The purpose of the present study is to show what can be achieved from AEM data by using different inversion approaches and the associated geological modelling implications. Groundwater has been poorly understood in the Peace Region of NE British Columbia (Canada), an area of significant natural gas development. The Peace Project is a collaborative effort aimed at providing baseline information to First Nations communities and government to help make informed groundwater management decisions. The present study is part of The Peace Project designed to locate and map shallow aquifers. The study area is situated in the Peace Region, involving an area of about 1960 km$^2$. The dataset consists of approximately 4500 line-km of AEM data (Viezzoli et al., 2018), located in the North Western part of the Peace River Project (Fig. 1).

The geological setting of the area is dominated by its position between the Cordillera Orogenic Belt, to the west, and Alberta Foreland Basin to the east. According to the stratigraphy of the nearby areas (Jørgensen et al., 2016), the lithostratigraphical formations that are within the expected penetration depths of the SkyTEM method (2-400 m) are, from below: the Nordegg Formation composed by calcareous mudstones, the Buckinghorse Formation composed by shales, silty mudstones and siltstones, the Sikanni Formation composed by alternating layers of sandstone and siltstone, the Sully Formations composed of mainly shales and siltstones and the Dunvegan Formation mainly composed by sandstone with subordinate conglomerates (Jørgensen et al., 2016). Quaternary deposits include different kind of depositional facies. Among these, one can find the resistive glaciofluvial deposits and conductive glaciolacustrine deposits.

In 2017, Aarhus Geophysics Aps processed a portion of the EM dataset in the north-west corner of the Peace project area, starting from raw data, adopting state of the art methodologies aimed at reducing artefacts in the data, and therefore in the derived models (Auken et al., 2009). The geological and hydrogeological interpretations, for the entire dataset in the North Western area, were carried out by GEUS in 2017.

Fig. 1 - Right panel: Canada - adapted from www.google.it/maps. Central panel: The green polygon is the Peace Project Main Area - adapted from www.geosciencebc.com. Left panel: The red polygon outlines the area of the dataset located in the N-W part of the Peace River Project. The two solid red lines (A-B) are two cross-sections used for testing different types of regularization. The black polygon (Area1), within the red one, outlines the area involved in the present study. Adapted from Petrel Robertson, 2015
The present study represents a Peace River Project integration involving an area of about 19 km by 11 km (Fig. 1, Area 1) within Peace River Project. This study has been developed to obtain different types of geophysical models testing several inversion strategies. The key contribution expected from different inversion models is therefore to better resolve layers boundaries, lateral and vertical extent of resistivity features. How these final models could change the subsequent geological interpretation has been thoroughly investigated.

In order to assess the potential and limits of different types of geophysical inversions 4 synthetic models were performed. These models have been carried out considering the general geological structures observed in British Columbia (Jørgensen et al., 2016).

From the SkyTEM data acquired in the Peace Region, many cross sections have been produced. 30% of these cross sections, located in the Area1 (Fig. 1, left panel) has been inverted applying settings analyzed for synthetic models. We have selected one cross-section, located in Figure 1, for presentation. We show different sharp inversions in order to study how working on different sharp settings implies the models complexity evolution. The project goal is to better outline sedimentary units specifically within Quaternary deposits. These features could potentially host groundwater resources. We present a subsequent rough geological interpretation of the cross-section A (Fig. 1) based on sharp Laterally Constrained Inversion (LCI) sharp inversion. In order to improve the final result, the quasi-3D Spatially Constrained Inversion (SCI) have been performed.

The strategy. After studying the general geological structures of British Columbia, 4 different synthetic models have been built, using similar geological geometries. For each model 3 different inversion strategies have been carried out: 1) Smooth; 2) Few Layers; 3) Sharp (Vignoli et al., 2017). The first type of inversion discretizes the half-space with numerous layers having thickness logarithmically increasing with depth. The second type reconstructs petrophysical interfaces using a discretization with a limited number of layers. A relatively new type of inversion is the sharp method that promotes the reconstruction of blocky solutions using a parameterization characterized by many layers (as in the more traditional smooth inversion) (Zhdanov, 2002).

