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GEOELECTRICAL METHOD DEVELOPMENT FOR EXPLORATION OF NATURAL RESOURCES

Thesis of the doctoral dissertation (PhD)

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I. SCIENTIFICS BACKGROUND AND AIMS

Interpretations and subsequent decision-making processes can be done more conveniently and potentially more reliably if they are based on geophysical data analysis. Geophysical data analysis methodology has become an effective and standard tool for interpreting geophysical surveys for exploration of natural resources, engineering groundwater and environmental application. These were developed by many scientists and mathematicians having various dataset and goals (Keller and Frischknecht. 1966), (Menke. 2018), (Oldenburg and Li. 1994), (Turai and Dobróka. 2011), (Turai. 2011), (Turai. 2012), (Gyulai, et al. 2013), (Turai. 2004).

Nevertheless, the mathematical techniques do not possibly represent subsurface structure well due to many reasons: the non-uniqueness of mathematical solutions, limitations imposed by underlying physics, incomplete data coverage, limited measurement, technical problems, noise in the field data, etc. Despite all the progress made in the direction of reducing the model uncertainty and enhancing the resolving power of the geophysical data analysis, there are still some open questions and challenges to be addressed.

In a broader perspective, my Ph.D. research is directed to geoelectric method development for exploration of natural resources (with special emphasis on the solution of forward, inverse problems and geostatistical technique). The development of forward and inverse modelling methods play an important role in geophysical data processing. My dissertation aims to apply a combination of data processing and inversion tools to develop new methods of scientific value. The result of the novel methods will be tested by using field data sets to examine its validity.

The dissertation consists of two main parts. In the first one, a geostatistical method using the Fuzzy C-mean clustering is introduced. The other main chapter presents more special results of the solution of the TAU-transformation using theMonte Carlo method. To solve the TAU-transformation problem a linearized Gaussian Least Square inversion method is developed and applied for a pole-dipole TDIP dataset measured in Mongolia.

The Fuzzy C-mean (Dunn. 1973), (Prasad, et al. 2016) clustering applied on a dataset of two physical properties measured over core samples from the gold deposit in the Yamaat area, Mongolia. In general, statistical methods are essential for the geological modelling and analysis of rock physical properties. Sometimes in practice, geostatistical approaches are challenging to apply to the field data. The purpose of my research is to develop an advanced geostatistical

technique for mineral exploration using the chargeability, resistivity and magnetic susceptibility data measured on core samples. In this thesis, it is shown that the Fuzzy C-mean clustering (FCM) is capable to distinguish the different types of bedrocks distributed in the research area. This method is useful for the quick processing of rock physical properties and may aid the interpretation of the data of geophysical surveys and mineral exploration.

The TAU-transform was introduced (Turai. 1985) for the interpretation of IP data. The IP measurements are widely used in ore exploration. The TAU-transform was developed to process time-domain induced polarization datasets measured in Schlumberger electrode array. Many studies have confirmed its successful applicability both to field data and laboratory measurements (Turai and Dobróka. 2011), (Kiss, et al. 2016), (Abordán and Szabó. 2020), (Szabó, et al. 2019), (Gyulai and Szabó. 2014), (Szabó, et al. 2013), (Turtogtokh, et al. 2018). The aim of my study was to develop the data processing for the TDIP multichannel electrode system, as well as to improve the interpretation of TDIP data for exploration of natural resources based on previous research in our department. This part shows how TAU- transform using mathematical tools for data processing can be utilized in the interpretation of Pole-Dipole geoelectric induced polarization data determining the time constant spectrum as well as the Weighted Amplitude Values (WAV). These results prove the applicability of the method to data analysis in field surveys and may aid the interpretation of induced polarization surveys for exploration of natural resources.

II. ACCOMPLISHED INVESTIGATION

In this thesis, I aimed to develop a data processing method for the TDIP multichannel electrode system, as well to improve the interpretation of TDIP data for exploration of natural resources. based on previous research in our department as well as to apply an advanced geostatistical technique for mineral exploration using the chargeability, resistivity and magnetic susceptibility data measured on core samples. All method developments were tested with self-developed MATLAB programs.

As the first step in my dissertation, I attempted to apply the mathematical tools of FCM cluster analysis. As the research has demonstrated, that the FCM algorithm was effectively applied to distinguish the numerical classification of the bedrock of the area based on the properties of rocks collected from core samples. As a consequence, I suggest applying the Fuzzy C-mean algorithm for the classification of the physical properties of rocks containing valuable raw

materials. FCM algorithm can determine a correlation between physical properties, which can be used to improve the geological and geophysical model of the investigated area.

As the second step, geophysical data processing in the TDIP has shown itself as an important and effective tool for exploration of natural resources. The recovered images from the induced polarization survey are interpreted by geologists to understand the near-surface geological structures and to guide further exploration activities such as spotting drill holes. However, does not always provide an exact near-surface image that reliably reflects the structural and physical properties of the target due to many reasons.

