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Late Visean tholeiitic rocks of the Mechraa Ben Abbou Basin (Northern Rehamna, Western Meseta, Morocco): Petrography, geochemistry and geodynamic setting

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Abstract

The magmatic activity related to the Moroccan Variscides is expressed in the Mechraa Ben Abbou Basin (Northern Rehamna, Western Meseta, Morocco) by Visean basic rocks represented by gabbros, dolerites and basalt sills. Basic rocks display an equigranular textures for the gabbros, intersertal ophitic and subophitic for the dolerite and the basalts are mostly porphyritic and have vacuoles within the microlithic matrix. These rocks show a simple primary mineral association made up of plagioclase, clinopyroxene, and iron oxides, chlorite and calcite as secondary minerals. Thirteen geochemical analyses carried out on these rocks suggest a tholeiitic continental affinity. These rocks were originated in a post-collisional scenario that have inherited their orogenic signature after the subduction of the Rheic Ocean during Late Devonian.

Keywords: Mechraa Ben Abbou Basin, tholeiitic, orogenic context, subduction of the Rheic Ocean.

Introduction

The Moroccan segment of the Variscan Belt is well exposed, in the northern boundary of the West African Craton (WAC), which took place due to the closure of the Rheic Ocean and the collision between Laurussia and Gondwana[1-3]. In Morocco, the Meseta is the best territory that shows the effects of the Variscan orogeny[4,5]. The Meseta is subdivided into two major geological domains which are the Western Meseta and Eastern Meseta. In the Western Meseta (Figure-1), the Hercynian magmatic activity is essentially represented by three igneous massifs; i e. Jbilet, Rehamna and the Moroccan Central Hercynian Massif[6-12].

During the Late Carboniferous (Late Visean – Namurian), the magmatic evidences are materialised in Western Meseta by pillow lavas and basic sills[6-10,12], and in the Eastern Meseta by an explosive volcanism that consists mostly of andesite to dacite[13,6].

The most of these studies do not lead to a consensus on the interpretation of this magmatism, nevertheless, several points remain disputed. However, on basis of the mineralogical and geochemical features, several authors provide contradictory interpretations on the genesis process and evolution of these rocks, assigning them to extremely different geodynamic contexts.

According to Kharbouch[6], Aarab[7] and Remmal[8] the Late Carboniferous magmatic rocks, in the Western Meseta, show geochemical features correlated to intraplate tholeiitic series. Meanwhile Roddaz[9] and Roddaz et al.[14] proposed that the ignous rocks interbedded into Namurian series are calc-alkaline type, when their placement is synchronous of the foreland basin establishment.

In the Eastern Meseta, the geochemical analysis indicates that the Viseo-Namurian volcanic rocks of an active margin environment[13,6].

The whole Hercynian massifs of the Moroccan Meseta, including Rehamna massif, are characterized by bimodal magmatic events: granites[15-19] and basic rocks (i. e. dolerite dykes, gabbroic, and basalt flows)[6,8,12,20,22].

The geodynamic evolution of the Rehamna massif during the upper Visean is marked by several magmatic events related to the Variscan orogeny. In the Gada Jennabia syncline, an integral part of Mechraa Ben Abbou Basin (Northern Rehamna), the basic magmatic event is dominated by sills of variable thickness of gabbros, dolerites and basalts.

The main objectives of the present paper are: i. the characterization of the basic magmatic event through geochemical analysis associated with petrographic and mineralogic study, thus so far missing, ii. the establishment of geodynamic model, iii. the correlation of this magmatism with the tectono-sedimentary analysis in order to illustrate the history of the Mechraa Ben Abbou Basin, and iv. the comparison with

synchronous magmatic series that mark the Hercynian chains in Morocco and Western Europe.

Geographical and geological setting

The Rehamna Massif belongs to the Western Meseta, located approximately 120 km north of Marrakech and 130km south of Casablanca. It is divided into two major parts: Northern Rhamna and Southern Rehamna[23]. The Southern Rehamna is subdivided into three main structural units separated by the Median (part of the Western Meseta Shear Zone, WMSZ, and the Ouled Zednes Faults[24,46,47] which are: the Western Rehamna that belongs to the Coastal Block, the Central and Eastern Rehamna of the Centre of the Western Meseta. Baudin et al.[25] suggested a subdivision, based on the intensity of deformation and metamorphic grade, into high and low metamorphic units (Figure-2).

