Lithostratigraphic analysis and characterization of the upper miocene deformation of the Beni Bou Ifroure massif (Jbel Harcha Unit) eastern Rif Morocco

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Abstract. In the eastern Rif the unit of Jbel Harcha which is part of Beni Bou Ifroure massif, the latter belongs to the Rif chain which was formed during the Alpine orogeny. Lithostratigraphic analysis of the geological map and field investigations shows that this unit is constituted by carbonate facies of limestone attributed to the lower and middle Jurassic. At the level of upper Jurassic and Cretaceous we observe metamorphic terms presented by schists. The structural examination allows to distinguish two types of deformation the first one is penetrative which is materialized by a metamorphism of the formations of upper Jurassic and Cretaceous whose direction of the planes of schistosity varies between N125 and N140. This type is linked to a NE-SW shortening, attributed to the Tortonian and materialized by a set of open and normal faults of direction N040 to N045. The second type is generally characterized by brittle structures presented by dextral strike-slip faults of direction N120 to N140 that intersect the ancient accidents. This episode linked to a N-S to NW-SE shortening is responsible for the N070 thrusting of the Jurassic rocks in the study area.

1 Introduction

The eastern Rif is characterized by the presence of numerous rocky massifs that stand out in the regional topography and are dominated by Mesozoic carbonate facies (Guillemin and Houzay, 1982) with Rifan and Atlasian affinity. However, the flattened low-lying areas correspond to Neogene basins dominated by marly facies [1,2,3,4].

Among these structural domains, we distinguish the Beni Bou Ifrour massif, Kebdana and Gareb-Ziata massifs, Cap des Trois Fourches and Gourougou massifs separated by subsident Neogene basins such as the Melilla basin and the Gareb and Bou Areg plains. The Beni Bou Ifroure massif forms a horst structure, oriented NE-SW, framed on either side by the Neogen basin of Kert and the Quaternary basin of Gareb-Bouareg. It is subdivided into two distinct structural units [5,6], a unit located in the northeast and the most important, called Ouiksane, characterized by intrusions of iron deposits [7].

A unit located in the South called unit of J. Harcha which is the subject of our study. This study focuses on the lithostratigraphic description and characterization of the deformation of the unit of J. Harcha at the level of the eastern Rif foreland. The cartographic examination shows that these deformations are expressed at different scales of the outcrop and are superimposed on all the discontinuities of the structural legacy of previous tectonic deformation phases. The identification and characterization of these deformations are studied by a multidisciplinary approach highlighting the correspondences that exist between all the cartographic, stratigraphic, tectonic, structural and satellite imagery data. In this approach, we proceeded by a detailed descriptive study of all the tectonic structures which affect in a specific way the various geological formations of jbel harcha.

These data are processed and analysed according to the stratigraphic layout of these formations and the geometric organization of their deposits.

2 Geological Context

The study area is located 20 km east of the city of Nador and 8 km north of the city of Al Aroui. It is part of the regional geodynamic context of the Eastern Rif, which extends between Wadi Kart and Wadi Moulouya (Figure 1) [Reference of the map]. This region corresponds geologically to the foreland of the Rif chain. It is characterized by contrasting reliefs marked by a succession of several alignments of mountainous massifs that overhang areas of low relief represented by plains. This topographic arrangement is induced by a double structuring in

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horst and graben associated with phases of Neogene deformation. The Beni Bou Ifrour massif, the subject of this study, is composed of autochthonous metamorphic terrains of Mesozoic age, cut by laccolites and granodiorite veins (and affected by a network of NE-SW faults [5].

