Spectral Analysis of Alteration Zones: Worldview3 Data and Geological Interpretation

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Content

Alteration Zones: A Key in Mineral Exploration

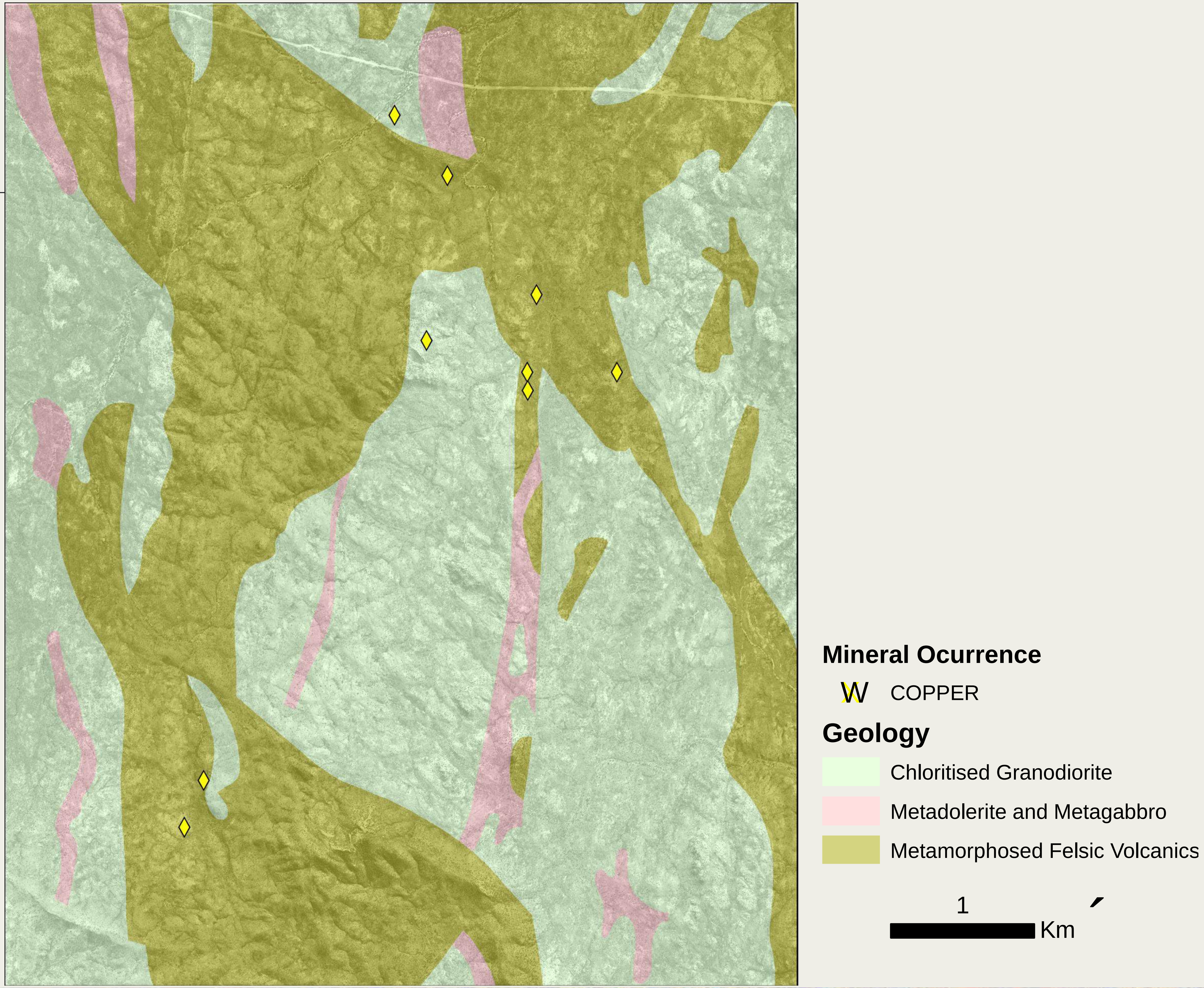
Alteration minerals exhibit unique spectral absorption features in the shortwave infrared (SWIR) range, typically between 1.2 and 2.5 micrometres. These features are linked to molecular vibrations in hydroxyl (–OH), carbonate (CO_3^{2-}), and sulphate (SO_4^{2-}) groups, which are diagnostic of specific alteration minerals such as kaolinite, muscovite, chlorite, and alunite. By capturing reflectance data across SWIR bands, multispectral and hyperspectral satellite sensors, such as WorldView-3, enable precise detection and mapping of hydrothermal alteration zones. This capability is especially valuable in mineral exploration, as it allows geologists to remotely identify potential targets associated with porphyry, epithermal, and IOCG systems before detailed fieldwork.

Common alteration minerals

- Phyllosilicates, such as clays (lepidolite, kaolinite, smectite, and illite), chlorite, and white mica, are alteration zones' most common alteration minerals.
- Sulfates, such as Alunite, Jarosite, Gypsum, and Pyrite (including ferrous iron).
- Ferric Iron oxide and hydroxyl such as Hematite and goethite.
- Carbonates, such as calcite and dolomite and Silica

Geology

- The geology of the study area includes Granodiorite, which is partially chloritized, and metamorphosed felsic volcanics, intruded by meta-dolerite and meta-gabbro.
- There are various mineralization zones, especially copper, in metamorphosed felsic rocks and granitoids.



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Remote Sensing Study

The main steps in this work

- Radiometric and Geometric corrections
- Layer Stacking VNIR and SWIR
- Build vegetation and water masks and apply it if required
- Band ratio and RGB composite
- Spectral Analysis using appropriate methods
- Interpretation of potential mineralization zones

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WorldView-3 Imagery

- WorldView-3, operated by Maxar Technologies, is a high-resolution Earth observation satellite launched in 2014. It delivers 30 cm panchromatic, 1.24 m multispectral, and 3.7 m SWIR imagery, making it ideal for applications like urban mapping, agriculture, and mineral exploration.
- A key strength of WorldView-3 is its 16-band sensor suite, including 8 VNIR and 8 SWIR bands. This enables advanced spectral analysis for geological studies, vegetation health, and land cover classification.
- **The SWIR sensor, with 8 bands from ~1195 to 2365 nm at 3.7 m resolution, is crucial for mapping alteration minerals.**

Band #	Band Name	Spectral Range	Center Wavelength (nm)	Bandwidth (nm)
1	Coastal	VNIR	427	30
2	Blue	VNIR	478	30
3	Green	VNIR	546	30
4	Yellow	VNIR	608	30
5	Red	VNIR	659	30
6	Red Edge	VNIR	724	40
7	NIR-1	VNIR	833	60
8	NIR-2	VNIR	949	100
9	SWIR-1	SWIR	1210	30
10	SWIR-2	SWIR	1250	30
11	SWIR-3	SWIR	1300	30
12	SWIR-4	SWIR	1640	60
13	SWIR-5	SWIR	1710	60
14	SWIR-6	SWIR	2100	100
15	SWIR-7	SWIR	2185	100
16	SWIR-8	SWIR	2260	100

