DCE 21

4th DOCTORAL CONGRESS IN ENGINEERING

DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

Symposium on Mining Engineering and Geo-Resources

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

4th DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

of the

2nd Symposium on Mining Engineering and Geo-Resources

Editors:

Maria de Lurdes Dinis, Rui Sousa, Vitor Ramirez

Porto
June 2021

This volume contains the abstracts presented at the Symposium on Mining Engineering and Geo-Resources, within the 4th Doctoral Congress in Engineering – DCE21, held online, between June 28th and 29th, 2021.

Title: Book of Abstracts of the 2nd Symposium on Mining Engineering and Geo-Resources

Edited by Maria de Lurdes Dinis, Rui Sousa and Vitor Ramirez

Published by: FEUP Edições

https://paginas.fe.up.pt/~dce/2021/symposia/symposium-on-mining-and-geo-resources/

First edition June 2021

ISBN. 978-972-752-287-3

Suporte. **Eletrónico**

Universidade do Porto, Faculdade de Engenharia, Departamento de Engenharia de Minas, Rua Dr. Roberto Frias s/n 4200-465 Porto, Portugal

WELCOME

The Organizing Committee of the Symposium on Mining Engineering and Geo-Resources welcome you to the 4rd Doctoral Congress in Engineering (DCE21), FEUP, Porto, Portugal. We are pleased to host the 2st Symposium on Mining Engineering and Geo-Resources in the Faculty of Engineering of Porto University organized in collaboration with the Instituto Superior Técnico (IST) and with the support of the research center CERENA. This is an excellent opportunity for doctoral and master students to share and discuss on-going research with peers, professors, and industry and develop networking opportunities with other researchers. This year the organization of the Symposium had the collaboration of PhD and Master Students from the following programmes:

- Doctoral Programme in Mining Engineering and Geo-Resources (PDEMGR/FEUP)
- Master Course in Mining Engineering and Geo-Environment (MEMG/FEUP)
- Doctoral Programme in Georesources (DEAGeo/IST)
- Doctoral Programme in Oil and Gas Engineering (DEAPet/IST)
- Master Course in Geologic and Mining Engineering (MEGM/IST)

The Symposium on Mining Engineering and Geo-Resources focus on a multidisciplinary, advanced and comprehensive approach to scientific or technological issues involved in the life cycle of a mineral resource. Research is preferentially concerned with the fundamental understanding of the basic processes that support the sciences and technologies involved in the application of engineering principles to the Earth Sciences.

Topics for submission for the Symposium on Mining Engineering and Geo-Resources were focused on: Mineral Exploration and Feasibility, Mining Extraction, Mineral Processing, Environmental Mining Impact and, Mining Life Assessment (including: Resources Assessment, Mining Planning, Mine Closure, Recycling, Life Cycle Assessment, Occupational Assessment, etc.) and Oil and Gas Engineering.

We would like to express our gratitude and appreciation for all of the reviewers who helped us maintain the high quality of manuscripts included in this Symposium Book of Abstracts. We would also like to extend our thanks to all members of the organizing team for their hard work and the scientific committee as well.

Let us wish that all the participants of the 2nd Symposium on Mining Engineering and Geo-Resources will have a wonderful and fruitful time at the Symposium. We hope that you will find it useful, exciting, and inspiring.

Symposium Chair

Maria de Lurdes Dinis, CERENA-Polo FEUP, Faculty of Engineering, Porto University.

On behalf of the Co-Chair, Organizing Committee and Scientific Committee

28 - 29 June, 2021

FEUP, Porto, Portugal

CONTENTS

COMMITTEES

Scientific Committee

Chair: Maria de Lurdes Dinis | FEUP

Co-Chair: Maria João Pereira | IST

Maria Cristina Vila | FEUP

José Marques | IST

Rui Sousa | FEUP

Organizing Committee

Chair: Maria de Lurdes Dinis | FEUP

Co-Chair: Maria João Pereira | IST

Maria Cristina Vila | FEUP

José Marques | IST

Rui Sousa | FEUP

Ana Rita Araújo | FEUP

Francisca Rey | IST

Joana Monteiro | FEUP

João Vermelho Neves | IST

Margarida Chalupa | FEUP

Rania Rebbah | FEUP

Vitor Ramirez | FEUP

PROGRAMME

Symposium on Mining Engineering and Geo-Resources

28th June DCE21 Common programme (https://paginas.fe.up.pt/~dce/2021/programme/)

9h00-9h30 - DCE21 *Welcome Session*, opening by Prof. António Ferreira (President of FEUPs Scientific Council)

09h30-10h00 - DEC21 *Plenary Session* by Rik Van de Walle (President of CESAER and Ghent University Rector)

28th June Session I Symposium on Mining Engineering and Geo-Resources

10h15 - Welcome Session (opening by Prof. Maria de Lurdes Dinis, FEUP/CERENA)

Chairs: Prof. José Marques (IST/CERENA), Prof. Cristina Vila (FEUP/CERENA)

10h30 - Invited Speaker - *Innovative Geophysical methodologies applied to mineral exploration: the Smart exploration project* (João Carvalho, LNEG)

11h00 - *Seismicity and active stress field derived from the inversion of focal mechanism data, South Atlas of Tunisia* (Harzali Makrem, ENIS/University of Sfax, Tunisia)

11h15 - *Generative Adversarial Network Applied to Ore Type Modelling* (Helga Jordão, IST/CERENA)

11h30 - Evaluation of mineral project investment using Multicriteria Decision-Making Aid (Andreas Tuhafeni, FEUP/CERENA)

11h45 - Invited Speaker - *Real-Time Mining - A Closed-Loop Concept for Mineral Resource Extraction* (Joerg Benndorf, Technical University Bergakademie Freiberg, Germany)

28th June DCE21 Common programme (https://paginas.fe.up.pt/~dce/2021/programme/)

14h30-15h00 - Workshop 1 - *Services provided to PhD candidates*, by FEUPs INOV office (Pedro Coelho, FEUP)

15h00-16h00 - DCE21 Virtual Poster Session

Chair: Prof. Maria de Lurdes Dinis (FEUP/CERENA)

- Ana Rita Pinto (MEMG/FEUP) *Study of the potential of steel slags in acid mine drainage treatment*
- Gil Abreu Leite (MEMG/FEUP) *Acid mine drainage treatment using industrial by-products as neutralization chemicals*
- Joana Monteiro (MEMG/FEUP) *Study of the stripping process on recovery of gold by activated carbon using alternative leaching reagents Sodium Thiosulphate and Bromide*
- Roberto Miele (IST/CERENA) *Geostatistical Seismic AVA inversion with self-updating rock physics*
- Vitor Colombo (PDEMGR/FEUP) *Why should every mining engineer learn physical computing and digital electronics?*

28th June Session II Symposium on Mining Engineering and Geo-Resources

Chairs: Prof. Maria João Pereira (IST/CERENA), Prof. Rui Sousa (FEUP/CERENA)

16h00 - Invited Speaker - *Introduction of circular economy in FILSTONE* (Miguel Goulão, FILESTONE)

16h30 - *A Numerical Model to Assess Temperatures in Underground Galleries* (Vitor Colombo, FEUP/CERENA)

16h45 - *Assessing complex and heterogeneous near-surface environments with geostatistical electromagnetic inversion* (João Narciso, IST/CERENA)

17h00 - Invited Speaker – Controlo de Processos – O caso de estudo de Neves Corvo (Alberto Barros, Somincor-Sociedade Mineira de Neves-Corvo, SA)

28th June DCE21 Common programme (https://paginas.fe.up.pt/~dce/2021/programme/)

18h00-18h45 - Social Program - *Virtual Port Wine Tasting*

29th June DCE21 Common programme (https://paginas.fe.up.pt/~dce/2021/programme/)

16h30 - Awards Ceremony - Symposium on Mining Engineering and Geo-Resources:

– Best student oral communication
– Best student poster presentation

KEYNOTE

Name: Joerg Benndorf

Position: Professor

Institution: Technical University Bergakademie Freiberg, Germany

Topic: Real-Time Mining - A Closed-Loop Concept for Mineral Resource Extraction

Short-Bio: Prof. Jörg Benndorf is a mining professional with 10 years' industry and 10 years' academic experience. In industry, he worked as project leader and project manager for large investment projects, mine planning engineer, operational engineer and consultant in Germany, Australia, USA, and Jamaica. His interests include process optimization along the whole mining value chain from exploration to processing. From 2012 to 2016 he was Assistant Professor of Resource Engineering at the Delft University of Technology in the Netherlands. His research focuses on methods of geomonitoring and real-time data integration, geostatistical modeling and geological risk assessment. Since 2016 he holds a full professorship in Geomonitoring and Mine Surveying at the University of Mining and Technology "Bergakademie" Freiberg in Germany. Prof. Benndorf graduated from the same university, he holds a PhD in Mining Geostatistics from TU Clausthal in Germany and an MPhil in Mining Engineering from the University of Queensland in Australia.

