Critical offset analysis of LoFS data from Valhall

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Motivation

- Less successful time-lapse stories for stiff-rock reservoirs

- Detect small velocity change

Critical offset monitoring

Stiff rock reservoir

↓

High velocity

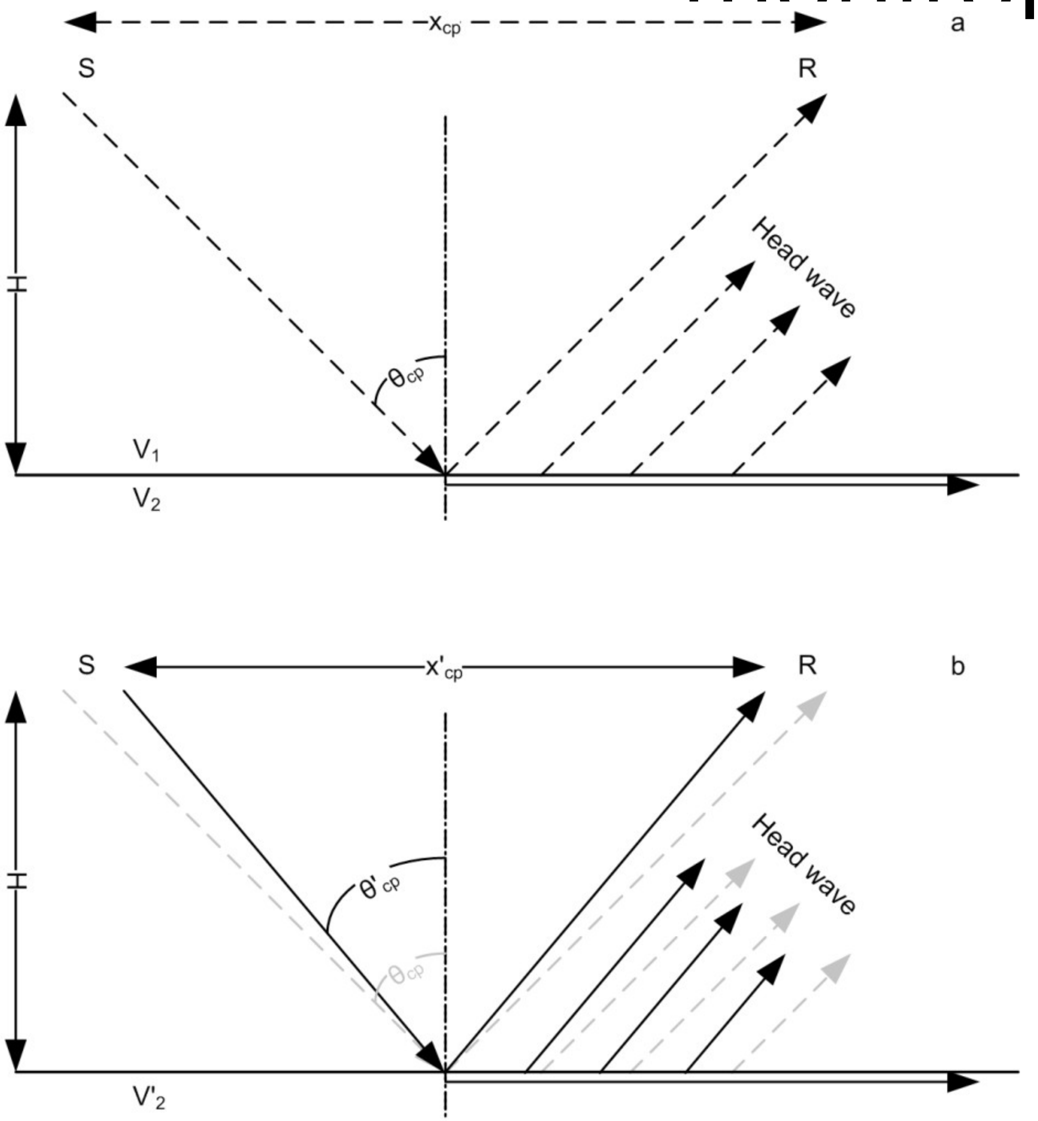
↓

Critical angle

↓

Critical offset

Basic principles of critical offset monitoring



- Critical offset is pure velocity dependent

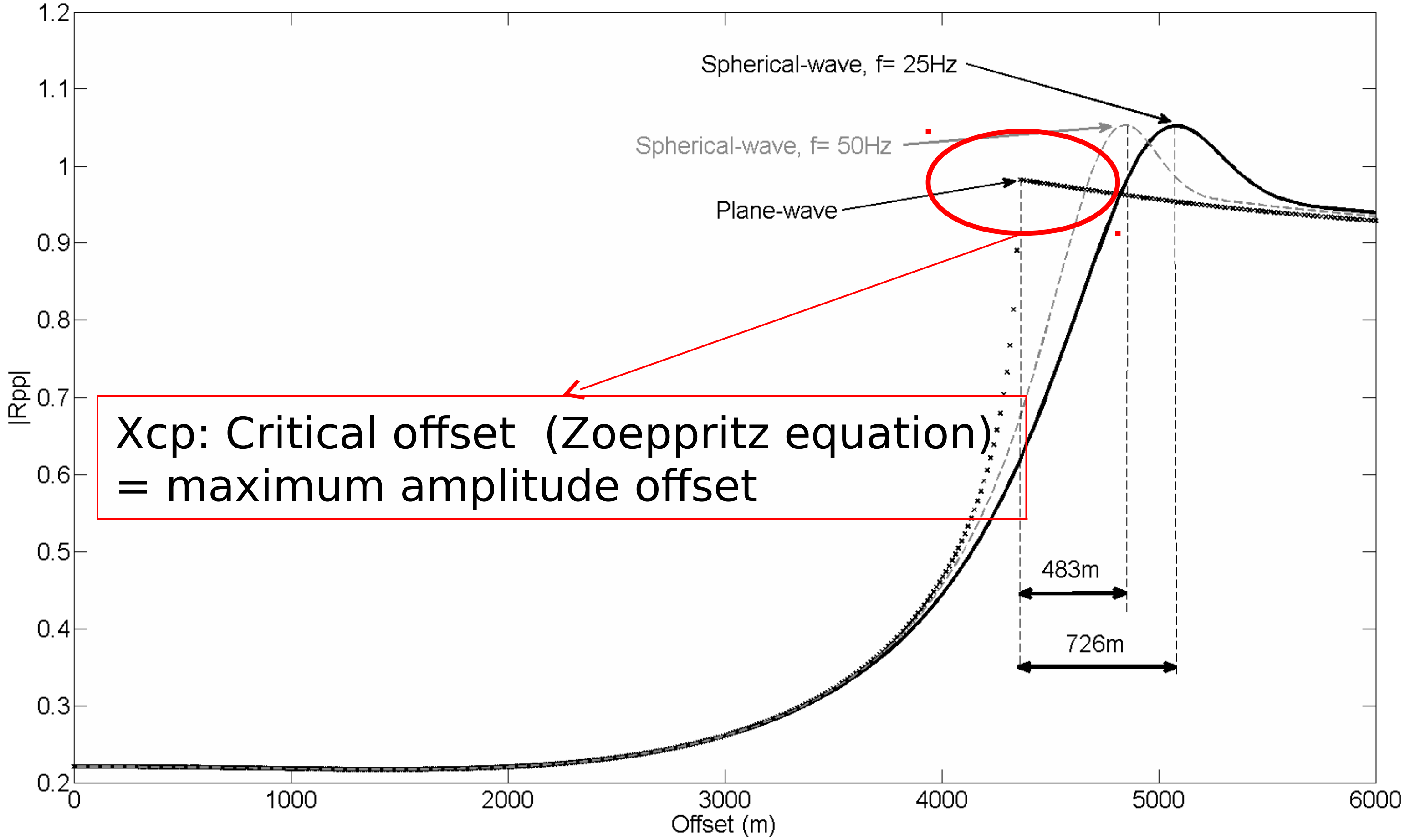
- Requirements:
  - Increasing velocity with depth
  - Acquiring long offset data