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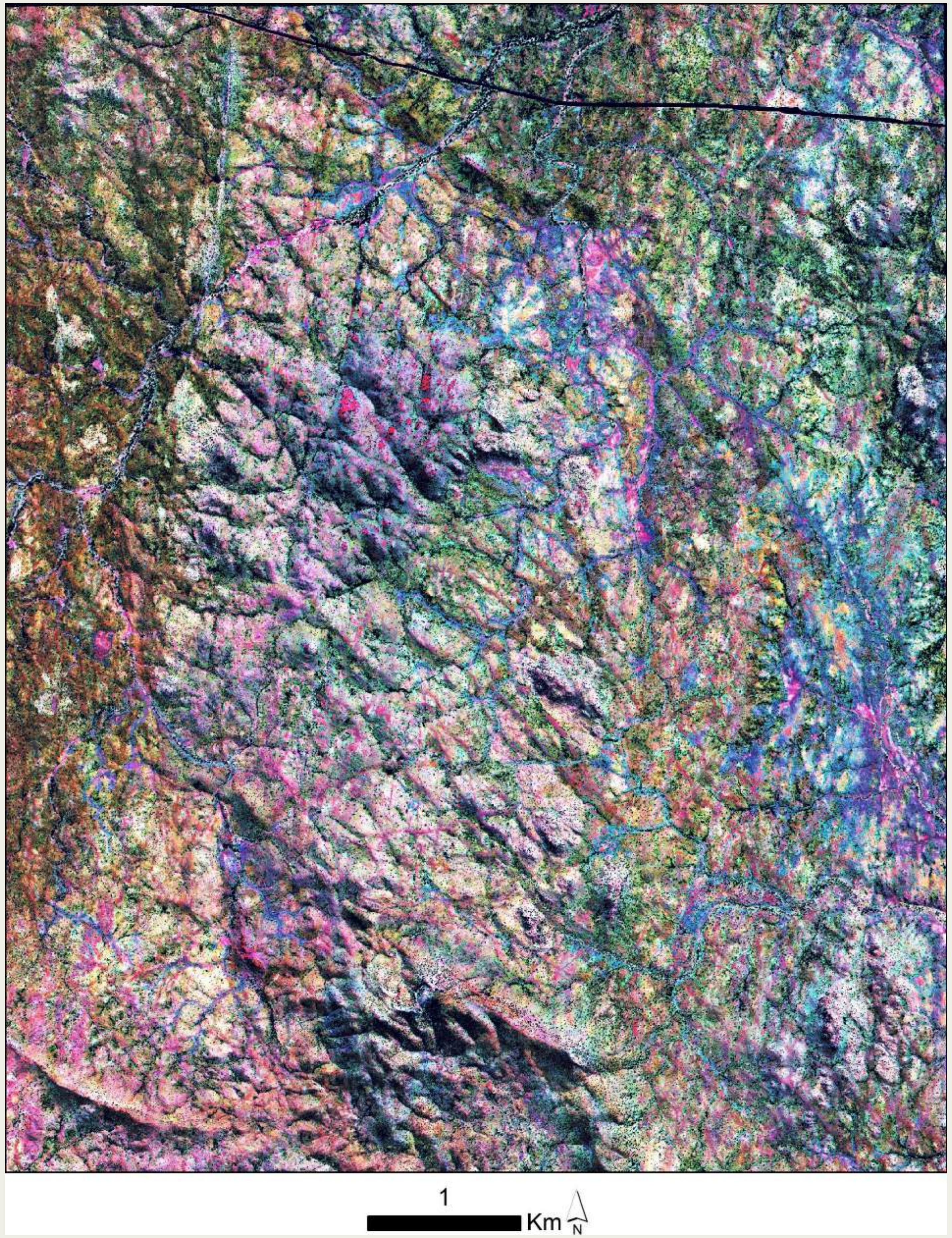
RGB Band Composite

- The **13-7-3 band composite** (SWIR-5, NIR-1, Green) in WorldView-3 is a powerful tool in geology, especially for lithological mapping, alteration detection, and mineral discrimination.
- Felsic rocks are a brighter colour than other units.
- Clay-altered rocks may appear bright red and pink, vegetation greenish, and iron-rich rocks or soils may appear bluish to purple, depending on the setting..



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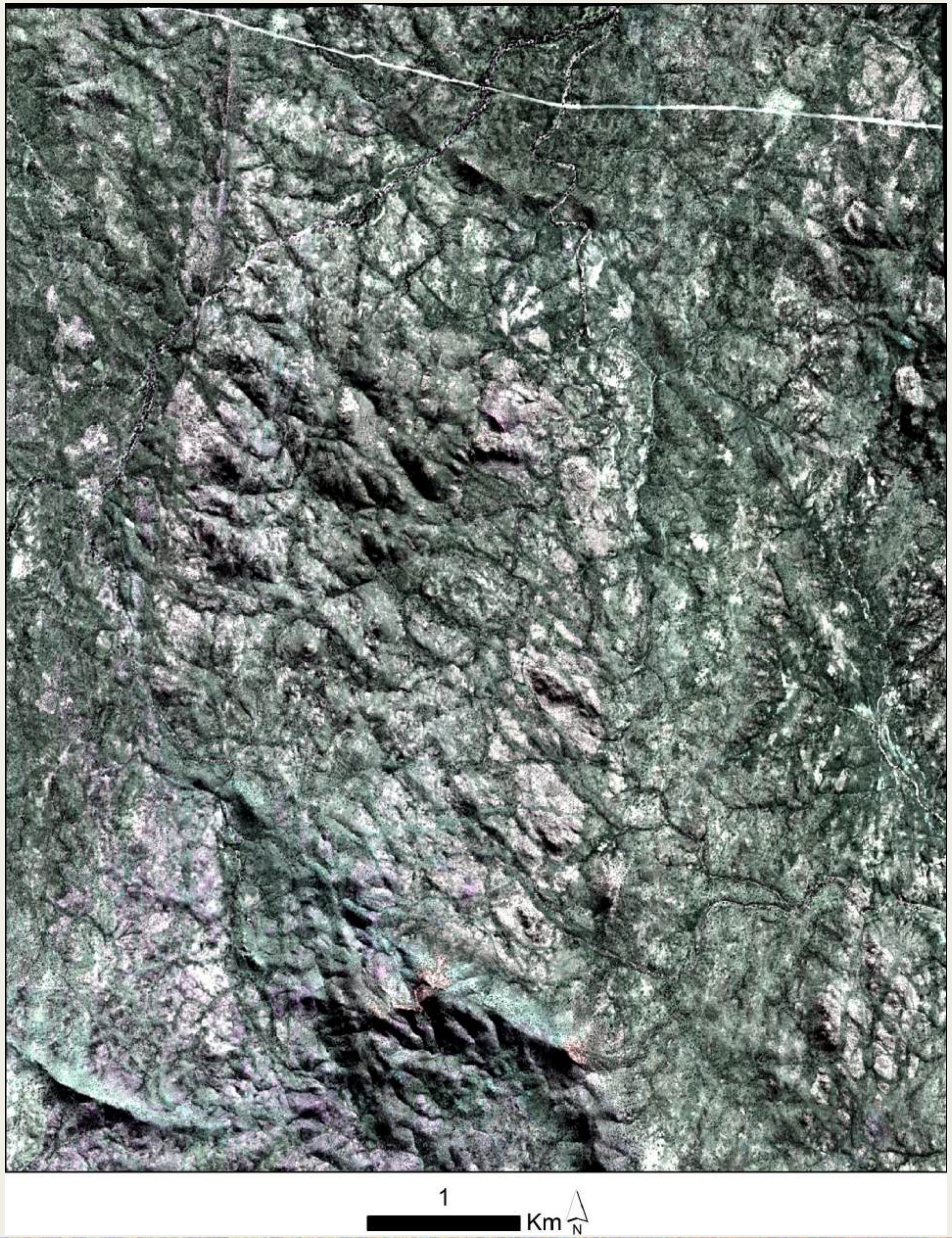
RGB Band Composite

- The **SWIR 7-6-5 band composite** focuses entirely on the shortwave infrared region, which is highly diagnostic for hydrothermal alteration minerals, including clays, and chlorite/epidote.
- Chlorite/Epidote are interpreted in greenish to grey, and clays are in pink to white.