Name: João Carvalho

Position: Auxiliary Researcher

Organization: Laboratório Nacional de Energia e Geologia (LNEG)

Topic: Innovative Geophysical methodologies applied to mineral exploration: the Smart exploration project

Short-Bio: João Carvalho olds a PhD in Physics (Solid Earth Geophysics, 2004) and a M.Sc. in Solid Earth Geophysics (1997) both at the University of Lisbon. Senior Geophysicist at LNEG where he develops and applies seismic and potential field methods to mineral resources exploration, seismic hazard, tectonics, environment, engineering, energy storage, hydrogeology, etc. Participated in more than 30 research projects, supervised multiple post-docs, M.Sc. and graduation scholars. Published more than 140 papers, chapters and abstracts in international peer-reviewed journals, books and international and national congresses.

Name: Alberto Barros

Position: Engenheiro de Controlo de Processo

Organization: Somincor – Sociedade Mineira de Neves-Corvo S.A.

Topic: Controlo de Processos – O caso de estudo de Neves Corvo

Short-Bio: Alberto Barros, licenciado em Engenharia de Minas e Geo-Ambiente pela FEUP em 2014 e mestre em Engenharia de Minas e Geo-Ambiente pela FEUP em 2016. Realização de estágio profissional na Somincor SA entre 2017 e 2018. Desde 2018 a desempenhar funções de Engenheiro de Controlo de Processo na Somincor SA com especial relevância nas áreas do Sistema de Controlo Distribuído (DCS-ABB), programação de lógica de controlo (ABB) e bases de dados digitais (Sistema PI – OSIsoft/AVEVA).

Name: Miguel Goulão

Position: Administrador Executivo da Filstone

Organization: Filstone - Comércio de Rochas, S.A.

Topic: Introduction of circular economy in FILSTONE

Short-Bio: Miguel Goulão foi administrador, gestor e presidente de conselhos de administração de variadíssimas empresas, dirigiu em funções executivas diversas Associações Empresariais, de onde se destacam a ARICOP, AHRESP, CTP e ASSIMAGRA. No plano político destaca-se o facto de ter sido Secretário-Geral da JSD, e Chefe de Gabinete no XV e XVI Governos Constitucionais, nas áreas da Ciência e Ensino Superior e Ambiente e Ordenamento do Território, respetivamente. Foi também Vereador na Câmara Municipal de Caldas da Rainha. Atualmente é administrador Executivo da Filstone, Presidente da ASSIMAGRA e Secretário-Geral da Plataforma para o Crescimento Sustentável (PCS).

ORAL

A Numerical Model to Assess Temperatures in Underground Galleries

Vitor Colombo[1], José Soeiro de Carvalho[1], Maria de Lurdes Dinis[1]
[1]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

Abstract
Underground mining is facing growing challenges related to the need to mine deeper and at higher temperatures, to operational expenditures associated with energy consumption, lower grade ores, environmental constraints, and social pressures. In this scenario we describe an improved numerical model to estimate temperature change in mining galleries in order to provide specific criteria for heat recovery projects, such as heat extraction from abandoned mines using closed-loop geothermal systems or from operating mines using the exhaust ventilation air. This model enhances approaches from previous models and includes key unused parameters, such as wall roughness and velocity profile modeling, allowing for a more realistic estimation of convective heat transfer phenomena, which is critical to predicting heat exchange in turbulent ventilation airflow. The model results agree with previous ones, and real data validation is underway.
Author Keywords. Heat Transfer, Underground Mining, Heat Recovery, Numerical Modelling, Geothermal Resources.

1. Introduction

Mining faces growing environmental, economic, social, and technical pressures. Full legal compliance has become an increasingly insufficient means of satisfying society's expectations concerning mining issues (Prno, 2013). From an energetic point of view, the mining industry is exceptionally electro-intensive: worldwide, mining consumes approximately 4% of all the power generated (International Energy Agency, 2017).
To address these challenges, a numerical heat transfer model was developed to support an underground mining operation’s energy efficiency through a better understanding of the thermal energy flows inside the mining galleries and how these flows relate to ventilation operations. The model performs calculations to estimate heat exchange inside an underground mining gallery, which allows for an estimation of the temperature change of ventilation airflow through the galleries network. This temperature increase is the critical parameter for optimizing the airflow and evaluating the possibility of recovering part of the thermal energy from the exhaust air. The model could also be applied to estimate heat recovery in closed-loop geothermal systems and to provide criteria for viability studies.

2. Materials and Methods

After an extensive literature review of numerical models to assess the temperature change and temperature state in underground mining galleries, some gaps were identified: parameters such wall roughness were neglected (even tough gallery walls are usually highly irregular), the turbulence of the airflow and the velocity profile were often overlooked, and few models incorporated convective heat transfer, from moving fluids to solid bodies.

Other heat sources such as people, illumination, and machinery were not present in most models. Part of those relied mostly on empirical formulae, others on energy balance equations, but none attempted to include all of the nuances related to heat transfer in underground galleries as the present model does.

2.1. Geometry and explicitly discretized energy balance equation

In order to simplify the problem’s geometry, the gallery was conceived as a cylinder, inside an infinite radi external cylinder, representing the rock mass, so it is possible to adopt cylindrical coordinates and to use the approach proposed by Ghoreishi-Madiseh et al.

(2012), to solve the differential equations. The energy balance equation is a second-order, three-dimensional differential equation, which corresponds to the transient heat transfer phenomena in a scenario where a fluid flows through a pipe at a different temperature. It was solved using the Finite Volume Method, assuming a volume cell such as shown in Figure 1.

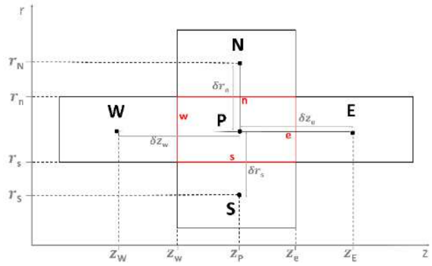

Figure 1: Volume cells and their relative position.

The explicit discretization is performed as described by Patankar (1980). The resulting equation is Equation 1, with coefficients as shown in Table 1.

$$T_P^* = T_P + a_1(T_N - T_P) + a_2(T_P - T_S) + a_3(T_E - T_P) + a_4(T_P - T_W) + a_5(T_r - T_f) + a_6(T_e - T_w) \quad (1)$$

a	1	2	3	4	5	6
Value	$\frac{\Delta t}{\Delta r}\left(\frac{2\alpha_n r_n}{{r_n}^2 - {r_s}^2}\right)$	$-\frac{\Delta t}{\Delta r}\left(\frac{2\alpha_s r_s}{{r_n}^2 - {r_s}^2}\right)$	$\frac{\alpha_e \Delta t}{\Delta z^2}$	$-\frac{\alpha_w \Delta t}{\Delta z^2}$	$hA\Delta t$	$-\frac{\Delta t}{\Delta z}u$

Table 1: Discretized energy balance equation's coefficients.

Where Δt is the time-step, Δr and Δz are the volume cell's height and length, α_p is the thermal diffusivity of the material at the point p, h is the convection coefficient, u is the fluid's velocity at the point p, and A is the volume cell's unit area. All variables are expressed in SI units, and further description of parameters are such as described by Colombo, Dinis, and Carvalho (2021), which also contains detailed information on boundary conditions and the algorithm created in Python to iteratively solve Equation 1.

3. Discussion

The model could be used for multiple purposes, and could analyze the heat transfer process in time, or present just an estimation for stabilized temperature state (Figure 2).

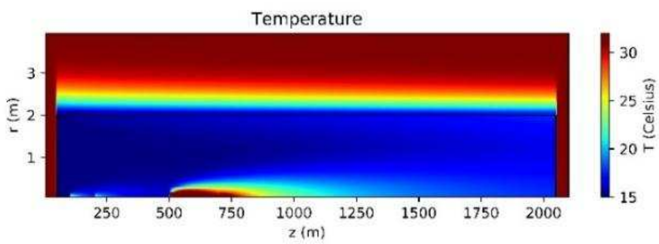

Figure 2: Stabilized temperature state for a gallery with machinery and personnel.

The model was tested for a typical closed-loop geothermal system, where water at 13 ºC is injected at 4 l/s in a gallery with a cross-section of approximately $10\ m^2$. The physical properties assumed for the rock were $\rho_r = 2500\ kg/m^3$, $c_r = 1100\ J/kg^0C$ and $k_r = 2.27\ W/m^0C$, and the rock mass temperature is 21 ºC; the gallery length is 5000 m. These conditions are similar to those of the geothermal system installed in Springhill Nova Scotia, and the results can be compared to those obtained by Rodríguez and Díaz (2009) and Ghoreishi Madiseh, et al. (2012), for similar input conditions. Figure 3 shows a plot of the water temperature versus traveled distance inside the galleries, comparing the results from this model to the mentioned authors'.

