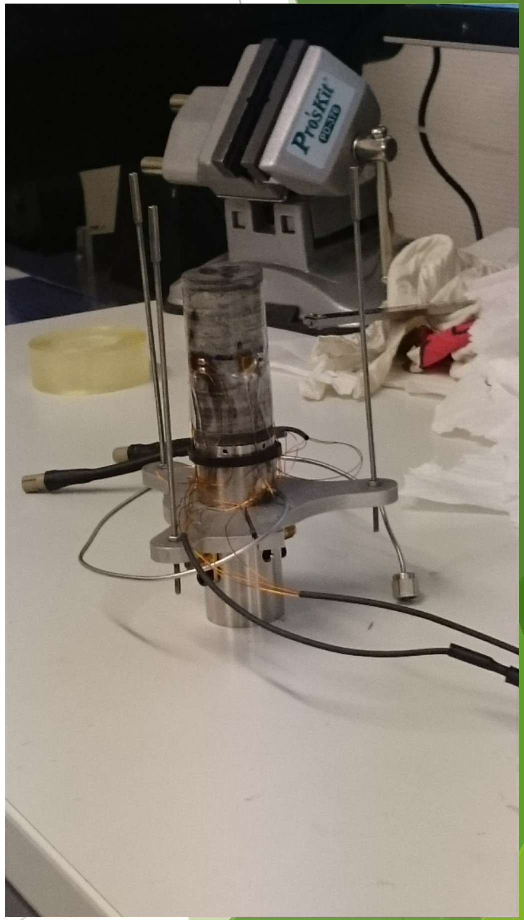
Laboratory Experiments

- Two experiments:
    - Constant stress and varying saturation. (done previously – data available)
    - Constant saturation and varying confining and axial stresses. (April 2015 – data processing)

- Measured ultra sonic velocities and low frequency velocities calculated from strain measurements. (E, υ)

- Three different orientations in each expirement to calculate the stiffness tensor elements and anisotropy parameters.





Data and Model

	Saturation	Frequency	Crack density	Stress
Saturation				
Frequency				
Crack density				
Stress				

