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Hydrothermal Alterations in Irbiben Gold Deposit (Tagragra Akka, Western Anti-Atlas, Morocco): Petrographic and Geochemical Characterization

Tokpa Kakeu Lionel-Dimitri Boya[1], N'Guessan Nestor Houssou[1], Marc Ephrem Allialy[1], Allou Gnanzou[1], Lamia Erraioui[2], Benyounes Maamar[3], Souad M'Rabet[2]

[1]Geology of Basement and Metallogeny Laboratory (GBML), Training and Research Unit of Earth Sciences and Mining Resources, University of Felix HOUPHOUET-BOIGNY, Abidjan-Cocody, Côte d'Ivoire
[2]Georesources and Environment Laboratory, Department of Geology, Faculty of Sciences, University Ibn Tofail, Kenitra, Morocco
[3]Managem Group, Tower A, Twin Center, Casablanca, Morocco
Email: lionelboya2000@yahoo.fr

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Abstract

Irbiben is a small gold deposit of the Precambrian inlier Tagragra d'Akka located in the Moroccan western Anti-Atlas, approximately 160 km southeast from Tiznit. Petrographic study shows that host rocks of Irbiben deposit are green schist facies metamorphic rocks, like metamorphic sandstone and schist, meta-pelite and quartzite. Gold is located in quartz veins or host rock with frequent injections of quartz. The petrographic characterization of alteration through the description of the alteration profiles and the comparative study of protolith and altered rocks showed a development of dominant quartz and calcite in mineralization wall-rocks. In moving away from it, there is rather sericite and chlorite. These phenomena are materialized respectively by the development of SiO_2 and CaO in the wall-rocks but rather that ferromagnesian elements (FeO, MgO) and K_2O away from the mineralization. These trends were demonstrated by the geochemical study through Harker diagrams, description of alteration profiles, comparative study of protolith and altered rocks, and use of a new alteration index, MIA, elaborated during this work.

Keywords

Irbiben Gold Deposit, Hydrothermal Alteration, Petrography, Geochemistry, Morocco

1. Introduction

The Irbiben gold deposit, formerly operated by the Akka Mine, is located in the Akka Tagragra inlier. It is located about 160 km Southeast Tiznit city, in the Western part of the Moroccan Anti-Atlas. This area is known for its numerous deposits, including the Imiter and Zgounder silver deposits as well as the Tiouit gold deposit. The inlier, outside Irbiben, also allowed the exploitation of gold in other sites such as Iourirn, Ifarar and Angarf.

As part of our missions in this area, we have made some observations: the presence of traces of hydrothermal activity in the wall rock of the mineralization. Indeed, in addition to the deformation caused by the placement of the gold-bearing quartz veins in the host rocks, a change, however minor, affects these in their mineralogy and their chemistry. This is why this paper proposes to identify and characterize this hydrothermalism through a petrographic and geochemical study of alteration.

This work deals with the study of hydrothermal alterations in Irbiben. Several studies [1] [2] [3] [4] have shown that there are close links between the development of gold mineralization and hydrothermal alterations. Indeed, this type of association occurs in deposits of the Tagragra of Akka [3] [5] of which Irbiben is a part of.

2. Global Geological Framework and Location

Morocco is subdivided into several structural domains which are from north to south: the Rifain domain, the Mesetian domain, the Atlasic domain, the Anti-Atlasic domain and the Saharan domain. Our study area is located in the Akka Tagragra inlier which is part of the Western Anti-Atlas area (**Figure 1**).

This inlier is made of a Precambrian basement and a slightly deformed Palaeozoic cover. The Irbiben deposit is located in its eastern part (**Figure 2**), to

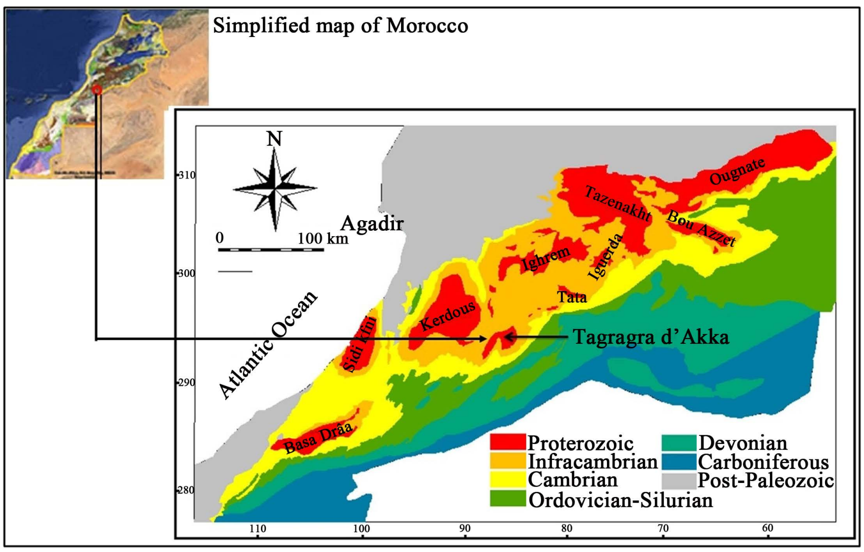

Figure 1. Simplified geological map of the Anti-Atlas and its location in Morocco, with the location of the Tagragra of Akka inlier (Soulaïmani, 1998, modified) [6].

