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Infrared Spectroscopy for Real-Time Detection of Swelling Clays in Geothermal Wells. A Case of Olkaria, Kenya

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ABSTRACT

Geothermal energy, a promising and sustainable alternative to fossil fuels, relies on the efficient drilling and operation of geothermal wells. Drilling these wells encounters numerous formidable challenges that can give rise to unanticipated expenses and hazards. Swelling clays like smectite, pose substantial impediments during the drilling process and wellbore development within the Olkaria geothermal field. These impediments include incidences such as bit balling rendering penetration practically impossible, differential sticking, wellbore collapsibility, and an escalation in unproductive time. Various methodologies for identifying these minerals have been established, yet their utility in addressing this predicament remains largely unexplored. Notably, the existing techniques for mineral identification, such as laboratory X-ray diffraction (XRD) analysis of well logs, are both time-consuming and unsuitable for real-time monitoring. The present methodology in use for the on-site detection of swelling clays involves the application of the methylene blue test. However, this method is constrained by its subjective nature, semi-quantitative character, specificity to particular clay mineral types, and its incapacity to provide comprehensive structural information. Infrared Spectroscopy (IR) enables the analysis of the interaction between matter and electromagnetic radiation in the infrared portion of the electromagnetic spectrum. The advantages of IR spectroscopy lie in its ability to provide on-site, real-time data without the need for time-consuming sample transportation to a laboratory. Spectral signals from SWIR spectroscopy can be utilized to identify and quantify various clay minerals within the drill cuttings, enabling geothermal operators to make informed decisions promptly. This method offers the potential to streamline drilling operations, improve casing design, and reduce non-productive time, ultimately contributing to the success and sustainability of geothermal energy projects. Drill cuttings obtained from wells OW 922, OW 925, and OW 740 were subjected to dual analytical techniques, namely X-ray diffraction (XRD) and infrared (IR) spectroscopy. Initially, XRD analysis served to confirm the presence of swelling clays within the well samples. Following this confirmation, the samples were subsequently subjected to IR spectroscopic analysis. During the IR spectroscopic analysis, characteristic Hydroxyl (OH) Stretching Bands, which are commonlyassociated with swelling clays, were distinctly observed as absorption bands within the shortwave infrared (SWIR) region, falling within the spectral range of 1.4 to 2.5µm on the electromagnetic spectrum. Ferrous (Fe^{2+}) absorption bands were additionally identified at around 2.3µm, providing evidence of the existence of nontronite, a distinct variety of smectite clay mineral. This observation underscores the applicability and effectiveness of IR spectroscopy as a viable real- time method for the detection of swelling clays during the process of geothermal well drilling.

1. INTRODUCTION

The Olkaria Geothermal field, situated in the Central Kenya Rift, has been the site of continuous drilling operations since the 1950s. Its located on the floor of the Kenya Rift Valley and is approximately 140 km northwest of Nairobi, 11 km northwest of Lake Naivasha. The field has witnessed the drilling of over 300 wells of varying depths. These wells span a range between 1000 and 3000 meters, with certain contemporary wells reaching depths of 3500 meters. However, there are many fields along the Kenyan rift valley.

Geothermal development involving deep drilling has been conducted in the Eburru, Menengai, and Olkaria geothermal fields, with more recent activities extending to the Paka and Korosi fields. Currently, appraisal drilling is ongoing at Paka, while exploratory drilling continues at Korosi. These two fields are located significantly farther north compared to the previously mentioned geothermal fields, with a combined total of over 15 deep wells drilled to date.

