Understanding Seismic Data: Time, Depth and Geology (G082)

Tutor(s)

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Overview

This course is designed to provide seismic interpreters, managers, geophysicists and geologists with a broad understanding of seismic imaging and processing. Emphasis will be placed on an understanding of industrial methods and workflows, differentiation of signal from artifacts, and connecting seismic data to geological settings for prospect evaluation and generation. The limited amount of quantitative seismic theory that is included is linked to the fundamentals of seismic data acquisition and processing, imaging, model building and interpretation through the incorporation of case studies. The eight course sessions continually build on the material from previous sessions and are tied to the underlying geology.

Duration and Logistics

A 4-day in-person classroom course, consisting of lectures and exercises. A digital manual will be provided for the course.

Level and Audience

Intermediate. The course is intended for seismic interpreters and geologists involved in the use and evaluation of seismic data.

Objectives

You will learn to:

1. Outline the principal strengths and limitations of depth imaging.
2. Assess the uncertainties of depth imaging and strategies to reduce these.
3. Establish the fundamentals of marine- and land-based seismic from acquisition to pre-processing.
4. Examine the processing steps leading to post- and pre-stack time migration, and post-stack depth migration.
5. Evaluate various migration parameters used in the application of pre-stack depth migration and how they affect the PSDM image.
6. Gauge the accuracy of time to depth conversion by application of pre-stack depth migration, as well as seismic to well tie and residual depth correction.
7. Demonstrate the fundamental differences between depth and time migration and the improved imaging results when depth migration is utilized to resolve lateral velocity variations.
8. Evaluate the link between the pre-stack depth image and the underlying geological settings.
9. Analyze the complex structural geometries associated with salt tectonics and their significant associated imaging challenges.

10. Differentiate signal from artifacts.
11. Assess the construction of geological models utilizing our common understanding of velocity estimation, anisotropic parameters and different geologic settings.
12. Connect seismic data to geological settings for prospect evaluation and generation.

Course Content

Session 1: General Review and geological motivation: prospect generation, seismic processing and imaging

We start with a brief review of various geologic settings, subsurface geometries, and exploration/exploitation targets to demonstrate our motivation for improving our understanding of seismic data. A general description of basic concepts and methods used in time and depth imaging from various case studies sets the geophysical foundation for the course. The main objectives of depth imaging: correct image, depth and dip are stated and explained utilizing the relationship between the prestack depth migrated (PSDM) image and well drilling results. Understanding the limitations and strengths of the seismic image impacts the determination of the geologic risks associated with exploration and exploitation. We will review the primary play and prospect elements in general, and more specifically with relation to illuminating their subsurface geometries, reservoir properties and fluid content derived from seismic data. Discussions will include consideration of the geological evolution and some basic structural techniques to assess the viability of the interpreted geometries, recognition of possible limitations and error accompanying reservoir characterization, the uncertainties associated with their interpretations, and the potential for reducing those uncertainties using the seismic imaging and processing techniques that are discussed in the course.

Session 2: Time domain processing: marine and land

An explanation of recording, pre-processing and processing of marine seismic data, including OBN dual sensor summation, denoise, deghosting and SRME demultiples, provides a foundation for deciphering interpretable data. We then cover the fundamentals of land seismic acquisition and pre-processing and the different challenges it presents in progressing from raw field records to producing data suitable for prospect evaluation. This behind-the-scenes look at acquisition, pre-processing and detailed velocity analysis is especially important onshore since decisions made during pre-processing can affect the ability to successfully identify a reliable prospect. For land pre-processing, this includes refraction and residual statics, deconvolution, denoise, velocity analysis and 5D interpolation. We use practical examples, demonstrate the basic concepts of how/why these applications are used, with tips for what to look out for when processing a land seismic dataset.

Session 3: Depth migration: post stack, prestack and parameters

The objective of this chapter is to review depth migration, including ray and wave based migration, to accurately image the true subsurface geology. Building on the wave and ray equations examined in the previous sessions, we cover the basic concepts of ray-based Kirchhoff summation depth migration and then move on to tackle the building blocks of wave equation depth migrations: downward continuation and imaging condition. We will explain the differences between depth migration based on the acoustic wave equation and the elastic wave equation. A critical component of the implementation of PSDM is the selection and use of optimal migration parameters to image the details of the subsurface geology more accurately. We will examine operator dip, migration aperture and frequency range selection. By reviewing a series of case studies, we will highlight the advantages and limitations of the construction of image gathers by various PSDM algorithms. We conclude with a discussion of PSDM stacking procedures as well as construction of a migrated image via inversion process.

