Seismic Damage Zones and Their Impact within Thrust and Fault Systems*

David Iacopini[1] and Rob W. H. Butler[1]

Search and Discovery Article #41017 (2012)**
Posted September 17, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

[1]Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom (d.iacopini@abdn.ac.uk)

Abstract

3D reflection seismic data provide interpreters with the ability to map structures and stratigraphic features in 3D detail to a resolution of a few tens of meters over thousands of square kilometers. Despite these great advances, still great uncertainty exists as to the patterns of deformation that develop within deep water submarine thrust belts. While the superficial structure and spacing of major folds may be visible, in most cases the trajectory of thrust faults is highly conjectural. Even where seismic data are excellent, structural interpretations conventionally define thrusts by breaks and apparent offsets of seismic reflectors. Yet this may not be sufficient to identify the position of thrusts, their associated splays and the zones of damaged wall-rocks. Finally, many interpretations rely on theoretical “end-member” behaviors of thrust geometry where concept as strain localization or mechanics of multilayer are for avoided simplicity and outcrop studies indicate that such descriptions are unsatisfactory. In order to fill these gaps and improve the 3D visualization of such deep water structures, in addition to the conventional mapping of reflector amplitudes, we use seismic attributes mapping that uses variations in the amplitude and phase of the seismic wavelet and tracks these through entire data volumes. In general, seismic attributes improve the signal interpretation and are calculated and applied to entire 3D post-stack seismic volumes.

By showing clear 3D seismic examples from deepwater structures and accretionary prism systems we indicate how 3D seismic image processing methods can map strain and damage through amplitude/phase properties of the seismic signal revealing narrow thrusts, plus distributed faulting and strain called "Seismic Damage Zones". Moreover, within accretionary prims seismic image processing fine-tunes the main seismogenetic structures and highlight the main fluid pathways. This is done by quantifying and delineating the short-range anomalies on the intensity of reflector amplitudes and collecting these into "disturbance geobodies”.

This seismic image processing method represents a first efficient step toward a construction of robust techniques to investigate sub-seismic strain and displacement within subsurface geology.

References

Chester, F.M., and J.M. Logan, 1986, Implications for mechanical properties of brittle faults from observations of the Punchbowl fault zone, California, in C. Wang, (ed.), International structure of fault zones: Pure and Applied Geophysics, v. 124/1-2, p. 79-106.

Dutzer, J.F., H. Baseford, and S. Purves, 2010, Investigating fault-sealing potential through fault relative seismic volume analysis, in B.A. Vining, and S.C. Pickering, (eds.), Petroleum geology; from mature basins to new frontiers: Proceedings of the 7th Petroleum Geology Conference, v. 7, p. 509-515.

Faulkner, D.R., A.C. Lewis, and E.H. Rutter, 2003, On the internal structure and mechanics of large strike-slip fault zones: field observations of the Carboneras fault in southeastern Spain: Tectonophysics, v. 367, p. 235-251.

Iacopini, D., and R.W.H. Butler, 2011, Imaging deformation in submarine thrust belts using seismic attributes: Earth and Planetary Science Letters, v. 302/3-4, p. 414-422.

The Virtual Seismic Atlas
"sharing the geological interpretation of seismic data"

Seismic Damage Zones and Their Impact within Thrust and Fault System

D. Iacopini

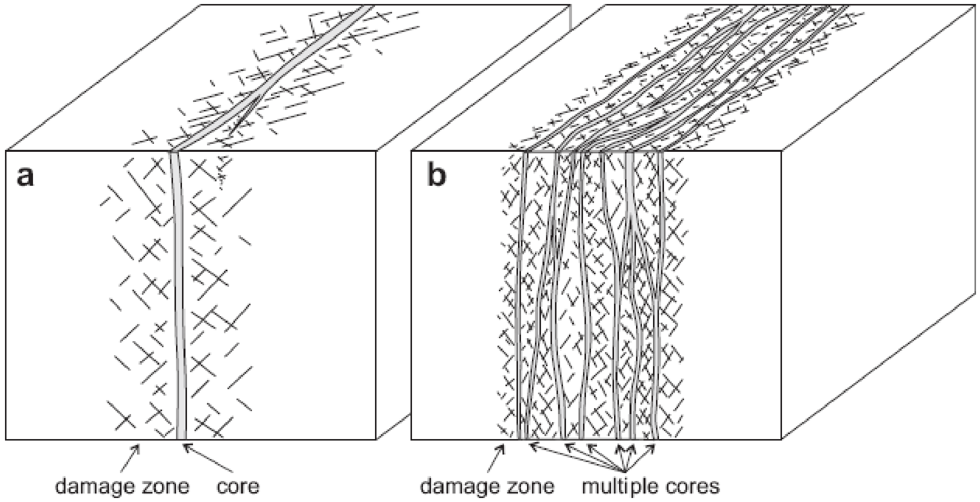
R.W.H. Butler

Outline

- Damage zones: outcrops to seismic scale
- Seismic Damage zones in deep water thrust system : description, architecture
- Working Hypothesis: signal processing as a tool to investigate Seismic Damage Zones
- Structural interpretation of Seismic Damage Zones
- Impact on deformation and restoration models

1 4 9 5
UNIVERSITY OF ABERDEEN

Damage zones: conceptual models



Chester & Logan, 1986
Faulkner et al., 2003
Core: cm to m
Damage: cm to up 200 m

At Seismic scale (Dutzer et al, 2010)
They include all type of deformation features
Seismic Fault Distortion Zone (SFDZ)
Scale gap!
typical bin spacing of 12.5 to 25m
Fresnel zones frequency dependent!
Sealing potential strictly linked to SFDZ!

