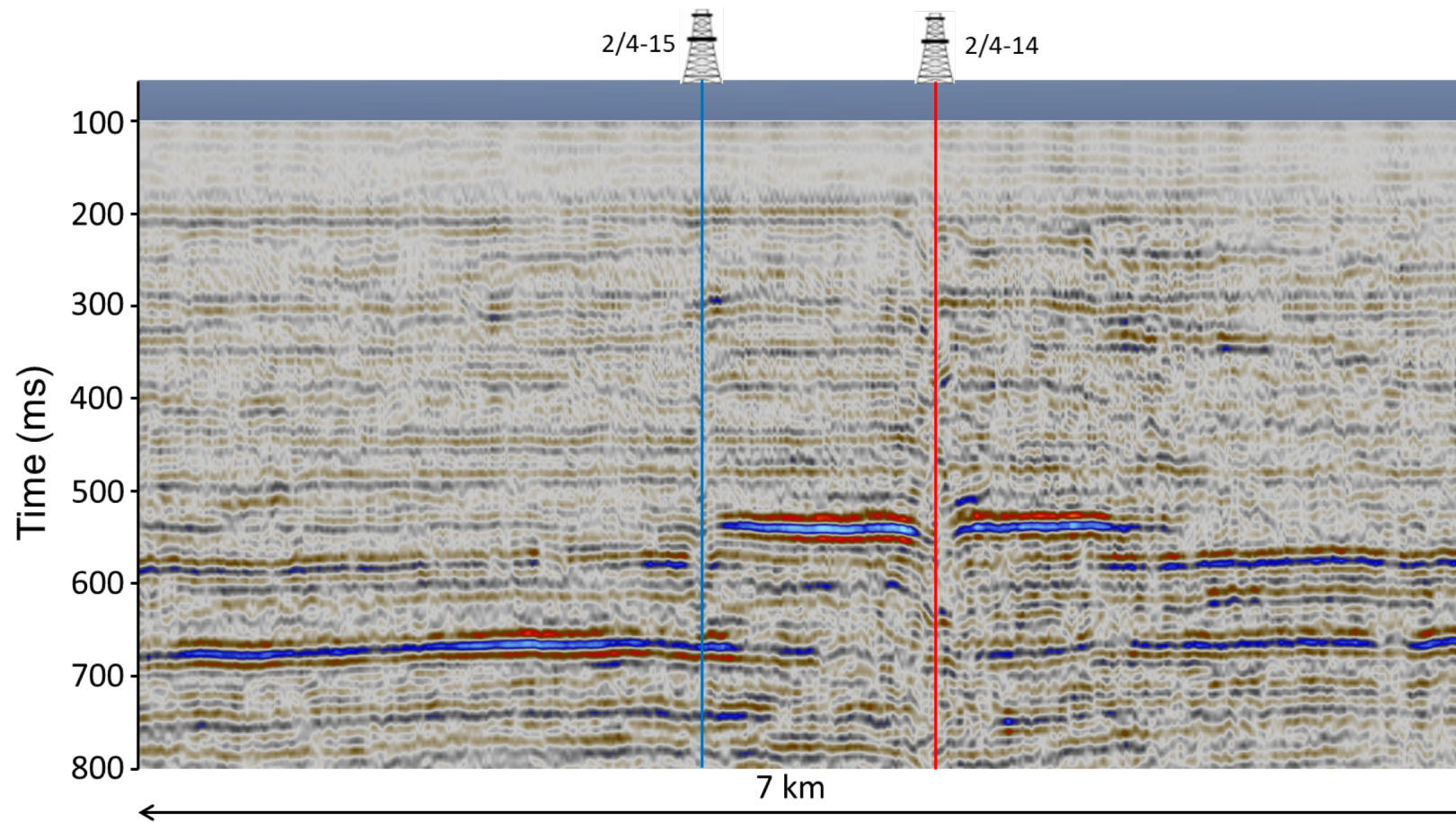# Using diving waves for time-lapse seismic studies and overburden characterization

