A 3D GEOLOGICAL MODEL OF THE NASIA SUB-BASIN, NORTHERN GHANA – INTERPRETATIONS FROM THE INVERSION RESULTS OF REPROCESSED GEOTEM DATA

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SUMMARY

Inversion of regional-scale airborne electromagnetic (AEM) data was used in building a 3D geologic model of the Nasia Sub-Basin, Northern Ghana. Geological interpretation of the AEM data was guided by a priori knowledge obtained from previous research in the area, geological maps and reports. A key requirement of the modelling process was to define the subsurface stratigraphy of the area, chiefly to provide 1) a detailed stratigraphical context for hydrogeologic use, 2) a repository of comprehensive stratigraphic knowledge of the study area which will be easily accessible.

The AEM measurements, consisting of GEOTEM data, was originally collected for mineral exploration purposes. The B-field data have been (re)processed to enhance the resolution and inverted by using spatial constraints to preserve the lateral and vertical coherence. During the processing and inversion phases, the regularization strategies and associated parameters have been tuned by following an iterative approach characterized by a tight collaboration between geologists and geophysicists to retrieve the geophysical model that is in the best agreement, not only with the geophysical data, but also with the geological expectations. The new (pseudo-)3D inversion showed very different features with respect to the previous Conductivity-Depth Images (CDI). The new geophysical model led to new interpretations of the geological settings and to the construction of a comprehensive 3D geomodel of the basin based on the integration of AEM and borehole information. Nevertheless, in order to have a model, suitable for hydrogeological characterization, it will be necessary to include more details regarding the upper, weathered zone as the AEM survey was optimized to have a very deep penetration and not an extremely high shallow resolution. These aspects will be remedied by the inclusion, for example, of the interpretations from Electrical Resistivity Tomography (ERT) data, which will provide the necessary resolution in the upper sections.

Key words: 3D Geological Modelling, AEM Inversions, ERT, Geological Interpretations, Reprocessing and Inversion of pre-existing data.

INTRODUCTION

Initial applications of AEM methods were merely for mineral exploration. More recently, AEM data have been applied to both geological subsurface characterization and groundwater investigation (Jørgensen, et al. 2017; Jørgensen, et al. 2015; Jørgensen, Møller, et al. 2013; Høyer, et al. 2015; Oldenborger, et al. 2014; and many others). In Ghana, these later applications are, however, quite limited despite the existence of various available datasets, originally collected for other scopes. With the required efforts, these existing datasets can be reprocessed and properly inverted to reconstruct the realiable electrical resistivity distribution of the subsurface, which, in turn, can be interpreted to improve upon the current understanding of the underlying geology and provide vital leads to groundwater resources development. The reprocessing and inversion of pre-existing datasets to be used for detailed reconstruction of the subsurface for 3D geological modelling and groundwater mapping is definetly not a very common practice (especially in the West African Sub-region).

This study demonstrates the effectivness of reprocessing and proper inversion of existing AEM dataset to assist in the 3D geological modelling, hydrogeological conceptualization, and numerical modelling in a partially metamorphosed sedimentary terrain in Northern Ghana. Here, access to water of appropriate quality and quantity for various uses has been a challenge. This is largely owed to low success rates in drilling prolific boreholes in the area.

The approximately 5,300 km^2 area of the Nasia Basin falls within the Guinea Savannah Ecological Belt. This area is associated with an annual rainfall of 1000-1300 mm/annum which peaks between late August and early September. Torrential rains within this peak season create serious drainage problems as the ability of the soil to absorb the rainwater is low due to the largely impervious nature of the various formations (a function of the porosity and permeability of the geological material), creating high amounts of runoff leading to high levels of erosion, a significant constraint on agriculture (http://www.fao.org/docrep/004/ab388e/ab388e02.htm

The area is underlain by Neoproterozoic sediments grouped into three; Bombouaka (oldest), Oti (middle) and Obsoum (youngest). The Bombouaka and Oti groups outcrop in the study area. The Bombouaka rocks were deposited in deltaic, fluvial and nearshore environments (Carney, et al. 2010). The Oti group represents the transition from shallow marine environments abutting a rifted margin into a marine foreland basin sequence (Carney, et al. 2010) (Figure 1).

