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X-Ray Diffraction (XRD) Analysis of Local Rock Minerals from the Geological Zones of Dembek and Wariab Villages, West Papua

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Abstract. This study aims to characterize the minerals in rock samples from Dembek and Wariab Villages, South Manokwari Regency, West Papua, using the X-ray Diffraction (XRD) method. XRD was used to identify crystalline phases and mineral compositions in the rocks, as well as to understand the geological conditions and mineral resource potential in the area. Rock samples were systematically collected from both locations and analyzed using an X-ray diffractometer. The analysis results show that the rocks from Dembek Village are dominated by quartz (SiO_2), Sodium Aluminum Silicate ($Na_{1.45}$ $Al_{1.45}$ $Si_{0.55}$ O_4), Potassium Aluminum Silicate ($KAlSi_2O_6$ and $KAlSiO_4$), Potassium Silicon Fluoride (K_2SiF_6), Albite (Na (Si_3 Al)O_8), Magnesium (Mg), Sodium Magnesium Aluminum Silicate ($Na_3MgAlSi_2O_8$), and Potassium Magnesium Silicate ($K_2MgSi_5O_{12}$). The rocks from Wariab Village contain a more varied range of minerals from two sampling points, namely, at the WRB-L1 location, consisting of halite (NaCl), quartz (SiO_2), Potassium Magnesium Fluoride ($KMgF_3$), Potassium Magnesium Silicate ($K_2MgSi_5O_{12}$), anorthite ($CaAl_2Si_2O_8$), and Potassium Aluminum Silicate ($KAlSi_2O_6$). The WRB-L2 location consisted of fluorite (CaF_2), Potassium Silicon Fluoride (K_2SiF_6), sylvite (KCl), sodalite ($Na_4Al_3Si_3O_{12}Cl$), and Sodium Aluminum Silicate ($Na_{1.65}$ $Al_{1.65}$ $Si_{0.35}$ O_4). These differences in mineral composition reflect variations in the formation environment and geochemical processes that occur at each location.

1 Introduction

The Australian, Eurasian, Pacific, and Philippine Sea plates converged to create a complex geological structure in eastern Indonesia, including the Bird's Head area on the island of Papua. Subduction of the Caroline-Pacific oceanic crust beneath the Australian continental crust created the Manokwari Trench, a convergent border of tectonic plates in the northern region of this province. In the Bird's Head area, this trench is a source of seismic activity, especially in relation to significant strike-slip faults such as the Koor, Sorong, Ransiki, and Yapen Faults [1]. Two large earthquakes with a maximum magnitude of 7.7 Mw rocked the Bird's Head region of Papua on January 3, 2009, along the Koor fault line, seriously damaging Sorong and Manokwari. On April 21, 2012, another powerful earthquake with a magnitude of 6.7 Mw struck close to Ransiki, resulting in injuries and structural damage. According to Kalaneh and Agh-Atabai [3], seismology research seeks to identify locations that are vulnerable to future earthquakes to mitigate their negative effects on humans.

Ground motion estimates ranging from 0.06 g to 2.01 g at a 10% danger level during a 50-year period were obtained from Papua Island's earthquake hazard mapping using the PSHA method [7]. As this has never been done before and is anticipated to assist in identifying and mapping local geological conditions that are susceptible to earthquake hazards, our research combines geophysical methodologies with petrology-based geology to assess earthquake hazards in the Ransiki district, South Manokwari Regency. Because it is less invasive and more cost-effective, the geophysical approach is considered advantageous for geological disaster investigations [8]. To determine the strength and resistance of rocks to seismic forces, a geological technique using petrographic analysis was used to gather precise information about the mineralogical characteristics and texture of the rocks.

West Papua is known for its rich and diverse geological formations; however, many of its mineral resources remain underexplored. Understanding the

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mineral composition of rocks in this region is crucial for both academics, and based on the correlation between geophysical data and geochemical characteristics, particularly the identification of constituent minerals and rock classification, it is important to carry out rock characterization to support the interpretation and analysis of geophysical data, namely using Powder X-Ray Diffraction (XRD). XRD is useful in the context of geochemistry, geology, and geophysics [9].

The Ransiki region is located to the west of the highlands of the northern Bird's Head Peninsula (Kemum High) and borders the Arfak Mountains to the north. The Arfak Mountains stretch in a northwest orientation, with the highest peak rising over 2,900 m, and steep slopes descending sharply eastward toward the coast and southward toward the Ransiki lowlands. To the west of the Ransiki Fault, there is a highland area with two large lakes at elevations between 1,800 and 1,900 m, while the Kemum High has experienced significant erosion. The Ransiki lowlands consist of alluvial and littoral plains at the southern tip of the Arfak Mountains, which form a delta from eroded areas that receive high amounts of rainfall. The Ransiki River meanders in its upper reaches and winds down its lower course. Large sediments form a Holocene delta in northwestern Cenderawasih Bay.

Our research aimed to characterize the minerals present in rock samples from Dembek and Wariab, understand the geological conditions, and highlight the differences in mineral composition between the two locations. The main objective of this study was to identify and characterize the crystalline phases and mineral compositions of rock samples collected directly from the villages of Dembek and Wariab.

2 Materials and Methods

2.1 Research Location

The location of this research is based on a study of geological disaster risk analysis, particularly earthquakes, focusing on the Ransiki District, which is the main strike-slip Ransiki fault line and serves as the capital of the South Manokwari Regency, where regional spatial planning development continues. Geographically, the research area is located at 134.133° E-134.199° E and 1.547° S-1.477° S, covering an area of approximately 50 km² (Fig. 1).

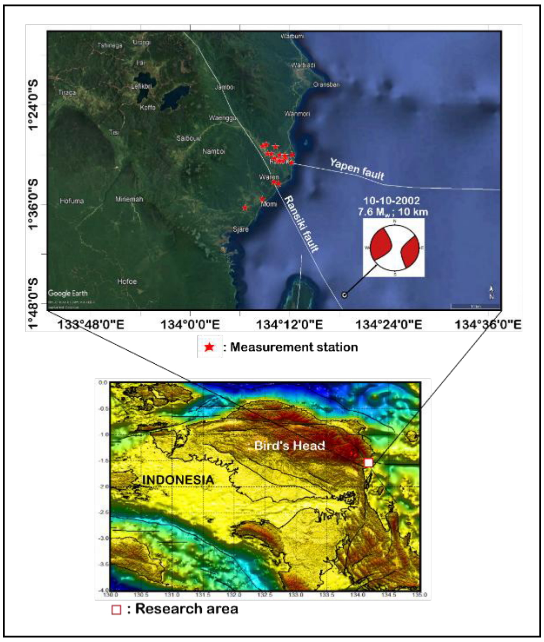


Fig. 1. Geophysical and Geochemical Research Location in Ransiki District, South Manokwari Regency, West Papua Province, as the main Ransiki fault line.