Bjarte Foseide, NTNU

Izzie Yi Liu, NTNU
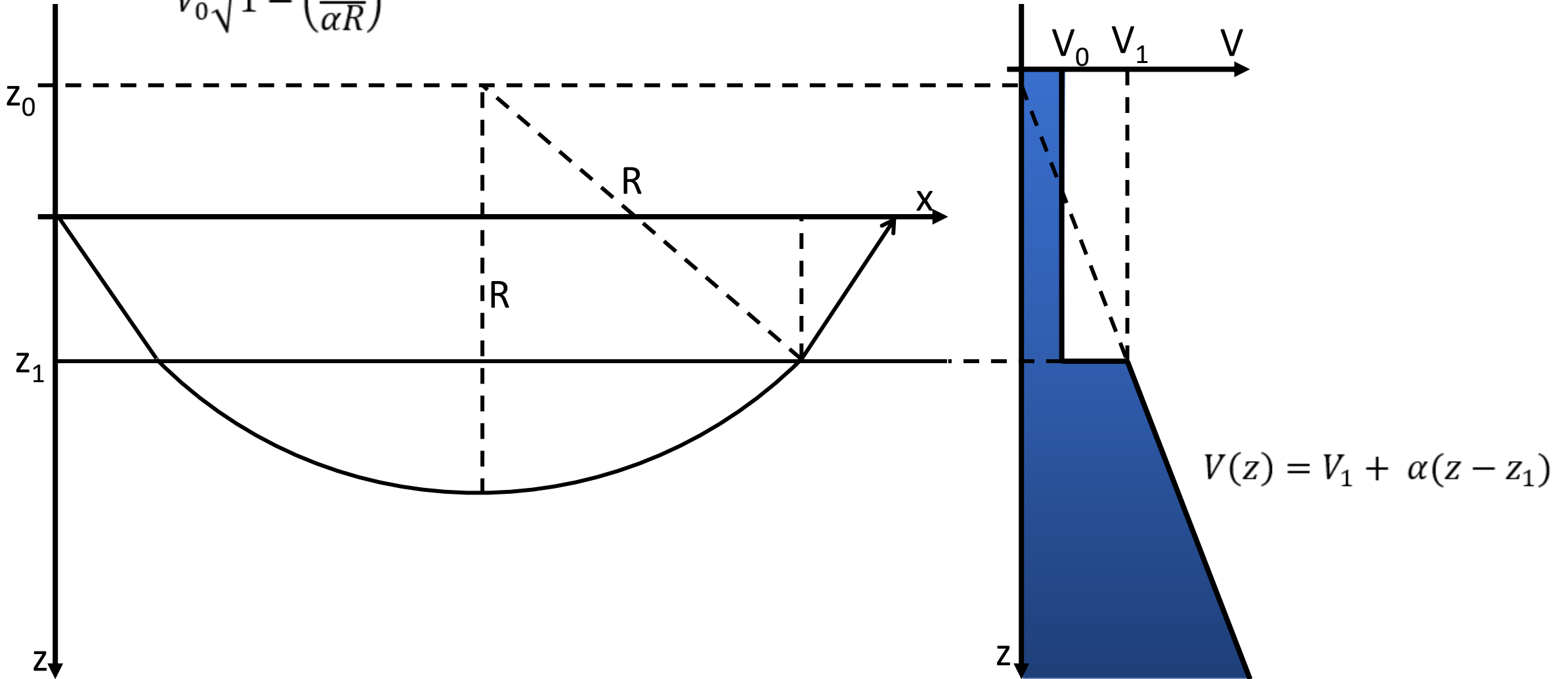
Martin Landrø, NTNU

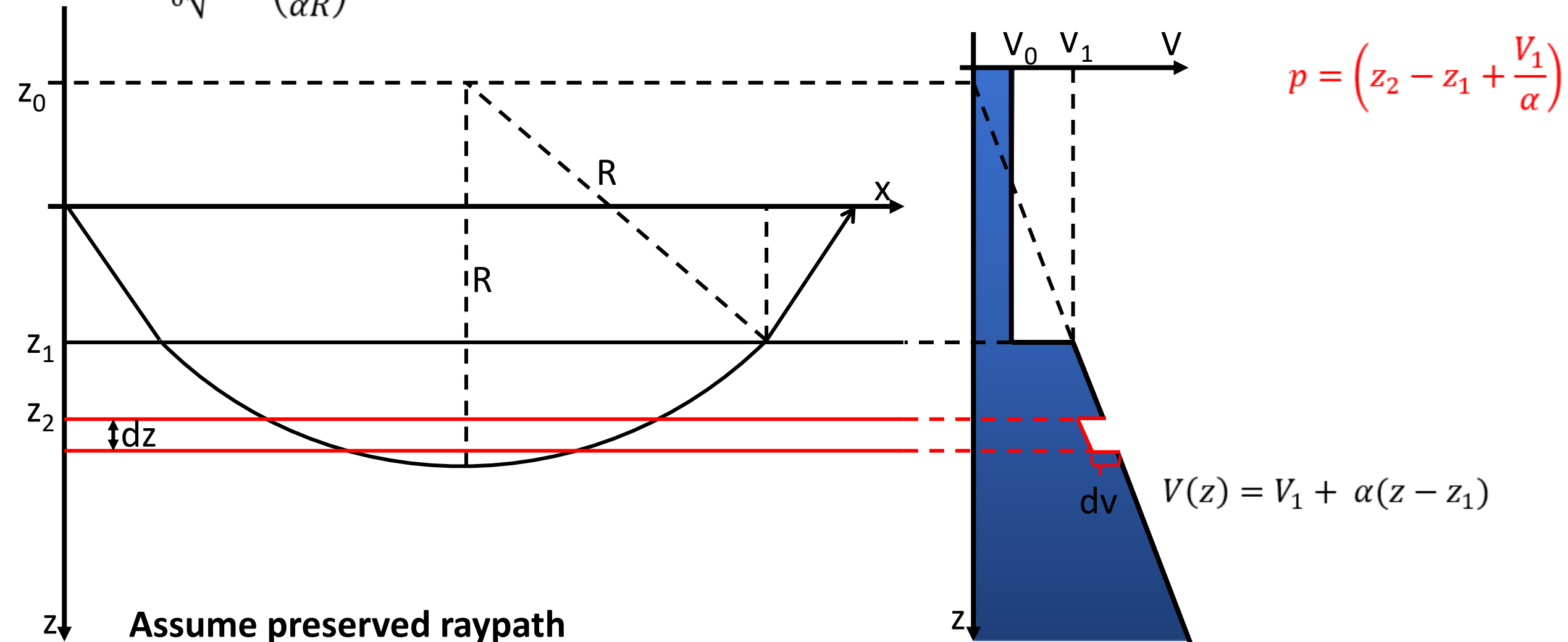# Underground blowout -2/4-14

Diving waves – need velocity gradients

$$T = \frac{2z_1}{V_0\sqrt{1 - \left(\frac{V_0}{\alpha R}\right)^2}} + \frac{2}{\alpha} arccosh\left(\frac{\alpha R}{V_1}\right)$$. Kazei et al. (2013)

$$V(z) = V_1 + \alpha(z - z_1)$$

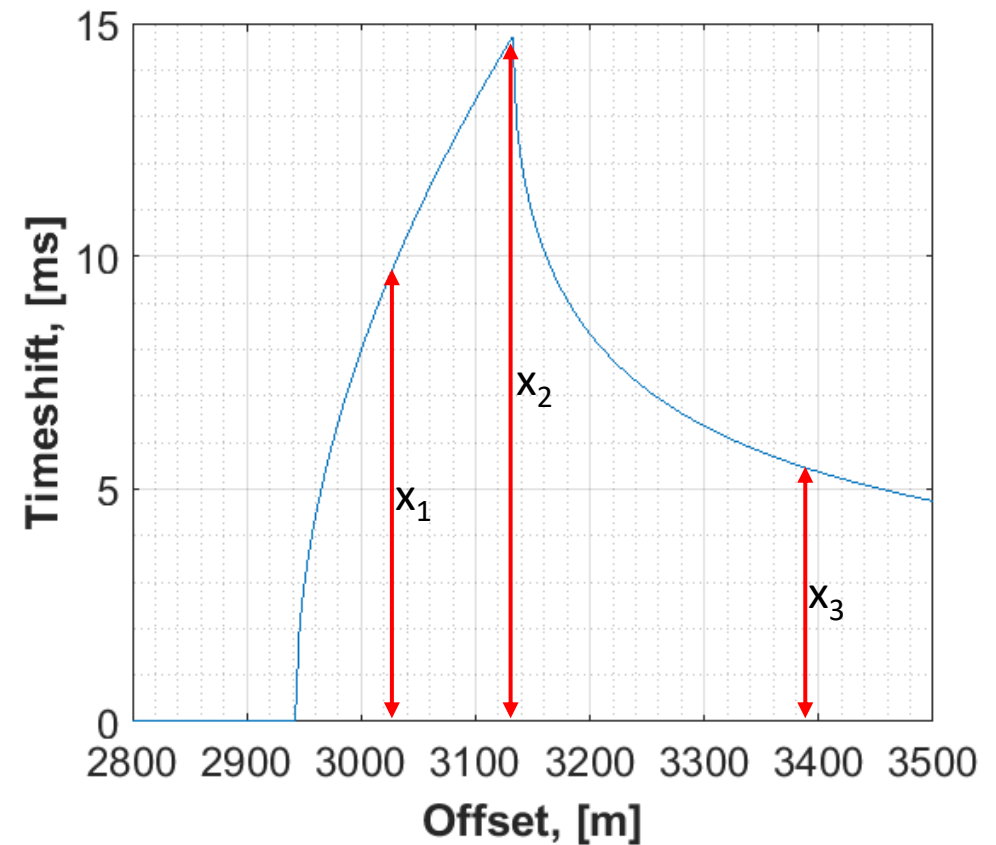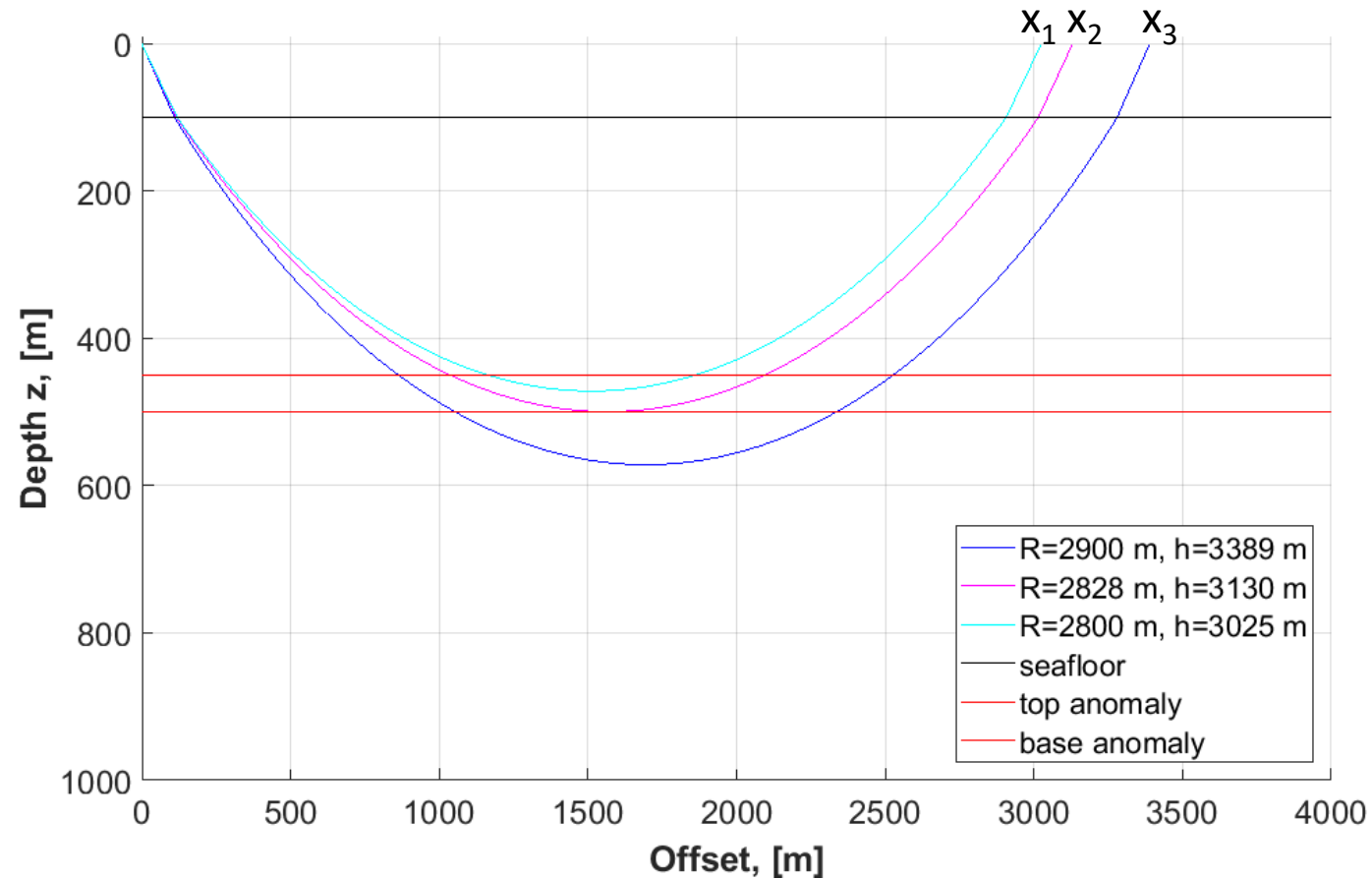# The thin sand layer time-lapse seismic problem

