



JEAS.pdf

Nov 4, 2021

5284 words / 29883 characters

A. M. IDKHAN

IDENTIFICATION OF POTENTIAL MINERAL IN A MINING AREA ...

Sources Overview

8%

OVERALL SIMILARITY

1	www.arpnjournals.com INTERNET	4%
2	Aryadi Nurfalaq, Andi Jumardi, Rahma Hi Manrulu, Alfian Nawir, Emi Prasetyawati Umar. "Geoelectric Sounding for Identification of Aquif... CROSSREF	1%
3	Laureate Higher Education Group on 2019-06-08 SUBMITTED WORKS	<1%
4	U R Irfan, I Alimuddin, I B Pasalli. "The Influence of Topography to the distribution of Ni-laterite deposits of Mangguruh Area, Sebuku Isl... CROSSREF	<1%
5	Dewashish Kumar, Gaurav Kumar, Archana Kumari. "High resolution geophysical and geospatial mapping of quaternary sediments for ... CROSSREF	<1%
6	Higher Education Commission Pakistan on 2013-08-23 SUBMITTED WORKS	<1%
7	TechKnowledge on 2020-02-13 SUBMITTED WORKS	<1%
8	Federal University of Technology on 2021-08-18 SUBMITTED WORKS	<1%
9	Sultan Qaboos University Language Center on 2017-12-18 SUBMITTED WORKS	<1%
10	link.springer.com INTERNET	<1%
11	researchrepository.wvu.edu INTERNET	<1%
12	Universitas Bung Hatta on 2021-01-28 SUBMITTED WORKS	<1%

Excluded search repositories:

- None

Excluded from document:

- Bibliography
- Quotes
- Citations

Excluded sources:

- www.arpnjournals.org, internet, 62%



IDENTIFICATION OF POTENTIAL MINERAL IN A MINING AREA PLAN USING GEOELECTRICAL INVESTIGATION

Muhammad Ichsan Ali¹, GufranDarma Dirawan¹, A. Muhammad Idkhan² and Abdul Hafid Hasim¹

¹Department of Civil Engineering and Planning Education, Universitas Negeri Makassar, Makassar, Indonesia

²Department of Mechanical Engineering Education, Universitas Negeri Makassar, Makassar, Indonesia

E-Mail: ichsan209@gmail.com

ABSTRACT

This geological structure estimation is done by flowing an electric current under the surface, then analyzing the different electrical resistance depending on the rock's quality, the degree of density, and soil moisture conditions. The research location is in East Kabaena, Bombana Regency, Southeast Sulawesi Province. The type of tool used is the G-Sound, a cheap and reliable resistivity (gEOelectric) measurement tool. The gEOelectric method used in this exploration is the resistivity method with the Schlumberger Method electrode configuration. Then the interpretation of the gEOelectric survey data using the IP2Win software represents a sounding point. The results of field investigations found that the limonite layer with groundwater content had a resistivity value range of 0.28 -20.00 ohm-m. Then the limonite layer with a few chunks of rock with a resistivity value of 50.00 - 150 ohm-meters. The saprolite layer contains groundwater with a resistivity value of 100-200 ohm-m. The bedrock layer with a resistivity value greater than 5.034.00 - 23.351.00 ohm-m is the lowest part of the laterite profile. The nickel laterite is in the limonite and laterite layers with a resistivity value of 50.00 - 150 ohm-m with an estimated layer depth between 3 - 50 meters. The thickness of the layer ranges from 8 - 15 meters. Boring tests must accompany the use of gEOelectric tools for the identification of soil structures. Interpretation of gEOelectric data on metallic mineral resources includes the interpretation of gEOelectric data into geological conditions.

Keywords: geological structure, limonite layer, nickel laterite, resistivity meter, schlumberger method.

1. INTRODUCTION

As a material for strategic industrial needs and high technology, nickel can generate enormous added value [1]. The use of nickel reserves by only exporting as raw material eliminates many opportunities that can be obtained compared to domestic processing [2]. Apart from obtaining added value, it also supports the downstream industry's development, creates job opportunities, and controls and develops more advanced technology [3], [4]. The associated minerals in raw materials will be carried away to cause more losses caused by non-optimal management [5], [6].

The management and utilization of exploited mineral resource potential will undoubtedly have quite a challenge because there are other potential natural resources such as forestry, agricultural and marine areas in the mining business license area. Optimizing the potential of mineral resources requires a strategic environmental study to determine the direction of the mining activity management policy so that it is hoped that it can minimize the potential for damaging environmental impact pollution [7]. Mineral resource management can also increase the economic growth of other sectors, thereby accelerating regional development's pace while minimizing the potential environmental impacts so that the benefits of mineral resources can be optimized [8]. To exploit mineral resources in an area, it is necessary to recognize each existing source's potential size to analyze the feasibility of developing development activities.

Indonesia is one of the world's largest nickel producers. As a non-renewable resource, this enormous nickel potential will eventually run out [9], [10]. Therefore, nickel resource management requires long-term planning to get the most optimal benefits for development

progress. In laterite nickel mining, an estimate is needed to calculate the resource before the mining process occurs. Resource estimation plays an essential role in determining the quantity and quality of sediment. Because the results of reasonable and accurate estimates that are following their existence in the field can determine the investment that will be invested by investors as an investment in the mining business, the method of mining that will be carried out, even in estimating the time it will take for the company to carry out its mining business so that it can reduce the amount of cost and provide benefits for the company itself.