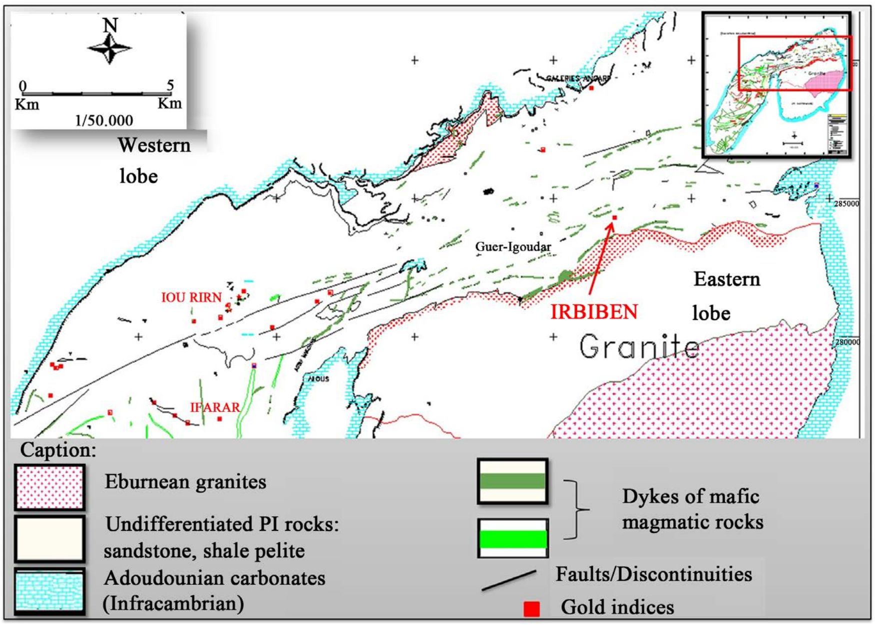

Figure 2. Simplified geological map of Akka inlier at 1/50,000, with the location of Irbiben (AGM Geology Service 2007, modified).

the south of the large ENE shear-zone crossing through much of the inlier, about 20 kilometers from the Iourirn mining center.

3. Lithology

The Irbiben deposit consists of rocks of both sedimentary and magmatic origin, with mineralization hosted in the sedimentary rocks. The age of the host is attributed to the Paleo-Proterozoic [7].

The sedimentary rocks consist of greywacke and sandstone alternating on a metric scale with pelites (**Figure 3**). These formations have been affected by the known epizonal metamorphism in the region, hence the presence of meta-sandstones, meta-greywacke, meta-pelites, quartzites and sandy shales in places. The sandstone material is dark gray and the pelites are black in color. The sandstone schist is distinguished from the other formations by their degree of schistosity. Meta-sandstones are sometimes deformed and injected with quartz. They can be mineralized. All these formations of the base are affected by the schistosity S_1 which follows the stratification S_0, forming a fabric S_0S_1 of medium direction N60. The schistosity S_2 is observed in several places and of direction near from N10 to N15. Some meta-sandstones are crossed by carbonate veins.

The proportion of quartz of certain silicified sandstones where the effects of regional epizonal metamorphism have not been detected, their hardness and their appearance make it possible to assimilate them to greywacke.

Magmatic rocks consist of diorite and quartz micro-diorite outcropping in the form of dykes, aplite vein and massive granite.

The dykes are scattered in the deposit near the mineralized structures and further in the southern part of the deposit where they are in contact with the

