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Rethink GroundWater Mapping and Management Strategies for Unconventional Uydrocarbons using Airborne EM

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Summary

The need to map, extract, manage and regulate Groundwater for unconventional hydrocarbons exploration requires a multidisciplinary approach in which Airborne Electromagnetics can play a significant role. Denmark undertook a large Ground water mapping campaign over more than a decade that allowed securing long term sustainable groundwater management. The Airborne EM provided a crucial component of this project. It required proper planning, data quality and calibration, processign, modelling and integration. We suggest that parts of this model can be applied also to the Groundwater issues that Canada is facing for unconventional hydrocarbons activities. Many steps of the workflow can be applied as are, or slightly adapted. Results presented herein illustrate its benefit, upgrading significantly the existing hydrogeological knowledge.

Introduction

The need to map, extract, protect and manage ground water has become apparent in Canada over the last few years. Both the industry and the regulators realize the importance and sensitivity of groundwater as a delicate, heavily disputed resource and also a politically hot theme. Unconventional plays need a lot of water. So do oil sands and bitumen plays operations. The water used in the exploration cycle needs to be disposed of safely.

As pointed out by Hayes (2013) and George (2013), this situation calls for new interdisciplinary approaches by Petroleum Geologists and Hydrogeologists. It represents both a responsibility and a great opportunity: **"**Petroleum geologists and hydrogeologists working in industry have an essential role in developing new groundwater resources and providing assurance that development does not impact aquifers and aquatic ecosystems**"** (George, 2013). Interestingly, at this stage, geophysics and the professional figure of geophysicist does not seem to have a relevant role neither in regulations nor in the standard workflow to address groundwater issues

In Denmark, the need to map and manage the groundwater resources came for other reasons, mainly managing the balance between agricultural demands and processes and drinking needs. However the issue was the same: know more about the groundwater resources to manage, protect, extract, regulate, with long term sustainability in mind. There obviously are many similarities between the existing approach in Canada and the Danish one. The main difference is that, in Denmark, Airborne Electromagnetics (AEM) played a central role and was crucial to the success of the Groundwater mapping program. This approach goes way beyond the exercise of acquiring AEM data in the first place entailing well-thought long term mapping campaigns, survey planning, calibration, proper data processing and inversion, data integration. We present it here, suggesting that parts of it can be successfully applied to several regions of exploration within Canada, providing a significant contribution towards the GroundWater issue as a whole.

Theory and/or Method

The Danish Government has fully understood the importance to manage and preserve groundwater for current and future generations. In 1998 it began an ambitious nation-wide groundwater mapping programme, which will be completed by 2015, and having the purpose to get an accurate picture of Danish aquifers (Moeller et al, 2009). The application of innovative methods and tools constitutes a proven setup for conducting groundwater mapping on a large scale. Geophysics plays a fundamental role, through the use of Airborne EM (AEM) and ground-based methods. Another key feature is the use of rigorous data processing and protocols, together with the use of innovative 3D geological modelling. This approach made it possible to identify the main groundwater resources, their distribution and size, besides their degree of vulnerability, so that site-specific groundwater protection zones were established to prevent contamination from urban development and agricultural sources. Building on this experience, the Danish Minister of Environment supported the Rethink Water project (Klee, 2013), a network of over 50 Danish companies, organisations and institutions able to join knowledge among industry, researchers and governmental bodies in order to improve water safety and efficiency. The aim is to use this experience to propose the same approach (as a whole, or using only some of its constituent blocks) to other countries all over the World, by promoting knowledge transfer to the local partners.

To obtain the best results in Integrated Water Resource Management groundwater exploitation should be inserted into a long term strategy, by allocating appropriate resources for an administration that will ensure data collection and interpretation.

The Danish site-specific groundwater protection strategy consists of:

1) Spatially dense hydrogeological mapping based on existing data supplemented with new geophysical surveys, water sampling and hydrogeological modelling, in order to draw site-specific protection zones, stored in flexible and robust well documented databases.

2) Mapping and assessment of all past, present and possible future sources of contamination

3) Development of an action plan with agreements and regulations for future land use in the groundwater protection zones.

Groundwater mapping is often based only on drilling information, but, due to low borehole density, the hydrogeological setting often suffers from many uncertainties, so that a realistic hydrogeological model is hard to be achieved. This is where large scale geophysical campaigns can play a role. In the case of the Rethink Water project, the AEM data is used in conjunction with drilling to map aquifers. The winning feature of AEM is the intensive, detailed and large-scale dataset that can be delivered. Followed closely by accurate and rigorous data processing and inversion (Viezzoli et al., 2012) needed to provide an accurate 3D resistivity model of the subsurface, the end result is that the mapping results become more accurate and reliable. The applied data modelling protocols ensure that the geophysical results meet the quality required by groundwater mapping. Very importantly, they also unsure that data acquired over the years by different AEM contractors with different AEM systems are consistent and can the final results can be merged without being survey specific. Spatially dense (in the order of tens of meters spacing) and accurate 3D resistivity models are used to establish the basis of geological and hydrogeological models. The role of the boreholes is that of confirming the geophysical data, complement it and to provide critical information to assist the interpretation of geophysical model into a geological-hydrogeological view. It follows that these two datasets multiply their respective descriptive and modelling capabilities, when used together.

