Interpretation of Satellite Remote Sensing Data for Potential Gold Mineralisation Zones Over Danko Area and Environs, North -West Nigeria.

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Abstract- The Donko area, located in the Zuru Schist belt of northwestern Nigeria, is known to have significant gold mineralization potential resulting from the activities of artisanal miners (wild mining) in the area, which is characterized by a number of environmental impacts. There is a lack of detailed understanding of mineralization and its distribution in the area. This research aimed at using Landsat 9 OLI remote sensing data to identify and characterize gold mineralization zones in the Donko area and beyond. Regions of hydrothermal alteration were evaluated from band ratios 4/2, (iron oxide), 6/5 (ferrous) and 6/7 (hydroxyl) minerals respectively. Combination of these ratio results obtained from the three methods stated above was used to build a Sabin ratio map where 4/2 is red, 6/7 is green and 6/5 is blue The analysis and interpretation of the Sabin ratio image revealed that schist units are represented by yellow pixels, gneiss units display blue and green hues, and quartzite appears as purple pixels. Altered regions are shown as bright pixels. The lineaments trend predominantly in NE-SW and NW-SE directions, with a secondary set trending NW-SE; few lineaments follow N-S and E-W orientations. These lineaments, associated with tectonic activity, could potentially indicate zones of gold mineralization. The results indicate that the northeastern mining area and central regions have a high density of lineaments, whereas the southern area exhibits a lower density of lineaments. The high prospect areas for gold mineralization potentials are geographically located in the north-east, mining area, central parts of the study area.

Index Terms- Remote sensing, gold mineralization, hydrothermal alteration

I. INTRODUCTION

Nigeria is a country with abundant mineral resources, including gold. The northwest region of Nigeria is known to have significant gold deposits and various small mining activities take place in the area. However, the Donko area remains underexplored, and additional investigations are necessary to identify potential large gold deposits. Remote sensing is a crucial tool in mineral prospecting, with one of its established applications being the detection and mapping of alteration zones linked to gold deposits, as noted by [1]. Since the launch of Landsat in 1972, satellite remote sensing images have been extensively and effectively employed in mineral exploration efforts. Over the past three decades, gold has become one of the key mineral resources targeted through satellite remote sensing imagery. While gold itself cannot be directly detected by remote sensors, the associated minerals that often occur with gold can be identified by their spectral signatures. The Donko area, located in the Zuru Schist belt of northwestern Nigeria, is known to have significant gold mineralization potential resulting from the activities of artisanal miners (wild mining) in the area, There are adjacent areas explored by some authors (e.g. [2], [3], [4], [5]). They suggested that the area is highly mineralized and the mineralization is structurally controlled, occurring within veins of sheared zones and along river channels. The area and its environs is yet to be fully explored in terms of gold mineralization using scientific approaches, there is a lack of detailed understanding of gold mineralization and its distribution in the region. This call for this research aimed at addressing this knowledge gap by using satellite remotely sensing method. The study aims to combine satellite remote sensing data from Landsat 9 OLI with geological information of the region to assess the gold mineralization potential zones in Donko and its surroundings. This is achieved by mapping lithological units and hydrothermal alteration zones that may indicate gold mineralization, utilizing techniques such as False Colour Composite, Band Ratios, and Crosta-Selective Principal Component Analysis.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is bounded by latitudes 11^0 00'N to 12^0 00'N and longitude 05^0 00' E to 06^0 00'E, it covers the area of about 12100 square kilometers, as shown in Figure 1.0. The study area is located in the Zuru schist belt in northwestern Nigeria. It is part of the northern Nigerian basement complex that was affected by the Pan-African orogeny. There is a mining area located in Donko village, about 21.33 km from Donko town (Plate. 1). There is a crusher near the site where post-small-scale mining crushing activities take place (Plate.2). The major towns in the study area include: Zuru, Ribah, Donko, Maga, Dabai, Isgogo, Wasagu, and Kele as in (Figure1).