Synthetic results. The inversion results of synthetic models have generated an ensemble of hundreds of resistivity models that adequately fit the data given the assigned noise levels. The details of one synthetic model are found in Fig. 2 (left panels). The smooth inversion was parameterized with 30 layers and a homogeneous half-space of 100 Ωm as a starting model. This approach (Fig. 2, model b) is able to resolve qualitatively the bottom of glaciofluvial and glaciolacustrine deposits and the bottom of the Buckinghorse Formation as well, up to a

Fig. 2 - Left panels: Synthetic modelling results. a) the true model; b) smooth result; c) few layers result; d) sharp result (below each inversion, also the associated data residuals are presented: solid blue and red line is the data misfit respectively for HM and LM); e) legend of the electrical layers. Right panels: Sharp models with gradually changing complexity. Tight to loose settings from profile 1 to 6. Models are shaded with DOI and shown associated data misfit (red line).
depth of 300 m. The model b loses sensitivity in the central part, below the conductive layer (Buckinghorse).

The starting model of the few-layers inversion was parameterized with 3 layers and a homogeneous half-space of 100 Ωm (Fig. 2, left panels, c). The few-layers approach can resolve boundaries of glaciofluvial deposits but, it is not able to fully resolve the structure of glaciolacustrine deposits. The model loses sensibility for the Nordegg Formation. The data Misfit is generally acceptable except in the left part of the profile. Locally the model does not fit the data. The sharp inversion is parameterized with 30 layers (β1=27, β2=15, σH=2%, σV=10%, refer to Vignoli et al., 2014) and a homogeneous half-space of 100 Ωm is used as starting model. The sharp is clearly the most effective one in terms of reconstruction of geometries and retrieval of the correct resistivity values. The response of the strongly resistive formation (Nordegg) is clear as well as the lower contact of the Buckinghorse Formation.

**Results on real data.** 30% of the cross sections, located in the Area 1, have been inverted. The settings are the ones tested in the synthetic modelling. The inversion results gradually change (Fig. 2, right panels), passing from models that do not fit adequately the data but are capable of discerning basic resistivity structures, to models rich-in detailed resistivity features, but, at the same time, capable of reconstructing blocky solutions. We start from a simple model made up of few main blocks with different resistivity values to detailed geophysical model with quasi-smooth resistivity variations. The details of sharp inversion on a selected cross section are shown below.

A rough geological interpretation has been undertaken on cross section “A” (sharp model n.4 in Fig. 2) starting from the geological interpretation (Fig. 3, lower panel) carried out by

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**Fig. 3 - Upper panel:** Cross sections A: geological interpretations of the sharp result. Bedrock formation boundaries are delineated by thick grey lines. Interpretations in the drift succession are delineated by thin black dotted lines. Models are shaded with DOI and show associated data misfit (red line). Lower panel: GEUS geological interpretation. Vert. Exag. 10x.
GEUS in 2017 (Viezzoli et al., 2018). The lithostratigraphic formations observed in this section (Fig. 3, upper panel) are, from below: (1) the Buckinghorse Formation and (2) the Sikanni Formation. On top of these formations, the Quaternary sediments display a degree of vertical variations in resistivity due to the presence of internal heterogeneous structures.

The derived geological interpretation using the sharp inversion is characterized by: fully resolved layers thickness within the glacial cover; well resolved small hill structures in the middle of the modern valley, formed by glaciolacustrine deposits; clear resistive response from the heterogeneous bedrock formation; an uncertain interpretation of the lower boundary of Buckinghorse Formation. What is below the Buckinghorse has therefore not been interpreted.

Conclusions. The smooth approach may produce suitable models in environments where material properties vary gradually. The few layers approach is useful in models with simple geological geometries whereas the sharp approach provides a good combination of the two. The sharp model is capable of providing compact resistivity structures separated by clear contacts. This makes much easier the identification of the petrophysical interfaces, and, in turn, facilitates their subsequent geological interpretation. The derived preliminary geological interpretation of the cross section in Fig. 3 (LCI inversion result) does not take into account resistivity variations within the glaciofluvial deposits (“gfd” Quaternary unit, Fig. 3). On the other hand, the geological interpretation carried out by GEUS is based on a smooth-SCI inversion. In this type of inversion model parameter information migrates horizontally through spatial constraints, increasing the resolution of layers (Viezzoli et al., 2008). Therefore, in order to locate and map buried valleys within the Quaternary coverage, the quasi-3D SCI sharp inversion has been carried out. We have obtained different reasonable 3D sharp-models that have been used to improve the final geological interpretation.

References