Nickel laterite has an uneven distribution, and one day it will run out. Therefore, exploration is required before undertaking nickel mining. Exploration is a process of investigation to collect detailed and accurate data about natural resources in a place [11]. The existence of this stage will reduce the amount of capital, reduce the risk of failure, material loss, work accidents, and environmental damage [12]. One example of the exploration phase to determine laterite nickel deposits is the gEOelectric method or resistivity meter. This gEOelectric survey activity is part of a general investigation of mineral deposits' condition using the GEOelectric Method as part of mineral resource development planning [13]. This activity is the initial stage of the development and mining process of mineral resources. Recommendations from the analysis results of the data obtained in this activity become a reference for planning further activities.

GEOelectric investigation was carried out to determine the stratigraphy of the area along the Metal Mineral reserve area using the resistivity method. Furthermore, gEOelectric data is conveyed as a basis and material for consideration and as a reference for further



work planning. The distribution of mineral resource potential from one region to another is highly variable. It depends on the climate, rainy conditions (distribution and intensity of rain), topography, rock types that make up the area, aquifer types, and hydrological systems. The determination of landform units is done manually through visual interpretation of Digital Landsat ETM + images with several interpretation keys obtained from secondary data and surveyed in the field. Zoning potential can be obtained by overlaying all field parameters with a weighted overlay method using the Geographic Information System spatial analysis tool [14], [15].

Research using the resistivity geoelectric method has been carried out a lot and for a long time to determine the potential for groundwater, which is entirely accurate in showing the presence of water below the earth's surface [16]-[26], then with other investigations that can be carried out using the geoelectric method namely related to geological structure and metal mineral exploration [27]-[31]. Activities in the research carried out are part of the geoelectric method, where the dynamic method with the source of the disturbance is the injection of an electric current into the earth [13]. Geoelectric methods have proven successful in superficial research activities, such as metal mineral estimation [32]. The geoelectric method used in this study is the resistivity geoelectric method. Lateritic soil has a resistivity contrast to bedrock (peridotite rock) so that the estimation and thickness of lateritic soil and bedrock using this resistivity method will get better results.

2. RESEARCH METHOD

2.1 Condition and Location

The research location is in East Kabaena, Bombana Regency, Southeast Sulawesi Province. Achievement, the location from Makassar, can be reached via the Makassar - Kolaka - Bombana - Kabaena Island route, or Makassar - Kendari - Bombana - Kabaena Island. The cities of Kolaka and Kendari can be reached by plane from Sultan Hasanuddin Makassar Airport for 45 minutes. Furthermore, the journey is taken by road with four-wheeled vehicles for 4 - 5 hours to KassiPute Port in the capital of Bombana Regency from the two cities. From KassiPute Port to Kabaena Island by ship, it takes 4 hours.



Figure-1. Research location.

Topographical condition of the survey site: The topographical condition of the location-based on previous researchers and the interpretation of the Topographic map: The topography is weak to strong waves with a slope of varying from 1° to 40°, in some places there are slopes greater than 45°, slopes that are steep is found in the Rahadopi area and the northeastern part of Kabaena Island.

Land Status: This is an area of garden land with a weak to moderate undulating land classification-the land status at this location island mostly belongs to the community. However, to the north, the mining business license location is a protected forest.

2.2 Research Approach

The geoelectric method used in this exploration is the resistivity method with the Schlumberger Method electrode configuration. The main principle in applying this method is to interpret the subsurface hydrogeological conditions based on the rock's resistivity value variation to a given electric current. The measurement method uses geoelectric resistivity with the Schlumberger Rule electrode configuration [33]. In this configuration, current (I) is injected into the ground through two current electrodes (AB), and the magnitude of the potential difference (ΔV) will be recorded by the two potential electrodes (MN). The electrodes' arrangement is arranged so that the position of the current electrode (AB) is outside of the potential electrode (MN). The placement of the current and potential electrodes must be arranged so that the current electrode (A - B) is on the outside, and the



potential electrode (M - N)² is on the inside, which lies in a straight line.

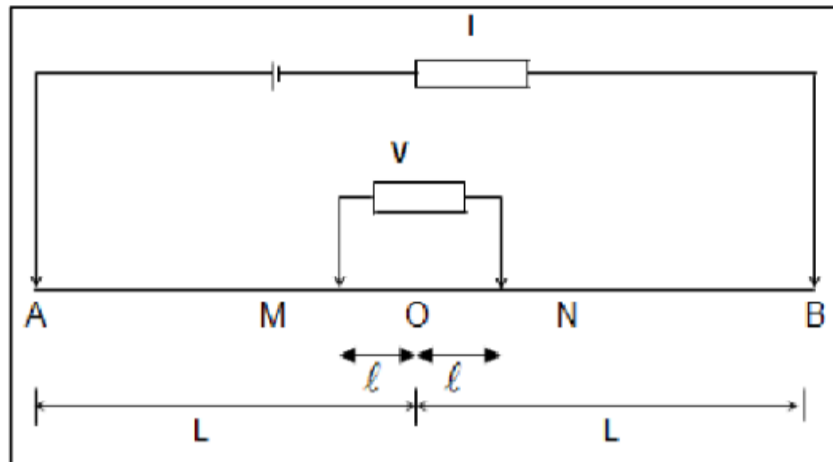


Figure-2. Schlumberger configuration.