Studied areas: The Mechraa Ben Abbou (MBA) basin, located in the Northern Rehamna, was formed during the Hercynian compressive kinematics as a Carboniferous pull-apart basin. It consists of the Gada Jennabia syncline between two large scale dextral strike-slip faults, which are the Foum El Mejez Fault in the East and the Leffaid Fault in the West, where the Carboniferous deposits accumulated. The area is transected by numerous transverse N60-N70 faults (Figure-3).

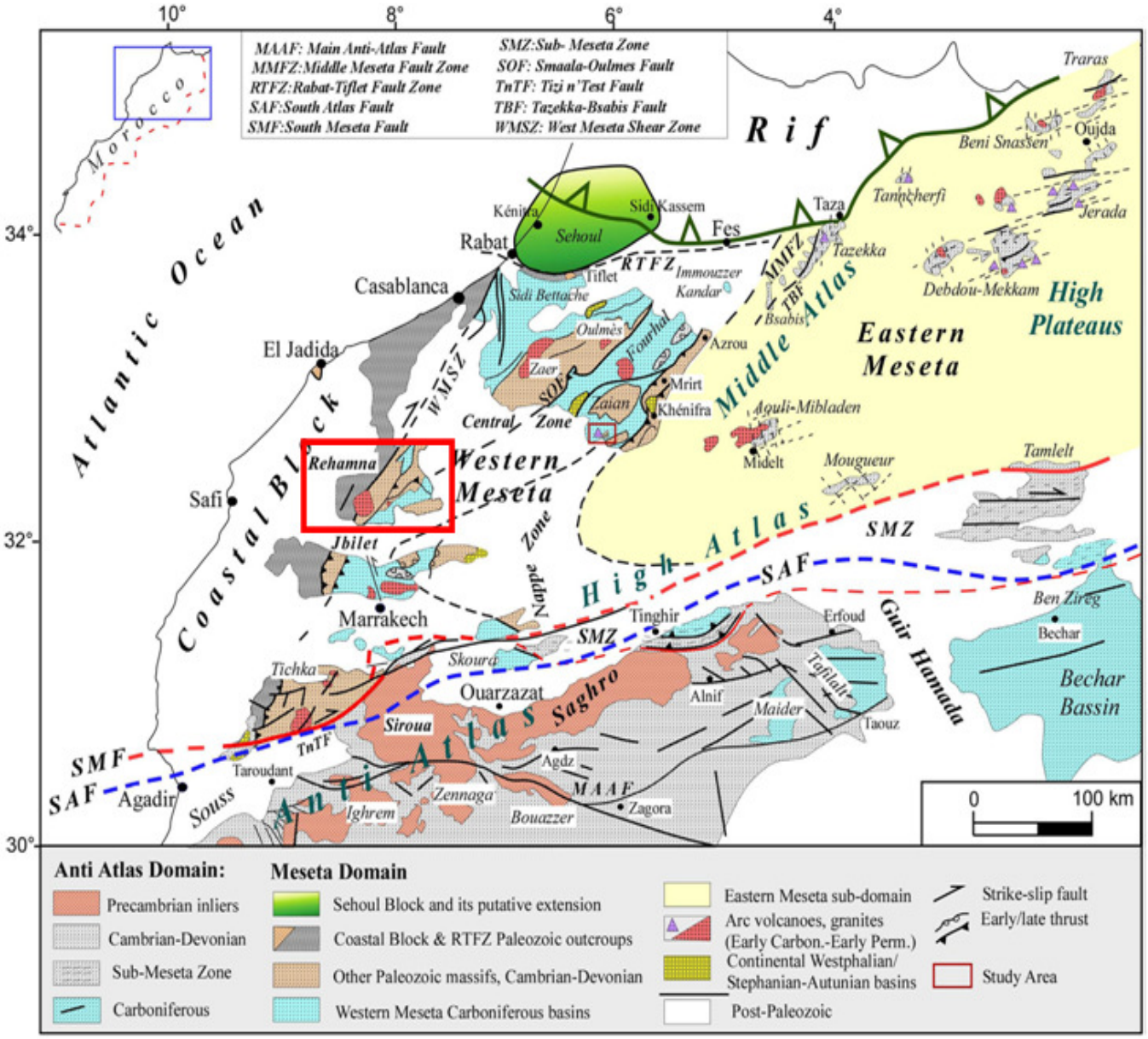

Figure-1: Major geological divisions in the northern region of Morocco; with the Visean basin and magmatic outcrops of the Western Meseta. Square shows the studied area.