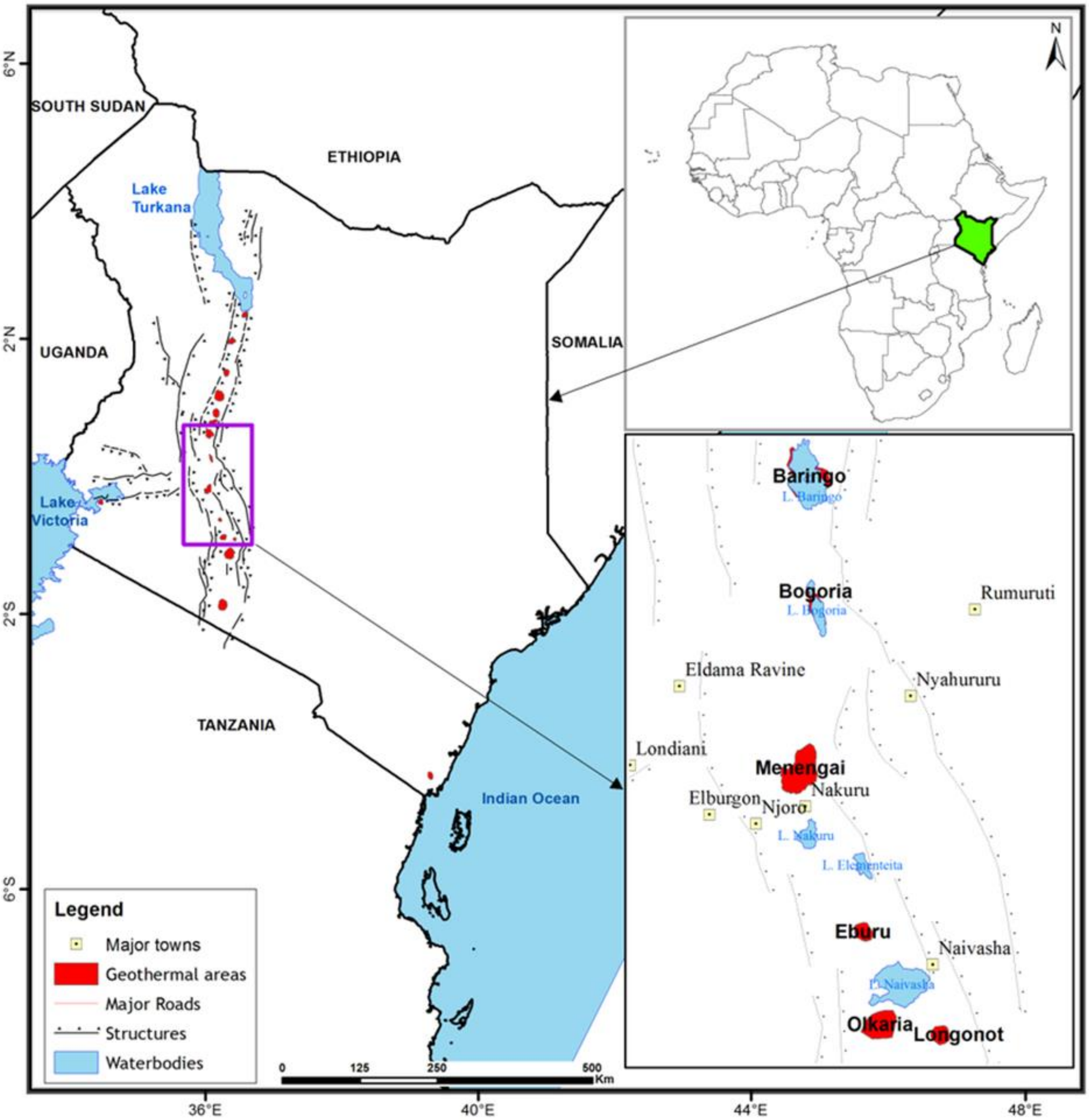

Figure 1: Map of the Kenya Rift showing the location of the Quaternary volcanoes (in black triangles) along the rift axis and the study area (in the green rectangle). Open circles are geothermal prospects in Kenya (Lagat, 2004)

1.2 Characterization of clay Minerals

Clay minerals are a group of silicates belonging to the hydrous aluminium silicates; they are small- sized particles ranging from 0.005mm. There are different types of clay minerals: smectite, kaolinite, and illite (Savitri et al., 2021). Infrared spectroscopy easily analyses Clay minerals since they are spectrally active under their wavelengths. Infrared spectroscopy can identify members of a clay group quantitively compared to XRD; for example, smectite group, XRD will identify it as one, but IRS will identify the group members in the smectite; the same appears for the kaolinite group (Savitri et al., 2021). Smectite and smectite-illite clays form between 50-200℃. These clays can partially seal reservoir top and sides, thus playing an important role in geothermal systems; by doing so, they create perched aquifers in the vadose zones. Chlorite and illite are the main alteration minerals within the reservoir. The clay alteration within the reservoir itself is mainly chlorite and illite. Smectite and illite-smectite are found at temperatures below 200℃. The transition to pure illite occurs at temperatures between 200-240℃.