The relationship between the electrode configuration distance (electrode geometry factor) and the measured electrical resistance value results in the apparent resistivity (ρ_a) value of the rock. This relationship can write in the following equation:

$$\rho_s = \pi \frac{(AB/2)^2 - (MN/2)^2}{MN} \frac{\Delta V}{I}$$

- ρ_s = Pseudo-Species Resistance (ohm-m)
 AB = Length of Electrode Current (meter)
 MN = Potential Electrode Length (meters)
 V = Potential Difference (mVolt)
 I = Strong Current (mA)

Sounding data is used¹⁰ to determine the vertical variation of rock layers below the surface. The data collection is by moving both current and potential electrodes. The selected configuration is adapted to field conditions. This sounding data can later be contoured or interpreted by the rock conditions below the surface. The expected result is to be able to localize potential areas following exploration objectives. The type of electrode configuration uses the Schlumberger Method. Each configuration has advantages and disadvantages as well as different sensitivity. For example, the Schlumberger configuration is susceptible to the vertical direction and does very well in Vertical Electrical Sounding (VES) [34]. The pseudo section data intended to provide a good picture of both laterally and vertically. This data is collected through a combination and arrangement of sounding point measurement locations so that the measurement points are distributed on the track, which can be used to make resistivity cross-sections quickly⁷ [35]. This system's advantage is that the lateral and vertical variations in resistivity values in the survey area can be illustrated.

2.3 Instrument

This instrument consists of two main components, namely a Potentiometer and a Commutator. The commutator unit functions as a converter of direct current into alternating current. Also, at the same time, a

mechanical rectifier of alternating current is received by the potential electrode (MN). This unit is equipped with a current regulator and a frequency regulator. The potentiometer unit functions as a voltage meter in the direction of the potentiometer principle. The unit is equipped with a highly sensitive galvanometer and a sliding potentiometer with a digital display. This resistivity meter uses a direct current source which is assembled from a dry battery. This tool is equipped with a 12-volt battery used as a motor drive and transistor trigger.



Figure-3. G-Sound geoelectric instrument.

The type of tool used is the G-Sound, a cheap and reliable resistivity (geoelectric) measurement tool. This geoelectric instrument is designed for portable measurements¹¹ with a current penetration depth of up to 100 m to 150 meters. There is no need to adjust the SP complicatedly; the SP value is corrected automatically through the adjusting button. The Current Source (current generator) technology included in G-Sound makes it a reliable, secure anti-short circuit system, where short-circuit conditions often occur when the AB (current) spacing is too close or at low impedance layers. G-Sound AG is upgrading resistivity to G-Sound to make acquisitions via a laptop and directly saved in ASCII format.

2.4 Geoelectric Data Interpretation

Measurement of apparent resistivity value (ρ_a) is the result obtained from field measurement activities. The variation in the apparent resistivity value is then further interpreted to obtain the real resistivity value. The work will be used IP2Win software produced by Moscow State University. The output form is shown the number of resistivity layers, the actual resistivity value, the thickness of each layer, the depth of each layer, and the elevation of the contact boundary between the layers.

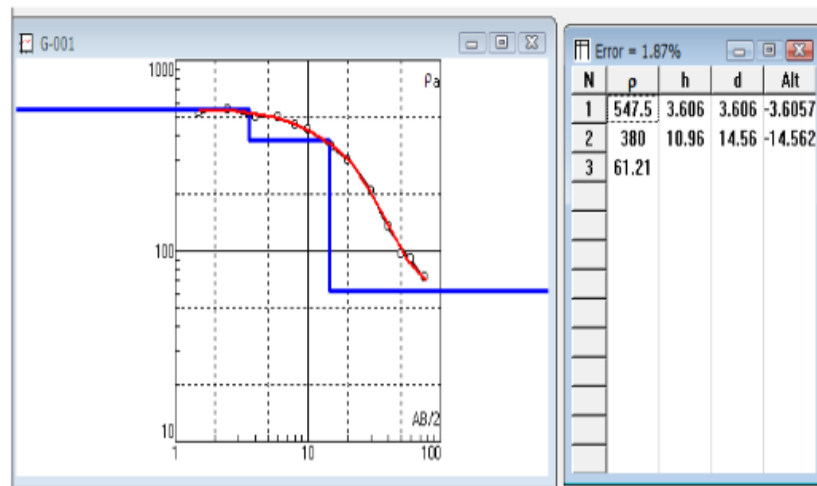


Figure-4. Interpretation of geoelectric data with IP2Win software.

The variation in the rock's resistivity value is then integrated with the geological conditions to interpret the aquifer's groundwater. The expected output at this stage is:

- Position the water carrier layer.
- The thickness of the water carrier layer.
- Groundwater quality.
- Lateral spreading of the water-bearing layer.
- The condition of the material below the surface.

Description of maps and hydrogeological sections. The interpretation of the geoelectric survey data using the IP2Win software represents a sounding point. The integration between several points will be used in the making:

- A resistivity cross-section that describes the relationship between sounding points.
- ISO-resistivity map that describes the relationship of resistivity values at a certain depth.
- Depiction of maps and hydrogeological sections using ArcView software with geographic information systems.

