J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

Optimization of Drilling Sample Handling in Laterite Nickel Exploration in Central Sulawesi

Risal Gunawan*[1], Yogi Laode Prianata[1], Ahmad Jeli Rinaldi[2], Juan Joaques[3]
[1] Department of Mining Engineering, University of Southeast Sulawesi, Kendari 93870, Indonesia
[2] Colorado School of Mines, 1500 Illinois St., Golden, CO 80401, United States
[3] Department of Mining Engineering, University of San Carlos, Cebu City, Philippines
*corresponding author e-mail: risalgunawan92@gmail.com

Article info
Received:
Jan 29, 2025
Revised:
Apr 5, 2025
Accepted:
Apr 16, 2025
Published:
Apr 18. 2025

Keywords:
Lateritic nickel exploration, drilling, sample handling.

Abstract
The exploration of lateritic nickel in Indonesia plays a crucial role in meeting the demands of the electric vehicle battery and stainless-steel industries. One of the critical aspects of exploration is proper handling of drilling samples to ensure the accuracy of geochemical and mineralogical data. PT. Cakrawala Resources Indonesia has implemented standard procedures for sample management at the Sambalagi Site. However, challenges remain regarding storage, transportation, and quality control, which may affect the integrity of exploration data. The purpose of this research study was conducted using a field study approach and technical analysis of sample handling procedures, covering site preparation, drilling, and storage in the sample house. The evaluation was carried out by observing the effectiveness of each stage and identifying factors that could potentially cause sample degradation. Additionally, a review of quality control system implementation was conducted, including sample duplication methods and blind sampling. The research results indicate that the applied sample handling methods comply with exploration standards. However, challenges remain, such as high humidity conditions that can affect sample quality and difficult-to-access terrain that may hinder transportation processes. While quality control measures have been implemented, optimization is still needed in record-keeping and storage to enhance data traceability. Improvements in sample house storage conditions, sample transportation optimization, and the implementation of a digital recording system are recommended to enhance exploration efficiency and accuracy.

1. Introduction

The exploration of lateritic nickel in Indonesia, particularly in Central Sulawesi, plays a strategic role in supporting the national mining industry. PT. Cakrawala Resources Indonesia, operating at the Sambalagi Site, has conducted exploration activities using drilling methods to obtain representative samples. This exploration process includes drill site preparation, sample collection, logging, and quality control to ensure the validity of the generated geological data [1].

Drilling sample handling is a crucial aspect of exploration, as sample quality determines the accuracy of geochemical and mineralogical analyses. Errors in handling can lead to data bias and hinder resource potential interpretation [2]. Therefore, strict procedural standards are required at every stage of exploration, from site clearing to sample storage in the sample house [3].

Indonesia possesses significant lateritic nickel reserves, primarily in Sulawesi, Maluku, and Papua. According to the Ministry of Energy and Mineral Resources (KESDM), approximately 80% of Indonesia's nickel reserves are in lateritic form, distributed in regions with tropical geological characteristics [4]. Lateritic nickel is widely used in the stainless steel and electric vehicle battery industries, both of which have seen increasing demand in recent years due to advancements in renewable energy industries [5]. Consequently, accurate and efficient exploration is essential to ensure the sustainability of raw material supply for these industries.

Lateritic nickel exploration techniques commonly employ diamond drilling to obtain intact and representative samples. This process follows a systematic sequence, including topographic surveys, drill site planning, drilling execution, and sample processing and storage in the sample house [39]. Selecting the appropriate drilling method is crucial to minimizing disturbances to soil layers and reducing the risk of sample contamination.

Furthermore, environmental and weather conditions at exploration sites also play a vital role in the success of sample collection. Rain or high humidity can alter the physical properties of samples, potentially affecting geochemical analysis results [6]. Therefore, strict protocols for sample storage and transportation must be implemented to maintain the integrity of the collected materials.

This study aims to evaluate the drilling sample handling methods applied at the Sambalagi Site and provide recommendations to enhance the effectiveness and efficiency of the exploration process [7]. By implementing improved standard operating procedures, lateritic nickel exploration in Indonesia is expected to yield more accurate and reliable results for mineral resource modeling.

2. Methodology

This study uses a qualitative descriptive approach with direct observation and documentation analysis methods. Observations were carried out systematically at the Sambalagi exploration site to record each activity stage, from drilling site preparation, sampling process, handling and labeling of samples, to sample examination at the sample house. In addition to observation, this study is also supported by document studies in the form of exploration SOPs, log sheets, and daily field reports. Informal interviews with field officers and laboratory officers were also conducted to strengthen observation data and obtain a comprehensive picture of field practices. All data were analyzed by comparing actual practices with applicable exploration standards, in order to assess the effectiveness of procedures and the level of compliance with established protocols.