$$\frac{\Delta x_{cp}}{x_{cp}} \approx \frac{1}{1-n_p^2}\frac{\Delta n_p}{n_p}$$

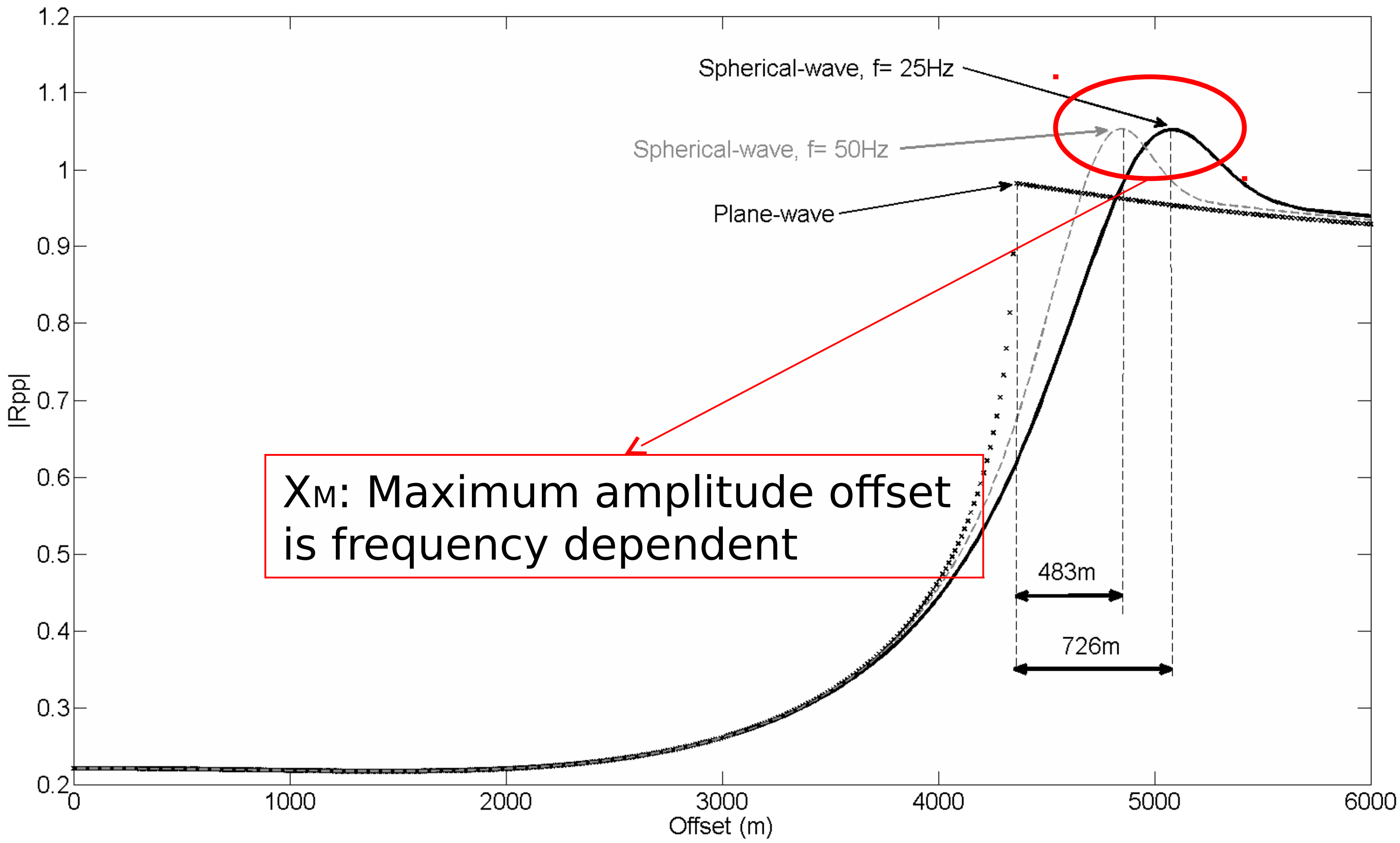
When $\Delta V_1=0$

$$\frac{\Delta V_2}{V_2} \approx -\left(1-n_p^2\right)\frac{\Delta x_{cp}}{x_{cp}}$$