3. RESULT AND DISCUSSIONS

The density of the original rock in the formation of laterite nickel is a significant factor. These rocks contain many olivines, which is the primary nickel carrier mineral [36], [37]. The highest concentrations of olivine are found in ultramafic rocks, komatiite, and olivine-bearing cumulate gabbro. In ultramafic rocks with soluble components (especially olivine), it will provide an excellent depositional environment for nickel [38]. Nickel is obtained from deposits formed due to oxidation and weathering of ultramafic rock containing nickel 0.2 - 0.4

percent. The types of minerals include olivine, pyroxene, and amphibole, which are found in tropical areas with high rainfall, thus supporting weathering and topographic, drainage, tectonic and geological structures. The formation of laterite nickel deposits is determined by several factors, namely: relatively sloping topography ($<20^\circ$), high intensity of fracture structures that occur in large areas, high rainfall, and the presence of nickel sources from the source rock itself [39], [40].

The geoelectric data analysis at the first location (West Kabaena Central) obtained variations in resistivity values ranging from 0.022 - 23,351.00 ohm-meters. The geological survey and geoelectric estimation results in the survey area show that it is dominated by ultra-alkaline rocks that have changed intense weathering. Geoelectric measurements are carried out with a maximum length (AB) = 150 m. Therefore, the measurement data can predict conditions up to a depth of 50 meters to 100 meters. The data classification is prepared using geological outcrop data on the surface, which can be described as overburden consisting of weathering material is clay-silt in size, and is sometimes found mixed with rock blocks with varying resistivity values of 10.00 - 200 ohm-m. The cover soil layer is the uppermost part of a laterite section. Its composition is plant roots, humus, iron oxides, and other organic remains. The typical color is dark brown and loose. The nickel content is so low that it is not picked up in mining. Overburden thickness averaged 0.30 - 6.00 meters. Dark red is a mass collection of goethite and limonite. Iron capping has a high iron content but a low nickel content. Sometimes there are hematite, chromiferous minerals [41].

Limonite layer with groundwater content, which has a resistivity value range of 0.28 -20.00 ohm-m. Then the limonite layer with a few chunks of rock with a resistivity value of 50.00 - 150 ohm-meters. The limonite layer is the result of the further weathering of ultramafic igneous rocks. Its composition includes the predominant iron oxide, goethite, and magnetite. The thickness of this layer averages 8-15 m. In limonite, plant roots, albeit in a tiny percentage. The appearance of ultramafic igneous rock blocks in this zone is not dominant or almost non-existent; generally, the minerals in ultramafic igneous rock have been converted into serpentine due to unfinished weathering. Fine-grained, red-brown, or yellow, the iron-rich layer of limonite soil covers the entire area. This layer is thin on steep areas and was lost due to erosion. Most of the nickel in this zone is present in the manganese oxide mineral, lithiophorite [42]. Sometimes there are minerals talc, tremolite, chromiferous, quartz, gibbsite, maghemite.

