SEISMIC AND GPR DIFFRACTIONS: TOWARDS THE NEXT GENERATION OF SMALL SCALE DISCONTINUITY IMAGING

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PROJECT OBJECTIVES

- Determine the basic geological features capable of generating measurable diffractions in the near surface and at reservoir depth.
- High-resolution 3D Ground Penetrating Radar (GPR) cubes and outcrop observations serve as a bridge between synthetic models and real seismic data.
- Assemble a catalog of typical diffraction signatures to identify and quantify sub-wavelength discontinuities in complex geology such as fracture corridors and salt flanks.

PROJECT RATIONALE

Production of carbonate reservoirs, unconventional shales and deformed reservoir units near salt diapirs is often controlled by discontinuities such as fractures or voids. The reflection seismic method is optimized towards imaging of continuous reflectors to delineate stratigraphic boundaries. As a consequence, reflection seismic is of limited use for characterization of small scale fractures and voids. Sub-wavelength discontinuities cause diffractions and generate scattered energy on seismic records. For decades diffractions have been noticed as chaotic criss-cross patterns on seismic profiles in fractured and deformed geology (e.g. Rieber 1937). Commonly such scatter is considered as noise and suppressed as much as possible during acquisition and processing. Diffractions present an opportunity to expand the resolution limit of subsurface imaging to the sub-wavelength scale.

SCOPE OF WORK

Diffractions are best visible on densely acquired unmigrated data. The first step towards the use of diffractions for characterization of small scale discontinuities in reservoirs is to understand the origin and nature of the diffraction signals recorded in seismic data. The analysis of diffractions has already started in collaboration with Tijmen Jan Moser and Michael Pelissier and is progressing along three main thrusts:

1) Integrate 3D Synthetic Modeling, 3D GPR Data, Outcrop Observations, and 3D Seismic Data:

Synthetic modeling is performed with the Ray-Born method (Moser 2012) which is a very efficient tool to model both diffractions and reflections in 3D. Classic ray tracing can not be used due to a lack of omni-directional radiation of scatterers. Finite difference modeling is computationally prohibitive for the fine grids needed to represent small scale discontinuities. In the Ray-Born approach models are built from regular grids of elementary point scatters. For a direct as possible verification of the modeled diffractions we use high-resolution 3D GPR data. GPR uses electromagnetic waves but has very similar kinematics in terms of reflection, refraction and diffractions. We have already acquired and processed several 3D GPR data sets in fractured and karstified outcropping reservoir analogues. With outcrop control the diffractions in the GPR data can be directly linked to geological features enabling the design of realistic models for synthetic data generation. The models are scaled in units of wavelengths making the synthetic data universally applicable to both the GPR-outcrop and the seismic scales. Hence the GPR cubes serve as a bridge between synthetic and real seismic data to decipher the origin of diffractions.

2) Determine the Geological Origin of Diffractions:

Geological scattering mechanisms and diffraction detection limits are not well understood. To date the majority of synthetic models of diffractions has encompassed perfectly flat planes and long straight lines. A typical example of such an overly simplistic model is shown in Figure 1. The corresponding linear diffraction pattern does not exist in field data which are dominated by arrangements of point diffractions with circular cross-sections on timeslices. The key question is what geological features generate point diffractions. Natural fractures are far from planar features, have limited extent and have significant roughness. Brittle rock deformation results in conjugate fracture systems and partitions the rock into blocks with sizes above and below the wavelength with many corners and edges. On well developed fractures small conjugate fractures cause steps and corners acting as wave scatterers. The alignment of such diffractions defines the main fracture trend. From our 3D GPR data we see that zones consisting of fractures with one millimeter or less aperture cause abundant diffractions. Such thin fractures with openings on the order of 1/500 wavelength are well below the 1/40 thin bed detection limit commonly known from reflection seismic imaging (Widess 1973). True amplitude Ray-Born models of basic fracture intersection geometries allow us for the first time to determine how fracture extent, width and roughness control the generation of diffractions recorded in GPR and seismic data. Once we can determine the basic geological features capable of generating measurable diffractions we can use them as basic building blocks for modeling of complex geometries such as fracture corridors in carbonates or deformed reservoir units near salt diapirs.