Amplitude change at critical offset

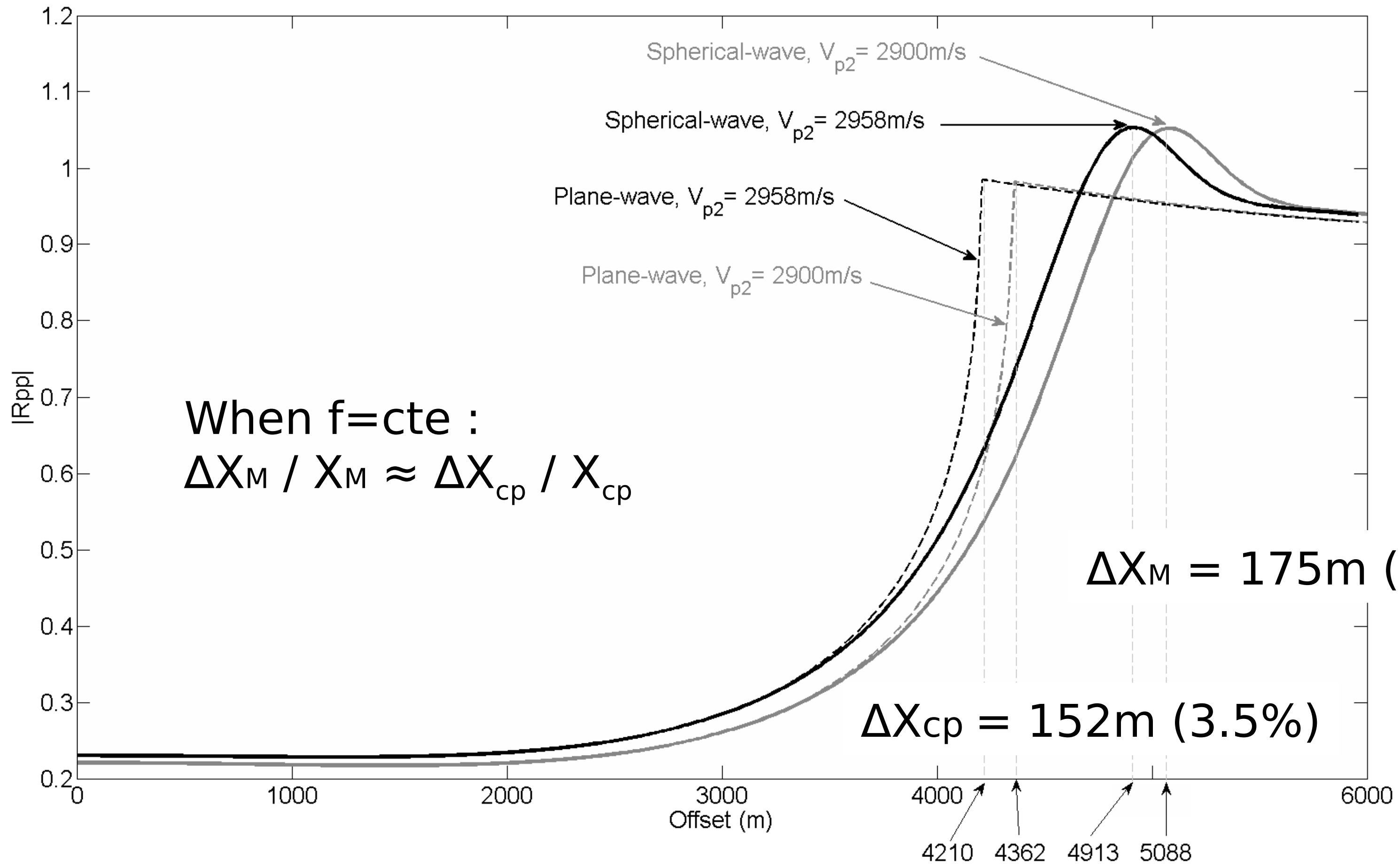


Amplitude change at critical offset



Maximum amplitude offset is easier to detect

Time-lapse properties of X_M



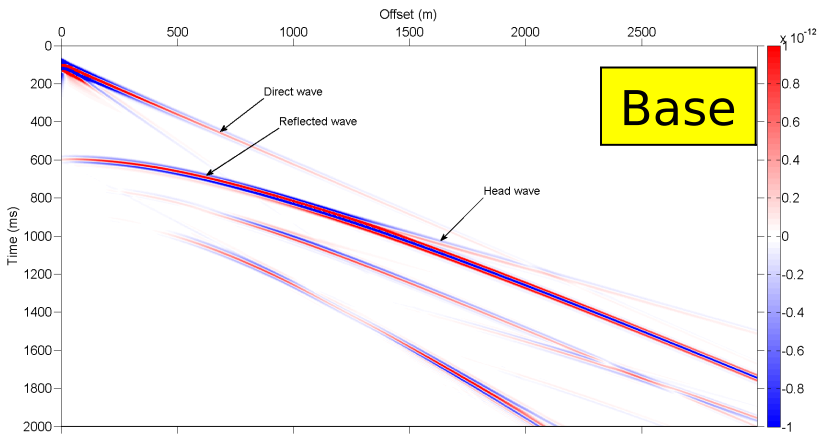
When f=cte :
$\Delta X_M / X_M \approx \Delta X_{cp} / X_{cp}$

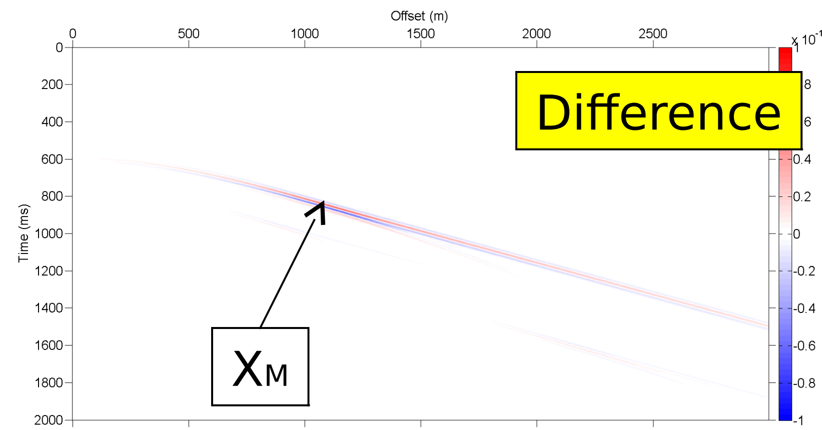
ΔX_M = 175m (3.4%)

