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Reconnaissance For Copper Ores: A Focus On Azurite, Malachite And Chalcopyrite In District Dir Upper, Khyber Pakhtunkhwa, Pakistan

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ABSTRACT

A comprehensive fieldwork-based reconnaissance study was conducted in Dir Upper to explore the potential of copper ore deposits. A total of eighteen sites were systematically selected for sampling, with a focus on identifying areas of significant copper mineralization. The collected samples were analyzed to determine the presence and distribution of copper ores, including chalcopyrite, malachite, and azurite. The findings of this study reveal that copper ores are predominantly hosted in hydrothermal veins within the study area. Notably, eight sites namely Band, Kotibusto, Rokhan, Merashpatai, Salool, Shaheed, Bibiyor, and Tangoo Banda exhibited rich copper mineralization, indicating promising potential for copper mining. In contrast, ten sites, Salamkot, Baikaray, Shao, Geero Khwar, Gomadund, Goryal, Samang, Gorrai, Patrak, and Nashnamal showed poor copper mineralization. This reconnaissance study provides valuable insights into the copper ore potential of Dir Upper, contributing to the understanding of the geological framework and mineralization patterns in the region. The findings of this research will be of particular interest to stakeholders, policymakers, and industry professionals involved in the copper mining sector of Pakistan, highlighting opportunities for future exploration and development.

Key word: Hydrothermal Veins, Copper Mineralization, Dir Upper Geology

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INTRODUCTION

Copper is a chemical element with the symbol Cu and atomic number 29. It is a soft, reddish-orange, ductile, and highly conductive metal that is widely used in various industrial and technological applications (Rusjan, D., 2012). It is an excellent conductor of electricity and heat, making it a crucial material in the production of electrical wiring, circuits, and electronics (Li & Wong., 2006). It is also used in architecture, plumbing, and transportation due to its durability, corrosion resistance, and attractive appearance (Voldez et al., 2012). According to the United States Geological Survey (USGS), copper is the third most consumed metal in the world, after iron and aluminum (Rauch, J.N., 2009). Its unique properties and versatility make it an essential material in modern society.

Copper is a vital metal in Pakistan's economy, with numerous applications in various industries. Pakistan is endowed with significant copper deposits, particularly in the province of Balochistan (Malkani & Mahmood., 2016). The Saindak Copper-Gold Project, located in Chagai District, is one of the largest copper mines in Pakistan, with estimated reserves of over 2 billion tons (Ghaffar, S., 2024). The copper industry plays a crucial role in Pakistan's economic growth, contributing significantly to the country's GDP. Copper is used extensively in Pakistan's manufacturing sector, particularly in the production of electrical goods, machinery, and transportation equipment (Shah, S.A.H., 2018). According to the Pakistan Bureau of Statistics, the country's copper imports have been increasing over the years, with a significant portion being used for industrial purposes. However, with the development of local copper mining and processing projects, Pakistan aims to reduce its reliance on imports and boost its domestic copper production.

Dir Upper, a district in Khyber Pakhtunkhwa, Pakistan, is known for its rich mineral resources, including copper. The region's unique geology, with its complex structure and varied rock formations, has created an environment conducive to mineralization. Copper deposits have been identified in various areas of Dir Upper, including the valleys of the Panjkora and Dir rivers. These deposits are often associated with other minerals, such as gold, silver, and zinc (Khan, S., 2017). The copper deposits in Dir Upper are primarily of the porphyry type, which are characterized by large-tonnage, low-grade mineralization. These deposits are often amenable to open-pit mining and have the potential to support large-scale copper production (Hussain, S., 2019). The development of copper resources in Dir Upper has the potential to contribute significantly to the local economy, creating employment opportunities and stimulating economic growth. However, the region's rugged terrain and limited infrastructure present challenges to mineral exploration and development.