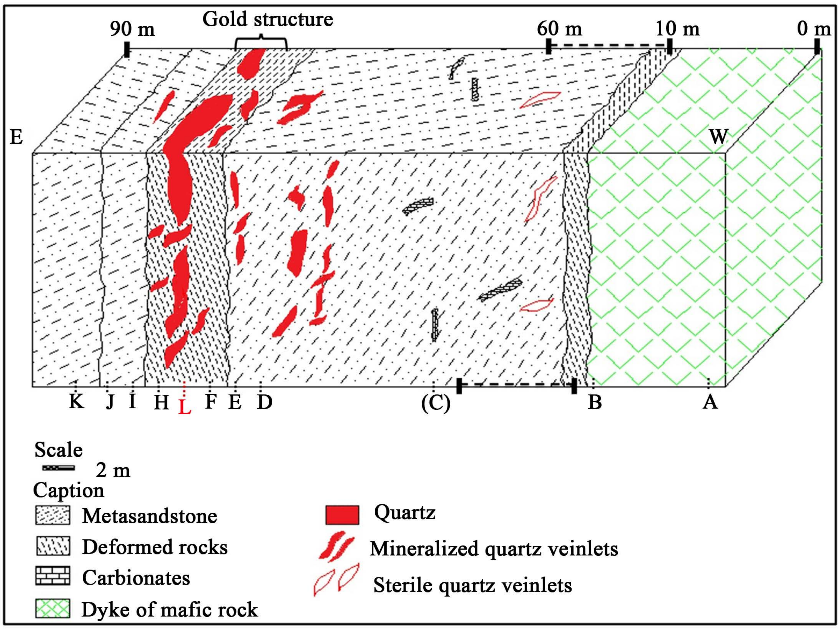

Figure 3. Geological mapping of the southern facing of TB-70 in the Irbiben deposit, with the location of the samples taken.

granite. They are generally of direction neighboring N40 to N60. Those in the southern part of the deposit have no direct link with the mineralization. Their thickness varies between ten to twenty meters and their variable extension can reach hundreds of meters.

The granite outcrops in the form of a massif. It presents in some places a clear limit with the dyke, of direction between N30 and N50. It intrudes the meta-sedimentary formations of the PI basement and occupies all the rest of the southern part of the eastern lobe of the inlier. Mortaji [8] assimilates it to granite with biotite or biotite and secondary muscovite.

The aplite there is lode, located in an intermediate zone between the granite and the dyke.

4. Materials and Methods

Twelve (12) samples were taken from the cross-bed siding at the level −70 m (TB-70), then in operation. They are designated A, B ... up to L (**Figure 3**). Eight samples designated IRBC43A to IRBC43H were also taken from the IRBC43 drill core that intersected the host formations and the NE gold quartz vein.

The petrographic study required a macroscopic and then microscopic flap, after preparation of thin plates.

Eight (8) samples were subjected to inductively coupled plasma mass spectrometric (ICP-MS) at the REMINEX research center of the MANAGEM group in Marrakech. These are two samples from the NE1 Irbiben structure of the −70 level and six from its vein wall and of the host on the sides of the vein.

Figure 3 shows the geological mapping of the southern cross-bench facing (TB-70), with the location of the samples taken and the gold structure.

5. Results and Discussions: Characterization of Hydrothermal Alterations

5.1. Alteration Petrography

5.1.1. Alteration Profiles Description

The study of alteration profiles in the Irbiben deposit required the prior observation of the hosting rocks crossed by the gold-bearing structure. Table 1 summarizes the results of the IRBC16 and IRBC43 drilling cores observations, in particular areas intersected by the gold structure.

The IRBC16 drilling intersects three gold levels. The first is materialized by a massive vein of smoky white quartz, arsenopyrite, pyrite and fine gold visible to the naked eye, while the second and the last correspond to a set of veins of smoky white quartz with arsenopyrite, pyrite and chalcopyrite carried by metapelites. The first gold level crosses a quartzite and the other two are hosted in metapelites.

The IRBC43 drilling intersects two gold levels. The first is a white gray quartz vein, brecciated, with pyrrhotite, pyrite, chlorite and sericite. Its fractures are filled with oxides and it crosses a metasandstone formation. The second gold level is rather a silicified meta-sandstone with numerous injections of gray quartz associated with carbonates. It is also with oxides, sericite, chlorite, pyrite, pyrrhotite and arsenopyrite. It marks a boundary between a metasandstone rock and a graphitized black metapelite.

These observations show the existence of different auriferous structures of the quartz veins. It is the host, metasandstone or metapelitic, with numerous injections of mineralized quartz.

The hydrothermal activity associated with the placement of the gold vein influenced the host rocks. This is reflected in an increase in their silica rate and an iron intake. This contribution is materialized by the deposition of ferriferous sulphide minerals such as arsenopyrite, pyrite or chalcopyrite that accompany the deposition of gold mineralization. The complete observation of the cores showed that the highest gold grades were found in the vein levels, where they could reach 14 g/t for the IRBC43 drilling or 13 g/t for IRBC16. The grades found in the metasedimentary material are less important, oscillating between 1 and 4 g/t.

Mineralized veins are mainly composed of silica and carbonates. This explains why the host rock affected by the hydrothermal fluid underwent enrichment in these elements, materialized by more developed quartz and calcite in the vicinity of the gold zone. The placement of the vein was also at the origin of the deformation detected in the host and materialized by a mylonitization.

5.1.2. Petrographical Characterization of Alteration

The mineralogical changes between the host rock and the wallrock of the gold vein reflect the decreasing impact of the hydrothermal fluid on the host by moving away from the vein. This is why we choose to highlight the comparative

Table 1. Synthesis of the macroscopic study of core drillings crossing the Irbiben NE1 gold structure and the meta-sedimentary host in the Irbiben deposit.

