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Eastern Anti Atlas Phanerozoic Granular Iron Formations (IFs): Nomenclature and Classification, Case of Ordovician Basin of Tafilalt

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ABSTRACT

In Morocco, the variety of ferruginous resources (dated Archean, Paleozoic and Mesozoic) shows a specific character illustrating the relationship between the geographic position and the geodynamic setting which allows deposition of several iron mineralized structures. The sedimentary iron is well manifested in the Paleozoic terranes, and assigns great relation with the Hercynean geodynamic regime, which marks the Gondwanean environment during this time. The results of these processes manifest as the establishment of exploitable iron Formations deposit situated in the Tafilalt Ordovician basin of the eastern Anti Atlas of Morocco.

Key words: Hercynean, Gondwanean, exploitable iron deposits, Tafilalt Ifs, Ordovician, Anti Atlas, Morocco

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INTRODUCTION

Iron Formations (IFs) originates from sedimentary deposition processing, and they are characterized by a high grade iron tenor which manifest as tiny or laminated chemical facies and contains more than 15% sedimentary iron. The ore is formed by iron oxides and hydroxides such as hematite (Fe_2O_3) and magnetite (Fe_3O_4) both constitute the major part of the mineralized rock. However, the rest assign silica and microcrystalline quartz forming the cherts. Furthermore, the valence statement of iron describes chemical precipitation which depends mainly to the diagenetic environments. In fact, there is well difference between the old IFs deposits dated Precambrian which characterizes interbedded layers of iron and cherts, and the Phanerozoic ferruginous formations commonly presented as small units containing oolithes, and drawing typical relation with the Ordovician and Jurassic episodes where the peneplanation was associated to the global humid climate.

In Morocco, the (IFs) are mostly concentrated in the Archean terrains of Aghalays, at the level of Ouled Delim situated in the Mauritanid chain, which offsets complex Eburnean structuration. Moreover, Iron appears also in the Paleozoic formations and generally in the Cambro-Ordovician terrains that characterize the Hercynean chain of Morocco. These formations exist in the Costal block at the level of Ben Slimane, in the Central massif at Ait Ammar, in western High Atlas at Tachilla, and in the Anti-Atlas at Imi n'Tourza, Tafilalt and Tan Tan.

This work focusses the great understanding of iron mineralization process and its influence by the regional geodynamic setting of the eastern part of the Anti-Atlas, especially at the level of Ordovician basin of Tafilalt, where we took samples for petrography and metallogeny analysis and observation's. In fact, the investigation of field and laboratory results accomplished by IFs library data let us to define a typical classification and nomenclature for Tafilalt Iron Formation.

GEOLOGICAL SETTING

The Ordovician basin of Tafilalt is located in the eastern part of the Anti-Atlas structural domain of Morocco [1, 2, 3, 4, 5, and 6] (Fig.1-a, 1-b). In this area, the Neoproterozoic inlier of Ougnat if formed by crystalline basement dated Panafricain orogeny [7, 8] (Fig.1-a, 1-b and 2). Above these formations, the Palaeozoic cover is gradually transgressive and marks SW-NE extension. The later characterize the lower Cambrian series [9, 10]. In the north

east of Ougnat the Middle Cambrian is assigned by local transgression. It is formed by pelitic sandstones commonly called '*Paradoxid schistes*', followed by sandstone bands of Tabanit unit. The latter is intruded by huge alcalin basalt intrusion. The rest of Paleozoic cover consists to Ordovician –Lower Carboniferous Series Totalizing 4 km thickness in depth [11].

Although moderate, the crustal extension of Cambrian and Devonian is more sensitive, and assign a generalized deformation which affects the whole area during the last episodes of the Hercynian cycle (Carboniferous – upper Permian). General tectonic setting of Precambrian basement draws a strik slip thrust faults, and folding of the Paleozoic covers [11-12]. After the collapse and erosion of the Hercynian belt which affect the terrains during the Triasic peneplanation, the extension of NW-SE axis was coupled by aciditic magma intrusion, followed by tholeiitic alkaline nourishment (CAMP event) [13-14].

The transgression manifests only are the north region margin closely to the High Atlas. The thin Triasico-Jurassic deposits are probably eroded during Jurassic-eocrectaceous emersion which affectes the almost part of Morocco except of the Atlantic margin [14-15].

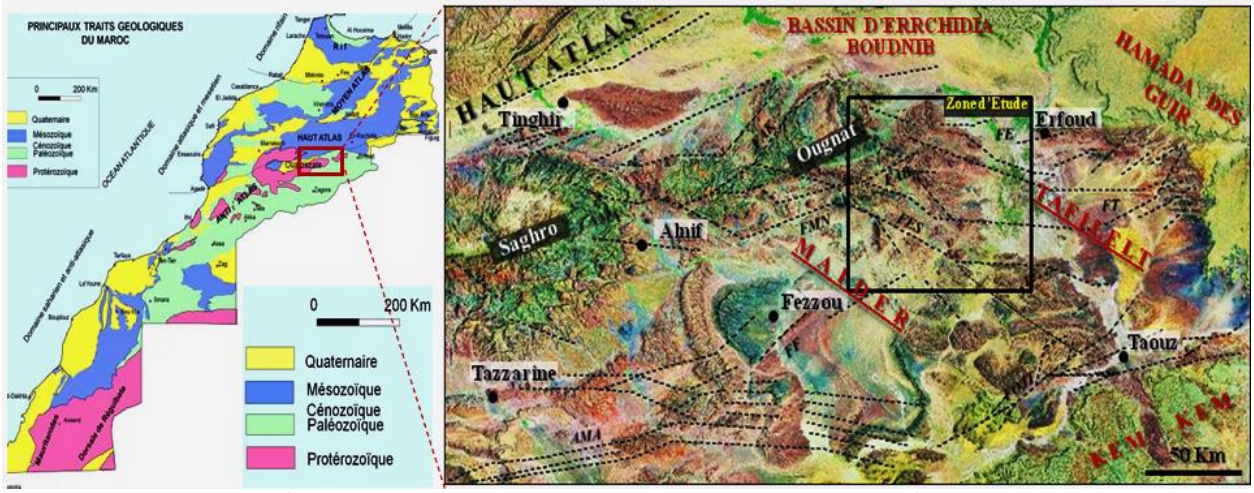

Fig.1-a (1) Satellite map of Morocco showing its structural domains position, (2) satellite map of the eastern Anti Atlas showing