ΔX_{cp} = 152m (3.5%)

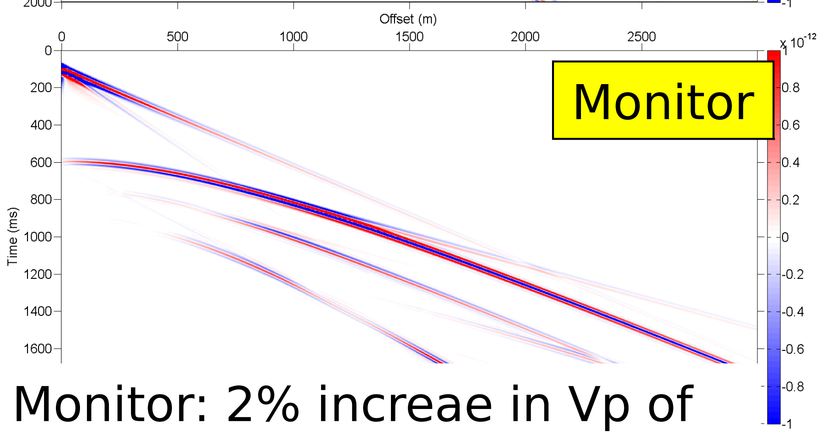
ρ

Synthetic modelling



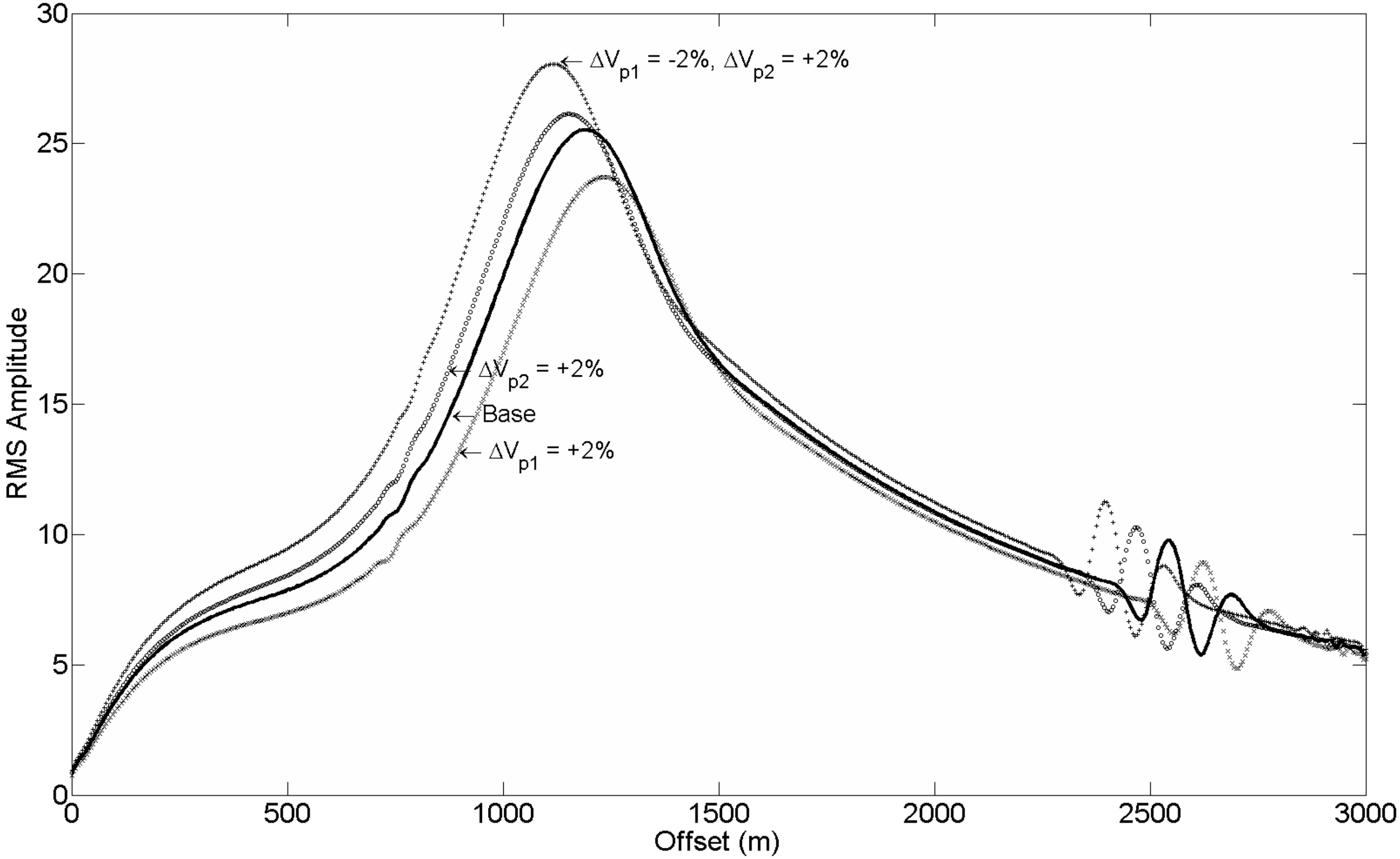


	Thickness (m)	V_p (m/s)	V_s (m/s)	(kg/m^3)
Layer 1	476	1904	1200	1750
Layer 2	725	2900	1500	1800