Swelling clays are one of the challenges that have been encountered in the Olkaria geothermal field in Kenya. Early characterization of swelling clays and identification of their zones of occurrence can significantly enhance geothermal well development. Specific groups of clay minerals which include smectite, kaolinite, vermiculite, and illite have considerable tendencies to experience large volumetric changes upon wetting or drying (Kariuki et al., 2004). These clay minerals have different water-holding capacities and swelling potential due to the differences in their mineral structure hence their importance in the characterization of expansive soils. Smectite and mixed-layer (smectite-illite) clays are the predominant clay alteration products that occur at shallower zones of the geothermal wells within a temperature range of 50 to 200°C (Gunderson et al., 2000). Identification and characterization of these clays in their zones of occurrence is paramount during drilling operations and development of geothermal wells and can be used to predict changes in the permeability of the reservoir (Meshram, 2016).

1.3 Problem Statement

The challenges encountered in high-temperature wells are typically more pronounced compared to those in shallower and cooler wells. The drilling process poses various issues, including but not limited to:

- Bit balling
- Differential sticking
- Well-bore collapsibility
- Unproductive time
- Difficulties in casing

These problems in geothermal swelling clays have not been solved yet. The current state of the art in geothermal drilling in Olkaria Kenya is that clay mineral analysis is often done long after the well has been completed. Identification of swelling clays and other general geological well logging analysis has been and is being done using binocular microscopes at the rig site, while petrographic and XRD analyses are done later in the laboratory. This study intends to determine the effectiveness of ATR and SWIR spectroscopy compared to the conventional method of XRD in the detection of swelling clays and establish how this method can be employed during geothermal well drilling to offer on-site solutions. Furthermore, this study will test how much sample preparation is needed to achieve certain level of accuracy in the various techniques, which will allow to apply a cost-benefit analysis for the various approaches. This will be used to come up with the most convenient technique to use for nearest real time detection of swelling clays to avoid challenges associated with swelling clays during drilling and address the wellbore stability problems

1.4 Significance of Infra-red spectroscopy

Infrared spectroscopy is now established as one of the widely used analytical techniques that measure the absorption or transmission of infrared radiation by a sample. It has been proven to be a powerful tool for characterizing and identifying organic and non-organic compounds. In addition, infrared spectroscopy is a special tool that can investigate complex systems' molecular structure and evolving nature. One significance of infrared spectroscopy is that it gives information on the existing functional groups in a sample. By giving accurate information regarding the existing materials in a sample, a sound decision that reduces costs in drilling can be made. In a recent study that was conducted with the aim of discovering the effectiveness of infrared spectroscopy in detecting soil nutrients, the result showed that the technique could detect even the smallest soil particle sizes (Xiao & He, 2019). This study implied that infrared spectroscopy has the potential to detect the smallest soil particles that other techniques can hardly notice.

2. DATASETS AND METHODOLOGY

Three wells (OW-922, OW-741 and OW-925) were selected for this research based on their previous drilling history, stratigraphy and preliminary binocular and petrographic analysis. OW922 was drilled to a depth of 2990m and lasted 156 days. This exceeded the anticipated duration of 100 days and was due to challenges associated with swelling clays. OW-925 is the fastest well ever drilled in Olkaria with a record completion period of 25 days. Though it's located in the domes area like OW-922, it never experienced any challenges.

2.1 Laboratory Measurements

Laboratory Measurements were performed in ITC University of Twente, Netherlands Geoscience laboratory. They included; XRD measurements, Spectroscopic measurements using the ASD field spec and ATR measurements. The following steps were involved.

2.2 Sample Preparation

Sample preparation for analysis of clay mineral depend on the reasons for analysis and the equipment available (Moore and Reynolds,1997). The samples were first separated using a metallic separator to ensure the two portions are good representation of the full sample. Grinding was done into a fine powder using a mortar and pestle to a homogeneous and well dispersed sample. Moore and Reynolds (1997) observed that vigorous machine grinding can destroy the clay mineral structure. This process was performed on all the samples.