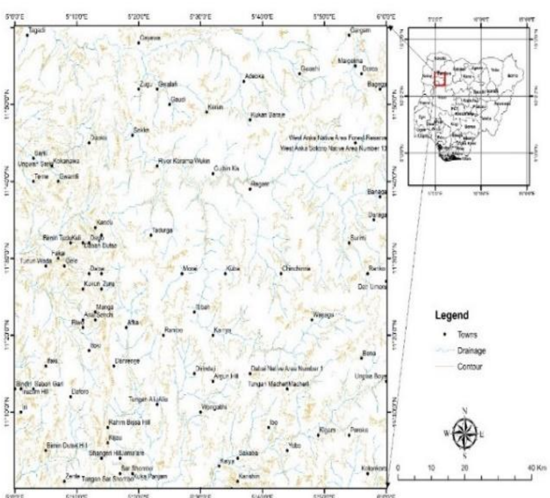

Figure 1 Map of Nigeria showing location of the study (Adopted from [6])

Plate 1 Mining site

Plate 2 crusher

The geological map of the study area is bounded by the longitudes 05^0 00'E to 06^0 00'E and the latitudes 11^0 00'N to 12^0 00'N, as shown in Figure 2 The rock types in this region include medium-grained granite, quartzite, quartz-mica-schist, schist-phyllite and psammitic schist, undifferentiated schist, granite-gneiss, migmatite and migmatite-gneiss. The overall geology of the area can be broadly categorized into the basement complex and sedimentary rocks. The bedrock complex comprises rocks of Precambrian age, as described by [7], and includes a migmatite-gneiss complex, older granite, and schist. The basement complex also includes quartzites and medium-grained granites, along with smaller rock formations such as quartz veins and pegmatites. The schist rocks are heavily foliated, exhibiting minor folds and lineations. These formations primarily occupy the northwest and southwest regions of the area Due to their fragile nature, differential erosion has primarily exposed these rocks along river valleys. They generally grade into quartzites, which appear as hills and ridges that trend northeast to southwest. In the area, there are two types of quartzite: a gray variety containing a significant amount of mica, and a brownish-white variety that is either poor in mica or devoid of mica minerals. The granites occur as intrusions dome-shaped, whale-jaw-like structures—penetrating the metasedimentary rocks and are associated with several pegmatites, aplites, and veins [8].

The Zuru schist belt is believed to be the largest and least explored schist belt in northwestern Nigeria [9]. The sedimentary rocks within this region belong to the Sokoto/Iullemenden Basin and the Taloka Formation, comprising sandstone, siltstone, and mudstone (see Figure 2). This basin is thought to have formed through tectonic epirogenic movement or stretching and rifting of the tectonically stable crust during the Paleozoic era [10].

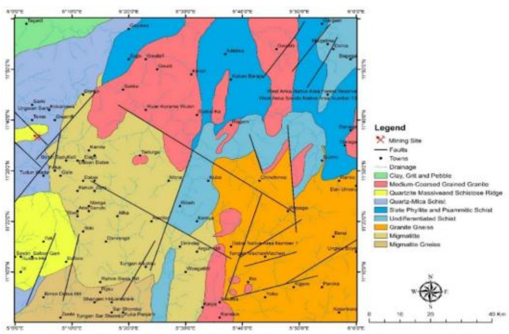

Figure 2 Geological map of the study area showing Donko area (adopted from [11])

III. MATERIALS AND METHODS

Landsat 9 (OLI) imageries covering the study area downloaded from USGS website (www.usgs.gov).
In this research, cloud-free Level 2 Terrain Corrected (L2T) Landsat 9 Operational Land Imager (OLI) data covering the Donko area (path/row 190/052) was obtained from the USGS Earth Explorer platform (https://earthexplorer.usgs.gov) on February 17th, 2024. The data was specifically selected to support mapping of rock units and to identify hydrothermal alteration zones associated with gold mineralization potential. The imagery is georeferenced to the Universal Transverse Mercator (UTM) Zone 31N coordinate system using the WGS-84 datum.