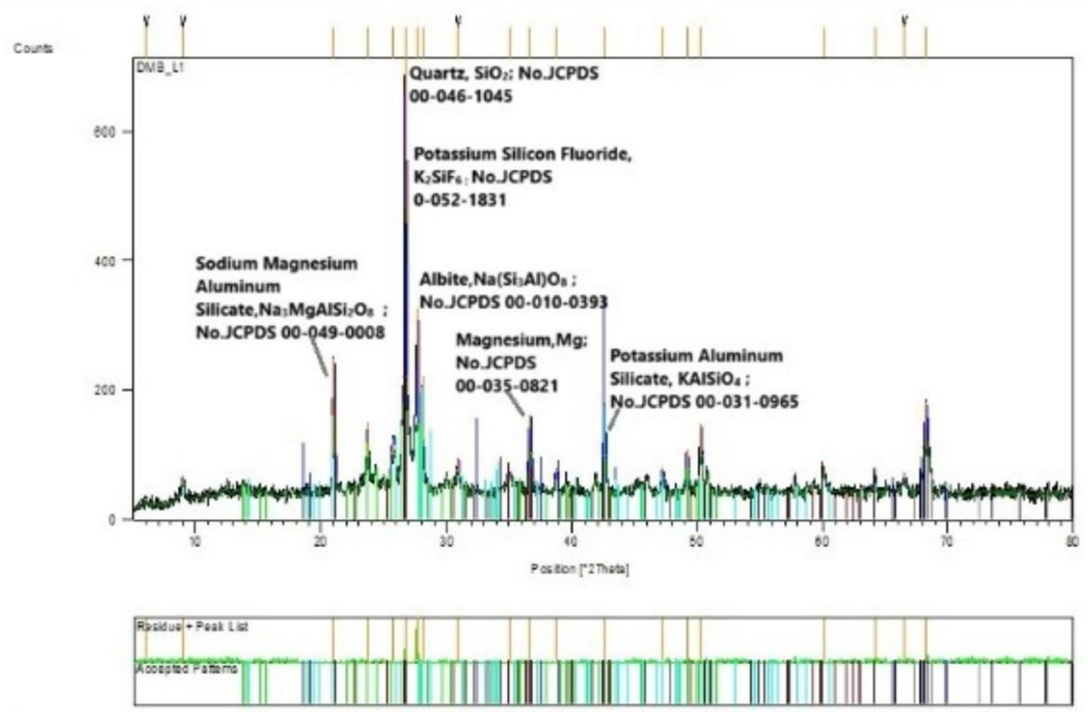
2.2 Data Analysis

Systematic rock sampling was conducted by Dembek and Wariab. Two sampling points in Dembek were used: DMB-L1, DMB-L2, and DMB-L3. Two sampling points in Wariab were used: WRB-L1 and WRB-L2. The samples were analyzed using an XRD scanning range of 2θ from 0° to 80°. Comparison with standard mineral databases using ExperthighScore software.

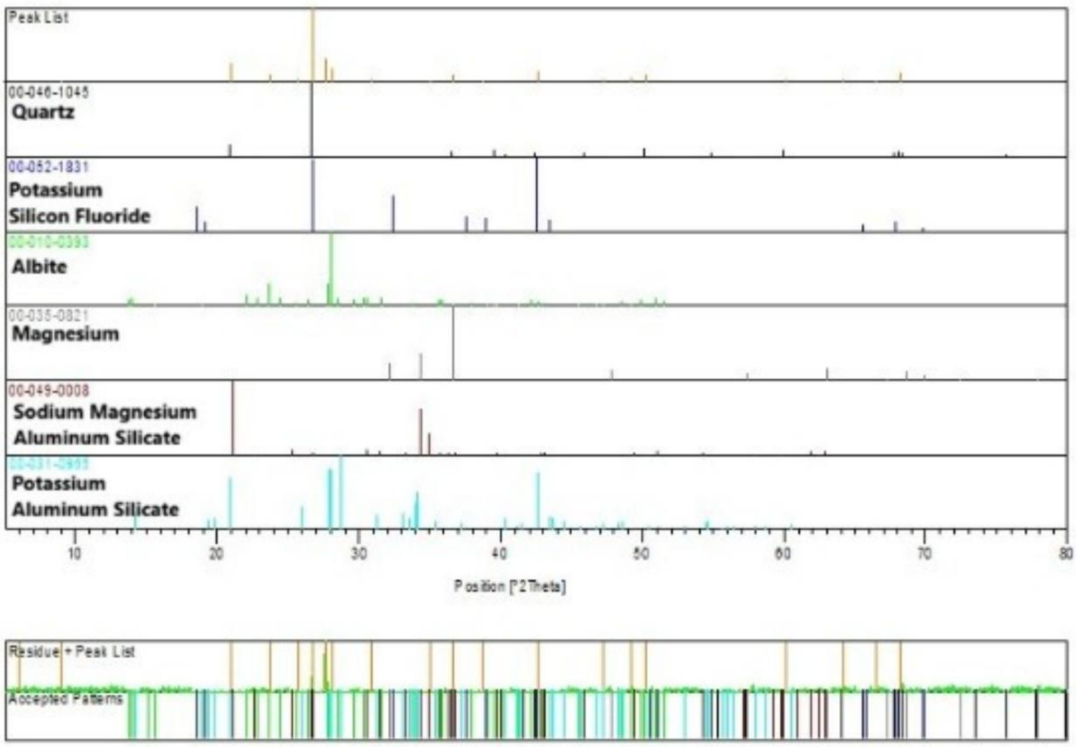
3 Result and Discussion

3.1 Analysis results of samples from Dembek Village: DMB-L1, DMB-L2, DMB-L3

Fig. 2 shows the diffractogram of a sample originating from the Dembek village/DMB-L1. L1 code indicates a sample taken from a deeper layer. Fig.2.a shows the residue pattern and the list of peaks as well as the accepted pattern. Fig.2.b shows the residue pattern and the list of reference peak images refers to JCPDS.