2.3 Separating Clay from the material

To isolate the clay fraction from the mixed powder, the powder was first suspended in one liter of distilled water. The suspension was vigorously mixed and allowed to settle for a duration of one hour. After one hour, the upper 200ml portion of the suspension was carefully extracted using a pipette. This extracted portion was then subjected to centrifugation at 2000 rpm for a duration of 9 minutes, following the guidelines specified in the USGS manual. Subsequently, the supernatant (the liquid portion above the sediment) was gently poured off, leaving behind the sediment at the bottom of the centrifuge tubes. The sediment was then dried in an oven at 100°C for a period of one hour.

2.4 Oriented Aggregate Mounts

To facilitate the identification of clay minerals, the clay fraction was prepared as an oriented aggregate mount. This involved mixing approximately 0.25 grams of the clay fraction powder with

1.5 ml of distilled water and spreading the resulting mixture on a glass slide. This preparation method, as described by Moore and Reynolds (1997), is crucial for ensuring accurate and quantitative representation during X-ray diffraction (XRD) analysis.

According to Moore and Reynolds (1997), XRD samples should possess specific characteristics to provide reliable data. These characteristics include being smooth, flat, sufficiently long, adequately thick, and consistent in composition throughout their depth. By adhering to these criteria, the samples can yield precise and quantitative information during XRD analysis. Changes in the d-spacing, which indicate expansion or contraction, can be observed along this axis during subsequent treatments. These treatments involve procedures such as air drying, glycolation with ethylene glycol, heating to 400°C, and heating to 550°C.

In the present investigation, exclusive glycolation involving treatment with ethylene glycol was undertaken subsequent to the initial X-ray diffraction (XRD) measurement. This procedural step serves to enhance the characterization of clay minerals and their properties, as the treated fractions exhibit an additional feature absent in their untreated counterparts.

2.5 Glycolation with ethylene glycol

The ethylene glycol treatment plays a significant role in identifying swelling clays in X-ray diffraction (XRD) analysis. XRD measurements were performed using Bruker D2 Phaser diffractometer located at the Geoscience Laboratory of ITC, University of Twente.

X-ray data were obtained by operating the instrument at a voltage of 30 Kv and 10mA to generate CuKα radiation. A Lynexe silicon strip detector was used. Each scan ranged from 6-80 2Φ range using a 0.005 step size. A scan duration of minimum of 1 hour was used in order to improve peak intensity and to enable detection of minerals in trace amounts. The output was diffractograms consisting of a sequence of peaks of 28 varying count intensity and d-spacing as given by the Brags law($n\lambda=2d\sin\Phi$) where λ is wavelength of the incident beam, d is spacing between crystal planes and Φ is the angle between the crystal plane and the diffracted beam, n is an integer of the reflected waves from different layers. Mineral identification was done by using an automatic search and scan or manually searching by mineral name in DIFFRAC. EVA version 3.1 software against an inbuilt reference mineral database. Several best match peaks were generated by the software, but the ultimate likely mineral was selected by the user. Besides mineral identification, DIFFRAC. EVA software was used for semi-quantification of mineral percentages in the whole rock powder scans

2.6 Spectroscopic Measurement

Both spectroscopic measurements on the oriented aggregate mounts and on whole chips, which were separated during the initial stage of sample preparation, were conducted using the AD FieldSpec 3 and ASD FieldSpec Pro instruments. Infrared spectroscopy was employed for these measurements, offering a non-destructive approach to mineral analysis with minimal sample treatment requirements.

Infrared spectroscopy serves as a dependable tool for assessing mineralogy and mineral chemistry. It provides valuable insights into the composition and characteristics of minerals. Particularly, in the short wave infrared (SWIR) range, spanning from 1.3 to 2.5 micrometers (μm), infrared spectroscopy has proven to be effective in mineral analysis spans from 1.3 to 2.5 micrometers (μm)(Simpson & Rae, 2018). By studying the energy emitted and absorbed by minerals in this range, valuable information about their properties and composition can be obtained

3. RESULTS

The pattern collected on the untreated (not solvated with ethylene glycol) and extracted fine fractions showed peak located at 7.5 reinforcing the results of the whole rock analysis. The value at this angle is typically for smectite and it shifts to 5.6 upon treatment by ethyl glycol.

Upon identification of Smectite in the XRD analysis, spectroscopic measurements were conducted on the samples to ascertain the specific types of smectites in the samples. The smectite group of swelling clays were identified after spectral interpretation with GMEX spectral analysis guides and USGS spectral library.