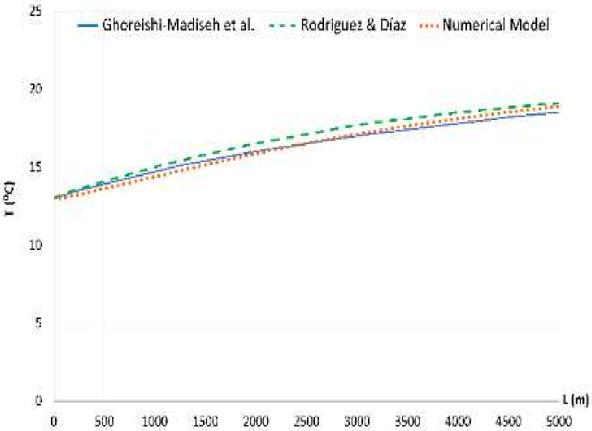

Figure 3: Mean water temperature versus gallery length.

4. Conclusion

The proposed model is a tool to support energy efficiency improvement in underground mining galleries. It brings together different approaches, such as heat recovery in closed-loop geothermal systems for abandoned galleries and heat recovery from the ventilation's exhaust air in operating mines, combines different models previously developed, and includes parameters that are relevant in mining but were not considered beforehand, such as wall roughness and the presence of other heat sources inside mining galleries. The results obtained are compatible with other models', but the model is yet to be tested and validated in a real case so that it can be adjusted and improved with empirical parameters.

References

Colombo, Vitor, Maria Lurdes Dinis, and José Soeiro de Carvalho. 2021. "Numerical Model to Assess the State and Increase of Temperatures in Underground Mine Galleries: A Tool to Support Heat Recovery Projects." *International Journal of Terrestrial Heat Flow and Applications* 4 (1): 110–18. https://doi.org/10.31214/ijthfa.v4i1.69.

Ghoreishi Madiseh, S. A., Mory M. Ghomshei, F. P. Hassani, and F. Abbasy. 2012. "Sustainable Heat Extraction from Abandoned Mine Tunnels: A Numerical Model." *Journal of Renewable and Sustainable Energy* 4 (3): 0–16. https://doi.org/10.1063/1.4712055.

International Energy Agency. 2017. "Key Wold Energy Statistic 2017." *International Energy Agency*. https://doi.org/10.1017/CBO9781107415324.004.

Patankar, Suhas V. 1980. *Numerical Heat Transfer and Fluid Flow*. Washington: Hemisphere Publishing Corporation.

Prno, Jason. 2013. "An Analysis of Factors Leading to the Establishment of a Social Licence to Operate in the Mining Industry." *Resources Policy* 38 (4): 577–90.

Rodríguez, Rafael, and María B. Díaz. 2009. "Analysis of the Utilization of Mine Galleries as Geothermal Heat Exchangers by Means a Semi-Empirical Prediction Method." *Renewable Energy* 34 (7): 1716–25. https://doi.org/10.1016/j.renene.2008.12.036.

Assessing complex and heterogeneous near-surface environments with geostatistical electromagnetic inversion

Narciso, J.[1], Azevedo, L.[1], Van De Vijver, E.[2]
[1]CERENA/DECivil, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[2]Department of Environment, Ghent University, Gent, Belgium

Abstract
The uppermost tens of meters beneath Earth's surface are the portion of the Earth that is more impacted by human activities. Thus, it is a highly dynamic region of the subsurface, hard to characterize. During the last decade, geophysical methods, mainly electrical and electromagnetic methods, have been progressively and successfully applied in near-surface characterization of complex and heterogeneous subsurface environments, for the identification of environmental hazards and the characterization of groundwater and mineral deposits. The near-surface modelling through geophysical data involves solving an inverse problem. The most common geophysical inversion methods are still based on deterministic approaches with limited capabilities of modelling such complex systems. This work contributes to improving the modelling and characterization of these heterogeneous subsurface environments introducing a novel geostatistical frequency-domain electromagnetic inversion methodology able to provide a small-scale characterization of the spatial distribution of the subsurface electrical conductivity and magnetic susceptibility and assess the uncertainty about the predictions.
Author Keywords. Near Surface Modelling, Geostatistical Simulation, FDEM inversion.

1. Introduction

The near surface of the Earth supports most of human activities and yields much of the water and mineral resources. The ability to characterize the near surface and its physical, chemical and biological properties is perennial to several of these activities and can be attained using both invasive and non-invasive techniques. Invasive techniques are generally expensive and slow to acquire and process and only provide information about the subsurface at sparse locations. The application of non-invasive geophysical techniques in near-surface characterization of complex and heterogeneous subsurface environments has increased considerably during the last decade, mainly electrical and electromagnetic methods, as a result of increased computational resources and the intrinsic ability for rapid and spatially comprehensive subsurface characterization. The quantitative near-surface modelling through geophysical data involves solving an inverse problem: predicting the spatial distribution of the relevant subsurface properties from the observed geophysical data (Tarantola, 2005). A geophysical inversion tries to solve an ill-posed and nonlinear inverse problem with multiple solutions. The most common techniques for near-surface modelling and characterization are unable to effectively integrate existing direct measurements of the subsurface and are mainly deterministic approaches where no uncertainty is considered. In this work, we introduce a novel geostatistical frequency-domain electromagnetics (FDEM) inversion methodology able to provide a small-scale characterization of the spatial distribution of the subsurface electrical conductivity (EC) and magnetic susceptibility (MS) and assess the uncertainty about the predictions, improving the modelling and characterization of these complex and heterogeneous subsurface environments. This inversion model accounts for observed data as represented by borehole data and integrates effectively this information in the inverted models. Synthetic and real application examples are used to illustrate this inversion method.

2. Methodology

The proposed iterative geostatistical inversion technique of FDEM data (Figure 1) predicts the spatial distribution of EC and MS and develops using the same global geostatistical seismic inversion framework proposed in Azevedo and Soares (2017). It relies on three main ideas: i) the perturbation of the model parameter space with stochastic sequential simulation and co-simulation; ii) the computation of synthetic FDEM data and the sensitivity of these responses towards vertical changes in EC and MS, through a one-dimensional forward model; iii) and the convergence is ensured by a global stochastic optimizer driven simultaneously by the mismatch between true and synthetic FDEM data weighted by the predicted depth of investigation as provided by the forward model.

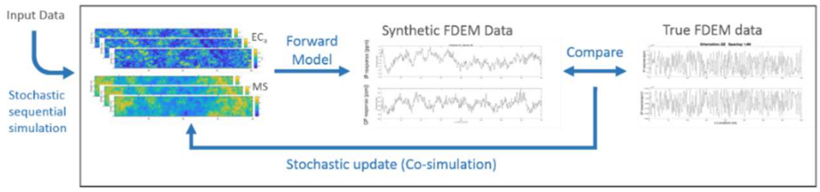

Figure 1: The proposed iterative geostatistical FDEM inversion technique.

The iterative geostatistical FDEM inversion may be summarized in the following steps:

1) Simulation of two ensembles of *Ns* models of EC and MS given borehole data and a variogram model that describes the expected spatial continuity pattern of each property with stochastic sequential simulation (Soares, 2001);
2) Calculation of the Ns synthetic FDEM data for each pair of EC and MS models simulated in 1) using a one-dimensional FDEM forward model (Hanssens et al., 2019);
3) Compute the local similarity (*S*) between true and synthetic FDEM data per offset and coil configuration;
4) Build three auxiliary variables by selecting the EC and MS that ensure the highest *S* at a given iteration. Store the corresponding *S* values;
5) Integrate the sensitivity analysis of each FDEM data to variations in EC and MS in depth in the auxiliary *S* variables computed in 4);
6) Generate a new ensemble of EC and MS models using co-DSS (Horta and Soares, 2010) using the auxiliary variables resulting from 5) as secondary variables;
7) Iterate and repeat steps 2-7, while the global convergence of the method, expressed in correlation coefficients, reaches a pre-defined threshold.

3. Application and results

The proposed iterative geostatistical FDEM inversion methodology was applied to a 3-D benchmark landfill data set, developed based on real data collected at a mine tailing disposal. After the generation of the true synthetic three-dimensional models for EC and MS, nine “boreholes” were extracted equally spaced along the same transect (Figure 2). These data are considered as available experimental in-situ data for the iterative geostatistical FDEM inversion and were used to model the variograms used in the inversion. Synthetic FDEM data were generated along the same transect (Figure 3) mimicking the different transmitter-receiver (loop-loop) configurations of a multi-receiver FDEM sensor most used in near-surface surveys, with 3 offsets in horizontal coplanar (HCP) configuration, 1, 2 and 4 meters , and 3 offsets in perpendicular (PRP) configuration, 1.1, 2.1 and 4.1 meters.