Session 4: Seismic Velocities: Estimation techniques and anisotropy

It is important that seismic interpreters and geologists understand and provide input to the geological models utilized in PSDM. These models include the subsurface geometry, velocity, and anisotropic fields, where the anisotropic fields mimic variations in rock properties. In that context we will examine common industrial and theoretical aspects of velocity estimation techniques and their advantages and limitations to provide crucial insights on the capability of seismic data to map exploration and development targets correctly and accurately. We start with a review of the various definitions of velocity fields including stacking, root mean square (RMS), normal moveout (NMO), Dix conversion, interval, vertical and residual velocities. This is followed by explanation and demonstration of simple to advanced velocity analysis techniques including ray-based reflection tomography and wave based full waveform Inversion (FWI). A discussion of anisotropy follows to explain the relationships between azimuthal anisotropy and the estimation of fracture orientation and density for unconventional and fracture dependent exploration and exploitation. The chapter concludes with a discussion on the accuracy of time to depth conversion done by application of PSDM, as well as seismic to well tie and residual depth correction.

Session 5: Faulted and Folded Geology: Imaging and Interpretation

In a seismic context faults and fault zones are commonly manifested as the juxtaposition of contrasting velocity bodies and the termination of the laterally continuous velocity boundary. Similarly folds alter the lateral continuity of velocity boundaries such that the geometry and amplitude of seismic reflections can be altered significantly. We will review the impact of faulting on the seismic image and how incorrect imaging of these structures has plagued the industry. Focus is given to accurately imaging faults and resolving seismic “fault shadows” along with the higher accuracy and resolution required to assist unconventional drilling programs. The anisotropic models used as input to PSDM and the corresponding image they produce are critical factors in the vertical and lateral positioning of events on a seismic image are crucial in optimal placement of a well borehole.

Session 6: Salt - evolution and tectonics, interpretation for model building and prospect generation, imaging and interpretation of sub-salt and pre-salt prospects

The complex structural geometries associated with salt tectonics pose significant imaging challenges. Here we will review the genesis of salt structures and their varying structural domains to provide a geological foundation for different seismic acquisition and processing strategies. The discussion will include a brief review of evaporite deposition, salt basin geometries, and the fundamental mechanisms driving salt deformation. Outcrop and sub-surface examples provide analogs to decipher the progression from autochthonous to allochthonous salt bodies, and then the evacuation of salt and the associated structural geometries. Particular attention will be given to identifying key stratal and structural geometries associated with salt deformation and kinematics that aid in the interpretation of salt bodies. A PSDM volume is ‘as good as the velocity model’ used as input to the migration. This invariably introduces geological interpretation into the processing workflow which mandates an integrated effort between the seismic interpreter and seismic processor. The goal being to develop viable velocity and anisotropic parameters for different geological settings and models. We will build on our previous reviews of seismic velocity models and salt to demonstrate the importance of this integration through examination of several imaging case studies. These examples illustrate the links between different velocity models and the resulting PSDM images in a variety of different geological settings. These include areas impacted by salt tectonics, thrusting, extension, and unconventional plays. Sub-salt exploration is common in many basins and the imaging and interpretation challenges created by complex salt geometries can be a significant hurdle for seismic interpreters and processors. These issues include less sub-salt illumination and the resulting image artifacts from multiples, converted waves or algorithm noise. To help differentiate coherent signal from coherent noise, we review imaging of converted waves below salt bodies, prism waves near salt bodies and interbed multiples to decipher the sub-salt coherent noise that is part of the depth migrated data. This enables us to differentiate noise from signal when interpreting the subsalt section. To improve sub-salt imaging new seismic acquisition and depth imaging methods are continuously being introduced to the marketplace including Ocean Bottom Node (OBN) surveys and elastic RTM PSDM processing of OBN data. We will review this evolving methodology including the different aspects and capabilities of elastic RTM PSDM, sub-salt imaging by use of converted waves and use of the recorded horizontal components of OBN surveys and their impact on the selection of sub-salt drilling locations.

Session 7: Stratigraphy: Seismic Amplitudes and Interpretation

Along with correctly imaging structural geometries, another key aspect of depth imaging is its ability to correctly preserve seismic amplitude. This is directly linked to evaluation of amplitude related prospects as well as selection of drilling locations. Illumination analysis techniques, including both ray-based and full wave equation-based methods will not only provide insight on amplitude extraction from depth migrated data, but will also create a framework for analyzing amplitude maps. This requires examining the theoretical basis of least-squares RTM (LSRTM) by interrogating data examples where it has been used. In addition, PSDM gathers can be used as input to impedance inversion for reservoir characterization and lithology and fluid prediction. A case study of a stratigraphic driven exploration example using PSDM gathers as input for impedance inversion demonstrates the advantages of using these gathers compared to use of time domain gathers as input to impedance inversion.

Session 8: Seismic processing and imaging projects QC

Synthetic and real data examples of PSDM demonstrate the fundamental differences between depth and time migration, the improved resolution of lateral velocity variations utilizing PSDM, and the impact on accurately imaging the structure, dip, and depth to target. We will explain why accurate velocities are extremely critical for depth migration and the importance of post-migration processing by linking back to the input velocity model. This includes examining the gather conditioning, stack enhancements and even industry standard EBCDIC headers. More importantly, we will demonstrate why inaccurate depth velocities might jeopardize the subsurface image and demonstrate the optimal way to achieve a depth domain seismic image – using PSDM or alternatively using inversion. Post processing enhancements routinely done in execution of processing and imaging projects will be described and explained.