Based on the AEM and borehole data, and guided by existing knowledge, a 3D geological model of the area has been developed. This was done using Geoscene 3D grounded on a cognitive voxel modelling approach (Jørgensen, et al. 2013), in which limitations of the AEM grids, including the non-unique nature of geophysical data, are considered together with knowledge driven interpretations.

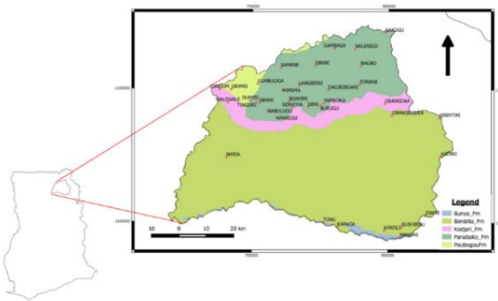

Figure 1 Map showing geology of Nasia basin (modified after Carney et. al 2010).

METHOD AND RESULTS

The AEM survey covers the entire study area with a line spacing of 2km. A denser area with a line spacing of 200m is found to the north of the area. To guarantee the more reliable reconstruction, the geophysical data have been reprocessed (Figure 2), for example, by considering the minimum possible (time-gate-dependent) lateral stacking and by taking into account the current oscillations in the transmitter, while an iterative approach has been followed to better address the inherent non-uniqueness of the geophysical inversion. In particular, the specific choice of the inversion strategy and associated parameter has been careful selected during a close interaction between geophysicists and geologists (Jørgensen et al. 2017; Vignoli et al. 2017; Ley-Cooper et al., 2014). This in order to get the geophysical model that at the same time is compatible with the AEM data, and also with the other geological information and prior knowledge.

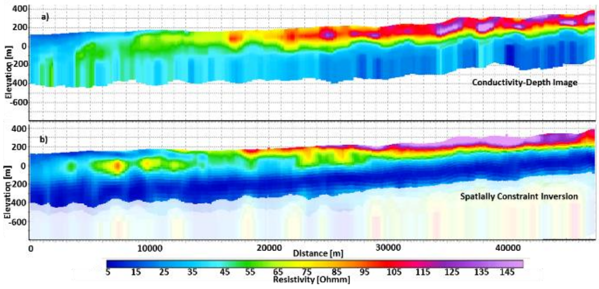

Figure 2 a. Comparison between the original Conductivity-Depth Image (CDI) and, b. one of the new (smooth Spatially Constrained Inversion) results

Spatially Constrained Inversion (SCI) of the original B-field GEOTEM data were conducted. The obtained (pseudo-)3D inversion is based on a 1D non-linear forward modelling (Auken et al., 2014) and is capable to retrieve the tiny resistivity variations necessary for accurate geological modelling. In general, this kind of accuracy might not be necessary for mineral exploration. In this respect, Figure 2 shows the comparison between the original CDI results against the new SCI. The differences are evident.

Subsequently, the SCI result was gridded and used as a basis for the geological modelling (Figure 3). The resistivity grid was combined with borehole data in Geoscene 3D. Within the framework of the project, ten boreholes were drilled with the deepest reaching 150m below the surface, while the deepest borehole used, extended to ca. 764m, was drilled by Soviet Geological Survey Team (SGST) between 1962 and 1966 for oil exploration purposes (Bozhko, 2008). Boundaries which marked the various lithostratigraphical units were defined; this was done based largely on the characteristic conductivity/resistivity signatures of the various units (Figure 4) with the boreholes serving as guides where possible.

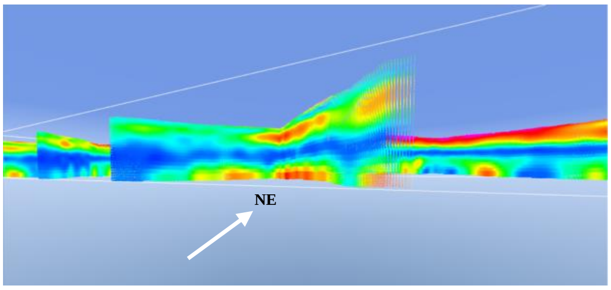

Figure 3 NE facing 3D AEM grid (quasi 3D model) within Geoscene 3D

The formations of the Bombouaka group were marked out based on the resistivity signatures (Figure 4) as follows,

a. The Tossiegou (basal unit) is made up of fine-grained sandstones and siltstones with a low to moderate resistivity.
b. The Poubogou (overlies the Tossiegou) and is made up of mudstones and siltstones which record low resistivities.
c. The Panabako (topmost formation) consists largely of medium-grained feldspathic quartz arenites. Moderate and high resistivities; the upper Panabako formation having very high resistivities.