RGB Channel	Band #	Center Wavelength (nm)	Mineralogical Sensitivity
Red	15 (SWIR-7)	~2185	Mg-OH, some carbonates, talc, serpentine
Green	14 (SWIR-6)	~2100	Fe/Mg-bearing clays (chlorite, epidote), some amphiboles
Blue	13 (SWIR-5)	~1710	Al-OH minerals (muscovite, illite, kaolinite, sericite)



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False Colour Composite

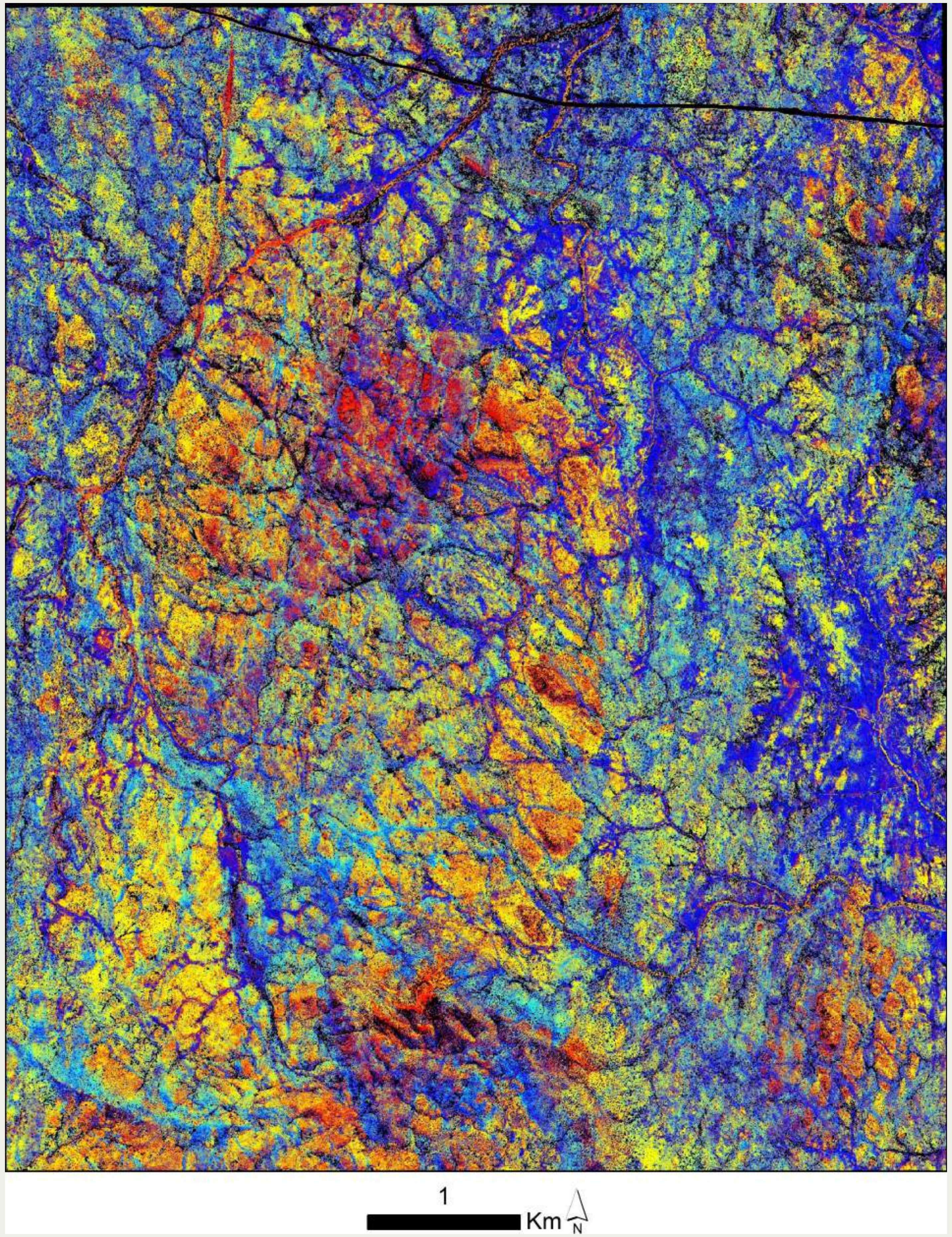
Clay-Iron Oxide-Chlorite/Epidote

- Clays are orange to red; Iron oxide is yellow to green, and chlorite/epidote are blue to purple.

Red: SWIR7/SWIR6

Green: VNIR5/VNIR2

Blue: SWIR6/SWIR7



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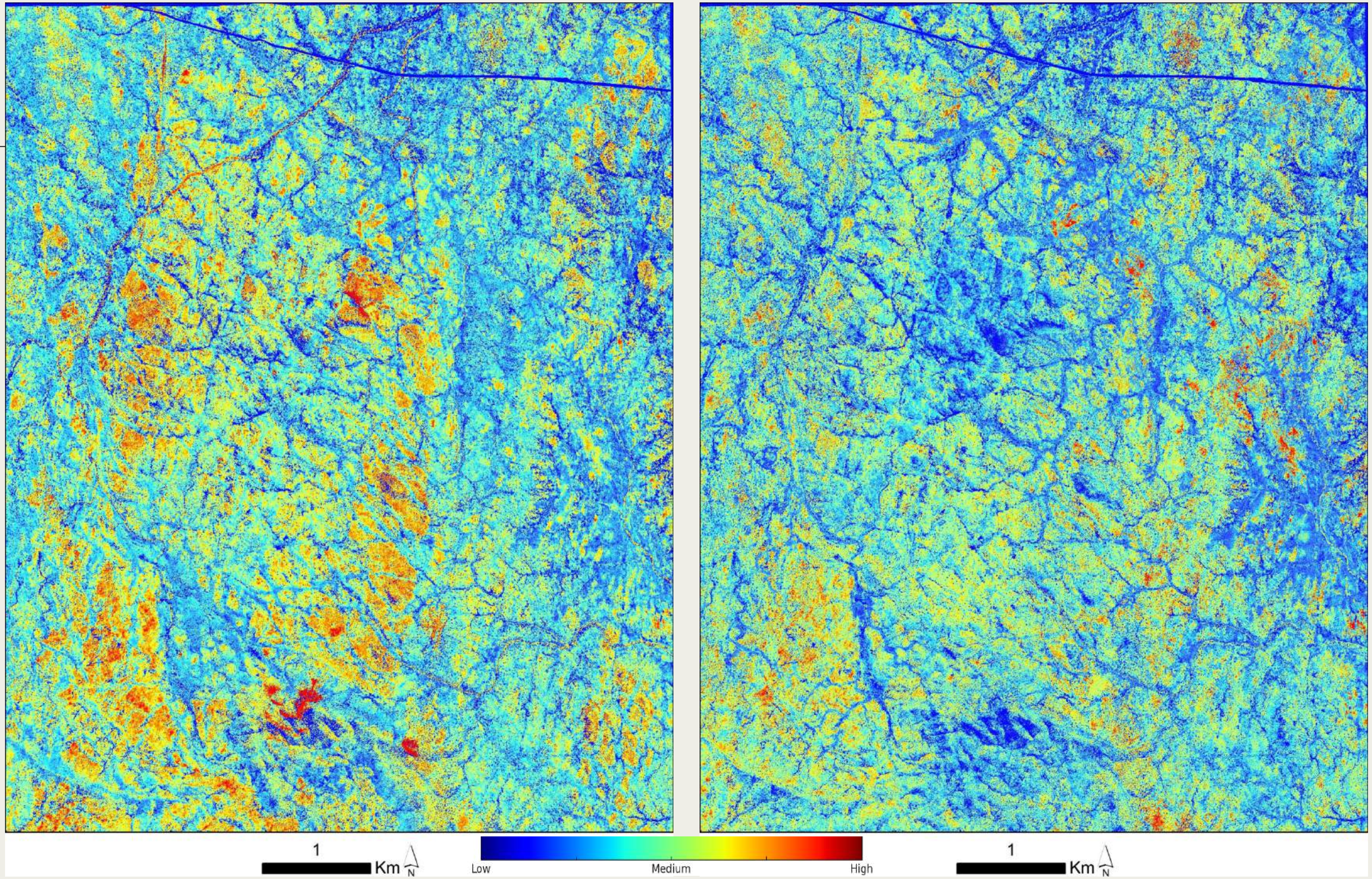
Band Ratios