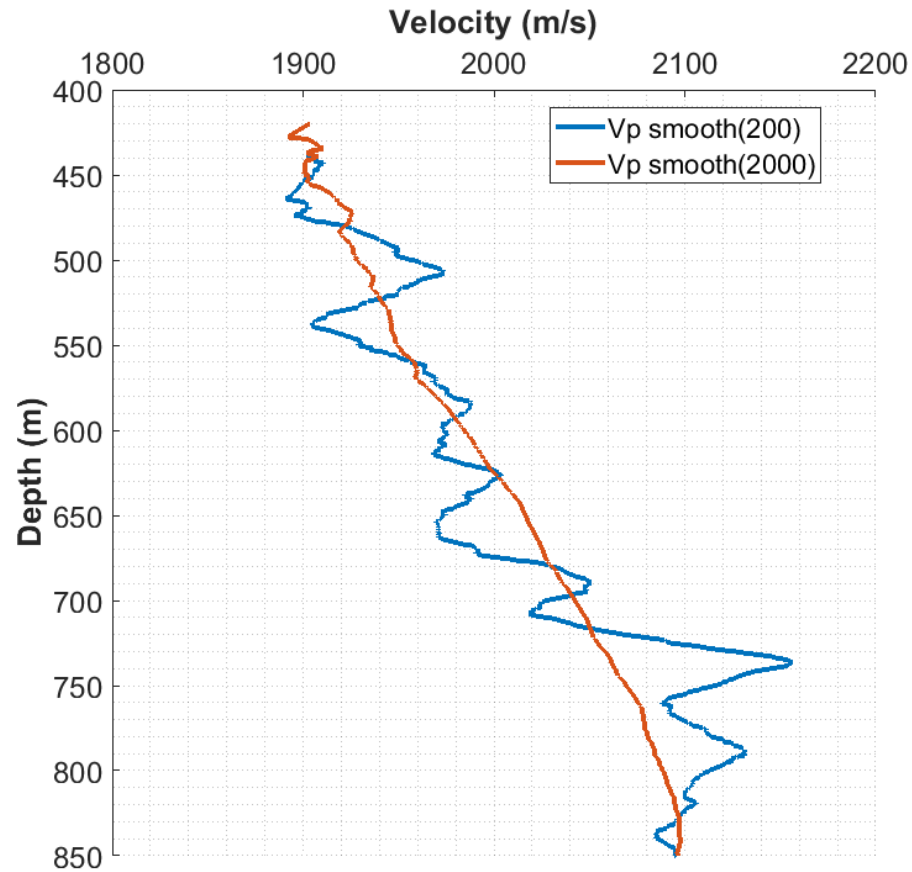$$T = \frac{2z_1}{V_0\sqrt{1-\left(\frac{V_0}{\alpha R}\right)^2}} + \frac{2}{\alpha}arccosh\left(\frac{\alpha R}{V_1}\right) - \frac{2Rdv}{V^2}\left(arccos\left(\frac{p}{R}\right) - arccos\left(\frac{p}{R}+\frac{dz}{R}\right)\right)$$

