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Trace Elements Mineralization – Gala-En Nahal Area Gadarif State – Sudan

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Abstract

Gala En Nahal area constitute late Precambrian Alpine-type mafic-ultramafic rocks, considered as ophiolites masses. These ophiolite masses are deformed, sheared and dismembered. They consist of serpentinized chromitiferous ultrabasic rocks, metagabbro, diorite and dykes of various composition. Later talc magnesite schist and biribrite are formed as an alteration product of the mafic ultra-mafic rocks. Industrial minerals such as chromite, talc, asbestos and magnesite have been reported. Samples are taken from biribrite rock and subjected to (XRF) and (AAS) analysis. The results of analysis show sigificant values for Au, PGE, Ni, Co and Ag Analysis of Talc-carbonate rocks also show ore minerals of Ni-Co arsenide, pyrite, and chalcopyrite silica-carbonate stock works are surface criteria for mineralization.

Introduction

Gala En Nahal area is located in the South-Western part of Gadarif State near the border line between the Sudan and Ethiopia and at the northern side of the alluvial plains of the Blue Nile-Dinder and Attshan rivers.

Longitudes 34°52′ - 35°01′ E and latitudes 13°28′-13°35′ N

Figure 1 Map of Sudan showing Qala El Nahal area (Al-Gadarif state).

It lies about 65 km to Gadarif town, 700 km SW to Port Sudan, 450 km NE Khartoum.

Gala En Nahal complex represent late – Precambrian Alpine – type mafic – ultramafic rocks. These ultramafic complex was considered as a part of postulated ophiolite zone, extending from Kenya to Arabia Figure 1 through Ethiopia, Sudan and Egypt.

Abdel Rahman1983 (1) considered Gala En Nahal – as ophiolite – fragment disposed along or near an ancient geosuture. This ophiolite occurs along a major linear belt, which according to (Vail, J.R. 1983) (8). indicates a subduction zone, which had been disrupted by igneous intrusions and offset by faults.

These ophiolite masses are deformed, sheared and dismembered. They consist of magmatic rocks including serpentinized chromitiferous ultrabasic rocks, met gabbro, and dykes of various compositions. The ancient rocks were presented by the pr Cambrian basement schist's (quartz-sericite schist, mica- quartz schist, quartz- chlorite schist, quartz schist, Andalusite- quartz schist).

Similar ultrabasic/serpentinite complex were recorded in central and eastern Africa. These include Tulu Dimtu in Wollega province (Ethiopia) (Warden et all 1982) (9), and at Sker Kena . In Egypt such ultrabasic/ serpentine complexes were recoded also about 50Km north of Wadi El Allagi (Hunting Geology and Geophysics 1986) (5). These ultrabasic rocks of Egypt are usually completely serpentinized, carbonatized, silicified and are alteration zones. This phenomenon has also been observed in Gala En Nahal area. The distribution of these ophiolitic ultrabasic complexes seem to be controlled by major deep – seated faulting, with northwest and east – north east trends.

In Sudan similar mafic – ultramafic masses occur in Ingessana – Blue Nile province. This complex comprises all the elements of a dismembered ophiolite succession which serpentinized ultramafic rocks with podiform chromite, layered gabbro, basic dykes, pillow basalts thin sediments, and plagio-granite. The contacts are sheared and the belt is highly disrupted. Vail (1983) (8) reported the similarities in trend of the faults in Blue Nile, southern Sudan, Uganda, and Najd faulting in Saudi Arabia. In the Red Sea Hills ophiolites are recorded in Onib, at Jebel Tohado and Wadi Amur. The Onib ophiolite complex shows entire oceanic crust sequence from pillow lavas to pyroxenites and peridotites at the bottom (Hussein et all 1984 (6).

Similarly as in southern Blue Nile Red sea Hills ophiolites are party dismemberd as a result of deformation. The lowermost part of the complex has been sepentinized but shows no silicification and/or carbonatization.

Based on field evidence and previous information lithologic unite are summarized in table 1:

Table 1 Rocks stratigraphic sequence in Qala En Nahal area.