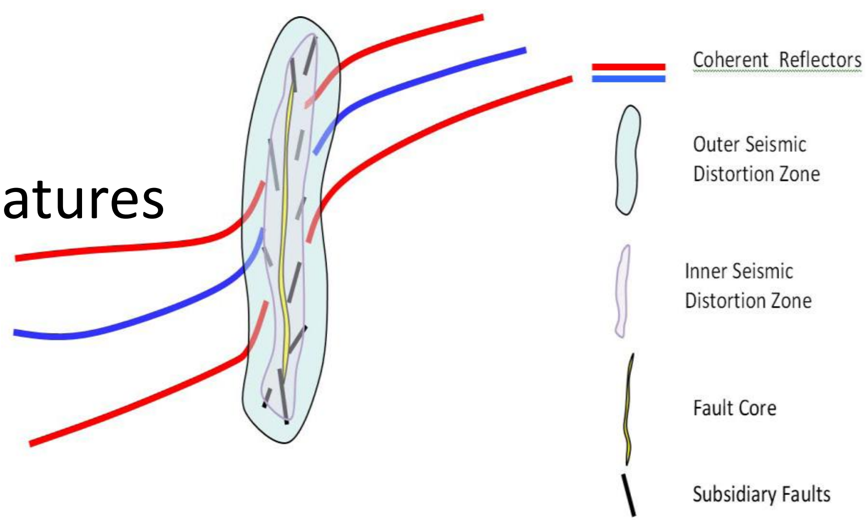
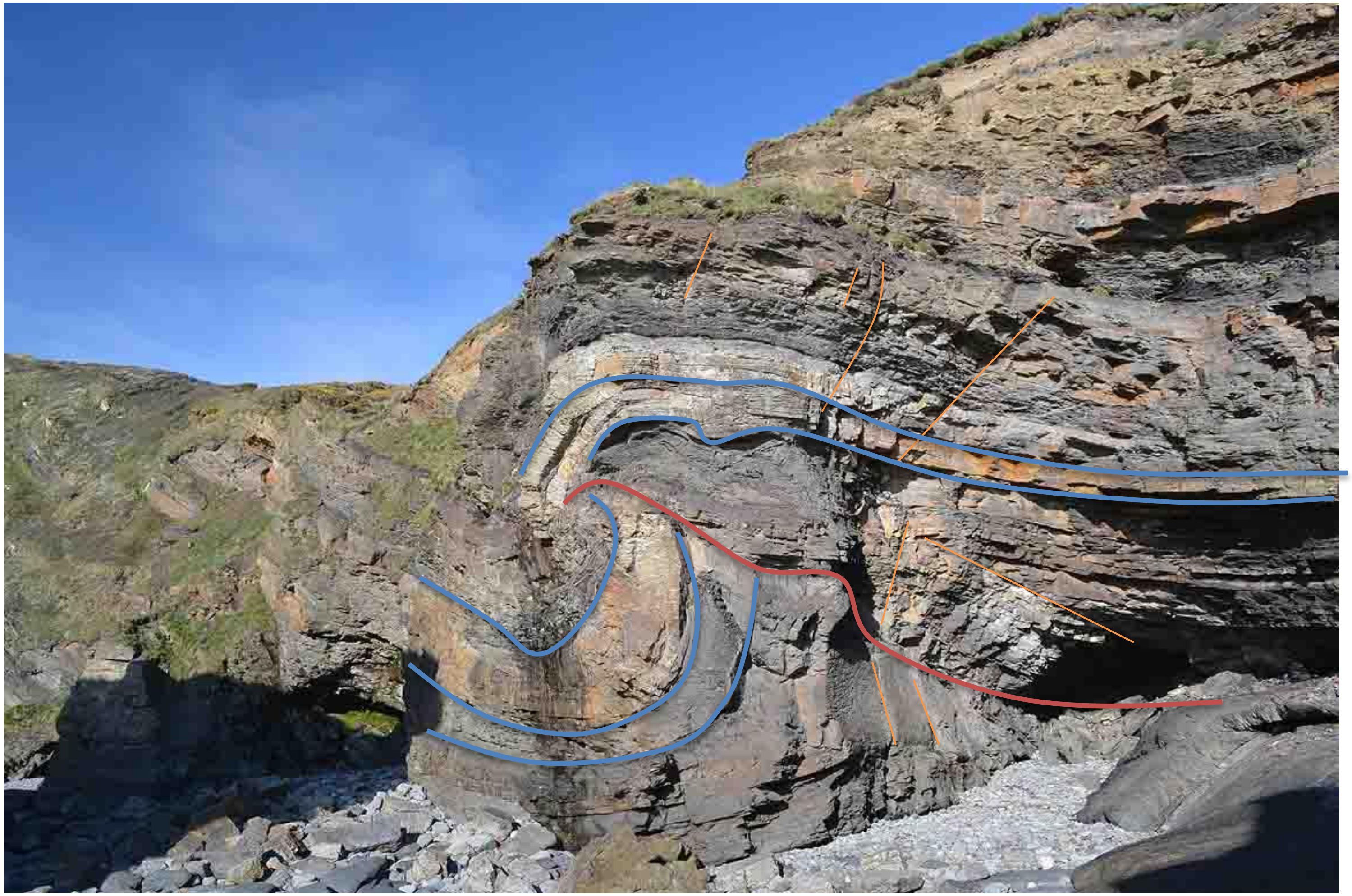


Figure 1 – Schematic demonstrating the Inner and Outer Seismic Distortion zones associated with faulting.

Fold thrust structure :The outcrops analogues

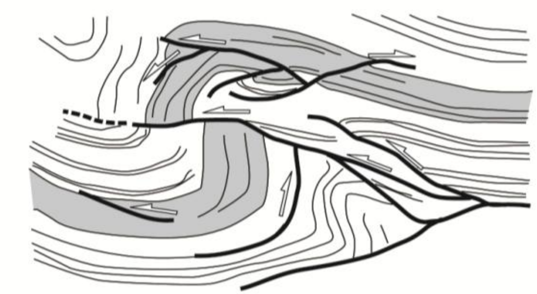


Broadhaven: fold thrust structure in Carboniferous deltaic sandstones and shales, SW Wales

Fold thrust structure in turbidites system/1

Thrust in Waitemata (Miocene) turbidites, Army Bay, New Zealand

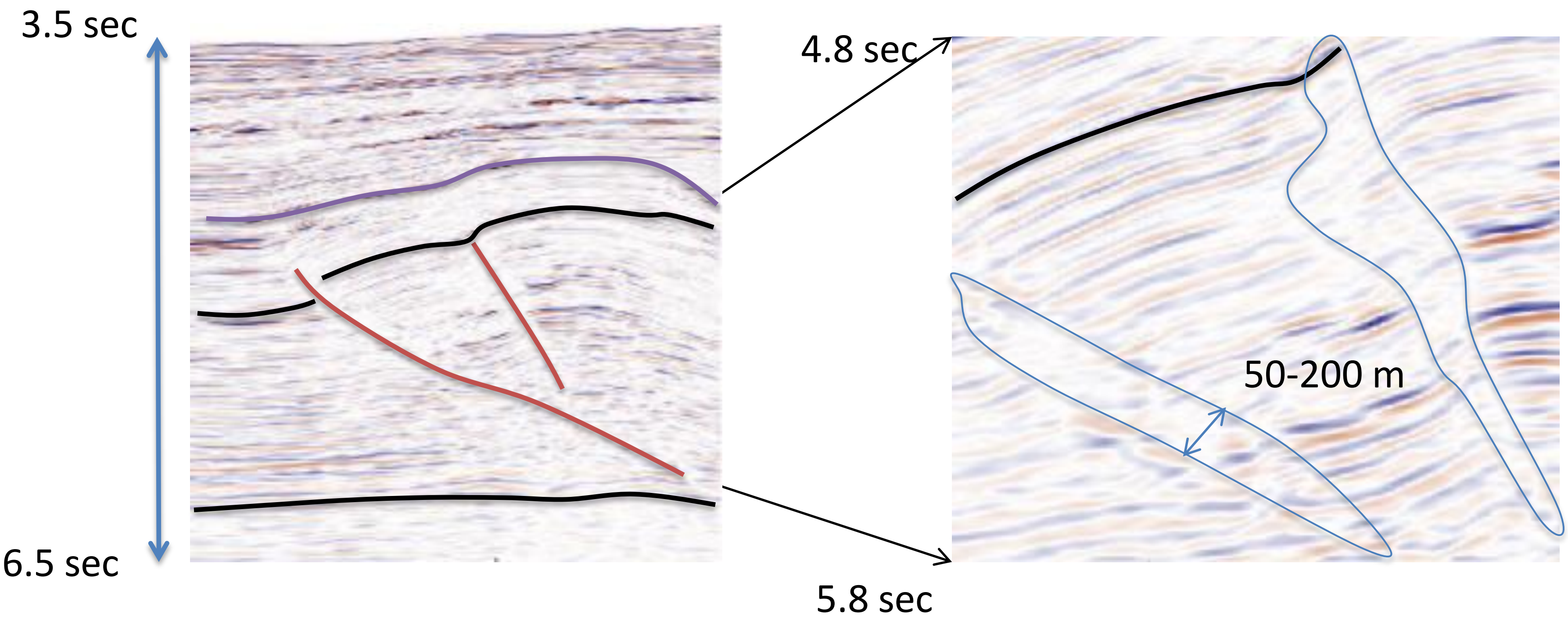
Fold thrust structures in turbidites system



- Thrust faults are surrounded and dominated by associated fractures (meter) and deformation bands (cm-meter)
- It is proven that those structures affects the permeability of the thrust system
- What do we observe at seismic scale?