Processing of the Landsat 9 data was carried out using ENVI 5.3 software, where the imagery was enhanced through layer stacking and sub-setting techniques to improve visual interpretation and analysis. The Landsat 9 OLI dataset consists of nine spectral bands (bands 1-9) and two thermal infrared (TIR) bands (bands 10–11), as summarized in Table1

Table 1 Landsat 9 OLI/TIRS data spectral characteristics Landsat 9 OLI/TIRS data spectral characteristics(https://www.usgs.gov/landsat-mission)

Satellite	Sensor	Band (Wavelength/µm)	Spectral region	Spectral resolution (m)	Covering size (km)
Landsat 9	OLI/ TIRS	1 (0.43 0.45)	Coastal aerosol	30M	185km
		2 (0.45 - 0.51)	Blue		
		3 (0.53 - 0.59)	Green		
		4 (0.64 - 0.67)	Red		
		5 (0.85 - 0.88)	Near IR (NIR)		
		6 (1.57 - 1.65)	SWIR		
		7 (2.11 - 2.29)	SWIR		
		8 (0.50 - 0.68)	Panchromatic	15m	
		9 (1.36 - 1.38)	Cirus	30m	
		10 (10.60 - 11.19)	Thermal infrared (TIRS) 1	100m	
		11 (11.50 - 12.51)	Thermal infrared (TIRS) 2		

IV. METHODOLOGY

The different rock units, alteration minerals, and structural features within the research area were identified and distinguished using several remote sensing techniques. These included false color composite (FCC) images, band ratio (BR) analyses, and selective (Crosta) principal component analysis (PCA). These methods enhance specific spectral features and structural details, facilitating detailed geological and mineralogical mapping of the area.

V. FALSE COLOUR COMBINATION (FCC) AND BAND RATIONING (BR)

False Color Composite (FCC), commonly known as the Red-Green-Blue (RGB) composite technique, is a valuable method for enhancing subsurface features and facilitating visual interpretation of multispectral satellite images [12]. In this study, a composite was created by combining bands 7, 4, and 3 (assigned to RGB) to produce an FCC image. This combination effectively highlights and discriminates the main lithological units within the study area, allowing for better visualization and geological interpretation of the surface features.

Band ratio is a crucial image enhancement technique used to improve the visibility of surface details and features in multispectral images. By dividing one spectral band by another, this method helps to suppress the effects of illumination variations and topographic influences, thereby creating more distinct spectral signatures [13]. Additionally, band ratios emphasize specific characteristics or features that may not be readily apparent in the original raw bands, making them valuable for mineral and lithological discrimination [14].

VI. PRINCIPAL COMPONENT ANALYSIS (CROSTA-PCA METHOD)

The Crosta-PCA (Principal Component Analysis) method, as described by [15], was selectively applied to two sets of Landsat 9 OLI data to enhance specific mineral features. The first set included bands 2, 4, 5, and 6, which were used to highlight and target iron-oxide minerals, while the second set comprised bands 2, 5, 6, and 7 to emphasize hydroxyl-bearing minerals. The PCA processing generated four principal component (PC) bands—PC1, PC2, PC3, and PC4. For each dataset, PC4 and PC2 were specifically utilized to enhance and delineate alteration minerals associated with iron oxides and hydroxyl minerals, respectively, facilitating targeted mineral exploration within the study area.

VII. RESULTS AND DISCUSSION

Lithologicalmapping

Lithological discrimination mapping, frequently uses remote sensing coupled with geographic information system (GIS) [16]

FalseColourCombination(FCC)

VNIR-SWIR bands of Landsat 9 OLI data were used to generate a unique FCC image. Bands In the study, Landsat 9 bands 7 (2.11–2.29 µm), 4 (0.64–0.67 µm), and 3 (0.53–0.59 µm) were assigned to the red, green, and blue channels respectively to create a false-color composite (FCC) image. This FCC (7, 4, and 3) image, shown in Fig. 3, effectively discriminates various geological features and rock units within the research area.

The spectral properties of different metamorphic rocks such as schists, gneisses, and quartzite can be identified based on their color representations. In the FCC image, schist units appear as dark brown to brown and purple hues, gneiss displays a range of cyan, green, and red tones, and quartzite appears as bright-colored pixels. Water bodies are represented as black pixels. This visualization aids in differentiating geological contacts and understanding the spatial distribution of rock types across the study region.

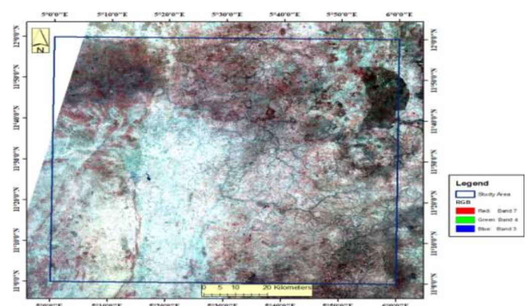

Figure 3 False colour combination image of Landsat 9 OLI (743) discriminating several rock units in Donko area.