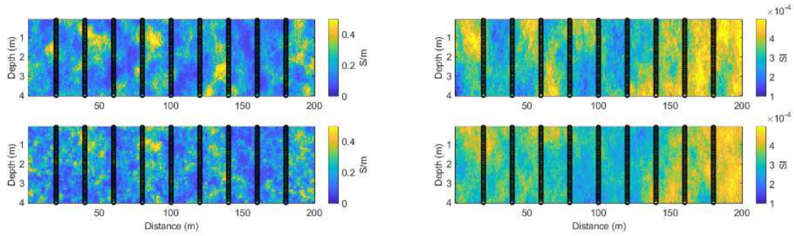

Figure 2: True EC (top left) and true MS (top right) models compared to simulated models of EC (bottom left) and MS (bottom right) and borehole locations (black lines).

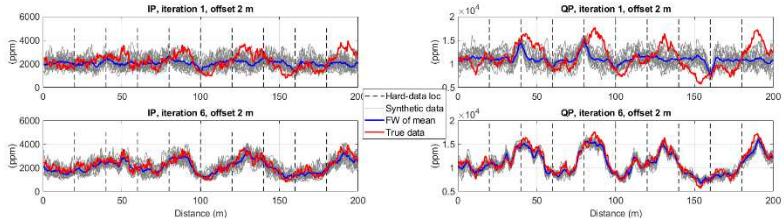

Figure 3: Synthetic IP and QP data for the 2 m HCP coil configuration, per model realization and the mean of the model realizations (grey and blue, respectively) calculated from the model realizations, compared to true IP and QP data (red).

4. Conclusions

This work introduces an iterative geostatistical FDEM inversion method able to predict the spatial distribution of EC and MS at the small-scale. It allows better modelling and characterization of the near-surface and can be applied to characterize complex and heterogeneous subsurface environments of different types and nature, predict the spatial distribution of the properties of interest and assessing the spatial uncertainty associated with the inverted properties.

References

Azevedo, L., and A. Soares. 2017. “Geostatistical Methods for Reservoir Geophysics”. *Advances in Oil and Gas Exploration & Production*, Springer.

Hanssens, D., S. Delefortrie, J. De Pue, M. Van Meirvenne, and P. De Smedt. 2019. "Frequency-Domain Electromagnetic Forward and Sensitivity Modeling: Practical Aspects of modeling a Magnetic Dipole in a Multilayered Half-Space". *IEEE Geoscience and Remote Sensing Magazine*, 7(1), 74-85.

Horta, A., and A. Soares. 2010. “Direct Sequential Co-simulation with Joint Probability Distributions”. *Mathematical Geoscience*, vol. 42, no. 3, pp. 269–292.

Soares, A. 2001. “Direct Sequential Simulation and Cosimulation”. *Mathematical Geoscience*, vol. 33, no. 1, pp. 911–926.

Tarantola, A. 2005. “Inverse Problem Theory and Methods for Model Parameter Estimation”. *Philadelphia: Society for Industrial and Applied Mathematics*. 358 pp.

Acknowledgments

This work was supported by the Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) through the project SFRH/BD/139577/2018. The gratefully acknowledge the support of the CERENA (strategic project FCT-UIDB/04028/2020). We also thank Schlumberger for the donation of the academic licenses of Petrel.

Generative Adversarial Network Applied To Ore Type Modelling

Helga Jordão[1], Amílcar Soares[1]
[1]CERENA/DECivil, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

Abstract
In complex geological environments, the characterization of the spatial domain of different ore types has been one of the most important challenges in the assessment of mineral resources and reserves. Ore type modelling requires an expert geological control and is high time consuming. In this paper we propose a machine learning model, a Generative Adversarial Network (GAN), for delimiting the geological domains of an orebody conditioned on drillhole data. The experiments and validations showed that the geological models produced by the GAN can achieve high accuracy and diversity when compared with models drawn by the geology.
Author Keywords. Ore Type Modelling, Deep Learning, Generative Adversarial Networks**.**

1. Introduction

In the evaluation of mineral resources, it is extremely important to characterize the spatial domains of the mineralizations with different production or metallurgical treatment, the ore types, since the subsequent evaluation of resources is dependent on the sample values and the spatial continuity patterns of metal grades inside the domains of each ore type. Ore type modelling is a fundamental stage both in the exploration phase and in the stages of production in which the domains of the ore types are systematically updated with more information (new samples from bore holes). This ore types modelling procedure is a very high time-consuming and resource-intensive and becomes a problem when there is a need for frequent updating of geological resources.
In this short paper, we implement a Generative Adversarial Network (GAN) (Goodfellow et al., 2014), based on the Pix2Pix method (Isola et al., 2017) that reproduces, not the unknown geological reality about the morphology of the ore types, but the procedures of geological interpretation of the same ore types. This is based on two steps: first the system learns from the historic of a given area of the mine, with drilling samples and a morphological model built with these samples; in a second step, it is able to reproduce this modelling capacity, in the same geological environment but in new situations where only the drilling samples are available. After the training and testing, the generator neural network, is able of reproducing, with great precision and accuracy, the interpretation of the expert/geologist in new situations, of the same reality, just based on the available bore-hole data. This approach mitigates the problem of time-consuming of traditional expert geological interpretation of the ore type boundaries.

2. Materials and Methods

This study was conducted with real data from a volcanogenic sulphide deposit, located at South of Portugal. For illustration purposes an area with just two ore types, stockworks and massive sulphides ore, was chosen, hereafter designated by oretype A and B. For training and testing the GAN, a database was established. 2D parallel sections (images with a size of 256 x 256 pixels) were collected from a 3D geological model built by the geologists. For each section of the geological model, the corresponding drillhole samples that intersect the section was also obtained. A special conditional GAN (cGAN), the Pix2Pix model (Isola et al., 2017), was employed to draw the limits of the two orebody types (A and B) conditioned on the drillhole samples. In the cGAN (Fig. 1), the generator is trained on the pairs of train images (I_{train}) (geological model drawn by geology) and the conditioned images I_{cond} (drillhole samples). The generator is fed with the conditioning image (conditioning sample data) and outputs the generated image (I_{gen}), the envelop of the ore types. The paired images I_{cond} and I_{gen} passes throw the discriminator, and the generator is updated via the adversarial loss given by the discriminator plus the L1 loss between the I_{gen} and the corresponding I_{train}. At alternative steps, the discriminator receives true and false paired images and is updated via adversarial loss (Isola et al., 2017). The quality of the generated geological models was evaluated by the number of ore type mismatches between the I_{cond} and the I_{gen} at sample drill hole locations and using Intersection over Union (IoU) metric, also known as the Jaccard Index (Jaccard, 1901). IoU measures the overlap between two areas. In this study, the overlap between the area of the generated geological model and the ground truth geological model drawn by the geology.

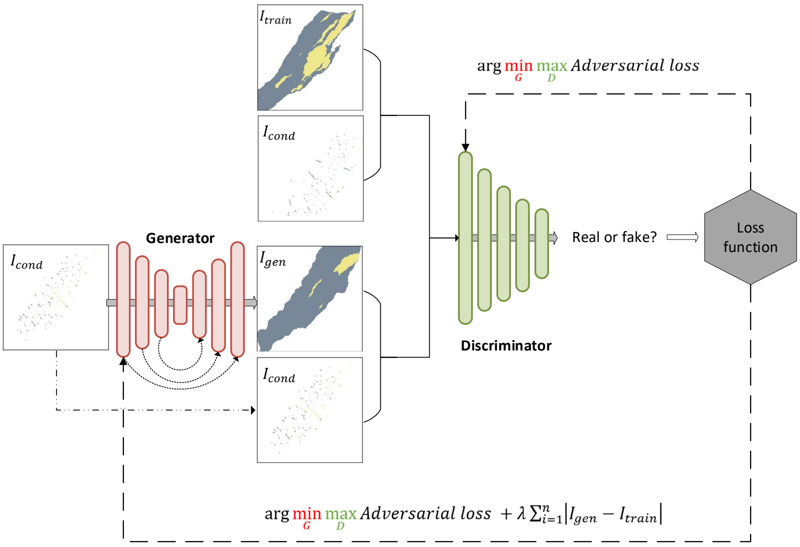

Figure 1: cGAN framework.

3. Discussion

The final generator was evaluated using the test dataset. Several geological models conditioning to drillhole samples were generated presenting, on average, 5% of mismatches at sample locations, and 0.92 and 0.81 of IoU for ore type A and B, respectively. Figure 2 illustrates 4 examples of generated geological ore type models. High performance is presented in the example 4 with IoU values higher than 0.9 for both ore types and sample mismatches lower than 4%. A lower performance, such as example 2 showed that the generator had difficulty in drawing the frontier between ore type A and B and the external limit of geological orebody. Also, we noticed that low values of mismatches do not always guarantee high values of IoU, or vice-versa (see second and fourth examples from Fig. 2).