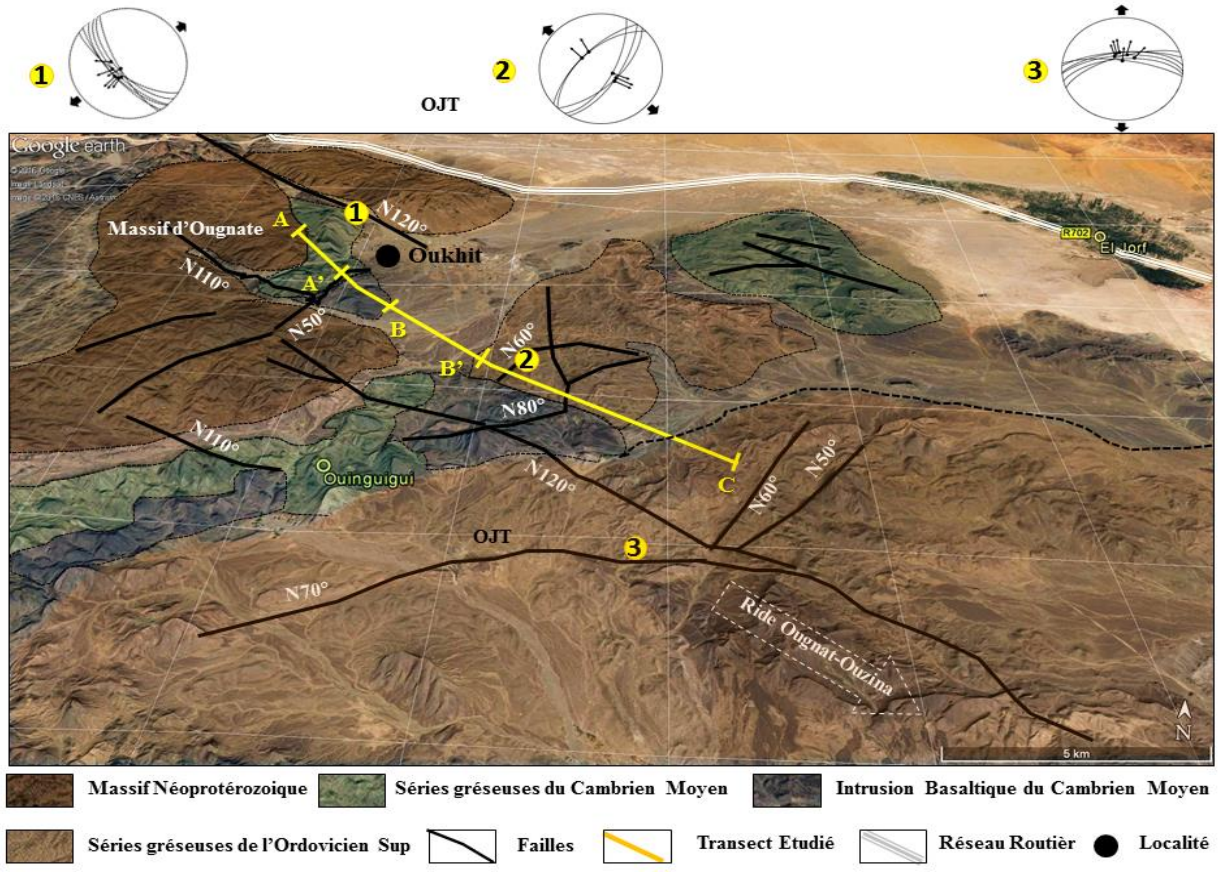

Fig.1-b Tafilalt bain google earth map's showing the most geological formations

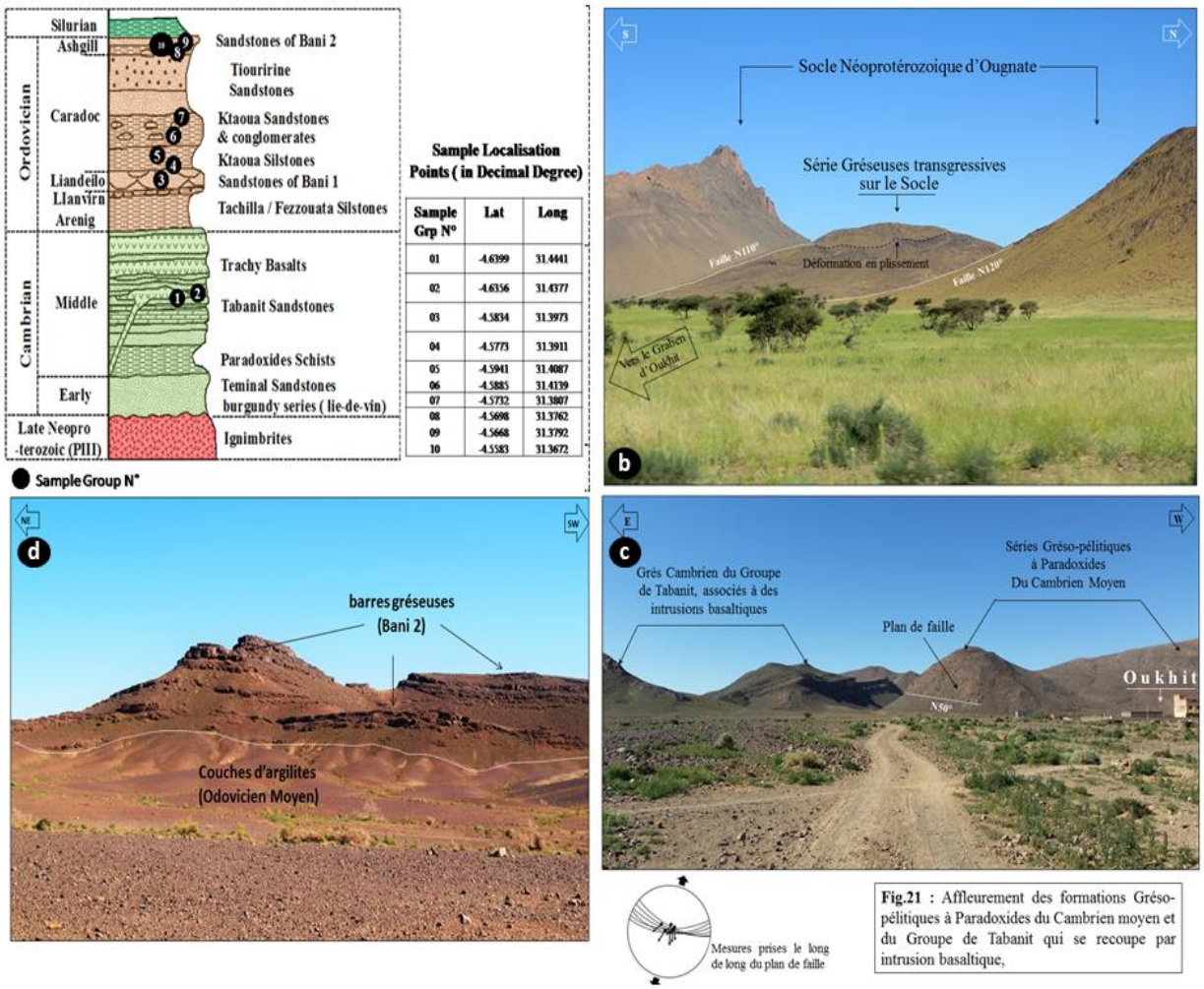

Fig.2 (a) lithostratigraphics column of eastern Anti Atlas, (b) local middle Cambrian transgression on the Ougnat Neoproterozoic basement, (c) Middle Cambrian Paradoxides schist behind Oukhit, (d) Upper Ordovician formation of Bani 2 (ferruginous facies)

The Upper Cretaceous transgression dominate the Anti-Atlas except of at the level of Precambrian outcrops, and the compressive tectonic of Neogene inverses the whole domain during the Atlas orogeny, using for that the paleozoic and Mesozoic herited faults, and giving to Ougnat axis a folded form [11].

MATERIAL AND METHODS

To distinguish the typology of the Iron Formation of Tafilalt, we process our study by petrography and metallogeny studies and interpretations, based on the observation of iron mineralized fraction in stand of thin sections and polished surfaces prepared form collected samples (Fig.4).

Note that, all sample preparation, thin section and polished surfaces conception has proceeded in the 'Geo-resources and environment Laboratory in the faculty of science and technology of Fez, Morocco'

The interpretation of the results obtained from laboratory observations let us describe and understand the petrography and the repartition of iron in these rocks, which allow us to define an appropriate classification of these Ifs.

RESULTS AND DISCUSSION

According to the field exploration, the stratified green sandstones of Middle Cambrian are intruded by basaltic dykes and silts, showing an indicator of Cambrian rifting (Fig.5). These intrusions present a nourishment source of ferromagnetic minerals, and especially iron, which is detected in the behaviours of these Cambrian sandstones (Fig.4).

The microscopic observations of the thin section which are prepared from the samples of these formations illustrate that iron oxides are precipitated as kind of Hematite (Fe_2O_3) and Magnetite (Fe_3O_4) in siliceous matrix where they are deposited as granular or oolthic form (Fig.5-1).

However, the lower Ordovician formations characterize the Bani 1 quartzic-sandstones and assign a very low iron tenor. The Hematite is the dominant iron mineral, and it is poorly concentrated in the total rock (Fig.5-2).

The Ktaoua groupe of the upper Ordovician shows an iron mineralization which keeps always the oolithic form, with dominant Hematite and Magnetite in sandstone phases. Actually, it is a huge mineralized sandstone extension which comes more important on the Asghill series where the iron oxide mineralization occupies large surfaces [16] (Fig.5-3) (Fig.6).

