Novel Exploration Techniques for solving problems

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Abstract

This talk will consist of three parts. The first part will address the ground and airborne electromagnetic and magnetic geophysics combined with seismic reflection and seismic refraction to get complimentary information to drill logs. This integrated approach to explore paleochannel systems for shallow gas, define oil sands and heavy oil resources, or explore for groundwater and aggregates is efficient and cost effective. The second part will address an integrated approach to oil sands exploration and delineation and outline a recommended approach for exploration of both surface mineable and in situ oil sands leases in the vicinity of Fort McMurray, Alberta. The third part will address the advances in AVO processing and analysis and the road ahead.

Part 1: Electromagnetic and Magnetic Methods for Exploring Incised Valley Systems for Shallow Gas

Sand and gravel filled Quaternary, Tertiary and Cretaceous aged incised valleys are common in the WCSB. In the Sousa area very shallow paleochannels may be sealed by glacial fluvial clays and some are charged by gas migrated from deeper reservoirs. Wells in the Sousa area have been completed at less than 100 m. Potentially many other areas of the WCSB may contain similar shallow gas reservoirs in paleochannels. Inexpensive exploration tools are needed to facilitate an economic return from this particular hydrocarbon resource.

The low cost, high spatial density and 3-dimensional mapping capability of airborne electromagnetic (AEM) surveys have made them indispensable for mining exploration and they have also found use for environmental site characterization, groundwater and aggregate exploration. Electromagnetics is useful to differentiate clay and shale from aggregate and porous rocks, and AEM can rapidly and cost effectively survey large areas to a depth of approximately 250 metres. The sand and gravel which fills some of WCSB paleochannels produces a distinct resistivity contrast to clay and shale. An integration of AEM, ground EM or resistivity, seismic and well logs allows for a detailed interpretation of the characteristics of the incised valleys and facilitates targeting locations with potential for shallow gas reservoirs and traps.

Airborne magnetic methods are already established as cheap and powerful tools for mapping strongly magnetic (primarily basement) structures. Recent improvements in instrument resolution and acquisition techniques have allowed for the utilization of magnetic methods for mapping the weakly magnetic intra-sedimentary structures. Conventional fixed-wing, high-resolution magnetic field data over the WCSB can also map a large number of sinuous anomalies, which have been interpreted to represent buried channel systems.

Channel systems can create two very different and distinct magnetic anomaly patterns. One arises from a channel eroding a cut into a horizon that is magnetic. The channel is marked by a magnetic low. The other arises if a magnetic material is deposited in a channel and the surrounding rocks are not magnetic. The channels in this case are marked by magnetic highs. Since the heavy mineral magnetite gives rise to most magnetic anomalies and tends to concentrate in coarse aggregate, magnetic highs along channels may map potential shallow reservoirs. Both these channel systems occur in the WCSB.

Part 2: An Integrated Approach to Oil Sands Exploration and Delineation.

The geology of the Athabasca Basin can be extremely complex on a local scale. In order to address this complexity, it is important to develop an integrated cost effective approach to exploration and development. This paper outlines a recommended approach for exploration of both surface mineable and *in situ* oil sands leases in the vicinity of Fort McMurray, Alberta.

The depths of investigation vary from 0 to 100 metres in the surface mineable and from 0 to 250 metres in the in-situ area. Objectives of exploration programs include:

- Delineation of rich oil sands of McMurray Formation
- Presence and thickness of Clearwater Formation
- Mapping Paleozoic surface
- Groundwater sources
- Delineation of surficial deposits
- Siting of facilities
- Presence of basal water sands

At present, the drill hole density on many leases varies from 16 or more wells per section to less than 1 well per section. In order to provide additional information between wells, a number of complementary geophysical surveys are recommended as summarized in the following table:

Geophysical Survey	Area	Objective
Airborne electromagnetic:	surface mineable and *in-situ* area	Presence of Clearwater Formation Delineation of rich oil sands Siting of facilities Delineation of surficial deposits
Airborne magnetic:	surface mineable area	Basement structure
Seismic reflection:	*in-situ* areas	Mapping Paleozoic surface
Seismic refraction:	Surface mineable and *in-situ* areas	Mapping Paleozoic surface
Transient electromagnetic soundings:	Surface mineable and *in-situ* areas	Thickness of Clearwater Formation Groundwater sources Delineation of rich oil sands Presence of basal water sands

In order for the geophysical surveys to provide complementary information to the drill data, there is a necessity for a mappable contrast in physical properties at the geological horizons of interest. Borehole geophysical logs provide the detailed information required to determine the effectiveness of both the airborne and surface geophysical techniques.

This approach allows the lease owner to cost effectively integrate diverse data sets in the evaluation of their lease. This paper provides an overview of the cost effective approach which relies upon the integration of geology with borehole, surface and airborne geophysical methods. There is also a discussion of the advantages as well as pitfalls in application of the integrated lease evaluation method.

Part 3: Advances in AVO and the Road Ahead

AVO processing and analysis has evolved significantly since the early 80's and Shuey's classic paper. The industry has moved past simple gradient analysis and brought AVO into the World of inversion.

Simultaneous AVO Inversion is a unique product which has proven to be a useful tool in both exploration and reservoir characterization. Its inputs are partial angle or offset stacks and logs. Its outputs are volumes of P Impedance (Ip), S Impedance (Is) and Density. When the high angles necessary for density determination are not present, density is constrained to follow the character of the P Impedance. Recent advances have enabled the algorithm to be configured to determine Vp/Vs directly and simultaneously with P Impedance and Density. It turns out that Vp/Vs is a very good control on residual normal moveout – critical to any good AVO analysis.

Traditionally, partial angle stacks are used as input. For each partial stack, a unique wavelet is estimated. Solid models of Ip, Vp/Vs and Density are also computed from the available logs. As in post-stack inversions, only the low frequencies from these models are used to complete the low frequency band of the final inversion. They in no way affect the higher inversion frequencies and the inversion can be effectively considered to be "blind" to the wells. All the models, all the partial stacks and all the wavelets are input to a single inversion procedure. There is no intermediate stage or separate estimations of P and S reflection coefficients from weighted stacking. More recently, the ray-tracing necessary to construct the partial stacks can be done and re-fined within the inversion algorithm. This allows the input of partial offset stacks rather than partial angle stacks. The result is greater control over ray-tracing and the quality of the angle data.

One further innovation is compensation for anisotropy. At large angles, when density effects become significant, anisotropy can have an equally large effect.

The analysis of the final inversion is most easily done in cross-plot space. Cross-plots of Is vs Ip (for example) from logs might show the reservoir to be separable from other litho-facies. The identical cross-plots can be made from the inversion data and the same regions of interest in cross-plot space highlighted and viewed in 3D perspective.

We will review the theory of full-stack and AVO inversion and present some