Data and Model

X Shale

Oveburden clay rich shale

Vp=3000 m/s, Vs =1500 m/s, ,density=2.4 g/cc, epsilon=0.2 and delta=0.1

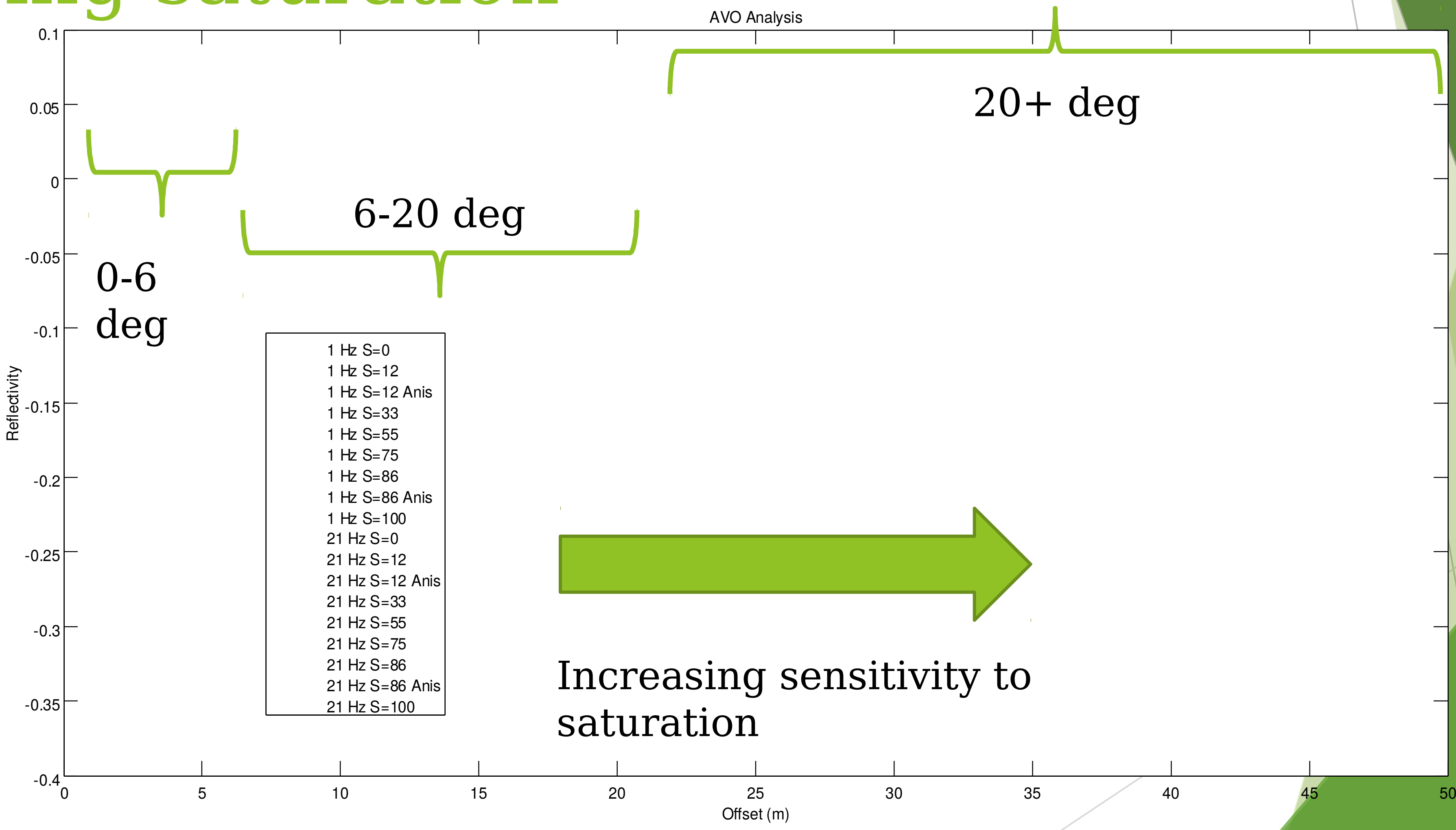
Mancos Shale

Reservoir silt rich shale

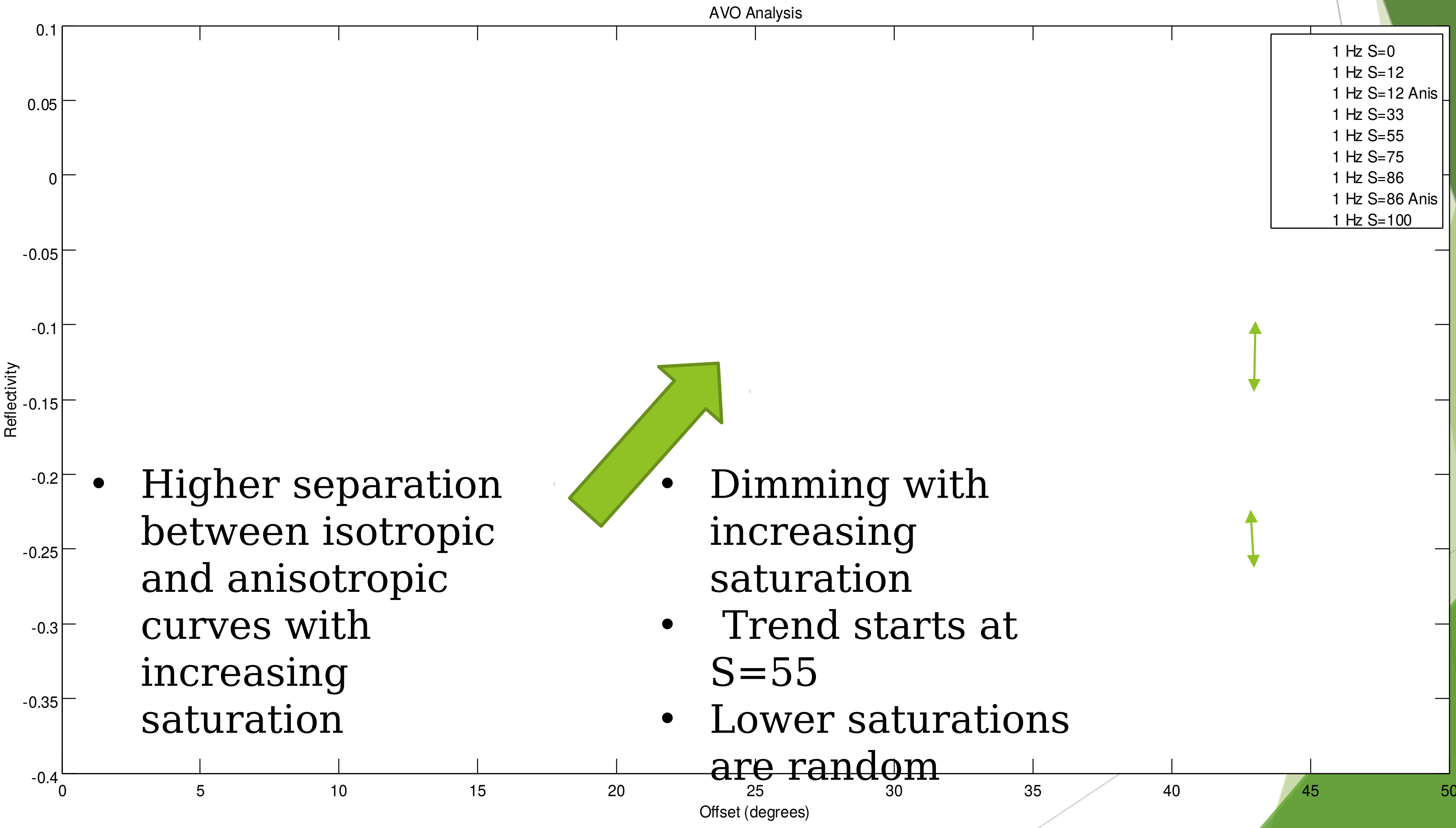
Lab data

Results

Two freq. (1 Hz & 21 Hz) while varying saturation



