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Combined Inversion of Seismic and Magnetotelluric for Gas Exploration in the Canadian Foothills

Seismic is the method of choice to identify sedimentary boundaries in the Canadian Foothills. However, there are a number of reasons why in some areas the quality of a seismic image can be so poor that its interpretation is hardly possible. These areas are unfortunately not related to boundaries of hydrocarbons - mostly gas reservoirs.
Magnetutelluric (MT) can distinguish between different lithologies based on their electromagnetic resistivity. The MT data quality is not necessary poor in the same areas where seismic data is as the acquisition of the different data sets and its physics is quite dislike. Hence, could the two methods complement each other? Is common inversion of seismic and magnetotelluric data an option for gas exploration in the heavy structured thrust belt environment of the Canadian Foothills?

Traditionally recordings of seismic measurements are the only areal source of geophysical information in the Canadian Foothills. An artificial explosion sets up an acoustic signal which, after being reflected at an acoustic impedance contrast, can be re-collected at the surface. A vast amount of experience has been gained with the interpretation of acoustic reflections. In particular during the last 15 years lead the recording of the signal in an areal fashion to 3D seismic representations. Under favorable conditions the vertical seismic resolution decreases only slightly with depth within the first few 1000 meters below surface.
As the cost of acquisition of 3D seismic on land in remote, rugged terrain is expensive, however, many areas are covered with just 2D profiles or with ‘sparse acquisition’ 3D seismic.
Rough topography, poor coupling of receivers and steep outcropping geological strata are causes for poor quality seismic data. Several areas in the Canadian Foothills are declared as environmental sensitive zones with often limited possibility for artificial explosions. Complex carbonate thrust edges embedded in sediments often lead to poor lateral resolution of the seismic image. More subsurface uncertainty comes with the acoustic transverse anisotropy of particularly shales, which the wavefield of a reflected reservoir has to pass twice.
The reality is that poor seismic data quality is often adjacent to more favorable seismic conditions, which allow much higher seismic resolution. The structural seismic interpretation in poor quality areas is often very difficult and cannot support the regional geological conditions. Thus drilling targets within carbonate thrusts cannot be located or the resolution of the reservoir interpretation leads to very risky drilling decisions. Therefore, there remain potentially considerable gas accumulations, which remain untapped with seismic data alone.

Electromagnetic methods are among the oldest geophysical methods and have been used in deep earth studies as well as diverse shallow applications. One of these methods is magnetotelluric (MT). MT measures components of the electric and magnetic field at the surface in response to a grounded dipole source. Apparent resistivity and phase can be calculated and related to the earth’s properties. It is commonly assumed that the fields are measured far from the source. The decay rate with depth of the signal is a function of the frequency of the signal. With the ‘controlled source audio magnetotelluric’ technique a range of different frequencies are employed to scan various depth ranges. With the depth of the lithology the resolution of MT decreases exponentially. The electrical resistivity of the earth depends next to its lithology on the type of pore fluids, temperature and chemical variations.

Recent advances in acquisition equipment have made area wide recording very cost effective. Generally it is not problematic to acquire MT data in rugged mountainous terrain. Last year several 3D inversions of MT data were presented that solve the computer intensive multi-station and multi-frequency problem by e.g. non-linear conjugate gradient applied directly to the minimization of the objective function. Thus, a much higher lateral resolution of the complex geology could potentially be achieved. Is there an emerging opportunity to combine this technique with the data of seismic measurements?

Consider the integration of independent geophysical data with different physical meaning, acquisition type and resolution power. Seismic serves the impedance – depth space whilst MT serves the resistivity – depth space. Using both data, could the space of possible solutions of one data type reduce the space of solutions for the other? In particular, could MT help to better define the geology than the regional geological model in areas of poor seismic? Generally the noise conditions are favorable for MT in most poor seismic quality areas, as there are few fences, electrical power transmitters or pipelines.

Can a geological model be produced by joint tomographic inversion of both data types? Which would be favorable conditions for the application. What kind of computing power is likely to be involved?

What are the theoretical and practical issues involved in combining surface seismic and surface MT data by combined tomographic inversion in areas where seismic alone can not sufficiently explain the subsurface in the Canadian Foothills. A step further in improvement of the subsurface data is a step further towards the discovery of new gas accumulations. Is this a challenge that PIMS scientists would like to tale on with for a week in Vancouver in May?