What does the seismic tell us?

At larger seismic scale in deepwater system, same effect but different scale!!
The SDZ represents an area of significant uncertainty within the seismic volume .



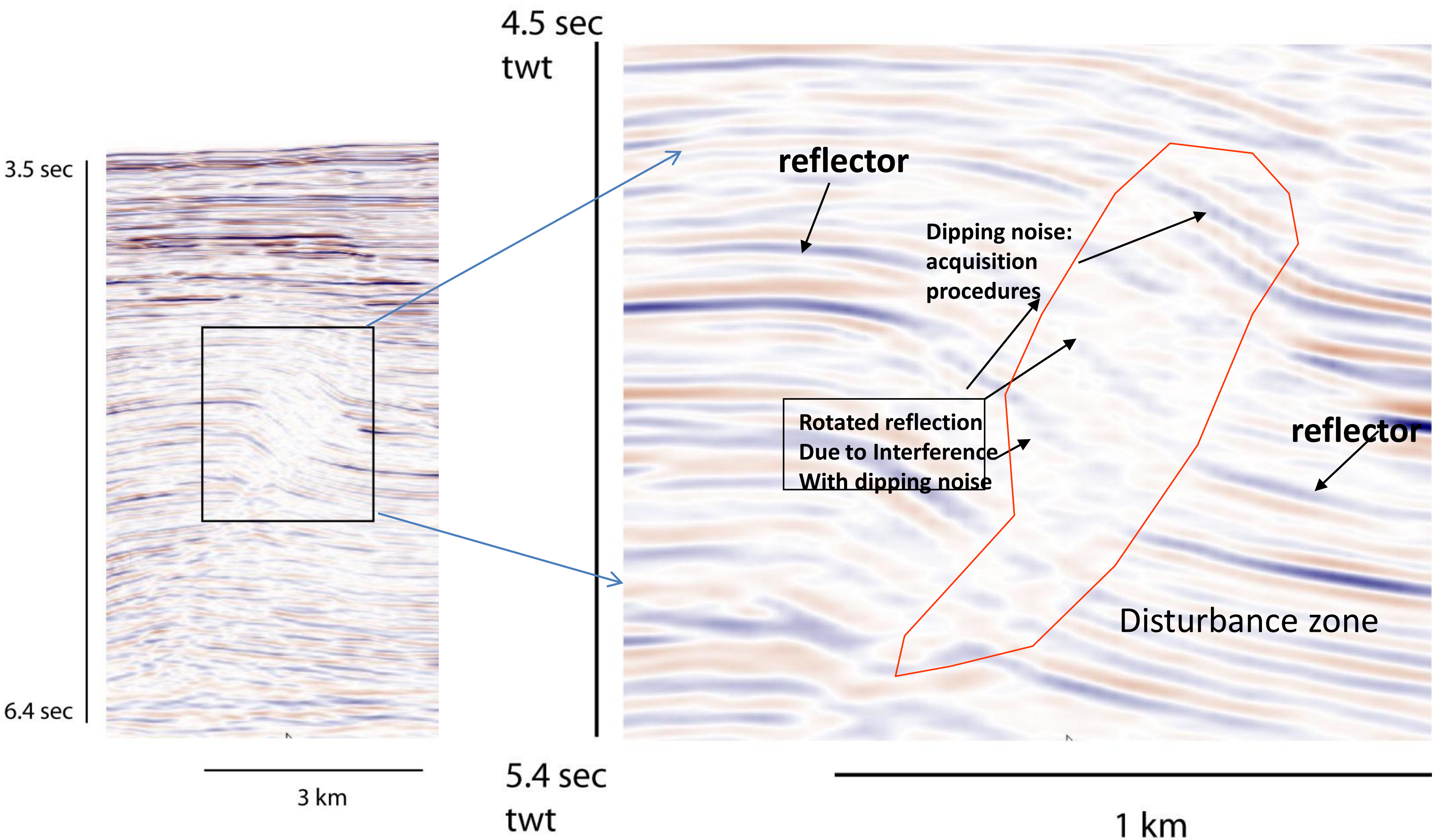
Signal is distorted either by changes in geology associated with deformation or by imaging problems due to presence of deformation structures

UNIVERSITY OF ABERDEEN

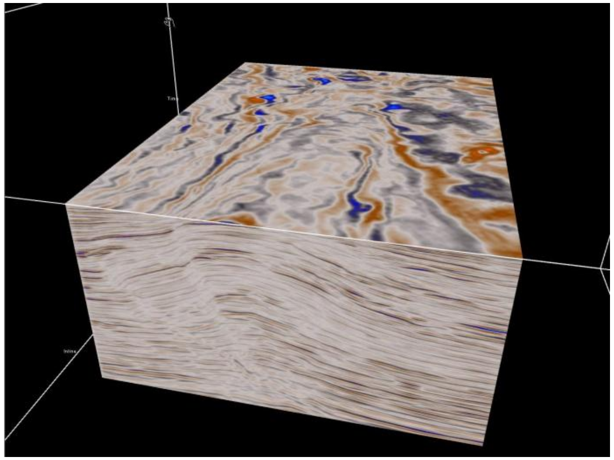
What does the seismic tell us?

Systematic damage of the signal!

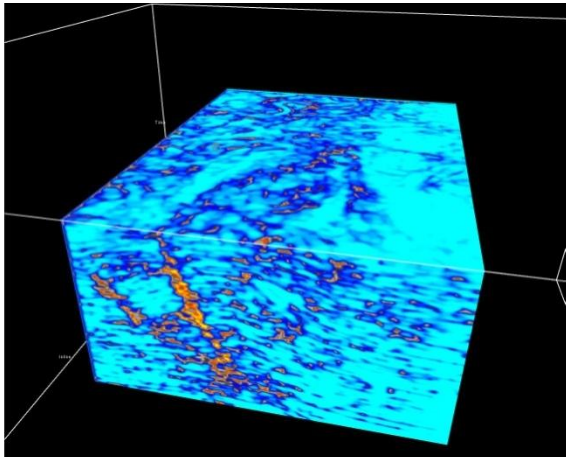
Can we map inside the seismic damage zones?