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Montmorillonite and nontronite are the main smectite group of minerals identified in this study occurring in the upper alteration sequence. They were identified based on the following criteria

2.7 Montmorillonite

Montmorillonite identified in the study area is characterized by an intense and sharp water feature between 1911-1917 nm and major but broad Al-OH band between 2214-2225 nm with no major feature in the longer wavelength region

2.8 Nontronite

Nontronite is a dioctahedral smectite where the Fe2+ mineral is the dominant species. Compositionally, it consists of more than 30% Fe2O3 (Pontual et al., 2008). Analogous to montmorillonite, it was identified by the presence of deep H2O absorption between 1911-1917 nm with iron diagnostic absorption feature occurring at between 2296-2298nm

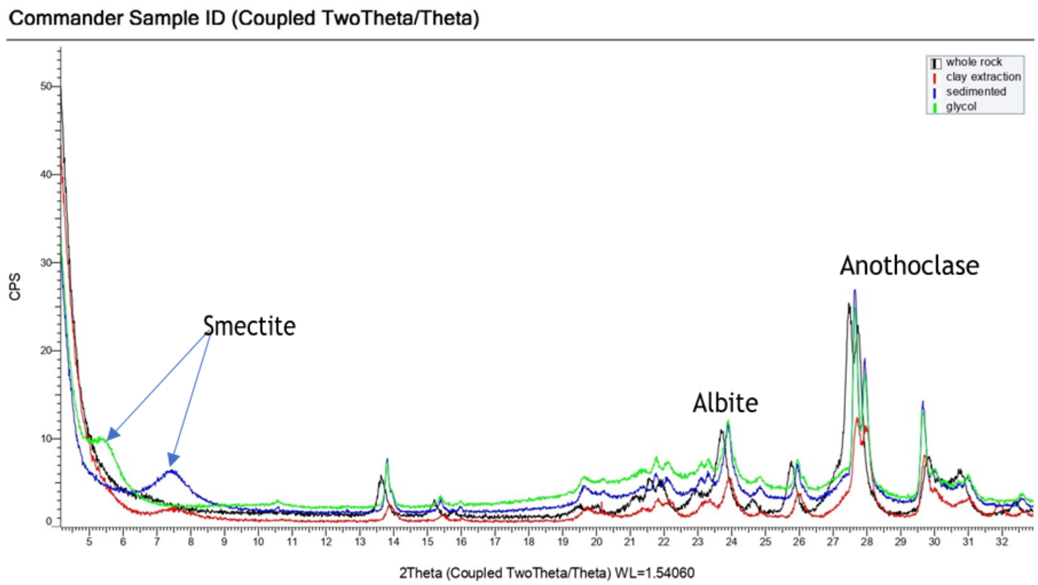

Figure 2: XRD X-ray diffraction patterns of the untreated and treated extracted fraction of sample OW 922: 310-312 showing the smectite peak signature at 7.5 (Untreated) and 5.6 treated. Additionally, peaks were assigned to Anorthoclase and Albite as shown.

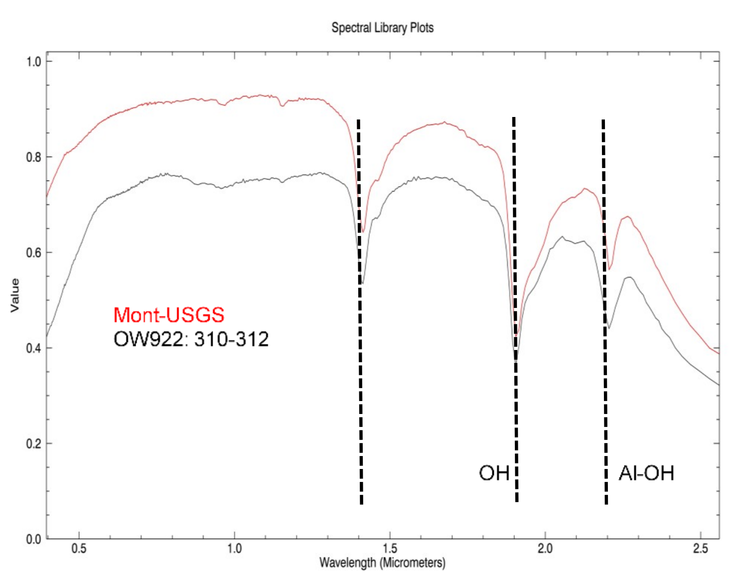

Figure 3: XRD X-ray diffraction patterns of the untreated and treated extracted fraction of sample OW 922: 310-312 showing the smectite peak signature