Band ratios (BR)

Figure 4 presents a false-color RGB composite image based on specific band ratios, known as Sabin's ratios, using bands 4/2, 6/7, and 6/5. These ratios are employed to highlight the relative spatial distribution of different alteration mineral zones within the study area. In this image:

- Iron-oxide mineral zones are represented in pink,
- Clay-hydroxyl mineral zones appear in green,
- Ferrous mineral areas are shown in blue.

The distribution indicates that iron-oxide minerals are predominantly widespread in the central and northern parts of the region, mainly underlain by migmatite and schist. Clays and hydroxyl-bearing minerals are mainly identified in the northeast, northwest, and southeast, underlying schist, granite, and quartzite formations. The areas where red (iron-oxide) and green (clays and hydroxyl) minerals overlap often produce a yellowish tone, which commonly encloses linear features of probable tectonic origin. These features suggest zones of hydrothermal alteration and potential mineralization, highlighting the zonation pattern associated with tectonic and hydrothermal processes.

The band ratio composites (BRs) using ratios 4/2, 6/7, and 6/5 were generated and assigned to the RGB channels to discriminate rock units and potential alteration zones in the study area, as illustrated in Fig. 3. This composite effectively highlights the main geological features: schist units are depicted as yellow pixels, gneiss units appear in blue and green tones, quartzite is shown as purple pixels, and altered areas are characterized by bright pixels. The spectral properties of alteration minerals underpin these classifications, enabling detailed mapping of different rock types and hydrothermal alteration zones crucial for mineral exploration and geological analysis.

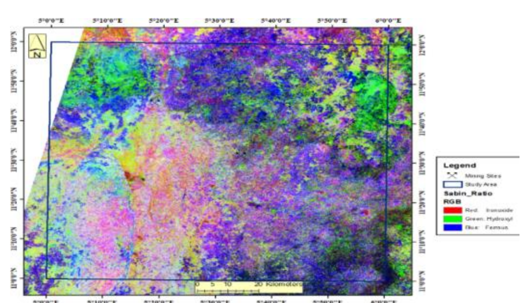

Figure. 4 Sabin ratio (4/2, 6/7, 6/5 in RGB) highlighting various rock units

Mineral mapping

Band ratio (BR) and false colour composite (FCC)

Mapping of alteration minerals associated with gold mineralization was carried out using specific band ratio composites (BRs) derived from Landsat 9 OLI data, selected based on their laboratory spectral characteristics. The Landsat 9 BR (4/2) image, shown in Fig. 5a, emphasizes iron-oxide and hydroxide minerals, which appear as red pixels, aiding their identification. The BR (6/5) image, depicted in Fig. 5b, was utilized to detect unaltered rocks and ferrous silicate minerals such as pyroxenes and olivine, which also appear as red pixels due to their spectral signatures. Furthermore, the BR (6/7) image, presented in Fig. 5c, effectively maps clay and carbonate minerals—key indicators of alteration—manifesting as red tones, particularly concentrated around the gold mineralized zones. These band ratio composites facilitate a detailed spectral-based assessment of alteration zones relevant to mineral exploration. mineral distribution related to gold mineralization in the study area.

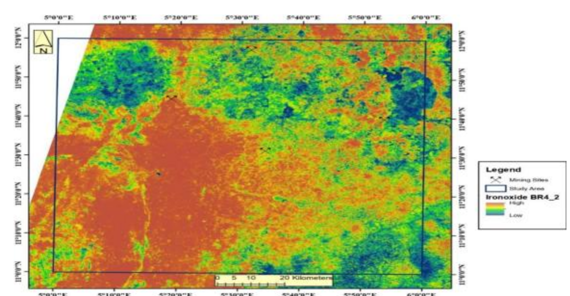

Figure 5 (a) BR 4/2 mapping iron-oxide;

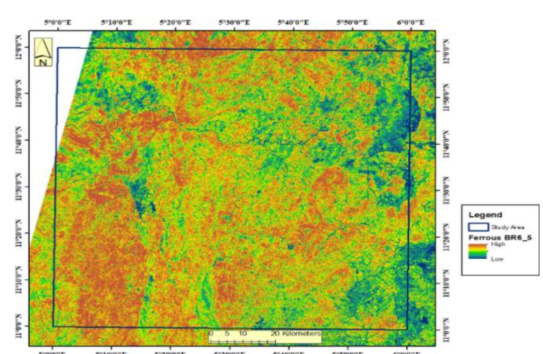

Figure 5 (b) BR 6/5 targeting unaltered rocks and silicate or ferrous minerals;

