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Assessment of morphological and geological environment of manganese containing area in South West of Côte d'Ivoire

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Abstract

The vast majority of manganese indices in the southern Ivorian are closely associated with the birimian formations. Manganese containing formations are mainly located in the upper part of the birimian, particularly in a volcanic and sedimentary environment. Indeed, the Guitry environment includes sedimentary, volcano-sedimentary, and metamorphic formations intruded into various granitoids. Their alteration leads to three major genetic types of minerals: ore in forms of interstratified lenses in the schist from direct oxidation of gondites; dismantling ore from these lenses, forming clusters of blocks, resulting from in situ fragmentation of the previous ore; hardened ore linked to the process of alteration and leaching of the above mentioned ores, then a concentration of manganese following a lateritic type pedological profile. The most economically interesting deposit consists of dismantling surface areas, including highly enriched clusters (90 % of exploitable ore), where manganese is found only in the form of secondary oxides, packaged in a clay soil. During the eburnean orogenesis, the initial manganese containing sediments were transformed to varying degrees in metamorphic rocks. Soils derived from the alteration of these birimian rock formations are known as brunified soils.

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Introduction

While the morphogeology is characterized by landscapes whose appearance depends on the nature of rocks, the morphopedology is a pedological and geomorphological approach to the study of soils aiming to show that the beginning and the evolution of soils are also dependent on the relief. It is also a naturalist approach of the study of landscapes (Benabbas *et al.*, 2008; Rossi,1989).

Pedology integrates morphological and geological information through data on texture, natural soil drainage, profile, and derived series (Closson *et al.,* 1999).

The foundations of the geomorphopedological approach are based on the fact that the model is a major element of agrarian landscape structure. By combining concepts of space and time, this method proceeds from general to particular. Loukili *et al.* (2004), see the landscape as a nested set of interrelated structures, the biggest including and explaining the smallest (Bertrand *et al.*, 1985).

The achievement of such inventories are done on field, based mainly on observations of soil accurately described (surveys, profiles, reference sectors), but highly located in the space.

That is why we based the characterization of geological and pedological of manganese containing environment of Lauzoua on field studies. Field studies are known to make clear the microstructural features of localized deformation zones, including minerals precipitations, and the understanding that the physical processes that govern at various scales these mechanisms are fundamental. In fact, it is to observe a few rocky outcrops, to describe the entire pedological horizons and landscape elements (vegetation, effects of human activities, geomorphology, hydrology, native rocks or substrates) whose spatial organization can define the whole or any part of a pedological cover (Baize and Girard, 1998).

Existing studies on the manganesiferous sites of Côte d'Ivoire were interested in the search for manganese mining while overlooking soil aspect (Grandin, 1968 ; Grandin and Perseil 1977), whereas the soil is an essential component of development.

The objectives of the investigation are to study the morphology and geology environment of manganiferous sites in relation with soil formation and physicochemical properties in order to better apprehend the future use of these soils for sustainable development.

Material and methods

Site of the study

The manganese mine of Lauzoua is located south of the leaf of Guitry (limited by the meridians 5° West and 6° West and the parallels 5° North and 6° North). The region of Guitry is covered by the tropical forest. The climate is hot and humid with heavy annual rainfall (1470 mm / year) governed by two dry seasons and two rainy seasons, with temperatures varying from 27 to 37°C.This area is drained by numerous rivers (Go, Boubo, Davo, Bolo, and Dagba) flowing into lagoons (Makey, Tadio, and Nyouzomou Katibo) and, communicating with the sea near the town of Guitry.

Methods

Geological prospection consisted in identifying and describing the rocky outcrops on the face and the rest of the perimeter of the permit. The material used mainly consisted of geological prospecting tools. Rocks samples in the exploration area were collected during the field work and thin layers were manufactured in the PETROCI laboratory of Abidjan. These thin sections were studied in the laboratory of the Department of Geology.

A lithological description was then made for each dark well by identifying the horizons in which the description focused on texture, color, presence or not of organic matter, general structure, cohesion, porosity, abundance and length of the roots, structure, and drainage. The observations of soil were made following the change in topography. Thus we have considered profiles of top, mid, and bottom of slope. Soil samples (12 samples) were collected on three profiles. The study of morphopedologic environment is based on a morphopedological diagnosis and the recognition of likely pedologic systems (Ruellan and Dosso, 1993) by soil profiles. To this end, compilation of available cartographic documents and variable related documents known to be correlated with soil properties are commonly performed.