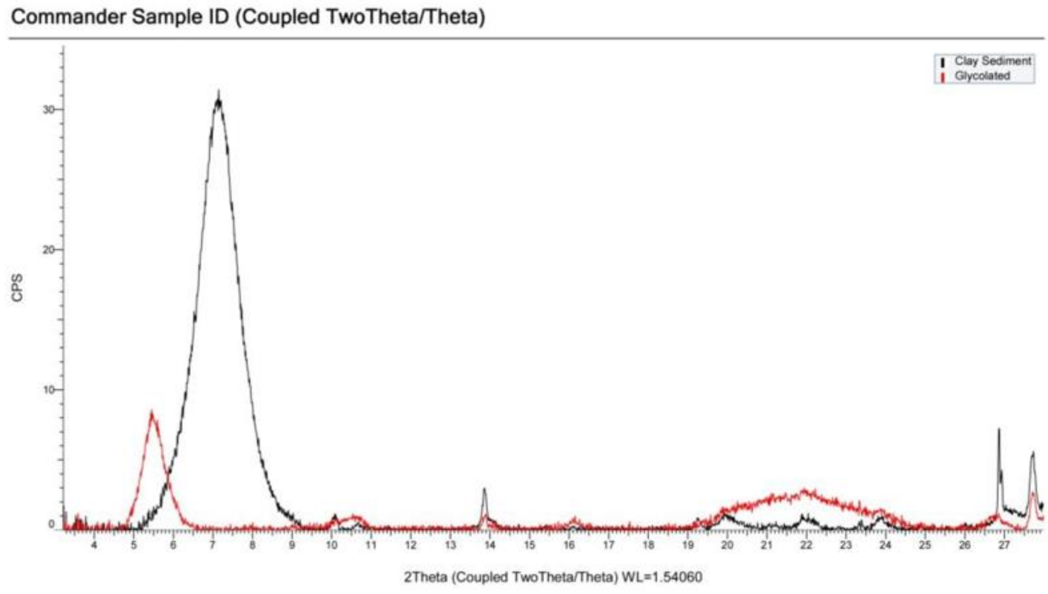

Figure 4: XRD X-ray diffraction patterns of the untreated and treated extracted fraction of sample OW 922: 310-312 showing the smectite peak signature