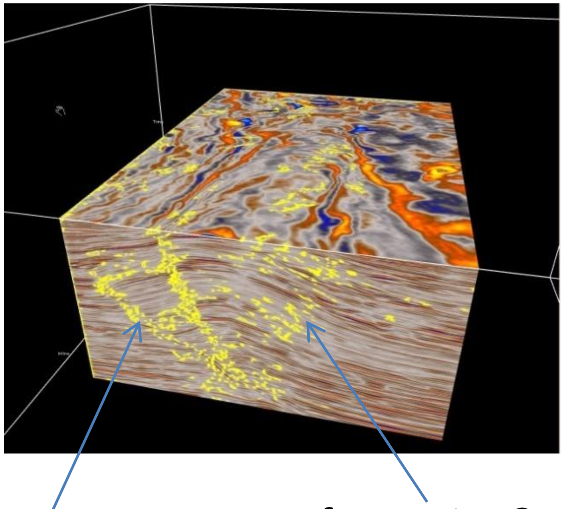
Hypothesis : Seismic damage zones as seismic expression of deformation in seismic



Original Amplitude cube



Coherency cube



Coherency geobodies draped on original volume dataset

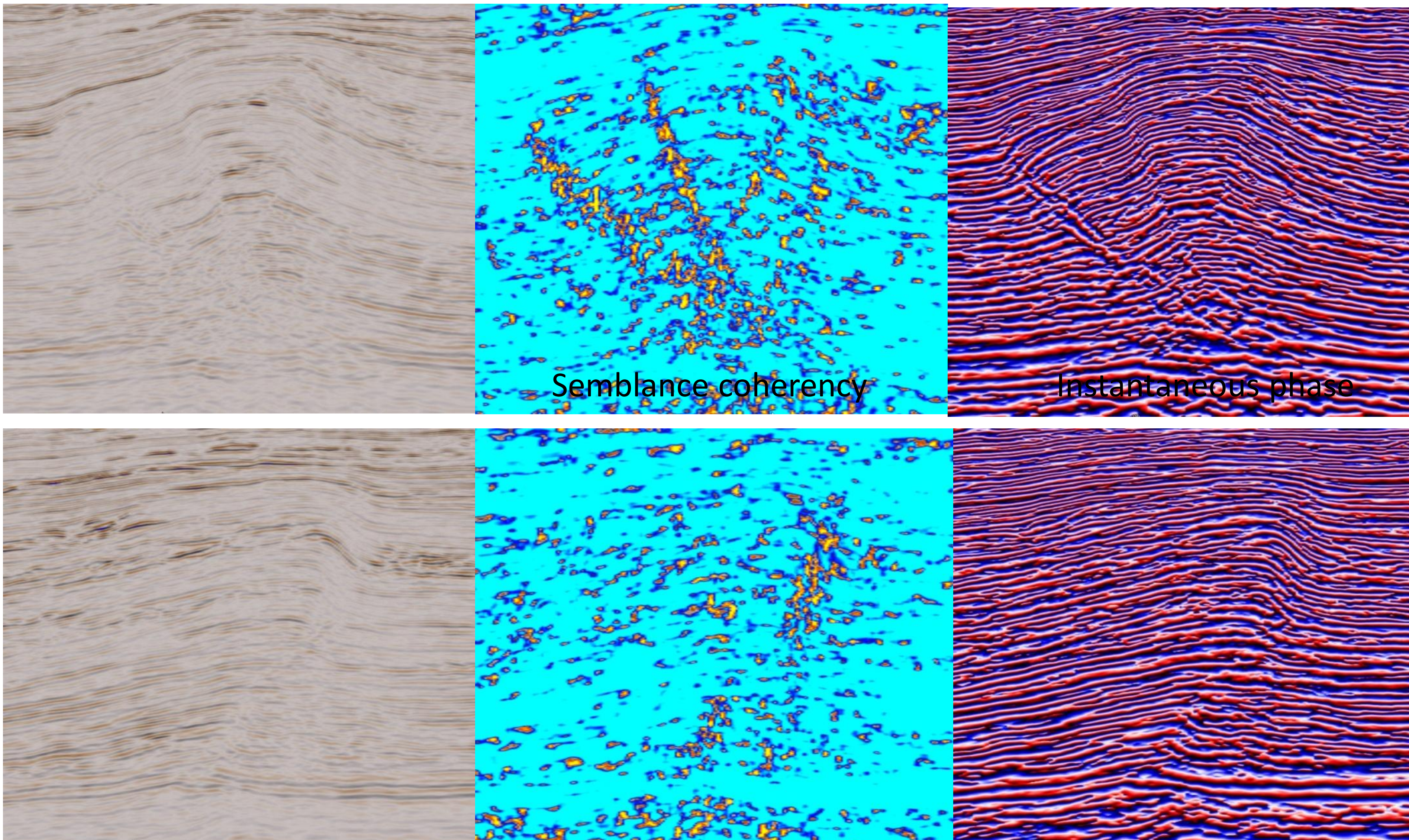
Iacopini,D, Butler, R, 2011

1495
UNIVERSITY OF ABERDEEN

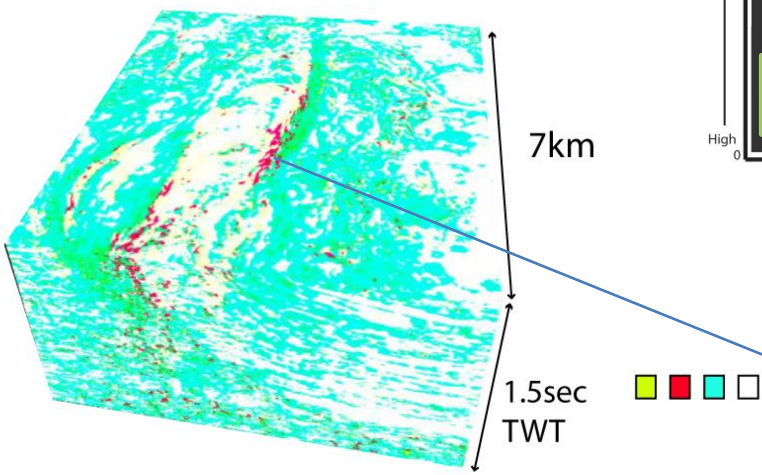
Test 1: Mapping damage zones using signal attributes

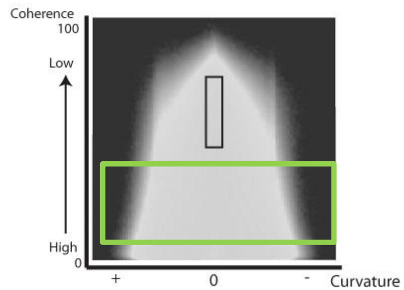
Semblance coherency

Instantaneous phase



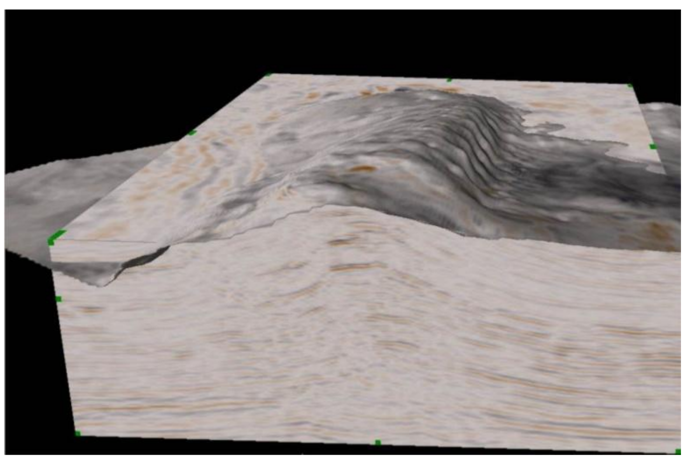
Investigating seismic properties within Seismic damage zones