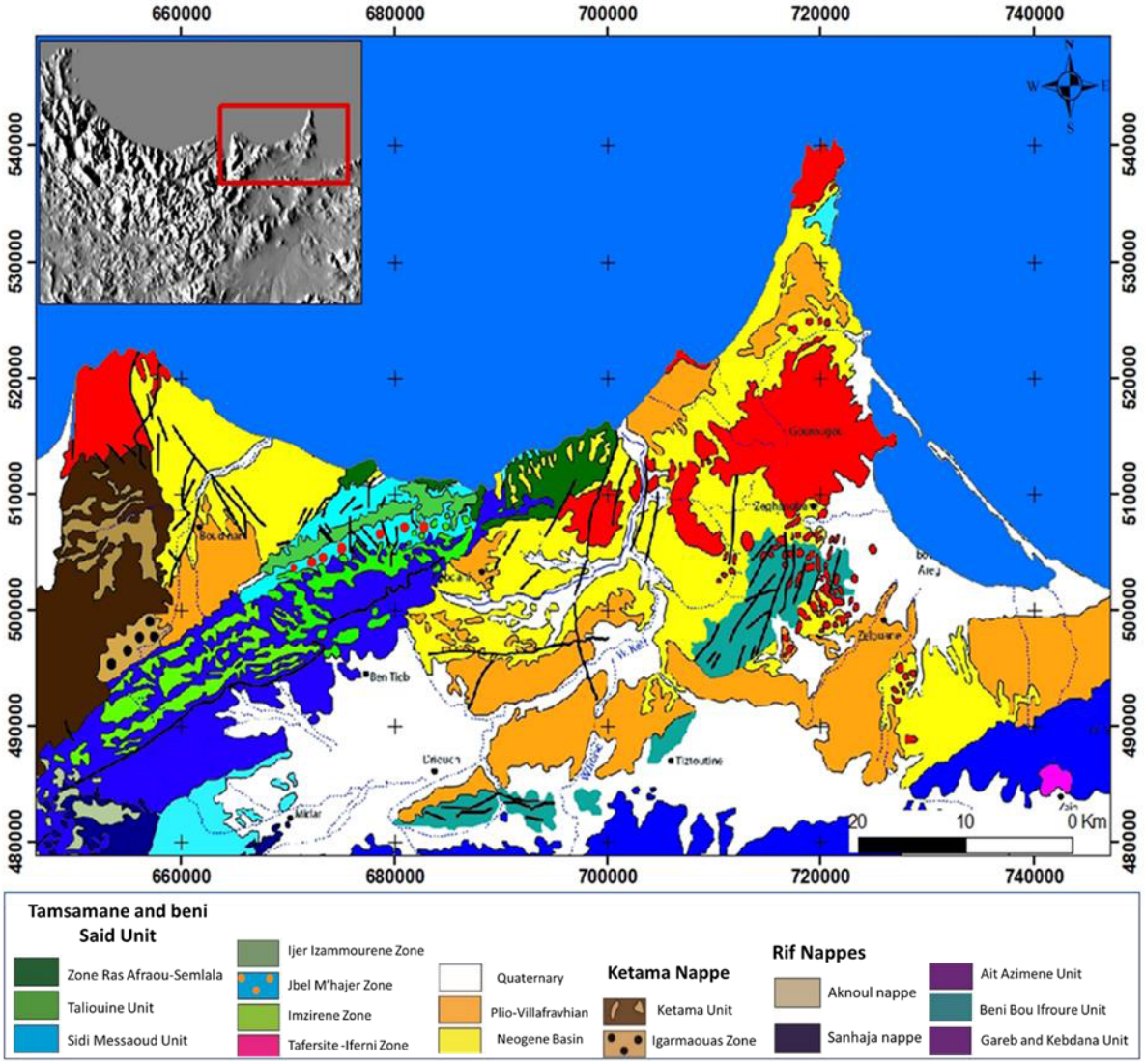

Fig 1. structural diagram of Rif shows the location of the study area (extracted from the geological map of Zeghanghane) [8]

The Kebdana massif located further east is constituted by a strongly folded wrinkle of the Atlas foreland (autochthonous), which corresponds to a complete Jurassic series from Lias to Malm [9] and by thrust elements of Rifan affinity. This massif is characterized by a plicative and tangential tectonics with a southern vergence [10].

The massif of Cap des Trois Fourches located at the northern end of the study area, consists of a metamorphic basement of Palaeozoic age [8], a Tertiary series composed of three sedimentary cycles: à Tortonian cycle, a Messinian cycle and a Pliocene cycle, as well as Miocene rhyolitic volcanic flows in its northern part [11]. The Bou Areg and Gareb plains that extend between the Beni Bou Ifrour and Kebdana massifs correspond to two basins subject to strong subsidence that would be controlled by the play of normal faults [12,13].