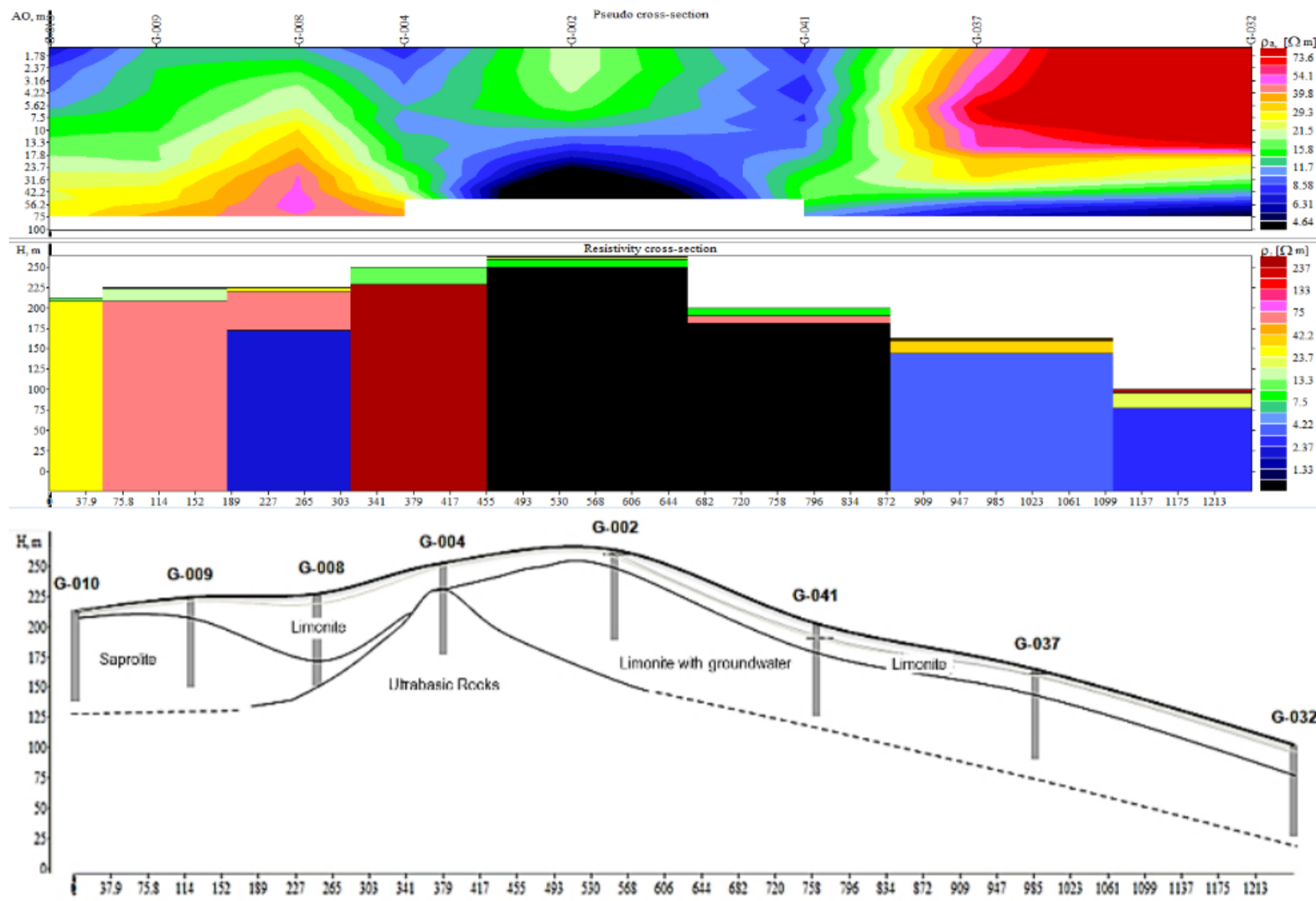


Figure-5. Pseudo and resistivity cross section I.

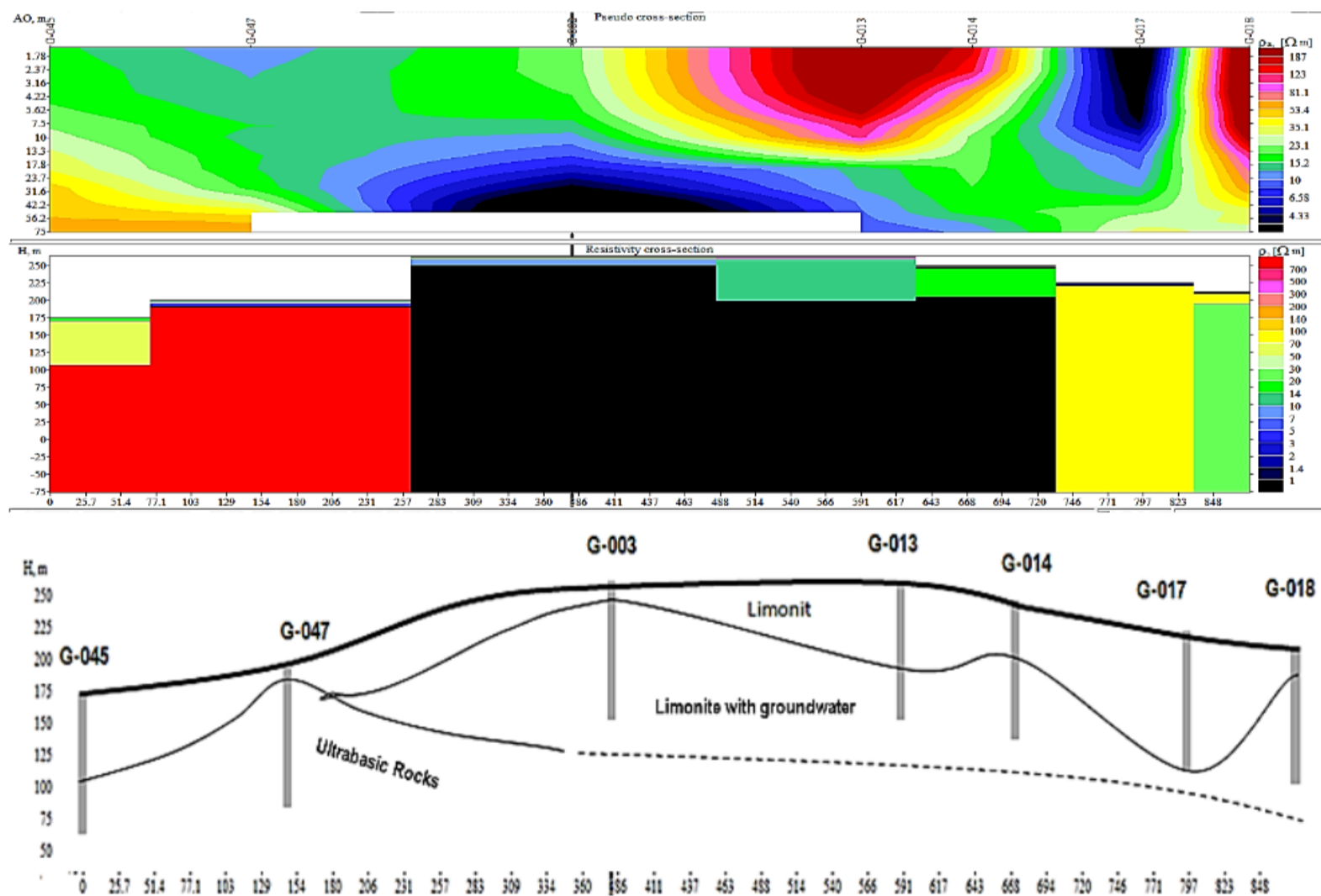


Figure-6. Pseudo and resistivity cross section II.

