AVO + Inversion

I will start with "Geophysical Methods" or "Multi-Physics" presentation, in which I show the importance of considering the whole range of geophysical data (seismic: velocity & density, gravity: rock density, magnetics: magnetic susceptibility, electromagnetics: resistivity) that could help in understanding the subsurface. The next step after a structural and stratigraphic interpretation is quantitative interpretation (QI). For QI, special, relative-true-amplitude processing is needed to assure that the reflections can be interpreted quantitatively in terms of lithology and pore fluids. For QI, the final resolution after processing is shown by the compactness of the Point-Spread-Functions (PSFs).

The complexity of the subsurface is looked at in terms of inhomogeneity and anisotropy. Inhomogeneity is well known, the earth consists of rock bodies with different lithologies and pore fluids, but in addition some properties can only be accurately described by including anisotropy. Clear examples are shales, where the stacking of clay particles cause wave propagation to be dependent on the direction relative to the orientation of the clay platelets. This is also in the case of cracks and fractures, which when "organised/systematic", say perpendicular to the minimum horizontal stress influences the wave propagation. Thinking the other way around, these rock properties can be derived from seismic AVA observations. The way the reflection amplitude changes with azimuth can be used to determine the presence of vertical fracture systems. In addition, amplitude changes with offset, or angle-of-incidence to be precise, can be used to determine changes in rock and fluids across interfaces. As the seismic waves are band-limited they interrogate only the "wavelength-average" rock properties. Diverse ways of averaging can be used to calculate so-called effective media. Acoustic Impedance (AI) is the rock property usually considered. AI is related to rock properties seen by normal incidence reflections. More information on the rock properties is captured in AVA related Elastic Impedance or even better Extended Elastic Impedance (EEI). AVA can be calculated using Zoeppritz equations, which are often linearized to provide inside into the influence of rock properties. Alternatively, it can be calculated using the wave equation, which will be demonstrated.

Then I concentrate on Rock Physics. Rock Physics deals with the relationship between elastic wave propagation properties (velocity, density, attenuation) and reservoir properties (porosity, permeability, fracture systems, saturations). Two basic kinds will be discussed. One for clastic rocks, the other for carbonate rocks. These are conventionally given by standard well-based statistical relationships, but recent case studies show that better results can be obtained using Machine Learning. For direct calculation of the seismic response to a reservoir filled with a pore fluid, it is necessary to know the dry rock skeleton properties. This is near to impossible, except based on a core. Therefore, an alternative is applied, namely having log measurement of the rock filled with a determined (known) fluid mixture, Gassmann's equation allows the calculation of its properties when the rock is filled with another fluid mixture (Gassmann fluid replacement algorithm). But the "averaging" of fluid properties in case of a mixture also depends on the distribution of the saturation (uniform or patchy). Exercises will help to see the significance of the topics discussed.

Finally, I will discuss a topic that is revolutionizing our workflows, namely that part of Artificial Intelligence that is called Machine. An important characteristic of Machine Learning that it allows a better use of the multi-feature space describing the rock properties. This will lead to better rock models.

Many exercises will deal with the use of AVA for PP, SS and PS data.

Inversion
The aim of inversion is to derive the rock properties from seismic data. However, there are several ways of inverting seismic data.
One kind is to invert the seismic reflection amplitudes to elastic parameters such as acoustic impedance. Examples are Bandlimited (Recursive), Sparse Spike, Coloured and AVO inversion. As seismic data is bandlimited, constraints are added to obtain absolute elastic values. A clear example is the use of a low-frequency (low-wavenumber) background velocity model. Apart from AVO, these are, although useful, all "poor man's solution" as the result is only approximately correct.
AVO inversion provides an opportunity to move away from acoustic impedance (AI) towards elastic impedance (EI) or even better extended elastic impedance (EEI) using the angle dependent reflection strengths. The true angle of incidence θ [0-90°) on a reflector is used in EI, but for EEI a parameter χ [-90°-+90°] is used, which has the unit of degrees, but clearly cannot be an angle of incidence. For specific values of χ the χ-trace correlates very well with certain rock parameters. These angles can be found by correlation with well logs, but also a physical poro-elastic interpretation can be given.

Another kind of inversion is the Full-Waveform-Inversion (FWI), which derives detailed elastic parameter models directly from seismic data. This approach compares synthetic seismic with observed seismic and adjusts the starting model iteratively till the synthetic data fits the observed data according to a set criterion. This method knows two critical steps, namely a forward modelling step (from model to synthetic seismic) and an inversion step (from synthetic-observed data difference to model updates). FWI, although compute intensive, is being applied increasingly to derive elastic parameters and high-quality images of the subsurface. But a second step is still needed to go from elastic to rock parameters unless these are explicitly included in the forward modelling. Note that to convert elastic to rock properties a rock-physics model is needed. For a clastic environment, such models are readably available, for carbonates an informed (using well logs) choice must be made which rock-physics model should be used.

In the last 10 years Machine Learning started to make successful inroads into AVO modelling and inversion. Various successful case studies will be discussed.

The course

In the course we will discuss extensively the opportunities provided by AVA, the pros and cons of the conventional inversion methods, the progress made in FWI and the new applications of ML. Apart from presentations, the learning will be enhanced by exercises, videos, summary presentations by participants and quizzes using "mentimeter".