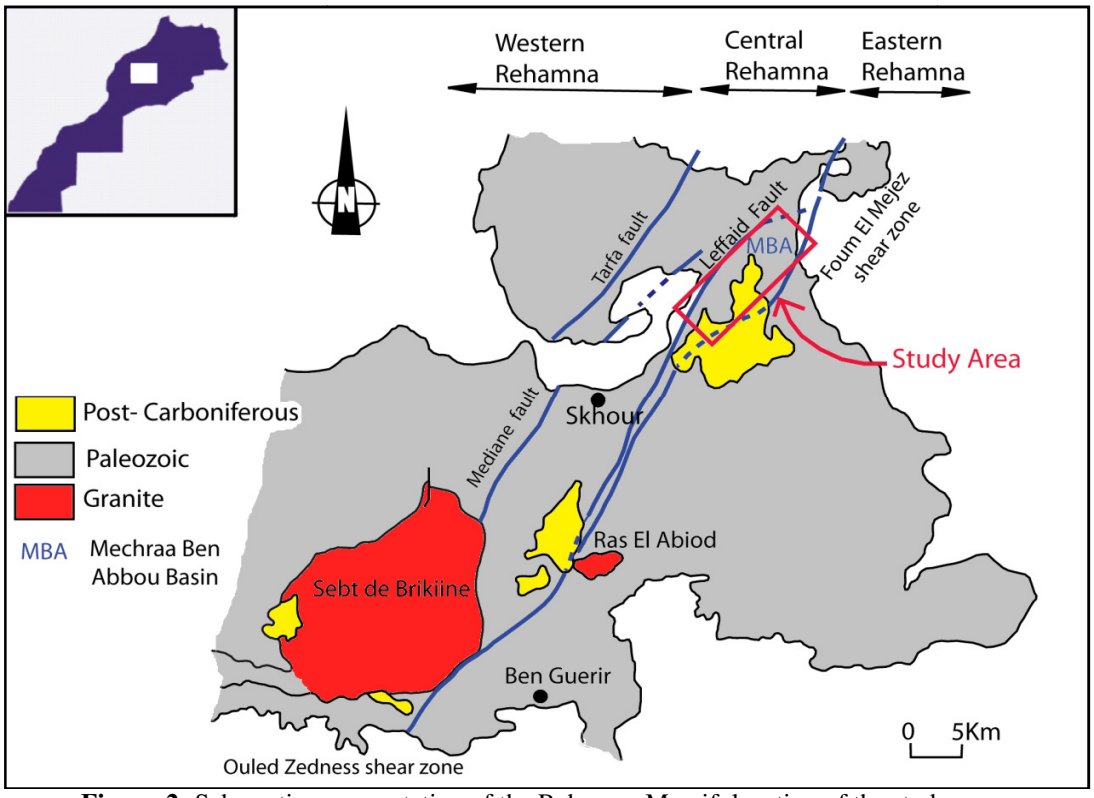

Figure-2: Schematic representation of the Rehamna Massif, location of the study area.