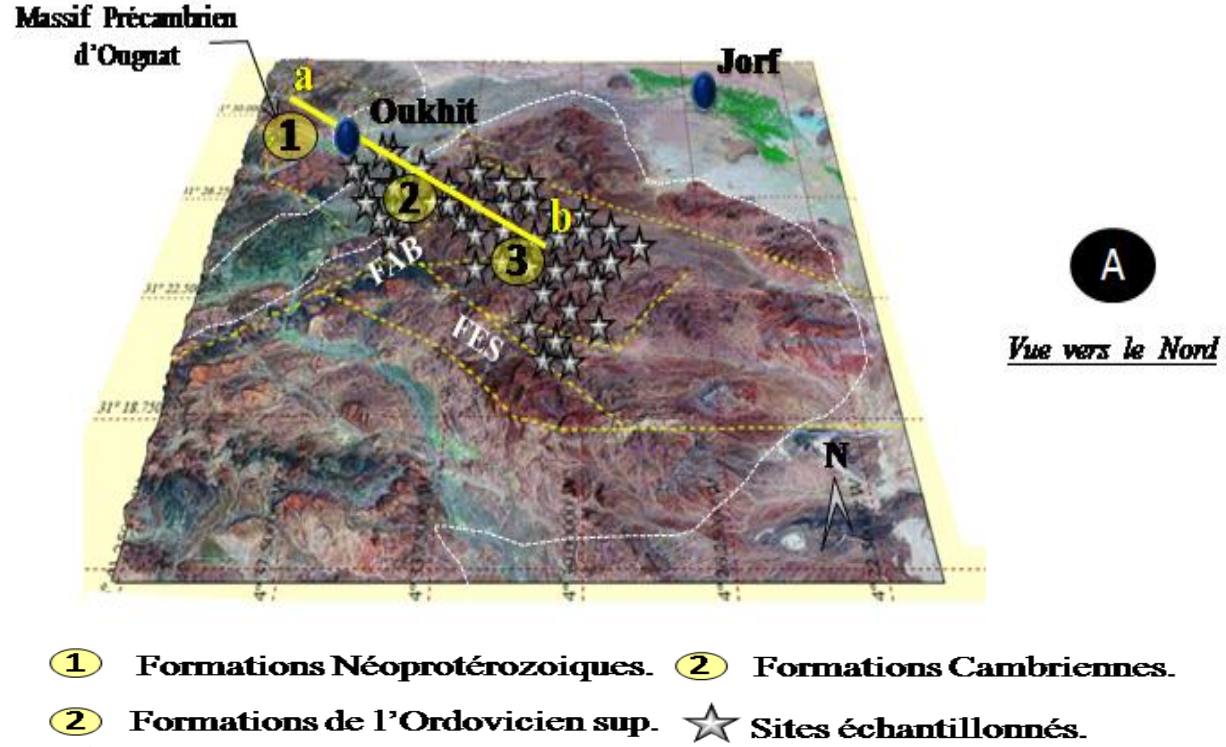

Fig.3: Tafilalt basin MNT model illustrating Ougnat Neoproterozoic basement and Cambro-Ordovician paleozoic cover, with positioning of the studied transect (ab) and location of sample stations, (A) north view

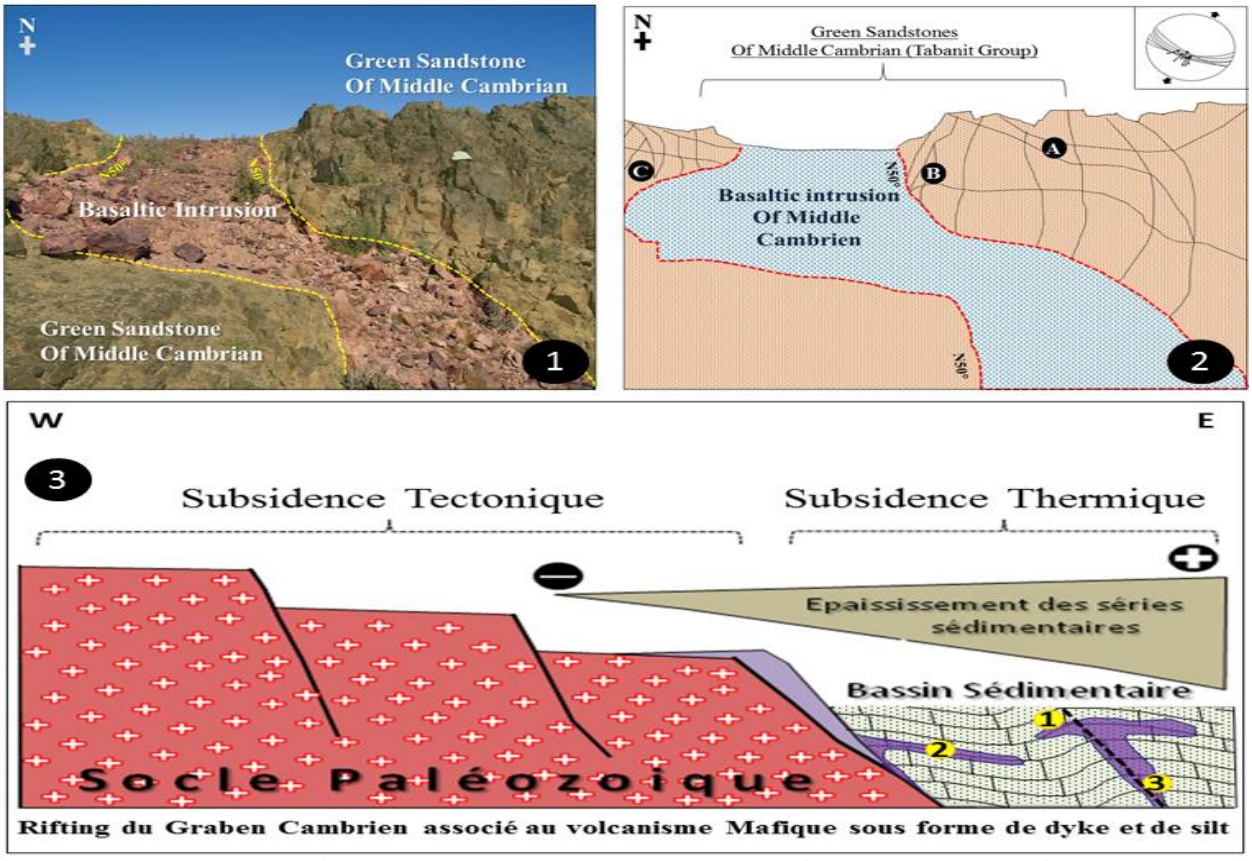

Fig.4 Bordering of middle Cambrian tholeiitic intrusion showing N50° faults in green sandstones facies