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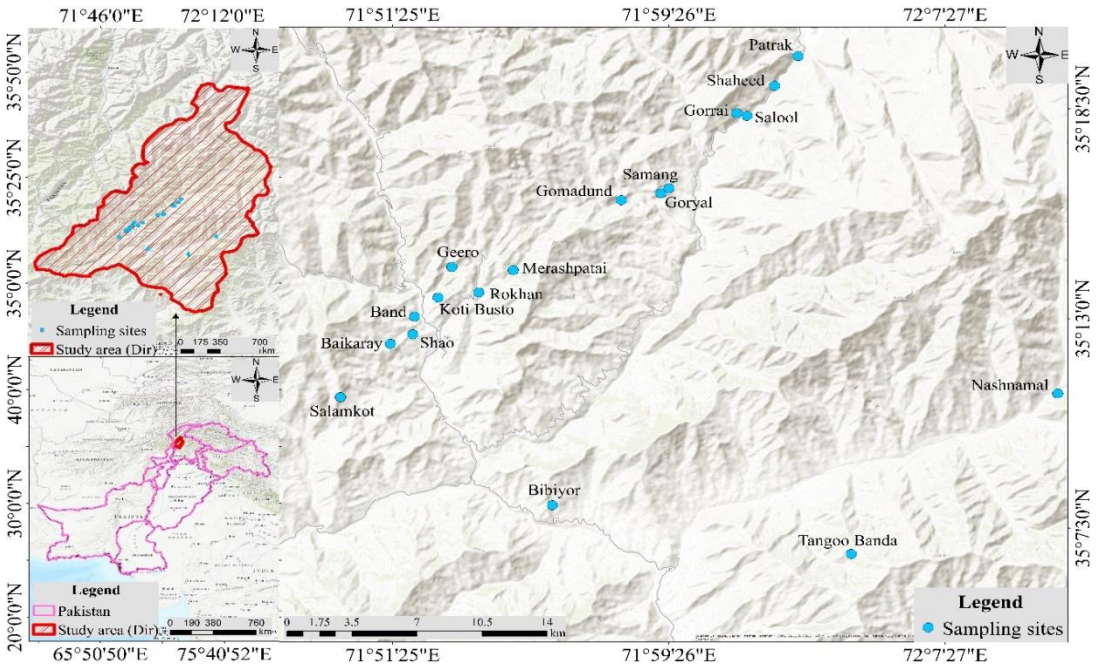


Figure 1: Copper bearing zones in District Dir Upper, Khyber Pakhtunkhwa, Pakistan

Dir Upper is located in the northwestern part of the Himalayan orogenic belt, which resulted from the collision between the Indian and Eurasian plates. The region is characterized by a complex tectonic history, involving multiple phases of deformation, metamorphism, and magmatism (Kazmi et al., 1997). The geological evolution of Dir Upper can be divided into several stages. The oldest rocks in the region are the Precambrian gneisses and schists, which form the basement complex. These rocks were metamorphosed during the Himalayan orogeny (Treloar and Izatt, 1993). During the Paleozoic era, the region was affected by multiple tectonic events, including rifting, subsidence, and volcanism. The Paleozoic rocks in the area include limestones, sandstones, and shales (Shah, 2009). The Mesozoic era saw the deposition of terrestrial and marine sediments, including conglomerates, sandstones, and limestones. The region was also affected by volcanic activity during this period (Khan, 2017). The Cenozoic era was marked by the Himalayan orogeny, which resulted in the formation of the Himalayan mountain range. The region was affected by multiple phases of deformation, metamorphism, and magmatism during this period (Hussain, 2019).

Copper ore mineralization in Dir Upper is associated with the Himalayan orogeny and the resulting magmatic and metamorphic activities. The copper deposits in the region are primarily of the porphyry type, which are characterized by large-tonnage, low-grade mineralization. The copper mineralization in Dir Upper is thought to have occurred during the Late Cretaceous to Early Paleogene period, when the region was affected by extensive magmatic activity. The copper deposits are associated with granitic and dioritic intrusions, which were emplaced during this period (Ahmad and Ullah, 2020). The convergence of tectonic plates in Khyber Pakhtunkhwa has played a key role in enriching the province with a diverse array of minerals and metals, (Malkani et al., 2017). The intense compressional forces associated with the Main Karakoram Thrust

