µXRF Application for Uranium Exploration (Case Study: Mamuju Deposit, Indonesia)

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Abstract. Micro X-ray fluorescence (µXRF) is an advanced analysis technique from conventional XRF (X-Ray Fluorescence) that allows analysis of smaller areas even inclusions with irregular shapes and non-homogeneous elements. This method has a spatial resolution up to 10 µm depends on the energy by X-rays so that the excitation beam at the smallest point of the sample surface can be detected. This study explains the application of µXRF to determine the type of deposit and the formation of uranium contained in Takandeang Village, Tapalang District, Mamuju Regency, West Sulawesi. The study began with surface geological and radiometry mapping, continued with geological drilling. Collected samples then undergo petrology, petrographic, and geochemical analysis. Three collected samples from drilling sample were analysed using the µXRF. From the analyses we found that the highest uranium anomaly is found in leucitite autobreccias. The anomaly that occurred in the study area was in the form of reconstitution of uranium elements in autobreccia rocks caused by hydrothermal activity which was also supported by magma type and structural control in the study area. In this study case we found that µXRF is useful for uranium exploration.

Keywords: Uranium, Sulawesi, µXRF, Autobreccia, Hydrothermal Alteration

1. Introduction

Mamuju consists of various kinds of rocks and dozens of formations. Some of which are igneous rocks, volcanic rocks, limestones, and sandstones. Micro X-ray fluorescence (µXRF) is an advanced analysis technique developed from conventional XRF that allows analysis of smaller areas even inclusions with irregular shapes and non-homogeneous elements. This method has a spatial resolution up to 10 µm depends on the energy by X-rays so that the excitation beam at the smallest point of the sample surface can be detected. [1]

Figure 1. Modified Geological Map of Mamuju Sheet, West Sulawesi (Atmawinata, S., & Ratman, N.)

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This research was conducted in Takandeang Village, Mamuju West Sulawesi, Indonesia with the aim of knowing the radioactive anomaly conditions in the TKDK-13 exploration drilling well rock. The area is located on the southwest side of Mamuju Sheet within the Adang Volcano rock unit. This unit consists of a mixture of volcanic breccia with lava inserts as well as tuffaceous pyroclastic rocks, sandstones, and claystones [2]. The main methods used to determine the elements in rock samples are XRF and µXRF.

1.1 Uranium in Sulawesi

Uranium exploration has been carried out at a number of target locations on Sulawesi Island. In the West Sulawesi region, radioactivity anomalies were found in a number of Triassic metamorphic rocks, as well as clastic rocks, intrusive and volcanic igneous rocks and tertiary sedimentary rocks [3]. The potential presence of Uranium has been discovered and further interpreted in Mamuju Field, West Sulawesi (Figure 1). Based on the research that has been done, uranium accumulates in lava rock from Takandeang and volcanic breccias, while limestone contains very little uranium content and is distributed unevenly [4].

2. Methods

The research began with collecting data in the field and doing laboratory analysis. Data were collected by performing geological and surface radiometric measurements in an area of 400 x 400 m around the TKDK-13 exploration well area located in Takandeang Village, Mamuju, West Sulawesi, Indonesia. Radiometric measurements were carried out using the Radio Spectrometer-125 (Mount Sopris).

Laboratory data processing consists of petrographic analysis and geochemical analysis. The geochemical analysis methods carried out in this study are the XRF and µXRF (M4 Tornado BRUKER) analysis. The analysis aimed to see if there were trace elements and main oxides in the specified sample so that it could form a spectral map of inanimate objects for each.

µXRF has the same basic principles as XRF. This method emits X-Ray which then characterize the X-Ray Fluorescence emission of the sample so that the elements in it can be analyzed. In the µXRF method, there is a significant difference in spatial resolution where conventional XRF is limited to the size of mm while µXRF has a spatial resolution of up to µm, this difference causes the excitation beam to be more concentrated at the smallest point in the sample. This reduction of the point of the x-ray beam is assisted by a special polycapillary optic [5].