This subsidence was active mainly during the Mio-Pliocene and slowed down during the Quaternary [14]. The Melilla Basin, framed by the two volcanic massifs mentioned above and whose genesis is linked to the main orogenic movements of the Rif during the Middle Miocene [9], has recorded three major sedimentary cycles: an upper Tortonian cycle, a Mesinian cycle and a Pliocene cycle [15,9].

The Gourougou strato-volcano located north of the Bou Areg plain is formed of calc-alkaline potassic

3 Methodology

Jbel Harcha (Figure 2) is an independent mountainous edifice that rises to 480 m, located in the SW extension of the Beni Bouyafrou Massif. It is presented as a horst structure consisting of

lavas related to Messinian rhyolitic volcanism and basic lavas of Plio-Quaternary age [11].
formations of age ranging from Mesozoic to Cenozoic (Figure 3). The raised reliefs of the central part are marked by a preponderance of massive carbonate materials of the Jurassic. It is framed on either side by Cretaceous sandstone and marlstone series that show fairly penetrative schistose deformations attributed to the Miocene.

Fig 2. Panoramic view of the unit of Jbel Harcha

This study begins with a regional geological survey. It consists of a bibliographical report of all the documents available to trace the geological history of the region and to place the sector considered in its regional geodynamic context.
This study is completed on a local scale by a detailed description of the outcrop to verify the stratigraphic connections [16] and the structural relationships between the different units of these terrains.

The aim is to define the structural domains by subdividing the studied area into different distinct components defined according to geological parameters such as lithology and structural position.

In addition, if the outcrop conditions allow, a geological map can be made at a scale adapted to the desired accuracy. This map must represent the nature and the outcrops of the grounds constituting the substratum as well as the overlying grounds. Moreover, this map must show all the useful clues concerning the structural elements (dips, folds, schistosity, faults and breaks, seams etc.

4 Results and discussions

The lithostratigraphic analysis (Figure 4) of the cartographic data (geological map of Zeghanghane at 1:50000) and the field data shows that the stratigraphic series is started by the Jurassic formations of which the Lower and Middle Lias is presented by massive limestones at the base and stratified white dolomites at the top, 100 meters thick with a dip of 25° towards SE (Figure 5), which are overlain by the upper Lias Ammonite-bearing bedded limestones and marlstones. The lithostratigraphic analysis (Figure 4) of the cartographic data (geological map of Zeghanghane at 1:50000) and the field data shows that the stratigraphic series is started by the Jurassic formations of which the Lower and Middle Lias is presented by massive limestones at the base and stratified white dolomites at the top, 100 meters thick with a dip of 25° towards SE (Figure 5), which are overlain by the upper Lias Ammonite-bearing bedded limestones and marlstones.