Core rilling	Level	Crossed old vein	Macroscopic description of the facies
IRBC16	19 to 23 m		**Superior hanging wall (ROOF)** Quartzite with quartz vein and chlorite
			GOLD STRUCTURE Smoky white quartz with traces of arsenopyrite, pyrite and presence of very fine visible gold
			Lower hanging wall (WALL) Quartzite rich in white quartz lodes, with pyrite, arsenopyrite and chalcopyrite filaments
	36 to 41 m		**ROOF** Mylonitized black metaplite very rich in smoky white quartz lode and veinlets, very rich in arsenopyrite, pyrite and chalcopyrite
			GOLD STRUCTURE Smoky white quartz lodes and veinlets with arsenopyrite, pyrite and chalcopyrite, hosted in metapelites
			WALL Black metapelite with pyrite quartz lodes, chalcopyrite and traces of arsenopyrite
	47 to 50 m		**ROOF** Black metaplite with quartz veinlets, arsenopyrite and rich in pyrite
			GOLD STRUCTURE Graphitized black metaplite rich in white quartz lodes with arsenopyrite, abundant pyrite and chalcopyrite
			WALL Pelitic meta-sandstone
IRBC43	120 to 123 m		**ROOF** Meta-sandstone with frequent injections of quartz deformed and oxidized with pyrrhotite and pyrite. Presence of chlorite and traces of carbonates
			GOLD STRUCTURE Oxidized and brecciated white gray quartz gray in its cracks, with chlorite, sericite, pyrrhotite, pyrite. Presence of very fine gold difficult to observe
			WALL Crushed and mylonitized meta-sandstone, with quartz injections in places
	127 to 129 m		**ROOF** Meta-sandstone with frequent injections of deformed white gray quartz,with chlorite, sericite, pyrrhotite, pyrite, carbonate in traces and oxidation of iron in quartz veinlets
			GOLD STRUCTURE Highly silicified meta-sandstone with gray quartz and carbonates, oxides, sericite, chlorite, abundant arsenopyrite, pyrrhotite and pyrite
			WALL Graphitized black metaplite, with brecciated quartz veins, pyrite, pyrrhotite and arsenopyrite

microscopic study of two samples, one considered as control rock and the other as altered rock.

The protolith is located 3 m from the gold vein. This is sample D. It is a metagreywacke composed of quartz, healthy plagioclases and micas. Automorphic and sub-automorphic quartz and plagioclases have an initial orientation. Micas are interstitial.

The altered rock constitutes the wall of the mineralization (sample F). This is a distorted meta-greywacke. It contains much more quartz, fewer healthy plagioclases, most of which are altered, sericite, chlorite, calcite and epidote.

Observing also the mineralized vein (sample L), we find that it is essentially dominant quartz and calcite. The altered rock contains, in addition to the minerals of the control rock, new minerals such as well-developed calcite and epidote. Furthermore, the proportions of the minerals common to both samples vary in terms of the distance to the vein. Sericite and chlorite have higher grades in the hanging wall. These observations are illustrated in **Figure 4**.

By approaching the vein, the host is enriched much more in quartz and calcite than in sericite and chlorite. The host is metasedimentary, which explains the presence of sericite and chlorite in its composition. However, in contact with the vein, it knows enrichment in these minerals. The hydrothermalism accompanying the placement of the vein influences the composition of the host rock by a contribution of silica and carbonates materialized by the appearance of quartz Q_{III} and calcite or the development of quartz Q_{II}. Alteration sericite originates essentially from the destabilization of pre-existing minerals such as plagioclases and chlorite comes from a neo-formation of minerals accompanying deposition of the mineralization. The various alterations are silicification which is the most important and which is associated with calcitization, sericitization and chloritization. Hanging walls are more marked by silicification and calcitization. These phenomena have already been observed in the Ifarar deposit [5].

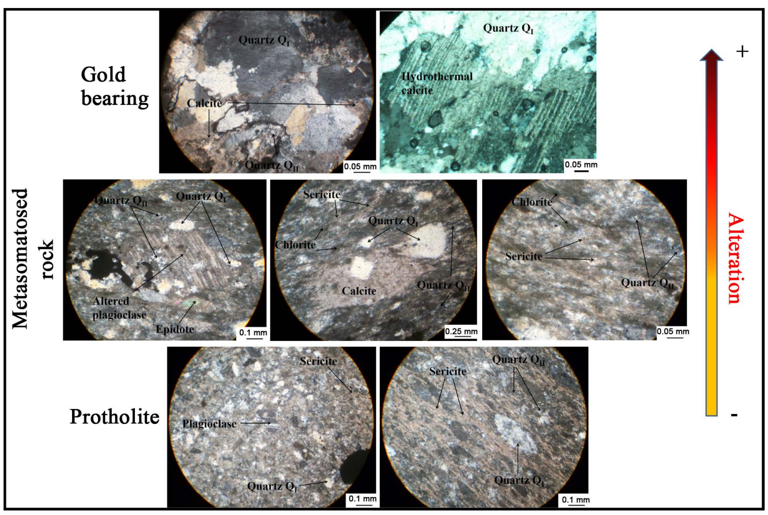

Figure 4. Microphotographs of thin slides showing the mineralogical evolutionof the gold-bearing vein to the control rock.