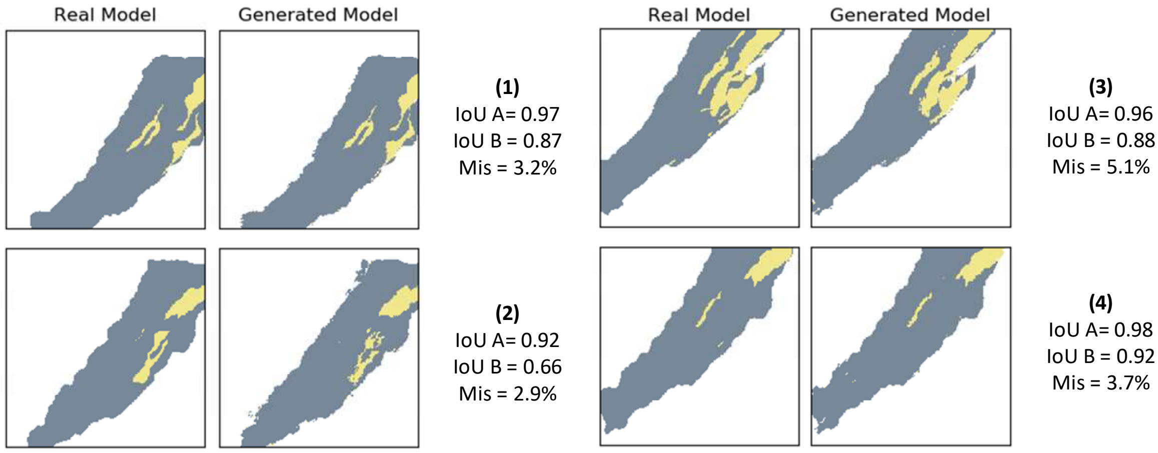

Figure 2: Real and generated geological models and their respective evaluation metrics (IoU – intersection over union and Mis - % mismatches at generated geological models at sample locations).

4. Conclusion

In this work, we proposed a conditional generative adversarial network as an end-to-end framework for generate geological models conditioned to drillhole samples. The experiments and validations showed that the geological models produced by the cGAN can achieve high accuracy and diversity when compared with models drawn by the geology. We consider that this first approach presents promising results for its application on real-time geological model management.

References

Goodfellow, I., Y. Bengio & A. Courville. 2016. Deep Learning (Adaptive Computation and Machine Learning series). The MIT Press.

Isola, P., J. Zhu, T. Zhou & A. A. Efros (2017) Image-to-Image Translation with Conditional Adversarial Networks. 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 5967-5976.

Jaccard, P. (1901) Distribution de la flore alpine dans le Bassin des Drouces et dans quelques regions voisines. Bulletin de la Société Vaudoise des Sciences Naturelles, 37, 241-72.

Acknowledgments

Funding was provided by Fundação para a Ciência e Tecnologia (PhD Grant SFRH/BD/115613/2016). The authors would also like to gratefully acknowledge the support of the CERENA (strategic project FCT-UIDB/04028/2020).

Evaluation of mineral project investment using Multicriteria Decision-Aid

Andreas Tuhafeni Salom[1,2], Miguel Tato Diogo[1,2] and Manuel Matos[1,3]
[1]Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal
[2]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal
[3]CPES-Centre for Power and energy Systems, INESC TEC - Institute for Systems and Computer Engineering, Technology and Science, Campus FEUP, Rua Dr. Roberto Frias, 4200 - 465 Porto, Portugal

Abstract
The examination of the demand and the supply of minerals is an ongoing debate for the government and private sector. At the centre of the discussion is the selection of mineral projects for investment. The decision to invest in the mining industry is influenced by many characteristics not common in other economic sectors, such as non-renewable resources, finite life, long lead time to production, slow outcomes effect, capital intensive, irreversible investment, uncertainty geological resources, complexity stakeholder relationship, and ambiguity and uncertain economic environment, and complicated risk factors. A holistic approach to assessing and evaluating the investment project opportunity and risk before accepting the project has become critical to decision-makers to make systematic and sustainable decisions. That will avoid irreversible illogical investment. A multicriteria decision aid [MCDA] tool will be established that integrate Geological, Corporate Governance-Political, Economic & Market, Social, Technological, Environmental and Legal [GC-PESTEL] factors and stakeholders' sentiments.
Author Keywords. AHP, Decision-Making, GC-PESTEL, Investment, MCDM, MCDA, Mineral Evaluation, TOPSIS.

1. Introduction

The future demand for mineral resources of any type is anticipated to grow exponentially as the global human population is estimated to progress toward 9 billion, to be reached about in 2050. Many people in developing countries live longer and aspire to increase their living standards to enjoy the infrastructure, services, and goods that the developed countries are currently experienced. The same vein is indispensable in developing innovative technologies such as autonomous electric vehicles and robotics systems to address issues such as reducing greenhouse gas emissions and demand production of low carbon "green" energy. New environmental regulation, terrestrial minerals, and metals supplies are under tremendous pressure will drive the minerals and metals demand exponentially. Other factors are public opposition, low grade/small deposits, and resource nationalism. The mineral demand has triggered investors and the government to search for minerals in areas that have never been explored or uncertain, such as the deep ocean crust. The complexity of these multi factors is due to the macro-environmental factors related to GC-PESTEL factors. In mining evaluation, those factors can refer to as Modifying Factors assessed by Competent Person when evaluating and classifying mineral resources and reserves following the Mineral Resource and Reserves reporting system such as JORC and SAMREC. Build on the above background. This research paper seeks to highlight the answer to the following primary question: How to evaluate the mineral project to achieve coherent and authentic/justifiable decisions by integrating stakeholder's perceptions using Multicriteria Decision Aid/Multicriteria Decision Making? The motivation is that the existing evaluation methods are incapable of incorporating conflict criteria. They are specific fragmented areas, such as geological or economic return, which is purely quantitative, leaving out qualitative factors such as geopolitical, environmental, social, governance and legal. Neither considers stakeholder's perceptions.

2. Materials and Methods

The literature review of the mining industry shows that many mining projects that decided geological and economic feasibility were delayed or cancelled because of political, legal, environmental, or social factors whose significance was not accurately evaluated. A decision-making problem is a process of finding the best option from all the feasible alternatives in the presence of conflicting criteria. The general form, multicriteria decision-analysis problems can be represented as a decision matrix with the corresponding weight vector below. Where $A = (A_1, A_2, \dots, A_m)$ are possible alternatives among which decision-makers have to choose, $C = (C_1, C_2, \dots, C_n)$ are criteria with which alternatives performance are measure, x_{ij} is the performance value of alternatives A_i concerning criterion C_j, w_j is the weight of criterion C_j.

$$\textit{Decision Matrix (D)=} \quad \begin{array}{c|ccccc|} & C_1 & C_2 & C_3 & \dots & C_n \\ A_1 & x_{11} & x_{12} & x_{13} & \dots & x_{1n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ A_m & x_{m1} & x_{m2} & x_{m3} & \dots & x_{mn} \end{array} \quad W = (w_1, w_2, \dots, w_n)$$

The criteria identification and evaluation process are critical in the MCDA as it links to the weighting established from stakeholders and options/alternative (Figure 1) evaluation. Zhou and Schoenung (2007) state three ways determine to criteria weighting: 1) by using existing generic weights; 2) by calculating weights using objective criteria; 3) by eliciting weights from sector experts or stakeholders. In this work's the weight of the experts and stakeholders will be significant. Therefore, the criteria weight will be determined based on the experts and stakeholders' inputs (Figure 2). The latter is preferred multicriteria decision analysis methods to be operative for this research. The traditional Analytical Hierarchy Process [AHP] and Technique for Order of Preference by Similarity to Ideal Solution [TOPSIS] are used to determine the weight from stakeholder and expects, while the novel version of MCDA will be used as an evaluation method to be classified mineral projects into three feasibility classes "Option to Expand', 'Option to Hold,' and 'Option to Abandon.' The classification will be based on the project performance score per factor and a classified independent from one another.

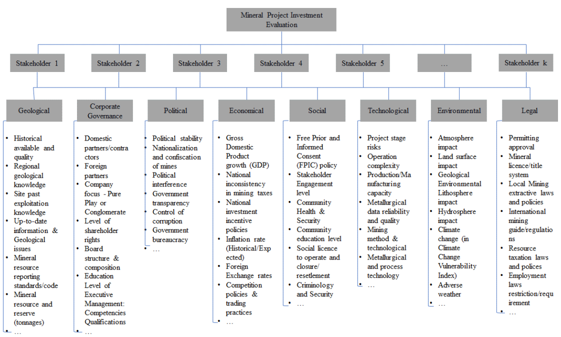

Figure 1: Hierarchy including the stakeholders' group*

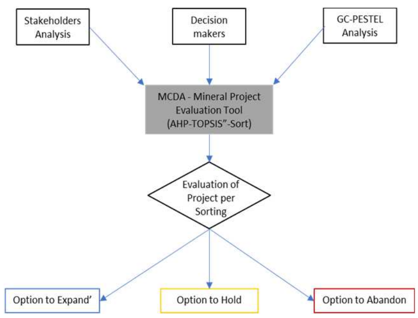

Figure 2: Factors and criteria selection research process

3. Discussion

The outcome of this work will be the mineral project multicriteria evaluation tool to be used support and evaluate the mineral projects for an investment decision. The proposed method will address the gap in the existing evaluation methods incapable of integrating qualitative and quantitative conflict criteria and stakeholders (experts & opponents) priorities. The method will build on the eight main factors/criteria and at least 100 sub-criteria that are amendable to support decision-makers evaluate the mineral project for investment decision as well as to justified and review their decision economical and straightforward.