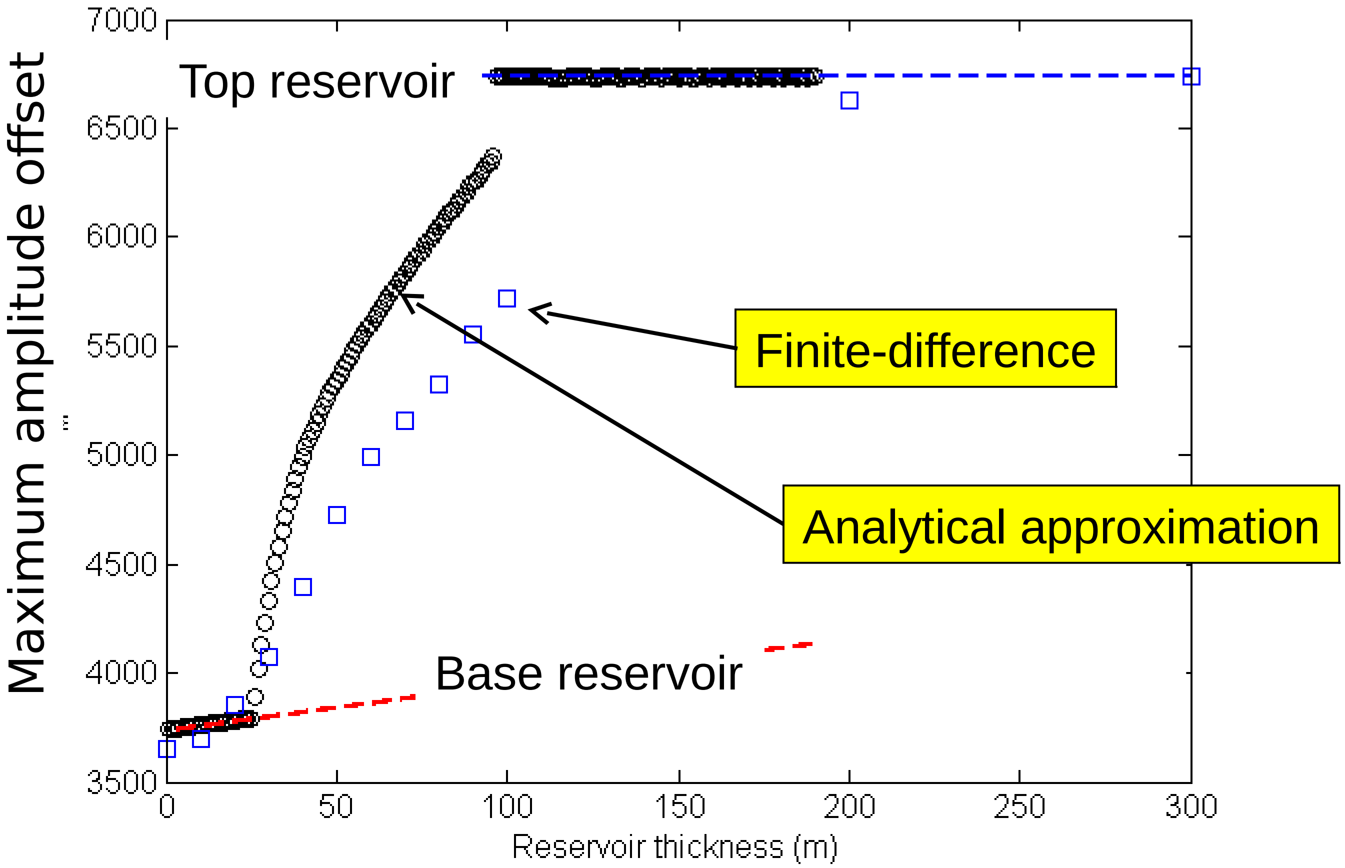
Monitor: 2% increae in Vp of Layer 2

Amplitude analysis of top reservoir

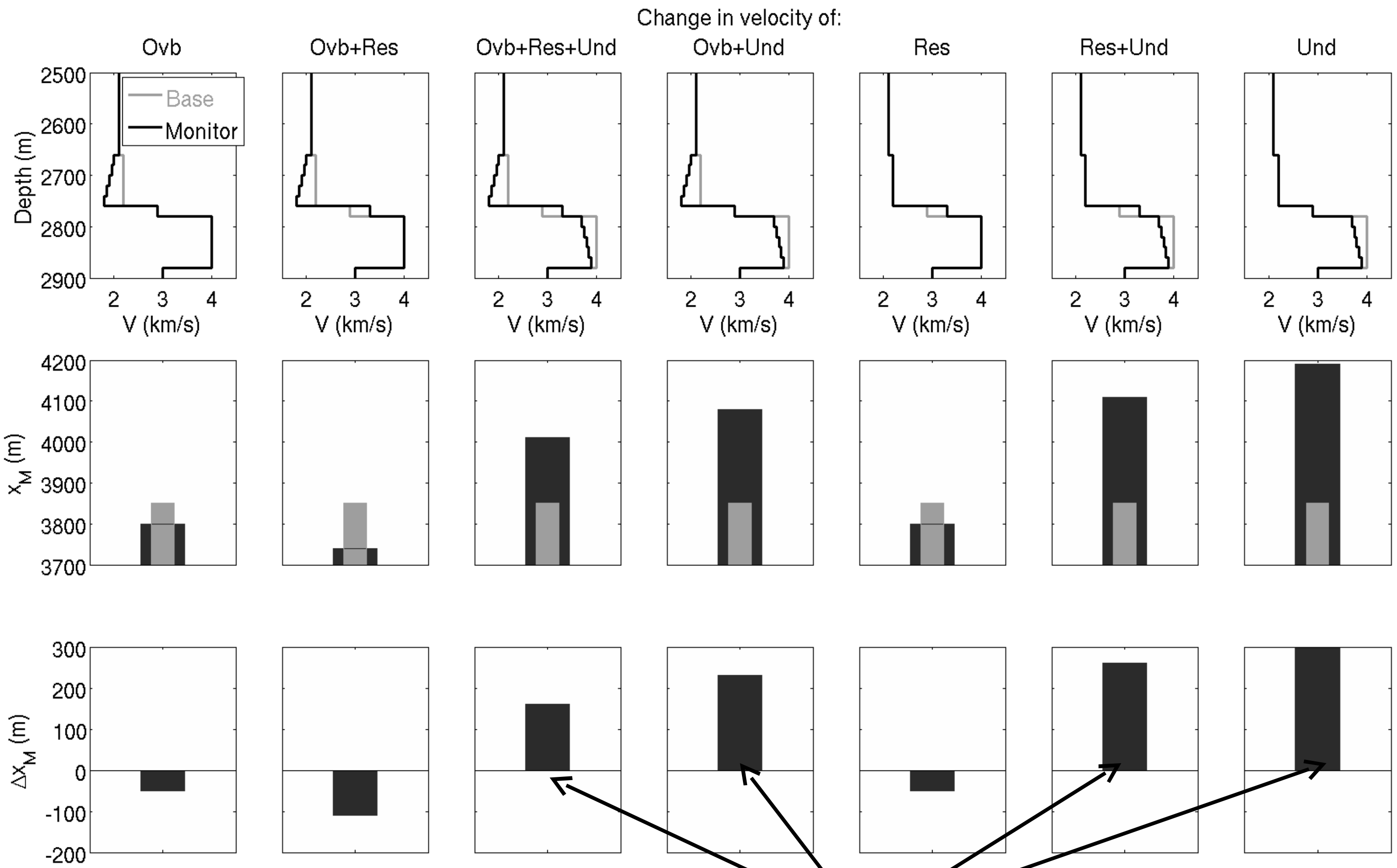


shift in X_M is mainly controlled by P-wave velocity
X_M is practically independent of S-wave velocity and density