5.2. Alteration Geochemistry

The oxide weight grades of the samples analyzed show notable variations for some, in particular SiO_2, for which they are between 82.49% and 54.52% (Table 2). The highest grade characterizes the gold vein and, on the mineralogical level, it is represented by an abundance of quartz minerals, in the form of 3 distinct petty-types. The quartz Q_{III} which is the most recent and resulting from the hydrothermal alteration is the most represented. From the host rock to gold structure, the amount of quartz of the rocks increases, which is corroborated by the geochemical analyzes which show a gradual increase of SiO_2 of 54.52% in the host rock to values reaching 64.57% in the hanging wall to be maximum in the vein (78.45% and 82.49%). This increase is caused by the interaction of the hydrothermal fluid at the origin of the aqueous silica supply as in the Ifarar deposit [5]. This influence is materialized on the ground by a silicification, more important in the level of the hanging walls and which is translated by a predominance of hydrothermal quartz Q_{III}.

Except for CaO and MnO grades that increase with the SiO_2 grade in the rock, the other analyzed oxides show downward tendencies as they move closer to the gold vein (Figure 5).

To understand better the impact of the gold vein on its host rock, an average of the oxide weight grades was calculated for samples from rocks equidistant from the vein on both sides. The evolution has therefore been followed from the gold-bearing structure, passing through the hanging wall to the more distant rocks. These new calculated grades are presented in Table 3.

Table 2. Geochemical analyzes in major elements of Irbiben samples.

	Host		Wall rock	Wall rock	Host		Gold vein	
	D	E	F	H	I	J	L1	L2
SiO_2	62.38	58.92	61.79	64.57	57.05	54.52	78.45	82.49
TiO_2	0.77	0.79	0.63	0.62	0.76	0.86	0.24	0.12
Al_2O_3	16.11	18.01	13.18	15.77	20.14	20.99	6.46	3
Fe_2O_3*	0.66	0.72	0.83	0.51	0.57	0.62	0.39	0.33
$FeO_{calculated}$	5.9	6.37	7.39	4.51	5.04	5.54	3.52	2.93
FeOtot	6.56	7.09	8.22	5.02	5.61	6.16	3.91	3.26
MnO	0.04	0.04	0.07	0.04	0.03	0.03	0.06	0.08
MgO	4.15	4.38	4.57	3.27	3.69	3.88	1.4	1.24
CaO	0.22	0.4	1.73	0.39	0.15	0.1	2.5	3.78
Na_2O	0.97	0.31	0.19	0.18	0.3	0.33	0.14	0.1
K_2O	3.27	4.35	2.84	4.58	5.99	6.03	1.9	0.71
P_2O_5	0.09	0.09	0.08	0.09	0.09	0.1	0.04	0.02
PF	4.13	4.71	4.93	4.47	4.96	5.47	3.78	3.83
FeO + MgO	10.71	11.47	12.79	8.29	9.3	10.04	5.31	4.5
Na_2O + K_2O	4.24	4.66	3.03	4.76	6.29	6.36	2.04	0.81

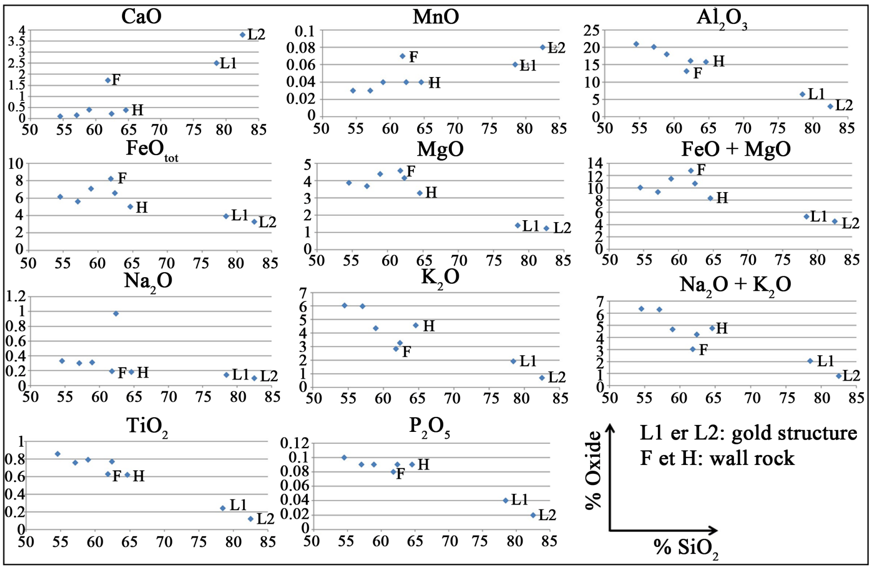

Figure 5. Harker diagrams of oxide variation of samples as a function of SiO_2.