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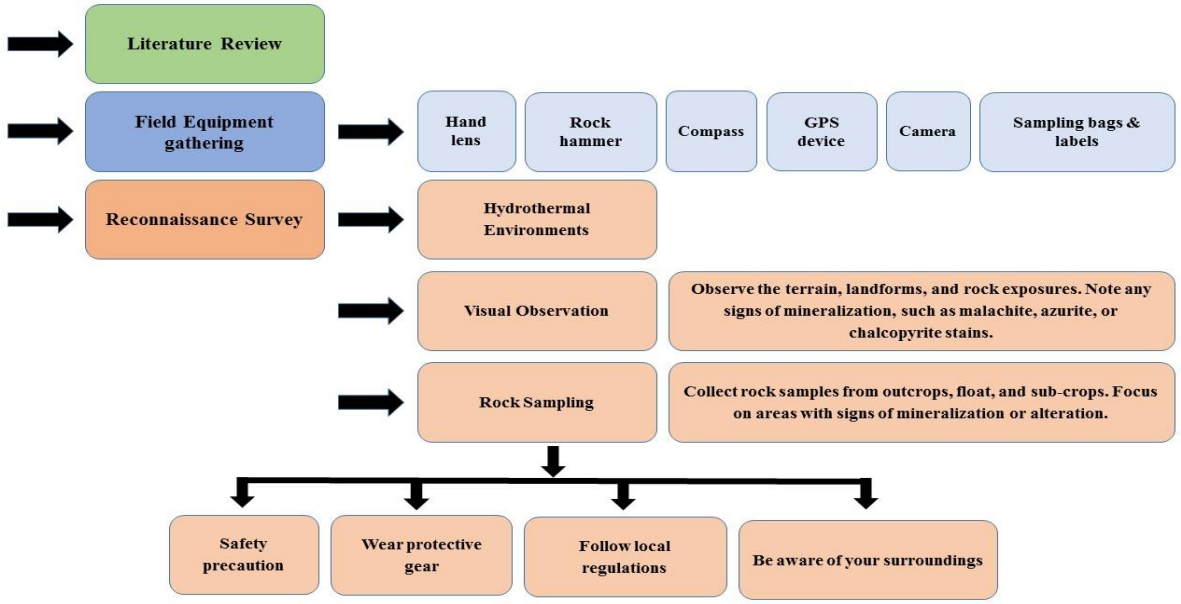
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and the Indus Suture Zone pushed rock formations containing valuable resources closer to the surface, making them readily accessible for mining and other economic activities (Shah, 2018).

Recent research suggests that the formation and association of copper mineralization is predominantly linked to convergent margins characterized by plate subduction (Khan, 1979; Tahirkheli, 1979; Bignold and Treloar, 2003; Dyar et al., 2008). The formation of copper ore minerals occurs in a hydrothermal environment, where hot water acts as a versatile agent, concentrating, transporting, and ultimately depositing the treasured copper. Upon cooling, this solution can leave behind massive, commercially valuable concentrations of copper-bearing minerals. For the past 20-30 years, geologists have tirelessly scrutinized northern Pakistan, eager to unravel the secrets of its tectonic past. Their extensive fieldwork has shed light on the complex forces that shaped this remarkable region (Shah and Lechler, 2004). Despite extensive water geochemistry research in Northern Pakistan, particularly following an Australian Agency for International Development study in 1992, exploration for copper and precious metals has remained relatively under-explored. (Searle and Khan, 1996; Kazmi and Jan, 1997). Despite decades of extensive water geochemistry research in Northern Pakistan, sparked by an Australian Agency for International Development study in 1992, the region's potential for copper and precious metals remains largely untapped, a hidden resource awaiting exploration (Halfpenny and Mazzucchelli, 1999). While Northern Pakistan has seen significant advancements in water geochemistry research, particularly since a 1992 study by the Australian Agency for International Development, the exploration of copper and precious metal deposits has been disproportionately neglected.(Shah and Lechler, 2004)

Research aim: To identify copper bearing areas in Dir Upper.

METHODOLOGY



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Figure 2: Research Methodology Flow hart

District Dir Upper (5000 sq.km) survey was conducted to identify geological indicators of hydrothermal activity, the geological process responsible for the formation of many valuable mineral deposits. They searched for hot springs, altered rocks, and other clues that point to the presence of mineral-rich fluids circulation. Samples were collected from the promising locations in the study area. Eighteen spots were identified as promising areas for copper mineralization.