Oxides determined in rocks and soils indicate that the materials are relatively rich in silicon and iron oxides and slightly hydrated (Table 1).

Table 1. Results of geochemical analysis of soils and rocks in the study area.

N° of profile	Horizon	Depth (cm)	SiO_2 (%)	Fe_2O_3 (%)	MnO (%)	Humidity (%)
O 24	A1	0 - 5	32.14	6.56	1.41	5.88
	A3	5-20	29.94	8.96	2.18	5.13
	B11	20 - 70	26.55	9.11	1.54	4.18
	B12	70-130	27.75	9.46	0.90	3.84
O 20	A1	0 - 5	31.77	6.28	2.70	10.43
	A3	5-20	33.40	6.69	2.70	10.25
	B12	20 - 40/50	34.20	6.97	1.93	6.97
	B21	40/50 - 120	25.27	7.84	1.67	6.98
O18	A1	0 - 3	40.72	5.12	4.11	11.64
	AB	3-40	43.33	8.12	4.63	19.55
	C	40-85	43.00	6.84	7.84	17.21

Results

Results presented here are related to the geomorphology dictated by the geology and the soils of the station. The major part of the relief in the area under study is dominated by a chain of hills oriented North-East, South-West, with summits ranging from 103 m to 144 m from South-West to North-East.

In terms of geology, manganese containing deposits of Lauzoua are located in a sedimentary and volcano-sedimentary birimian area, intruded by granodiorite dominant massifs. The sediments consisted mainly of arkose, arenite, politic sandstone, and lutites. They are poorly evolved and contain quartzofeldspathic detritical angular elements into clay-sericitic cement. The greenish volcanosedimentary series due to the abundance of chlorite and amphibole are represented by an undifferentiated volcanic complex.

Located at the extreme west of the Lauzoua area, hornblende and/or biotite metagranodiorites, are quite dark colored rocks with medium grain locally porphyroïdic. They represent the eastern edge of a large massif oriented NNE-SSW.

The main geological formations encountered in the study area (Fig. 1) are divided into mataarenites, ampelites, manganese containing ampelites (gondites), metarhyolites, metadacites, and undifferentiated metavolcanites. Metaarenites occupied the S-E strip of the permit. Macroscopically, it is a peppery, greenish colored rock. Microscopically, this facies is mainly composed of quartz grains, feldspath elements of varying sizes and more or less rounded shapes organized in a quartzo-feldspathic or chloritic matrix (Fig. 2). The percentage of feldspath compared to quartz is highly variable from one sample to another.

Locally, it shows microconglomeratic levels, where detritical quartz and feldspathic elements can reach a size of 1.5 to 2 mm (Fig. 2). We also observed millimetric beds beveled by ferromagnesic minerals in a finely grained facies.

Ampelites and manganese containing ampelites are found in centre and the north-west of the permit. Manganese containing ampelites are redeemed between typical ampelites and metaarenites (Fig. 3). The dominant facies are finely arranged black schist, graphitic in some places. They are cut by cracks and white calcite veinlets and number of quartz veins. The most manganese containing facies, with indurated appearance include gondites with manganese containing garnets and cubic pyrite.

Located in the northwest of the permits, metarhyolites and metadacites form a strip oriented North-East South-West. They are gray-clear to slightly dark gray, porphyritic by the presence of millimetric feldspath and ferromagnesic microliths.

Undifferentiated metavolcanites form the frame of the series of plateaus in the west of the chain of hills. They are very dark, dense and finely grained. Miscrocopic observations show tangled actinotes and relics of calcic plagioclase (high relief) plus almost rectangular opaque crystal minerals such as magnetite or cubic as pyrite. This composition is similar to that of an amphibolite derived from metamorphosed basalt (Fig. 4). Laminated or schistic formations have a direction varying one hand from N 048° to N 052°, with dips of 40° to 70° NW and, on the other hand, from N 043° with a dip of 50° SE , which highlights an antiform axis. The schistosity is locally jagged (Figure 5). Microscopic observations, show symmetrical shadow pressures referring to a pure flattening (Fig. 6) and sigmoid shadow pressures (Fig. 7) formed in sheared environment. In the latter case, the direction of the sigmoid asymmetry helps deduce the direction of the shearing.