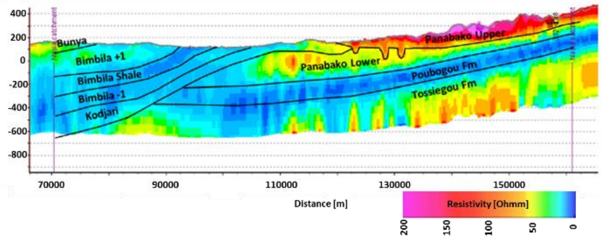

Figure 4 Vertical section through AEM grid with geological interpretations.

Within the Oti group, the formations marked out based on the conductivity signals are as follows,

a. The Kodjari formation (basal unit) consists of basal tillites, cap carbonates and tuffaceous material. These have a characteristic moderate to high conductivity.
b. The Bimbilla formation covers the largest portion of the study area and represents interlayered mudstones, siltstones and sandstones. These units recorded high conductivities which reduce while moving upwards to the Bunya sandstone formation, which is included in the Bimbila formation.

The first stage in the modelling process requires setting up a conceptual model (Figure 5) which serves as a guideline during the subsequent construction of the 3D geological model.

Guided by the resistivity signatures and borehole data, outlines of the various boundaries were traced. The reliability of the borehole data was hinged on the source of the data, this is factored into the modelling process to be used for uncertainty descriptions. The outlined boundaries are then used in populating the model grids by adding and editing voxel groups guided by an understanding of the geologic formations and structures (Høyer, et al. 2015b; Jørgensen, Møller, et al. 2013). The preliminary model is presented in Figure 5. From the model, eight formations within the two groups are identified.

Interesting geological features indicated by the AEM data are possible tunnel valleys generated by subglacial meltwater erosion i.e. 120-130 m at the base of Upper Panabako in Figure. 4 (Kehew et al. 2012). However, this still needs to be confirmed by additional sources of information before being included into the 3D geomodel. The features are not interesting only for scientific sake, but also because they might be important groundwater reservoirs. They might therefore foster the development of irrigation plans in the area based on deeper resources.

The presented 3D geomodel is mainly based on the AEM inversions characterized by a limited shallow resolution. The geomodel will be improved by the inclusion of further information supplied by existing or newly collected data (e.g., existing radiometric data, new ground-based electrical resistivity surveys) and previous studies (e.g., Fugro 2008).

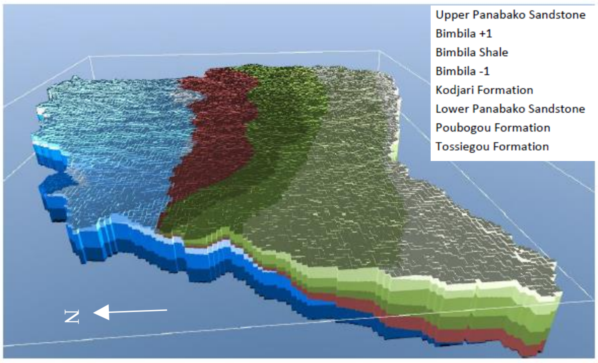

Figure 5 Preliminary 3D geological model of study area.

CONCLUSIONS

A 3D geological model has been successfully developed based on the interpretation of AEM data over a sedimentary terrain in Northern Ghana. The model is a 3D representation of the subsurface within the study area and is validated by available geological knowledge and field relations. The geological model appears to show deep elongate depressions with depths averaging 150 m. These are thought to be tunnel valleys of subglacial origin between the Upper and Lower Panabako successions. This finding could prove handy for the hydrogeology of the terrain as tunnel valleys elsewhere have been noted to be prolific groundwater storage zones. The presence of an unconformity within the Panabako is not lost by earlier researchers as it is sometimes described as eroded 'sugarloaf'' capping in the Upper Panabako above the Lower sequence from remote imagery.