3. Results and discussions

3.1. Preparation of Drilling Site

Before drilling begins, the field team must ensure that the site is prepared according to the work plan. The site preparation stages include:

a. Site Clearing, the designated drilling area is cleared of vegetation or any obstructing materials to ensure an uninterrupted drilling process [8]. Site clearing is a crucial initial step in preparing the drilling location. This process involves the removal of vegetation, rocks, or other materials that may hinder equipment operation or interfere with drilling activities [9]. Depending on terrain conditions, clearing is performed using heavy equipment such as bulldozers, excavators, or manually. The primary objectives of site clearing are to:

- Ensure the safety of the drilling team and equipment from potential hazards.
- Provide clear access for operational vehicles and heavy machinery.
- Prevent contamination of drill samples by external materials.

b. Topographic Survey, a topographic survey is conducted to determine the terrain characteristics and identify strategic drilling points while ensuring safe drilling conditions.

c. Drill Hole Marking, drill hole locations are determined using surveying instruments such as a total station or high-precision GPS, followed by the installation of markers [10]. Drill hole marking involves specifying precise locations using high-precision GPS or a total station [11]. Once the locations are confirmed, marker stakes are placed to ensure the designated spots remain unchanged during the drilling process. The procedure includes; Rechecking coordinate positions to avoid errors and installing wooden or concrete stakes labeled with relevant information, such as drill hole name and elevation [12].

Figure 1. Sampling

3.2. Sample Collection

Sample collection is a critical stage in exploration, where the drilling method used must be appropriate for the type of material being explored. The process includes:

a. Core Retrieval: The core extracted from the borehole must be immediately placed in a designated tray or box to prevent damage [13].
b. Detailed Logging: Each core is recorded in detail, including depth and material type (figure 1).
c. Sample Cleaning: The core is cleaned of dirt or contaminants to ensure sample integrity [14].

3.3. Core Cutting

Core cutting is a crucial stage in mineral exploration, particularly in drilling activities. After the core is retrieved from the borehole, the next step is to cut the core for specific purposes, such as archiving and analysis. This process is carried out using specialized cutting tools, such as precision saws, to ensure accurate and clean cuts without damaging the core sample.

a. Archiving: One part of the core is preserved as an archive for future data verification. Core storage is essential, as it allows for re-examination of test results and analyses when necessary. For instance, if laboratory results are questioned or if there are changes in analytical methods, the archived core can be reanalyzed to ensure data accuracy [15].
b. Analysis: The other part is sent to the laboratory for mineralogical and geochemical analysis [16]. In lateritic nickel exploration, this analysis aims to determine the chemical and mineralogical composition of the core samples, providing valuable information about the nickel deposit potential at the site. Analytical techniques may include X-ray fluorescence (XRF), mineral mapping, and metal grade analysis, all of which contribute to assessing the economic value of the explored mineral deposit [17].

Core cutting must be performed carefully to avoid damaging the samples, as this could impact analytical results. Specialized cutting tools, such as precision saws, are used because they can cut through hard materials without destroying the geological structure of the core. Additionally, the cutting process must adhere to standardized procedures to ensure the quality and integrity of each sample.

3.4. Core Cutting Logging and Labeling

Each core is labeled with essential information, including the borehole number, depth, and date of collection. These labels are made using waterproof ink to prevent information loss due to environmental factors. Logging and labeling are critical steps in mineral exploration to ensure data integrity and traceability. Every core retrieved from the borehole must be accurately labeled, serving as an identification marker and a reference for further analysis. This process requires precision and attention to detail to avoid errors that could lead to misinterpretation of data [18].

Figure 2. Logging and Labeling

The Core Labeling Elements includes:

1. Borehole Number: Each borehole drilled for core extraction is assigned a unique number. This number identifies the specific location from which the core was taken. Proper numbering is essential to ensure that the obtained data can be traced and mapped back to its geographical position in the field, facilitating geological mapping and further exploration planning [19].
2. Sampling Depth: The depth at which the core is retrieved is meticulously recorded [20]. This depth represents the vertical position of the explored material layers, providing crucial information on stratigraphy and mineral potential in the area. Core sampling depth is one of the primary data points used in constructing geological models and understanding material distribution beneath the surface.
3. Collection Date: Recording the date of core collection is essential for tracking when the sampling was conducted. This information helps identify changes or trends in the data over time and ensures that the analyzed cores are relevant to the ongoing exploration phase (Figure 2).