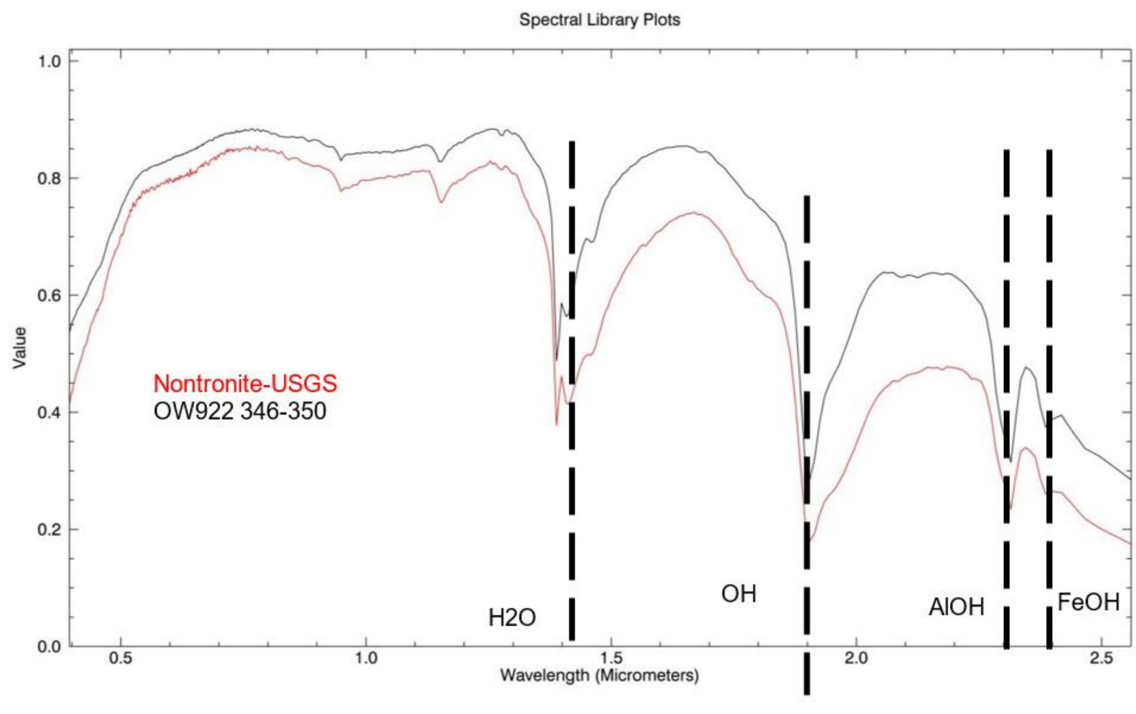

Figure 5: XRD X-ray diffraction patterns of the untreated and treated extracted fraction of sample OW 922: 310-312 showing the smectite peak signa

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4. DISCUSSION AND CONCLUSION

This study demonstrates the efficacy of utilizing combined X-ray diffraction and reflectance spectroscopy measurements for the analysis of extracted clay fractions, specifically targeting swelling clays. The findings reveal that the reflectance spectra can effectively discriminate between various types of smectites present in a given sample.

In the context of clay mineral identification, infrared (IR) spectroscopy emerges as a valuable tool for discerning specific minerals within a sample. The sharpness and intensity of IR absorption bands provide valuable insights into the structural characteristics of clay minerals. Notably, the simplicity and speed of sample preparation and measurements in IR spectroscopy contribute to its efficiency. This method involves minimal to no sample manipulation, resulting in time and cost savings.

While IR spectroscopy proves to be a cost-effective and expeditious option for qualitative analysis, it is essential to acknowledge the nuanced capabilities of X-ray diffraction (XRD). XRD, being more precise, furnishes comprehensive mineralogical data. Consequently, the choice between these techniques hinges on the analytical requirements of the study. In scenarios where rapid results are paramount, as in routine analyses or real-time detection of swelling clays during drilling operations to avert challenges associated with their swelling behaviour, infrared spectroscopy emerges as a preferred and swifter technique. Conversely, for a more detailed and accurate mineralogical analysis, XRD remains the method of choice.

5. RECOMMENDATIONS

Strongly advocate the adoption of infrared spectroscopy for on-site, real-time detection of swelling clays during drilling operations.

6. REFERENCES

Clarke, M. C. G., Woodhall, D. G., Allen, D., & Darling, G. (1990). Geological, volcanological and hydrogeological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya.

Lagat, J., Arnorsson, S., & Franzson, H. (2005). Geology, Hydrothermal Alteration and Fluid Inclusion Studies of Olkaria Domes Geothermal Field. Kenya Proceedings World Geothermal Congress, 12–13.

Savitri, K. P., Hecker, C., van der Meer, F. D., & Sidik, R. P. (2021). VNIR-SWIR infrared (imaging) spectroscopy for geothermal exploration: Current status and future directions. Geothermics, 96, 102178. https://doi.org/10.1016/J.GEOTHERMICS.2021.102178

Shackleton, R. M. (1996). The final collision zone between East and West Gondwana: Journal of African Earth Sciences, 23(3), 271–287.

Simpson, M. P., & Rae, A. J. (2018). Short-wave infrared (SWIR) reflectance spectrometric characterization of clays from geothermal systems of the Taupo volcanic Zone, New Zealand. Geothermics, 73(October 2017), 74–90. https://doi.org/10.1016/j.geothermics.2018.01.006

Wendt, J.I., Regelous, M., Niu, Y., Hekinian, R. And Collerson, K.D. (1999). Geochemistry Of The Lavas From The Garret Transform Fault: Insights From The Mantle Heterogeneity Beneath The Eastern Pacific. Earth Planet. Sci. Lett., V.173, pp.271-284.

X-ray Diffraction and the Identification and Analysis of Clay Minerals. (1989). Oxford University Press.

Yang, K., Huntington, J. F., Browne, P. R. L., & Ma, C. (2000). An infrared spectral reflectance study of hydrothermal alteration minerals from the Te Mihi sector of the Wairakei geothermal system, New Zealand. Geothermics, 29(3), 377–392.