Special polycapillary optic is used to reduce the point size of the X-ray beam to the order of µm depends on the energy used. This polycapillary optic accumulates X-Ray from various sources so that it can be focused on a small beam on the surface of the analyzed sample with an accuracy of up to µm. This causes spatial resolution to be increased and trace element analysis can be carried out with greater precision [5]. For the exploration stages, drilling is carried out in the area marked with a red dot on the map (Figure 3).

3. Results and Discussion

There are several steps taken both in the field and in the laboratory before carrying out the µXRF analysis. The following is a brief explanation

3.1 Initial Research

Based on the results of field mapping, it is known that there are five rock units around the TKDK-13 drilling well, Takandeang Village, Tapalang District (Figure 2).
From the mapping results, it is known that there are five rock units, namely leucitite autobreccia, phonolitic foidite lava, epiclastic breccia, tuffaceous sandstone, and coral limestone. Viewed from the surface radiometric distribution data, it is known that the highest anomalies are found in leucitite autobreccia rocks. The measurement of the total radiation dose rate was carried out in the field with a measurement range of 143.5 nSv / h to 4295.8 nSv / h. The maximum value of uranium equivalent radiation in the rock on the surface is 420.5 ppm and the minimum value is 0 ppm with an average of 34.159 ppm.

The drilling point is determined based on the highest anomaly in the leucitite autobreccia rock. A number of XRF and µXRF analysis points were determined on the 75 meter long core rock based on its macroscopic mineral features. XRF analysis was performed taken from coring samples after the drilling in the laboratorium at depths of 42.5 m (9D), 54.4 m (11D), and 57.2 (12D) while µXRF analysis was carried out at depths of 15.4 m (4D), 46.35 m (10D) and 57.2 m (12D).

3.2 µXRF Analysis

From the µXRF analysis, detailed element abundance data were obtained accompanied by a spectrum map of each element in the area studied

3.2.1 Sample 4D. In 4D Sample, abundant Ca elements were found up to 820 cps / eV. This element is thought to be derived from vein calcite. In addition, there are also elements of Fe, Na, Sr Mn, Al, and Mg as well as other elements such as S, Ti, and U in minor amounts. S elements are found around the leucitite breccia fragments, while U and Ti elements are scattered in the basic mass (Figure 3).
The results of the µXRF spectrum mapping of each element in the 4D rock samples

3.2.2 Sample 10D. In 10D Sample, an abundance of Fe element was found up to 800 cps / eV, this indicates an intense oxidation. In addition, elements of Si, Ca, Mg, Ti, Al and other elements were also found. This relatively high Si element comes from silica cement in the form of spadaite which fills the gaps between leucitite fragments (Figure 4).

![Figure 3. The results of the µXRF spectrum mapping of each element in the 4D rock samples](image)

![Figure 4. The results of the µXRF spectrum mapping of each element in the 10D rock samples](image)
3.2.2 Sample 12D. In 12D Sample also found an abundance of the element Fe up to 670 cps / eV. Macroscopically this intense oxidation process causes some of the body rock’s color to turn black. In addition, there are elements of Si, Fe, Na, Ca, K, U, Mg, Al, Mn, Ti, and Zr. Element Si is sourced from silica cement which covers most of the surface of the sample, while element U is recorded around leucite phenocrysts. Apart from silica, there is also a high element of Ca in this sample which is also derived from the calcite veins between the breccia fragments (Figure 5).