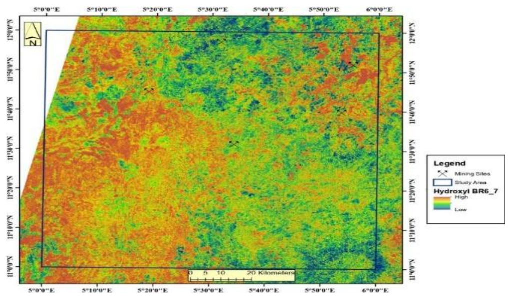

Figure 5 (c) BR 6/7 illustrating OH-bearing and carbonate minerals;

VIII. CROSTA-PCA (PRINCIPAL COMPONENT ANALYSIS)

Crosta-PCA, a selective principal component analysis technique, was applied to specific band combinations—bands 2, 4, 5, 6 for iron-oxide detection and bands 2, 5, 6, 7 for hydroxyl-bearing and carbonate minerals—due to their higher band loadings, which make them effective indicators of alteration mineral deposits and enhance the detection of hydrothermal alteration minerals. The PCA results (as shown in Tables 2 and 3) reveal that certain principal component (PC) images contain critical details that can be interpreted as representations of iron-oxides, hydroxyl/carbonate minerals, and ferrous minerals, providing valuable insights into the mineralogical alterations associated with hydrothermal activity in the area.

Table 2 presents the eigenvector loadings of principal components (PCs) 2, 4, 5, and 6 related to iron-oxide mineralization. Notably, PC2 shows positive contributions from band 6 (b6: 0.701074) and high negative contributions from band 5 (b5: −0.607634). This indicates that iron-oxide mineralization is primarily targeted in gneisses, quartzite, and some schist units, which appear as red tones in the PC2 image (Fig. 5b).

Additionally, hydroxyl-bearing and carbonate (H/C) minerals were identified through a selective Crosta PCA analysis of Landsat 9 OLI data (bands 2, 5, 6, and 7), as detailed in Table 3. These H/C minerals are targeted in PC4, which exhibits a significant negative eigenvector loading in b6 (−0.691013) and a high positive loading in b7 (0.528734).

Consequently, H/C mineral groups are visualized as green pixels on the PC4 image, owing to the negative contribution of b6, aiding in their spatial identification.From the Eigenvalues tables 2 and 3 below the percentages of the total variance by each PC for both iron-oxide and hydroxyl minerals were derived by computing the ratio of each

Eigenvector	Band2	Band4	Band5	Band6	Eigenvalues	Variance (%)	Cumulative %
PC1	-0.324229	-0.436638	-0.544333	-0.638690	223002721.555932	99.69	99.69
PC2	-0.373087	0.009050	-0.607634	0.701074	426458.955456	0.19	99.88
PC3	-0.751230	-0.308158	0.574660	0.102268	220482.179785	0.10	99.98
PC4	-0.751230	-0.845165	0.065184	0.300186	220482.179785	0.02	100.00
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Eigenvalue to the sum of all of them. The first components contain 99.69 % of the total variance: (223002721.555932/223703529.295677) x 100 foriron-oxide minerals and 99.50 % of the total variance (3.980141 /3.999999) x100 for hydroxyl minerals

Table 2 Landsat 9 OLI PCs data loadings of band 2, 4, 5 and 6 for iron oxide minerals

Eigenvector	Band2	Band5	Band6	Band7	Eigenvalues	Variance (%)	Cumulative %
PC1	0.499782	0.499852	0.500503	0.499863	3.980141	99.50	99.50
PC2	0.442326	0.531655	-	-0.641440	0.011616	0.29	99.79
PC3	0.698836	-	0.332032	0.243171	0.007137	0.18	99.97
PC4	-	0.539207	-	0.528734-	0.001105	0.03	100.00
	0.257282	0.420413	0.402184				
			-				
			0.691013				

Additionally, Fig. 6 depicts the Crosta composite, an RGB combination integrating iron-oxides (red channel), hydroxyl/carbonate minerals (green channel), and ferrous minerals (blue channel) for the study area. In this composite, hydroxyl minerals appear in yellow to orange hues, while iron-oxides are represented by bluish to cyan tones. Alteration zones are highlighted as bright areas, facilitating their spatial delineation and assessment within the region.