Therefore, the main mineral found in rocks in the area under study are quartz, plagioclase, the microcline and brown-green biotite clusters, with associated minerals constituted of pistachite, apatite, and zircon.

The manganese containing rocks of the volcano-sedimentary complex of Lauzoua include mainly gondites to dialogite ($MnCO_3$) or braunite (Mn_7SiO_{12}).

These gondites are metamorphosed equivalents of mangesese conataining silica or clay derived from volcanism. With a black or gray color, and very fine grains, they are mainly characterized by the presence of spessartine and quartz. There is often a little amphibole (tremolite or actinote). These rocks are locally collected in graphitic schist.

Their alteration leads to three major genetic types of minerals: lens ores, dismantling ores, and hardened minerals.

Lens ores

The lens ores interstratified in schist/gondites constituted the resistant armature of the chain of hills (Fig. 8). It consists of a black rock, very hard, very dense, which does not stain the fingers. This rock, loosely layered to schistosic, marked by thin layers of graphite, is traveled by many calcite white veinlets. The ore is effervescent in presence of acid.

Dismantling ore

The positioning of the dismantling ore is dependent on the surface topography (Fig. 9). It covers the heads of lenses in form of blocks clusters, chunks and granules or nodules embedded in the surface clay. These eluvial clusters highly enriched (90% of exploitable ore) are located on the plateau or in the upper slopes, where manganese is in the form of secondary oxides, packaged in a clay soil.

Hardened ore

It systematically presents a concretioned massif without bedding (Fig. 10). It is often crossed by veinlets with fibrous crystals and contains clay pockets. This ore occupies the hills on gentle slopes.

Discussion

Based on the lithological descriptions, we are in a volcano-sedimentary environment. Several types of structures were observed in this volcano-sedimentary series: stratification, flattening and shearing plans, in addition to a schistosity of crenelation N120°, indicating a final tightening phase of regional scope.

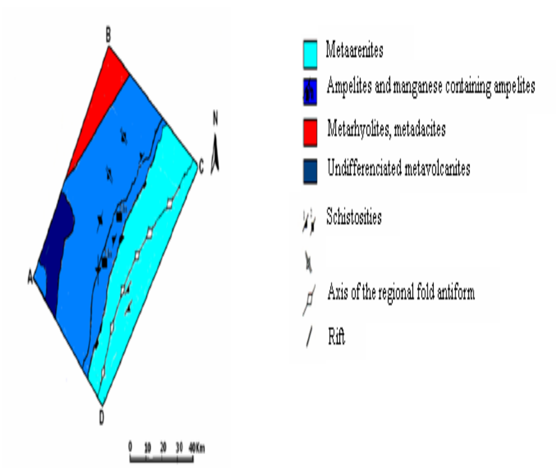

Fig. 1. Outline of geological formations of the study area Already recognized in the work of Vidal and Alric (1994), this crenelation has recently been better documented in the N-E of Ivory Cost by Pouclet *et al.* (2006), who included some major plicative structures WNW-ESE.

As for all Ivorian deposits, the origin of manganese can be fairly discussed.

Manganese can come from hot sources related to submarine volcanism and be deposited in the form of oxides or carbonates. It can also come from lava themselves. We could then find it in a dispersed form and absorbed by very fine clay sediments that characterize the period of the emptiness of its ophiolitic activity. In the presence of calcium, it might be concentrated in local accumulations of silica gels and give manganese containing jaspers. On the other hand, this manganese containing colloidal silica intimately included in the sediments, which will further form cinerites, contemporary manganese containing siliceous and clay tuffs, and ophiolitic emissions themselves (Pouclet *et al.* 2006).