This reconnaissance for copper ore in district Dir Upper, Khyber Pakhtunkhwa, Pakistan the first step in a long and exciting journey. The findings will guide future exploration efforts, paving the way for the responsible development of Dir Upper's copper resources. With careful planning and sustainable practices, this hidden treasure can not only bring economic prosperity to the region but also contribute to the country's overall development.

Eighteen localities were identified for having copper ore mineralization presented in Table 1.

Table 1: Locality of the collected rock samples

S.No.	Name	Location	S.No.	Name	Location
1	Salamkot	$35^0 10'56''N, 71^0 49'54''E$	10	Goryal	$35^0 16'17''N, 71^0 59'12''E$
2	Baikaray	$35^0 12'20''N, 71^0 51'21''E$	11	Samang	$35^0 16'25''N, 71^0 59'26''E$
3	Shao	$35^0 12'35''N, 71^0 52'00''E$	12	Salool	$35^0 18'23''N, 72^0 01'24''E$
4	Band	$35^0 13'03''N, 71^0 52'03''E$	13	Gorrai	$35^0 18'19''N, 72^0 01'42''E$
5	Geero	$35^0 14'21''N, 71^0 53'08''E$	14	Shaheed	$35^0 19'06''N, 72^0 02'30''E$
6	Koti Busto	$35^0 13'33''N, 71^0 52'44''E$	15	Patrak	$35^0 19'53''N, 72^0 03'11''E$
7	Rokhan	$35^0 13'41''N, 71^0 53'55''E$	16	Bibiyor	$35^0 08'06''N, 71^0 56'03''E$
8	Merashpatai	$35^0 14'16''N, 71^0 54'55''E$	17	Nashnamal	$35^0 11'02''N, 72^0 10'43''E$
9	Gomadund	$35^0 16'06''N, 71^0 58'03''E$	18	Tangoo	$35^0 06'49''N, 72^0 04'43''E$

FIELD FINDINGS

In the quest for copper ore deposits, a reconnaissance field work was conducted across Dir Upper, spanning from the elevated heights of Lowari Top to the southern boundaries of Khal. Areas exhibiting signs of ancient hydrothermal activity, manifested in mineralized zones, altered rock formations, and distinctive shear markings, were identified as prospective targets (Figure 1, Table 1)

Nestled in Dir's southwestern corner, Salamkot boasts copper deposits in the form of azurite and chalcopyrite, within quartz veins. The field work also revealed a distinct granodiorite intrusion, hinting at its potential role as the source of this metallic bounty. Field observations at Baikaray, located in the western part of Dir, revealed two exposed zones of copper mineralization. The first zone, which is approximately 5 feet thick, exhibiting prominent veins of azurite and chalcopyrite that stretch for 200 feet. The intense blue coloration of azurite and the brassy yellow color of chalcopyrite, confirming the presence of copper-bearing minerals. The second exposed zone at Baikaray, approximately 1-foot-thick, exhibits a complex interplay of malachite, chalcopyrite, and quartz, revealing a delicate mineralogy. Located in the heart of Dir, Shao boasts a copper-bearing zone measuring 150 × 4 feet, characterized by

