

Interpretation of Quaternary geology using airborne EM and seismic data: Horn River Basin, British Columbia, Canada

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Summary

This paper presents the results of a combined seismic and airborne electromagnetic (AEM) interpretation of the shallow Quaternary sediments and bedrock within an area of the Ootla 3D seismic survey carried out by Arcis Seismic solutions. The integration of the two data sets provided a more comprehensive interpretation than either data set on its own. Several potential paleochannels were located and the AEM data was shown to be able map the bedrock topography with enough accuracy to

Introduction

The Horn River Basin in northeastern British Columbia (Figure 1) is a significant shale gas play. The formation of interest, the Horn River shale, is composed of argillaceous, bitumenous limestone and dark, siliceous and calcareous shale of Devonian age (Gray and Kassube, 1963; Whittaker, 1922). The Horn river shale has extremely low permeability. Multi-stage hydraulic fracturing of the production wells is used to increase the permeability and allow gas to flow at an economic rate. Fracturing these horizontal wells requires significant volumes of water. In the Horn River basin between 80,000 to 100,000 barrels of water are required to fracture a single 1500 m horizontal well.

Sources of water for hydraulic fracturing are 1) surface water from rivers, streams and lakes, 2) shallow (less than 500 m) fresh water aquifers either in unconsolidated sediments or shallow bedrock, and 3) deeper (greater than 500 m) saline aquifers in bedrock. Although surface water has been the main source of water for hydraulic fracturing in the Horn River basin, there is significant interest from the operating companies and the British Columbia government to locate groundwater aquifers as an alternative water source.

This paper presents the results of using a combination of airborne EM (AEM) and seismic methods to map the unconsolidated Quaternary sediments and the shallow bedrock. The objectives were 1) to map a potential Quaternary paleochannel groundwater aquifer and 2) to use AEM to map the variation of Quaternary sediment thickness as input for static corrections.

In 2005 Arcis Seismic Solutions of Calgary, Alberta carried out the Ootla 3D seismic survey. The goal of the survey was to map the Horn River shale sequence. In 2010, Geotech Airborne Geophysical Surveys of Aurora, Ontario was flying a survey for shallow groundwater near the 3D survey area. Geotech approached Arcis to see if there were any shallow features within the 3D survey area that could be a potential shallow paleochannel. Four lines that contained a shallow seismic feature were selected (Figure 2) and flown with Geotech's VTEM AEM system (Witherly et al., 2004). The seismic and AEM data along these lines were jointly interpreted to provide an interpretation of the Quaternary sediments.

Theory and/or Method

The two-way time 3D seismic data volume was processed and then converted to depth. Since these techniques are well known we focus on the less known airborne EM acquisition, processing and inversion methodology.

Geotech's VTEM system is a helicopter towed time-domain electromagnetic system. The transmitter, consisting of a 26 m diameter loop with 4 turns of wire, has a peak dipole moment of 550,000 Am². The transmitter pulse width is 4.4 ms for 30 Hz frequency. The receiver measures the voltage of the vertical and in-line horizontal components of the magnetic field (B) and its time-derivative (dB/dt) in 32 off-time channels from 0.09 to 7.56 ms (channels 14 to 45). The nominal height of the receiver above ground is 30 m.

The time-domain profiles were inverted using layered and laterally constrained inversion software (Auken and Christiansen, 2004). The software is contained within version 4.0.1.716. of the Aarhus Workbench software. A Laterally Constrained Inversion (LCI) using smooth models is a reasonable approach for this data set since the geology is known to be layered and slowly varying laterally. The data were de-spiked and then averaged using a trapezoid-shaped filter to produce a sounding every 1.1 seconds along the profiles. The LCI method utilizes a least squares inversion algorithm with lateral constraints that smooth the variations between soundings. A nine layer model was used for the inversion.

Examples

The 4 depth migrated seismic lines were converted into Geosoft format and the upper 400 m of these sections were displayed as black and white sections. Figure 1a is an example of a depth migrated seismic section (line 43), Figure 1b is the corresponding AEM inversion (line 1000) and Figure 1c shows the seismic section with the AEM inversion overlain in colour. There is a conductive layer (6 to 10 ohm-m) approximately 40 m thick between 500 and 540 m above sea level (asl). The strong seismic reflector at approximately 500 m asl closely follows the bottom of this conductive layer and a discontinuous weaker reflector tends to line up with the top of the layer. This layer corresponds to the Cretaceous shale mentioned earlier and the more resistive material (larger than 50 ohm-m) above the shale is the unconsolidated Quaternary sediments. The more resistive values (larger than 200 ohm-m) within the Quaternary sediments correspond to areas containing coarser material. There is a thin layer (approximately 10 m thick) at the surface of moderately resistive (20 to 30 ohm-m) material.