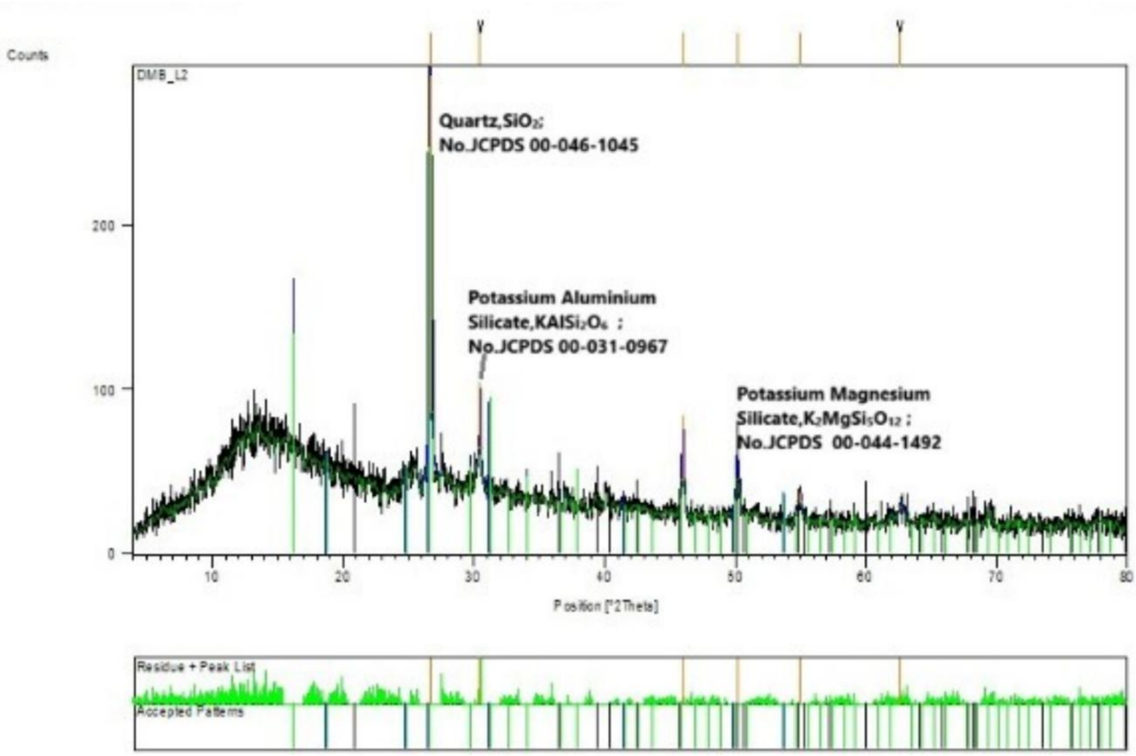
(a) The residue pattern and list of peaks, as well as the accepted pattern of DMB-L1.



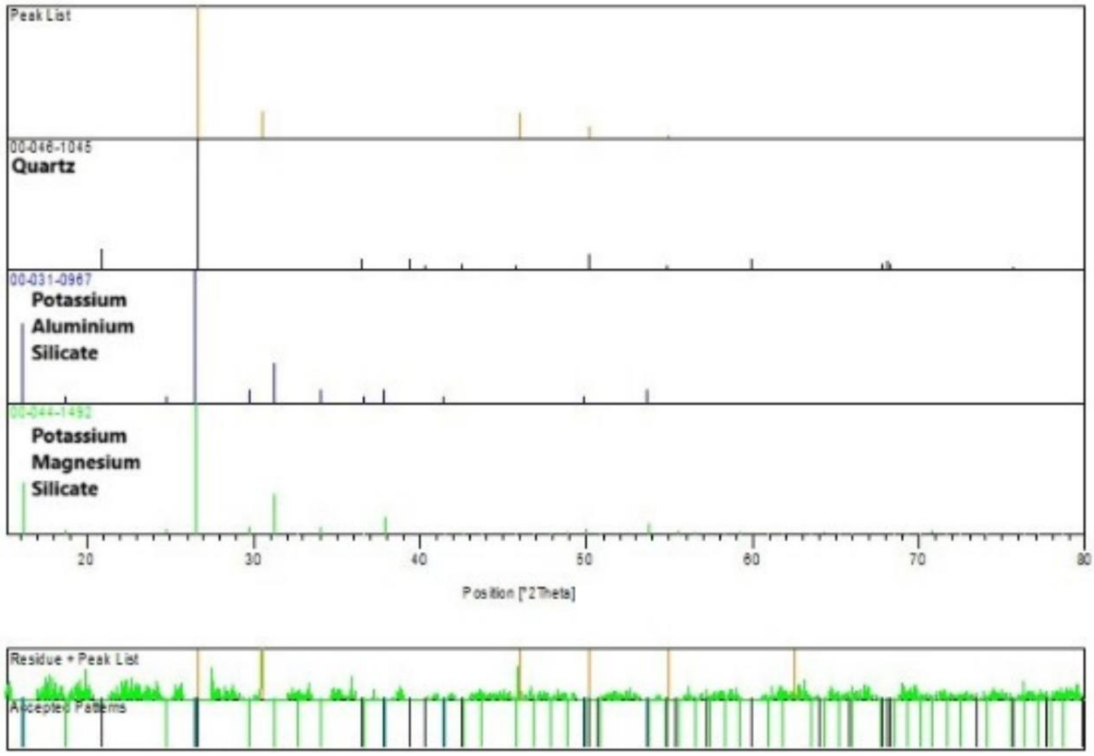
(b) The residue pattern of DMB-L1 and the list of reference peak images are shown in the JCPDS database..

Fig. 2. The diffractogram of a sample originating from Dembek village/DMB-L1.

Fig. 3 shows the diffractogram of a sample originating from the Dembek village/DMB-L2. The L2 code indicates a sample taken from upper layer 1. Fig.3.a presents the residue pattern and list of peaks, as well as the accepted pattern, and Fig.3.b shows the residue pattern and the list of reference peak images refers to JCPDS.