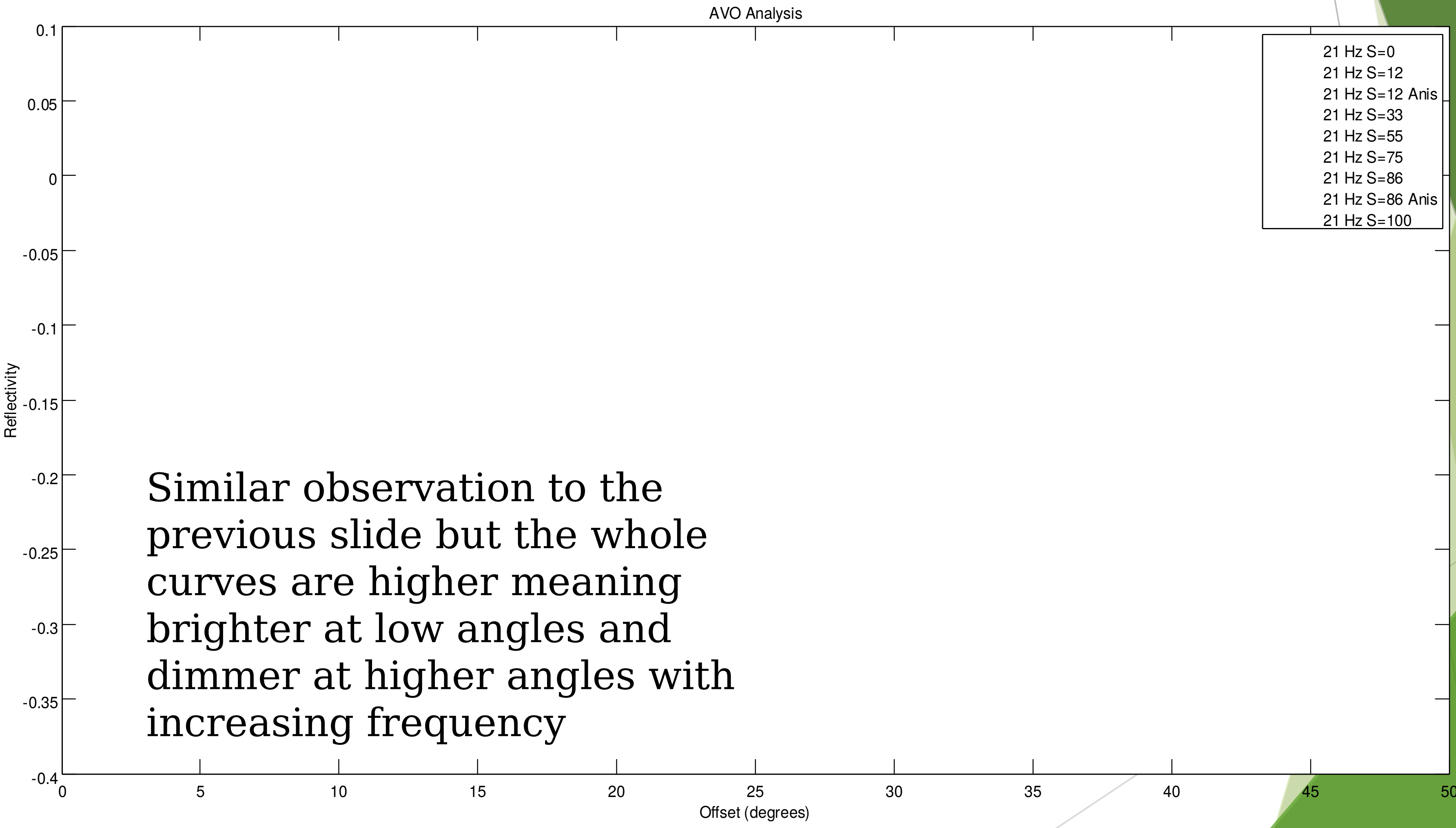
Shale samples measured at 1 Hz



- Higher separation between isotropic and anisotropic curves with increasing saturation

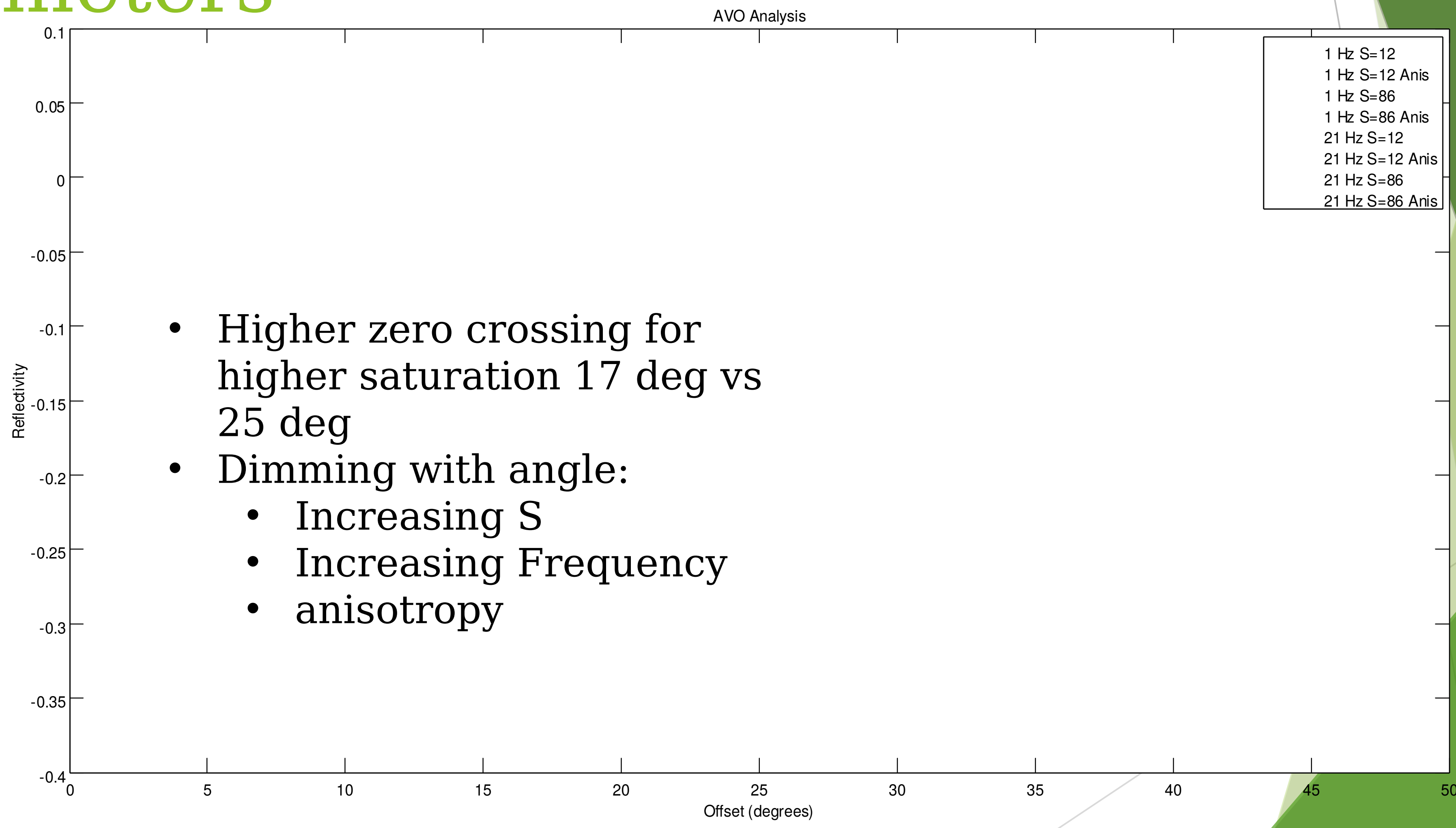
- Dimming with increasing saturation
- Trend starts at S=55
- Lower saturations are random