I also investigated the solution of the TAU-transformation using linearized Gaussian inversion method (well-determined problem M=N), in order to solve some issues, a logarithmic transformation and the Singular Value Decomposition (SVD) have been applied to define the unknown parameters in a dataset of Pole-Dipole electrode system, TDIP

I also developed a stable algorithm to solve the TAU-transformation through the overdetermined problem (GLSQ) based on previous research in our department. In this algorithm, the series expansion technique and a logarithmic transformation have been extended to define the unknown parameters. This algorithm is useful for the quick processing of induced polarization data (TDIP) and may aid the accuracy improvement of the interpretation of the geoelectric survey for for exploration of natural resources

I formulated a stable algorithm to solve the TAU-transformation through random generation based on the Monte Carlo method. In this solution, the algorithm of TAU transformation has been extended by the Monte Carlo technique to define the spectral amplitude (W) and time constant (TAU) of IP components. As well as WAV (Weighted Amplitude Value) were calculated based on this solution. This algorithm is useful for the quick processing of time-domain induced polarization data (TDIP).

Finally, in the dissertation, the combination of the TAU- transformation using other mathematical tools for data processing of Pole-Dipole electrode system in TDIP is applied, and successfully determined the induced polarization time constant spectrum as well as the Weighted Amplitude Value (WAV). Those results prove the applicability of the method to data analysis in field surveys and may aid the interpretation of induced polarization surveys for exploration of natural resources.

III. NEW SCIENTIFIC RESULTS

Thesis statement 1

a. I proved using Fuzzy C-mean cluster analysis that Cataclastic Granite and Diorite Porphyry can be distinguished on the basis of the resistivity and magnetic susceptibility of the core samples taken in the Yamaat mine area.

b. Using Fuzzy C-mean analysis, I calculated that the centre value of Diorite Porphyry resistivity is 8500 ohmm and the centre value of its magnetic susceptibility is 0.00113 SI units and these are significantly higher than in the case of Cataclastic Granite, which has a centre value of resistivity 3100 ohmm and has a centre value of magnetic susceptibility 0.00087 SI units.

Thesis statement 2

a. I proved using Fuzzy C-mean cluster analysis that Rhyolite, Cataclastic Granite, Diorite Porphyry and Andesite Porphyry can be distinguished from each other on the basis of the resistivity and chargeability of the core samples taken in the Yamaat mine area.

b. Using Fuzzy C-mean analysis, I calculated that the centre value of Rhyolite resistivity is 2467 ohmm and the centre value of its chargeability is 17 mV/V, the centre value of Cataclastic Granite resistivity is 5822 ohmm and the centre value of its chargeability is 12 mV/V, the centre value of Diorite Porphyry resistivity is 11590 ohmm and the centre value of its chargeability is 3 mV/V, and the centre value of Andesite Porphyry resistivity is 18094 ohmm and the centre value of its chargeability is 2 mV/V.

Thesis statement 3

a. I have established the solution of the TAU-transformation using non linearized Monte Carlo method in the thesis using field measured pole-dipole TDIP dataset. The amplitudes and the time constants of the time constant spectrum were defined by double random generation of the Monte Carlo techniques. Besides the relationship between measured and calculated data in the decay time interval was successfully determined.

b. I applied and tested the new method presented in Thesis 3a on the Yamaat gold deposit and I found that the polarization has 3 main components in this area. Based on this,

polymetallic ore formation is probable. The concentration of the ore mineral with the smallest time constant is only small, while in the case of ore mineral with the medium time constant, both the medium and high concentration areas appear, and in the case of ore mineral with high time constant medium and high concentrations are dominant.

Thesis statement 4

a. I have developed the solution of the TAU transformation based on the linearized inversion (well determined inverse problem) method for estimating IP components (unknown parameters) for exploration of natural resources from the Pole-Dipole data set. I have integrated a logarithmic transformation and the Singular Value Decomposition (SVD) into this algorithm. In this way, spectral amplitudes were clearly calculated by this method.

b. As an example, I tested the method presented in Thesis 4.a, on the first measured point in line2. It was found that the use of the logarithmic transformation ensure stable positive values of the spectral amplitudes.

Thesis statement 5

a. I developed a stable algorithm to solve TAU-transformation through the overdetermined series expansion inversion-based inversion method for estimating the spectral amplitudes. The algorithm is a stabilized version of the method, originally introduced at the Department of Geophysics (Dobroka and Turai, 2011) modified by introducing a logarithmic transformation of the unknown to ensure positive expansion coefficients in the geopysical inverse problem.

b. As an example, I confirmed the method presented in Thesis 5.a, on the first measured point in line2. The weighted average of the spectral amplitude was calculated. Based on this, it as shown that the main polarization amplitude is nearly the same at different time constant interval. It was demonstrated that 3 or 4 main polarization amplitudes at the relevant characteristic time constants appear at various choice of the number of unknowns.