$$p = \left(z_2 - z_1 + \frac{V_1}{\alpha}\right)$$

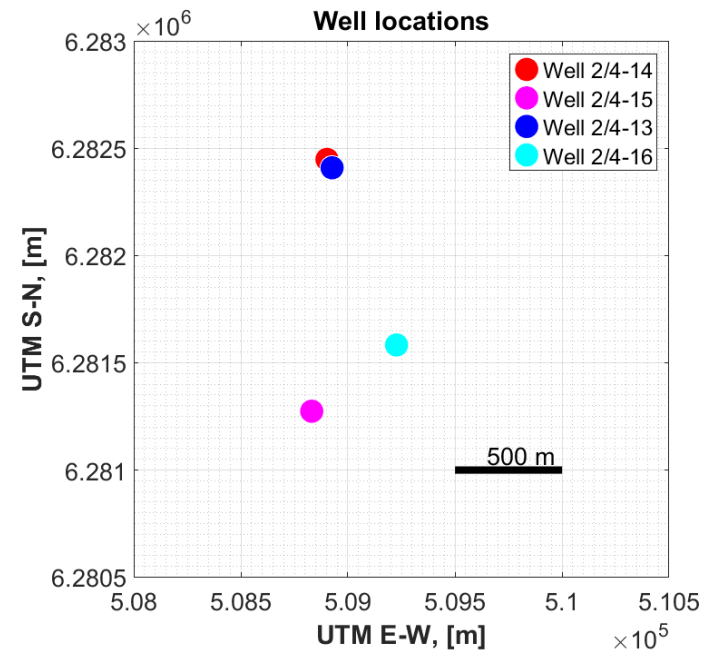$$V(z) = V_1 + \alpha(z - z_1)$$

Assume preserved raypath

Raypath of diving wave at different offsets and the corresponding timeshift
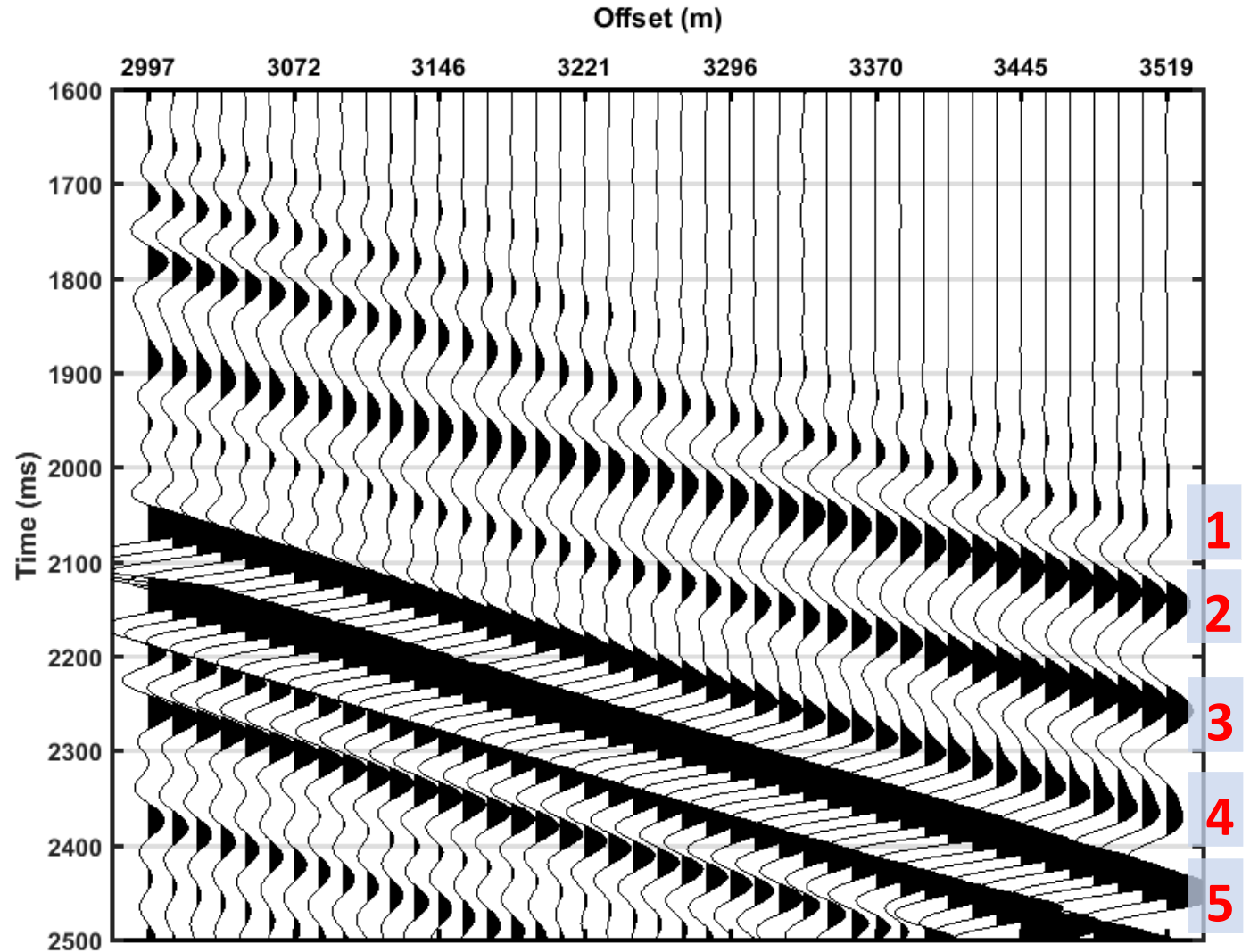
Velocity log from well 2/4-16

- Velocity log smoothed with a moving average.
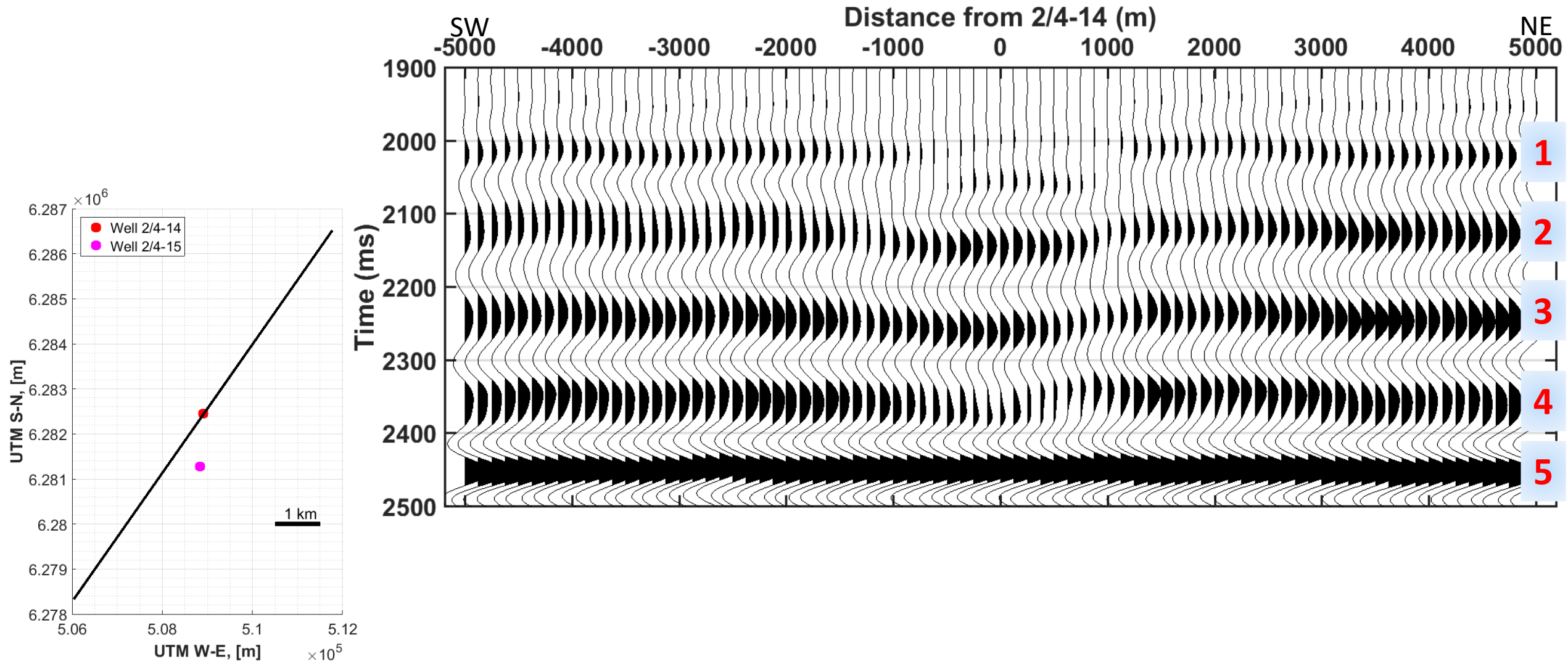- General gradient of 0.6 s^{-1}
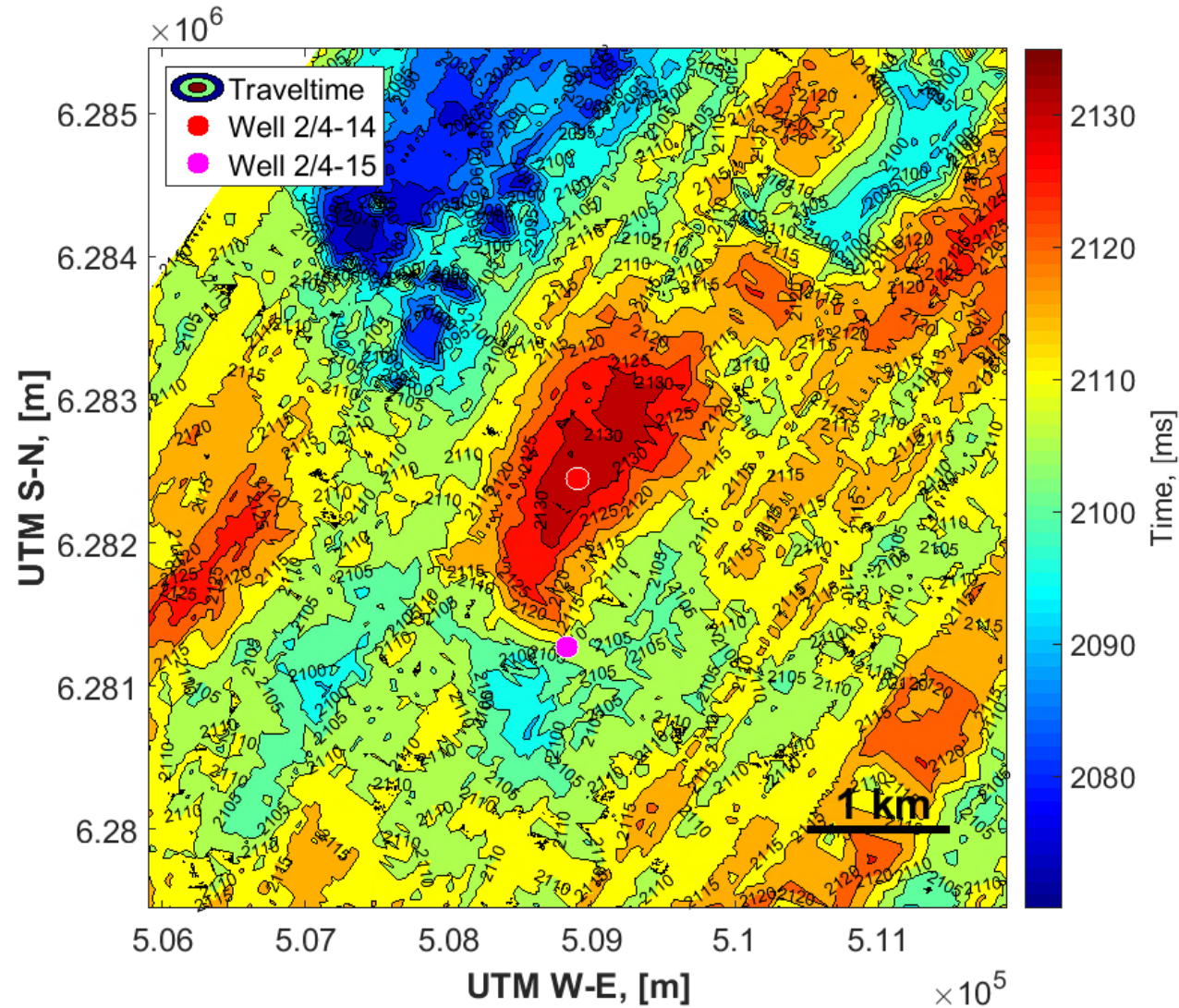
Low-passed shot gather, 2/4-14 field data