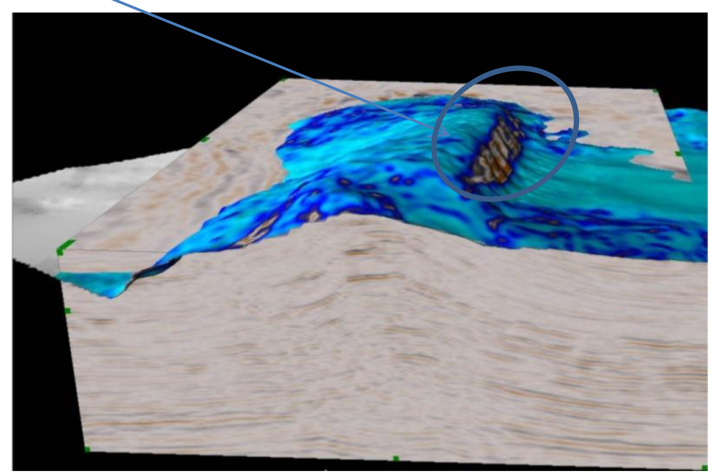




Red = zero curvature

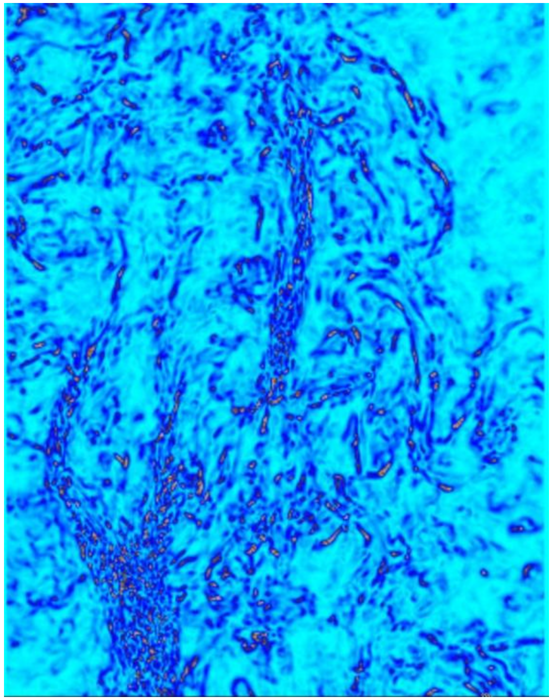
Should track low deformation zones!
Amplitude and coherency anomalies could imply a petrophysical signal...
Needs well log information to test this hypothesis.

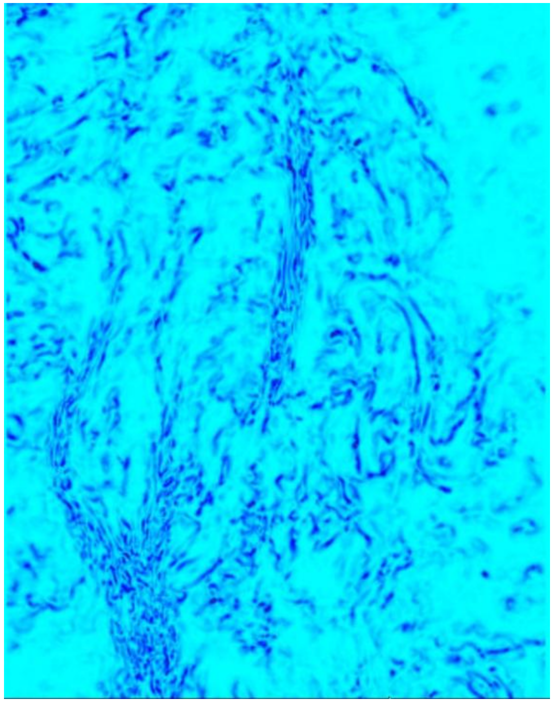


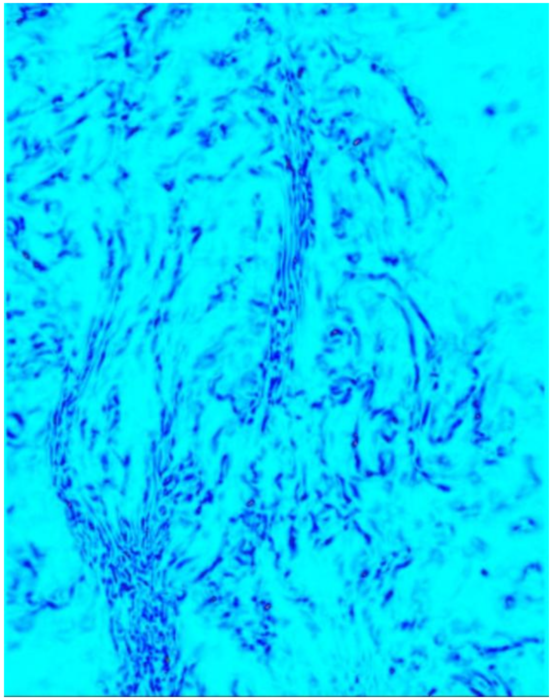


Test 3: damage footprint : noise? Signal?