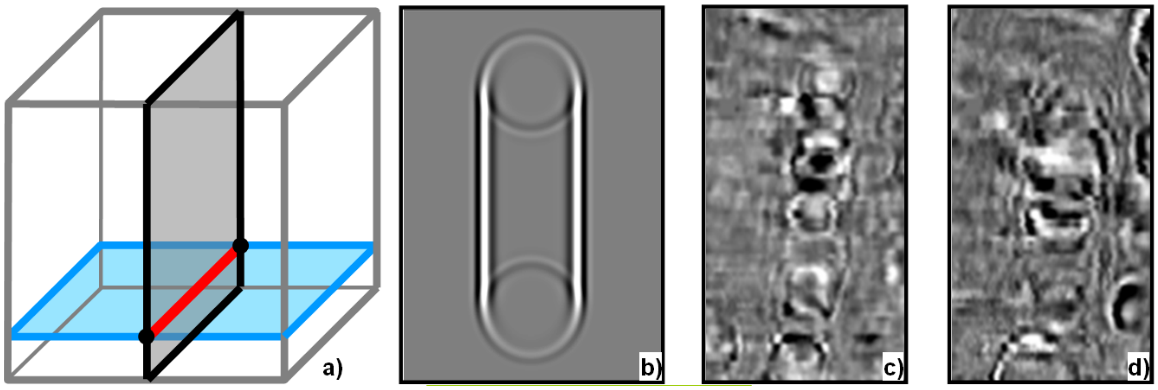

Figure 1. a,b) Intersection of a vertical and horizontal fracture causes a linear diffraction with two circular tipwaves as seen on a 3D synthetic data timeslice c) Conversely, strings of closely spaced circular diffraction are observed in 3D GPR field data. d) A deeper time slice of the same diffraction cluster shows mirrored half circles with a lower amplitude corridor in between.

3) Expand Diffraction Signature Catalogue

Currently availability of high resolution seismic data acquired with dense enough grid spacings to fully sample the steeply dipping diffraction tails is very limited. On the other hand full-resolution 3DGPR data including non-aliased diffractions can be acquired within a few days. For example as seen in Figure 2 the Cassis 3D GPR data contains hundreds of diffractions in different configurations (Grasmueck et al. 2011). Characteristic diffraction patterns from unmigrated 3D GPR data cube, combined with the interpretation of 3D migrated data and typical outcrop images are compiled in the Diffraction Signature Catalogue. These typical configurations can then be used like a dictionary to read and interpret diffraction patterns observed in seismic data. Until now our main focus has been on 200 MHz GPR data which we will extend to the 100 and 500 MHz center frequencies in order to gain insights on resolution and scaling behavior of diffractions.

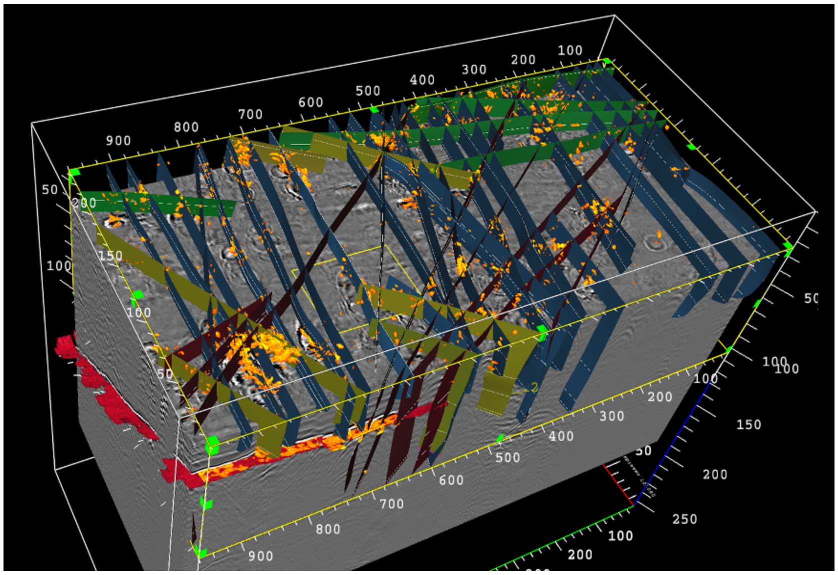

Figure 2. 3D view of the unmigrated Cassis 3D GPR data cube with steep fracture interpretations based on migrated data. Orange colored are volume rendered high amplitude clusters of focused diffractions indicating zones of intense fracturing and karstification.

EXPECTED OUTCOME

With the new knowledge about diffractions gained from True Amplitude Ray-Born Modeling, 3D GPR and outcropping reservoir units, seismic diffractions are promoted from noise to valuable signal. Diffractions make sub-wavelength discontinuities in complex reservoirs such as fracture corridors and salt flanks visible and quantifiable.

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