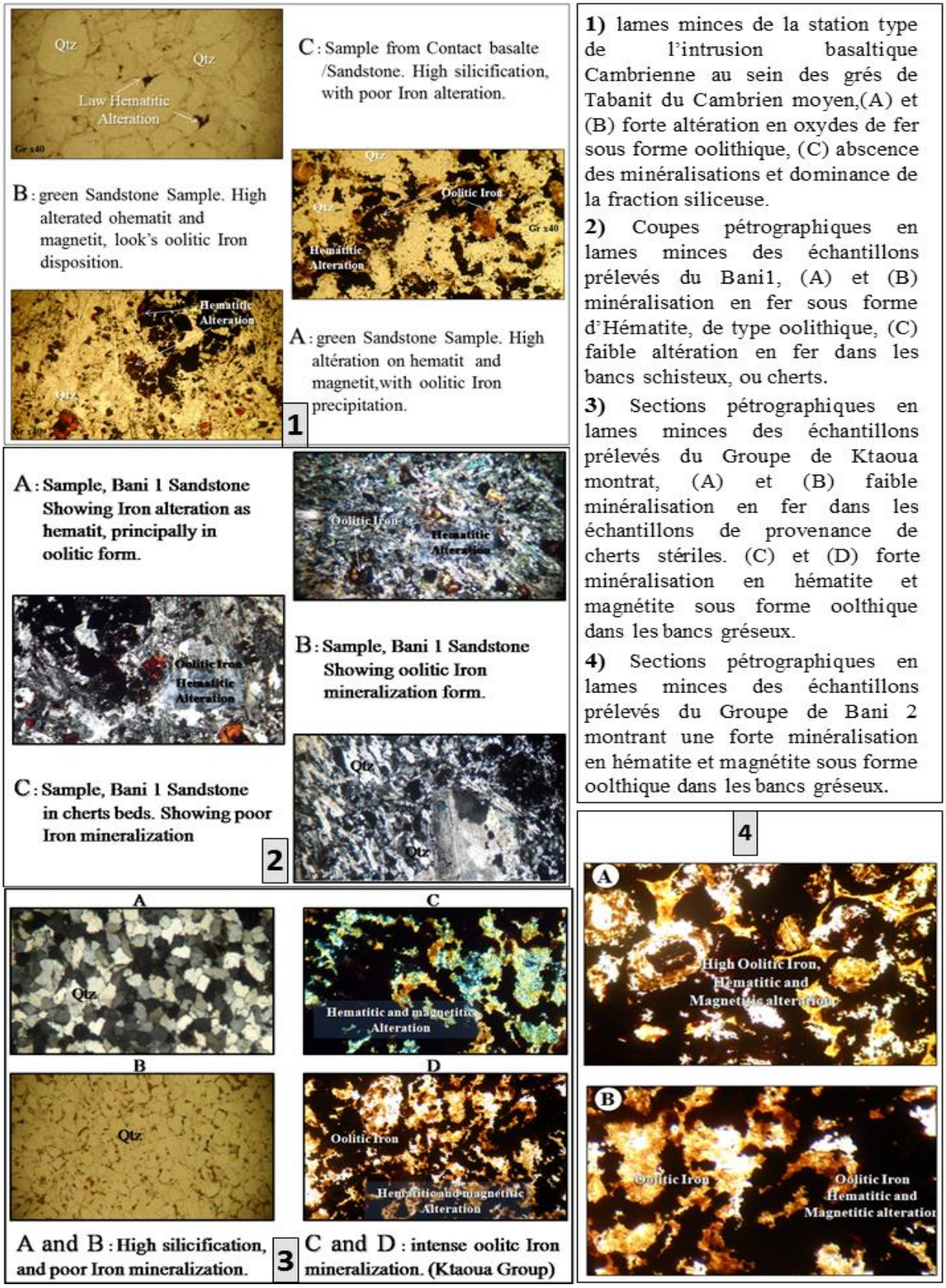

Fig.5 Thin section of O Upper Ordovician mineralized taken samples from Tafilalt Basin of Eastern Anti Atlas of Morocco. (1) Contact zone Tabanit green sandstones – tholeiitic basaltic intrusion of Middle Cambrian showing moderate oolithes iron alteration (A, B) and poor ferruginous mineralization in (C) whit abundance of silica fraction. (2) Bani 1 petrographic observations showing an oolithic hematitic alteration in sandy bands (A, B) and poor iron mineralization in argillic bands (C). (3) Ktaoua group thin sections illustrating a poor iron alteration in argillic or chert bands (A, B) and high ferruginous alteration as hematite and magnetite (oolithic form) in sandy bands. (4) High hematite and magnetite alteration in Bani2 sandstone bands