The saprolite layer contains groundwater with a resistivity value of 100-200 ohm-m. This zone is a zone of

Ni element enrichment. Its composition is iron oxide, serpentine around <0.4% magnetite quartz and the original



rock texture is still visible. The thickness of this layer ranges from 5-18 m. The boulders' appearance is widespread, and in the fractures of the original rock, magnesite, serpentine, onyx, and garnierite are found. The original rock blocks generally have high levels of SiO₂ and MgO and low Ni and Fe. a mixture of rock debris, fine-grained limonite, saprolite rims, veins from garnierite deposits, nickeliferous quartz, manganese, and in some cases, silica box-work, the formation of a transition zone from limonite to bedrock. Sometimes there is the quartz mineral filling in the cracks, the primary, weathered minerals, chlorite. Garnierite in the field is usually identified as colloidal talc with more or less nickeliferous serpentine. The structure and texture of the original rock are still visible [43].

Bedrock layers with resistivity values greater than 5.034.00 - 23,351.00 ohm-m. The bedrock layer is the lowest part of the laterite profile. Composed boulders are more massive than 75 cm and peridotite (bedrock) blocks and generally no longer contain economic minerals (metal content is close to or equal to bedrock). Bedrock is the original rock from nickel laterite, which is generally an ultramafic igneous rock, namely harzburgite and dunite, which in the fractures have been filled with iron oxide 5-10%, minor garnierite and silica > 35%. The permeability of the bedrock increases in proportion to the intensity of serpentinization. This zone is intensely fractured, sometimes opens, filled with garnierite and silica minerals. This fracture is thought to cause the root zone, namely the high-grade Ni zone, but its position is hidden [44].

The nickel laterite is in the limonite and laterite zone/layer with a resistivity value of 50.00 - 150 ohm-m. The depth ranges from 3 to 50 meters. Investigations using geoelectric must be accompanied by boring data to complement the data from geoelectric. The conditions of tropical and sub-tropical climates with high rainfall and sunshine throughout the day play an essential role in weathering and dissolving the elements present in the original rock, which dramatically supports the formation of laterite nickel deposits. Likewise, the temperature changes are quite large in helping the occurrence of mechanical weathering by forming cracks in the rock, facilitating chemical processes or reactions in the rock [45], [46].

The relief will help speed and intensity of chemical weathering in gentle hills with a slope of between 10 - 30 °. In sloping morphology, rainwater can move more slowly so that it has the opportunity to seep through rock fractures or pores. In the soil, CO₂ contained in groundwater plays a vital role in the chemical weathering process. Chemical weathering also occurs with the help of humic acids produced by decaying plant debris, which changes the solution's rock composition and pH.

When chemical weathering continues in the depths of the soil, which is due to water containing CO₂ seeping down to the groundwater-surface zone, accompanied by the decay of plants, causing unstable primary minerals such as olivine, serpentine, and pyroxene will decompose to produce Mg, Fe, the soluble Ni and Si which tend to form colloids from excellent silica particles.

After reaching the boundary between the limonite zone and the saprolite zone, groundwater flowing laterally produces dissolved Ca and Mg. All these dissolved products are transported slowly downwards, then fill in the rock's cracks and pores, causing the formation of new minerals through the dissolved elements' re-deposition. Fe, Ni, and CO form a concentration as a residue and fill the so-called saprolite zone [47].

The flow of electricity in a rock formation occurs mainly due to electrolyte fluid presence in rock fractures' pores[48]. Therefore, the resistivity of a rock formation depends on the rock's porosity and the type of fluid that fills the rock's pores. Porous rocks that contain water or saltwater are certainly more conductive (low resistivity) than similar rocks whose pores contain only air (empty). Generally, seismic methods in mining mineral exploration are used to determine subsurface structures. The shallow seismic reflection method can detect both lateral and depth variations in the relevant physical parameter, namely seismic velocity. It can produce an image of the appearance of the structure below the surface [49]. It can be used to limit stratigraphic features and some depositional features. The response to the propagation of seismic waves depends on rock density and other elasticity constants. Thus, any change in these constants (porosity, permeability, compaction) in principle can be known from the seismic method to allow for direct detection of the presence of subsurface structures associated with the presence of mineral mines. Each mineral mine/iron ore deposit has a different density. That is why if there is a mineral variation in a homogeneous environment, there will be different anomalies so that it can be estimated the minerals contained therein [50], [51]. Some deposits, such as mineral minerals, can be detected by gravity (gravity), but only to know the side rock profile (cannot directly detect the ore) through density anomaly.

4. CONCLUSIONS

Geoelectric methods and other geophysical data acquisition methods also face several challenges that can affect the data obtained. One of the things that one must face is noise in the acquired data. This noise arises due to interference, which causes other data to be recorded so that it is difficult for us to know the original data that was actually recorded on the receiver. In mineral exploration, the geoelectric method of induced polarization is used. The crushed polarization method can measure the chargeability value or the ability of a medium to store charge. The polarization in rocks and soils covers the spread or diffusion of ions to metal minerals and the movement of ions within the electrolyte. The main effect or the primary mechanism that occurs in a polarization process is electrode polarization, so that the presence of metal mineral content in the rock will increase the rock's chargeability value.

ACKNOWLEDGMENTS

This research was funded by the Professor's Acceleration Grant Program,) Universitas Negeri Makassar in 2020 (Grant Number:



2406/UN36.11/LP2M/2020, and received support from the Bombana Regency Government.