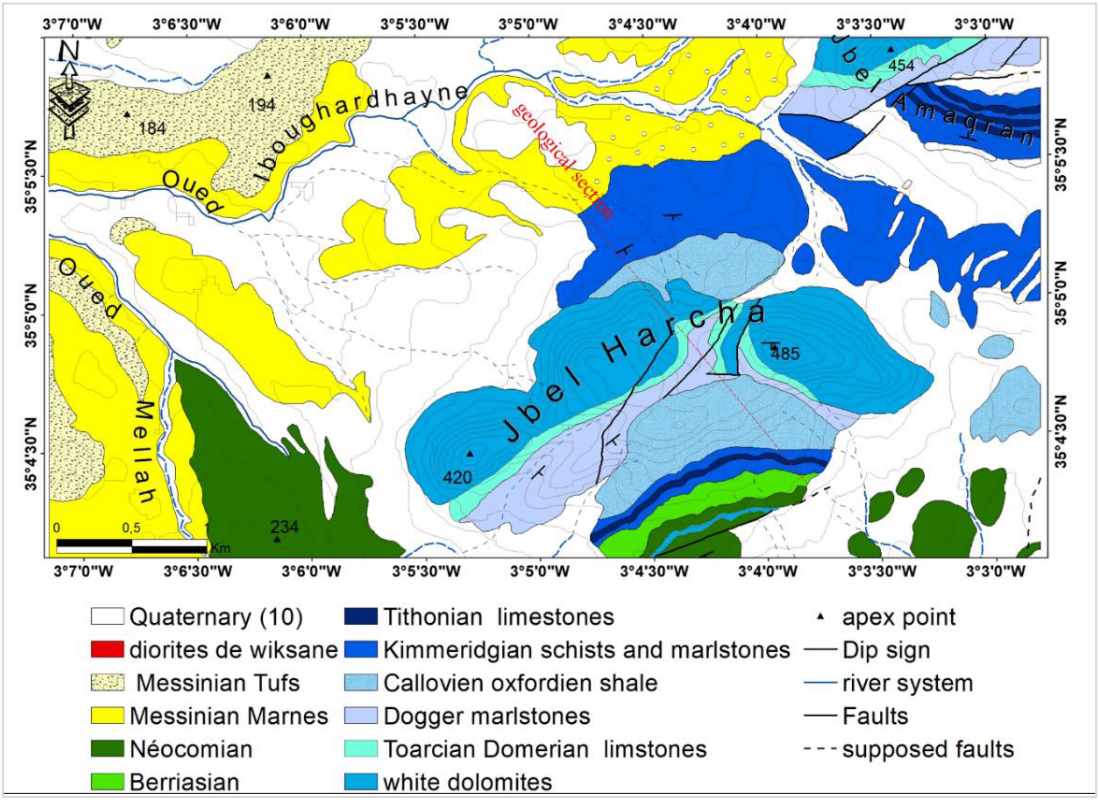

Fig 3. Geological map of Jbel Harcha, extracted from the geological map of Zeghanghane at 1/50000, modified

The Dogger is represented by marly-calcareous series alternating with small banks of Ammonite limestone 70 m thick (Figure 5), Callovian-Oxfordian presented by black shales and greenish sandstones at the base and marly-calcareous levels with Ammonites at the top. (Figure 5) Kimmeridgian-Tithonic characterized by alternating sericite shales and marlstone banks and small banks of limestones with Aptychus bars and by limestones with nannofossils at the base and calpionella at the top, the Cretaceous presented by shale-sandstone facies (Figure 5-C and Figure 5-D) and marlstones that lie in discordance on the underlying series.

Neogene outcrops on the plains where it rests unconformably on the Cretaceous; it is dominated by grey or greenish marl with a sub horizontal dip (Figure 5-E). Quaternary presented by encrusted surfaces on conglomerates or on ancient terraces and lower pink silts.