Spectral decomposition on the semblance coherency cube





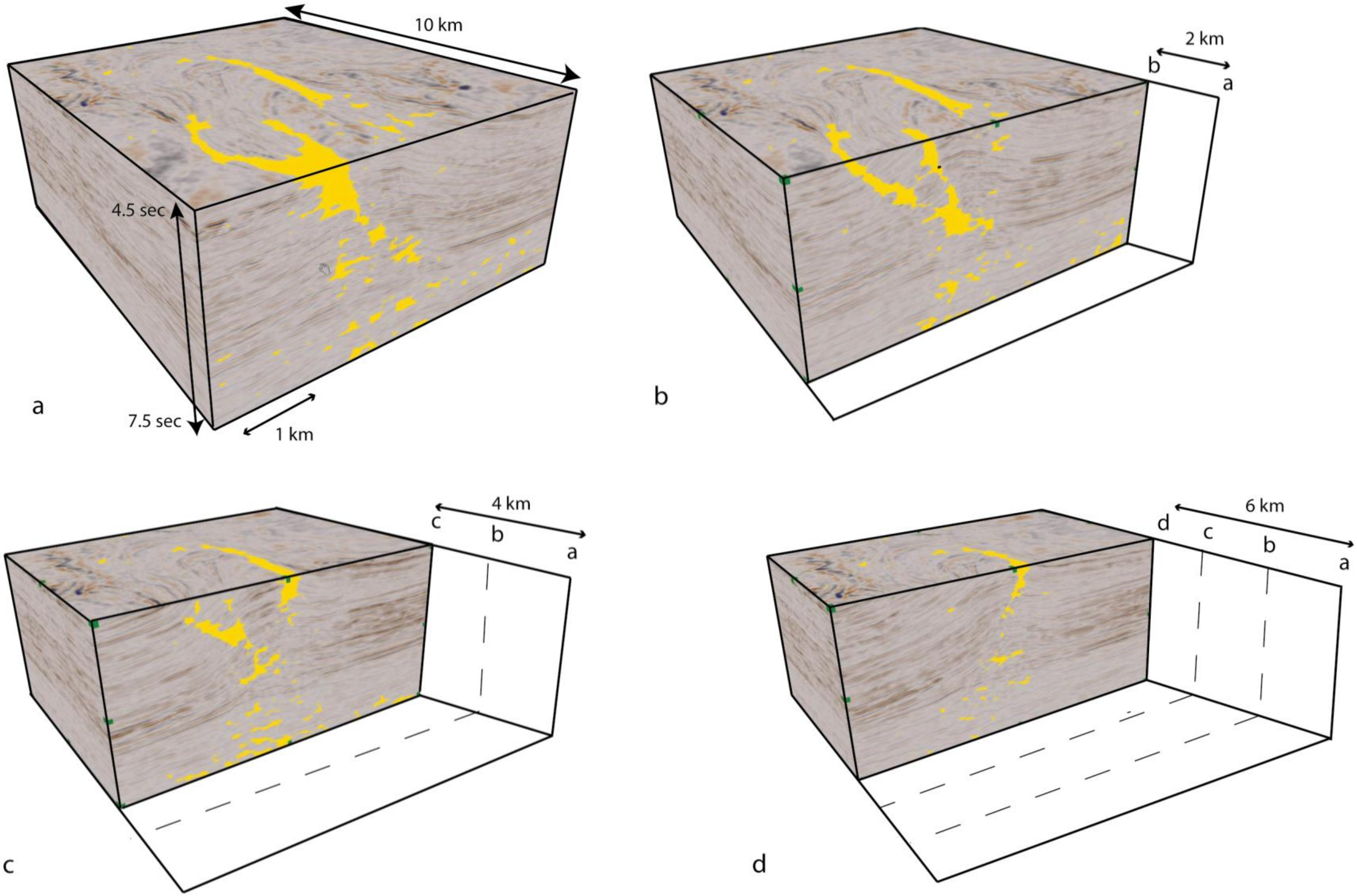


18 Hz 24 Hz 38 Hz

Problem:
How much the acquisition parameters and migration methods affects their Thickness?