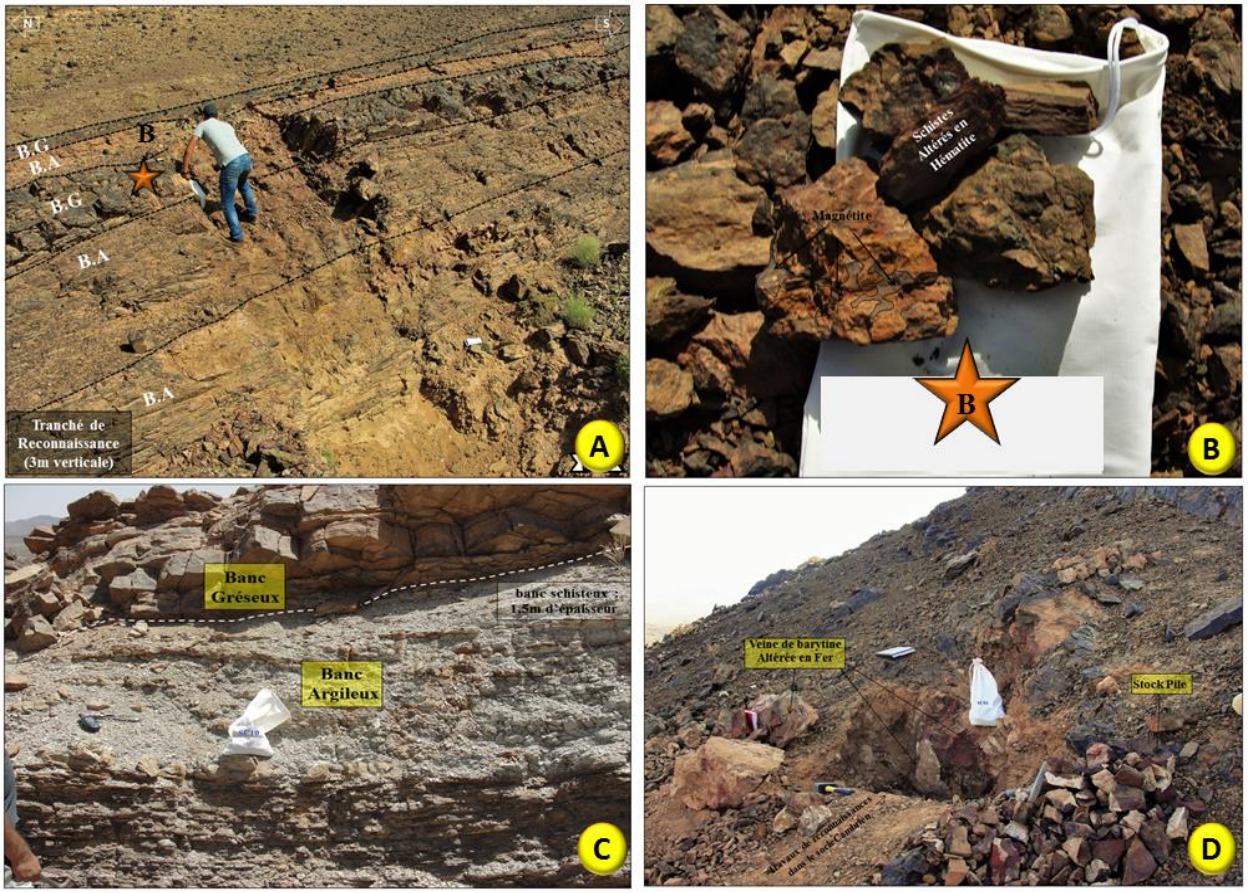

Fig.6 (A) interbedded schist sandstone bands and positioning of the sample station (B) sandstone bands sample showing high iron alteration as hematite and magnetite (C) schist band or chart (D) Sampled barite vein following stratification level

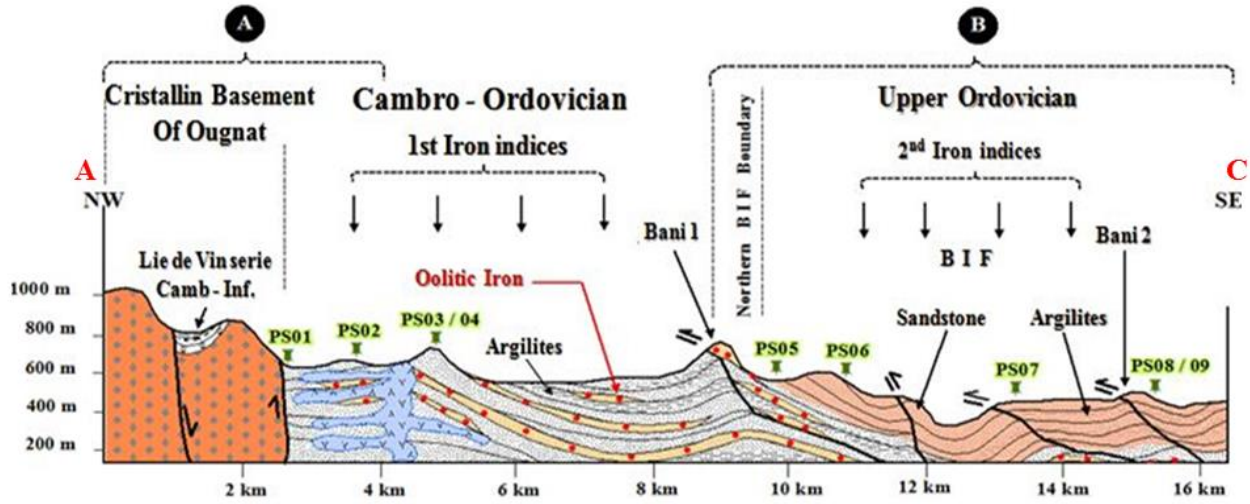

Fig.7 Geological cross section of the NE-SW studied transect, whit positioning of taken samples from point A to C

The Iron ore is mainly hosted in Bani 2 quartzitic sandstones of the Upper Ordovician [16]. The ore concentration dependent highly to the dynamics of this basin, where the clay phase marks a quiet and impoverished middle mineralization, while sandstone detrital facies has trigger the chemical iron precipitation process (Fig 7).

These detrital exhibit of Cambrian rifting, has contribute to the creation of space and to the development of thermal and tectonics subsidence (Fig.4), while the detrital and iron supply has provided by the basement of Ougnat-Ouzina, located in the NW of the ore [17, 5, 6] (Fig.7).