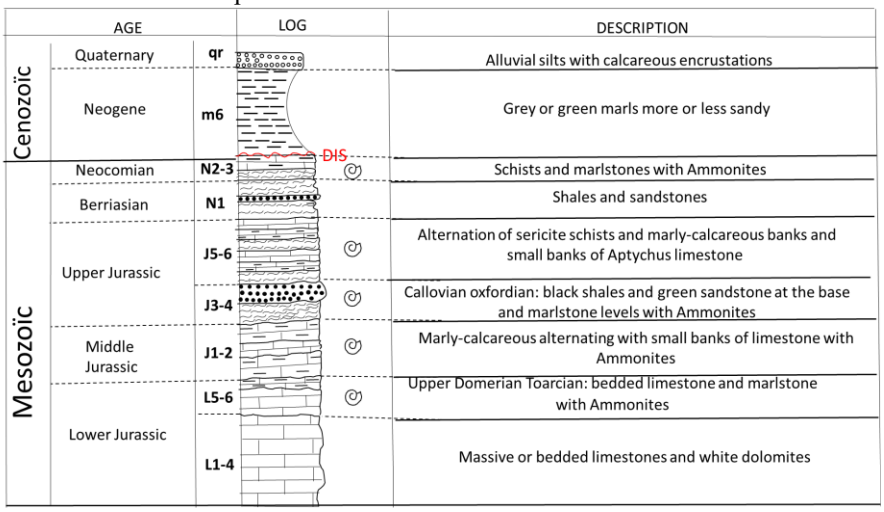

Fig 4. Stratigraphic log of the Jbel Harcha unit

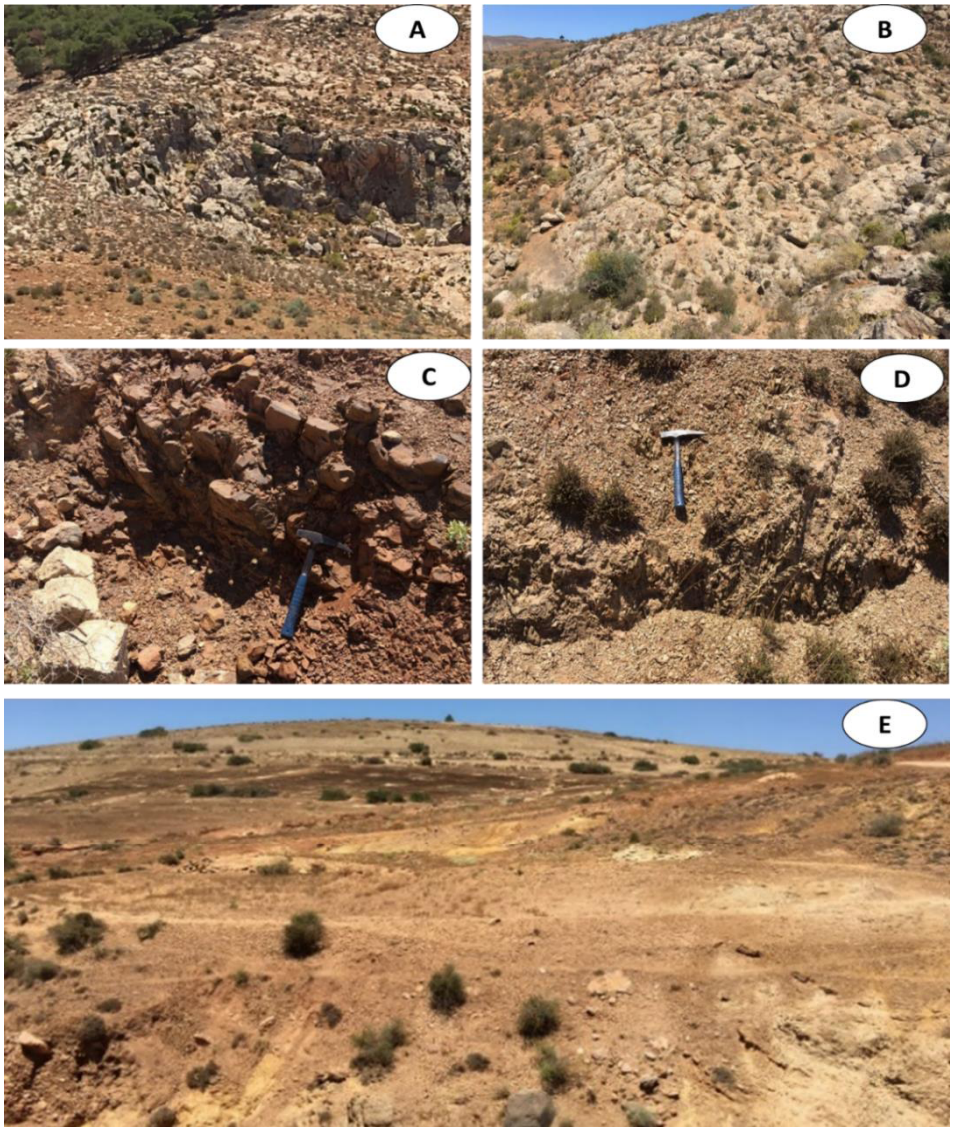

Fig 5. lithostratigraphic facies of the Jbel Harcha unit: A and B Jurassic carbonate; C and D: Cretaceous shale; E Neogene marl unconformity on Jurassic marl and limestone

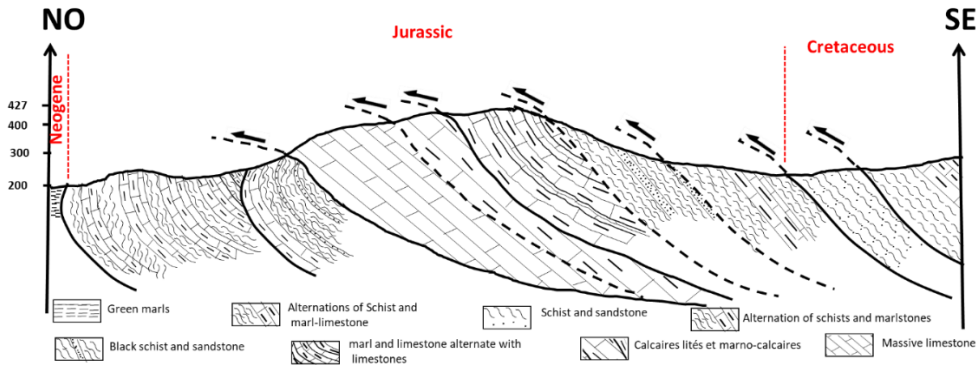

Fig 6. Schematic geological section NW-SE at the level of jebl Harcha

Structural examination shows that Jbel Harcha is a structural edifice marked by a partial superposition of several tectonic packages (Figure 7-A) of hectometric thicknesses engaged in scaling