In order to produce final models, other geophysical methods can also be integrated, such as seismic, electrical resistivity tomography, vertical electrical soundings and magnetic resonance soundings. Anciallary data, derived from new boreholes, pumping tests and groundwater head and chemistry mapping, are added to the entire dataset: it is hence possible to extract data directly related to hydrogeology (aquifer thickness, resistivity and transmissivity, quality of groundwater). The merging of all these different info into hydrogeological models is achieved through the interaction of experts in geophysics, geology and hydrogeology. Figure 1 shows schematically the entire workflow.

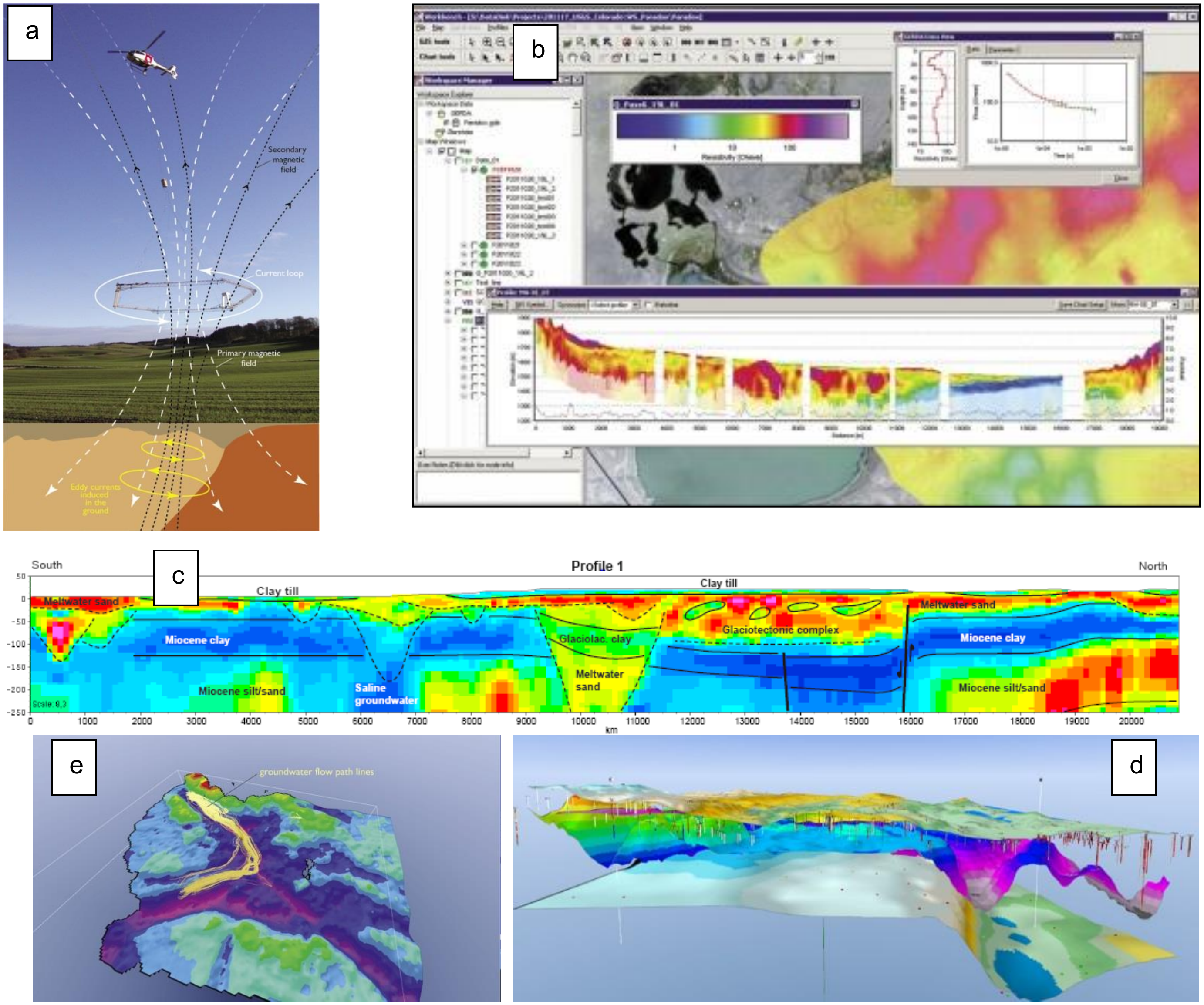

Fig. 1 *Schematic of workflow applied in Denmark for groundwater mapping. a) data acquisition, b) data processing and inversion to produce 3D resistivity model, c) geological conceptualization of resistivity model , d) geological model, e) flow model*