Superpositioning of headwave and diving waves + diving wave multiples gives amplitudes increasing with offset *(Kazei et al. 2013)*
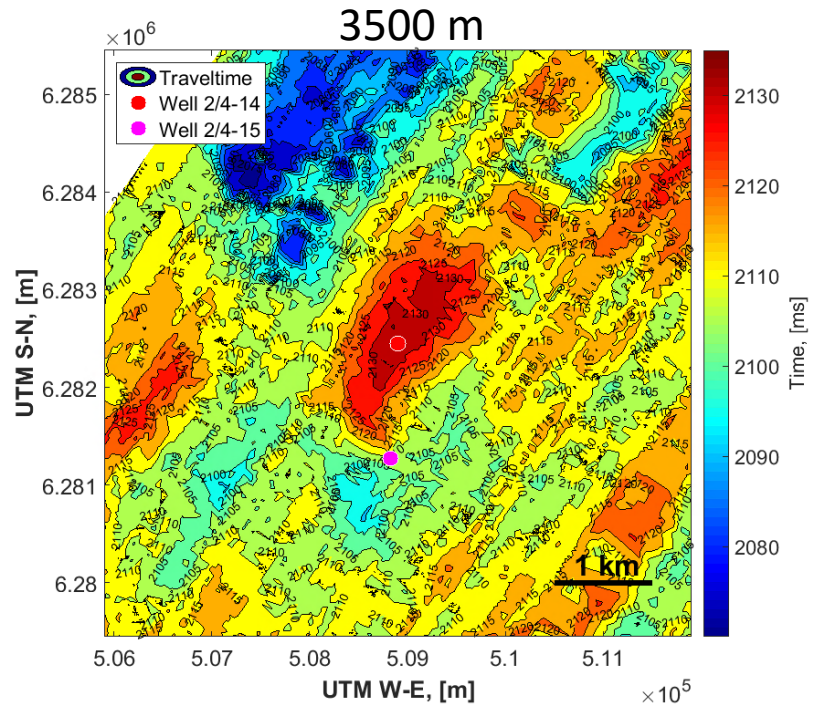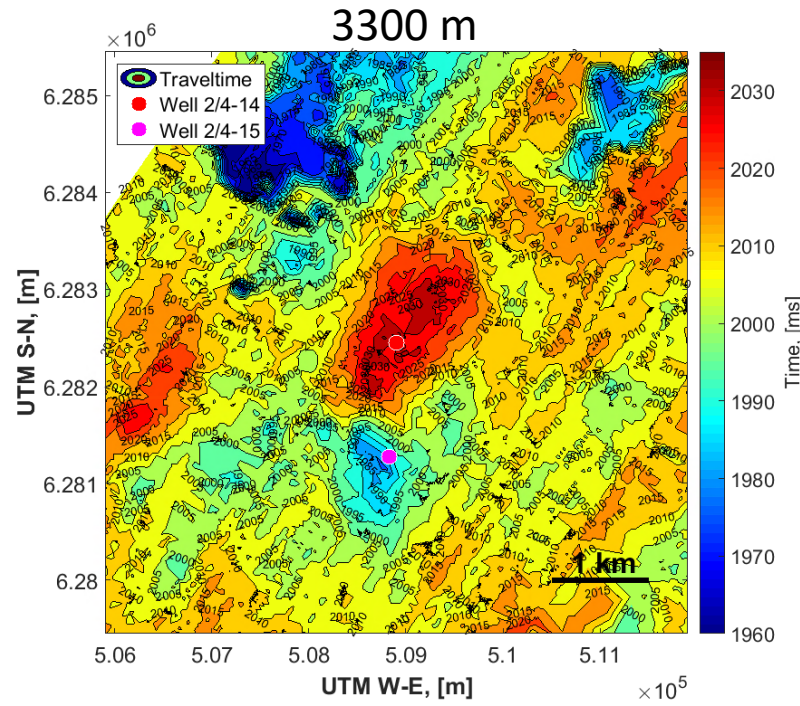
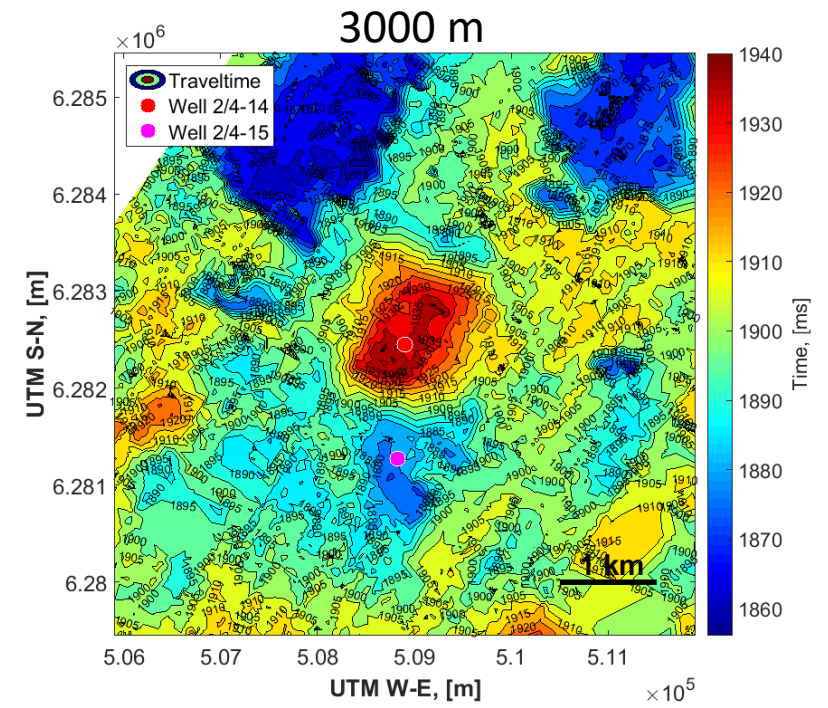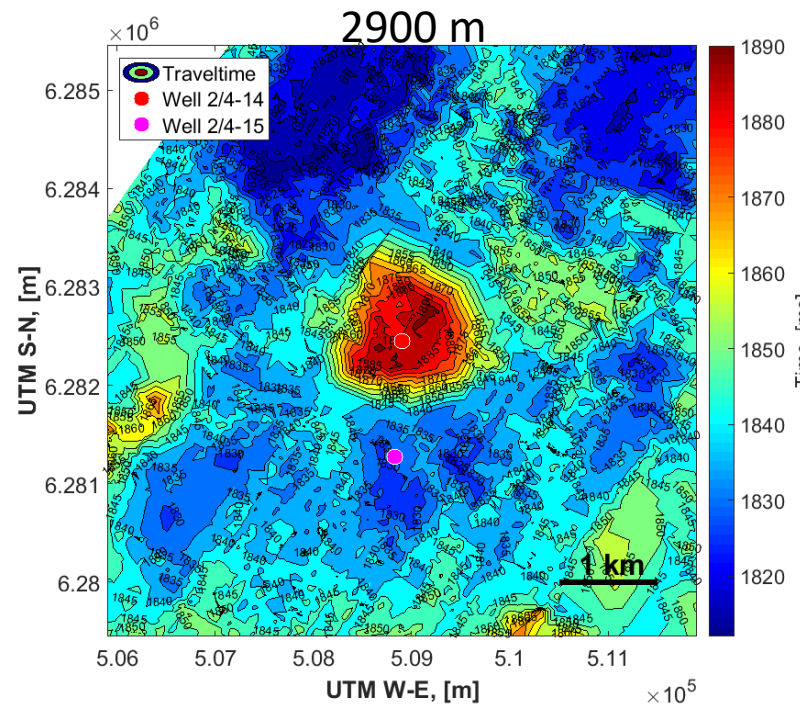# Seismic trace at 3500 m offset