Thesis statement 6

a. I have calculated the time constant spectra and WAV parameters based on the Monte Carlo solution over the measured pole-dipole IP profiles. As a result of the analysis, the 2D parameter section (vertical map of the WAV) was built along the Line_2.

b. The time constant spectra and WAV parameter distributions were calculated in the measured area based on the Monte Carlo solution. As a result of the analysis, WAV parameter maps were calculated for an area between Lines 2, 3 and 4 on the depth level -50m, -100m, and -150m.

Thesis statement 7

I summarized the interpretation of pole-dipole IP measurements to classify the ore formation. Based on this, it can be concluded that the type of ore formation is polymetallic with probably 3 components. The concentration of the ore mineral with the largest time constant is the highest. Of course, the specific types of the ore minerals can only be determined by further drilling-based geological exploration and geochemical analysis.

PRACTICAL APPLICATION OF RESULT

In the framework of my Ph.D. dissertation, I carried out inversion tools and advanced geostatistical method developments using MATLAB tools for the data processing of geoelectrical measurements. The combination of the TAU transformation and developed methods is capable of effectively processing the TDIP data set and estimating the physical parameters of formations that are necessary for the quantitative assessment for exploration of natural resources. Additionally, the FCM clustering is proficient in a clear analysis of the approximate value of physical properties. My dissertation provides the necessary mathematical formulations and algorithms applied for geophysical data processing and inversion, and presents the physical properties derived from the analysis of TDIP field data. In the future, I intend to apply all new developments for exploration of natural resources where other multi-channel electrode systems of the TDIP are used in the field survey. Another very significant application in the energy segment is the field of direct hydrocarbon research, where the IP method is suitable for the detection of productive hydrocarbon storage structures.

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I. LIST OF RELATED PUBLICATION AND PRESENTATIONS

JOURNAL ARTICAL

I. Byambasuren Turtogtokh., Endre Turai, Mihály Dobróka., Geophysical prospecting in Mongolia over the Yamaat gold deposit. **Proceedings of PhD Students Conference**, *ISBN 978-963-358-196-4,Peer-reviewed English language domesticpaper*, pp. 20-29. 2018.

II. Byambasuren Turtogtoh, Turai Endre, A geofizikai módszerek alkalmazásának az eredményei egy Mongolian aranykutatásban, **Műszaki Tudomány az Észak-Kelet**

Magyarországi Régióban 2018 Konferencia Előadásai. *ISBN 978-963-7064-38-8, konferencia előadás,* pp.416-419. Debrecen 2019.

III. Byambasuren Turtogtoh, Turai Endre., On the solution of the TAU-transformation using Monte Carlo method – an application for field measured pole-dipole TDIP dataset measured in Mongolia. ***Geoscience and Engineering journal*** *(accepted).*

IV. Byambasuren Turtogtoh., The solution of the TAU-transformation using series expansion inversion method with application to a Mongolian field measured TDIP dataset, ***Geoscience and Engineering journal*** *(accepted).*

CONFERENCE PAPER (SHORT AND EXTENDED ABSTRACT)

I. Byambasuren Turtogtoh, Endre Turai, Mihály Dobróka., Application of the fuzzy c-mean cluster analysis over the Yamaat gold deposit in Mongolia. **Geomates 2019 International Congress on Geomathematics in Earth & Environmental Sciences.** Abstract book, *ISBN978-963-7068-11-9 English language international conference abstract,* pp. 48., 2019.

II. Byambasuren Turtogtokh., The gold exploration over the Yamaat area in Mongolia using field measured vertical electrical sounding and petrophysical measurements. **The 50th Meeting of Young Geoscientists**, Abstract book, *English language international conference abstract*, pp. 33, 2019.

III. Byambasuren Turtogtoh, Endre Turai, Mihály Dobróka., Application of the TAU transformation over the pole dipole IP data in the gold deposit, **Near Surface Geoscience 20, EAGE annual conference online,** *international conference extended abstract (accepted).*

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I. The gold exploration over the Yamaat area in Mongolia using field measured vertical electrical sounding and petrophysical measurements. **The 50th Meeting of Young Geoscientists**, *conference presentation,* Ráckeve, Hungary. March 29-30, 2019.

II. Application of the fuzzy c-mean cluster analysis over the Yamaat gold deposit in Mongolia. **Geomates 2019 International Congress on Geomathematics in Earth & Environmental Sciences**. *conference presentation,* Pécs, Hungary. May 16-18, 2019.

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V. Monte Carlo solution of the TAU-transformation and its application for a field measured pole-dipole TDIP dataset**. Inverziós Ankét online,** University of Miskolc**,** *conferece persentation*, November 2-3, 2020.

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