REFERENCES

- [1] M. I. Ali. 2018. Environmental Pollution Knowledge of Small-Scale Miners in Bombana Regency, Indonesia. *Pollut. Res.* 37(1): 56-62.
- [2] K. Spitz and J. Trudinger. 2019. Mining and the environment: from ore to metal. CRC Press.
- [3] B. A. Wills and J. Finch. 2015. Wills' mineral processing technology: an introduction to the practical aspects of ore treatment and mineral recovery. Butterworth-Heinemann.
- [4] O. Östensson. 2020. The potential of extractive industries as anchor investments for broader regional development. World Institute for Development Economic Research (UNU-WIDER).
- [5] L. D. DeSimone and F. Popoff. 2000. Eco-efficiency: the business link to sustainable development. MIT press.
- [6] H. Lewis, J. Gertsakis, T. Grant, N. Morelli and A. Sweatman. 2017. Design+ environment: a global guide to designing greener goods. Routledge.
- [7] M. I. Ali. 2019. The Consequences of Illegal Mining in the Environment: Perspective of Behavior, Knowledge, and Attitude. *Int. J. Environ. Eng. Educ.* 1(1): 25-33.
- [8] M. R. Abidin and A. Arfan. 2019. Detection of Development and Density Urban Build-Up Area with Satellite Image Overlay. *Int. J. Environ. Eng. Educ.* 1(2): 40-45.
- [9] R. Herrington. 2013. Road map to mineral supply. *Nat. Geosci.* 6(11): 892.
- [10] R. Kurniawan and S. Managi. 2018. Economic growth and sustainable development in Indonesia: an assessment. *Bull. Indones. Econ. Stud.* 54(3): 339-361.
- [11] A. R. Olsen *et al.* 1999. Statistical issues for monitoring ecological and natural resources in the United States. *Environ. Monit. Assess.* 54(1): 1-45.
- [12] J. Lyle. 1999. Design for human ecosystems: landscape, land use, and natural resources. Island Press.
- [13] A. J. Patandean and A. H. Hasim. 2018. Geophysical Exploration in Hot Springs Region Soppeng Regency, Indonesia. *J. Ser. J. Phys. Conf. Ser.* Vol. 1028, doi: 10.1088/1742-6596/1028/1/012197.
- [14] M. I. Ali, G. D. Dirawan, A. H. Hasim and M. R. Abidin. 2019. Detection of Changes in Surface Water Bodies Urban Area with NDWI and MNDWI Methods. *Int. J. Adv. Sci. Eng. Inf. Technol.* 9(3): 946-951.
- [15] M. I. Ali, A. H. Hasim and M. R. Abidin. 2019. Monitoring the Built-up Area Transformation Using Urban Index and Normalized Difference Built-up Index Analysis. *Int. J. Eng. Trans. B Appl.* 32(5): 647-653.
- [16] T. O. Adeeko, D. O. Samson and M. Umar. 2019. Geophysical survey of basement complex terrain using electrical resistivity method for groundwater potential. *World News Nat. Sci.* 23: 154-165.
- [17] E. Manu, W. A. Agyekum, A. A. Duah, R. Tagoe and K. Preko. 2019. Application of vertical electrical sounding for groundwater exploration of Cape coast municipality in the central region of Ghana. *Arab. J. Geosci.* 12(6): 196.
- [18] M. D. Falah. 2020. Geoelectric Method Implementation in Measuring Area Groundwater Potential: A Case Study in Barru Regency. *Int. J. Environ. Eng. Educ.* 2(1): 1-8.
- [19] D. Kumar, K. Rajesh, S. Mondal, T. Warsi and R. Rangarajan. 2020. Groundwater exploration in limestone-shale-quartzite terrain through 2D electrical resistivity tomography in Tadipatri, Anantapur district, Andhra Pradesh. *J. Earth Syst. Sci.* 129(1): 1-16.
- [20] D. Kumar, S. Mondal and T. Warsi. 2020. Deep insight to the complex aquifer and its characteristics from high resolution electrical resistivity tomography and borehole studies for groundwater exploration and development. *J. Earth Syst. Sci.* 129(1): 68.
- [21] R. J. Owen, O. Gwavava and P. Gwaze. 2006. Multi-electrode resistivity survey for groundwater exploration in the Harare greenstone belt, Zimbabwe. *Hydrogeol. J.* 14(1-2): 244-252.
- [22] S. P. Devi, S. Srinivasulu and K. K. Raju. 2001. Delineation of groundwater potential zones and