In fact, we conclude that the Ordovician glaciation of the Anti-Atlas [17-21], was the key factor of the iron mineralization processing in Tafilalt during this stage of the Moroccan Paleozoic history [16].

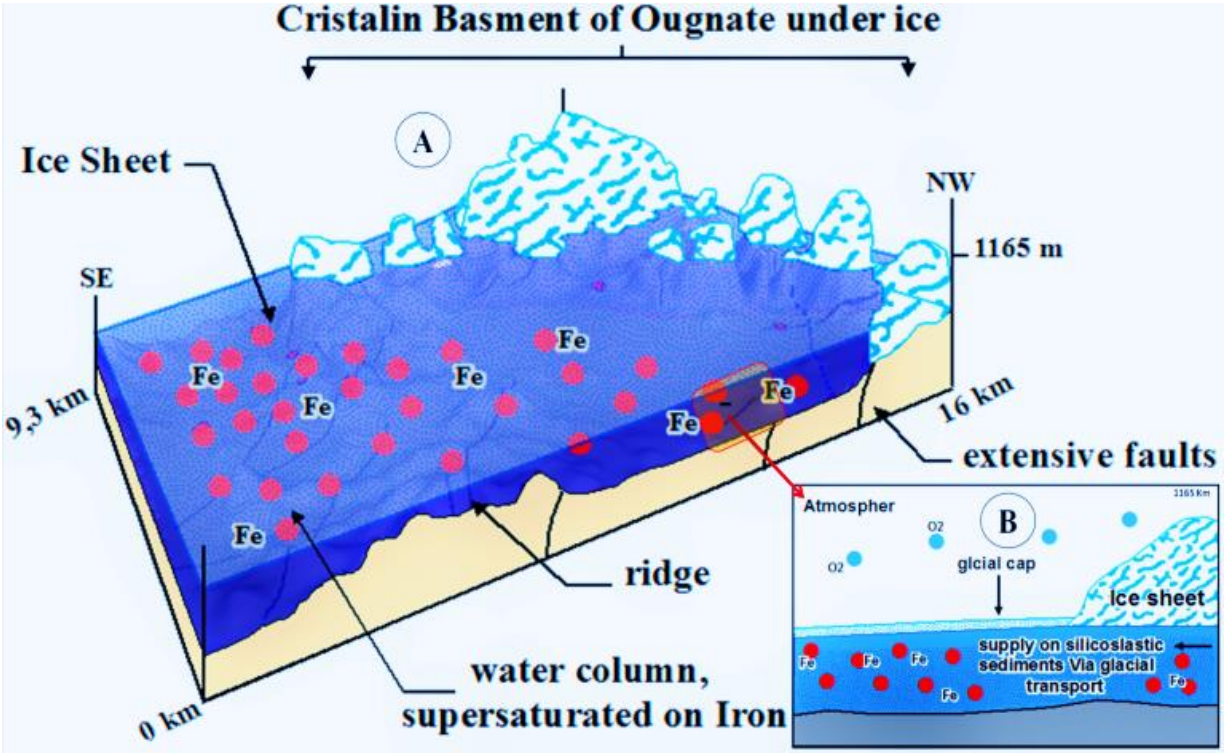

Fig.8 (A) Geodynamic model of Tafilalt basin with the super saturated sea environment on reduced iron (Fe), with appearance of the ice cap during Caradoc, (B) explanatory sketch of rich reduced iron sediments supply [16].

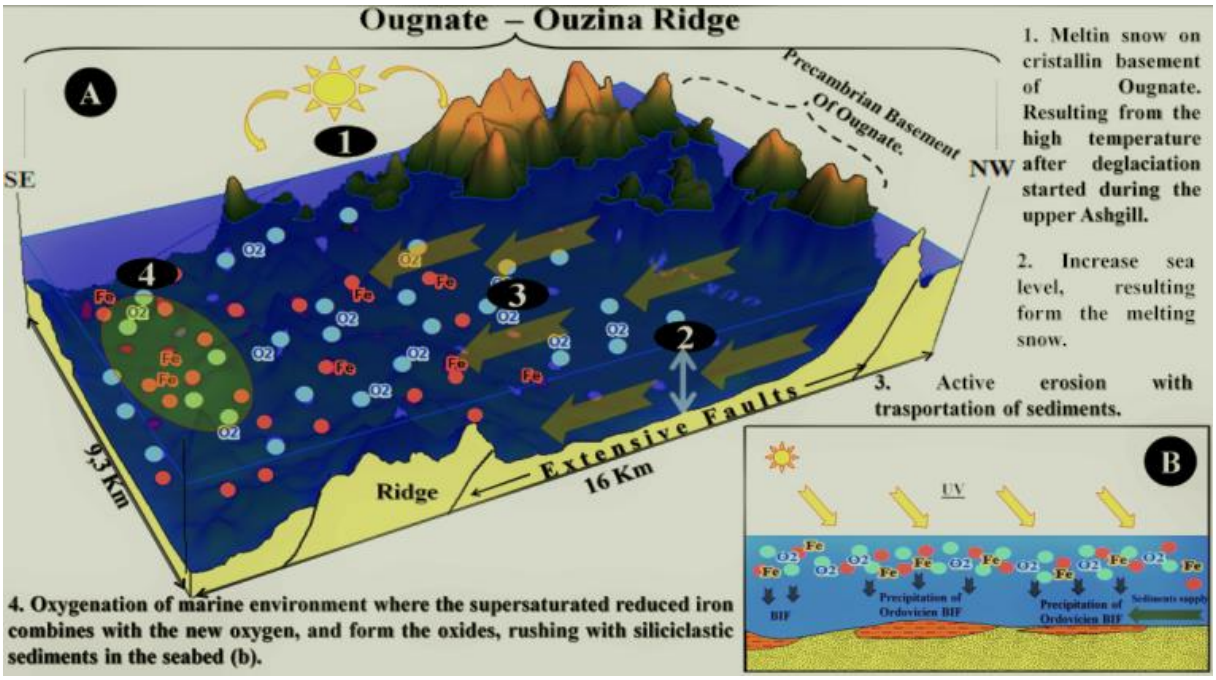

Fig.9 A) Geodynamics model of Tafilalt BIFs implementation processing, triggered by deglaciation phenomenon dating the Upper Ashgill. B) Explanatory sketch of the Oxygen intervention in the iron oxides formation process, and their precipitation in a delta environment [16]