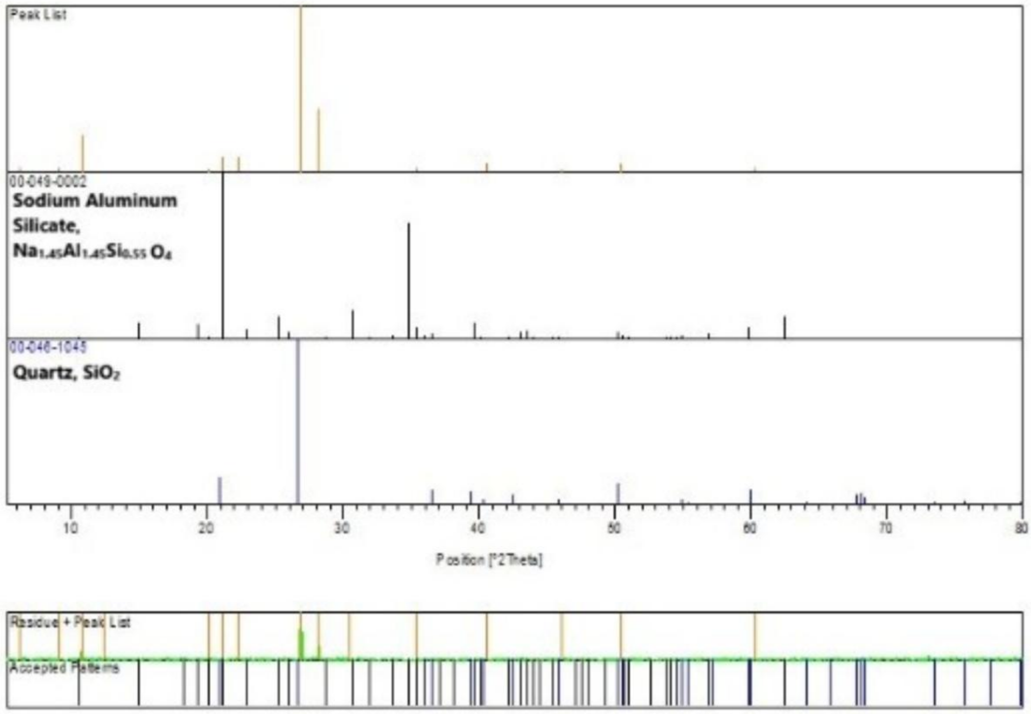
(a) The residue pattern and the list of peaks, as well as the accepted pattern of DMB-L2.



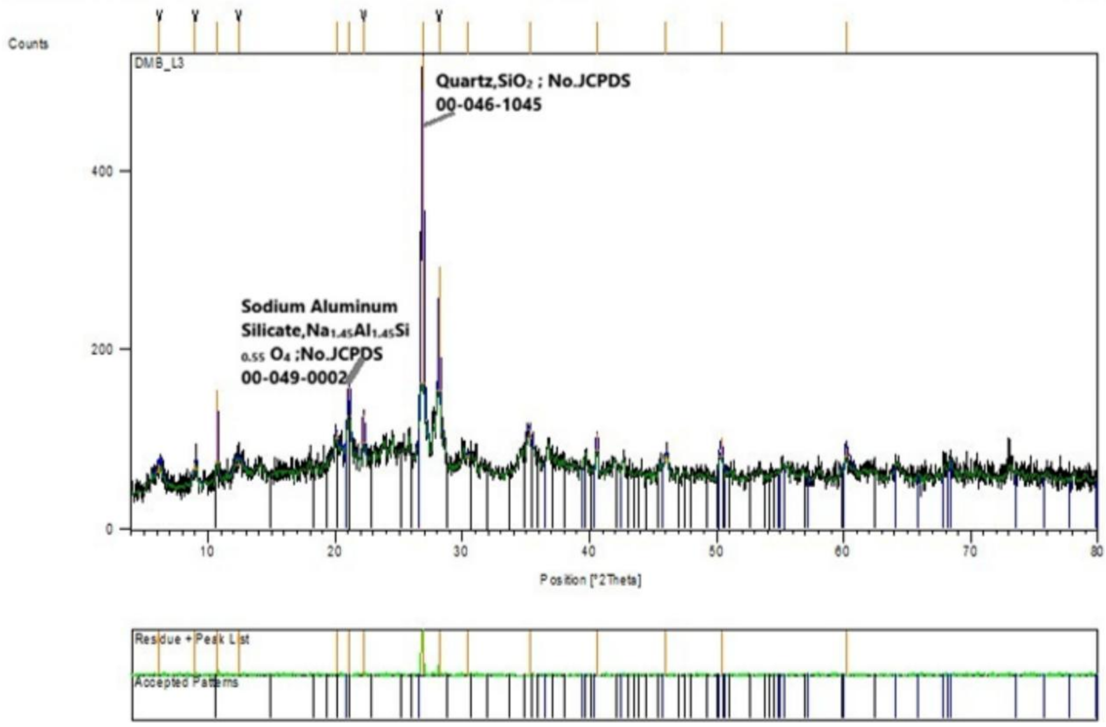
(b) The residue pattern of DMB-L2 and the list of reference peak images are provided in JCPDS.

Fig. 3. The diffractogram of a sample originating from Dembek village/DMB-L2.

Fig. 4 shows the diffractogram of a sample originating from the Dembek village/DMB-L3. The L3 code indicates a sample taken from upper layer 2. Fig.4.a presents the residue pattern and list of peaks, as well as the accepted pattern, and Fig.5.b shows the residue pattern, and the list of reference peak images refers to JCPDS.



(a) The residue pattern and list of peaks, as well as the accepted pattern of DMB-L3.



(b) The residue pattern of DMB-L3 and the list of reference peak images are provided in JCPDS.

Fig. 4. The diffractogram of a sample originating from Dembek village/DMB-L3.

3.2 Analysis results of samples from Wariab Village: WRB-L1, WRB-L2

The diffractogram of a sample from the Wariab village/WRB-L1 is shown in Fig. 5. A sample from the deeper layer is indicated by the L1 code. The residue pattern, list of peaks, and approved pattern are shown in Fig. 5.a. The residue patterns are shown in Fig. 5.b, and JCPDS is referenced in the list of reference peak pictures.