phenomena with vergence towards the NW (Figure 6). These deformations are posterior to an episode of metamorphism (Figure 7-D) related to NE-SW shortening attributed to the Tortonian. The Jbel Harcha stacking is obliquely framed by dextral, regional, N120-striking faults that intersect the N040 and N070 faults (Figure 8). These sliding phenomena are accompanied locally by rotations of the structures at the level of the lateral blocks. The evidence of these displacements is also verified by the conformable alignments of the hydrographic networks. In addition, the examination of the outcrop highlights oblique shearing phenomena and the ronchonment of these tectonic scales is crossed obliquely by a network of dropouts.

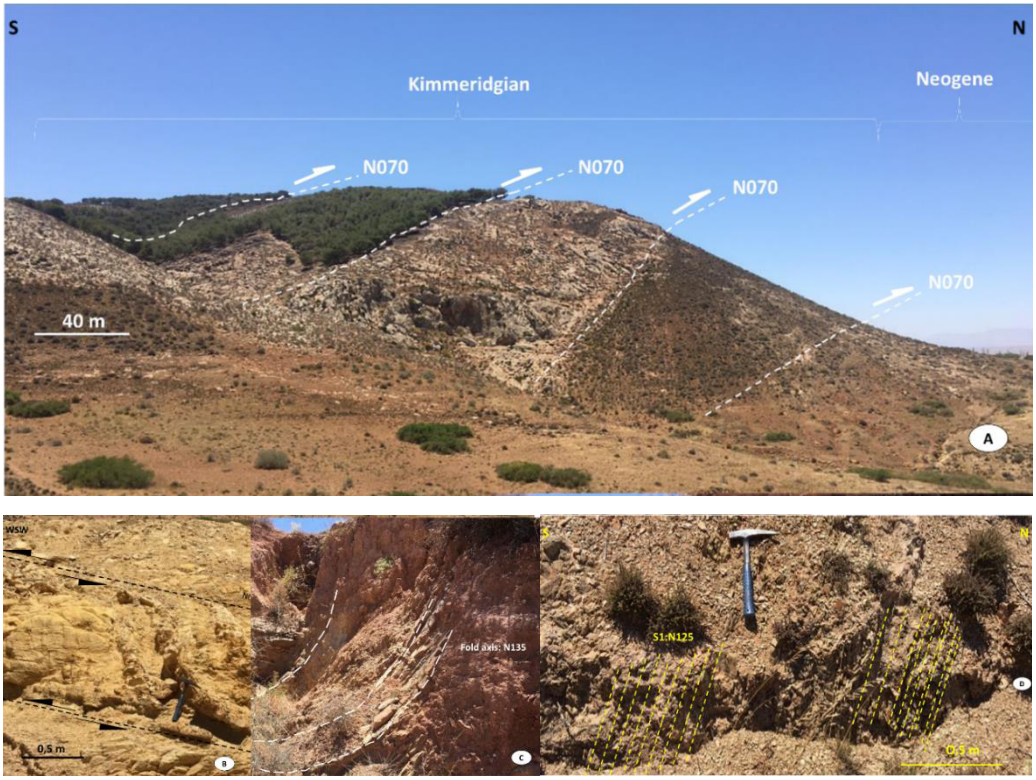

Fig 7. A) N070 thrusts in the Jurassic carbonates; B) crossover shows that there is a sinister displacement; C) folds related to the thrusts; D) schistosity axes