Band ratios are effective tools for highlighting specific alteration minerals. In ratio images, orange to red indicates higher concentrations of the target mineral, while blueish areas represent lower abundance or absence.



Clays: SWIR7/SWIR6

Iron Oxide: VNIR5/VNIR2

Band Ratios

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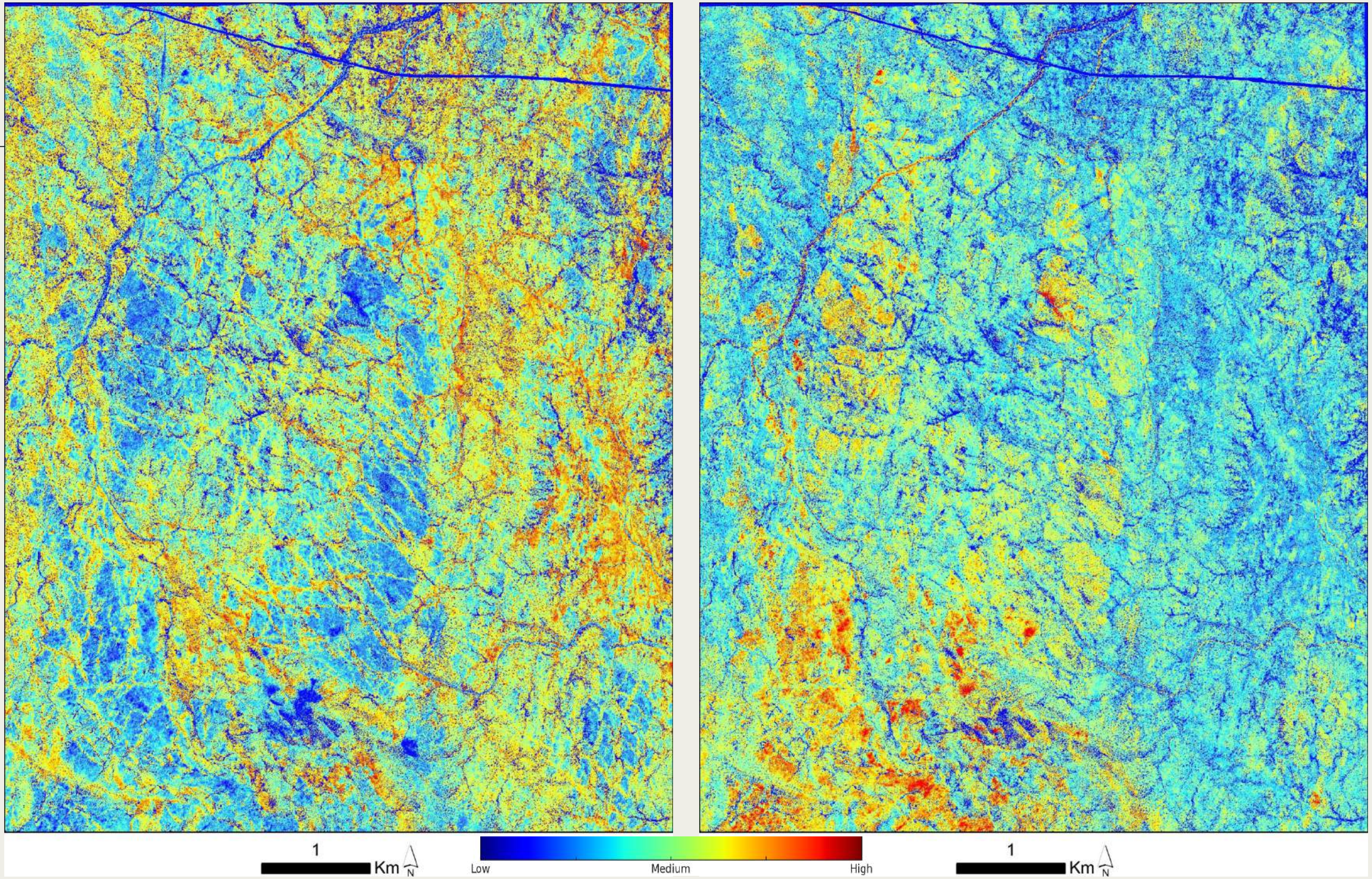