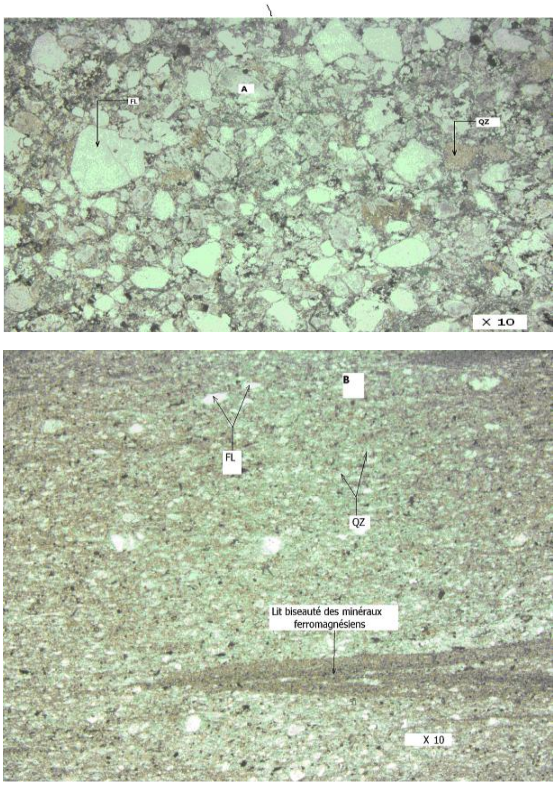

Fig. 2. Micromorphology of variable size quartz and feldspath detritic elements.

QZ: Quartz; FL: Feldspath

Depending on local conditions, the concentrations may be natural, both lithologically and level related, may present abrupt changes in sedimentation or levels when the geochemical conditions of the basin are modified. From a space point of view, manganese appears to have been concentrated in small basins in the vicinity of ophiolitic emissions.

This deposit could be more or less long, probably cyclic (frequent repetition of sequences of sterile sediments - mineralized sediments), but there are distortions in each path in a determined period, as evidenced by the clear alignment of mineralization in a defined stratigraphic horizon. During eburnean orogenesis, initial manganese containing sediments were turned to varying degrees to metamorphic rocks. Thus, under the action of metamorphism, initial manganese containing sediments will give rise to gondites, with a predominance of spessartine and quartz (Grandin and Perseil, 1977)

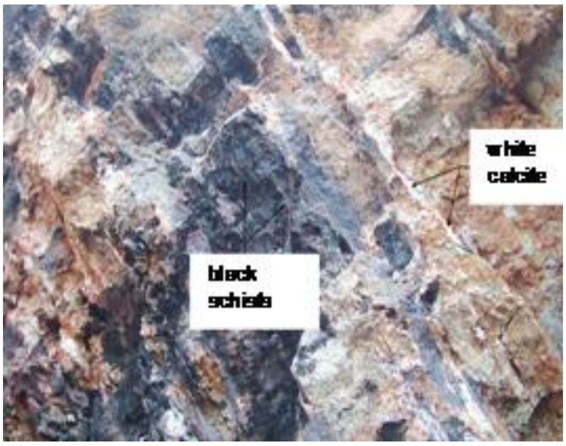

Fig. 3. Black schists and white calcites (manganese containing ampelites).

Relate to this episode, are local formations of manganese containing carbonates and silicates such as braunite (Mn7SiO4), dialogite (MnCO3) observed in the deposit of Lauzoua. The supergene alteration of these primary minerals will give rise to secondary formations represented mainly by oxides (Grandin and Perseil, 1977). Indeed, all deep searching (up to 60 m) made in the richest deposits of Mokta (Perseil and Grandin, 1985) showed a decline in soil oxides contents as the supergene alteration of initial manganese containing rocks lessened.

This finding, also made in deep trenches, seems to confirm the absence of primary concentration of oxides. This study suggest that the vast majority of Ivorian oxidized ores results from a supergene alteration, which is confirmed by the microscopic or Metallographic study of silicate or carbonate primitive rocks at different stages of alteration (Perseil and Grandin, 1985). Affected zone rarely exceeds 20 to 30 meters. The supergene alteration of Ivorian deposits may be placed in a general context of the laterization. By laterization we mean a chemical type alteration, which grows mainly in intertropical humid zones, and is characterized by dissolutions, damages, and neoformations.

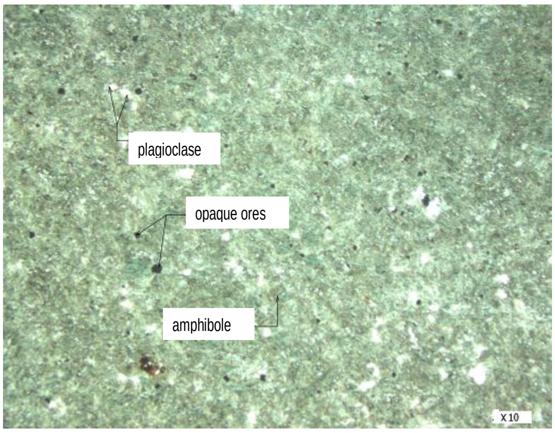

Fig. 4. Microphotograph showing an amphibolite (undifferenciated metavolcanite).