UNIVERSITY OF ABERDEEN

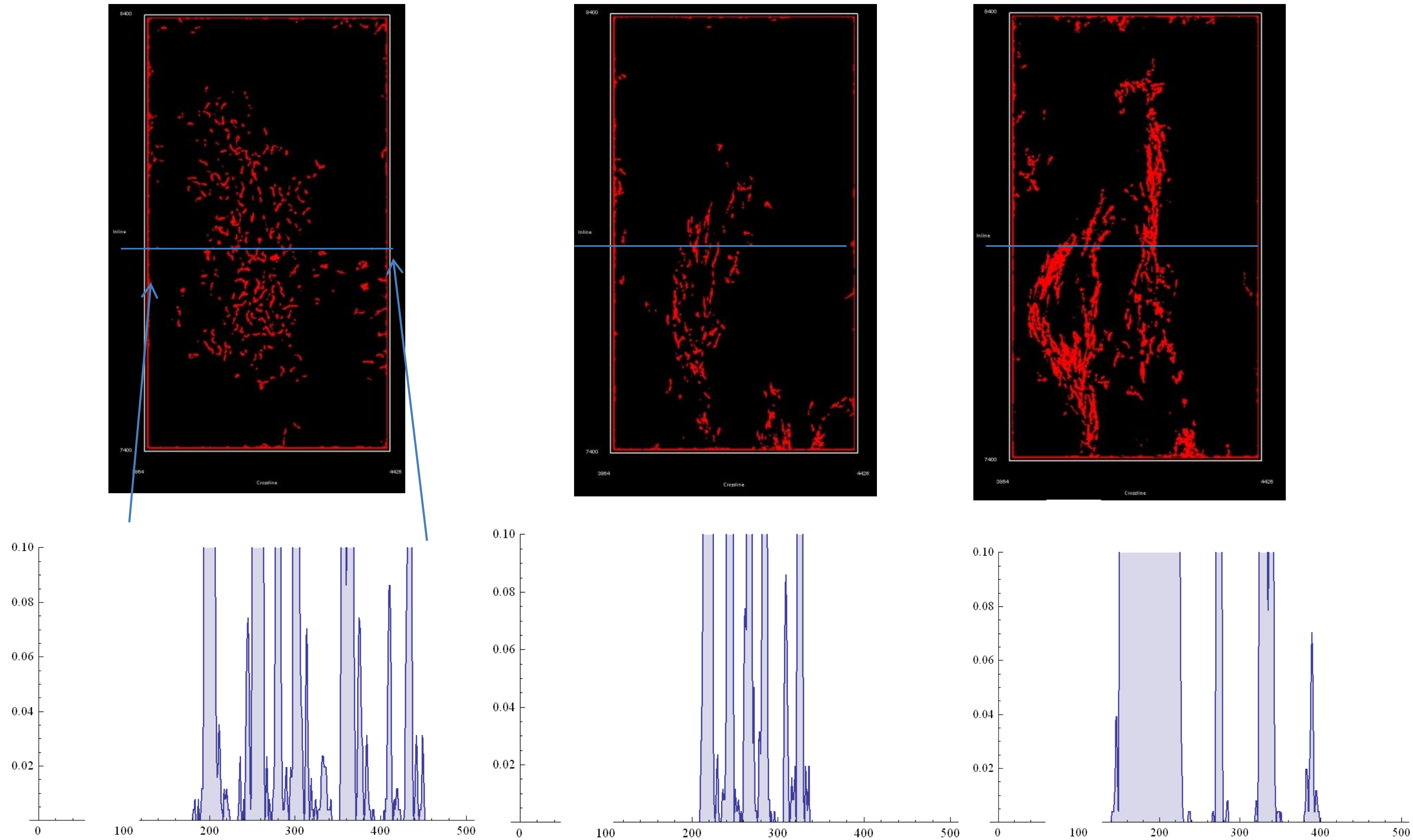
3D Architecture



UNIVERSITY OF ABERDEEN

3D Architecture

Damage zones distribution: *magnitude/thickness* of the signal disturbance



from the detachment **to the fault tip**

3D architecture

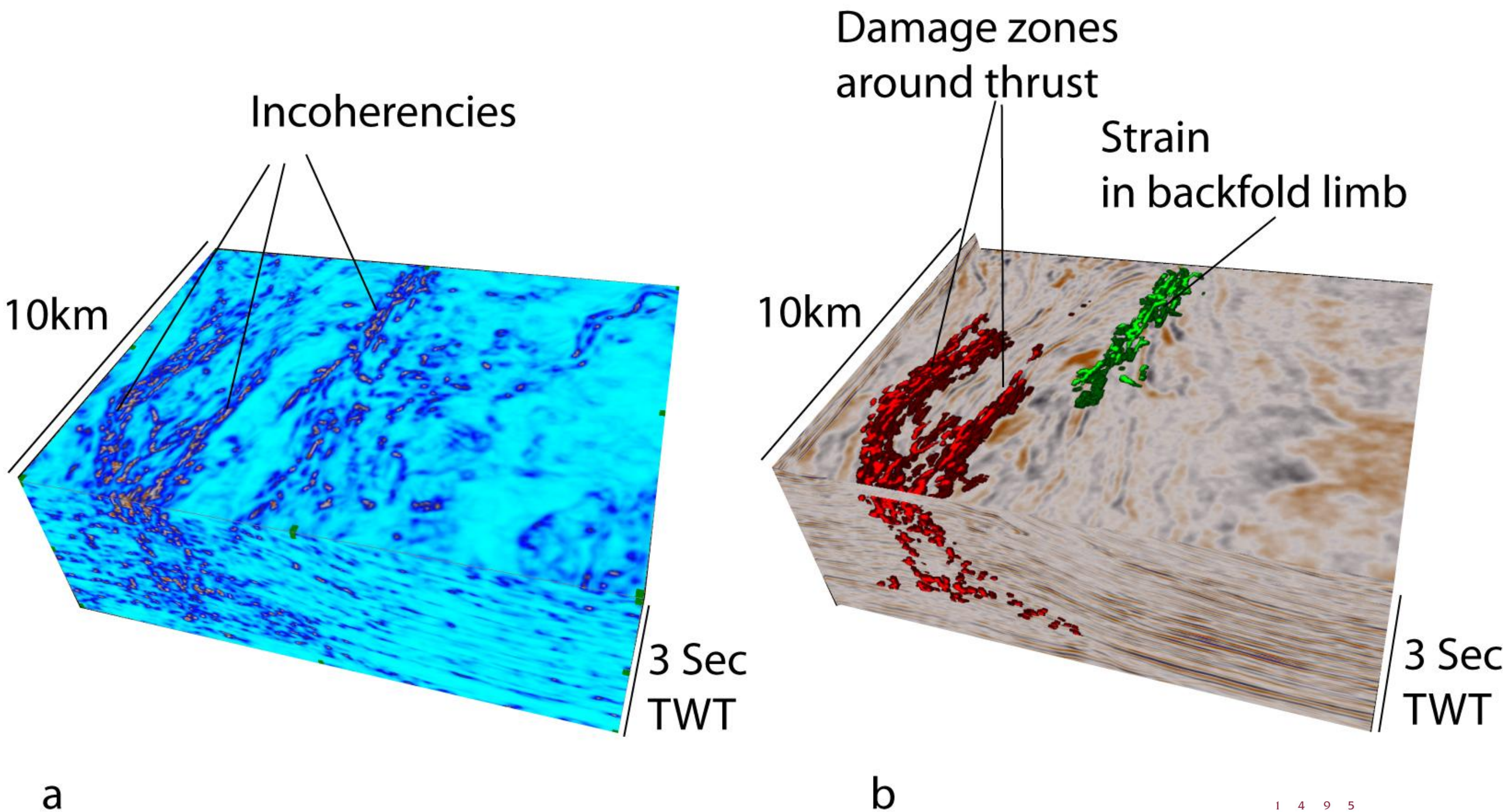
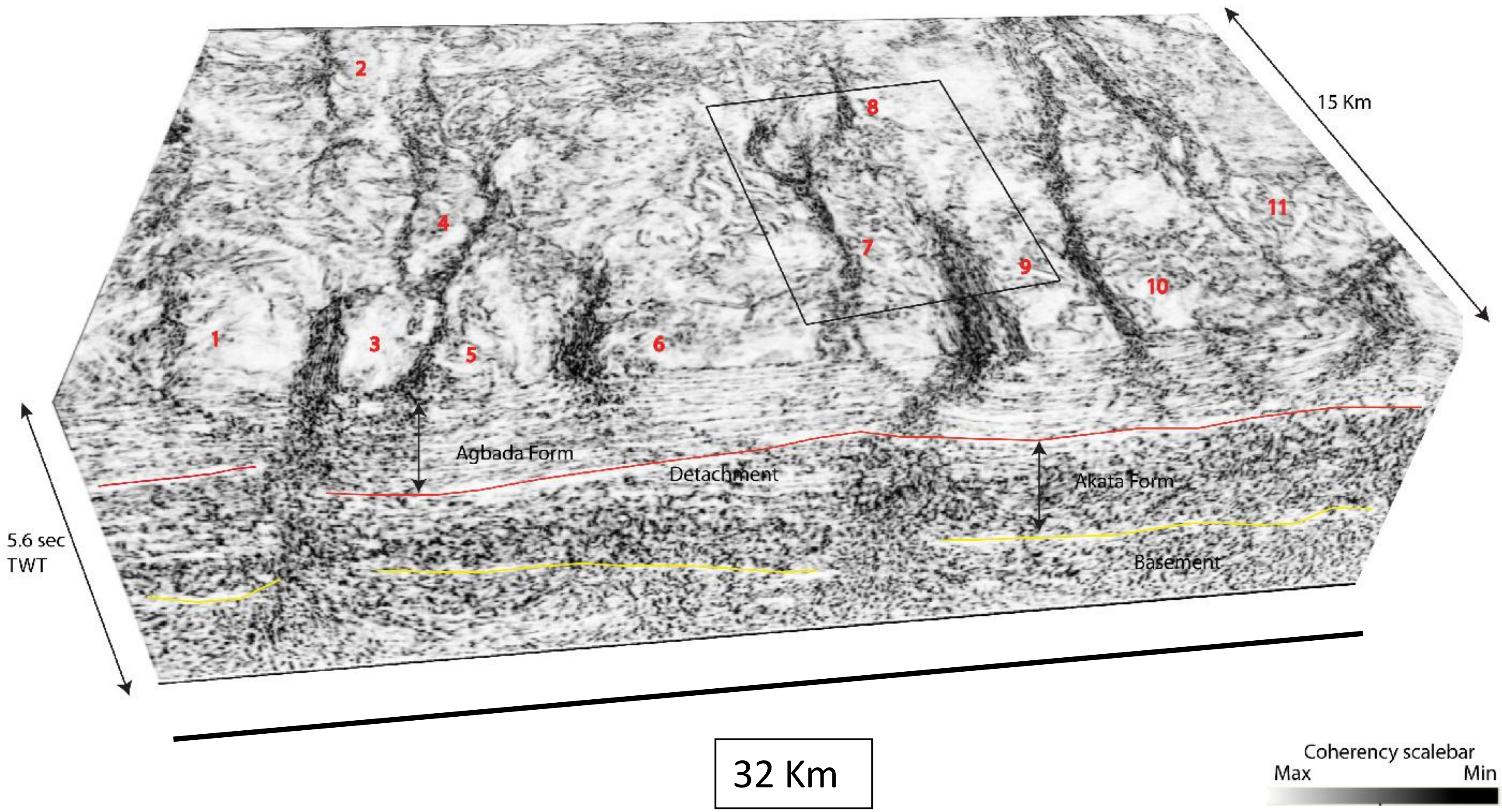