Chlorite/Epidote: SWIR6/SWIR7

White Mica: SWIR5/SWIR6

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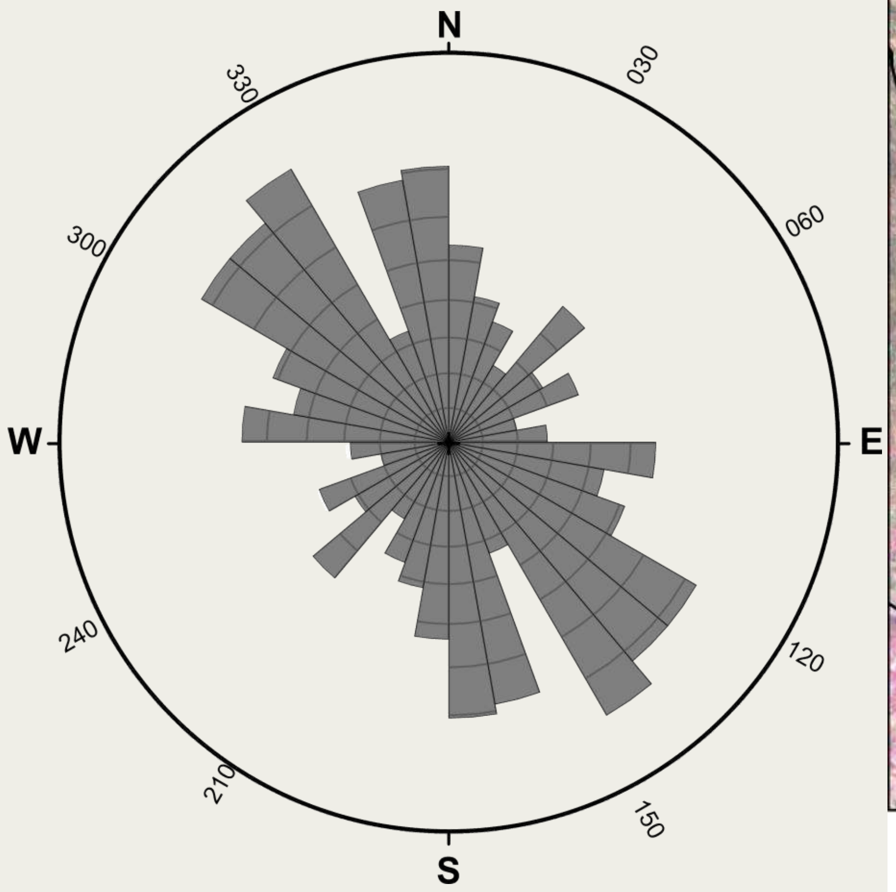
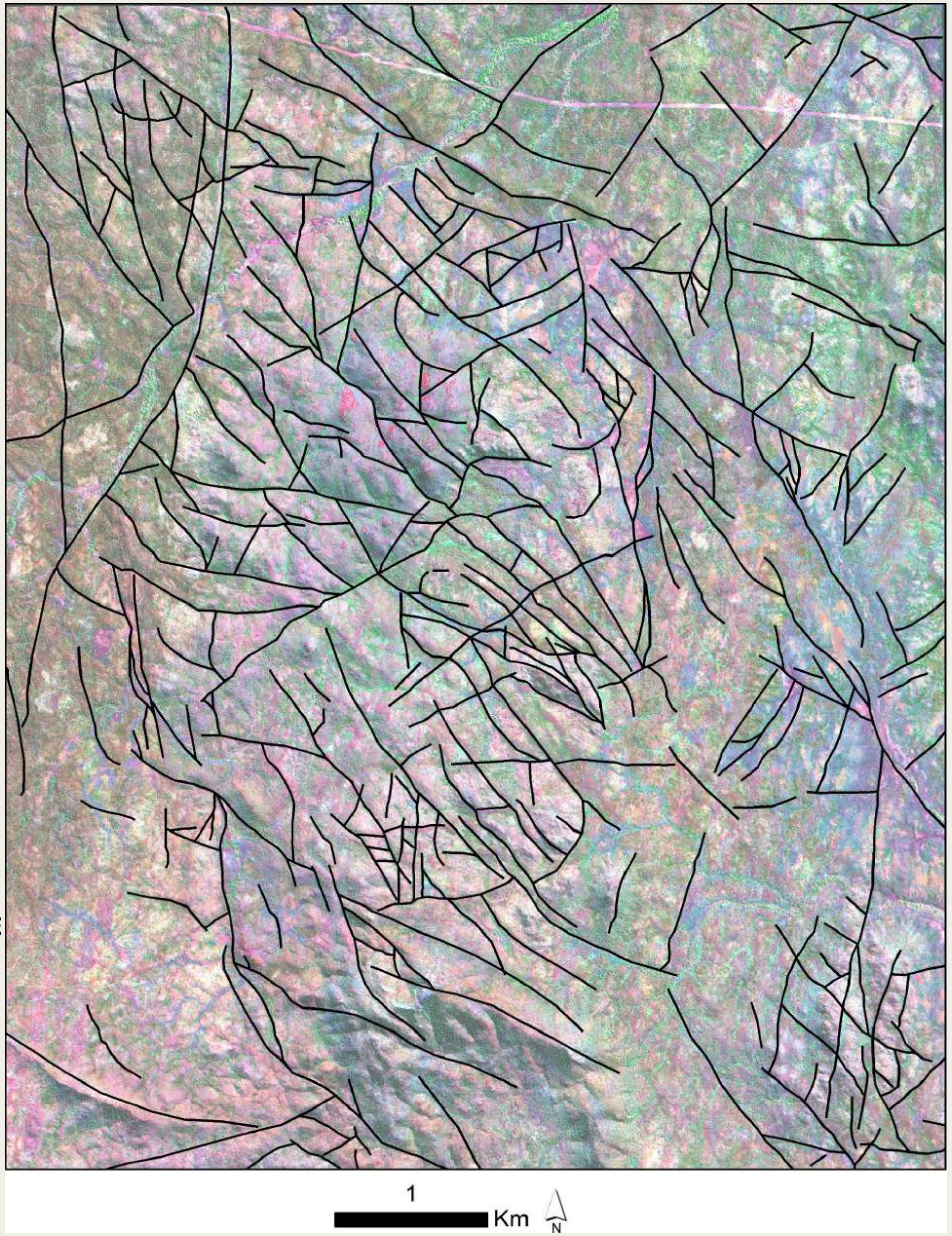
Lineament Analysis

- Structural lineaments observed in satellite imagery are linear or curvilinear features that often reflect underlying geological structures such as faults, fractures, shear zones, or lithological boundaries. These features typically appear as alignments of valleys, ridgelines, drainage patterns, or tonal variations as well as offset/deflection of geological units or geomorphic features. They are particularly evident in high-resolution imagery and digital elevation models (DEMs).
- Lineaments can be mapped manually through visual interpretation. Their identification is crucial in structural geology and mineral exploration, as they often control the localization of mineralization, hydrothermal alteration, and fluid pathways.
- In mineral exploration, structural lineaments help delineate zones of weakness in the crust that may have acted as conduits for mineralizing fluids. Integration of satellite-derived lineaments with geological maps, geophysical data, and field observations enhances structural interpretation and target generation. Remote sensing data like WorldView-3, especially when combined with DEMs such as SRTM, provide powerful datasets for mapping regional and local lineament patterns.

Lineament Analysis

- 30cm Worldview3 pan-sharpened and SRTM data were used to identify lineaments in the study area.
- The area has been affected by a high density of lineaments, which are mostly interpreted to be structural-related.
- The lineaments mainly strike NW-SE or NNW-SSE. Minor trends include NE-SW, E-W, and other orientations.





Alteration Mineral Mapping

- In this work, the Spectral angle mapper (SAM) method has been used to identify major alteration minerals in the study area.
- SAM is a widely used supervised classification method in remote sensing for mineral detection. It compares the spectral signature of each pixel in an image to known reference spectra by calculating the angle between them in n-dimensional spectral space. Smaller angles indicate higher similarity, allowing minerals with distinct spectral features, such as absorption bands in the VNIR or SWIR regions, to be accurately mapped.
- SAM is especially effective for distinguishing minerals like clays, carbonates, and iron oxides in hyperspectral or multispectral datasets, as it is insensitive to illumination and albedo variations.