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intertwining malachite and chalcopyrite. In the northern reaches of Dir, near Panakot, lies Band. Copper mineralization is observed in the sheared volcanic bedrock, indicating a structurally controlled mineralization. Nestled in Dir's northeastern corner, Koti Busto reveals copper mineralization in the form of malachite. The mineralized zone stretches 200 feet, with widths of up to 3 feet. These observations highlight the geological diversity and copper-rich mineralization in Dir, emphasizing the region's potential for further exploration and research. Lar Rokhan village in Dir's northeast revealed a prominent and thick vein of copper on the roadside. This discovery showcases malachite, azurite, and chalcopyrite in vibrant harmony. In northeast of Dir, Merashpatai, reveals a geological narrative etched in copper. Hydrothermal solutions whisper their secrets to a 5-feet altered zone (stretching 100 feet), adorning it with quartz veins carrying malachite, azurite, and chalcopyrite treasures. A 1980 adit, driven by the SDA (Sarhad Development Authority), delved deeper into this copper story, encountering a 6-feet mineralized zone within the N 40° E trending amphibolite rock. Northeastern Dir's Gomadund hides its mineral riches within a sheared zone. Exposed veins, 30-130 feet long and 4-6 feet thick, tantalize with their potential. SDA delved into this treasure trove with two adits back in the 1980s. Northeastern Dir's Goryal flaunts its mineral riches through veins of azurite intruding into dominant diorite. SDA, in the 1980s, tunneled into this treasure trove with two adits. Samang, nestled in Dir's northeast, hides a mineralized treasure within an altered zone. Stretching 100 feet long and just 1-foot-wide, this zone bears the mark of hydrothermal solutions, with quartz veins carrying copper as azurite. The country rock, amphibolite trending N 42° E and dipping north, cradles this mineralized gem. A trio of copper minerals - azurite, malachite, and chalcopyrite paint the landscape of Salool, nestled further northeast of Dir Upper's Sheringal. Nestled in the verdant embrace of Dir's northeast, Gorrai whispers secrets of mineral riches. Its veins, adorned with the captivating blue of azurite, beckon exploration and unravel tales of hidden wealth. These mineralized zones, like veins tracing their way through the earth, boast impressive dimensions, ranging from 40 to 100 feet in thickness **and** 4 to 14 feet in width**.** Shaheed, cradled in Dir's northeast, joins the chorus of mineralized zones, its veins singing in hues of azurite, malachite, and chalcopyrite. In Patrak (Dir Kohistan), the country rocks include amphibolites, gneisses and schist. Copper mineralization here is in the shape of azurite and chalcopyrite. In Bibiyor area of Dir Upper, the mineralized zone is about 3 ft thick and exposed along the strike length for about 15 ft. The mineralization in this area is in the form of malachite, azurite, and chalcopyrite**.** Ushairai Dara, in Dir's east, cradles Nashnamal, a land were copper whispers through veins of quartz. Like molten threads woven through ancient amphibolite, these veins, 10 feet thick and 30 feet long, bear the vibrant hues of azurite and chalcopyrite. A 1980s pit, a relic of past exploration, adds to the intrigue of this mineralized zone. Tangoo Banda, nestled in Ushairai Dara, Dir Upper, harbors a secret within its earth: a 2 feet thick sheared zone stretching over 200 feet, a treasure trove of copper painted in malachite, azurite, and chalcopyrite. There's more azurite than chalcopyrite in this rock. The rocks from Salamkot and Baikaray in Dir Upper both have copper minerals, but Baikaray has more azurite than chalcopyrite, while Salamkot has more chalcopyrite than azurite. Two copper minerals, chalcopyrite (yellow) and malachite (green), were identified in a rock sample from Shao, Dir Upper,