There are two regions on the bedrock (shale) surface that could be potential paleochannels; one at the western end of the line between 536700 and 541000 and one at the eastern end of the line between the two north-south lines. There is a depression on the shale surface associated with the western region indicating an area of potential erosion. The overlying Quaternary sediments have higher resistivity values and the shale appears to be slightly more resistive as well. The seismic reflection pattern within the Quaternary section is more complex in this region and the shale reflection is more disjointed. The eastern region is not as easy to recognize on the seismic section because of a gap in the seismic data but shows up as a subtle depression on the AEM inversion and again the resistivity values within the overlying Quaternary sediments are higher. The portion of the shale reflection next to the gap however has a similar character to the reflection of the western region.

The same two features can be seen on the other east-west line (line 1010) shown in Figure 2. The western feature is located between 53700 and 54070 and the eastern one is located between 547300 and 55150. The resistivity highs in the Quaternary sediments are more continuous within these

two regions for this line. The seismic character for the western region is very similar to the seismic character of the western end of line 1000.

Figure 2 is a 3D image showing the 4 seismic lines with the AEM inversion overlain in colour. Note the continuity of the seismic and AEM images at the crossover positions on these lines. The two potential paleochannel locations on lines 1000 and 1010 appear to connect and form roughly north-south channels (labelled W and E for west and east). The narrower features located on line 1010 are labelled A, B and C. Although there are several possible locations where these features may be located on line 1000, which location is associated with which feature on line 1010 is not clear.

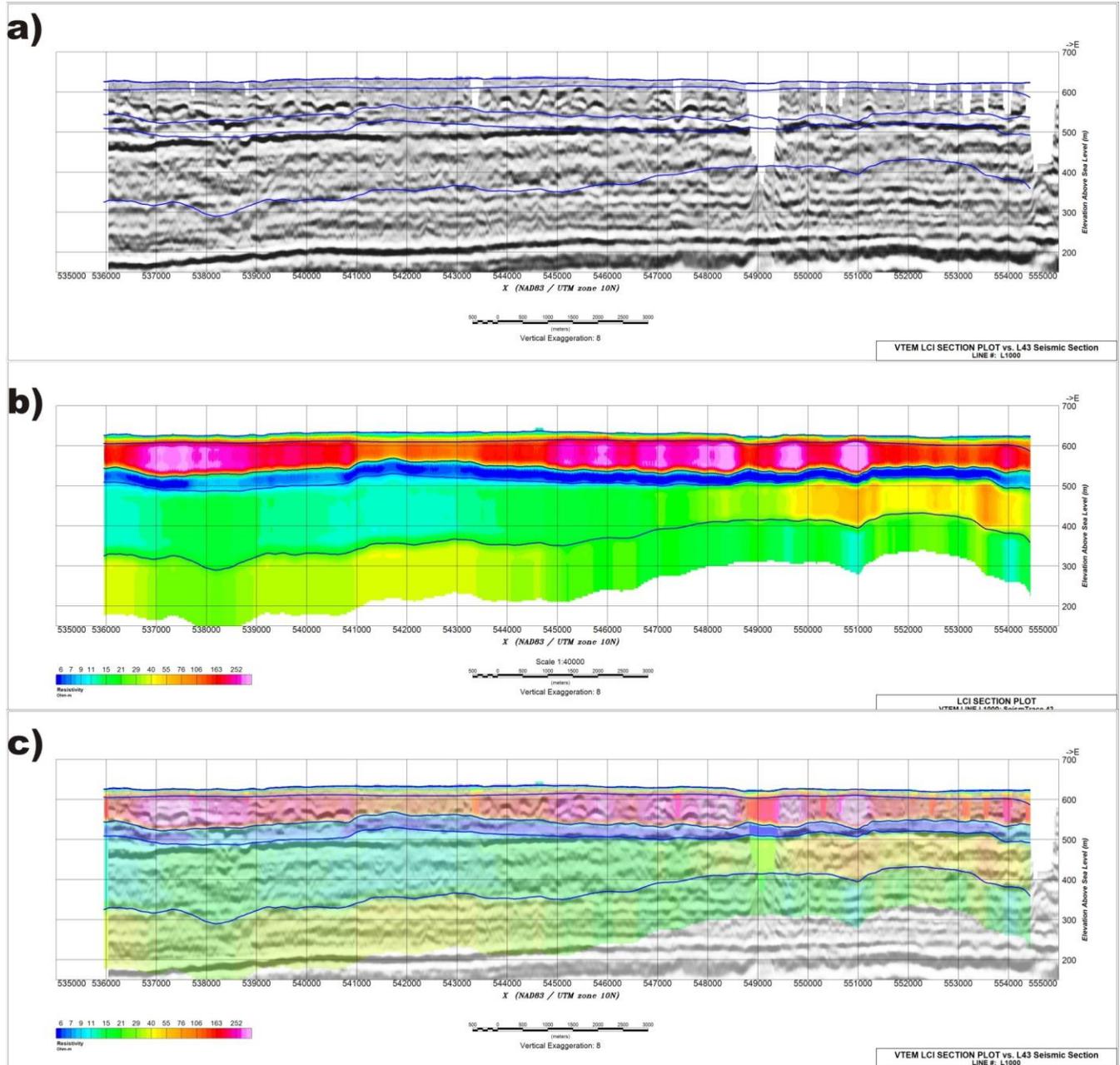


Figure 1 a) Upper 400 m of the depth migrated seismic section (line 1000) b) The corresponding AEM inversion and c) the depth migrated section with the AEM inversion overlain in colour.