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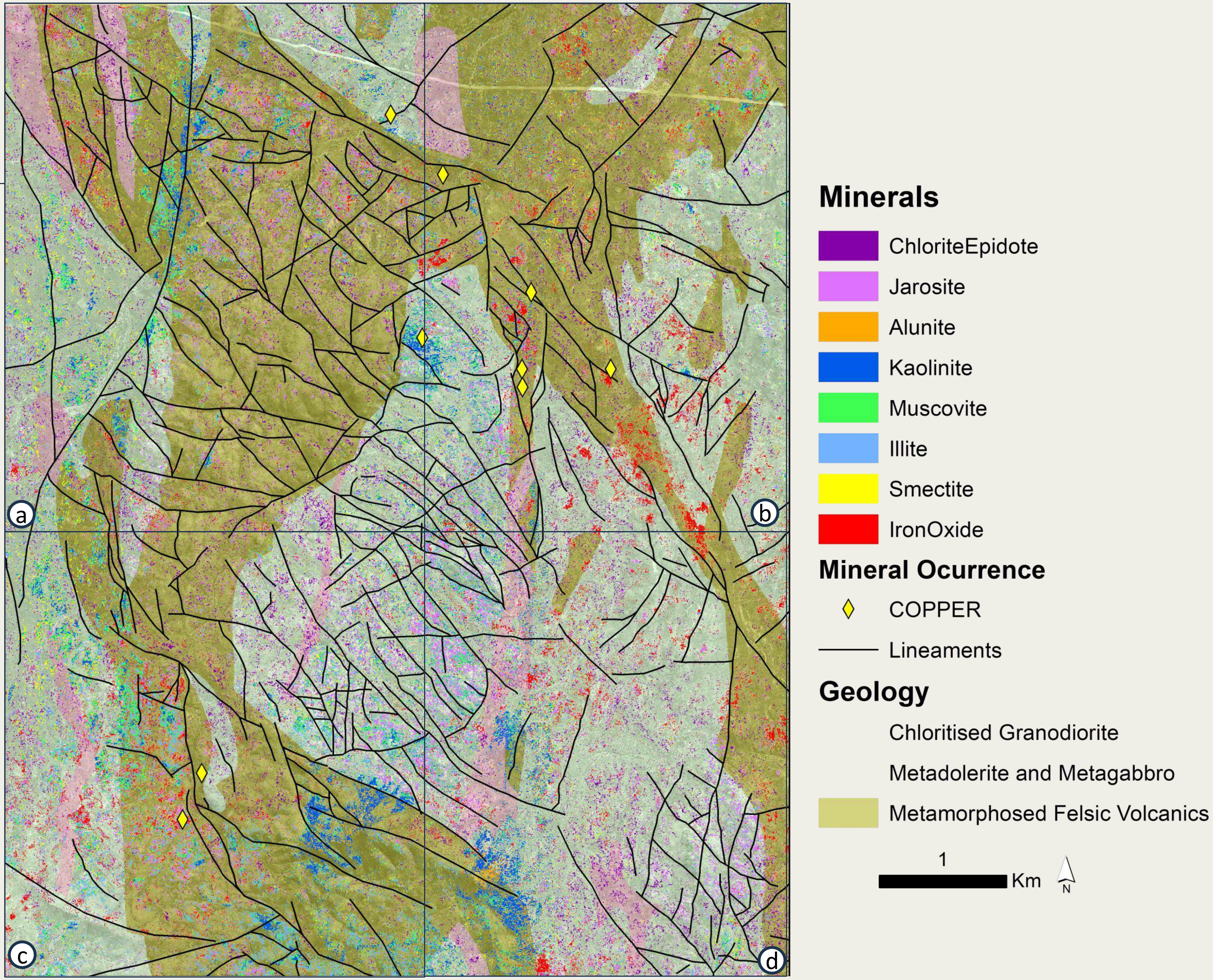
Alteration Minerals

- Final products of mineral mapping, indicating an assemblage of kaolinite, muscovite, iron oxide, illite, smectite, alunite, chlorite/epidote, and jarosite.



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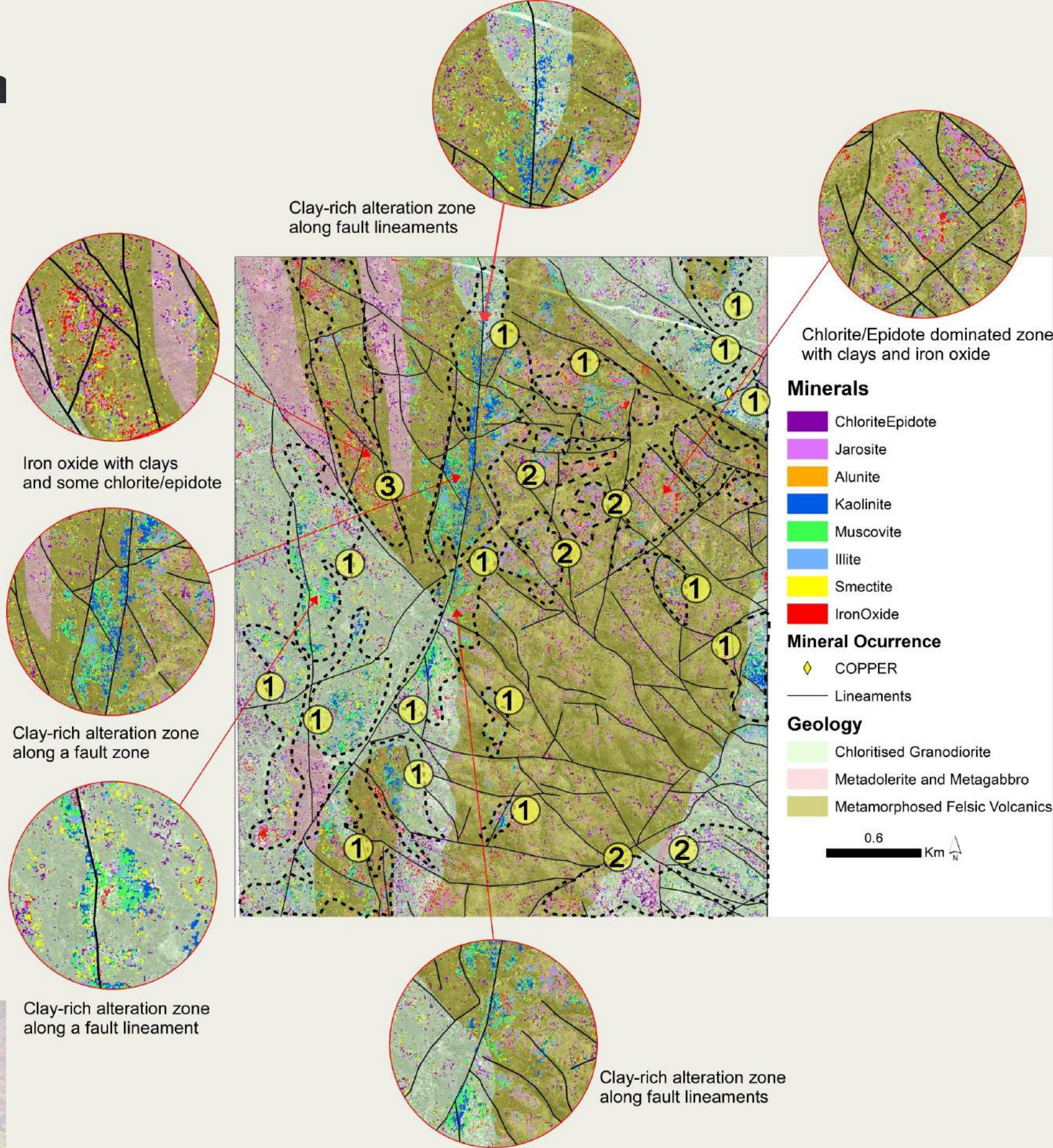
Potential Mineralization Zones-NW(a)

- **Zone 1** includes clay-rich alteration zones, including kaolinite, illite, smectite, and muscovite, in addition to iron oxide, jarosite and chlorite/epidote, mostly in granodiorite and meta-volcanics. These zones are well observed along the fault lineaments, indicating the potential structural role. These zones are considered high-potential mineralization zones. A known copper deposit is located in one of these alteration zones
- **Zone 2** is mainly dominated by chlorite/epidote, as well as minor iron oxide and clay minerals. They occur primarily in granodiorite and along fault lineaments in some areas.
- **Zone 3** is an iron oxide-dominated zone associated with kaolinite, muscovite, illite-smectite, and minor chlorite/epidote, and jarosite. This zone occurs along fault lineaments and is regarded as a high-potential zone.