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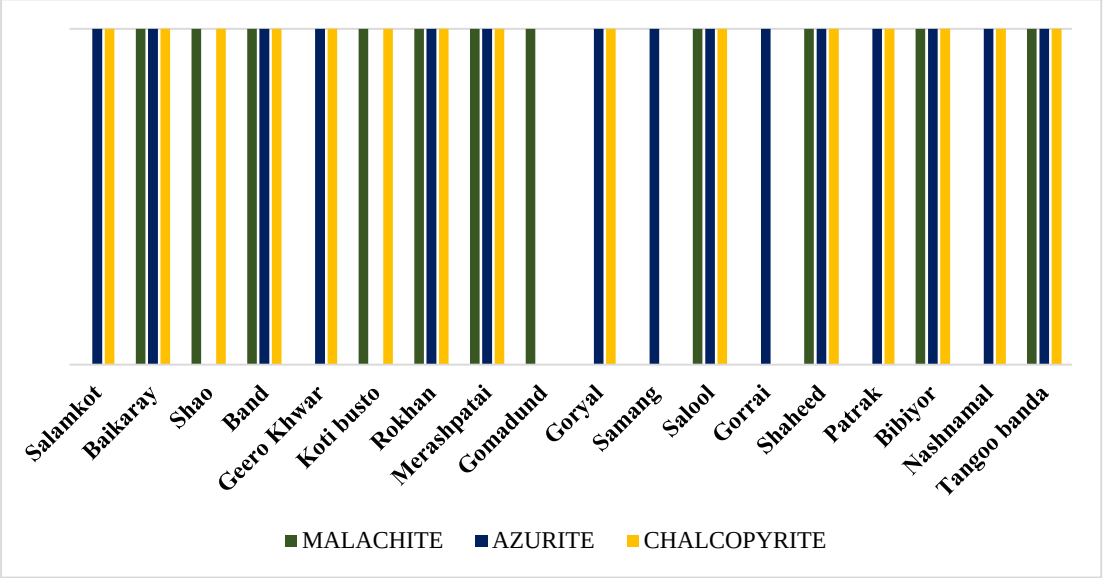
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through microscopic analysis, while rocks from Band in Dir Upper hold a trio of copper minerals: chalcopyrite, azurite, and malachite. Geochemical analysis reveals a dominant presence of chalcopyrite, suggesting promising copper mineralization, with trace amounts of malachite also detected. Chalcopyrite and azurite, two types of Cu mineralization, were found in the sample taken from Geero Khwar, Dir Upper. Compared to chalcopyrite, azurite grains are more developed and show excellent copper mineralization in the sample. In contrast, chalcopyrite and malachite, two forms of copper mineralization, are present in the rock sample from Koti Busto, Dir Upper. The rock sample from Rokhan, Dir Upper is thought to contain copper mineralization in the form of chalcopyrite, azurite, and malachite based on optical characteristics. The rock sample from Merashpatai, Dir Upper, has copper, in the form of minerals like chalcopyrite, azurite, and malachite. The presence of chalcopyrite exhibiting ideal cleavage characteristics significantly enhances the economic viability of this mineralized sample. Chalcopyrite paints the Gomadund, Dir Upper rock sample with its golden touch, while azurite adds a dash of azure, and malachite infuses it with verdant green. Among the minerals present, malachite reigns supreme, outshining both azurite and chalcopyrite. Unlike the Gomadund sample rich in malachite, the Goryal, Dir Upper sample showcases promising copper mineralization primarily through chalcopyrite and azurite. The Salool rock sample exhibits copper mineralization manifested in a multi-mineral assemblage, with chalcopyrite, azurite, and malachite identified as the key constituents. Chalcopyrite exhibits the highest abundance relative to azurite and malachite within the copper mineral assemblage observed in the Salool rock sample. Within the Dir Upper region, the rock sample from Gorrai exhibits copper mineralization identified through optical analysis as the mineral azurite. Conversely, Shaheed, Dir Upper rock samples display copper mineralization in the form of chalcopyrite, azurite, and malachite ores. Microscopic examination confirms the dominance of chalcopyrite within this assemblage. Although chalcopyrite is present, the cleavage planes are not well-developed, indicating imperfect cleavages within the ore.

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Figure 3: Presence of Copper Ores in different localities of District Dir Upper

Band, Rokhan, Merashpatai, Salool, Shaheed, Bibiyor, and Tangoo Banda boast a tri-treasure: malachite, azurite, and chalcopyrite. Salamkot, Baikaray, Geero Khwar, Goryal, Patrak, and Nashnamal sing a melody of copper with azurite and chalcopyrite. Shao dances to the rhythm of malachite and chalcopyrite. Koti Busto and Gorrai hold secrets in shimmering azurite alone. Gomadund paints with verdant malachite, while Samang whispers in azure with just azurite (Figure 3). This diversity of copper ores suggests that Dir Upper has the potential to be a significant source of copper.

CONCLUSION

The presence of various copper ores, including malachite, azurite, and chalcopyrite, indicates a significant copper resource in the region. These ores are found in multiple locations, suggesting widespread mineralization and potentially large reserves.

The association of copper mineralization with igneous rocks points towards a potentially larger mineral system. Igneous rocks often host various base metals, and copper can act as a pathfinder element, indicating the potential presence of other valuable minerals like lead and zinc

Analysis including Isotope study, petrography and geochemistry may be carried out for the samples got from these eighteen localities to find out the qualitative and origion aspects.

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