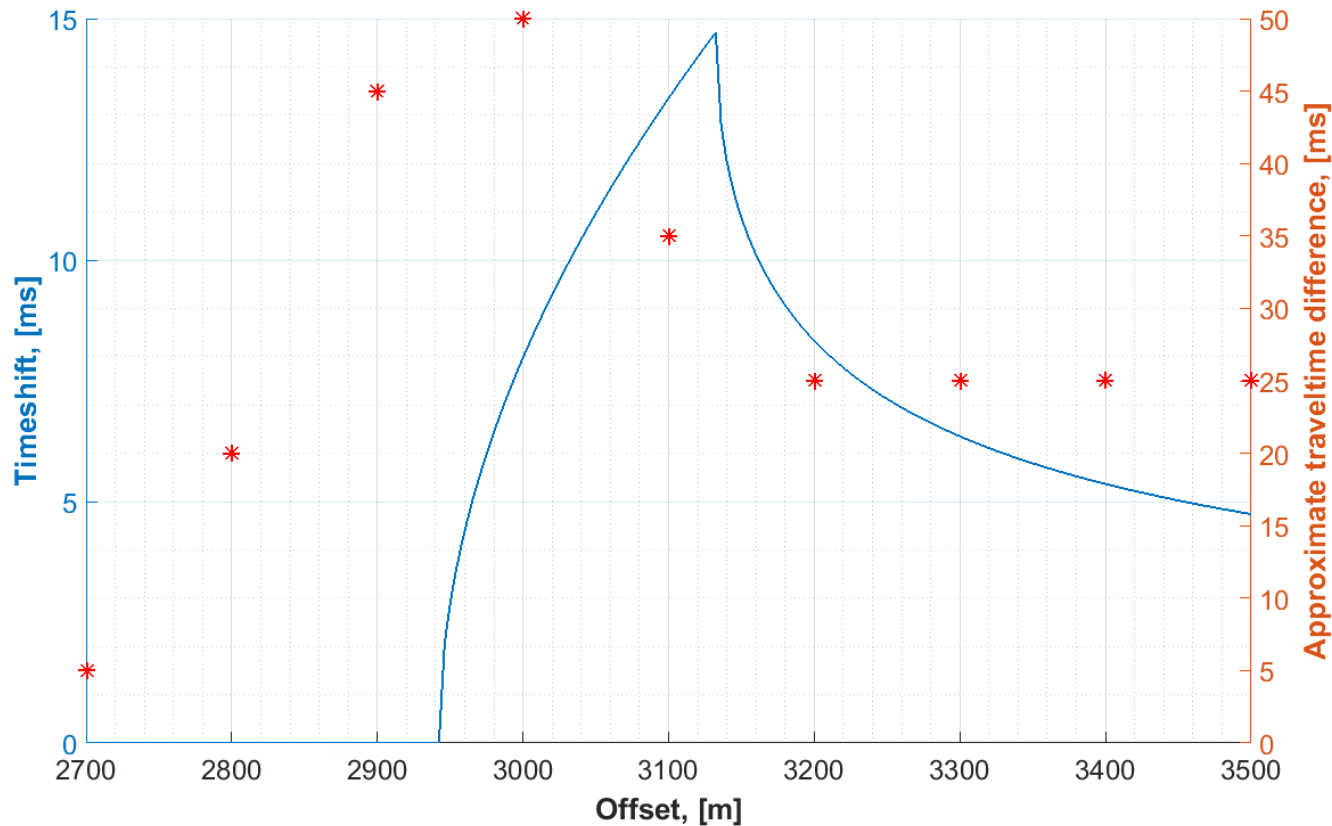# Second event at 3500 meter offset.