Table 3. Mean oxide grades calculated for samples situated at the same distance from the gold vein.

	Vein Au (L)	Wall rock F – H	E – I (2 m)	D – J (3 m)
SiO_2	80.47	63.18	57.985	58.45
TiO_2	0.18	0.625	0.775	0.815
Al_2O_3	4.73	14.475	19.075	18.55
Fe_2O_3*	0.36	0.67	0.645	0.64
$FeO_{calculated}$	3.225	5.95	5.705	5.72
FeO_{tot}	3.585	6.62	6.35	6.36
MnO	0.07	0.055	0.035	0.035
MgO	1.32	3.92	4.035	4.015
CaO	3.14	1.06	0.275	0.16
Na_2O	0.12	0.185	0.305	0.65
K_2O	1.305	3.71	5.17	4.65
P_2O_5	0.03	0.085	0.09	0.095
PF	3.805	4.7	4.835	4.8
FeO + MgO	4.905	10.54	10.385	10.375
$Na_2O + K_2O$	1.425	3.895	5.475	5.3

Al_2O_3 is considered immobile during alteration. The apparent variation of its grade is only a reflection of the mobility of the other components of the host rocks, such as FeO_{tot}, K_2O or CaO.

The ferromagnesian (Fe + Mg) grades of the rocks are associated with the proportion of ferromagnesian minerals such as chlorite (corresponding oxides: FeO_{tot} and MgO) and sericite (K_2O). The highest oxide grade by weight corresponds to the hanging wall. However, the initial rock is potentially rich in these oxides, with about 10.38%. The gold vein presents the lowest grade which is of 4.9%. Although the difference in grade between the gold vein and its hanging wall is significant (from 4.9% to 10.54%), it is not significant, as the rock is already rich in these oxides. This increase is due to a destabilization of the minerals of the host, such as plagioclases, the alteration of which produces sericite, which increases its proportion in the hanging walls. Moreover, the deposition of the mineralization is accompanied by the neo-formation of chlorite minerals. It is a previously observed iron chlorite and is described in other deposits of the Tagragra Akka inlier [3]. An increase in the proportion of chlorite in host rock causes in the hanging wall an increase in the grade of FeO_{tot} and MgO (Table 3), which corresponds to the analyzed and calculated grades. The plagioclases alteration which produces sericite and the neo-formation of ferric chlorite are hydrothermal events corresponding respectively to sericitization and chloritization of the host.

However, sericitization is much more related to the variation of alkalis elements, which increase significantly between the gold vein (1.42%) and the hanging wall (3.89%). The formed sericite mobilizes more K_2O and Al_2O_3 than ferromagnesians which are associated with chlorite. The highest grades of alkaline ($Na_2O + K_2O$), which are 5.3% and 5.47%, characterize the host rock originally formed from minerals containing potassium such as sericite or muscovite.

For the host rocks, the CaO grades varying from 0.16% to 0.27% are lower than that of the hanging walls, which is 1.06% (Table 3 and Figure 6). The highest grade is 3.14% and is associated with the gold vein.

In Irbiben, the gold quartz vein is predominantly composed of quartz, associated with calcite, as shown by the microscopic study (Figure 4). The lowest grades in host rock show a lack of calcite. The CaO grade of the vein and that of