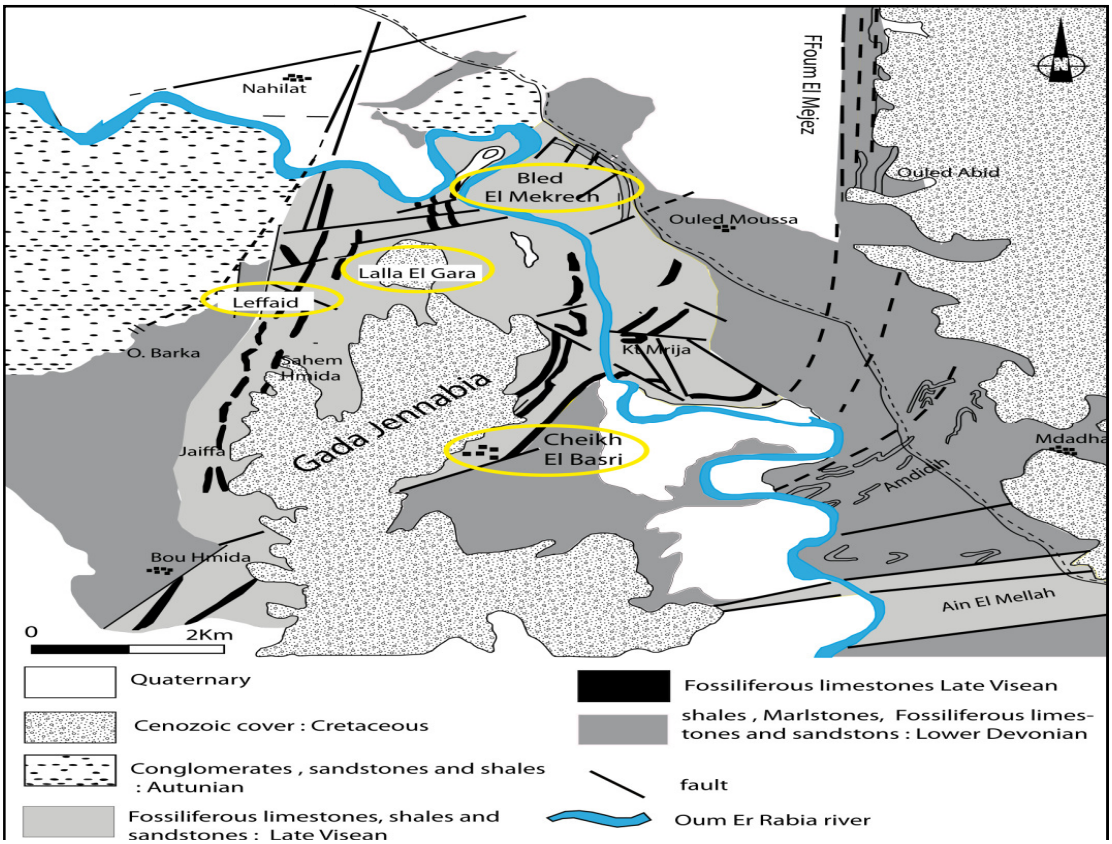

Figure-3: Geological map showing the volcanic rocks of the Mechraa Ben Abbou Basin.

Lithostratigraphic framework: During the Late Visean, The Western Meseta is marked by a tectonic instability corresponding to major phase of hercynian orogeny[20,26,27]. In Rehmana massif, the marine transgression took place during that time, while Tournaisian and Early Visean inferior represent a major hiatus[27].

During the Early Visean when the northern basins have been developped, the Rehamna region corresponded to an active plat-form on the edge of an emerged land which is nowday the Coastal Block[20]. However, the Rehmna region, from Asbian to Brigantian, accumulated pelagic sediment introded by continental tholeitique igneous rocks. The Visean basin in Southern Rehamna seems to evolve in parallel with the MBA basin. They are separated by a ridge corresponding to the Koudiat El Adam -Sidi Chahou anticlinorioum.

Four localities, consisting of Visean series interstratified with igneous rocks, have been studied in detail by measuring stratigraphic sections, Bled El Mekrech, Cheikh El Basri formations on the East flank, Lala El Gara Formation in the centre, and Leffaid Formation on the West flank (Figure-3). The lithological study of the Mechraa Ben Abbou Basin shows that the different Visean meta-sediment facies consist of siliciclatic, carbonate and pelagic sediments, dominated by shale, sandstone and limestone. These sedimentary successions are intruded by doleritic, gabbro and basalt sills (Figure-4).

The sedimentation is dominated at the base by plat-form deposits that contain fossiliferous limestones attributed to Late visean based on the occurrence conodents fauna, i.e. *Philipsia sp, Productus costatus, Martinia glara*, *Anticatonia costata, Dielasma sp* and *Leoblichia prammonoides*[28].

These series are overlied by sandy-pelitic deposits with a continental setting influence, where the metre to decametre thick igneous sills occur within these formations, while the whole series are folded and schistosed that provides the syn-tectonic feature of the latter (Figure-5). The igneous sills are arranged in N80-N60 shaped-bundles.