Fig 1

UNIVERSITY OF ABERDEEN

Consequences: lateral compaction…

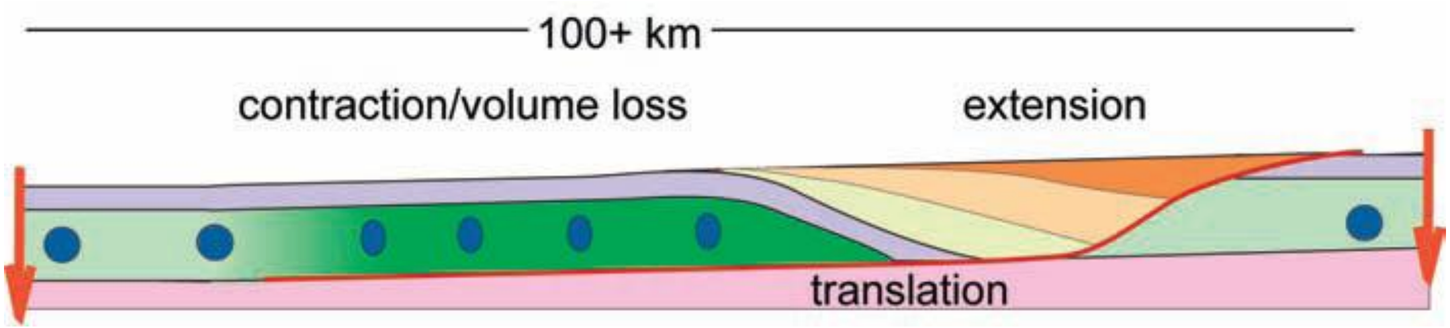
Localized incoherent zones
Dramatic impact of damage zones in deep water structures



10% of uncertainty in the lateral compaction / displacement accommodation!

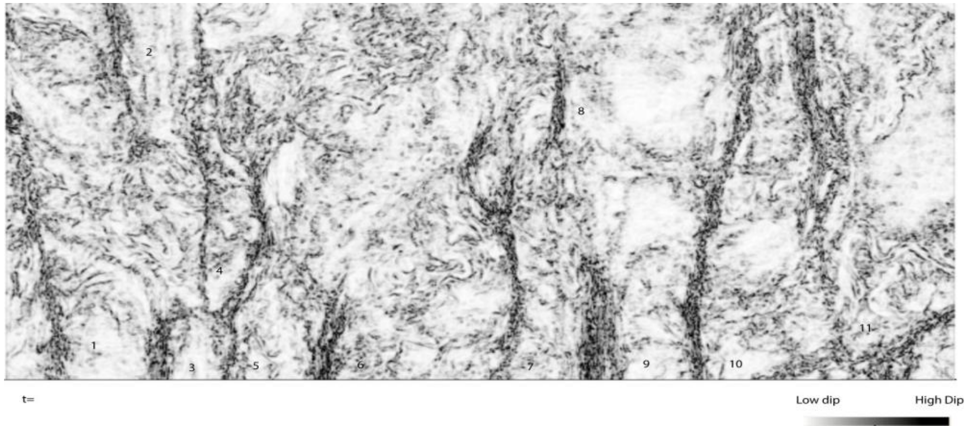
1495 UNIVERSITY OF ABERDEEN

Consequences: restoration



Butler & Paton, 2010, GSA

Future challenge:
how deformation is partitioned between localized thrusting, ductile deformation and lateral compaction?
How the acquisition/migration techniques affect the imaging of seismic damage zones?



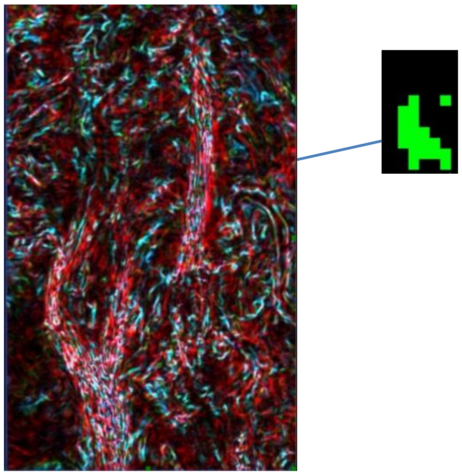
Total 10 to 20% of the the volume is affected by seismic damage zones!

Potential volume losses?
Lateral strain as well?

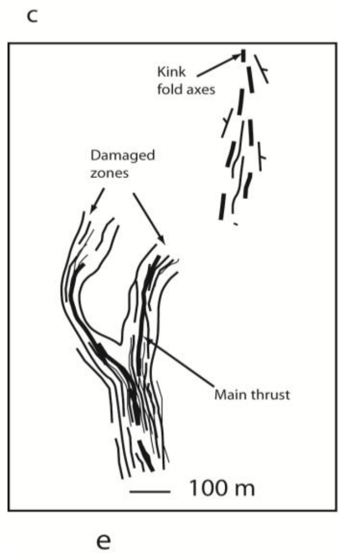
CHALLENGE FOR THE RESTORATION MODELS!

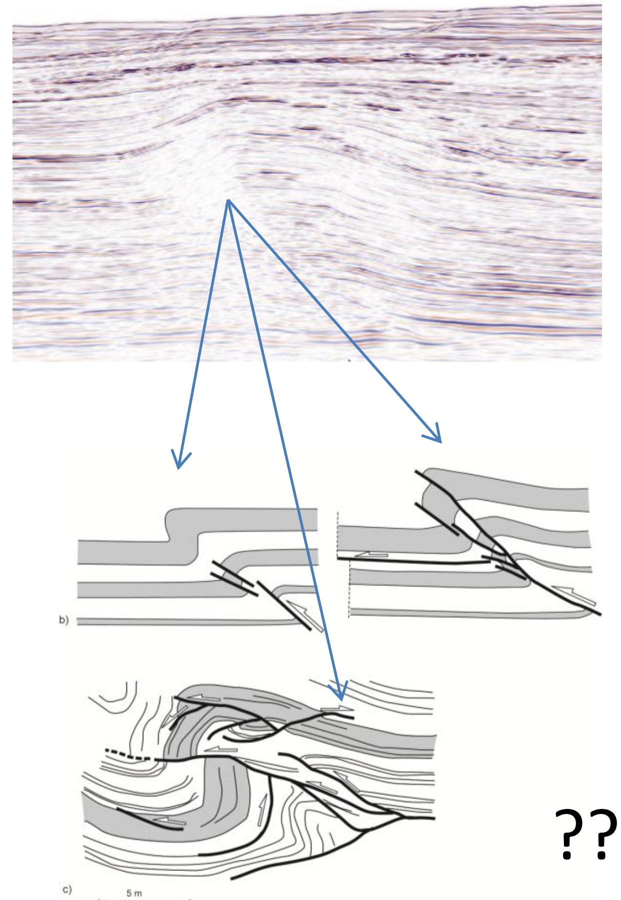
UNIVERSITY OF ABERDEEN

Challenges: Interpretation and uncertainty...



25m





Mapping Seismic damage zones....

Need constrain from wells!

Forward modelling in rock analogue systems

Need to improve acquisition and migration techniques!!

Need to constrain attributes with wells!!

Conclusions and challenge

- **Fact:**
- Seismic damage zones are systematically associated to deformation structures
- They represents broad zones where the seismic signal is strongly disturbed.
- They store information on the large scale deformation mechanisms and lateral damage of structure
- Deep water structures are largely affected by the seismic damage zones and need to be taken into consideration when applying restoration models
- **Hypothesis**:
- Seismic attributes potentially represents a powerful tool to map and distinguish structures within deformed areas.
- **Challenge:**
- More tests (well log) are needed to constrain their interpretation; Compare results from seismic having different acquisition and migration techniques.