Shale samples measured at 21 Hz



Similar observation to the previous slide but the whole curves are higher meaning brighter at low angles and dimmer at higher angles with increasing frequency

Data with measured anisotropic parameters



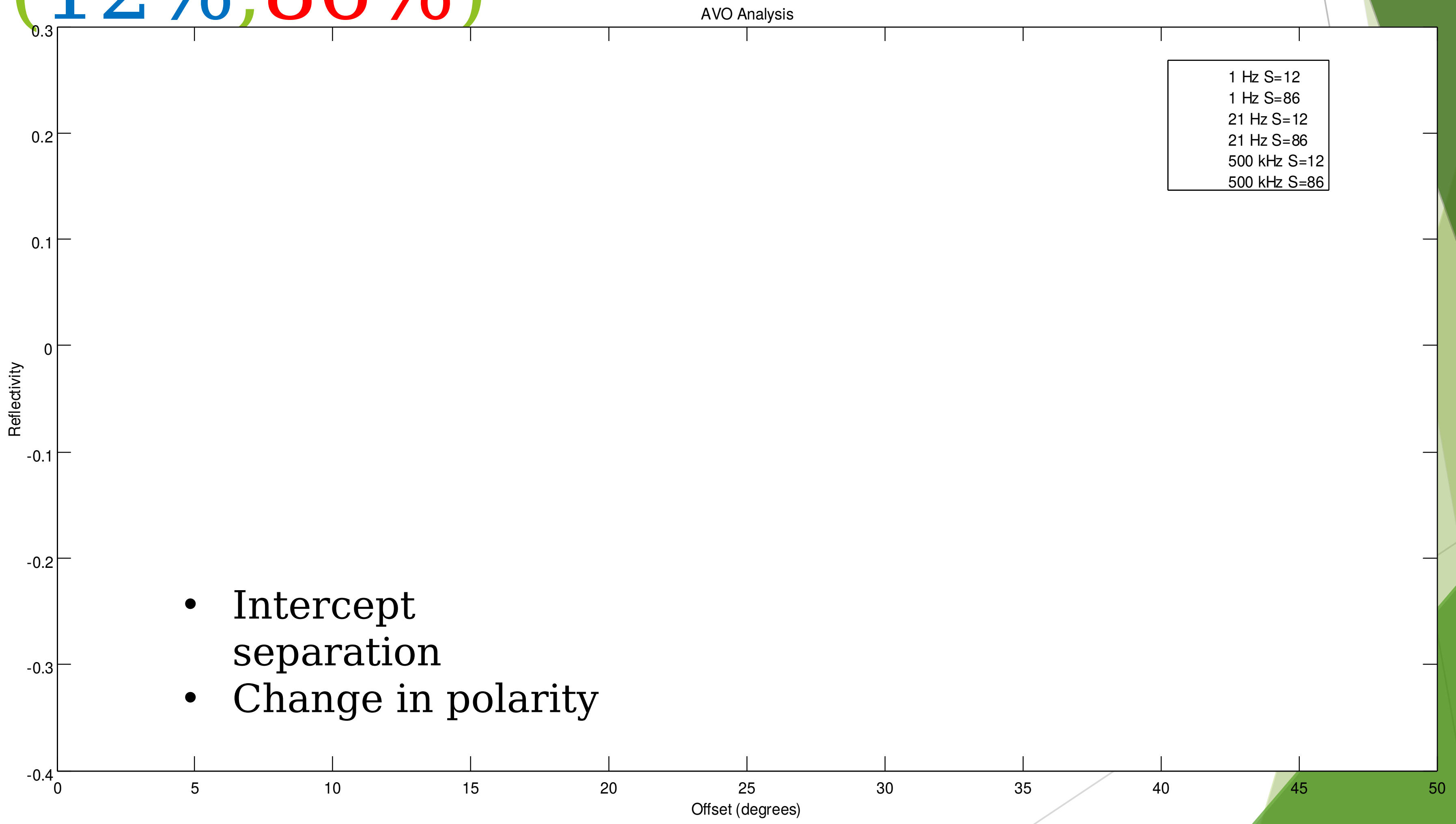
- Higher zero crossing for higher saturation 17 deg vs 25 deg
- Dimming with angle:
  - Increasing S
  - Increasing Frequency
  - anisotropy