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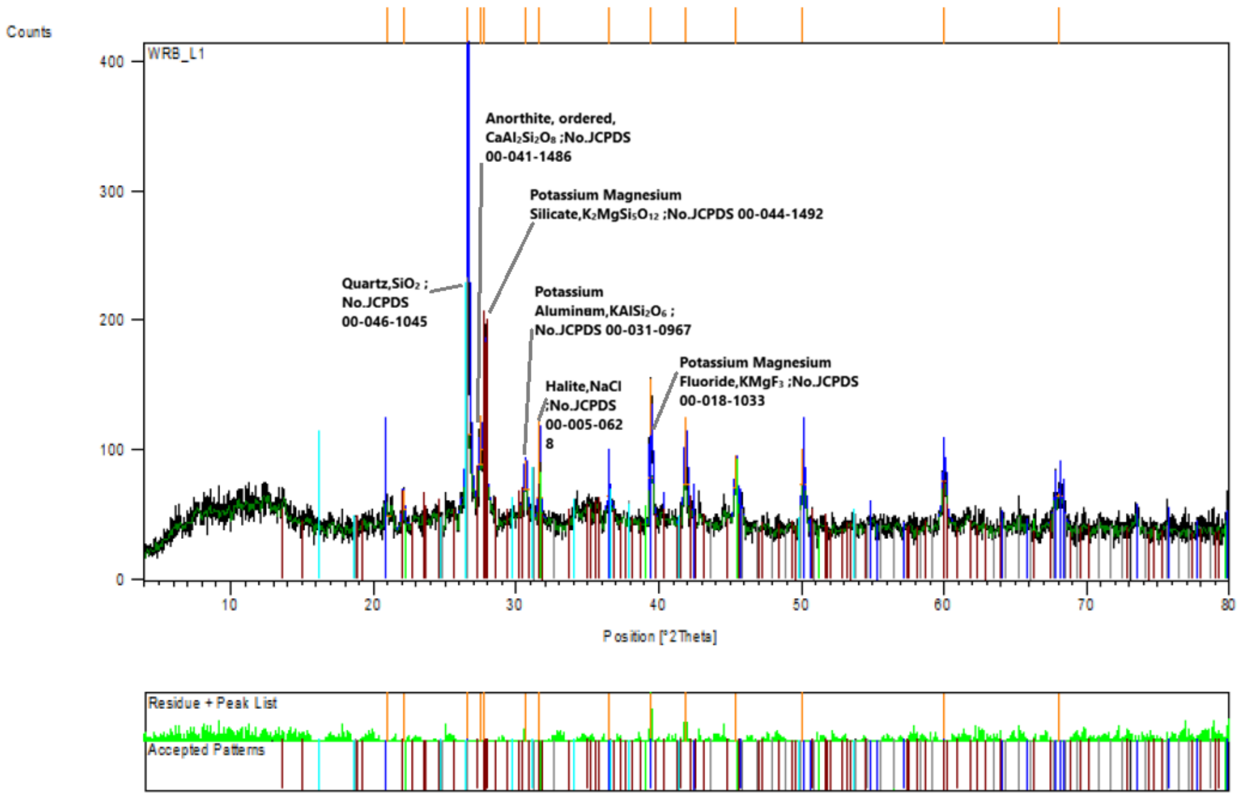
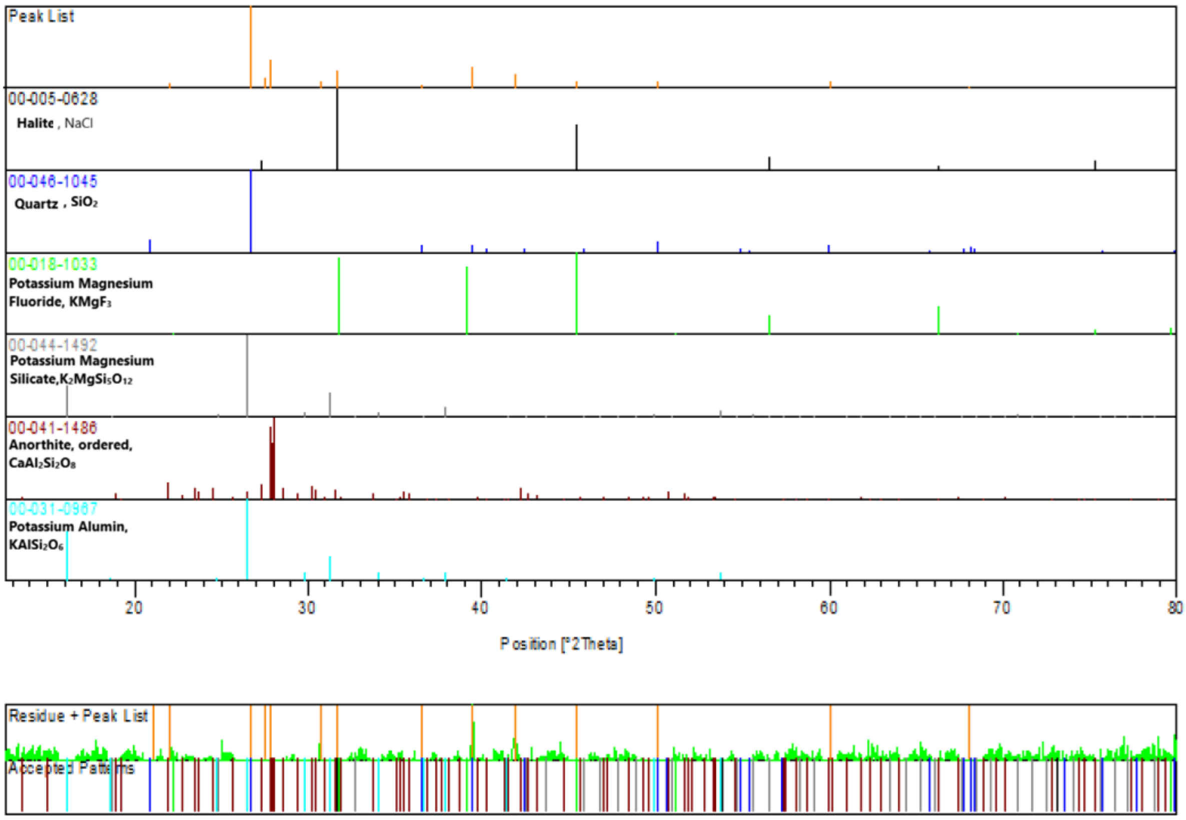