During laterization, manganese may, like iron, remain in true solution under its bivalent form, but can also form amphoteric hydroxides, which can be easily precipitated by hydrolysis (in low pH conditions) in tetravalent form. It will than constitute a residual products of lateritic alteration (Wedepolh, 2004).

The alteration of gondites depends largely on their composition. In gondites, oxidation of garnet occurs mostly from inside of crystal, along microcracks. Then the contour of grains fades, and it remains only cracked garnets and garnets hollowed out in cavities, drowned in a wad and psilomelanes base. Quartz can survive in more or less regular beds or beaches (Perseil and Grandin,1985).

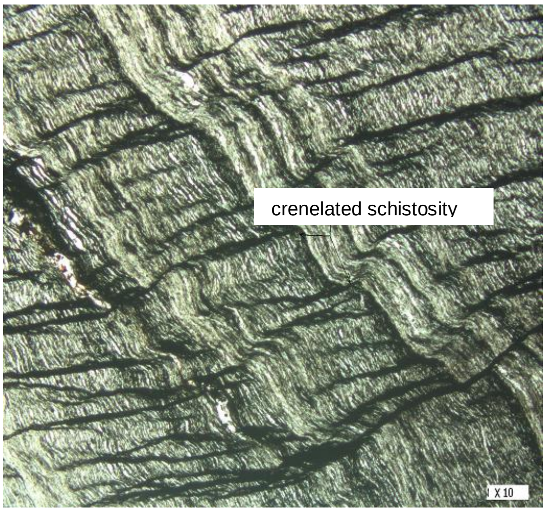

Fig. 5. Microphotograph showing a crenelated schistosity observed black schists.

The spessartines deteriorate fairly easily, but the occurrence of a rich ore is more difficult for gondites, dialogite, or braunite. The gonditic ores usually contain a fairly high proportion of silica, and to a lesser extent, of alumina and iron (Grandin, 1968).

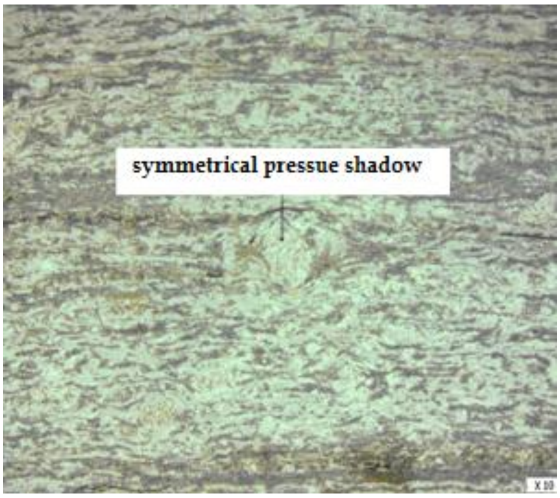

Fig. 6. Microstructure of a pure symmetrical flattening pressure shadow pure.

The gondites to dialogite or braunite are mainly found in the rich deposits of Mokta, and it is likely that this wealth is due in part to the alteration of these compounds. Rich minerals sometimes show a few relics.

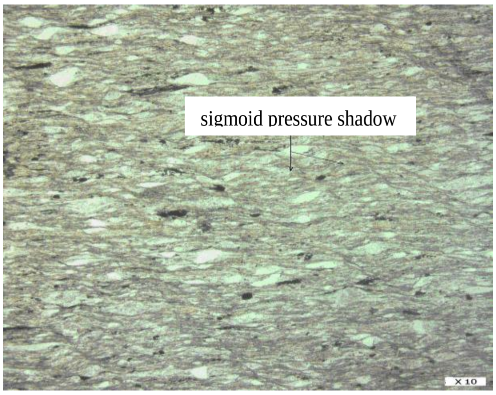

Fig. 7. Microstructure of shearing sigmoid pressure shadow.