Age	Rock Type	Description
Quaternay		Alluvium, diluvium, slope wash eluvium …etc
	Late stage Dykes	Quartz vein chlorite vein
Devonian	Acidic Rocks	Biotite granite plagioclase granite
Early Paleozoic	Basic	Micro diorite met gabbro
	Ultra-basic	Pyroxnite dyke silicified ultra-basic rocks (biribite) Talco– carbonatized ultrabasic rocks Peridotite and olivine pyroxnite (Termonite). Peridotite (serpentinized) Dunite and harzburgite (serpentinized)
PreCambrian	Metasediment	Schist (quartz-sericite schist, mica- quartz schist, Mica-quartz schist)…etc intercalated with Quartzite & lenses of thinly –layerd marbles.

Biribrite (Silicified Ultrabasic Rock)

This rock is detected in different localities in the mapped area. It caps many ultramafic bodies forming rough topography, or it occurs as patches within the serpentinite, and also along shear zones. It is rusty brown to dark brown or metallic yellowish in color. The color is a function of the amount and type of iron oxides and quantity of silica available.

It is fig-grained mostly cavernous and sometimes jasperoid, with conspicuous reticulated veining of silica and limonite. Babiker, 1977 (3), Abdel Rahman, 1993 (2) and others commented on the strange appearance of Ingessana biribrite which is of similar occurrence to that Gala En Nahal area, yet no explanation of its origin is completely convincing. However Fozzard, 1964 (4) described similar rock in Tanzania which he suggested had been formed by processes of lateralization. Biribrite in Gala En Nahal area is exposed at Jebal El Zarafa as well as on the southern side of Jebel El Fau.

The Jebal El Zarafa was studied in details. It is a high hill located on the southern side of Gala En Nahal town and rises up to 250 m above the surrounding plains covering an area of approximately 600.000 m^2. The rock is highly fractured, sheared and strongly silicified and ferrigunized.

Method of Investigation

Sampling has been made on two scales for regional and detailed prospecting.

- Regional prospecting: this include the collection of chip and bulk samples for different lithological units over the whole. Moreover, heavy mineral concentrates were gathered to prospect for gold and other minerals. Fifty five chip samples and 10 bulk samples were taken from the study areas.
- Detailed prospecting: detailed prospecting was carried out at the northern end of jebel El Zaraf based on chip sampling according to grid 50×100. A base line was set parallel to the geological strike perpendicular to the abovementioned line (profile), denoted by 0,I,II,III were laid out at 100 m interval. The sampling points along these profiles are 50 m apart. The area mapped is about 60,000 sq m. thirty chip samples each weighing about 100 gm were collected in an attempt to assess primary dispersion haloes.

Results were treated statistically to cover the following aspects:

- Application of normal statistical laws.
- Application of probability method (using probability curves) to define anomalies (ca values) and background thresholds (cb values) for Pt, Au, Ni, Cr and Cu.
- Calculation of coefficient of dispersion, anomaly contrast (g), standard deviation (s), and geochemical reverse (QH) for the same elements of (b) above.
- The correlation coefficient between the above-mentioned trace elements in (b) was computed

with the help of the computer using the SPSS program.

Results

This study discusses the geochemical interpretation of the results of the revealed trace elements contents in study area i.e distribution, patterns of dispersion and geochemical correlation. The trace elements considered are: Au, Pt, Ni, Co, Ag, Cr, Zn, Pb and Mn table 2 Biribrite of Jebel El Zarafa have been sampled according to 100x50 grid. Analytical results have revealed anomalous values for some of the trace elements as will be discussed later.

Geochemical results

Characteristics of the distribution and abundance of the elements of economic importance is as follow:

Gold component in biribrite ranges between 0.3 to 20 ppm, with the mean value is 10 ppm. Nickel has consistent high concentration in a range of 1470 and 5300 ppm. The vast majority of the analyzed samples contain Nickel in excess of 1000 ppm (< 0.1% Ni). Platinum is present in anomalous concentration in biribrite with lowest level being 0.14 ppm and highest level of 1.16 ppm.

Chromium is present in very high concentration at a range of 1900 and 2840 ppm, with chromite bodies within the serpentinite. Cobalt occurs in high anomalous values ranging 10 ppm and 365 ppm. Silver content in biribrite is ranging between 50 ppm and 100 ppm.

Trace Elements Distribution

Table 2 Trace Element Analysis of Rocks from the Study Area. All values in ppm.