4. Conclusions

The proposed method will be used in practice to demonstrate the feasibility and applicability to evaluate real case project with multi conflict criteria and stakeholder. The method will aid decision-makers to make systematic and sustainable decisions and avoid irreversible illogical investment that may have issues potential social resistance in mining project.

References

Zhou, X., & Schoenung, J. M. (2007). An integrated impact assessment and weighting methodology: evaluation of the environmental consequences of computer display technology substitution. *Journal of Environmental Management*, *83*(1), 1-24.

Seismicity and active stress field derived from the inversion of focal mechanism data, South Atlas of Tunisia.

Harzali Makrem
Water, Energy and Environment Laboratory, Engineering National School of Sfax (ENIS), University of Sfax, Sfax, Tunisia

Abstract
Seismicity is not uniformly distributed throughout in the southern Tunisian Atlas and is mainly distributed around active strike-slip faults, thrust-related anticlines and shear zones. In the present study, focal mechanisms of 14 events taken from 1987 to 2019 were studied on the basis of stress inversion of focal mechanism parameters in order to investigate the spatial variations of the stress regime and understand the detailed tectonics. Study of earthquake focal mechanisms reveals prevailing strike-slip faulting using the Win-Tensor program that changes into thrust faulting locally in relation to the complexity of the regional tectonic domain. Pressure/Tension axes are mostly horizontal and maximum horizontal stress directions (SH max) are directed mainly in NW-SE direction which corresponds to the slip character of the E-W strike-slip motion of Chotts faults and its splays. Furthermore, maximum (δ1) and minimum (δ3) principal stresses shows a subhorizontal trend and the intermediate principle stress (δ2) is vertically orientated, in fit with the prevailing strike-slip regime. Indeed, these orientations seem to shift, locally, from N to S where NW-SE directed δ1 turns towards N-S in some zones. Our observations are in strong alignment with the NW-SE Africa-Eurasia convergence, which is accommodated by an array of strike-slip movement along the major fault systems in this segment of Tunisian Atlas.
Author Keywords. Southern Tunisian Atlas, Focal Mechanism Data, Stress Inversion, Strike-Slip, Tectonics.

1. Introduction

The western Mediterranean region is a tectonically active region where the African plate collides with the Eurasian Plate. Several authors have pointed out that this ongoing deformation is connected with the production of complex orogenic belt, like the fold-thrust belt of Maghrebides and Atlas domains (Morel and Meghraoui 1996; Frizon de Lamotte et al. 2000). In the Southern Atlas of Tunisia, however, deformation resulting from the collision is accommodated, according to Gharbi et al., (2014) and Masrouhi et al., (2019) through the E-W- to WNW-ESE dextral strike-slip faults associated with E-W- to NE-SW thrust faults (Fig. 1).

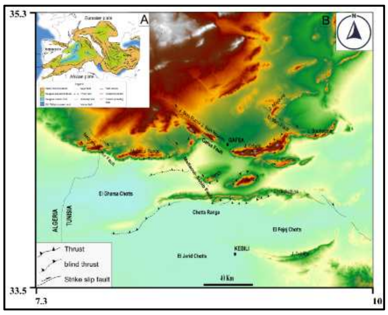

Figure 1: simplified map of the study area.

Deformation patterns along these fault systems related to the remobilization of major extensional faults inherited from the Cretaceous rifting (Chihi et al., 1992; Gharbi et al., 2013 and 2014; Soumaya et al., 2020). Earthquakes strike at a shallow depth in the Southern Tunisian Atlas and appear to cluster along the major lineaments (Bahrouni et al., 2013; Soumaya et al., 2018). The latest seismic activity shows a low to moderate magnitude (Mw <5.2) induced by the reactivation of major faults in the basement and crust (Soumaya et al., 2015) resulting from the northward motions of the African plate.

2. Materials and methods

In this paper, we considered the most updated seismic database involving 27 earthquakes recorded in Tunisia. The earthquakes focal mechanism data within the period 1957-2019 was recovered from previous works (Hfaiedh et al., 1985; Bahrouni et al., 2013; Soumaya et al., 2015; 2018) and the International Seismic Center agency. The inversion of the stress tensor (Win-Tensor program) draws from earthquake fault plane solutions, in which the hypothesis that the stress field is uniform in space and constant in time as well as the direction of fault slip occurs in the direction of maximum shear stress (Delvaux and Barth, 2010).

3. Results

The principal axes of compressive and the stress ratio (R'= 1.99) reflect the aspects of a prevailing transpressive strike-slip fault regime along the study area, with a maximum horizontal stress axis (150 ° E) and minimal horizontal stress axis (060 ° E) aligned northwest-southeast (Fig. 2).

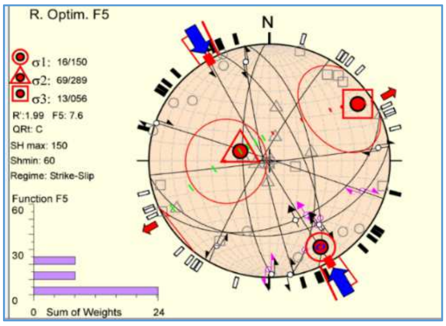

Figure 2: Formal stress inversion of 10 earthquakes focal mechanisms.

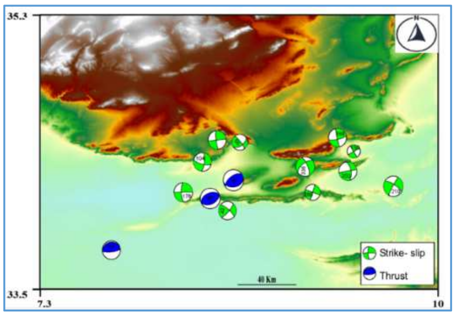

Figure 3: Simplified map showing focal mechanisms determined in this study.

The Ternary diagram indicates that the study area is dominantly under the effects of strike-slip faulting (Fig. 4) with steep dipping fault planes of different directions (Fig. 5) associated with the ongoing tectonic stress field along the active seismic structures. Focal mechanism solutions have also been obtained, however with a thrusting fault in a few localities (Fig. 3 and Table 2). The geometry and mechanism of the fault during an earthquake are represented in a focal mechanism solution. The diagram of Frohlich ternary diagram shows that the region is controlled by a dominant strike-slip faulting regime.

Most of the P- and T-axes are nearly horizontal and describe a strike-slip motion with NW-SE compression and NE-SW distension (Fig. 6). In a map view, the distribution of these earthquakes reveals a trend along the major faults and provides evidence of ongoing reactivation of pre-existing faults.

4. Discussion and Conclusions

The Southern Tunisian Atlas show a complex pattern of active deformation and display complex splays and Riedel shear structures. The study of seismotectonic evidence therefore indicates that its seismogenic region is developed as an elongated narrow band aligned with the active inherited faults involved since the Triassic in the deformation within the South Atlas of Tunisia (Gafsa fault, Negrine-Tozeur fault, Metlaoui fault, chotts range). E-W-trending dextral strike-slip faulting and NE-SW-to E-W-trending fault-related folding are associated with the complexity of the faulting system and high stress field in the area (Bahrouni et al., 2020). The stress inversion analysis obtained from the solutions of the focal mechanism reveals that in the area, a strike-slip stress field is prevailing. This consequence may be attributed to the regional stress field, which is primarily driven by the oblique convergence of Africa and Eurasia plates. The trigger of both historical and instrumental earthquakes appears to have been the active faults in the Southern Atlas (Bahrouni et al., 2013).

Gharbi et al., (2014) show that the moderate earthquakes can correspond to recent reactivation of inherited faults. They include earthquakes resulting from activity of more than one fault set, some of which remain buried at depth, often with obvious surface fault rupture.

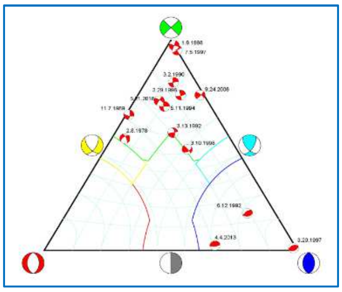

Figure 4: Rake-based ternary diagram.

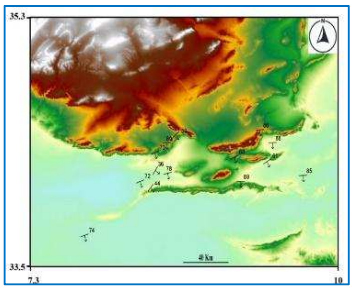

Figure 5: Tectonic map of the study area showing the dip directions calculated for individual events.