Examples

The first example (Figure 2) illustrates the spatial richness of within an AEM dataset, compared to the that obtainable boreholes only. The maps show the elevation of basement in part of the Spiritwood valley aquifer in Manitoba, as obtained from available boreholes and from duly reprocessed and reinverted AEM data (Aerotem system, cfr Sapia et al, 2014). The boreholes were less than 100 for this area. The AEM survey was flown at 400m line spacing, for a total of approximately 100.000 soundings and derived models).

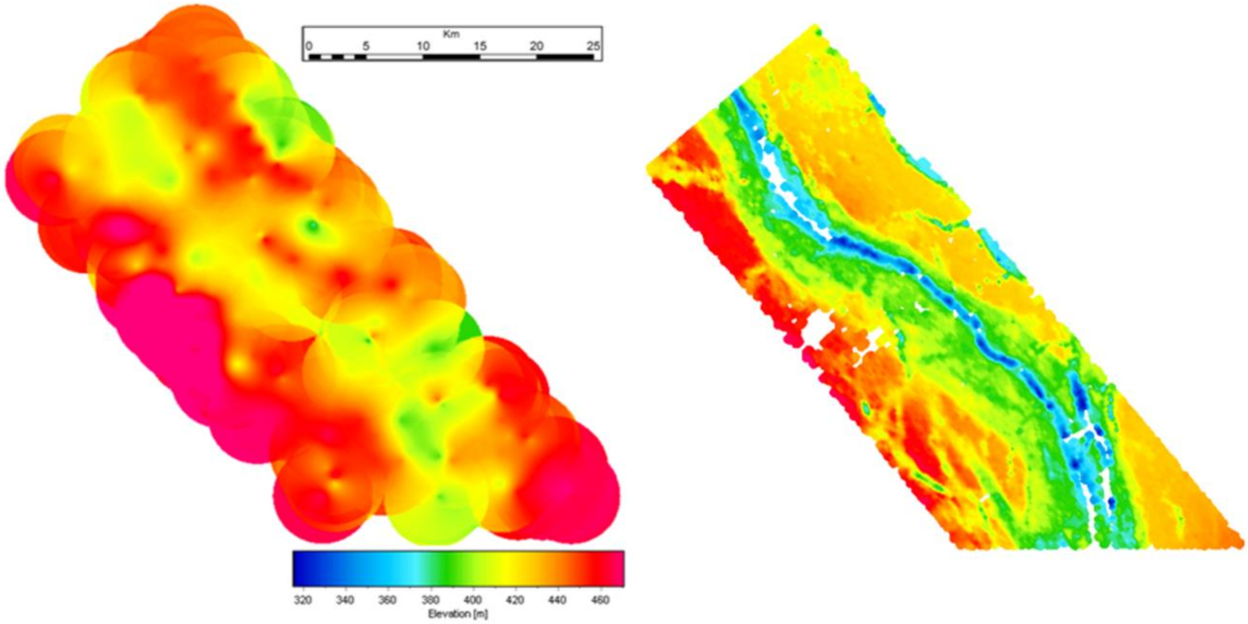

Fig 2: Elevation of bedrock (shale), from borehole data only (left) and from accurately processed and modelled AEM data (right) and boreholes (adapted from Sapia et al., 2014).

The improvements in hydrogeological knowledge translates immediately to economic benefits, as demonstrated by the results of another AEM survey conducted in the Platte River, Western Nebraska, USA (Figure 3): Here a large demand for irrigation requires a reasonable and efficient ground and surface water management. For this reason, USGS contracted an AEM survey that provided crucial info to define an accurate groundwater model. The black line shows the expected bottom of the aquifer bedrock, based only on borehole drilling, that is really different from that one resolved by AEM (base of the light blue layer), so that a completely new model was set, with 5 million cubic meters of previously undetected groundwater resource.