Rock Type	Ni	Cu	Co	Zn	Ag	Pb	Ni /Co	Cu/Co
Dunite Harzburgite	1456	21	80	39	0.5	17	18.2	0.3
Birbrite	1473	6.5	180	190	2.5	29.5	8.3	0.03
Talc- Carbonate	1190	4	180	415	3	21.5	6.6	0.02
Birbrite	1222	2.5	70	15.5	0.5	17.5	17.5	0.04
Massive Chromite	2025	33	105	41.5	1	21	19.3	0.34
Massive Chromit	245	3	50	245	1.5	5	4.9	0.05
Disseminated Chr.	2295	48.5	60	12	0.5	7	38.9	0.83
Talc- Carbonate	939	47.5	365	67	4	35	2.7	0.04
Talc-Carbonate	1925	25	65	32	1.5	13	19.3	0.3
Marble	83	12	155	16.5	4	59.5	0.5	0.08
Marble	80	246	125	77	3.5	51.5	0.6	2
Quartz vein	513	24	10	18.5	1	30.5	51.5	2.4
Quartz vein	32	23	80	48	1	31	0.4	0.3
Quartz vein	10	6.5	ND	3	0.5	38.5	ND	6.5
Quartz vein	1510	4.5	55	22.5	0.5	8	27.4	0.08

Show in table (2), the ultrabasic rocks from study area (samples 1-9) have the highest Ni values similar to ultrabasic rocks in the neighboring area (1). Biribrite and adjacent talc-carbonate rocks have the same nickel concentration as the massive dunite-harzburgite rocks. Moreover, biribrite and talc-carbonate rocks have remarked high Ni/CO ratio (17.3-38.3) and low Cu/Co between 0.4- 0.8. Chromite ores display typical low Ni/CO ratio in range of 2.6 to 8.2 and low Cu/Co between 0.02 and 0.13, while dunite-harzburgite yields Ni/Co of 18.2 and 0.3 for Cu/CO. since the Ni/CO and Cu/Co are very high in biribrite and talc-carbonate rocks relative to their primary source rocks i.e. dunite-harzburgite, it is possible that both Ni and Co were enriched by secondary process in the biribrite and talc-carbonatized rocks.

Geochemical Correlation of Trace element

The geochemical data obtained by the analysis of the samples from Jebel El Zaraf biribrite were processed by the program (SPSS). Correlations were carried out for 6 element: Mn, Fe, Cr, Ni, Au, and Pt for 21 samples.

The best correlation was found to be of Cr with Mn (0.8) and Fe with Mn (0.54), however weak positive coefficient of correlations could be inferred between Fe and Cr (r = 0.25). Gold and Fe show relatively good correlation with coefficient equals to 0.5. This suggests that the two elements Au and Fe were either deposited contemporaneously i.e (during the same time of formation) or they were of the same mineralizing solution.

Negative geochemical correlation with coefficient ranging between 0.23 and -0.44 are found to occur between the pairs Ni-Mn, Ni-Au, Au-Mn and Au-Mn and Au-Pt.

Nickel – Cr, Ni-Pt, Mn-Pt show insignificant correlation. Gold shows positive correlation with Fe and Cr and negative correlation with Ni, Mn, and Pt.

Table 3 Trace Element-Analysis of Biribrite-Jebel Elzarafa (Gala En-Nahal).

Pro. No.	Sa No.	Fe	Mn	Ag	Cu	Cr	Pb	Ni	Au	Pt
0	D- 1	74460	2100	-	120	4760	-	1470	18.58	0.9
	D- 2	64720	1900	-	110	4230	-	1380	13.2	0.72
	D- 3	107141	3500	-	130	9260	-	2150	15.47	1.16
	D- 4	75150	1300	-	N.D	6090	-	3020	18.07	0.76
	D- 5	86080	1800	-	N.D	2660	-	2790	1.05	0.26
I	D- 6	77240	300	-	50	5160	-	2120	0.39	0.68
	D- 7	72130	470	-	N.D	2510	-	3120	13.56	0.53
	D- 8	73990	2330	-	N.D	5510	-	3040	5.05	0.95
	D- 9	79370	2600	-	N.D	3720	-	2520	20.52	0.22
	D- 10	108200	2900	-	N.D	4380	-	2100	N.D	0.44
	D- 11	134590	4400	-	430	6200	-	3390	6.45	0.14
	D- 12	96210	7700	-	N.D	2843	-	2590	3.11	0.18
	D- 13	67660	2400	-	N.D	2450	-	2400	13.72	0.35
	D- 14	55710	2200	-	N.D	4510	-	2430	5.64	0.45
III	D- 15	-	-	100	110	3900	100	3500	0.34	-
	D- 16	-	-	90	120	1900	130	3900	0.38	-
	D- 17	-	-	60	140	3100	120	3400	0.43	-
	D- 18	-	-	50	130	3000	120	3900	0.21	-
	D- 19	-	-	50	160	2700	140	2900	0.28	-
	D- 20	-	-	80	180	2600	160	5300	0.40	-
	D 21	-	-	70	180	4500	110	3900	0.27	