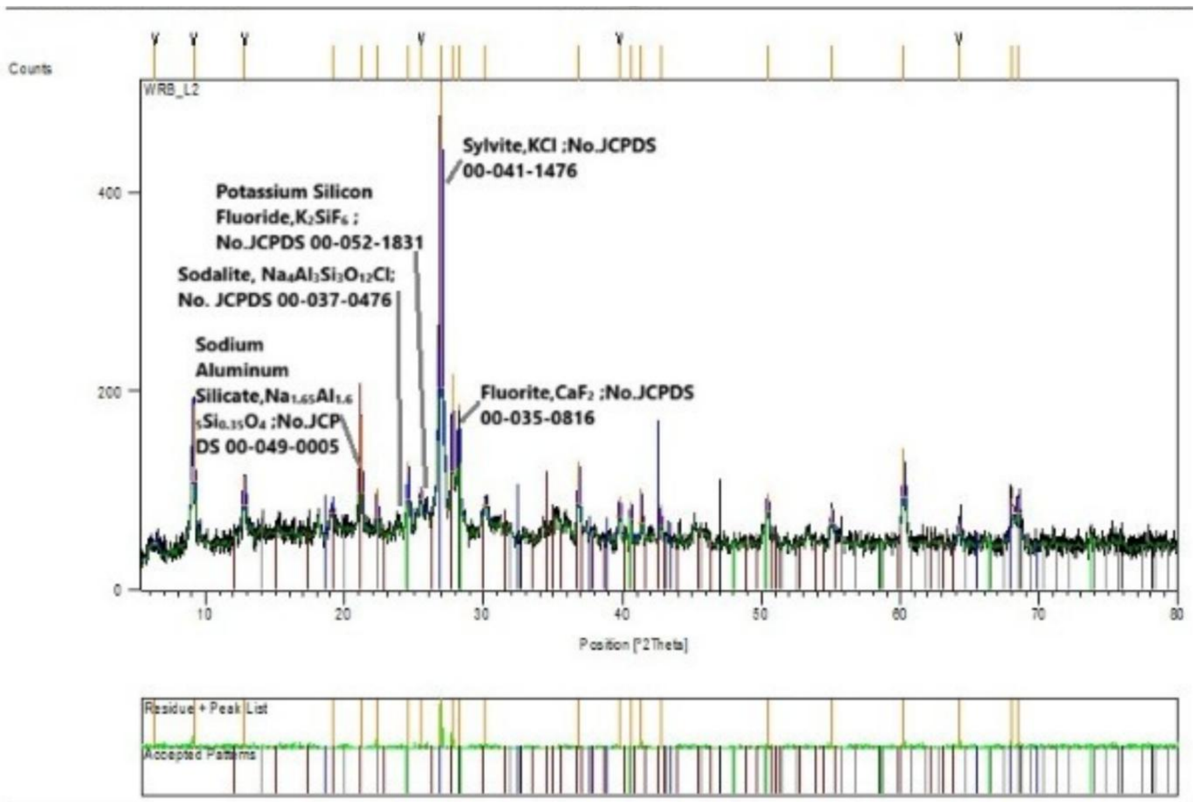
(a) The residue pattern and the list of peaks, as well as the accepted pattern of WRB-L1.



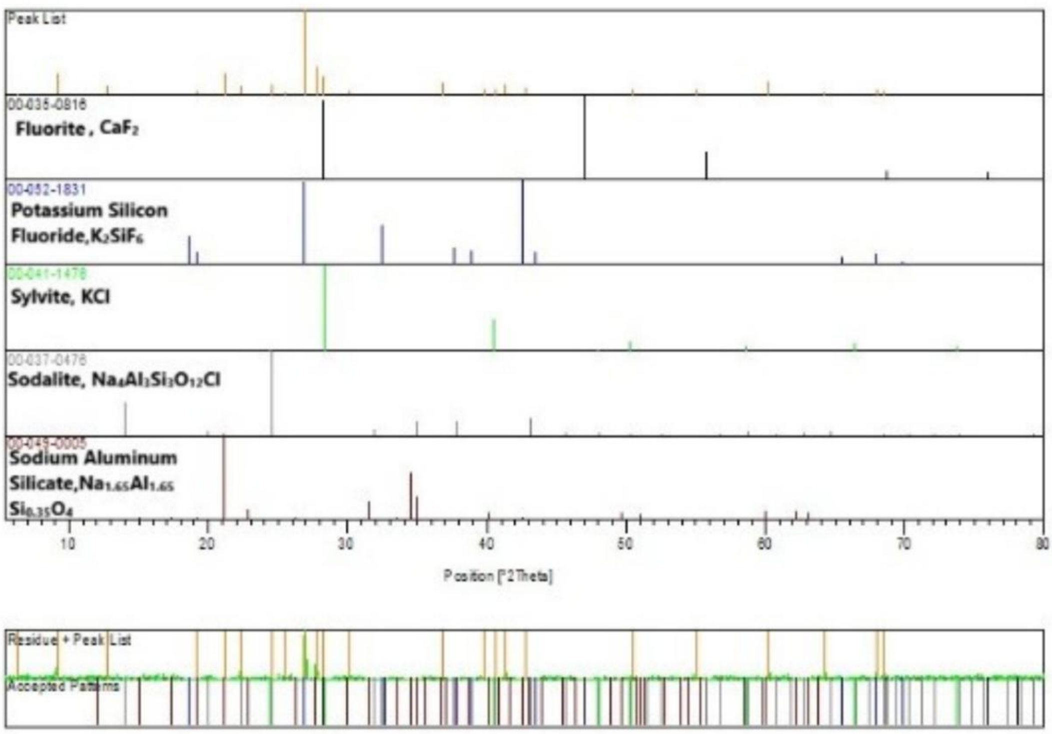
(b) The residue pattern of WRB-L1 and a list of reference peak images are shown in JCPDS.

Fig. 5. The diffractogram of a sample originating from Wariab village/WRB-L1.

Fig. 6 shows the diffractogram of a sample from the Wariab village/WRB-L2. L2 code indicates a sample from an upper layer. The residue pattern, list of peaks, and approved pattern are shown in Fig. 6.a. The residue pattern is shown in Fig. 6.b, and JCPDS is referenced in the list of reference peak pictures.



(a) The residue pattern and list of peaks, as well as the accepted pattern of WRB-L2.



(b) List of reference peak pictures and the WRB-L2 residue pattern refer to JCPDS.

Fig. 6. The diffractogram of a sample originating from Wariab village/WRB-L2

3.3 Mineral character analysis of samples from Dembek Village: DMB-L1, DMB-L2, and DMB-L3

As shown in Fig. 3 (a) and (b), the residual patterns and peak lists, as well as the accepted patterns referenced from JCPDS, indicate the mineral characteristics summarized in Table 1. The mineral features listed in Table 2 are indicated by the residual patterns and peak lists, as well as the acceptable patterns cited from JCPDS, as illustrated in Fig. 4 (a) and (b). As shown in Fig. 5 (a) and (b), the residual patterns, peak lists, and acceptable patterns quoted from JCPDS indicate the mineral properties listed in Table 3.

Table 1. Results of mineral character analysis of a sample originating from Dembek village/DMB-L1.