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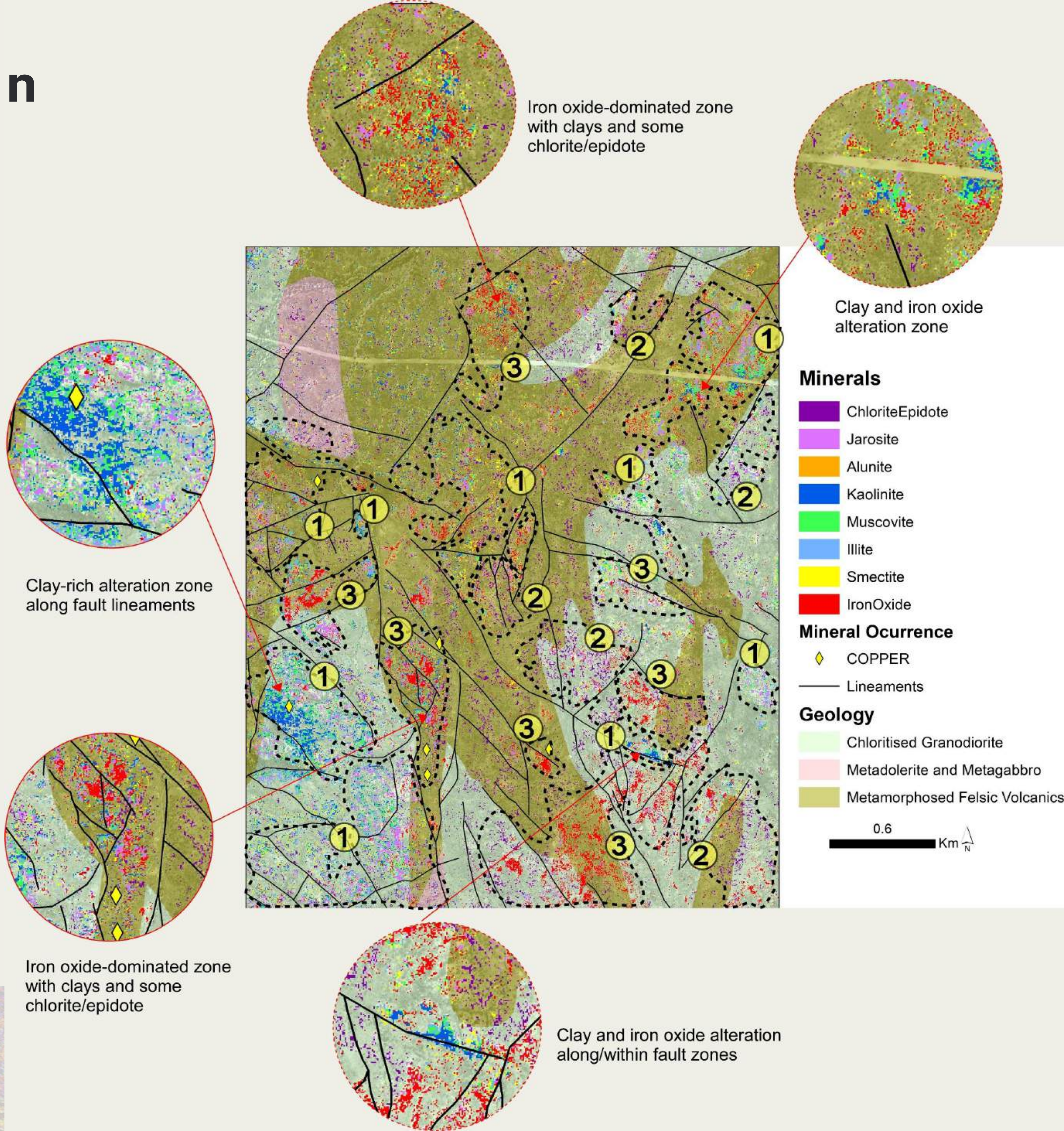
Potential Mineralization Zones-NE(b)

- **Zone 1** includes kaolinite, illite, smectite, muscovite, iron oxide, jarosite and chlorite/epidote, mostly in granodiorite and meta-volcanics. Some zones occurred along the fault lineaments, indicating the potential structural role in mineralization. There are known copper deposits in these clay-rich alteration zones.
- **Zone 2** is mainly dominated by chlorite/epidote, iron oxide jarosite, and clay minerals. They are mostly observed in granodiorite.
- **Zone 3** includes iron oxide associated with kaolinite, muscovite, illite-smectite, minor chlorite/epidote, and jarosite. Similar to clay-rich zones, they occur within networks of fault lineaments. Some known mineral deposits took place in these zones.



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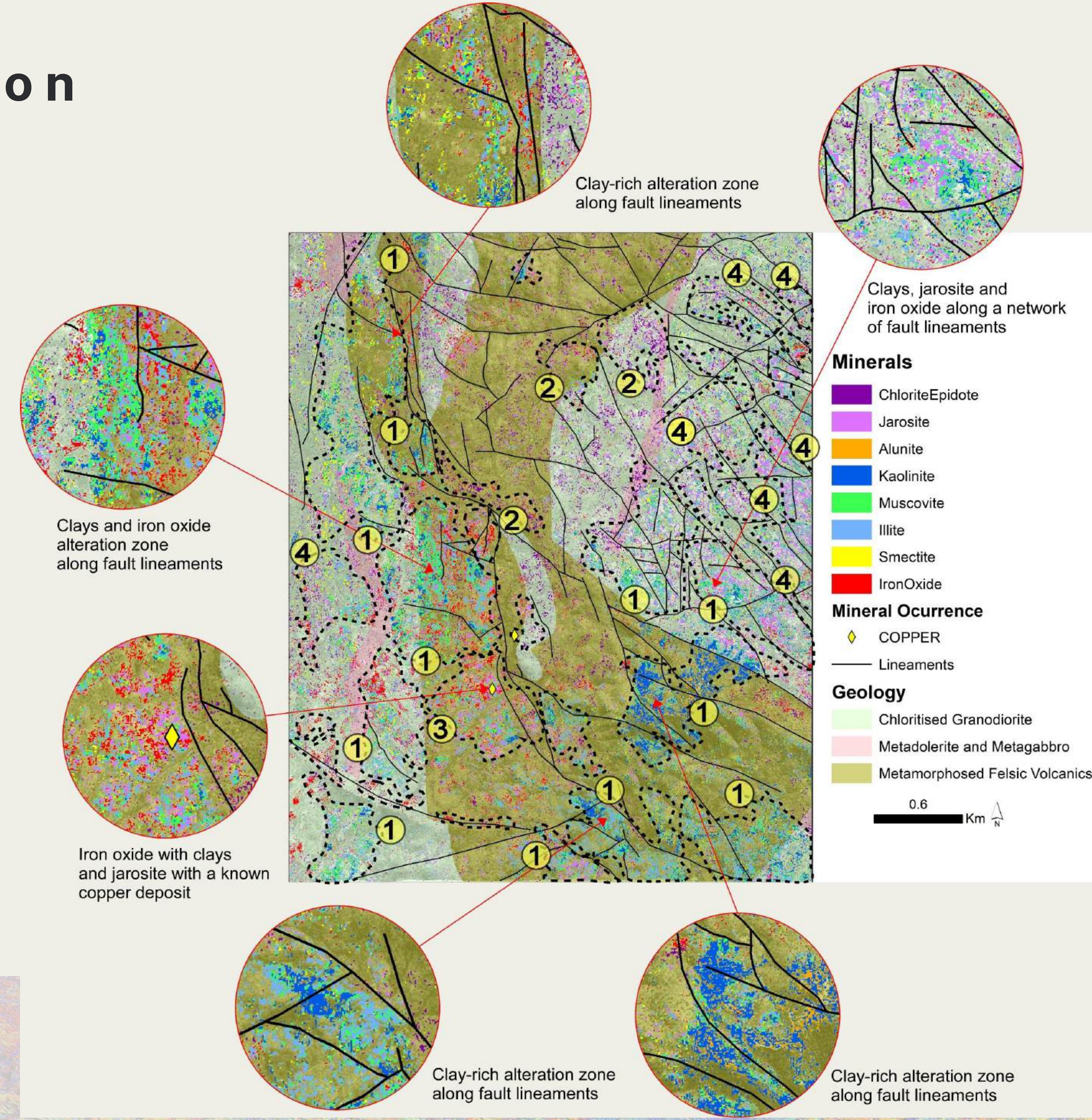
Potential Mineralization Zones-SW(c)