Table 4 Correlation/Variable All with All.

	Fe	Cr	Mn	Ni	Au	Pt
Fe	1	0.29	0.54	-0.44	0.47	0.2
Cr		1	0.88	-0.06	0.25	0.07
Mn			1	-0.23	-0.086	0.01
Ni				1	-0.44	0.05
Au					1	-0.01
Pt						1

Dispersion Patterns of Trace Elements

The general factors that control the geochemical dispersion of ore elements in the semi-arid environment are: Eh-Ph conditions, complexion agents, biological reaction, absorption and Base Exchange reactions, diffusion and solubility.

The dispersion of Au, Pt, Ni, Cr, Cu, in the study area is constructed in the form of iso- concentrate map. The morphology of haloes of these maps indicates that:

- The ore zone is elongated in N-S direction.
- The contents of the element gold increase towards the outer zones of the anomalous area i.e towards the content of the outer zones of the anomalous area i.e towards the contact of the biribrite in the talc-carbonate. Nickel content increase towards the inner zone of the biribrite reaching 0.52% in the upper part of the hill. In chromite crystals and talc-carbonate towards the outer contact of the serpentinite and grades upwards into calc-silicates and silicate in the form of quartz stock work. Tectonic structures (faults, shear zones ...etc.), which are believed to be related to the final stages of Pan African thermo tectonic events prevailing in NE African terrains, seem to be the controlling factors for localization of our bodies associated with ophilolitic complexes. Similar structure and similar mineralization zones have been reported in the bou Azzir ophiolitic in morocco. According to (3) gold may migrate in the oxidizing water in shear zone according to one or combination of more than one of the following processes:
- As a metal- Au apparently in solution or in a dispersion state as a colloid protected by various other colloids including silica and hydrous Fe-oxides, or/and: as hydro-complexes in the form of Au OH, Au(OH_2), or/and as various dissolved halides (mainly chloride complexes). Precipitation of gold takes place by a number of mechanisms; the following mechanism is assumed to be the most effective in the mineralization type of Gala En-Nahal:
- Sudden change (increase or decrease) of geochemical characteristics (PH) of the pregnant solutions.
- Precipitation of native gold by the ferrous-ferric transform reaction.
- Adsorption and/or coprecipititation of negative charge gold complexes and colloids by positively gels such as hydrous ferric oxides (limonite).
- Precipitation by manga nous ions where Au is commonly adsorbed or absorbed by hydrous manganese oxides.

Structure and metallotectonics of ore zone

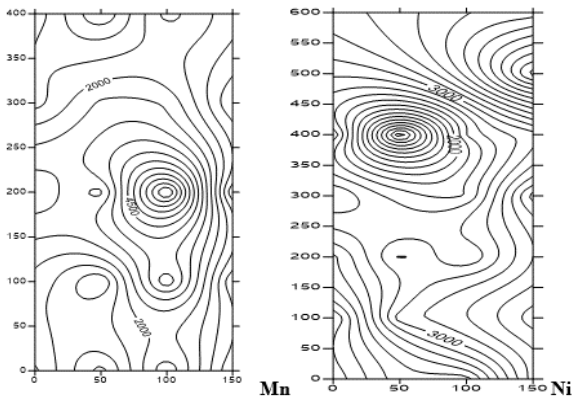
The area of Gala En-Nahal are highly tectonized; they show high degrees of alternations especially along shear zone. The main tectonic feature in the area of Gala En-Nahal is the NE-SW shear zone. This zone is a ductile zone which resulted in offsetting the sutures and dismembering the ophiolite belt. Gold mineralization is believed to be structurally controlled along the fracture zones; channel ways form the structure traps for hydrothermal fluids that precipitated the gold. Hydrothermal activity continued probably during a prolonged shearing movements, as has been found elsewhere in Sudan e. g Araiab district of NE Sudan.