Data and Model

Pierre Shale — Oveburden clay rich shale — Lab data

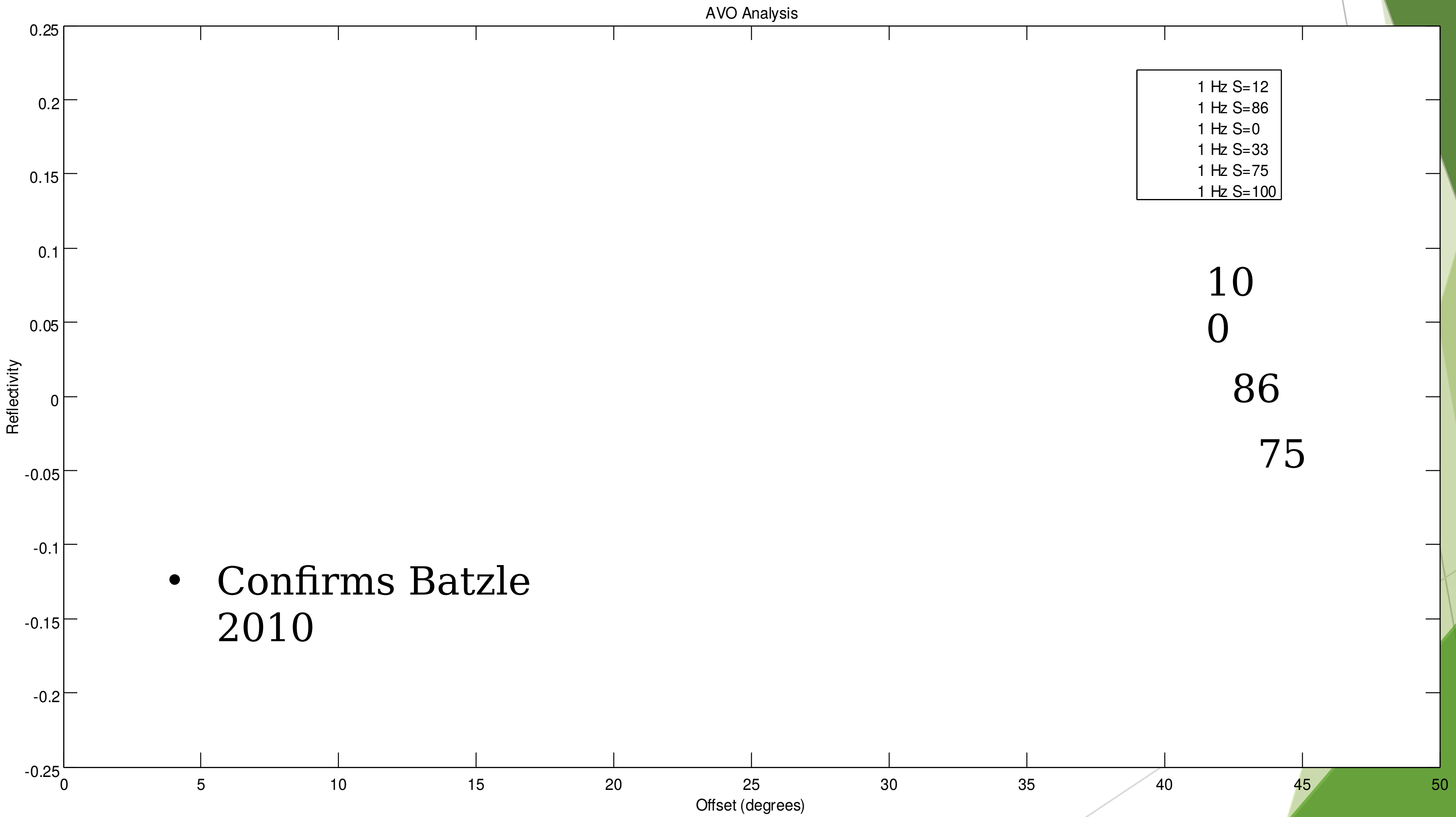
Mancos Shale — Reservoir silt rich shale — Lab data

3 Freq. (1 Hz,21 Hz, 500kHz), 2 Sat. (12%,86%)



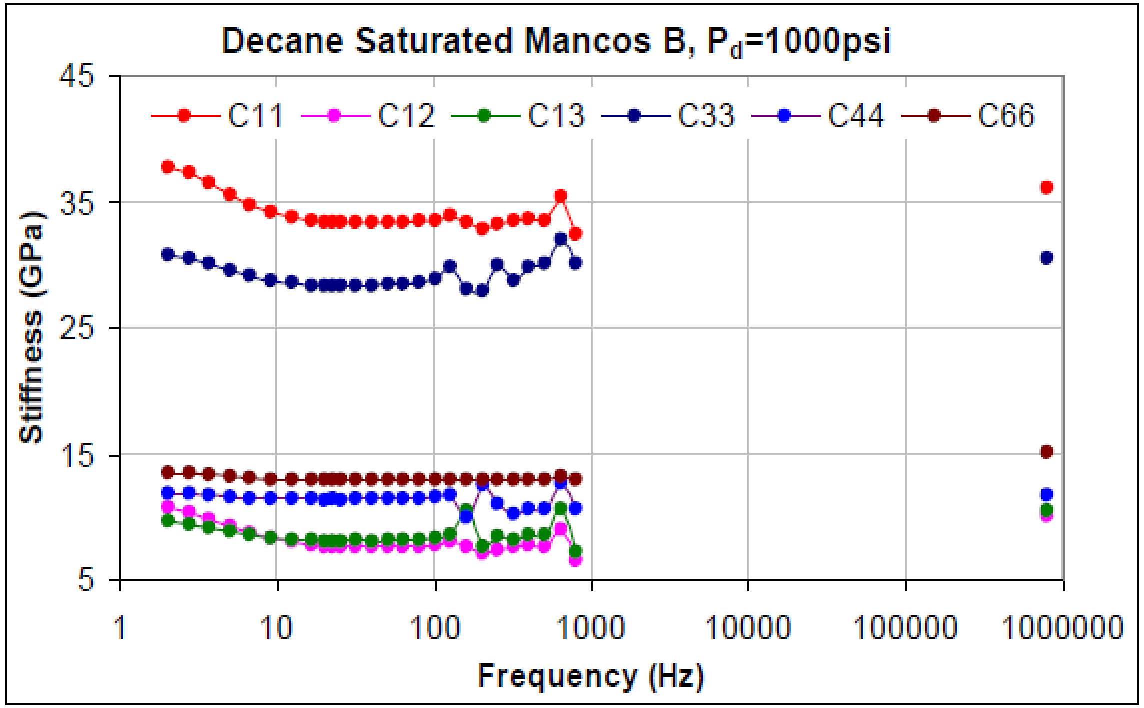
- Intercept separation
- Change in polarity