Second event at different offsets

- Start as round shape then get more elongated with higher offset.
- General traveltime difference bewteen anomaly centre and surroundings vary.
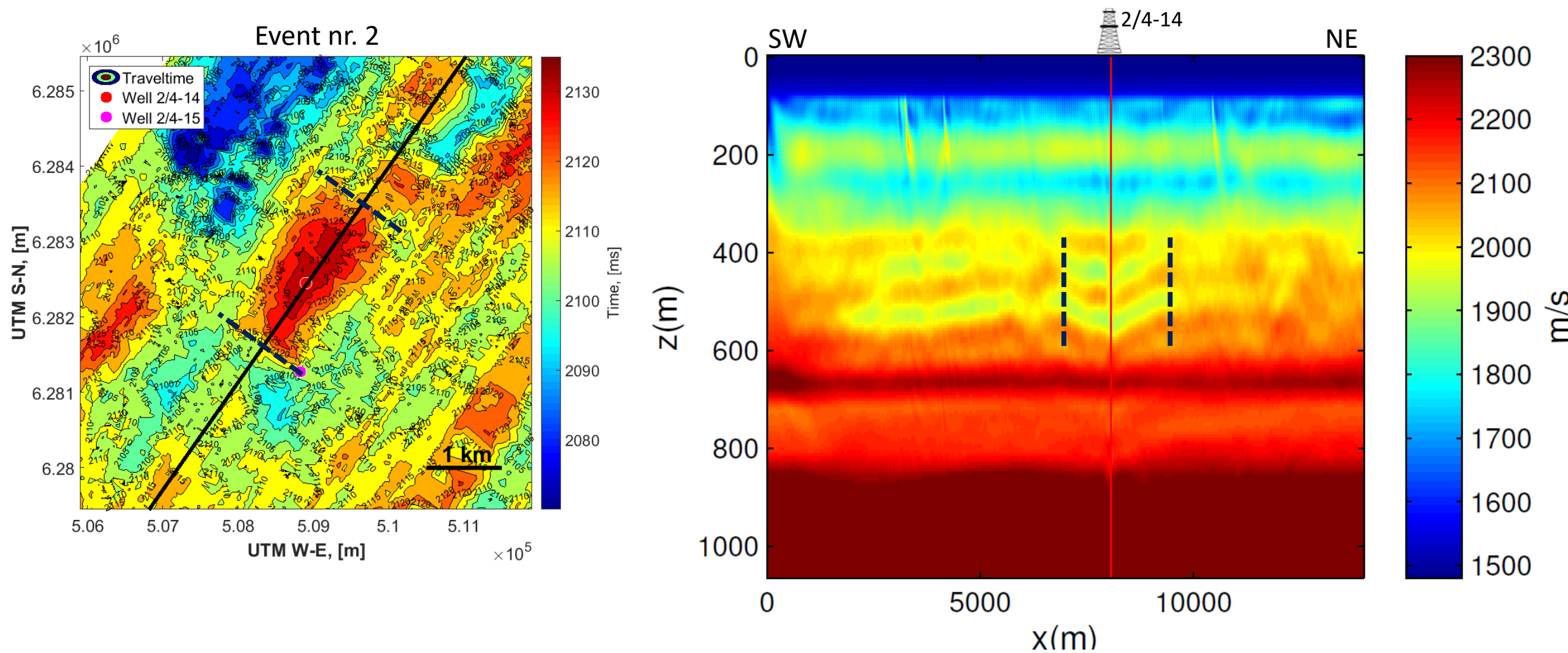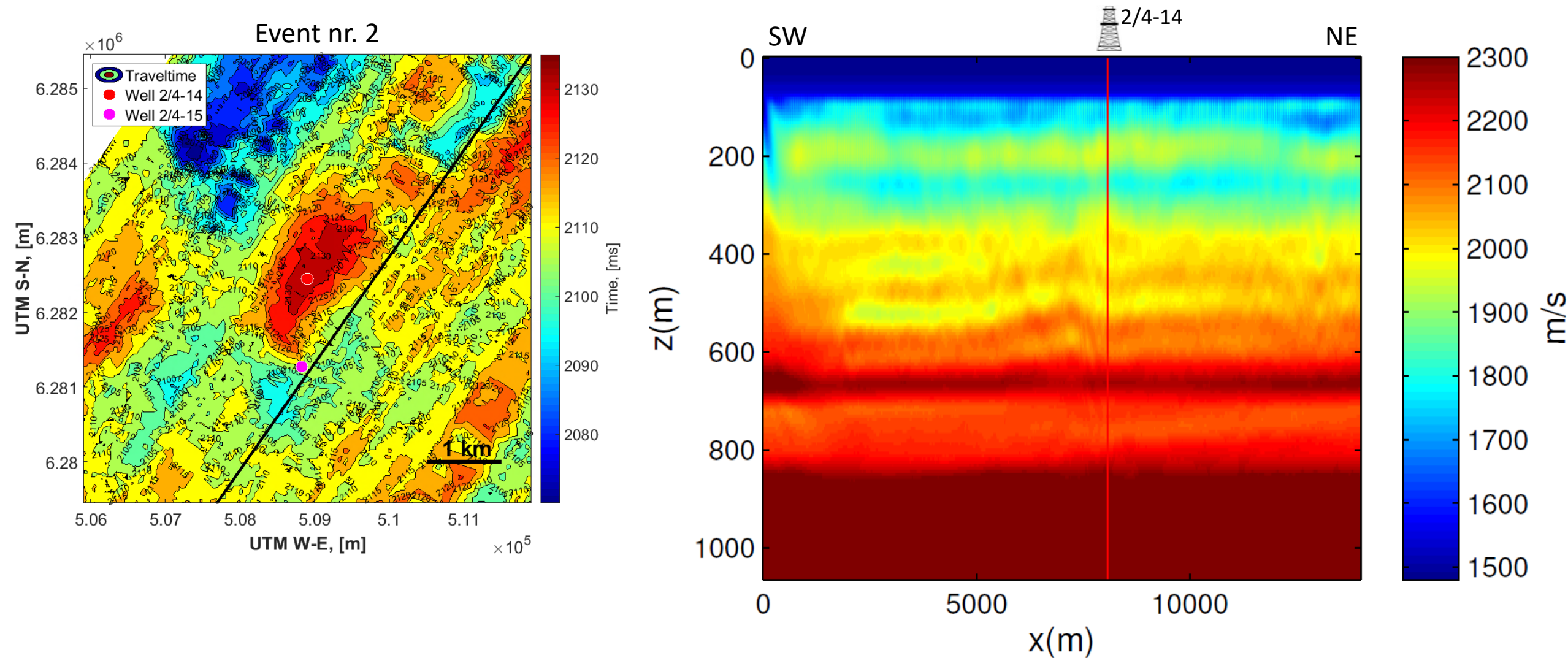
Traveltime differences and timeshifts

- Traveltime differences for second event.

- Similar behaviour with offset.