CONCLUSION

The correlation of the Ifs classifications proposed by various authors [22-30] and the obtained results through petrographic, and metallogenic studies conducted form the samples of the Ordovician Ifs of Tafilalt indicates that this iron mineralisation can be classified as a banded iron formation deposited during the Late Ordovician, in shallow sea environment occasionally influenced by waves, and subjected to climatic conditions characteristic of the 'snowball earth' event [16, 32, 21] (Fig.8 and 9). The observation and interpretation of the thin sections and the polished surfaces distinguishes the evolution of iron mineralization of oolitic form right from the Middle Cambrian, where the feeder source represented by the various mafic basaltic intrusion of Middle Cambrian which affect the region.

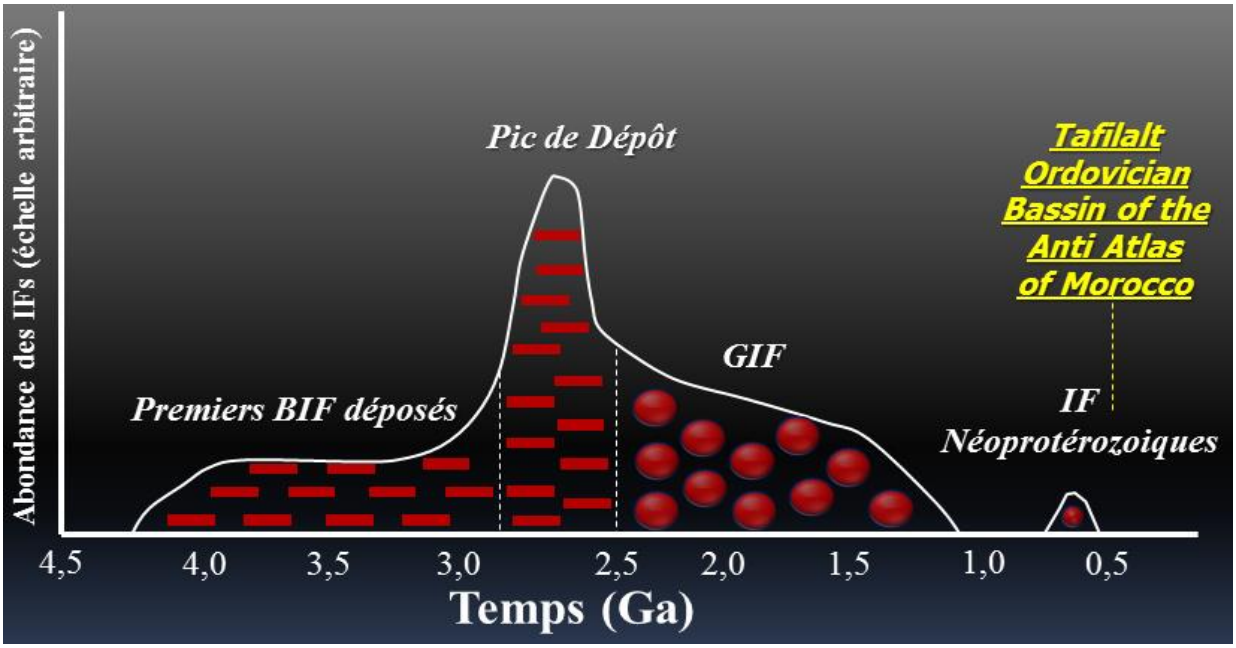

Fig.10 Tafilalt GIF classification according to [28, 30]

The Bani 1 sandstones illustrates a second phase of iron mineralization, which remains very weak, keeping always an oolitic iron form. Indeed, it is from the middle Ordovician, and especially in Ktaoua group, where is approved the quantitative and the qualitative iron mineralization. This granular iron form is probably caused by the intervention of the Ferro bacterias which generates this forme during the time of the super saturation by reduced iron. According to these results, it is clear that the IFs of Tafilalt basin illustrate a specific character stand of point geodynamic setting able to establish the necessary conditions for the formation of this ore during Upper Ordovician, where the climate has generated the snowball earth event.

In fact, and according to the IFs classification [32, 31] which attests the difference between the Precambrian and Phanerozoic IFs, where the firsts are basically interbedded cherts, and the seconds are commonly presented such small units formed by oolithes in intracratonic basins, we conclude that this second case corresponds exactly to the Tafilalt case. And we agree that these ferruginous formations correspond to the 'Granular Iron Formation' class, and manifests as kind of Sedimentary Rapitan iron ore of the Phanerozoic BIFs (Fig.10).

Through this study, we have demonstrated that iron mineralization in the Ordovician basin of Tafilalt is mainly as Oolitic or granular form, which lets us classify these formations as GIF or 'Granular Iron formations' kind of Rapitan type [16, 30], that are deposited during the Ordovician. The weather event 'snowball earth' dated this period, presents the key factor responsible of GIF deposit, in very exceptional geographical and geodynamic conditions.

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