REFERENCES

Auken, A., Christiansen, A.V., Kirkegaard, C., Fiandaca, G., Schamper, C., Behroozmand, A.A., Binley, A., Nielsen, E., Effersø, F., Christensen, N.B., Sørensen, K., Foged, N., Vignol, G. (2014). An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data. *Exploration Geophysics*, 46, 223-235.

Ayite, A., Awua, F., & Kalvig, P. (2008). Lithostratigraphy of the Gambaga massif. *The Voltaian Basin, Ghana, Workshop and Excursion*, (pp. 41-44).

Bozhko, N. A. (2008). Stratigraphy of the Voltaian Basin on evidence derived from borehole drillings. *The Voltaian Basin, Ghana. Workshop and Excursion*, (pp. 7- 12).

Carney, J. N., Jordan, C. J., Thomas, C. W., Condon, D. J., Kemp, S. J., & Duodo, J. A. (2010). Lithostratigraphy, sedimentation and evolution of the Volta Basin in Ghana. *Precambrian Research, 183*, 701-724.

Fugro Airborne Surveys Interpretation (2008). *Airborne Geophysical Survey over the Volta River Basin and Keta Basin Geological Invterpretation Summary Report.*

Høyer, A. -S., Jørgensen, F., Sandersen, P. B., Viezzoli, A., & Møller, I. (2015a). 3D geological modelling of a complex buried-valley network delineated from borehole and AEM data. *Journal of Applied Geophysics, 122*, 94-102.

Høyer, A.-S., Jørgensen, F., Foged, N., He, X., & Christiansen, A.V.(2015b).Three-dimensional geological modelling of AEM resistivity data - A comparison of three methods. *Journal of Applied Geophysics, 115*, 65-78.

Jørgensen, F., Menghini, A., Vignoli, G., Viezzoli, A., Salas, C., Best, M.E. & Pedersen S.A.S (2017). Structural Geology Interpreted from AEM Data-Folded Terrain at the Foothills of Rocky Mountains, British Columbia. *2nd European Airborne Electromagnetics Conference.* Malmö, Sweden

Jørgensen, F., Høyer, A.-S., Sandersen, P. B., He, X., & Foged, N. (2015). Combining 3D geological modelling techniques to address variations in geology, data type and density - An example from Southern Denmark. *Computers & Geosciences, 81*, 53-63.

Jørgensen, F., Møller, R. R., Nebel, L., Jensen, N.-P., Christiansen, A. V., & Sandersen, P. B. (2013). A method for cognitive 3D geological voxel modelling of AEM data. *Bulletin of Engineering Geology and the Environment, 72*(no. 3-4), 421-432.

Kehew, A., Piotrowski, J. & Jørgensen, F. (2012). Tunnel Valleys: Concepts and Controversies – A Review. *Earth-Science Reviews*, 113, 33-58.

Ley-Cooper, A.Y., Viezzoli, A., Guillemoteau, J., Vignoli, G., Macnae, J., Cox, L., & Munday, T (2014). Airborne electromagnetic modelling options and their consequences in target definition. *Exploration Geophysics, 46*, 74-84

Oldenborger, G. A., Logan, C. E., Hinton, M. J., Sapia, V., Pugin, A. J., Sharpe, D. R., . . . Russell, H. A. (2014). 3D Hydrogeological Model Building Using Airborne

Electromagnetic Data. *Near Surface Geoscience 2014-20th European Meeting of Environmental and Engineering Geophysics 2014.*

Sapia, V., Oldenborger, G. A., Viezzoli, A., & Marchetti, M. (2014). Incorporating ancillary data into the inversion of airborne time-domain electromagnetic data for hydrogeological applications. *Journal of Applied Geophysics, 104,* 35-43.

Vignoli, G., Sapia, V., Menghini, A. & Viezzoli, A. (2017). Examples of improved inversion of different airborne electromagnetic datasets via sharp regularization. J*ournal of Environmental and Engineering Geophysics 22 (1),* 51-61