- electrical resistivity studies for groundwater exploration. *Environ. Geol.* 40(10): 1252-1264.
- [23] D. W. Urish and R. K. Frohlich. 1990. Surface electrical resistivity in coastal groundwater exploration. *Geoexploration.* 26(4): 267-289.
- [24] M. I. I. Mohamaden and D. Ehab. 2017. Application of electrical resistivity for groundwater exploration in Wadi Rahaba, Shalateen, Egypt. *NRIAG J. Astron. Geophys.* 6(1): 201-209.
- [25] K. Kalaivanan, B. Gurugnanam, M. Suresh, K. P. Kom and S. Kumaravel. 2019. Geoelectrical resistivity investigation for hydrogeology conditions and groundwater potential zone mapping of Kodavanar sub-basin, southern India. *Sustain. Water Resour. Manag.* 5(3): 1281-1301.
- [26] O. O. Bayewu, M. O. Oloruntola, G. O. Mosuro, T. A. Laniyan, S. O. Ariyo and J. O. Fatoba. 2018. Assessment of groundwater prospect and aquifer protective capacity using resistivity method in Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria. *NRIAG J. Astron. Geophys.* 7(2): 347-360.
- [27] P. Egbelehulu, A. Mallam, N. Abdulsalam and T. Adewumi. 2020. A Review of Electrical Methods as A Worthy Tool for Mineral Exploration. *Pakistan J. Geol.* 1(ahead-of-print).
- [28] S. Ghosal, A. Singh, S. Agrahari and D. Sengupta. Delineation of Heavy Mineral Bearing Placers by Electrical Resistivity and Radiometric Techniques along Coastal Odisha, India.
- [29] S. Uhlemann, J. Chambers, W. E. Falck, A. Tirado Alonso, J. L. Fernández González and A. Espín de Gea. 2018. Applying electrical resistivity tomography in ornamental stone mining: challenges and solutions. *Minerals.* 8(11): 491.
- [30] C. Caselle, S. Bonetto and C. Comina. 2019. Comparison of laboratory and field electrical resistivity measurements of a gypsum rock for mining prospection applications. *Int. J. Min. Sci. Technol.* 29(6): 841-849.
- [31] R. Arjwech, P. Sriwangpon, K. Somchat, P. Pondthai and M. Everett. 2020. Electrical resistivity tomography (ERT) data for clay mineral mapping. *Data Br.*, p. 105494.
- [32] J. M. Reynolds. 2011. An introduction to applied and environmental geophysics. John Wiley & Sons.
- [33] J. S. V. Van Zijl. 1969. A Deep Schlumberger Sounding to Investigate Electrical Structure of the Crust and Upper Mantle in South Africa. *Geophysics.* 34(3): 450-462.
- [34] W. Lowrie and A. Fichtner. 2020. Fundamentals of geophysics. Cambridge university press.
- [35] Loke, Meng Heng and Barker R D. 1996. Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. *Geophys. Prospect.* 44(1): 131-152.
- [36] F. P. Lesnov. 2010. Rare Earth Elements in Ultramafic and Mafic Rocks and their Minerals: Main types of rocks. Rock-forming minerals. CRC press.
- [37] R. N. Scoon and W. J. de Klerk. 1987. The relationship of olivine cumulates and mineralization to cyclic units in part of the Upper Critical zone of the western Bushveld Complex. *Can. Mineral.* 25(1): 51-77.
- [38] H. Papunen. 1998. Geology and ultramafic rocks of the paleoproterozoic pulju greenstone belt, western Lapland. *Integr. Technol. Miner. Explor. Pilot Proj. nickel ore Depos. Tech. Rep. 6.5.* Turku Univ. Dep. Geol. 55: 55.
- [39] M. Elias. 2001. Global lateritic nickel resources. in CSA Australia Pty Ltd., New Caledonia Nickel Conference.
- [40] M. Elias. 2002. Nickel laterite deposits-geological overview, resources and exploitation. *Giant ore Depos. Charact. Genes. Explor. CODES Spec. Publ.* 4: 205-220.
- [41] Y. N. Vodyanitskii. 2009. Mineralogy and geochemistry of manganese: a review of publications. *Eurasian Soil Sci.* 42(10): 1170-1178.
- [42] R. Yongue-Fouateu, R. T. Ghogomu, J. Penaye, G. E. Ekodeck, H. Stendal and F. Colin. 2006. Nickel and cobalt distribution in the laterites of the Lomié region, south-east Cameroon. *J. African Earth Sci.* 45(1): 33-47.
- [43] W. Fu *et al.* 2018. Garnierite mineralization from a serpentinite-derived lateritic regolith, Sulawesi Island, Indonesia: Mineralogy, geochemistry and link to



hydrologic flow regime. *J. Geochemical Explor.* 188: 240-256.

- [44] M. Cathelineau *et al.* 2017. Multistage crack seal vein and hydrothermal Ni enrichment in serpentinized ultramafic rocks (Koniombo massif, New Caledonia). *Miner. Depos.* 52(7): 945-960.
- [45] K. Bucher and M. Frey. 2002. *Petrogenesis of metamorphic rocks.* Springer Science & Business Media.
- [46] W. S. Fyfe. 2012., *Fluids in the Earth's crust: Their significance in metamorphic, tectonic and chemical transport process*, vol. 1. Elsevier.
- [47] K. Misra. 2012. *Understanding mineral deposits.* Springer Science & Business Media.
- [48] J. Cai, W. Wei, X. Hu and D. A. Wood. 2017. Electrical conductivity models in saturated porous media: A review. *Earth-Science Rev.* 171: 419-433.
- [49] G. M. Cameli, A. Ceccarelli, I. Dini and A. Mazzotti. 2000. Contribution of the seismic reflection method to the location of deep fractured levels in the geothermal fields of southern Tuscany (Central Italy). in *Proceedings World Geothermal Congress.* pp. 1025-1029.
- [50] K. F. E. Anderson, F. Wall, G. K. Rollinson and C. J. Moon. 2014. Quantitative mineralogical and chemical assessment of the Nkout iron ore deposit, Southern Cameroon. *Ore Geol. Rev.* 62: 25-39.
- [51] V. Lishchuk, C. Lund, P. Lamberg and E. Miroshnikova. 2018. Simulation of a mining value chain with a synthetic ore body model: Iron ore example. *Minerals.* 8(11): 536.