Moderate to large-magnitude earthquakes in the region have fault plane solutions consistent with NE-SW and E-W reverse faults, with seismic slip vectors close to the azimuth of maximum compressive stress. Pressure axes measured are predominantly subhorizontal and maximal horizontal stress directions (SH max) suggest a mostly NW-SE direction.

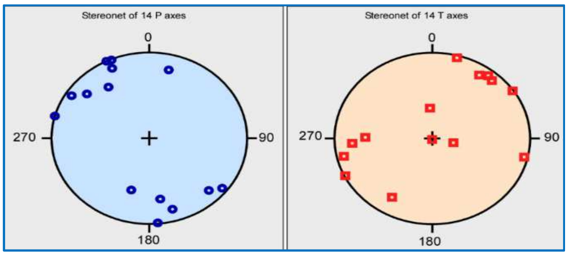

Figure 6: Stereographic P- and T-axes plots containing both focal mechanism solutions.

References

Bahrouni, N., Bouaziz, S., Soumaya, A., Ben Ayed, N., Attafi, K., Houla, Y., El Ghali, A., Rebai, N., 2013. Neotectonic and seismotectonic investigation of seismically active regions in Tunisia: a multidisciplinary approach. *Journal of Seismology* 18, 2.

Bouaziz, S., Barrier, E., Soussi, M., Turki, M.M., Zouari, H., 2002. Tectonic evolution of the northern African margin in Tunisia from paleostress data and sedimentary record. *Tectonophysics* 357, 227–253.

Delvaux, D., 2012. Release of program Win-Tensor 4.0 for tectonic stress inversion: Statistical expression of stress parameters. EGU General Assembly, Vienna, 2012. *Geophysical Research Abstracts*, 14, EGU2012–EGU5899.

Frohlich, C. 1992. Triangle diagrams: Ternary graphs to display similarity and diversity of earthquake focal mechanisms. *Physics of the Earth and Planetary Interiors*, 75(1–3), 193–198.

Hfaiedh, M., Ben Ayed, N., Donee, L. 1985. Etude néotectonique et seismotectonique de la Tunisie nord-orientale. Notes Serv. geol. Tunisie, 51, pp. 41–55 (ONM-Tunis).

Morel, J. L., Meghraoui, M. 1996. Goringe-Alboran-Tell tectonic zone: A transpression system along the Africa-Eurasia plate boundary. *Geology*, 24(8), 755–758.

Outtani, F., Addoum, B., Mercier, E., de Lamotte, D.F., Andrieux, J., 1995. Geometry and kinematics of the south Atlas front, Algeria and Tunisia. *Tectonophysics* 249 (3–4), 233–248.

POSTERS

Study of the potential of steel slags in acid mine drainage treatment

Ana Pinto[1], M. Cristina Vila[1,2], Mafalda Oliveira[3], Joana Dias[1,4]

[1]Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

[2]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

[3]Somincor-Sociedade Mineira de Neves-Corvo, S.A., Complexo da Mina de Neves Corvo, Aptd. 12, Santa Barbara De Padrões, Beja

[4]LEPABE - Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

Abstract

Acid mine drainage (AMD) is a common environmental problem associated to mining industry which is a result of the exposure of sulphide minerals to oxygen and water in the presence of oxidizing bacteria (Gazea et al., 1996). In general, areas affected by AMD present low pH values, high content of dissolved metals and high acidity. When released into the environment without treatment, these AMD polluted waters can lead to the degradation of ecosystems. Steel slag is considered a waste product generated during the steelmaking process. Due to its characteristics, it can have a lot of applications, for example, in civil engineering as a cement admixture, in agriculture as a fertilizers and soil improver or in mining industry as a neutralizing agent.

The aim of this work is evaluating the efficiency of steel slags in AMD treatment. In the first phase was performed the characterization of AMD from Somincor and the steel slags from SN Maia. Both products were characterized chemically. The steel slag was submitted to the particle size analyze, determination of pH, neutralizing capacity, free CaO and sulfur content. The AMD was characterized for pH, conductivity, redox potential and dissolved oxygen. The second phase consisted of batch tests using 50 mL of AMD and 10 g of steel slags kept under agitation for 48 h. During that time, the liquid and solid phases after 0,5 h, 2 h, 24 h and 48 h were chemically analyzed and the pH was registered. In last phase, column tests were performed using columns with 5 cm diameter and 50 cm heigh where 1.5 L of AMD were circulated through steel slag material. Samples of the liquid phase were collected and analyzed at different stages of the test. In these experiments different columns configuration and amounts of slags were tested.

Although experimental work is still in progress, preliminary results are encouraging for the use of steel slag in the treatment of acid mine drainage.

Author Keywords. Acid Mine Drainage, Slags, Leaching, Neutralizing Agent, pH

References

Gazea, B., Adam, K., & Kontopoulos, A. (1996). A review of passive systems for the treatment of acid mine drainage. *Minerals Engineering*, 9(1), 23-42.

Acid mine drainage treatment using industrial by-products as neutralization chemicals

Gil Abreu Leite[1], Maria de Lurdes Dinis[1,2]
[1]Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal
[2]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

Abstract

This work aimed to investigate whether two industrial by-products could be used as neutralization chemicals in acid mine drainage treatment. Acid mine drainage represents a serious environmental concern, both in active mines and after mine closure, due to the acidic pH and high concentration in sulphates and metals.

Two different industrial by-products were used in this study: calcium fluoride (CaF_2) sludge from the phosphate industry (PS) and limestone cutting sludge wastes (LS). Selective samples from these materials were analyzed for particle size distribution and chemical composition. The particle size distribution was determined by the sieve method, and a laser diffraction analyzer was used for the fraction below 74 µm (Malvern Mastersize 2000). The chemical composition was determined by X-ray fluorescence (X-MET7500 Oxford).

The acid mine drainage solution was collected from the Vale das Gatas mine, an abandoned mine located in northern Portugal. This mine was exploited until 1986 with a focus on wolframite, cassiterite and scheelite. Chalcopyrite and other common sulphides are also present in the mineralized veins. A waste rock pile is the main source of acid mine drainage. The solution was characterized for pH, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO), acidity and chemical analysis for the concentration of the mains cations (Fe^{2+}, Mn^{2+}, Al^{3+}, Ca^{2+}), total iron and sulphate anions (SO_4^{2-}). A two-stage batch test was performed with PS samples at L/S 10:1 and 3:1 for 24 hours, with stirring. The tests were stopped after one and 12 hours to measure pH, EC, DO, and ORP. After settling, water samples from the supernatant were taken for sulphate and metal analysis. The sludge was filtered, and the solid cake was analyzed for metals concentration.

Batch experiments were also carried out with the LS samples. Four beakers of 250 ml were filled with 150 ml of acid mine drainage solution and different weight of LS samples were added: 10 g, 25 g, 50 g, and 100 g. Measurements of pH, EC, OD, and ORP, were made every 24 hours for seven days. Column experiments were performed with the two types of materials individually. A column was filled at 1/3 of the total volume with the solid material and completed with AMD solution. The treated solution was collected from the top of the column and analyzed every 24 hours for pH, EC, DO, and ORP.

The batch experiments with PS samples showed a neutralization effect on mine solution after one hour of reaction (the initial pH was approximately 5). A similar result was observed in the column filled with PS. After seven days, the pH stabilized at 7.3 for batch tests and 7.1 for the column tests. During the batch tests with LS samples, the pH increased from 5 to 9 and stabilize at 8.3 value, after seven days. The columns tests presented a pH of 8.7 after one hour and stabilized in 8.6 value after seven days.

The preliminary results of this work show that PS samples promoted the neutralization of the acid mine drainage solution. However, the amount of calcium ions present in the PS samples is not sufficient to generate the necessary alkalinity to increase the pH up to suitable values for metals precipitation (e.g., pH ~ 9-9.5 for Mn). The final pH for both experiments (batch and column tests) with this by-product was approximately the same, which may be caused by the saturation of the solution with calcium ions and therefore the residence time did not have a significant effect after the first hour of reaction. As expected, the LS samples had a better efficiency in the neutralization of the solution and in final pH values suitable for metals precipitation (Al, Fe, and Mn, in particular). The next steps are to promote the oxidation of the resulting solutions from the batch and column tests to assess the efficiency on metals precipitation and removal from the solution.

Author Keywords. Acid Mine Drainage, Neutralization, Industrial By-Products, Mine Water, Industrial Sludge.

Study of stripping process on recovery of gold by activated carbon using alternative reagents - Sodium Thiosulphate and Bromide

Joana Monteiro[1], Aurora Futuro[1,2], Rui Sousa[1,2]

[1]Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

[2]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

Abstract

During the last twenty years, the concept of sustainable development has taken a large impact on mining operations leading to an increasing demand for greener alternatives when extracting and recovering minerals.