While the manganese containing protore of Lauzoua has a precambrian origin, the occurence of the deposit, economically speaking would have occurred in the tertiary (Grandin and Perseil, 1977). In general, the secondary evolution of Ivorian deposits is quite complex. There are often the successions of two generations of oxides and numerous pseudomorphosis. The reason for that could be the succession and the alternation of very different climates during their long evolution, and the numerous resulting variations of the hydrostatic level (Perseil and Grandin, 1985).

Fig. 8. Partial View of interstratitied lenses in schists

In the area of Lauzoua there are metagranodiorites and birimian rocks represented by volcano-

sedimentary formations. Under the action of atmospheric conditions these rocks will undergo alteration processes. These intensive processes cause the rupture of crystalline networks. The components of the rocks are individualized in simple forms: SiO_2, Fe_2O_3, MnO, etc.., which will be immobilized, or be removed, or partially recombined, depending on the drainage conditions.
Soil is the result of all these changes in relation to organic matter. Indeed, the pedological covering, with harmonized lithic and crumby indurate formations, which serves as support vegetation, helps understand the stages of the genesis and evolution of the observed surface formations, and their influence on forest dynamics and the phytogeographical distribution (Beyala *et al.*, 2001).
The comparison of the results of the analysis made on rock and soil samples reveals that :

Fig. 9. Partial view of the dismantling ore.

Silica is present in almost identical proportions in both the soil in the rocks. This seems obvious given the volcano-sedimentary environment. Iron is present in the soil with relatively high levels, probably because of differential alteration processes: the removal of certain elements involving the concentration of others.

The high concentration of manganese in the rocks, while very low in soils can be explained by a very thorough leaching process.

The reverse evolution of the levels of manganese and iron along the toposequence suggests a replacement of iron by manganese; however, iron and manganese levels found in soils analyzed could not permit any mining exploitation.

Lauzoua belongs to the area of soils moderately leached. From our field studies, we have identified brunified land whose vast expansion suggests the possibility of introducing new crops in this region already dedicated to agriculture. And we are currently witnessing a strengthening of the links between production and land, as was noted Cheverry and Gascuel-Odoux (2002). At present, agriculture must control the flow of elements while contributing to the preservation of the environment (Surendran and Murugappan, 2010), hence the need to take into account pedogenetic differentiation factors, topography (Colinet, 2003), as well as the history of contributions on the site (Arrouays *et al.*, 2000) because we know that the levels of elements in a soil, at a given period, result from pedogenetic evolution of the material with its own contents, the rocks chemistry influencing the soil's one, and the balance input/loss which can be greatly influenced by human activities (Janjirawuttikul *et al.*, 2011; Warin *et al.*, 2004).

Fig. 10. Partial view of Hardened ore.

Therefore, it is important to take into account the existence of this geomorphological continuum, in line with the idea put forward by Wright *et al.* (2004) who proposed to focus on the continuum of variation more than cutting into very different strategies, or the idea consisting to establish the link between the variability of the functional diversity of vegetal populations and ecosystem properties (Ansquer, 2006). The crumby formations observed, combined with the use of lands and the rates of the vegetal covering, allow making a distinction between geoecological units which constitute an important basis for assessment of the potential of a given ecosystem (Yusuf and Yusuf, 2008).

Conclusion

The geological context of the deposit indicates the presence in its western part, of massive green rocks (amphibolites green hornblende), and in its eastern part, of a chain of hills composed of interstratified green rocks in locally graphitic schist.

The gondites to dialogite ($MnCO_3$) or braunite (Mn_7SiO_{12}) are the primary ore deposit of Lauzoua. It is their alteration that gives rise to three types of minerals: interstratified lens ore in schist, dismantling ore of these lenses forming blocks clusters, resulting from the in situ fragmentation of the preceding ore, and hardened ore linked to the alteration and the leaching of above mentioned ore, then reconcentration of manganese in a lateritic type pedological profile.

The more economically attractive part of the deposit consists of dismantling surface areas, including very rich clusters (90% of exploitable ore), where manganese is found only in form of secondary oxides packaged into a clay soil.

This work allowed establishing a link between the geology and the different types of manganese ore. Indeed, the study of the natural environment is gaining interest when combined with geological and geomorphological information. This is called the geo-morpho-pedological approach. The geology provides an overview of the system but imprecisely locate the position of the clay layer responsible for the landslide for example. Geomorphology clarifies this localization through elements reflecting the possible presence of a crumbly rock.

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