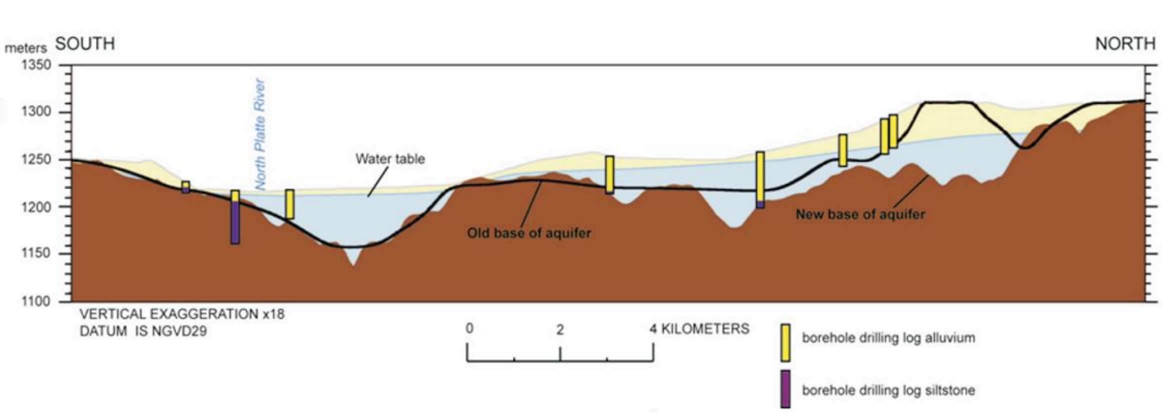

Fig. 3 *Hydrogeological section provided by the AEM survey. The columns show the boreholes with stratigraphic info, the black line represent the bottom of the aquifer based only on the boreholes. Notice the greater thickness of the aquifer on the right side, on the contrary of what expected (Courtesy: USGS Scientific Investigation Report: 2011-5219).*

As mentioned earlier, one of the crucial aspects of using AEM for large scale projects is data consistency across different AEM systems and over time, and accuracy of measurements and modelling in general. As virtually any geological survey –or other company using a lot of AEM- is painfully aware of, obtaining seamless results across datasets acquired over time and with different systems is not granted. However, provided proper protocols are enforced, this should be achievable with new data. The positive outcome that this approach can produce is rendered by Figure 4. Even if the surveys were carried out by different companies over many years, with different instrumentation, the end result is a seamless geological map. Pre-existing data can, in some instances, also be recalibrated across datasets (Sapia et al, 2013).

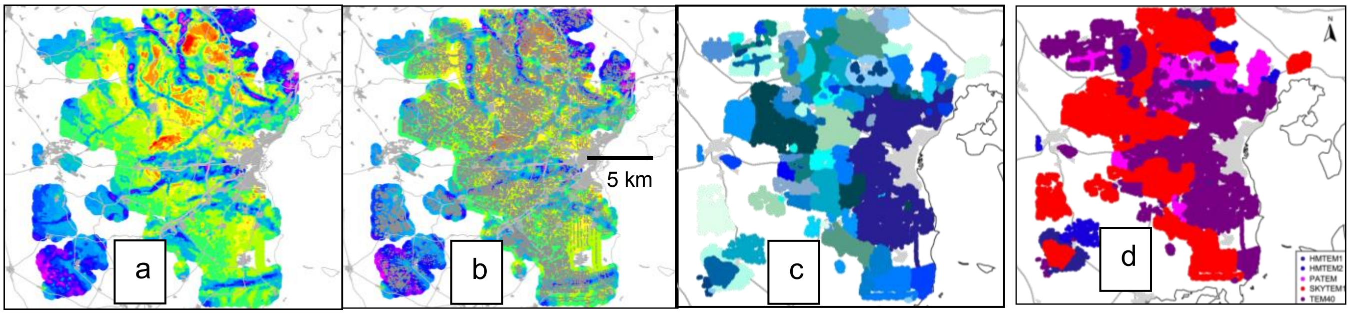

Figure 4. The effect of accurate calibration and protocols in the Aarhus area. a) map of elevation of impermeable layer; b) location of the measurement points from which it was created; c) color code of the different mapping projects and surveys (94 projects, over 10 years); d) color code of different instruments used for the mapping.

The hydrogeological settings in large parts of Canada are similar to those in Denmark. Given the size of the projects involved, the types of organizations that are likely to commission large scale hydrogeological studies, we suggest that parts of this approach can be readily and successfully applied in Canada. The establishment of a series of local AEM calibrations sites (cfr Foged et al. 2010) is an integral part of it, and highly advisable.

Conclusions

The Danish model proves that airborne electromagnetics can play a formidable role in the efforts to map, manage, extract, protect Groundwater. Properly planned, carried out and modelled, it allows refining -at times redefining- existing hydrogeological knowledge, basing it on a large amount of accurate data, easy to integrate with ancillary information. The Danish experience and its rigorous approach can be put at good use in Canada within the field of mapping, management and regulation of Ground water for unconventional hydrocarbon exploration and development.

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