- Unrealistically high traveltime differences given the assumtions?
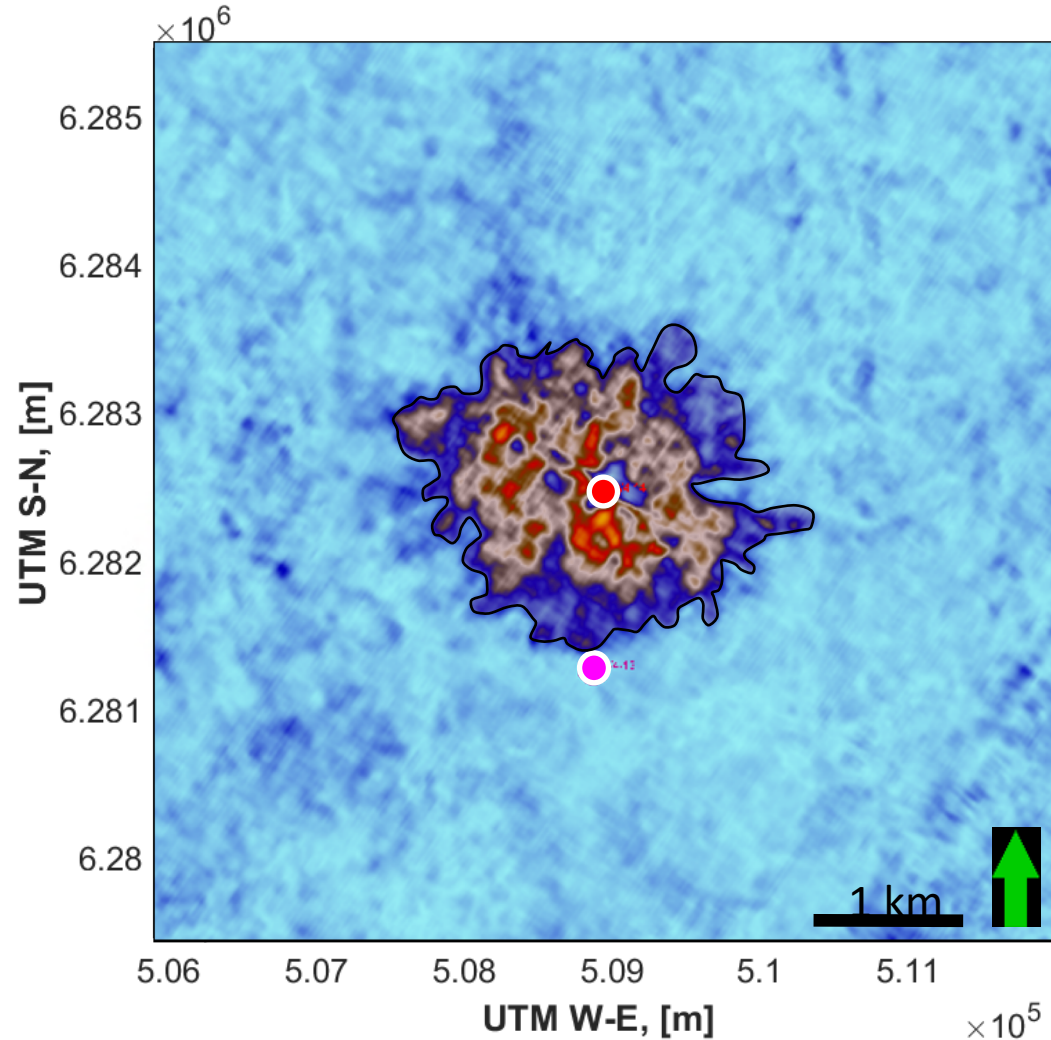
Full Waveform Inversion (preliminary results)

Event nr. 2

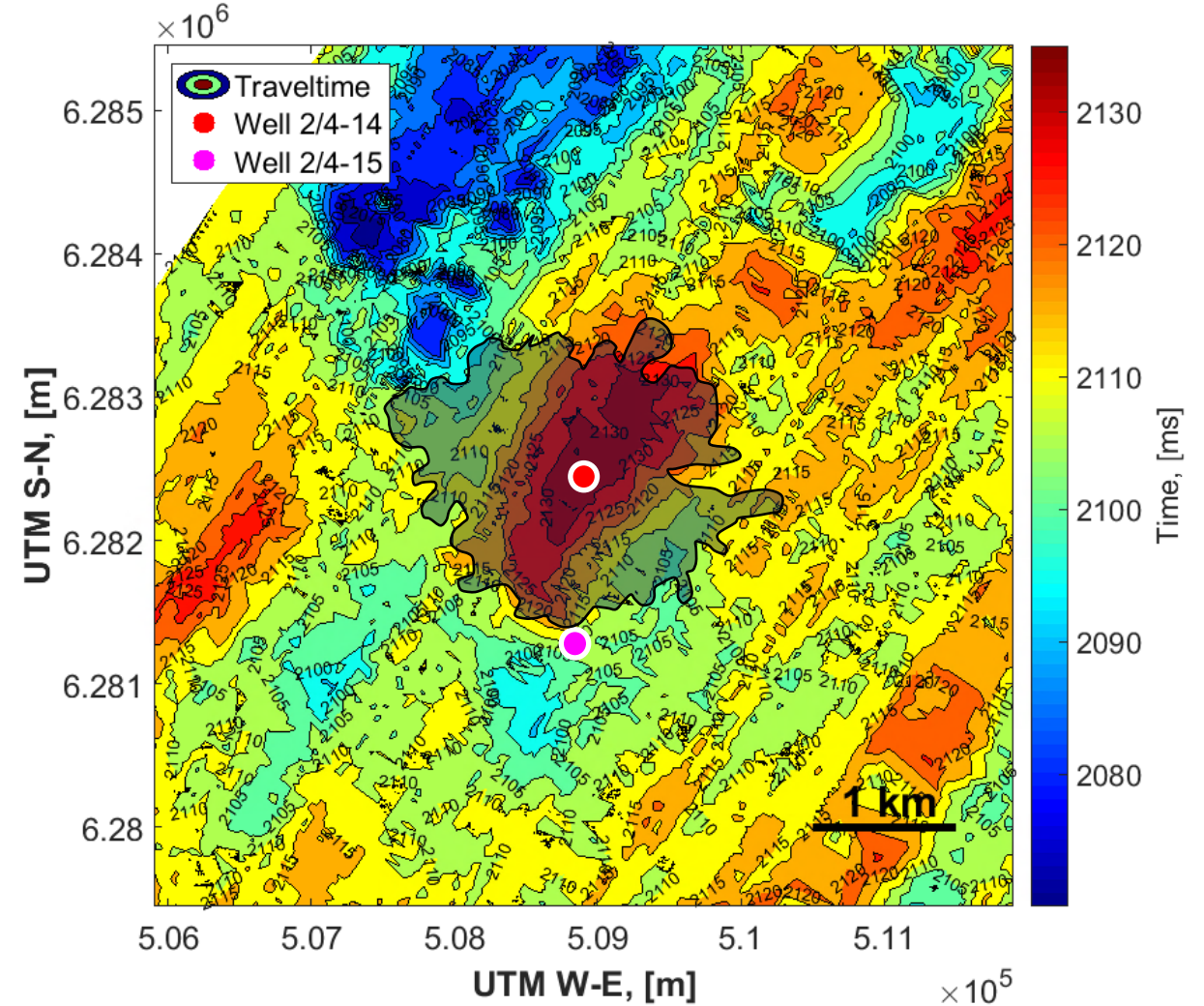# Full Waveform Inversion (perlimenary results)

Comparison with reflection data

RMS amplitude 10ms time-window at 524ms

Event number 2 with reflection data overlay

Summary and further work

- High offset events, i.e. refractions and diving waves, have information that can be used for monitoring shallow velocity anomalies.

- Diving waves has the potential to be used for time-lapse analysis.

- A simple method of mapping traveltimes of high offset events can give indications of velocity anomalies.

- FWI gives depth estimates. Still under progress.

- Finite difference modeling to better understand 3D and 4D behaviour.

Acknowledgements

- Thanks to Statoil for permission to use the 3D data, and CGG for preparing the 3D data

- ROSE project for financial support