Compound Name	Chemical Formula	Pos. [°2Th.]	d_{HKL}	Crystal system	No.JCPDS Card
Quartz	SiO_2	26.7176	1 0 1	Hexagonal	00-046-1045
Potassium Silicon Fluoride	K_2SiF_6	42.5523	0 2 1	Hexagonal	00-052-1831
Albite	$Na(Si_3Al)O_8$	28.0999	2 2 0	Anorthic	00-010-0393
Magnesium	Mg	36.6767	1 0 1	Hexagonal	00-035-0821
Sodium Magnesium Aluminum Silicate	$Na_3MgAlSi_2O_8$	21.0319	2 2 0	Orthorhombic	00-049-0008
Potassium Aluminum Silicate	$KAlSiO_4$	27.6724	1 3 1	Orthorhombic	00-031-0965

Table 2. Results of mineral character analysis of a sample originating from Dembek village/DMB-L2.

Compound Name	Chemical Formula	Pos. [°2Th.]	dHKL	Crystal system	No.JCPDS Card
Quartz	SiO_2	26.7176	1 0 1	Hexagonal	00-046-1045
Potassium Aluminium Silicate	$KAlSi_2O_6$	30.4950	3 3 2	Cubic	00-031-0967
Potassium Magnesium Silicate	$K_2MgSi_5O_{12}$	54.9210	8 0 0	Cubic	00-044-1492

Table 3. Results of mineral character analysis of a sample originating from Dembek village/DMB-L3.

Compound Name	Chemical Formula	Pos. [°2Th.]	dHKL	Crystal system	No.JCPDS Card
Sodium Aluminum Silicate	$Na_{1.45}Al_{1.45}Si_{0.55}O_4$	21.0936	2 2 2	Cubic	00-049-0002
Quartz	SiO_2	26.640	1 0 1	Hexagonal	00-046-1045

3.4 Mineral character analysis of samples from Wariab Village : WRB-L1 and WRB-L2

The mineral properties listed in Table 4 are indicated by the residual patterns, peak lists, and acceptable patterns referenced from JCPDS, as shown in Fig. 6 (a) and (b). As shown in Fig. 7 (a) and (b), the residual patterns and peak lists, as well as the accepted patterns referenced from JCPDS indicate the mineral characteristics summarized in Table 5.

Table 4. Mineral character analysis results from a sample from Wariab village/WRB-L1.

Compound Name	Chemical Formula	Pos. [°2Th.]	d_{HKL}	Crystal system	No.JCPDS Card
Halite	NaCl	31.6491	2 0 0	Cubic	00-005-0628
Quartz	SiO_2	26.6562	1 0 1	Hexagonal	00-046-1045
Potassium Magnesium Fluoride	$KMgF_3$	39.4429	1 1 1	Cubic	00-018-1033
Potassium Magnesium Silicate	$K_2MgSi_5O_{12}$	27.7871	4 0 0	Cubic	00-044-1492
Anorthite, ordered	$CaAl_2Si_2O_8$	27.5185	0 4 0	Anorthic	00-041-1486
Potassium Aluminum Silicate	$KAlSi_2O_6$	30.6703	4 2 0	Cubic	00-031-0967

Table 5. Results of mineral character analysis of a sample originating from Wariab village/WRB-L2.

Compound Name	Chemical Formula	Pos. [°2Th.]	d_{HKL}	Crystal system	No.JCPDS Card
Fluorite	CaF_2	28.2239	1 1 1	Cubic	00-035-0816
Potassium Silicon Fluoride	K_2SiF_6	26.9465	0 1 1	Hexagonal	00-052-1831
Sylvite	KCl	27.7522	2 0 0	Cubic	00-041-1476
Sodalite	$Na_4Al_3Si_3O_{12}Cl$	24.5728	2 1 1	Cubic	00-037-0476
Sodium Aluminum Silicate	$Na_{1.65}Al_{1.65}Si_{0.35}O_4$	21.1871	2 0 1	Tetragonal	00-049-0005

The results indicated a significant difference in mineral composition between Dembek and Wariab. In Dembek Village, the rocks are dominated by Quartz (SiO_2), Sodium Aluminum Silicate ($Na_{1.45}Al_{1.45}Si_{0.55}O_4$), Potassium Aluminum Silicate ($KAlSi_2O_6$ and $KAlSiO_4$). Additionally, Potassium Silicon Fluoride (K_2SiF_6), Albite ($Na(Si_3Al)O_8$), Magnesium (Mg), and mixed silicates such as $Na_3MgAlSi_2O_8$ and $K_2MgSi_5O_{12}$ were also found. Meanwhile, in Wariab Village, the mineral composition is more varied, at point WRB-L1, Halite (NaCl), Quartz, Potassium Magnesium Fluoride ($KMgF_3$), Anorthite ($CaAl_2Si_2O_8$), and Potassium Aluminum Silicate were found. At point WRB-L2, Fluorite (CaF_2), Potassium Silicon Fluoride, Sylvite (KCl), Sodalite ($Na_4Al_3Si_3O_{12}Cl$), and Sodium Aluminum Silicate were present. This difference reflects variations in the formation environment and geochemical processes occurring at each location.

Dembek tends to show a dominance of silicates and primary minerals, whereas Wariab exhibits a diversity of evaporite and fluoride minerals, indicating more complex weathering and deposition processes. This difference reflects variations in the formation environment and geochemical processes occurring at each location. Dembek tended to show a dominance of silicates and primary minerals, whereas Wariab exhibited a diversity of evaporite and fluoride minerals, indicating more complex weathering and deposition processes. From the results of this study, it can be concluded that mineral characterization through XRD provides a clear picture of the local geological conditions. [2] Indeed, the strength of XRD in determining unit cell parameters, crystal systems, and phase identification underpins the analyses presented here. Dembek Village shows a dominance of stable silicate minerals, whereas Wariab Village has a higher mineral complexity, reflecting different geochemical dynamics. This study not only enriches geological data in West Papua but also opens opportunities for the exploration and sustainable utilization of mineral resources.

The XRD-based mineralogical investigation of rock samples from Dembek Village and Wariab Village (South Manokwari, West Papua) underscores the value of powder X-ray diffraction in delineating local geological conditions and inferring the tectonic and depositional drivers. In our work, Dembek's assemblage is dominated by silicate-rich phases (e.g., quartz SiO_2, sodium/aluminum silicates, and potassium silicates), whereas Wariab shows a more diverse mineral suite including halite, fluorite, sylvite, sodalite, and other evaporite/fluoride-bearing phases. These observations can be interpreted in a broader geological geochemical context.