- **Zone 1** includes assemblages of clay minerals with iron oxide, jarosite, and chlorite/epidotes in granodiorite and meta-volcanics. In some areas, they are controlled by fault lineaments.
- **Zone 2** is mainly dominated by chlorite/epidote with some iron oxide, jarosite, and clay minerals, mainly in granodiorite.
- **Zone 3** includes iron oxide, kaolinite, muscovite, illite-smectite, minor chlorite/epidote, and jarosite. Known mineral deposits took place in these zones.
- **Zone 4** includes a mixture of clays and jarosite, some iron oxide, which mainly occur along parallel NNW-SSE fault lineaments.



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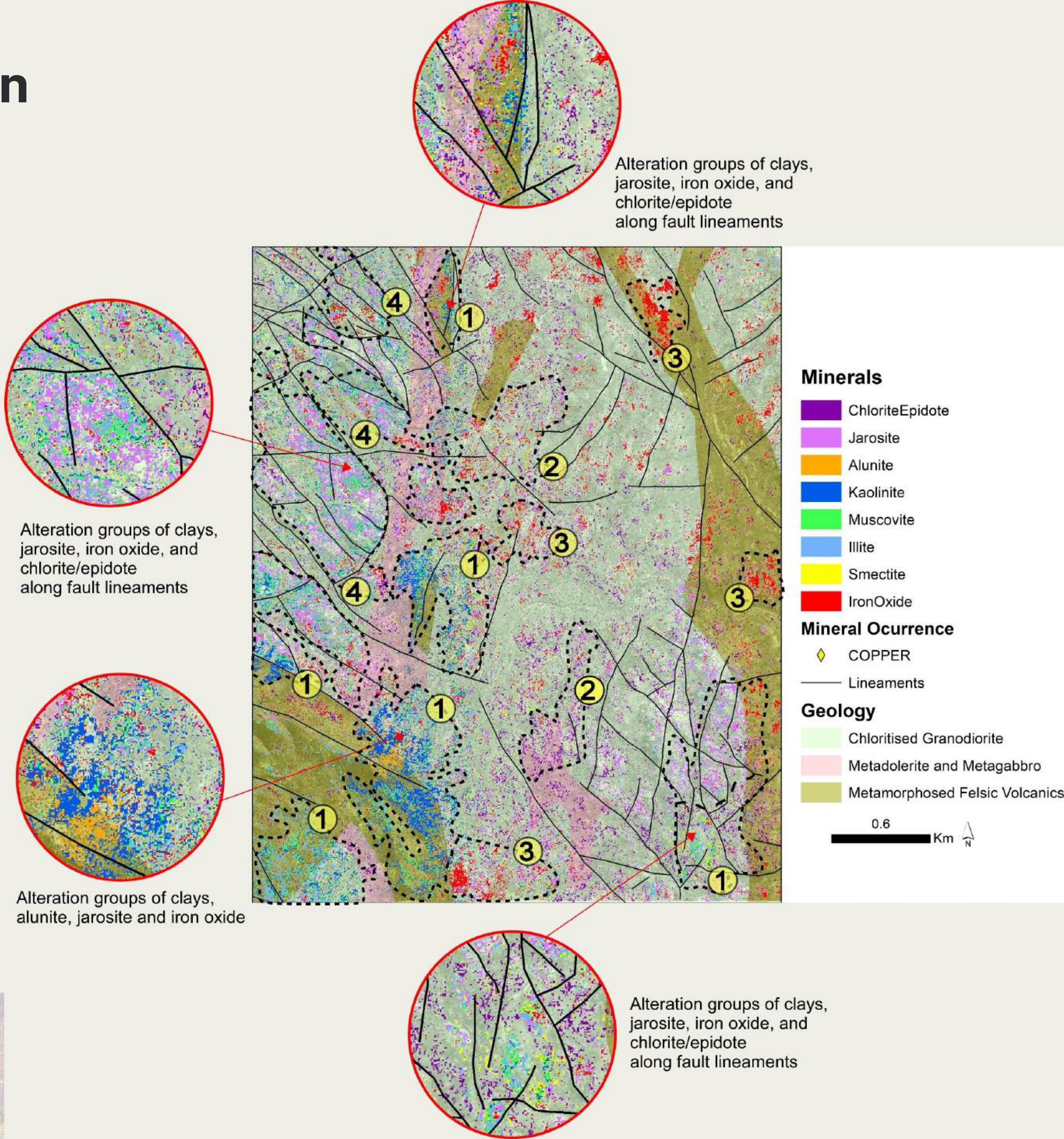
Potential Mineralization Zones-SW(d)

- **Zone 1** Dense zones of kaolinite and other clays are associated with iron oxide, and some jarosite and chlorite/epidotes, mainly along fault lineaments.
- **Zone 2** Chlorite/epidote-dominated areas with jarosite, iron oxide and minor clays mainly in granodiorite.
- **Zone 3** Areas dominated by iron oxide with clays, chlorite/epidote, and jarosite.
- **Zone 4** A combination of clays and jarosite, some iron oxide, which mainly occur along parallel NNW-SSE fault lineaments.



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Technical Notes

- Known mineral deposits occurred in both alteration zones, dominated by clay minerals or iron oxide, mainly in granodiorites. Therefore, potential zones 1 and 3 in granodiorites are considered higher priority than other alteration zones.
- Several alteration zones are observed along the fault lineaments or within networks of fault lineaments. Therefore, structural geology played an important role in developing the potential mineralization zones.
- High resolution WorldView-3 data with 8 SWIR bands (3.7m) provides an excellent opportunity for mapping alteration zones, which are useful step into mineral exploration.

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