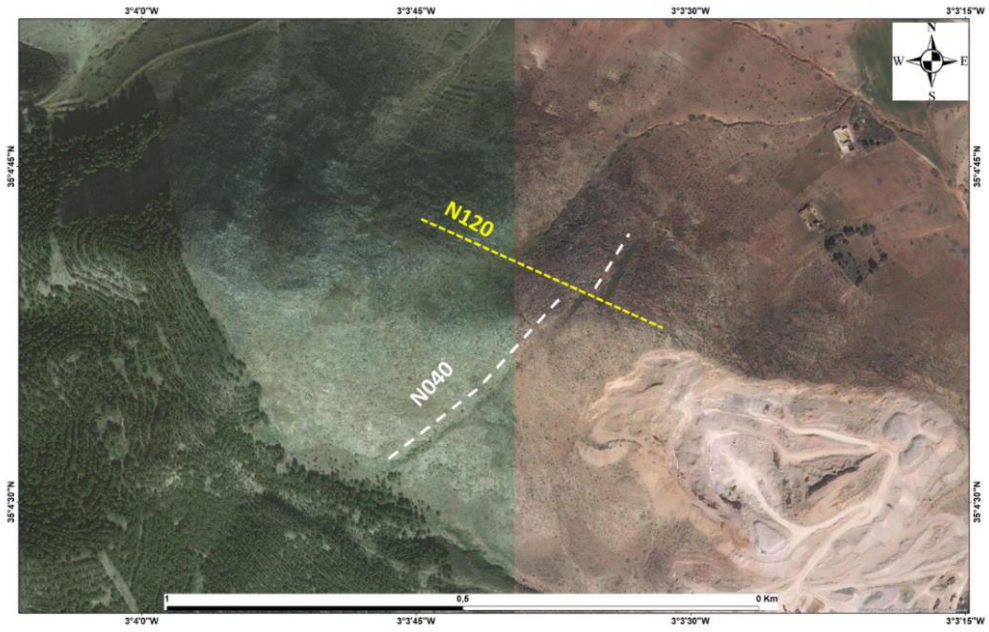

Fig 8. satellite image shows the intersection of faults N040 and N120

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These fault structures are also described on a smaller scale in the Lias carbonate masses where they are accompanied by lateral displacement of the massive compartments. Moreover, the operation of these dextral faults N120 is combined with other less important senestial sliding faults N25 and N45 that are part of the same family of faults affecting the Albran Sea such as the Yusuf fault [17, 18], and the Idrissi fault [19, 20].

The system of these thrust faults is consistent with the scaling phenomena and is part of a compressive context associated with a NW-SE shortening phase.

The Jurassic and Cretaceous carbonate and shale facies are correlated with those described by [3] at the Tamsamane massif. They show the same Mesorif deformation system [21, 22], this allowed us to structurally link the Beni Bou Ifrour massif to the Domane du Rif.

5 Conclusion

The lithostratigraphic analysis of Jbel Harcha shows that it is constituted by carbonate formations of the Jurassic and alternations of detrital and marlstone series of the Cretaceous with a volcano-sedimentary episode in the Berriasian, these formations are surmounted in unconformity by a Miocene calcarenite.

The structural analysis shows that the Mesozoic terrains are subjected to polyphase tectonics of the Tortonian presented by normal faults N040 to N045 and unstuck faults N070 linked to a NE-SW shortening which is responsible for the observed metamorphism. Then these grounds are undergone to a tectonics of post-Tortonian sliding, responsible for regional unstuck faults of direction N120.