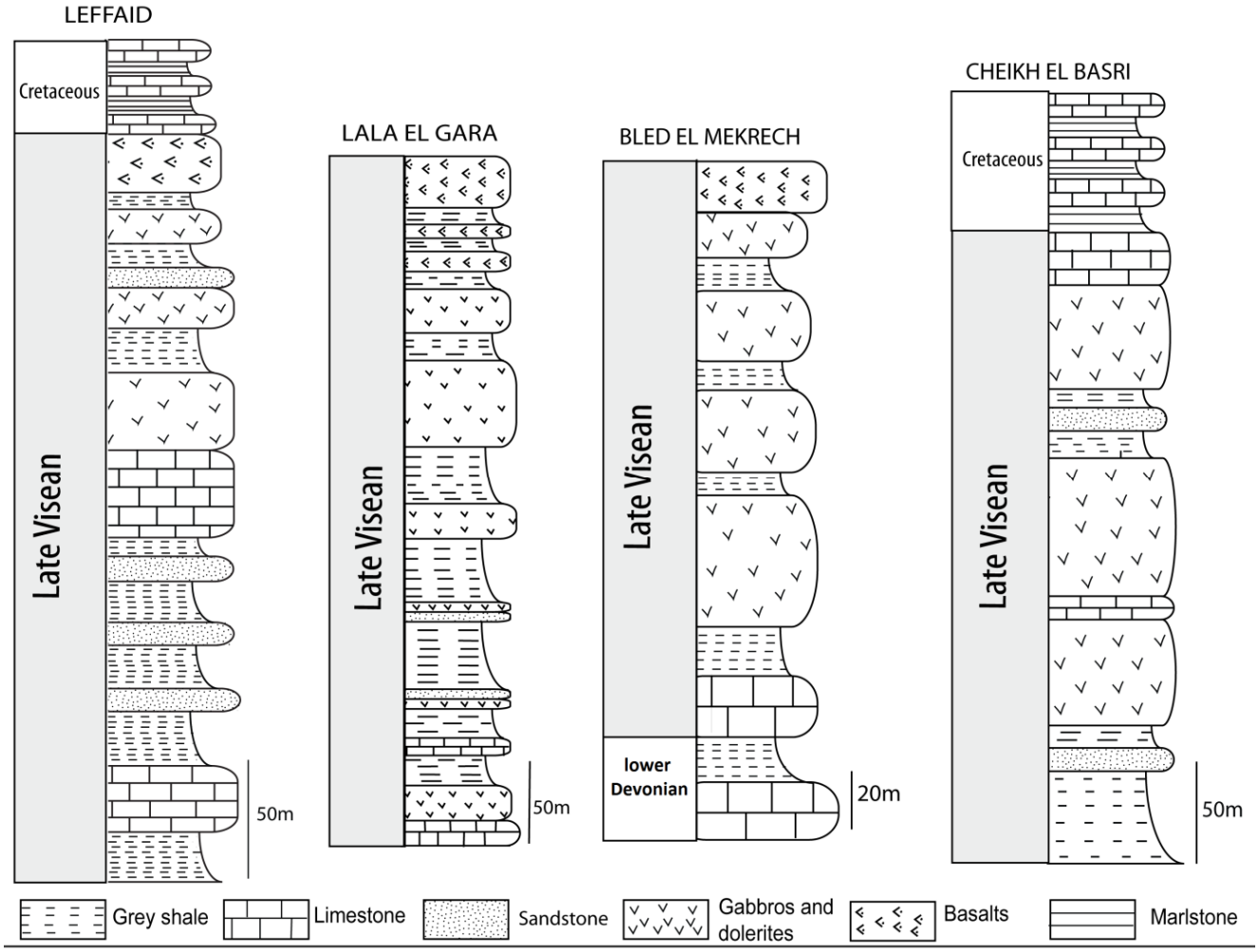

Figure-4: synthetic stratigraphic logs of the sedimentary sets of the MBA basin Bled El Mekrech, Cheikh El Basri formations on the East flank, Lala El Gara formation in the central, and Leffaid formation on the Westflank.