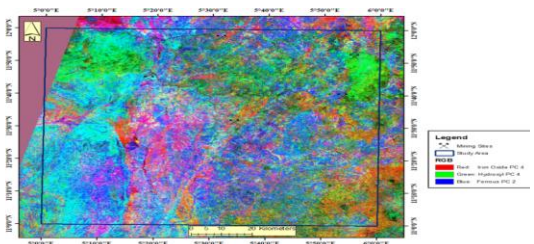

Figure 6 PCA (Crosta method) RGB combinations of iron-oxides, hydroxyl/carbonate and ferrous minerals in Donko area.

IX. LINEAMENTS EXTRACTION FROM LANDSAT IMAGERY

GIS and remote sensing techniques were utilized to analyze and interpret lineaments within the study area. Lineaments were identified through two methods: automatically, using the PC1 Geomatics line extraction tool algorithm, and manually, via visual interpretation of the pan-chromatic band (band 8) of Landsat 9 OLI data. The resulting lineaments were exported as GIS shape files and imported into ArcGIS 10.3 for further analysis, which included line density calculations and statistical evaluations. To assess the kinematic orientations of the lineaments, their directions and trends were plotted on a rose diagram using the Rockworks line tool algorithm, providing insights into their structural trends within the region.

The resulting map (Fig 7a) indicates a high density of lineaments in the northeastern, mining, and central regions, while the southern part exhibits lower lineament density. The rose diagram reveals that the predominant lineament trends are NE-SW and NW-SE, which are closely associated with tectonic activities such as fractures, faults, and shear zones in the area. Additional trends include N-S and E-W, although these are less prominent. These tectonic features could serve as potential zones for gold mineralization. The lower lineament density observed in the northwest, central, and southern parts may be due to dense vegetation cover and deep weathering processes affecting the underlying rocks.

Figure 7a. Illustrates the extracted lineaments and the corresponding rose diagram (Fig. 7b) derived from Landsat imagery of the study area.

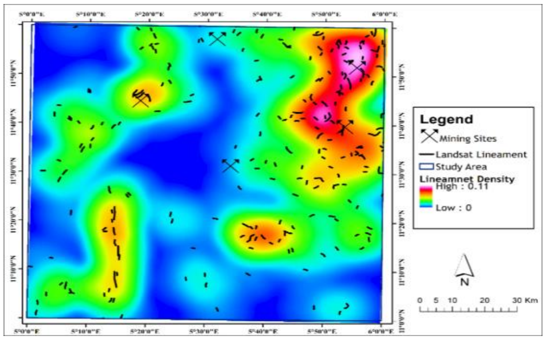

Figure 7 (a): Extracted Lineaments from the Landsat 9 OLI Imagery of the Donko area amd beyond

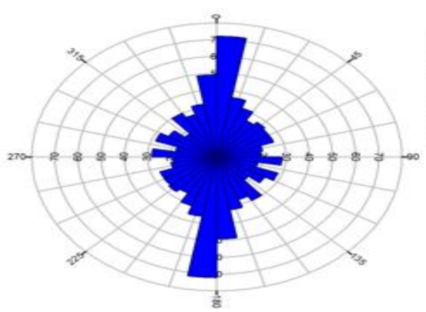

Figure 7 (b): Rose diagram of lineaments extracted from the Landsat 9 OLI Imagery of the Donko area

CONCLUSION

Landsat 9 OLI data were analyzed to investigate rock units and alteration minerals associated with gold mineralization in the study area. Techniques employed included Fast Fourier Convolution (FCC), Band Ratios (BRs), and Principal Component Analysis (PCA, Crosta method). These analyses facilitated the mapping of rock units and the identification of a comprehensive global distribution of alteration minerals, such as iron oxides, hydroxyl/carbonates, and ferrous minerals. The results revealed notable variations in the abundance and spatial distribution of these alteration minerals across different major rock formations, pointing to areas with higher potential for gold mineralization. Specifically, high-prospect zones are located in the northeast, the central part of the study area, and around the existing mining site.

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