Thin layer effect

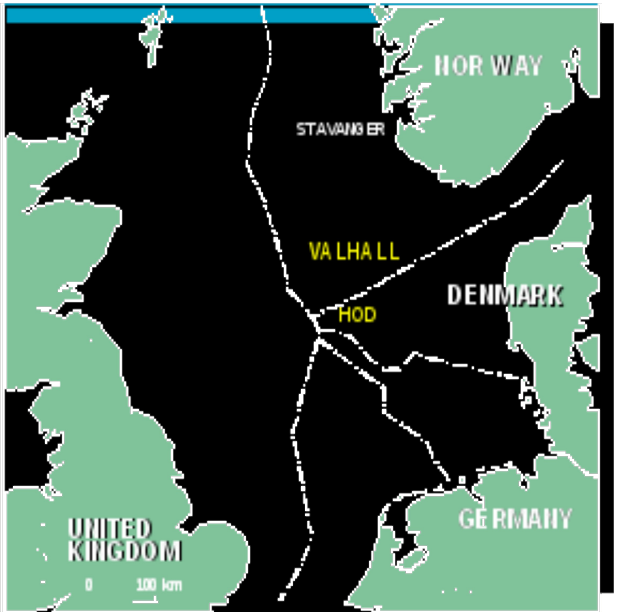


Synthetic result, Valhall representative



Underburden velocity change => $+\Delta X_M$

Valhall LoFS-data



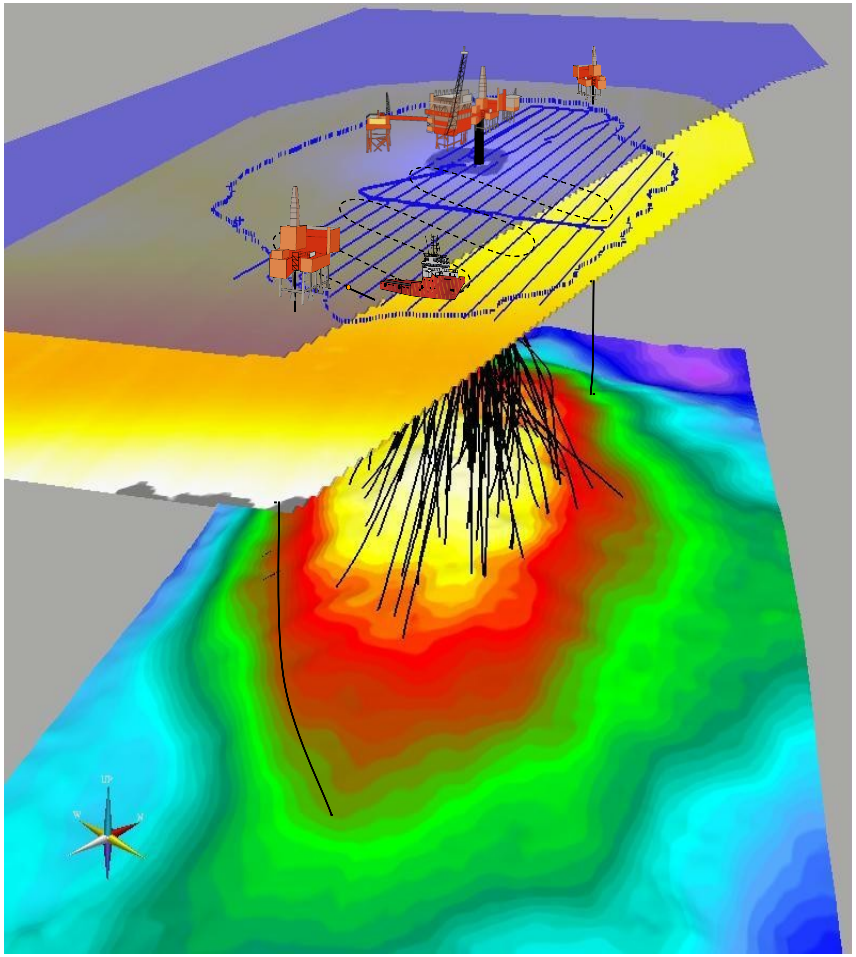
Barkved and Kristiansen 2005

- Chalk reservoir
- High porosity
- 10-60m reservoir thickness

Compacting in the reservoir and stretching in the overburden
Reservoir compacts (~8 m)
Seafloor subside (~5m)
full field permanently-installed 4D OBC, LoFS (Life of Field Seismic), in 2003

