Advanced Seismic Data Acquisition & Processing

Jaap C. Mondt

What kinds of Geophysical Data could be used?

Various kinds of geophysical data are available. They are usually separated into Seismic and Non-Seismic or Multi-Physics data. Seismic is, without any doubt, the main method used in the oil and gas industry. Non-Seismic data (gravity, magnetics, electrical, electromagnetics, spectral, etc.) is the main source of information for either the early exploration reconnaissance stage or in shallow subsurface applications (engineering, mapping pollution, archaeology, Geothermal, CO_2 sequestration, etc.)
Seismic has its limitations and therefore also non-seismic methods are used successfully as complementary tools in subsurface evaluation. In combination with seismic data, they can significantly reduce the uncertainty of subsurface models as they measure different physical properties of the subsurface. Controlled Source EM for example responds to reservoir resistivity and can thus be used to differentiate between hydrocarbon- and brine-filled reservoirs.

Why Seismic data and why Processing?

Seismic data is one of the main sources of information on the subsurface. We not only need to obtain the structure that could contain hydrocarbons, but also the rock properties so we can decide on whether we are dealing with reservoir rocks (sandstone, carbonates, even shales), sealing rocks (shales, salt) or source rocks (shales, coals). To know what type of rock is present is important, but also what its porosity is and whether it is fractured, as that is important for permeability (How easy do the hydrocarbons flow through the rocks). To obtain the best image of the subsurface we first need optimum acquisition. Optimum in the sense of “fit for purpose”. There are several criteria that need to be satisfied. Firstly, the area covered during acquisition should be the prospective area extended sufficiently to provide full-fold and fully migrated data. An acquisition principle that should be adhered to as much as possible is symmetric sampling, which means equal shot and receiver spacing and equal in-line and crossline distances (for a 3D). A noise spread (trial acquisition with closely spaced receivers and shots) is acquired in each new area to determine the needed shot and receiver intervals, the bandwidth, etc. The shot and receiver station spacing should be such that no spatial aliasing of the data occurs. Surface and subsurface diagrams are useful to see what CMP spacing and offsets in each CMP gather results from the surface geometry of shots and receivers. The data recorded is the ground motion which gives a continuous (analogue) signal in time which needs to be digitized for the processing. This digitization needs to be done so that neither temporal nor spatial aliasing occurs. Hence, the complete wave-field which arrives at the surface must be faithfully represented by discrete/digital data.
Although all the information is present in the so-called shot or field records, processing is needed to make them accessible for interpretation. In interpretation, we try to obtain a true image of the “geology” of the subsurface. Processing can be divided into a) signal processing steps and b) wave-propagation based processing steps. Signal processing steps are, for example, static corrections, removal of shot-generated noise by velocity filtering, shortening of the wavelet by de-convolution, NMO correction, etc. The wave-propagation part consists of migration or imaging. For wave propagation we need, in principle, to use equations describing full elastic wave propagation in an inhomogeneous, anisotropic, visco-

elastic earth (what really happens in the subsurface) and in case of very high frequencies a poro-elastic earth model. However, these equations would lead to very complicated and computer intensive processing algorithms. So, we usually simplify our description of the wave propagation. What we do is to use "*appropriate approximations*". This means that we use simplifications that will still solve the problem at hand, that are still appropriate. The one most often used is the one-way acoustic wave equation which describes only a single reflection per reflection ray-path and ignores density. It only uses a velocity depth model and only considers P-wave propagation. This will provide us, for example, with migration algorithms/operators (for time- as well as depth migration). It can give a migration output that may show the errors of ignoring anisotropy, attenuation, wave conversions, etc. An improvement is to use the two-way wave equation. This is implemented in Reverse Time Migration (RTM).

Despite the use of this acoustic approximation in our processing, amplitudes can still often be used to determine pore-fluids and pre-stack migrated data can be used in AVA analysis for deriving shear wave properties. But note that if we model, as in inversion, a synthetic geophysical quantity, say related to amplitudes, such as the reflection coefficient we need to include densities across the interface and for AVA we need to include density and shear velocity to interpret the pre-stack seismic amplitudes (as the effect of these properties is contained in the observed data).

The ultimate dataset is the one that can be inverted using Full Waveform Inversion (FWI), that means multi-azimuth, short and long offset recordings. This can be acquired using Ocean Bottom Nodes (OBN), sometimes a combination of streamer acquisition and sparse OBN.

Processing

As mentioned before, the aim of processing is to obtain an image of the subsurface which depicts as faithfully as possible the geology. Some people would say that processing basically consists of "imaging" and the rest of the processing is pre- and post-processing. Whether you see it like that or not is not that important.

In common practice, we split up the processing into a sequence of small steps, which can be done in any sequence needed, hence endless permutations are possible. These operations need optimal parameter choices specific to each project. Also, during processing, it is important to prevent aliasing from occurring when going from one domain to another (un-aliased data in shot gathers can turn into aliased data in common midpoint (CMP) gathers).

The objective of processing can also be subdivided into three sub-objectives: 1) Improving signal-to-noise (S/N) ratio by static corrections and filtering, 2) Improving vertical resolution by de-convolution and 3) Improving horizontal resolution by migration. Sub-objectives 1 and 2 make use of signal processing, whereas sub-objective 3 makes use of wave propagation.

An alternative is to use Full Waveform Inversion (FWI). In FWI we aim at obtaining a velocity-depth model of which the synthetic data matches the observed data. This will directly give the elastic parameters and in addition allows a much better seismic image of the subsurface.

In Quantitative Interpretation the rock properties are linked with the derived elastic parameters. Special processing is needed in that case.

More and more use is made of Machine Learning, part of Artificial Intelligence, as it allows a much more versatile and less time-consuming approach in designing acquisition and processing.

The Course
The above items will be dealt with in the course; by presentations, videos and by doing many practical exercises to enhance the learning.

Learning methods and tools
The course uses a Learning Management System, called Moodle. In Moodle different modules provide study material, videos, and exercises. Also, each part contains a quiz which is meant to reinforce the learning.

Requirements
A good understanding of the basics of geophysics.