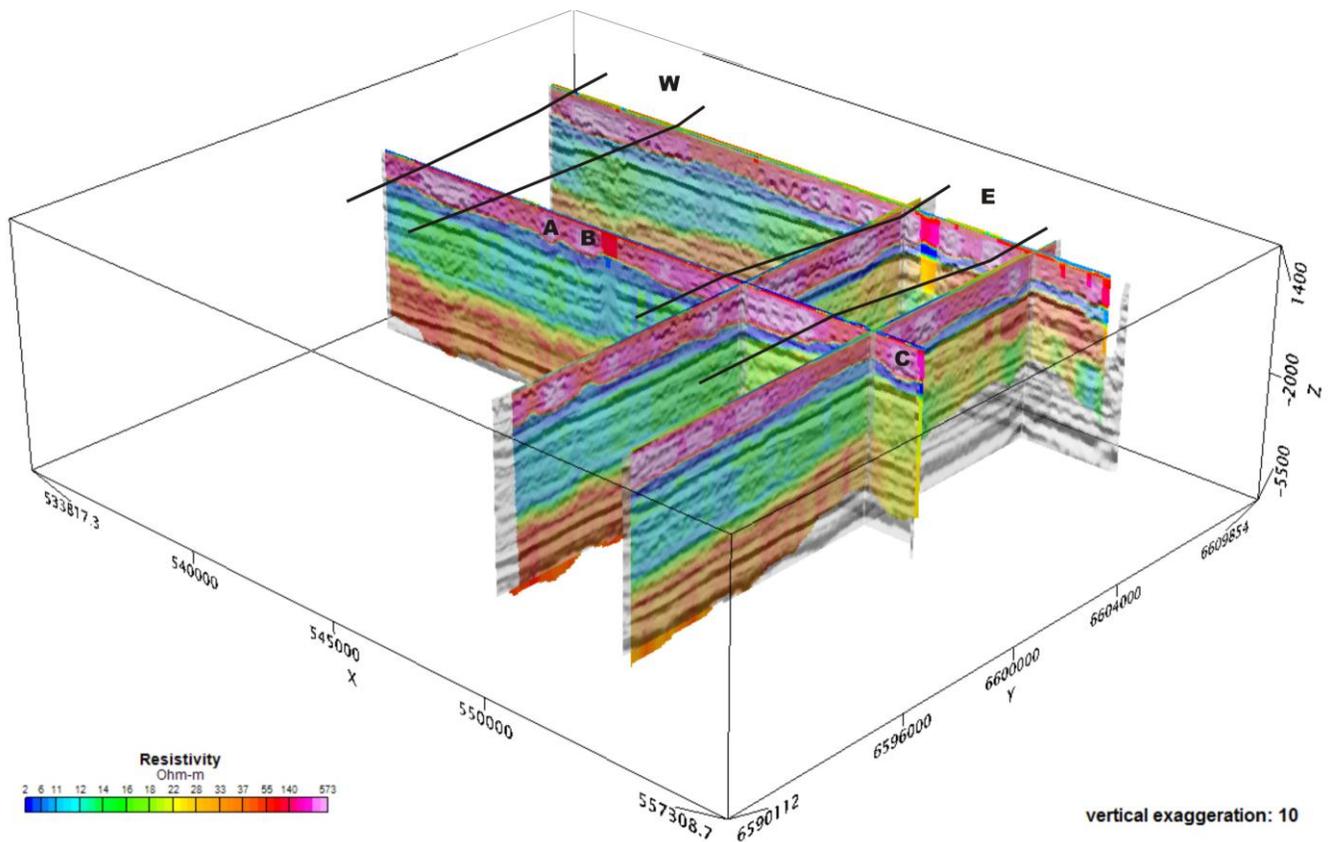


Figure 2 3D image of the 4 seismic lines with the AEM inversion overlain in colour. The two potential paleochannels are labelled W (west) and E (east). A, B and C are smaller features on line 1010 that could also be channels.

Conclusions

The integration of the two data sets provide a more definitive interpretation of the shallow geology than either of the methods by itself. The combined interpretation shows the location of several potential paleochannels. The AEM data set provides a detailed map of the bedrock topography that can be used as input to seismic static correction programs.

References

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