In Gala En-Nahal area the NE-SW shear zone is regarded as the tectonic feature which played the major role in mineralization of the biribrite and adjacent to the structural feature.

Gold in Biribrite

Jebel El Zarafa biribite (Gala El-Nahal area) is 250m in height, 1.5 Km in length and 500 m in width. It consists of siliceous red-brown jasper like facies with iron oxide staining and is developed on talc-rich red serpentinites. The dominant mineralized composition is that of serpentinites with accessories limonites, hematite, and pyrite chrome. This biribrite has shown the existences of gold mineralization in anomalous content ranging from 0.3 to 20 ppm. The biribrite and the carbonated facies are located along a shear zone .small quartz stock works veins and pockets of amorphous silica with aresenopyrite are found in talc-carbonate rocks surrounding the biribite.

Similar facies were described in Ambed formation (Morocco) at Feetaze River and cove gold, associated with sulphides of carbonate replacement deposits, at which silicification is common place of gold-arsenic (antimony) deposits. According to (Khalil, B.D. 1986) (7) the jaspariod is extensively hydrothermal .



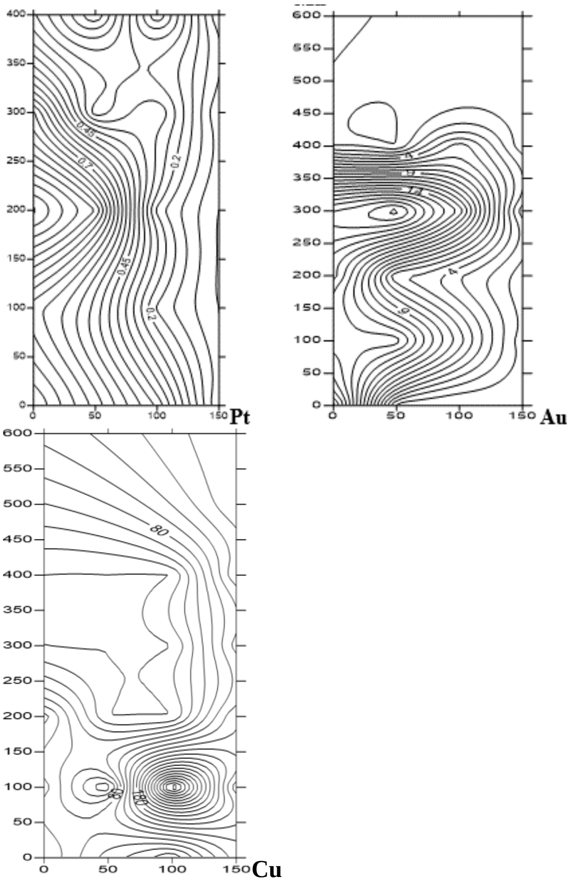


Figure 2 Isoconcenstrate maps of trace elements of ultra-basic rocks in Gala En Nahal.

Characteristics of Gold mineralization

Ore Control

The major controlling factor for gold mineralization is the NE-SW shear zone, which considered as depositional traps. This zone has well developed fractures and channels for the mineralizing fluids. Theses late stage mineralizing fluids have permeated through fractures and shear zones. Field observations and mineralogical investigations show that the most outstanding features of wall-rock alteration are:

- Silicification of serpentinite by Si-rich solution with formation of vein lets and quartz stock work along the shear zone.
- Ferrignization of the host rock (serpentinites).
- Chloritization of the serpentinized rocks.

Mineralogy of Jebel El Zarafa Biribrite

The ore minerals of Jebel El Zaraf have been strongly tectonized and display several phases of crystallization. The main ore minerals are gold, Ni ores, pyrite, aresenopyrite, sphelerite, Pt, Mn ores, and chromite. The gangue mineralas include silica and iron oxides and hydroxides (limonite and magnetite). This siliceous red-brown jaspear-like facies has well developed on talc-rich serpentinites associated with bodiform chromite.