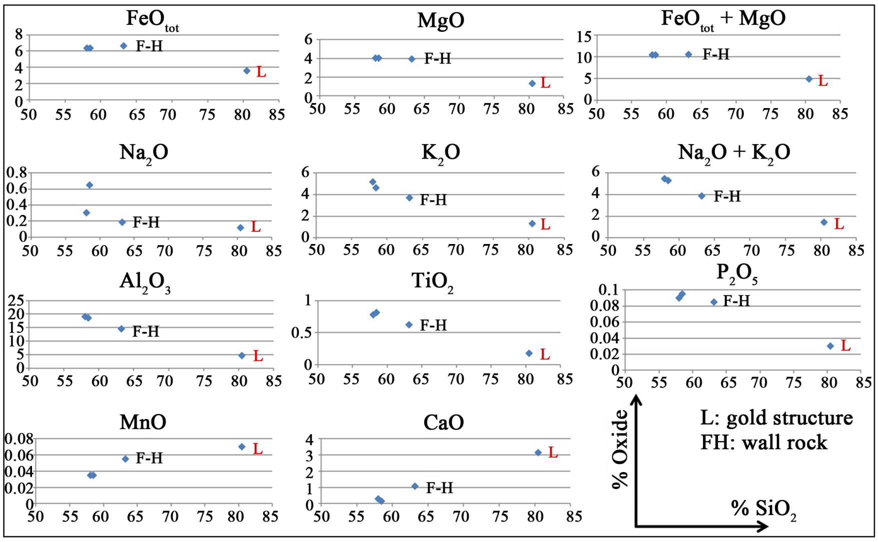

Figure 6. Harker diagrams of oxide variation of the samples as a function of SiO_2, obtained from the mean of the grades for equidistant samples of the vein.

the hanging wall reveal the influence of the hydrothermal fluid on host rock by a carbonate supply. The orogenic gold deposits are characterized by aquo-carbonic fluids [9] [10] [11] and their circulation is almost always associated with the addition of CO_2, K and S, with a slight addition or loss of other major elements [9]. The presence of carbonates has also been reported, associated with the quartz of these veins [12]. In Irbiben deposit, the mineralogical changes observed in the host rock make it possible to suspect a fluid of this type. Its interaction with the initial calcium (detected by geochemical analysis) of the host rocks caused the formation of hydrothermal calcite in the hanging walls, by alteration of the plagioclases. The formation of hydrothermal calcite in the deposit corresponds to calcitization.

The mobility of trace elements such as boron, barium, strontium and lead should be considered in the study of hydrothermal alterations. **Table 4** presents the correlations between the major elements and significant traces in the study of the alteration.

Boron which is generally associated with hydrothermal minerals has good correlations with K_2O (0.82) and FeO_{tot} (0.68). In the Irbiben deposit, in addition to the ferrous sulphide minerals, some hydrothermal minerals may be ferriferous, such as the chlorite which accompanies mineralization. Changes in K_2O are associated with sericitization. Boron associates with sericite and chlorite, which explains its high grades in the host rocks of the deposit (101 ppm to 123 ppm), except in the vein where values are very low (31 ppm to 52 ppm).

Barium has also a good correlation with TiO_2, FeO_{tot} and K_2O. These oxides have their grades which increase with the alteration. Its strong negative correlation with calcium (−0.80) reflects the significant substitution of calcium from the host rocks by barium. This explains why the host rocks are not rich in calcite.

Table 4. Correlations matrix between major elements and traces revealing the alteration.

	SiO_2	TiO_2	FeO_{tot}	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	B	Ba	Pb	Sr
SiO_2	1												
TiO_2	−0.97	1.00											
Fe_2O_{tot}	−0.76	0.70	1.00										
MnO	0.39	−0.42	−0.18	1.00									
MgO	−0.64	0.71	0.39	0.18	1.00								
CaO	0.61	−0.64	−0.43	0.90	−0.04	1.00							
Na_2O	−0.41	0.55	0.31	−0.15	0.56	−0.20	1.00						
K_2O	−0.85	0.80	0.46	−0.66	0.28	−0.78	0.11	1.00					
P_2O_5	−0.18	0.09	0.41	−0.42	−0.52	−0.53	−0.33	0.38	1.00				
B	−0.88	0.82	0.68	−0.39	0.36	−0.58	0.27	0.82	0.38	1.00			
Ba	−0.90	0.89	0.68	−0.67	0.33	−0.80	0.35	0.89	0.40	0.85	1.00		
Pb	−0.06	0.06	0.41	−0.27	−0.20	−0.14	0.24	−0.06	0.15	0.10	0.21	1.00	
Sr	−0.10	0.16	0.25	0.25	0.15	0.23	0.37	−0.09	0.00	0.26	0.12	0.44	1.00

In the Irbiben deposit, variations in lead and strontium are not significant, indicating poor mobility of these elements during alteration.

❖ **New MIA alteration index**

This work led to the development of a new index of alteration MIA, resulting from the modification of that of Ishikawa, modified by substitution in the previous formula of sodium by total iron. It is calculated from the weight percentages of oxides and is obtained by the formula:

$$MIA = 100 * (MgO + K_2O)/(MgO + K_2O + CaO + FeO_{tot})$$

Its use has shown certain tendencies, notably an evolution of the inverse index to that of the SiO_2 grade in the samples (Figure 7).

The enrichment of iron and calcium is related to the preliminary observations: the development of hydrothermal calcite and newly formed chlorite when getting close to the the mineralized vein. Iron-bearing sulphides are also more abundant at this level, as shown by the metallographic study. From another angle, the variation of this index shows an increase in magnesium and potassium when getting away from the gold structure. This tendency shows the development of sericitization. On the other hand, chlorite in this case is rather magnesian. Differences have been detected both in the microscope and in the microprobe [3].