The Use of Waterproof Ink, labels containing critical core information are written using waterproof ink to prevent fading or loss due to environmental factors such as rain, humidity, or exposure to groundwater. Waterproof ink ensures that the recorded data remains legible, even when cores are stored under conditions prone to moisture or extreme weather in the field [21]. Proper and consistent logging and labeling are crucial in mineral exploration, as errors in this process could lead to data misinterpretation, potentially affecting exploration decisions and mineral reserve development [22].

3.5. Temporary Core Storage

Labeled core samples are placed in core boxes with proper arrangement to minimize damage risks. These boxes are stored in locations protected from extreme weather conditions, such as under tents or in field warehouses [23]. Temporary core storage is a crucial step in the exploration process to maintain sample integrity and quality. After labeling and marking, cores must be properly arranged and stored securely until they are ready for further analysis. Proper storage not only prevents sample damage but also ensures that recorded data remains accurate and easily traceable when needed [24].

The Core Arrangement in Core Boxes includes:

a. Organized Arrangement: Labeled cores are placed carefully in core boxes to maintain geological structure and stratigraphic sequence. Proper arrangement ensures that the original order of the core is preserved, preventing data confusion. Poorly arranged cores can result in misinterpretation or sample damage.
b. Minimizing Damage Risks: Neatly arranged cores in core boxes help reduce risks such as breakage or surface scratches, which may affect analysis results. Protective materials such as foam or padding are often used inside core boxes to prevent excessive pressure or impact that could damage the samples [25].

Storage Location Considerations:

a. Protection from Extreme Weather: Core boxes must be stored in a sheltered area to prevent exposure to extreme conditions such as rain, excessive heat, or strong winds. Ideal storage locations include field tents or warehouses with roofs and walls to protect cores from environmental factors that may cause physical or chemical changes in the samples. Storing core boxes in open, unprotected areas can lead to moisture absorption or thermal degradation, which could alter the sample's properties [26].
b. Security and Accessibility: In addition to weather protection, core boxes should be stored in a secure and accessible location to prevent theft or accidental damage. Proper security ensures that the samples remain intact and can be retrieved quickly for further analysis or verification. Good accessibility also allows exploration teams to efficiently locate and handle the core when needed.

Importance of Proper Core Storage, adhering to proper storage procedures ensures that sample quality is maintained throughout the temporary storage period before being sent to a laboratory for further analysis. Additionally, well-managed storage helps preserve core-related information, making it accountable and available for future reference. Mishandled or lost core samples can lead to inaccurate interpretations, ultimately impacting strategic decisions in exploration projects [27].

3.6. Field Documentation

Documentation is a crucial aspect of sample handling, ensuring that field data is accessible and usable for further analysis. Proper documentation includes; the core photographs with a clearly defined measurement scale [28] and Field notes detailing material descriptions, geological structures, and observed anomalies [29]. A well-organized documentation system guarantees that collected data can be efficiently accessed and utilized for interpretation. Without proper documentation, field data may become difficult to interpret, potentially affecting the quality of exploration decisions. The Key Elements of Field Documentation includes:

a. Core Photographs with a Clear Measurement Scale, core photographs serve as an essential visual record. These images must be taken with clarity, covering all relevant core sections while including a measurement scale to accurately determine dimensions and orientation. The scale provides a vital reference for depth identification and spatial relationships within the core. These photographs are particularly valuable for geological mapping and verification of recorded material descriptions [30]. Core images are typically taken against a neutral background with adequate lighting to highlight surface details such as material texture and structural features. It is essential to document the borehole number, depth, and sampling date to ensure the photographs are directly linked to recorded data.

b. Field Notes, the Field notes provide descriptive information about the materials found in the core, along with observations on geological structures and anomalies encountered during drilling. This documentation aspect is indispensable as it offers detailed explanations that may not be fully captured in photographs alone. Key components of field notes include:
   - Material Description: Detailed documentation of rock type, mineral composition, and texture. This section includes physical characteristics such as color, hardness, porosity, and grain size.
   - Geological Structure: Notes on stratigraphic layering, rock formations, fractures, and any significant variations in orientation. Documenting structural changes helps in understanding the geological processes affecting the area.
   - Observed Anomalies: Any irregular geological features, such as sudden lithological changes, unexpected mineralization, or fault zones. Identifying these anomalies is crucial as they may indicate potential mineral deposits or geological hazards [31].

Importance of Proper Documentation, aWell-maintained documentation ensures that geologists and other exploration team members can accurately interpret the geological conditions, even if they were not present during fieldwork. It also facilitates data verification and minimizes the risk of errors or information loss. Additionally, proper records allow for more efficient data analysis and interpretation.

