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

David Iacopini¹ and Rob W. H. Butler¹

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¹Geology 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


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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
Damage zones: conceptual models

At Seismic scale (Dutzer et al, 2010)
They include all types 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!

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

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 turbidrites 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.
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 coherency geobodies draped on original volume dataset.

Iacopini, D, Butler, R, 2011
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

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

18 Hz 24 Hz 38 Hz
3D Architecture

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

*from the detachment*  

*to the fault tip*
3D architecture

Fig 1

a

Incoherencies

10km

3 Sec TWT

b

Damage zones around thrust

Strain in backfold limb

10km

3 Sec TWT
Consequences: lateral compaction...

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

10% of uncertainty in the lateral compaction / displacement accommodation!
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 volume is affected by seismic damage zones!

Potential volume losses?
Lateral strain as well?

CHALLENGE FOR THE RESTORATION MODELS!
Challenges: Interpretation and uncertainty...

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 represent 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 represent 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.