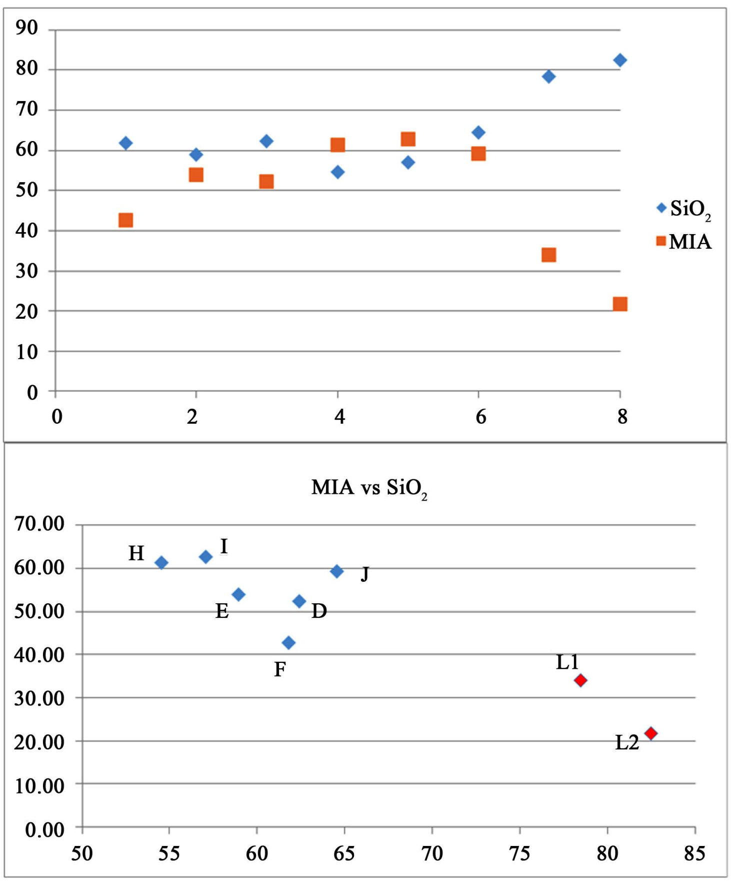

Figure 7. Comparative variation of MIA and SiO_2 (upper); Variation of the MIA index as a function of SiO_2 content (bottom).

5.3. Discussion

The gold mineralization of Akka Tagragra inlier is carried by quartz veins and hosted by metasedimentary and igneous formations. Unlike the main deposit Iourirn in dykes of basic magmatic rocks [3], no dyke was intersected by gold veins at Irbiben. However, as at Iourirn where hydrothermal alterations were noted by Zouhair [7] and Benbrahim [3] the hydrothermal phenomena were recorded in Irbiben. The placement of these veins has led to the formation of quartz with recrystallization texture, iron chorite, recognized by Benbrahim [3] and sericite. The newly formed calcite associated with quartz corresponds to what has already been described by Dubé and Gosselin [12]. The interest of this study was to demonstrate the hydrothermalism accompanying the setting of inlier mineralization. Following the example of the Ishikawa alteration index, the new MIA index developed in this study will show enrichment in iron and calcium in placement of gold veins in similar deposits. However, it would be interesting to carry out a further mineralogical characterization of the hydrothermal minerals by microprobe. Moreover, a combined study of fluid inclusions in the host rocks to compare them to metasomatised rocks would better characterize the hydrothermal fluid.

6. Conclusions

The host formations of the Irbiben deposit are composed of rocks generally metamorphosed in the green schist facies. They are predominantly sandstone schists and metasandstone, to which are added metapelites, quartzites and grauwakes. A granitic massif south of the deposit and diorite dykes has been identified.

The hydrothermal activity has led to the formation of secondary minerals such as calcite, sericite, chlorite or quartz Q_{III}. These mineralogical changes are reflected in the chemical composition of the rocks, resulting in a much higher silica and calcium grade, much more important in the hanging walls accompanied by an increase in iron. These tendencies could be corroborated by the use of the new MIA alteration index bringing out the iron enrichment accompanying the calcitization, as well as the matrix of correlations showing the mobility of certain elements such as calcium and barium, or still the very positive correlation between boron, potassium and iron. By moving away from the gold structure, the predominant ferromagnesian and alkaline grades are due to sericitization and chloritization but also and above all to a predisposition of the host, initially rich in these elements. Such changes noted in the hanging walls and the host rock of the Irbiben deposit reveal aquocarbon mineralization fluid of the orogenic deposits. The latter can influence the host rock by adding aqueous silica. Its CO_2 component associated with the Ca of host rocks causes the formation of hydrothermal calcite in the hanging walls. This explains the importance of silicification and calcitisation in the hanging walls.

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