References

1. M. Achalhi, P. Münch, J. Cornée, A. Azdimousa, M. Melinte Dobrinescu, F. Quillévéré, H. Drinia, S. Fauquette,G. Jiménez-Moreno, G. Merzeraud, A.B. Moussa, Y. El Kharim, & N. Feddi, Thelate *Palaeogeogr. Palaeoclimatol. Palaeoecol*. **459**, 131-152, (2016), https://doi.org/10.1016/j.palaeo.2016.06.040
2. A. Azdimousa, J. Bourgois, *J. African Earth Sci.* **17**, 975-980. (1993), https://doi.org/10.1016/0899-5362(93)90039-S
3. A. Azdimousa, G. Poupeau, H. Rezqi, L. Asebry, J. Bourgois, L. Ait Brahim. Bulletin de l'Institut Scientifique, Rabat, 9–18. (2006).
4. M. Bernini, M. Boccaletti, R. Gelati, G. Moratti, G. Papani, & J.E. Mokhtari. *J. Pet. Geo*l. **22**(1), 115-128. (1999), https://doi.org/10.1111/j.17475457.1999.tb00462.x.
5. S. Kerchaoui. Etude géologique et structurale du massif des Beni Bou Ifrour (Rif oriental, Maroc). Doctoral dissertation, Paris 11 (1985).
6. N. Lebret. Contexte structural et métallogénique des skarns à magnétite des Beni Bou Ifrour (Rif oriental, Maroc) Apports à l'évolution géodynamique de la Méditerranée occidentale Doctoral dissertation, Université d'Orléans, (2014).
7. M. Bouabdellah, N. Lebret, E. Marcoux, & M. Sadequi, Les mines des Beni Bou Ifrour-Ouixane (Rif Oriental): un district ferrugineux néogène de type skarns "The Beni Bou Ifrour-Ouixane mines (Eastern Rif), Neogene Skarn Type Iron Deposits", (2012).
8. A. Faure-Muret, Carte géologique du Maroc au 1/50 000, feuille de Zeghanghane. Notes Mém. Serv. Géol. Maroc, **370**, (1996).
9. M. Guillemin, J.P. Houzay. *Notes & Mém. Serv. géol*. Maroc **314**, 7–239, (1982).
10. Y. Hervouet, P. De Luca. *Earth Sciences Bulletin France*, **7**(3), 305-310, (1978).
11. J. Hernandez. Le volcanisme miocène du Rif oriental (Maroc): géologie, pétrologie et minéralogie d'une province shoshonitique Doctoral dissertation, minéralogie d'une province shoshonitique Doctoral dissertation, (1983).
12. J.P. Rampnoux, J. Angelier, B. Colletta, S. Fudral, M. Guillemin, G. Pierre, Tectonique. Tome 6, numéro **4**, 439-464, (1979).
13. M. Guillemin, R. Wernli, Le sondage de Kariat-Arekman et le Néogène du bassin de Nador (Maroc Nord-oriental). Notes du service géologique du Maroc, **43**(321), 255-262, (1987).
14. D. Frizon de LaMotte, Contribution à l'étude de l'évolution structural du Rif oriental (Maroc), Thèse 3e unit, Univ. Paris XI, Orsay, (1979).
15. J. Morel, Evolution récente de l'orogène rifain et de son avant-pays depuis la fin de la mise en place des nappes (Rif, Maroc), Doctoral dissertation, Paris 11, (1988).

16. A. Farah, A. Algouti, A. Algouti, F. Hadach, *In E3S Web of Conferences* **240**, 04001. EDP Sciences, (2021), https://doi.org/10.1051/e3sconf/202124004001
17. P. Martínez-García, J.I. Soto, M. Comas, *Geo-Marine Letters*, **31**(1), 19-36, (2011), https://doi.org/10.1007/s00367-010-0212-0
18. F. Estrada, J. Galindo-Zaldívar, J.T. Vázquez, G. Ercilla, E. D'Acremont, B. Alonso, C. Gorini, *Terra Nova*, **30**(1), 24-33, (2018) https://doi.org/10.1111/ter.12304
19. V. Tendero-Salmerón, M. Lafosse, E. D'acremont, A. Rabaute, O. Azzouz, G. Ercilla, ... & J. Galindo-Zaldivar, *Front. Earth Sci.,* **233**, (2021), https://doi.org/10.3389/feart.2021.645942
20. V. Tendero-Salmerón, J. Galindo-Zaldivar, E. d'Acremont, M. Catalán, Y.M. Martos, A. Ammar & G. Ercilla, *Mar. Geol.,* **443**, 106696, (2022), https://doi.org/10.1016/j.margeo.2021.106696
21. A. Jabaloy-Sánchez, A. Azdimousa, G. Booth-Rea, L. Asebriy, M. Vázquez-Vílchez, J. Martínez-Martínez. M., & J. Gabites, *Tectonophysics*, **663**, 150-17, (2015), https://doi.org/10.1016/j.tecto.2015.02.003
22. A. Azdimousa, A. Jabaloy-Sánchez, P. Münch, J.M. Martínez-Martínez, G. Booth-Rea, M. Vázquez-Vílchez, ... & F. González-Lodeiro, *J. African Earth Sci.* **150**, 657-67, (2019), https://doi.org/10.1016/j.jafrearsci.2018.09.018