Figure 5. The results of the μXRF spectrum mapping of each element in the 12D rock samples
From the results of the µXRF analysis, it is known that there has been an intense zeolite alteration in the drill rock. This can be seen from the change in phenocryst of leucite with the initial formula K[AlSi2O6] to analcime which has the formula NaAl(Si2O6)(H2O). This change occurs due to the release of elemental K due to the alteration process at low temperatures. In addition, some of the basic mass of the rock which consists of glass is altered to become heulandite. In rocks also found amorphous silica material known as spadaite with the formula Mg(SiO2)(OH)2(H2O), this silica cement is quite common in leucite mineral bearing rocks. The increase in Fe in 10D and 12D samples also shows the occurrence of oxidation at a certain depth to form oxide minerals.

3.3 Correlation of data with the surrounding geological environment

The results of the µXRF analysis showed similar elemental changes in rock samples both in phenocryst and bed mass. Most of the leucite phenocrysts and the base mass of glass and pyroxene have undergone zeolite alteration which causes the release of K element. This alteration causes leucite to convert to analcime while some of the basic mass is converted to heulandite. This alteration is getting more intense in the area around the mineralization center which occurs along with the increase in Fe and U concentrations. In the drilling rock, the intense oxidation process is found on the surface and in the core rock at a depth of 50-60 m. The area also found the highest levels of U in it.

The existence of zeolite mineral groups indicates that the alteration occurs due to the formation of fractures which are flowed by hydrothermal fluid flows at low temperatures. This zeolite alteration is in varying degrees from very light with only a thin layer around the fragment to a strong degree where the zeolite partially replaces the basic mass and phenocryst components of the rock. This alteration is quite common in alkaline rocks, especially in the leucite mineral which is part of the feldspatoid mineral group. The presence of this zeolite can also indicate the presence of decay and hydration of the base mass of volcanic glass in both hydrothermal systems and hydrated environments with low temperatures (Spurgin et al., 2019).

The presence of calcite veins mixed with silica material and volcanic glass also indicates that the formation of fractures causes the influx of fluid flow that precipitates these minerals in it. This calcite vein probably originates from rock remains in older formations, while the clay material that fills the fractures and gaps between fragments is an indication that the hydrothermal system has a low temperature [6].

Figure 6. Spectrum map comparison between 4D (left) and 12D (right) samples.

In Figure 6, we can see the difference in the composition of the two samples where the dominant element in the 4D sample is Ca while in the 12D sample there is iron enrichment. The concentration of U element in the 4D sample was predominantly distributed in the base mass, while in the 12D sample it was found around the leucite phenocryst.
Hydrothermal alteration in rocks causes a leaching process that disturbs the equilibrium of the elements in it. As a result of this process, incompatible elements that have frozen in the rock are released due to their tendency to be in the melt phase, resulting in enrichment of incompatible elements, especially uranium, thorium, and potassium in hydrothermal solutions which then carry them to certain locations in the rock which causes enrichment.

Based on the results of the analysis carried out, it is known that there has been a fairly intense alteration in the leucitite autobrecciation rock along with an increase in the element uranium, so it is suspected that this mineralization is a volcanic type based on IAEA 2013. This mineralization originates from leucitite autobrecciation lava rock while uranium enrichment occurs due to the hydrothermal alteration process which causes the release of U element in the base mass and is concentrated in the leucite phenocryst.

4. Conclusion

The research field in Takandeang Village, Tapalang Subdistrict, Mamuju Regency, West Sulawesi consists of five lithological units, namely leucitite autobrecciation rocks, epiclastic breccias, phoidite phonolytic lava, tuffaceous sandstones, and coral limestone. μXRF results show that U are disseminated in some area within the leucite phenocryst among with the enrichment of Fe and Ca. Uranium deposits are found in the host-rock in the form of leucytite autobrecciation rock. This uranium deposit is thought to have been formed due to volcanic activity from the Adang Volcano Formation which then accumulated due to hydrothermal alteration processes and was supported by the presence of structures in the area.

Uranium mineralization in the research field is of a volcanic-related deposit type. The enrichment of element U accompanied by Fe occurs due to zeolite alteration which causes this element to be concentrated from the base mass to phenocryst leucite which is converted into analisime.

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