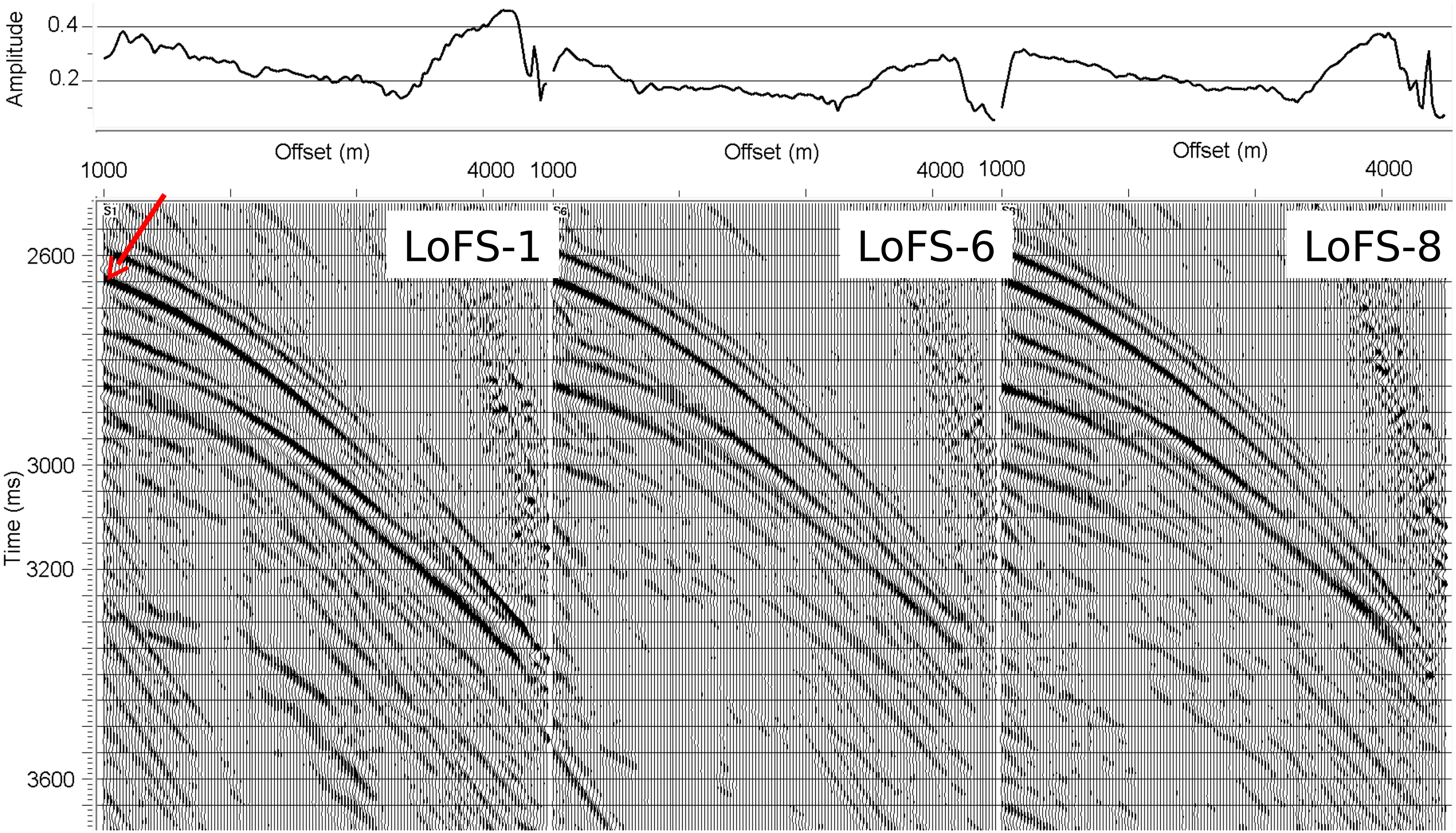
Why LoFS data?

- Velocity increase at top reservoir
- High repeatability
- Max offset = 5000m (over critical offset)
- Overburden noise is not severe