Comprehensive field documentation is essential for regulatory compliance and supports technical reporting requirements. It ensures that exploration findings can be reliably communicated to stakeholders, regulatory bodies, and investors, reinforcing the credibility of the exploration project [32].

3.7. Quality Control

To ensure accurate exploration results, quality control is implemented at every stage of sample handling. Several steps taken includes; Sample Duplication where Collecting duplicate samples to test data consistency is essential [33] and Blind Sampling which Introducing unlabeled control samples to ensure objective analysis results [34].

3.8. Sample Transportation Process

a. Sample Preparation Before Transportation, before samples are sent to the sample house, it is essential to ensure they are properly prepared. Some necessary preparation steps include:
   - Core Arrangement in Core Boxes: Core samples extracted from drill holes are neatly arranged in core boxes to prevent damage during transportation. Proper arrangement is also crucial to maintain the correct sequence and depth of the cores.
   - Labeling and Documentation: Each core must be labeled with essential information such as drill hole number, depth, and sampling date. Proper documentation ensures that transported samples can be easily tracked and identified.
   - Protective Packing: Samples must be wrapped with protective materials, such as foam or waterproof plastic bags, to prevent physical damage or contamination. Proper packing also helps maintain the sample's condition, even during long-distance transportation or unfavorable weather conditions [35].

b. Types of Transportation Equipment, selecting the appropriate transportation equipment is crucial for moving samples from the drilling site to the sample house. Some key factors to consider include:
   - Location Accessibility: Drilling sites are often located in remote areas with difficult terrain. Therefore, the type of vehicle used must be suitable for the terrain conditions, such as 4x4 trucks, off-road vehicles, or even helicopters if the location is exceptionally far and difficult to reach.
   - Sample Safety: Transportation must be carried out carefully to prevent damage to the samples. The chosen vehicle should provide a secure and stable storage area for core boxes and protect samples from vibrations or shocks that could cause deterioration.

c. Transportation Route and Travel Time, transporting samples to the sample house requires careful route planning, especially when drilling sites are in remote locations (Figure 3). Factors to consider in planning sample transportation include:
   - Travel Duration: Long transportation times pose a risk of sample degradation, especially if exposed to extreme temperatures or high humidity. Therefore, the transportation journey should be efficiently planned using the safest and fastest route.
   - Security During Transport: Since the transported samples are valuable, their security during the journey must be a priority. The personnel responsible for transportation must ensure that only competent and experienced individuals handle the samples.

d. Weather and Environmental Conditions, adverse weather, such as heavy rain or extreme heat, can damage samples during transportation. Therefore, transportation should account for potential weather conditions. Using covered vehicles or additional protective packaging, such as waterproof covers, can be an effective mitigation strategy.

e. Storage at the Sample House, Upon arrival at the sample house, samples must be immediately stored in a secure location, protected from environmental factors that could degrade them, such as excessive heat or high humidity. The transported cores should be neatly arranged in an organized storage system to allow easy access when needed for further analysis.

Figure 3. Transportation Process

3.9. Challenges in Sample Transportation

Challenges in Sample Transportation

- Remote Locations: One of the main challenges is that exploration sites are often remote and difficult to access, requiring specialized transportation equipment and careful logistical planning.
- Sample Damage: Improper handling during transportation can cause physical damage to samples, such as breakage or deterioration, which may affect analysis results and data interpretation.
- Extreme Weather: Harsh weather conditions, including extreme heat or heavy rainfall, can worsen transportation conditions and damage samples if not properly anticipated [36].

Mitigation Strategies

- Thorough Planning: Careful planning before transportation, including selecting the appropriate transportation equipment and safe routes, is essential to ensure samples reach the sample house safely.
- Proper Packaging: Using suitable packaging materials, such as foam or waterproof protective covers, can help safeguard samples from damage caused by impacts or extreme weather conditions.
- Supervision and Monitoring: Continuous monitoring of sample conditions and transportation processes can help detect and address potential issues during transit [37].