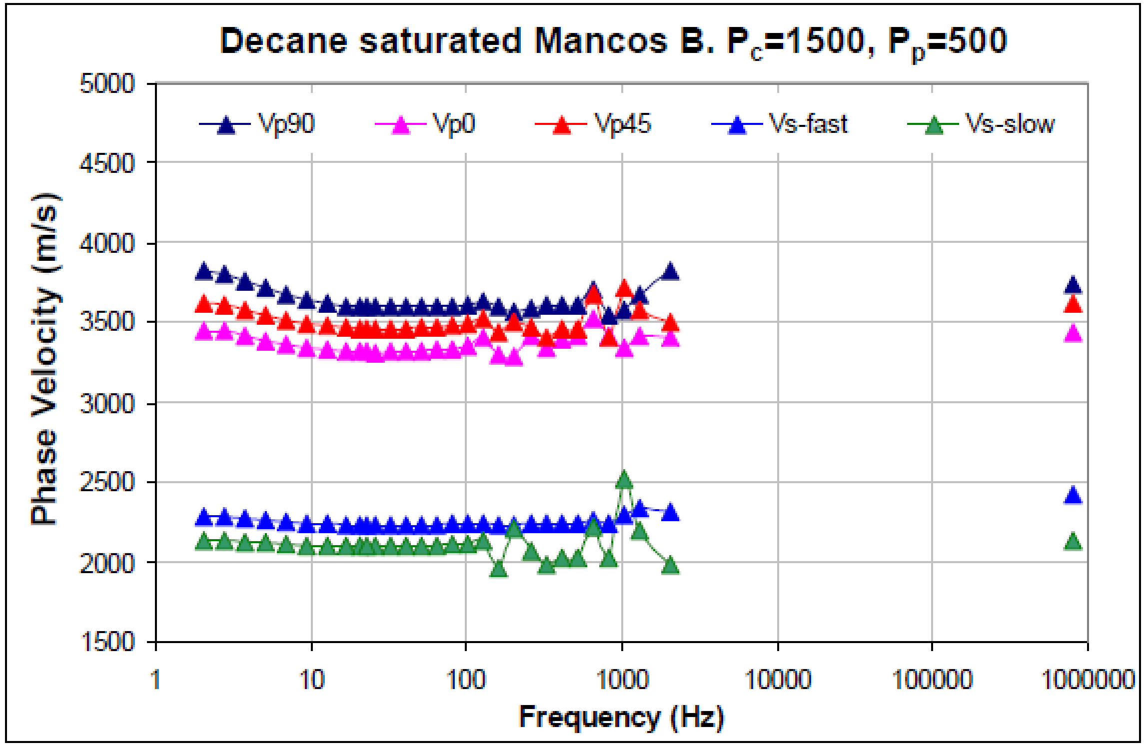
1 Hz and varying saturation



- Confirms Batzle 2010

Plots from Batzle and Sarker 2010

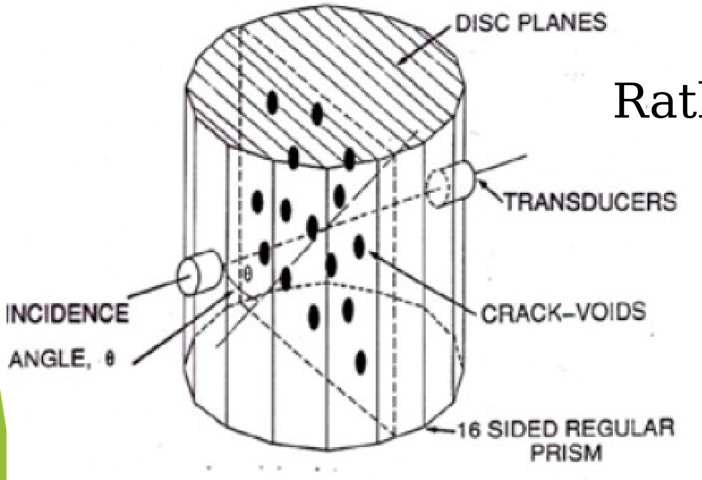




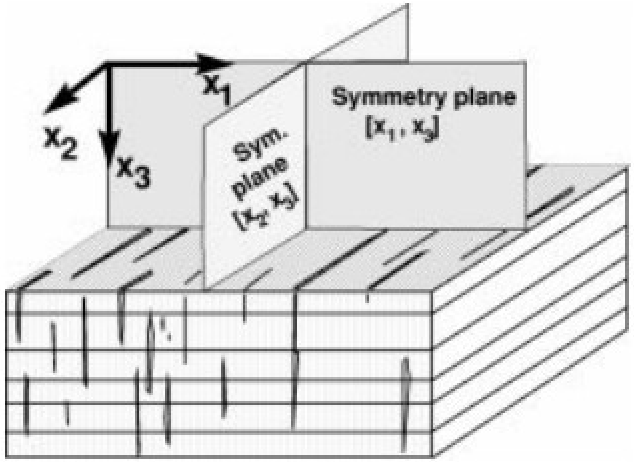
Sensitivity to Cracks

$$\overleftrightarrow{C} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{pmatrix}$$

$$\begin{bmatrix} \frac{\nu_s^2}{1-2\nu_s} & \frac{\nu_s(1-\nu_s)}{1-2\nu_s} & \frac{(1-\nu_s)^2}{1-2\nu_s} & 0 & 0 & 0 \\ \frac{\nu_s(1-\nu_s)}{1-2\nu_s} & \frac{\nu_s^2}{1-2\nu_s} & \frac{(1-\nu_s)^2}{1-2\nu_s} & 0 & 0 & 0 \\ \frac{(1-\nu_s)^2}{1-2\nu_s} & \frac{(1-\nu_s)^2}{1-2\nu_s} & \frac{(1-\nu_s)^2}{1-2\nu_s} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-\nu_s}{2-\nu_s} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-\nu_s}{2-\nu_s} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