First, the prevalence of quartz and primary silicates in the Dembek samples may reflect formation in a relatively stable, crystalline bedrock environment, possibly volcanic or plutonic in origin, or metamorphosed equivalents, which is consistent with the tectonic activity in the region (plate convergence, faulting) mentioned in the introduction. Such framework rocks tend to maintain silicate mineral dominance and resist extensive chemical weathering or fluid alteration. In contrast, the Wariab samples' inclusion of halite, sylvite (KCl), and fluorides (e.g., CaF_2, K_2SiF_6, $KMgF_3$) suggests more advanced geochemical reworking, possibly involving evaporitic or hydrothermal fluids, or late-stage enrichment in a basin/evaporite setting.

Moreover, the differences in mineral assemblages between the two villages may reflect the contrasting formation and post-formation processes.

- In Dembek, the silicate-rich assemblage may indicate minimal fluid infiltration, limited evaporitic alteration, and dominant magmatic/volcanic or basement rock origins.
- In Wariab, the presence of halite, fluoride, and chloride minerals suggests emplacement or post-depositional modification in a setting where saline fluids, evaporation, and halogen-rich geochemistry played a role, perhaps associated with fault-controlled fluid flow or shallow basin evaporation influenced by the tectonically active setting of the Bird's Head region.

These differences are likely to be significant when interpreting the geophysical results (such as natural frequency mapping) and seismic hazard assessments in the region. For example, harder crystalline silicate-rich rocks (such as those at Dembek) have higher shear-wave velocities and thus higher natural frequencies, whereas rock units enriched in evaporite or altered minerals may have lower velocities, more fractures, or weaker cohesion, influencing seismic wave behavior. This is directly linked to the introduction note about low-frequency values associated with alluvial or softer sediments and high-frequency values with volcanic rocks. Your mineralogical data provided the ground truth for this interpretation. Global studies linking rock composition (SiO_2 content) with seismic wave velocity support the relationship between mineralogy and seismic behavior [10].

The marked difference in mineral assemblages between Dembek (dominated by quartz, sodium–aluminum silicates, and potassium silicates) and Wariab (including halite, fluorite, sylvite, sodalite, and other evaporitic/fluoride phases) suggests distinct genesis and geochemical regimes. In the larger context of tectonically active regions (such as the study area in West Papua), crystalline silicate dominated lithologies often reflect primary igneous or metamorphic conditions, whereas the presence of halite, sylvite, and fluoride minerals likely signals environments of evaporation, saline fluid concentration, or hydrothermal alteration. This interpretation aligns with petrographic and XRD studies showing that mixed primary silicates and secondary evaporites can capture changes in depositional or alteration regimes[4].

In addition, recognizing the diversity of minerals (especially the rare fluoride/halide phases) in Wariab may have resource exploration implications. Minerals, such as fluorite (CaF_2) and sylvite (KCl), are economically relevant, although the grain size, concentration, and deposit size must be considered. The presence of such minerals suggests that the area warrants further detailed exploration of evaporite-fluoride-rich horizons or vein systems. This aligns with your statement that the study "opens opportunities for exploration and sustainable utilization of mineral resources."

Moreover, from the perspective of structural geology and seismic hazards, the connection between rock mineralogy, shear-wave velocity, and seismic response is critical. The geophysical observation in your introduction — that alluvial sediments produce low natural frequencies while denser volcanic rocks produce higher frequencies — can further be tied to mineralogical composition: denser silicate phases (e.g., quartz and feldspars) tend to have higher moduli and velocities, whereas evaporitic or highly porous minerals (halite and sylvite) may reduce mechanical strength and increase attenuation. Recent studies emphasize that the mineralogical quantification provided by XRD (and allied methods) improves the fidelity of geophysical velocity models and hence seismic hazard characterization[6, 11, 13]. XRD application on sedimentary rocks showing mineralogical variations can support discussions of mineralogical differences between locations (dominant silicates vs. evaporites/fluorides) [12].

In summary, our study successfully demonstrates how systematic XRD mineral characterization in a tectonically complex region (the Bird's Head zone) can enrich the understanding of local geology, support seismic hazard interpretation (by linking mineralogy to rock mechanical/physical properties), and highlight mineral resource potential. Future work may build on this by integrating quantitative phase analysis (e.g., Rietveld refinement), petrographic thin-section work, geochemical assays (XRF/ICP), and perhaps linking mineralogical data directly to shear-wave velocity or seismic attenuation measurements, thereby closing the loop between geochemistry, petrology, and geophysics.

4 Conclusion

This study successfully characterized the mineral composition of local rocks from Dembek and Wariab Villages, South Manokwari Regency, West Papua, using X-ray Diffraction (XRD) analysis. The results reveal clear mineralogical distinctions between the two geological zones. Rocks from Dembek Village are dominated by silicate minerals, such as quartz (SiO_2), sodium aluminum silicate, potassium aluminum silicate, albite, and magnesium-bearing silicates, indicating a stable crystalline formation environment, possibly linked to magmatic or volcanic origins with limited chemical alteration. In contrast, rocks from Wariab Village exhibit a more diverse mineral assemblage**,** including halite (NaCl), fluorite (CaF_2), sylvite (KCl), sodalite ($Na_4Al_3Si_3O_{12}Cl$), and potassium or sodium aluminum silicates. This composition reflects influences of evaporitic, hydrothermal, or saline fluid activity, suggesting a more complex geochemical evolution and depositional history.

These mineralogical contrasts imply different geological processes and tectonic settings between the two sites. Dembek's silicate-rich composition suggests high structural integrity and strong resistance to seismic stress, whereas Wariab's evaporite- and fluoride-bearing minerals may indicate weaker rock cohesion and enhanced susceptibility to deformation. Such findings are significant for correlating mineral composition with geophysical parameters, such as shear-wave velocity and natural frequency, providing valuable input for seismic hazard assessment in the South Manokwari region.

Overall, XRD-based mineral characterization provides essential insight into the geochemical, petrological, and tectonic framework of West Papua. The identification of economically valuable minerals such as fluorite and sylvite also opens opportunities for further exploration and sustainable resource utilization. Future research integrating the XRD results with petrographic, XRF, and seismic velocity data is recommended to strengthen the link between mineralogy, rock mechanics, and seismic response in this tectonically active region.

Authors contributions statement: DS: Conceptualization, investigation, data processing, and manuscript writing; RL: investigation, data collection, and original draft writing; JVM: data analysis, manuscript writing, and editing; LASL: manuscript writing, and editing; RT: manuscript writing, and editing.

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