3.10. Sample Inspection at the Sample House

Sample inspection at the sample house is a crucial step after samples arrive from the field to ensure their integrity, completeness, and suitability for analysis. This process involves a series of procedures to verify that the received samples match the documentation and are ready for further analysis. Careful inspection helps prevent errors in analysis that could impact exploration results and decision-making. Sample Inspection Process at the Sample House includes:

a. Sample Quality and Completeness Check, samples received at the sample house must undergo a visual inspection to ensure there is no physical damage, such as broken or deteriorated core samples. This inspection includes:
   - Core Condition: Checking whether the core remains intact and is not broken or crushed during transportation. Damaged cores can affect geological, mineralogical, or geochemical analysis.
   - Sample Completeness: Ensuring that all samples recorded in the documentation have been received in full. This process requires verification of the number of core samples, drill hole numbers, and sample depths based on field data.

b. Label and Documentation Verification Labels on each core must be checked to ensure that the recorded information is accurate and complete. Purpose of Verification, label and documentation verification aims to prevent confusion or errors during sample analysis. It is also crucial for maintaining sample traceability and ensuring that each sample can be mapped to its exact location and depth. Some essential details that must be included on core labels are:
   - Drill Hole Number: Confirming that the drill hole number on the label matches the field documentation.
   - Sampling Depth: Checking whether the depth on the label corresponds to the recorded sampling depth in field forms or logs.
   - Sampling Date: Verifying the sampling date to ensure that the information is accurate and reflects the relevant exploration period [31].

c. Storage Condition Check Received samples must be immediately stored in appropriate conditions, protected from environmental factors that could degrade them, such as high humidity, extreme temperatures, or direct sunlight exposure. This check includes:
   - Proper Storage: Samples must be neatly arranged in a storage facility with controlled temperature and humidity. Core boxes should be placed on racks or in a protected area.
   - Storage Environment Conditions: Monitoring environmental conditions in the sample house is essential. The room should have adequate ventilation, and samples should be kept away from heat sources or excessive humidity. If necessary, periodic humidity and temperature measurements can be conducted.

d. Sample Arrangement and Organization After visual inspection and documentation verification, samples must be properly arranged and organized to facilitate retrieval for further analysis. Importance of Organization; Proper organization assists in laboratory analysis and simplifies record-keeping and sample retrieval when needed [38]. This organization involves:
   - Grouping by Location or Depth: Samples can be grouped based on their collection location or depth to simplify retrieval and mapping.
   - Arrangement in Core Boxes: Cores should be arranged in core boxes in the correct order, following stratigraphic sequences and depths to avoid confusion or misinterpretation of data.

e. Inspection Recordkeeping All inspection steps carried out at the sample house must be documented in a sample inspection log (Figure 4). This record-keeping process includes:
   - Sample Receipt Date: Recording the date when samples arrive at the sample house.
   - Sample Condition: Noting the physical condition of samples, such as whether the cores are intact, damaged, or have other issues.
   - Inspection Findings: Recording inspection results, including sample completeness, any damage or missing data, and whether the samples are ready for further analysis.

   Importance of Recordkeeping; These records provide an audit trail to ensure that every step in sample management is properly conducted. They also help maintain accountability and transparency throughout the exploration process [39].

   Challenges in Sample Inspection at the Sample House
   - Sample Damage: Damage occurring during transportation or storage can hinder analysis, especially if the core contains critical geological structures or layers.
   - Documentation Errors: Mistakes in recording essential information such as depth or drill hole numbers can lead to difficulties in data interpretation or even errors in geological modeling.
   - Suboptimal Storage Conditions: Uncontrolled humidity or temperature can degrade samples, affecting analysis results and compromising long-term data reliability.

Figure 4. Sample Inspection at the Sample House

Mitigation Strategies

- Maintaining Proper Storage Conditions: Ensuring that temperature and humidity in the sample house are kept within appropriate ranges to prevent sample deterioration.
- Training Inspection Teams: Providing training for personnel responsible for sample inspection to improve accuracy in verification and data recording.
- Infrastructure Maintenance: Keeping the sample house and storage facilities in good condition to ensure long-term functionality and efficiency [40].

4. Conclusion

This study examines the drilling sample handling procedures for lateritic nickel exploration at the Sambalagi Site, PT. Cakrawala Resources Indonesia. The analysis results indicate that the implemented procedures comply with exploration standards, particularly in sample collection, logging, and storage. However, several challenges remain in storage and transportation aspects, which may affect the quality of the obtained geological data. The implementation of strict standard operating procedures, including meticulous record-keeping and proper packaging, is crucial to ensuring that the collected samples can be optimally utilized for further analysis. Additionally, the quality control measures applied at each stage of exploration have proven effective in minimizing potential errors in data processing.

Acknowledgment

The authors express gratitude to PT. Cakrawala Resources Indonesia, particularly the exploration team at the Sambalagi Site, for the opportunity and support provided in conducting this research. The support in the form of data access, field facilities, and cooperation from the entire exploration team has played a crucial role in ensuring the smooth execution of this research. The author also extends appreciation to colleagues who have contributed to various technical and administrative aspects, as well as to all parties who, although not mentioned individually, have contributed to the completion of this research. It is hoped that the findings of this study will be beneficial for the development of lateritic nickel exploration in Indonesia.

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