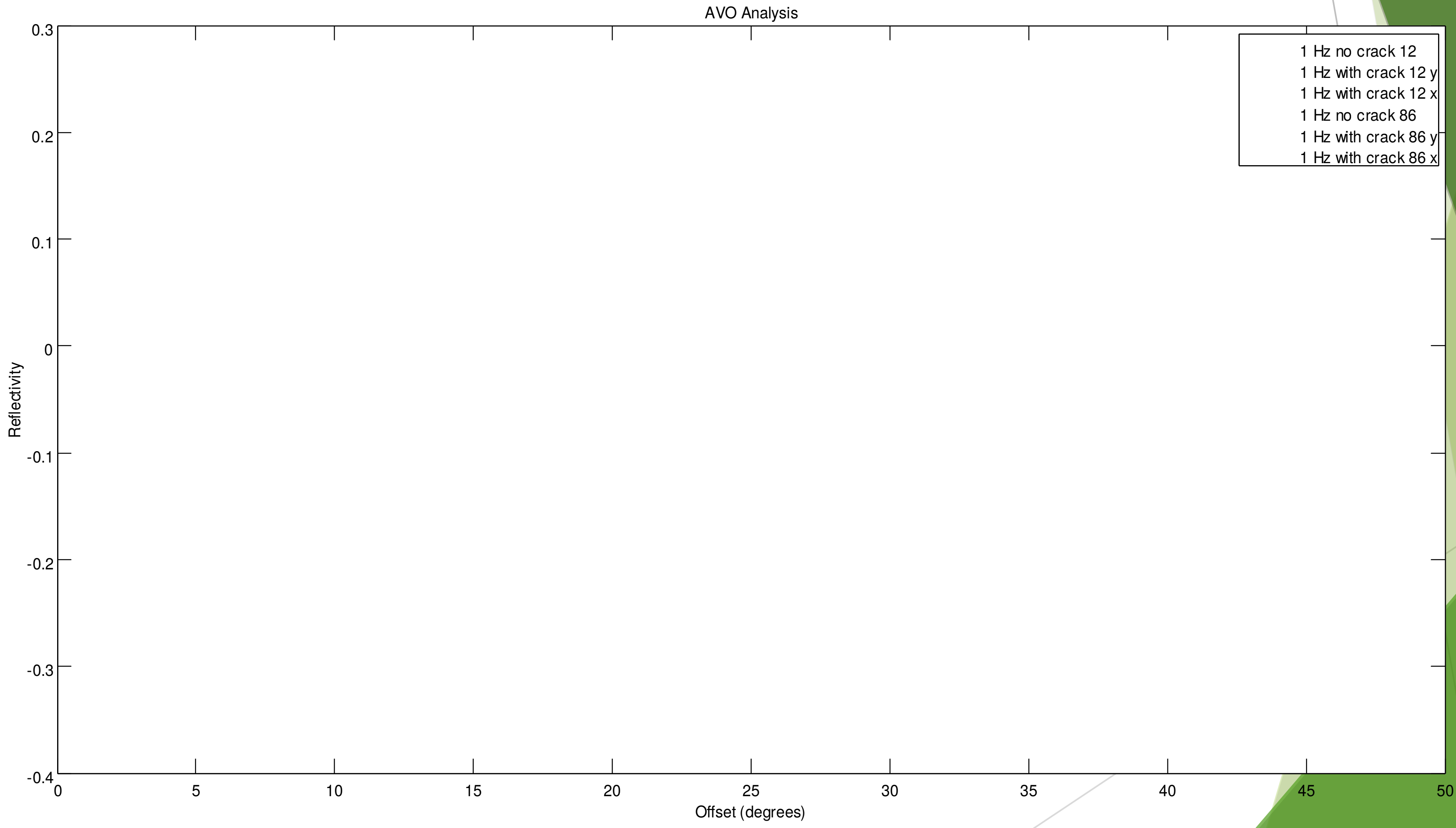
Rathore 1995



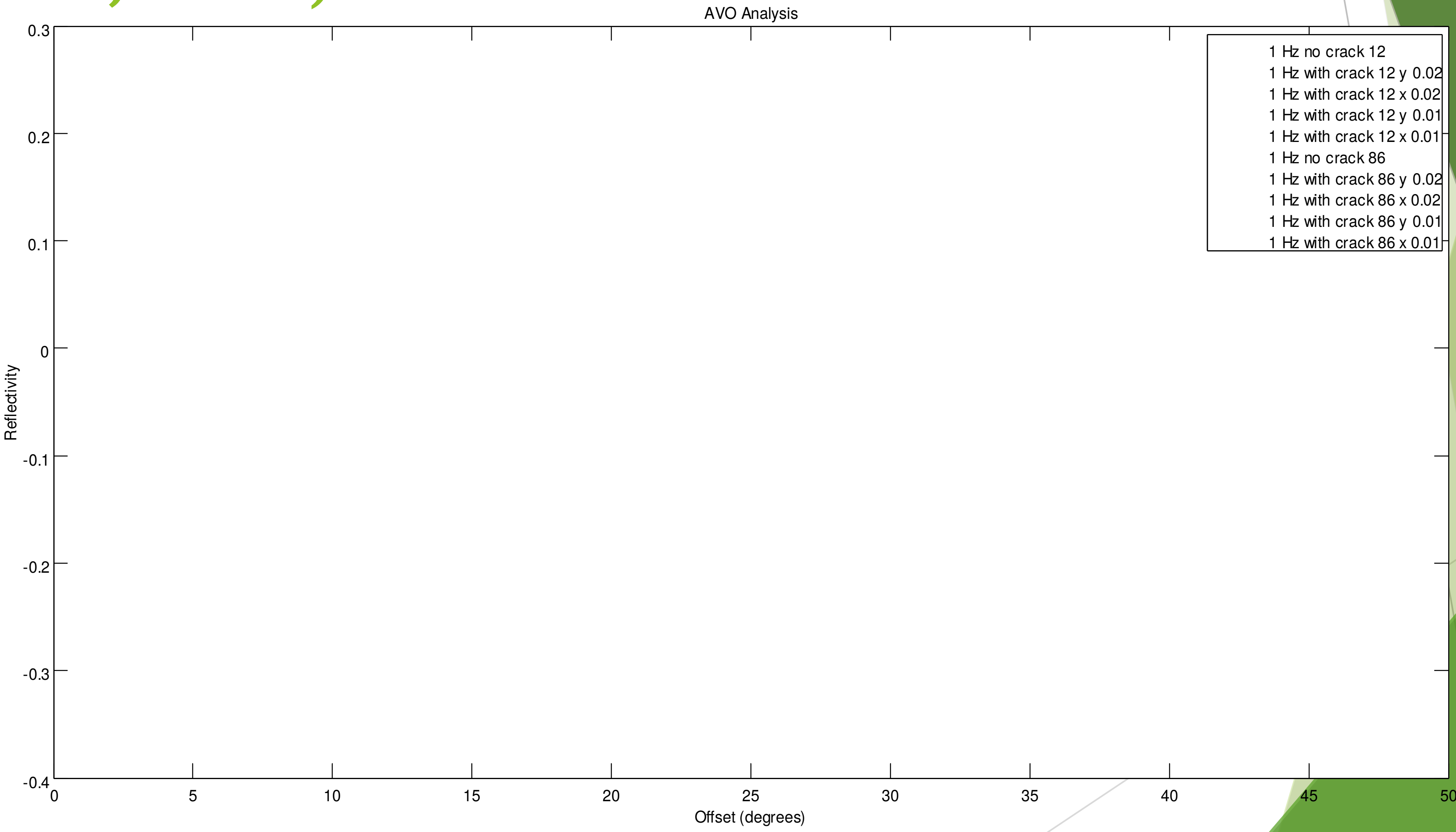
Tsvankin

$$\mathbf{c}_{\text{orthor}} = \begin{pmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 & 0 \\ c_{12} & c_{22} & c_{23} & 0 & 0 & 0 \\ c_{13} & c_{23} & c_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & c_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & c_{66} \end{pmatrix}.$$

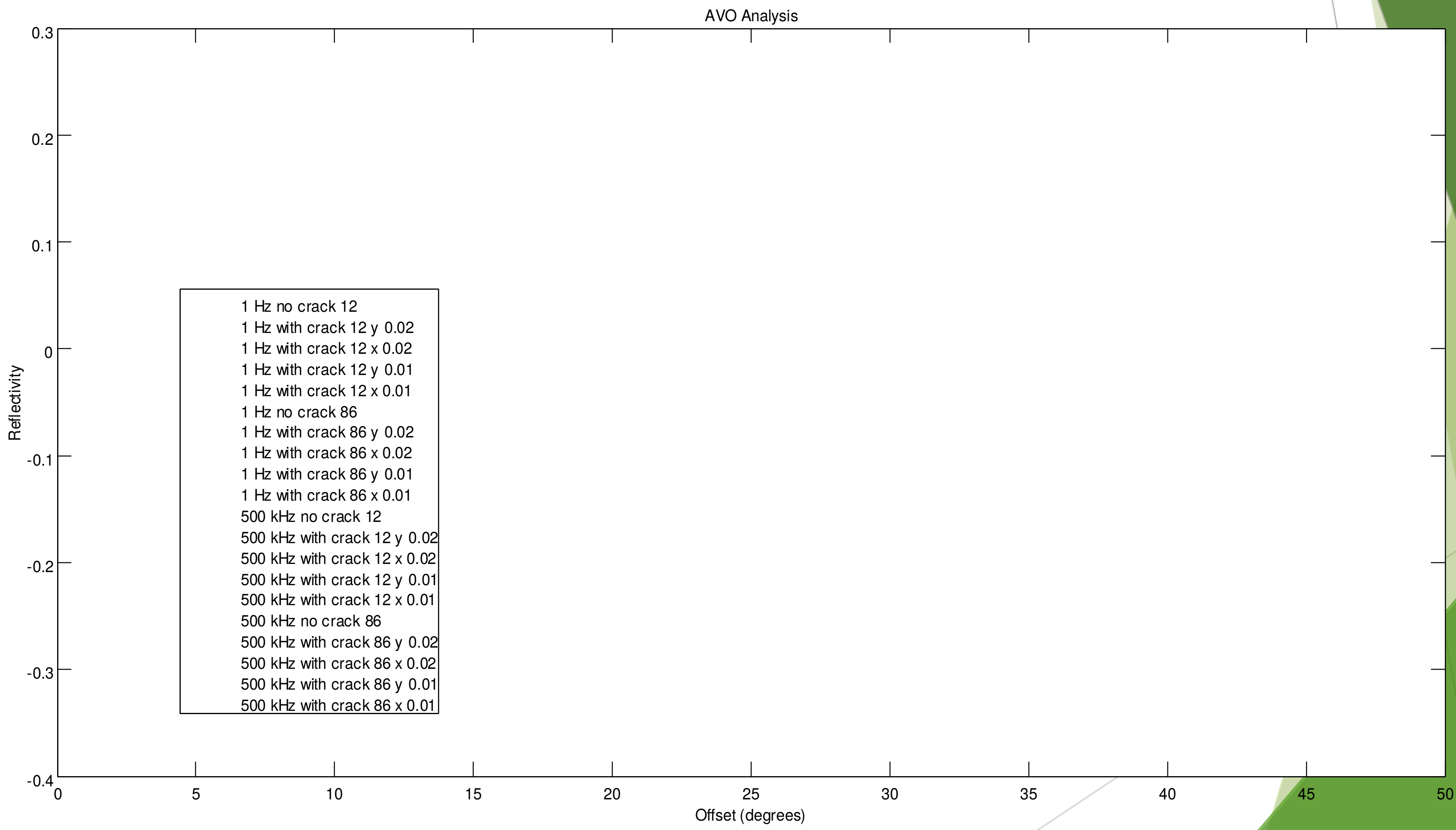
Adding vertical cracks to 1 Hz, S=12% & 86%



Varying crack density (1 Hz, S=12%,86%)



Adding 500 kHz



Conclusion

- Sensitivity to saturation at angles higher than 20
- Higher affect of anisotropy with higher saturation
- Dimming reflectivity with increasing saturation for angles higher than 20
- Lack of saturation trend for low saturations until ~S=55%
- The higher the frequency the brighter the reflectivity at low angles and the dimmer it gets at higher angles
- At higher saturations, larger separations between zero intercepts of the different frequencies
- Small influence of cracks at angles higher than 30

Next

- Include the stress varying data in the analysis after processing
- Plot all the data on intercept-gradient for further analysis

Acknowledgment

- PhD student: Dawid Szewczyk
- Supervisors: Rune Holt / Per Avseth
- Sintef