Genesis of the Gold in Jebel El Zarafa Biribite

The most important aspect of the genesis of gold mineralogy in biribrite is the location along the shear zones or on top of the serpentinte massives in the upper Proterozoic ophiolite, within quartz carbonate gangue related to the serpentinites. This model is similar to Bou Azzir gold deposits of Morocco.

The genesis of quartz-carbonate ores and iron-oxides and their age of mineralization is a subject of controversy. Many authors related the genesis to hydrothermal solutions of Cambrian age or to metasomatic processes. Biribrite may be resulted from the weathering process of the serpentinite. In Jebel El Zarafa biribrite gold mineralization is associated with sulphides; in Bou Azzir (Morocco), sulphurasenndes or aresenides.

According to (1) the gold is transported by Co-S-C1-Na-K-B-rich fluids along tectonic contact and as a result of increase in PH, gold was precipitated with these minerals and silica.

Reserve

The preliminary gold reserve from a layer/meter thick, an area of 60,000 m2, and average element (Cav) equal 10 ppm is calculated by following the formula: QH=S.H.(S.G).Cav.10=60,000 2.5 ×10 ×10 can be estimated as (1.500) tons.

Platinum Group Elements (PGE)

Platinum group of elements (PGE) has been recently reported from Ethiopia where associated with biribrite along shear zones or on top of the serpentinite massive of upper Proterozoic age. Enrichment of the platinum group of elements may either be related to hydrothermal mineralization or to secondary processes of laterization enrichment. Such lateritic deposits have become target for possible economic concentration of platinum group elements (PGE).

Fourteen chip samples collected from Jebel El Zarafa biribrite have shown platinum contents ranging between 0.14 and 1.16 ppm with mean value of 0.55 ppm. Platinum a shows reliable positive geochemical correlation with Fe and insignificant positive geochemical correlation with Au.

The anomalous content of (PGE) in biribrite support their secondary processes of literization on the other hand (2) has considered the enrichment of platinum group of elements to be magmatogening. PGE in the form of nuggest have not yet been observed in the study area.

Nickel

In the area covered by reconnaissance study varieties of rocks were collected to prospect for nickel anomalies. Among the different rock types biribrite shows the highest anomalous content of Ni Jebel El Zarafa biribrite was chosen for detailed prospecting through profiling. The results show high nickel contents.

The general ideas related to weathering of serpentine follw this sequence:

- The process of weathering serpentine is broken down into its constituents, which are dissolved by water.
- Then the metals contained in these serpentine are leached out and precipitated in different depths.

- Nickel, originally uniformly disseminated in the rock, now accumulate at a definite depths.
- The lowest level of the Jebel has anomalous Ni content ranging between 0.147% to 0.21%. The average anomalous contents is 0.19%. The middle level has anomalous contents between 0.251% - 0.3045 % with o.25% average. The highest level has anomalous content of nickel between 0.24 % - 0.53 % with average concentration of 0.28 % which represents the highest content of nickiliferous biribite. This nickiliferous serpentinite is characterized by silicification and ferrugnization resulting in the characteristic hardness and brown colourization of the host rock. In conclusion, Jebel El Zaraf has nickiliferous laterite mantle on the highest watershed, with nickel bearing weathered serpentinite along linear crushed zone east of the Jebel.

Conclusions

- Deposited tectonic disruption due to repeated deformational cycles Qala En-Nahal complex display the following cricteria characteristic for ophiolitic complex
  - i- Full range of lithologic assemblage**:** (layered gabbros periodotite, pyroxinite, pillowed basalts and calc-silicates)**.** Now all of these are serpentinized.
  - ii- Regional structural position and internal structure: the complex is aback arc marginal basin with linear trail concordant coinciding with the general regional geological strike.
  - iii- Characteristic mineral and element assemblages usually associated with ophiolitic viz: pod form chromite deposits, sulphides of Ni, Cu,Co (occurring as anomalous element content disseminated in pyroxenites).
  - iv- Native Au, PGE, Alloys (forming manute inclusions within the nickel sulphides). The anomalous elements content of the above mentioned metals are found to be specially enriched in biribrite cap rock. Out of the above mentioned minerals and elements and only chromite and talc are now being mined in small scale.
- Stream sediment sampling method (heavy concentrated- black sands- mineralogical method) and lithochemical method (secondary dispersion) proved to be usefull tools for detailed prospecting to reveal secondary haloes, blind and/or ore convered showings.

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