Barkved et al. 2003

Example of CMP amplitude analysis



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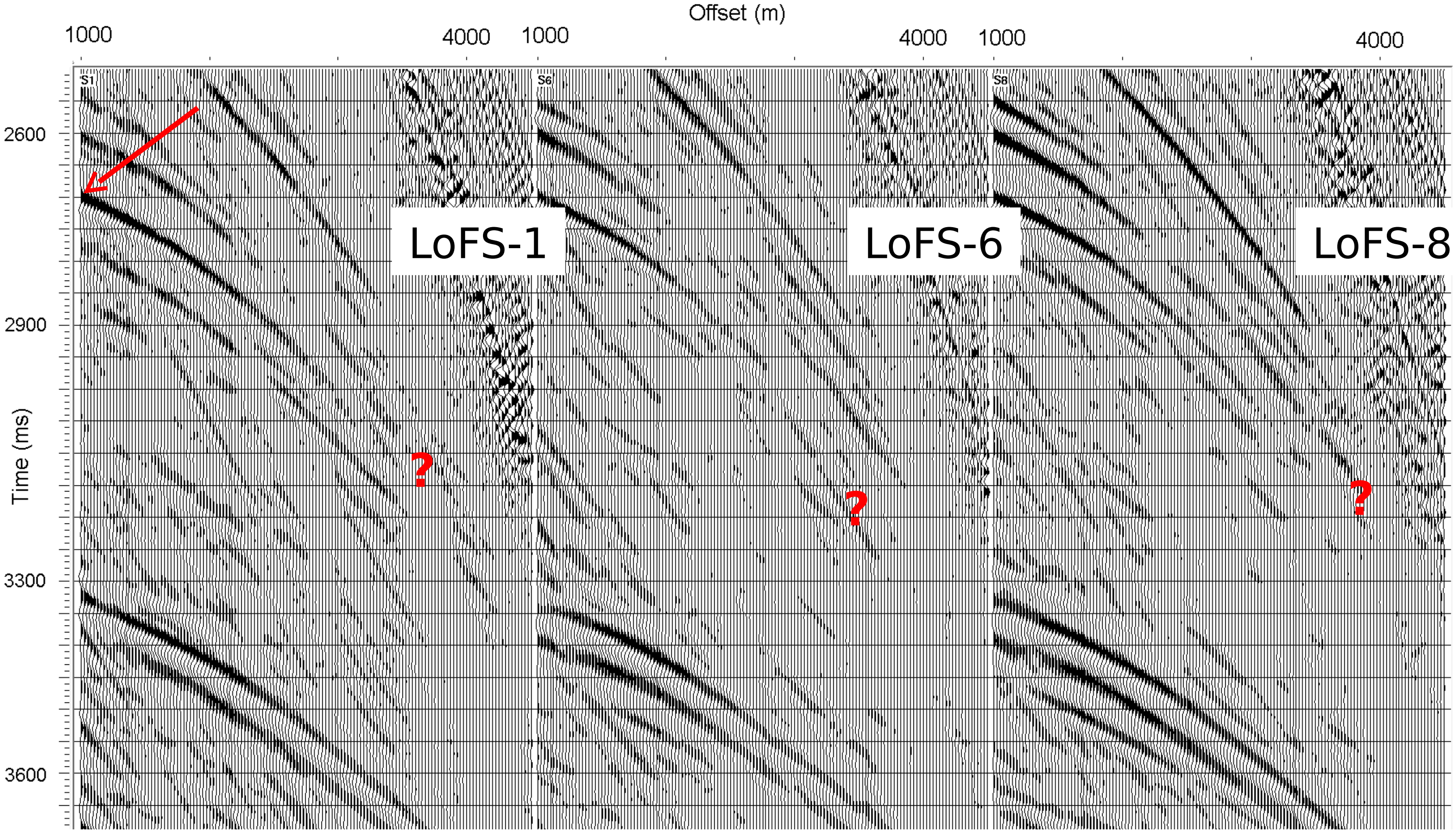
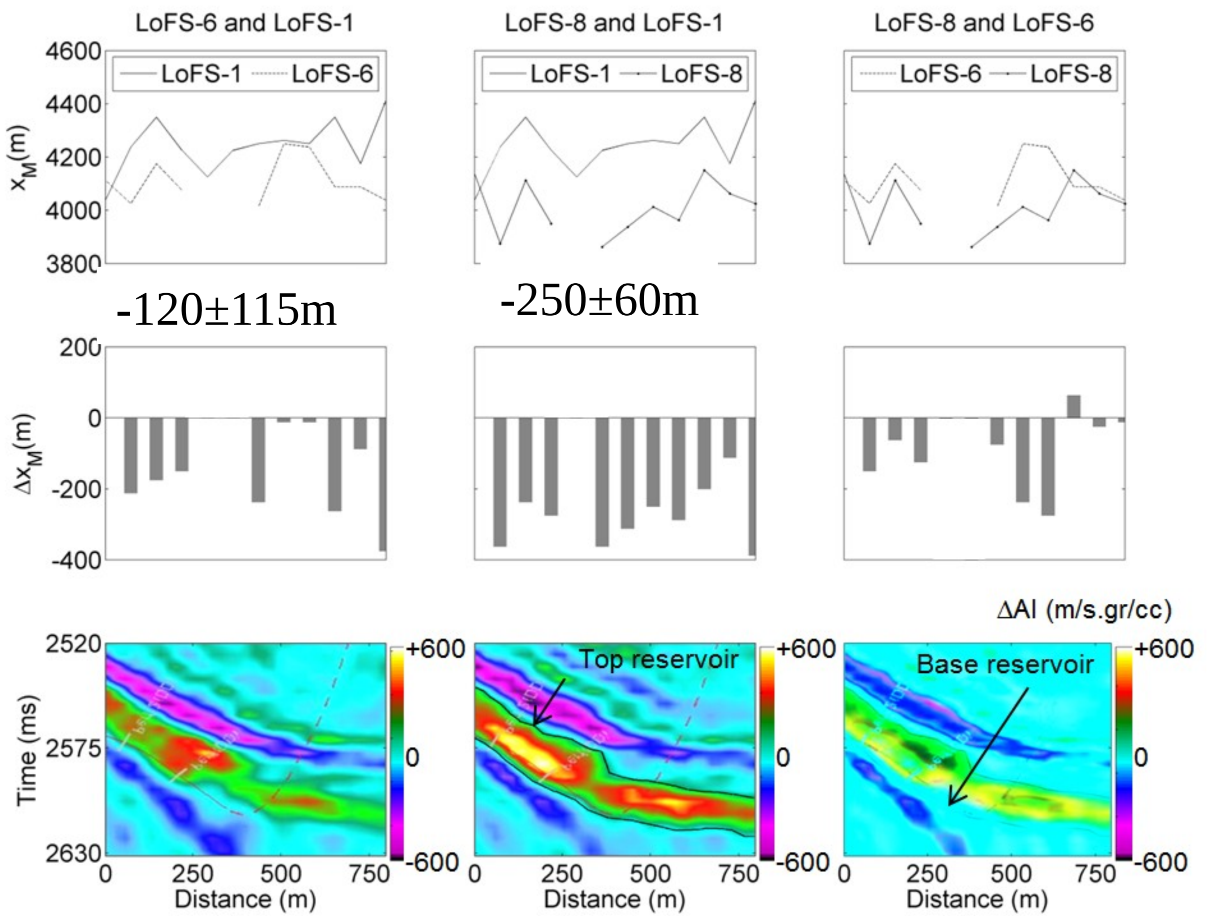


It is not easy to find the maxium amplitude offset in every CMP

Monitoring of X_M



Only negative change in XM =>Negligible change in Underburden?

Inversion for Δx_M

P-wave velocity (m/s):

	LoFS-1	LoFS-6	LoFS-8
Overburden	2200 m/s	-14%	-26%
Reservoir	2900 m/s	+14%	+26%

Overburden thickness undergoing change= 200m
Reservoir thickness =20m

Combining conventional 4D with 4D refraction analysis => density estimation

From conventional 4D: $$\frac{\Delta AI_{\mathrm{Res}}}{AI_{\mathrm{Res}}} \approx 15\%$$

From critical offset 4D: $$\frac{\Delta V_{\mathrm{Res}}}{V_{\mathrm{Res}}} \approx 14\%$$

$$\frac{\Delta \rho_{\mathrm{Res}}}{\rho_{\mathrm{Res}}} = \frac{\Delta AI_{\mathrm{Res}}}{AI_{\mathrm{Res}}} - \frac{\Delta V_{\mathrm{Res}}}{V_{\mathrm{Res}}} \approx 1\%$$

Conclusions

- Method:
  - maximum amplitude offset instead of critical offset monitoring
  - potential to monitor velocity changes in stiff-rock reservoirs
  - pure velocity estimator
  - sensitive to P-wave velocity of reservoir and overburden
  - independent of density and S-wave velocity
  - complementary to conventional 4D
- Maximum amplitude offset is
  - frequency dependent
  - beyond critical offset => long offset acquisition
- In case of a thin layer, underburden velocity becomes important.

Aknowledgement

- Valhall group (BP Norge, Norske Shell, Amerada Hess and Total E&P Norge).
- Research Council of Norway (NFR).
- Børge Arntsen, Alexey Stovas and Amir Ghaderi