Gold hydrometallurgical process starts with the leaching stage, in which gold ions are dissolved into an aqueous solution. Cyanide is the most applied reagent in the leaching and recovery of gold from ores, mostly because of its chemical stability and lower costs. However, due to its toxicity and nefarious impacts on the environment, considerable attention has been given to the study of cleaner/greener alternatives. After the gold dissolution, it is required to recover gold ions, maintaining the other dissolved metals in the solution, to obtain a purified gold solution. Activated Carbon is one of the methods applied to recover gold from leaching solutions. The hydrometallurgy process ends with the electrowinning stage, in which the gold is recovered from the purified solution.

The main objective of the present work is the study of the purification process using activated carbon to extract gold from the leaching solution (stripping stage). Two environmental friendly leaching reagents were applied - Sodium Thiosulphate and Bromide.

The experimental work started with the leaching of the gold ore using solutions of Sodium Thiosulphate and Bromide. The next step was the adsorption of gold with activated carbon from coconut shells. A kinetic evaluation was carried to determine the adsorption capacity of the carbon, as well as the maximum gold adsorbed.

The last part of this work included the study of the stripping process, varying some parameters such as temperature, ethanol content and solid-liquid ratio. In line with this, it was possible to find suitable conditions for the stripping process. The most promising conditions were temperature of 95 ºC, 15% Ethanol and a S/L ratio of 1:20.

Author Keywords. Gold Leaching, Cyanide, Sodium Thiosulphate, Bromide, Adsorption, Stripping.

Geostatistical Seismic AVA inversion with self-updating rock physics

Roberto Miele[1], Bernardo V. Barreto[2], Paula Yamada[2], Luiz E. Varella[2], Anderson L. Pimentel[2], João F. Costa[2], Leonardo Azevedo[1]

[1]CERENA/DECivil, Instituto Superior Técnico, Lisbon University, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

[2]PETROBRAS – EXP/GEOP/TGEO, Av. Henrique Valadares, 28 - Torre B 3º andar, 20231-030, Rio de Janeiro-RJ, Brasil

Abstract

Three-dimensional subsurface models of rock properties, such as porosity (ϕ), volume of mineral phases (V_{min}) and fluid saturation (S_f), are fundamental for reliable reservoir characterization and field development. The geostatistical rock physics AVA inversion (Azevedo et al., 2019) is an iterative method that allows to directly predict the spatial distribution of such properties from seismic reflection data, by the integration of well-log data together with a calibrated rock physics model. The latter is a set of mathematical equations that links the petrophysical and the elastic domains (Mavko et al. 2019).

In this seismic inversion method, the calibration of the rock physics model is carried out manually by selecting the appropriate model parameters, so the predicted elastic logs fit the observed well log data. Given the calibrated rock physics model, the iterative inversion starts by simulating three-dimensional volumes of S_f and co-simulating ϕ and V_{min}, using direct sequential simulation and co-simulation (Soares 2001; Horta and Soares 2010). A facies distribution volume is then obtained from the petrophysical models through Bayesian classification. By applying the calibrated rock physics model, P- and S-wave velocities (V_P, V_S) and Density (ρ) volumes are directly computed. Synthetic seismic data is finally calculated from V_P, V_S and ρ, and compared to the real seismic to drive the convergence of the iterative procedure both at the local and global scales.

The direct application of a rock physics model calibrated on a limited set of available well data and the lack of uncertainty quantification represents a main downside of this methodology, limiting the exploration of the elastic parameters space and the set of possible geological scenarios considered, also affecting the models' convergence. To overcome this problem, we integrate the concepts of Statistical Rock Physics (Avseth et al. 2005) and self-updating joint distributions into this inversion framework. To do that, we first build a three-dimensional multivariate distribution representing the uncertainty and possible variability of the V_P, V_S and ρ values calculated at each models' node, based on the prior knowledge on the study case. Elastic models are then generated by sampling from these distributions. The mismatch between synthetic and real seismic volumes will finally provide information to update each multivariate distribution at each iteration, to generate more accurate models.

The method was tested on a one-dimensional synthetic case and on a three-dimensional real case with a blind well, to assess locally the performance of the proposed geostatistical inversion method. The results obtained demonstrated the capability of the inversion methodology to retrieve accurate petro-elastic models while considering rock physics model uncertainty and exploring a wider range of possible geological scenarios in terms of elastic properties.

Author Keywords. Geostatistical Seismic Inversion, Stochastic Inversion, Statistical Rock Physics.

References

Avseth, Per, Tapan Mukerji, and Gary Mavko. 2005. "Quantitative Seismic Interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk". 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511600074.

Azevedo, Leonardo, Dario Grana, and Catarina Amaro. 2019. "Geostatistical Rock Physics AVA Inversion." *Geophysical Journal International* 216 (3): 1728–39. https://doi.org/10.1093/gji/ggy511.

Horta, Ana, and Amílcar Soares. 2010. "Direct Sequential Co-Simulation with Joint Probability Distributions." *Mathematical Geosciences* 42 (3): 269–92. https://doi.org/10.1007/s11004-010-9265-x.

Mavko, Gary, Tapan Mukerji, and Jack Dvorkin. 2019. *The Rock Physics Handbook*. Third edition. Cambridge, United Kingdom: Cambridge University Press.

Soares, A. Direct Sequential Simulation and Cosimulation. *Mathematical Geology* 33, 911–926 (2001). https://doi.org/10.1023/A:1012246006212.

Why should every mining engineer learn physical computing and digital electronics?

Vitor Colombo[1], José Soeiro de Carvalho[1]
[1]CERENA-FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal

Abstract

Mining is a particular engineering field: it brings together different knowledge from most scientific areas. Yet, it constitutes a singular and unique universe that is hard to understand to anyone who does not belong to it. Mining is engineering's first contact with nature at its most primitive state. The mining challenges demand a deep understanding of nature. Thus, a mining engineer should, first of all, be a scientific knowledge aggregator and someone willing to search for out-of-the-box solutions.

Mining problems are not closed-solution problems; what is best for a particular mine may be the worst solution for another, even if of the same ore or located in the same region. Therefore, mining engineers must have a varied set of knowledge tools, so they have the basis to deal with diverse, complex situations.

Physical computing is the field that allows us to understand and interact with nature, using digital equipment through hardware and software designed to specific ends and tasks. It could be understood as a lens set through which we can see beyond what our limited analogic perception allows us. It is an interface between science and nature that helps us understand it more profoundly and at different levels.

In mining, electronic systems and informatization have profound and significant consequences: to begin with, they can eliminate the need to expose workers to hostile environments and situations (Henriques and Malekian 2016), not to mention the optimization of operations, economic savings, and logistic gains. However, the value of preventing a worker from being exposed to a potentially dangerous situation is intangible. Safety systems, such as fire detection systems in underground mines, gas detection, real-time temperature monitoring, and even rock collapse predictive systems, are all based on sensor networks, which avoid exposing workers to in-situ inspections. Some of them are not even a novelty, such as real-time monitoring systems in mines based on optical fiber that dates back to the 80s (Dubaniewicz, Chilton, and Dobroski 1991).

This kind of network has been changing the environmental scientists' perspectives, as it allows for the acquisition of enormous amounts of data, which can base new and advanced solutions for scientific problems (Novas et al. 2017). For mining engineers to grasp such possibilities, it is fundamental to understand at least a tiny bit of physical computing and digital electronics. Open source platforms such as Arduino are great environments for autonomous (and enjoyable) learning. The possibilities are infinite, and there is so much to be done in mining-related operations regarding the digital world.

We present an unpretentious approach for an autonomous network of rock and air temperature monitoring system developed to test a numerical model of temperature change in underground galleries.

We used (and learned) Python programming, Arduino and Raspberry Pi boards, ZigBee radio networks, energy consumption economy and low power applications, DIY printed circuits, and even the mystery of MOSFETS!

Author Keywords. Physical Computing, Digital Electronics, Remote Monitoring, Wireless Sensor Networks, Mining.

References

Dubaniewicz, T.H., J.E. Chilton, and H. Dobroski. 1991. "Fiber Optics for Atmospheric Mine Monitoring." In *Conference Record of the 1991 IEEE Industry Applications Society Annual Meeting*, 66:1243–49. IEEE. https://doi.org/10.1109/IAS.1991.178021.

Henriques, Valdo, and Reza Malekian. 2016. "Mine Safety System Using Wireless Sensor Network." *IEEE Access* 4: 3511–21. https://doi.org/10.1109/ACCESS.2016.2581844.

Novas, N., J. A. Gázquez, J. MacLennan, R. M. García, M. Fernández-Ros, and F. Manzano-Agugliaro. 2017. "A Real-Time Underground Environment Monitoring System for Sustainable Tourism of Caves." *Journal of Cleaner Production* 142: 2707–21. https://doi.org/10.1016/j.jclepro.2016.11.005.

AWARDS

Best student oral communication:

Generative Adversarial Network Applied to Ore Type Modelling

Helga Jordão (IST/CERENA)

Best student poster presentation:

Study of the potential of steel slags in acid mine drainage treatment

Ana Pinto (MEMG/FEUP)

AUTHORS INDEX

ISBN. 978-972-752-287-3

www.fe.up.pt/dce21
dce@fe.up.pt