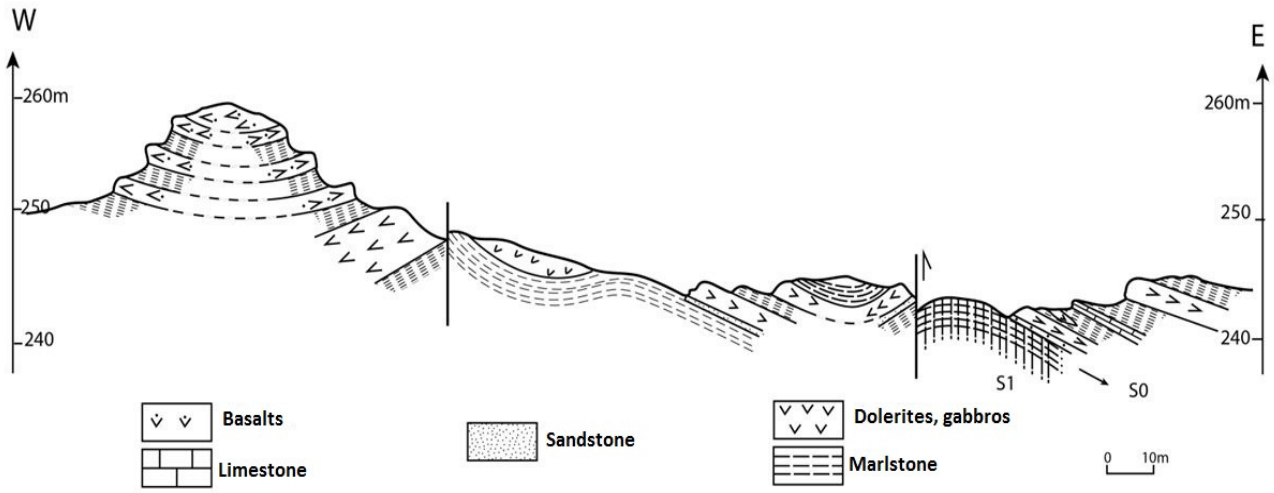

Figure-5: Geological section showing the basic magmatic rocks of the studied area in Lala El Gara Formation.

Petrographic and geochemical analysis

Petrography and microstructure: The igneous rock described herein shows two diverse textures, therefore, they are granular and microgranular for the gabbros and ophitic, subophitic and intersertal for the dolerites (Figure-6a-c). Basalt sills are mostly porphyritic to microlithic and show vacuoles within the microlithic matrix (Figure-6d). These rocks are characterized by large-grained, 2-3mm, in the core of the sills and fine-grained rims (50 microns). The primary paragenesis of the dolerites and the gabbros consists of Ca-plagioclase associated with augitic clinopyroxene. Plagioclase occurs frequently as phenocrysts polysynthetic and Carlsbad twinned, showing an interstal texture. Occasionally, plagioclase occurs as Ophitic texture-laths inside clinopyroxene. The plagioclase is the most abundant than augite-clinopyroxene. Accessory minerals are typically opaque.

Basalt lava flows consist predominately of phenocryst plagioclases (Figure-6). The basalts are highly vesicular where the vesicles are filled by calcite, chlorite and sericite. The secondary minerals, i.e. Chlorite, calcite and iron oxide, are frequent in veins and microcracks of these rocks.

Geochemestry: Chemical analysis consists of thirteen samples of igneous rocks that were carried out in the Managem Laboratory (Marrakech, Marocco). The major elements were performed by X-Ray fluorescence and the trace elements by ICP-MS (Table-1).

In the Na_2O+K_2O/SiO_2 diagram (Figure-7), the analysed basic rocks plot in the basalt field ($46.02<SiO_2<52.29$wt%), On the diagram SiO_2 –Nb/Y, most of basalts from Mechraa Ben Abbou basin are referred to as subalcalin (Figure-7). The high compatible element contents ($4.49 < MgO < 10.38$wt%, $17 < Ni < 268$ppm, $52 < Cr < 174$ppm) provide an evolved character that correspond to low ferromagnesian content. The titanium contents (<1.5wt%) are typical among low–Ti tholeiitic basalt of continental affinity[29]. Relatively high calcium contents ($4.65 < Ca < 13.74$wt%) are opposed to those of sodium $2.5<Na< 4.77$wt%.

La/10-Y/15-Nb/8 diagram[34] shows that the analysed samples are placed in the field of orogenic tholeiitic series, in agreement with the tardi to post-orogenic character of these intrusive rocks (Figure-8). Furthermore, the ratio $Zr/Y > 3$ interpreted that these igneous rocks are originated during subduction zone processes. Likewise, all the basic lavas characterized by low-grade of TiO_2, while transition elements provid as well a major feature of orogenic volcanism.

In rare-earth-element (REE) chondrite-normalised plots, the tholeiitic basic rocks show parallel patterns of light rare-earth-element (LREE) enrichment relative to heavy rare-earths-element (HREE). These samples display a slightly positive Eu anomaly reflecting the role of plagioclase in crystal fractionation processes (Figure-9).

The volcanic and subvolcanic igneous rocks of the Mechraa Ben Abbou basin have a simple mineralogy. The plagioclase and clinopyroxene are the main minerals of the gabbros and dolerite, those rocks show granular and microgranular textures for gabbros, ophitic to subophitic and intersertal for dolerites. The basalts are highly vesicular with vacuoles filled by calcite, chlorite and sericite.

Through the various geochemical diagrams, including Al_2O_3 and TiO_2 contents, the LREE fractionation compared to the HREE in the REE patterns, lead to the same result. Therefore, the tholeiitic volcanic rocks of the Mechraa Ben Abbou Basin are originated in orogenic contexts, i.e., lately or after the Variscan collision. Post-Carboniferous basic magmatism (e.g., Permian or Triassic in age) are absent in the studied area.

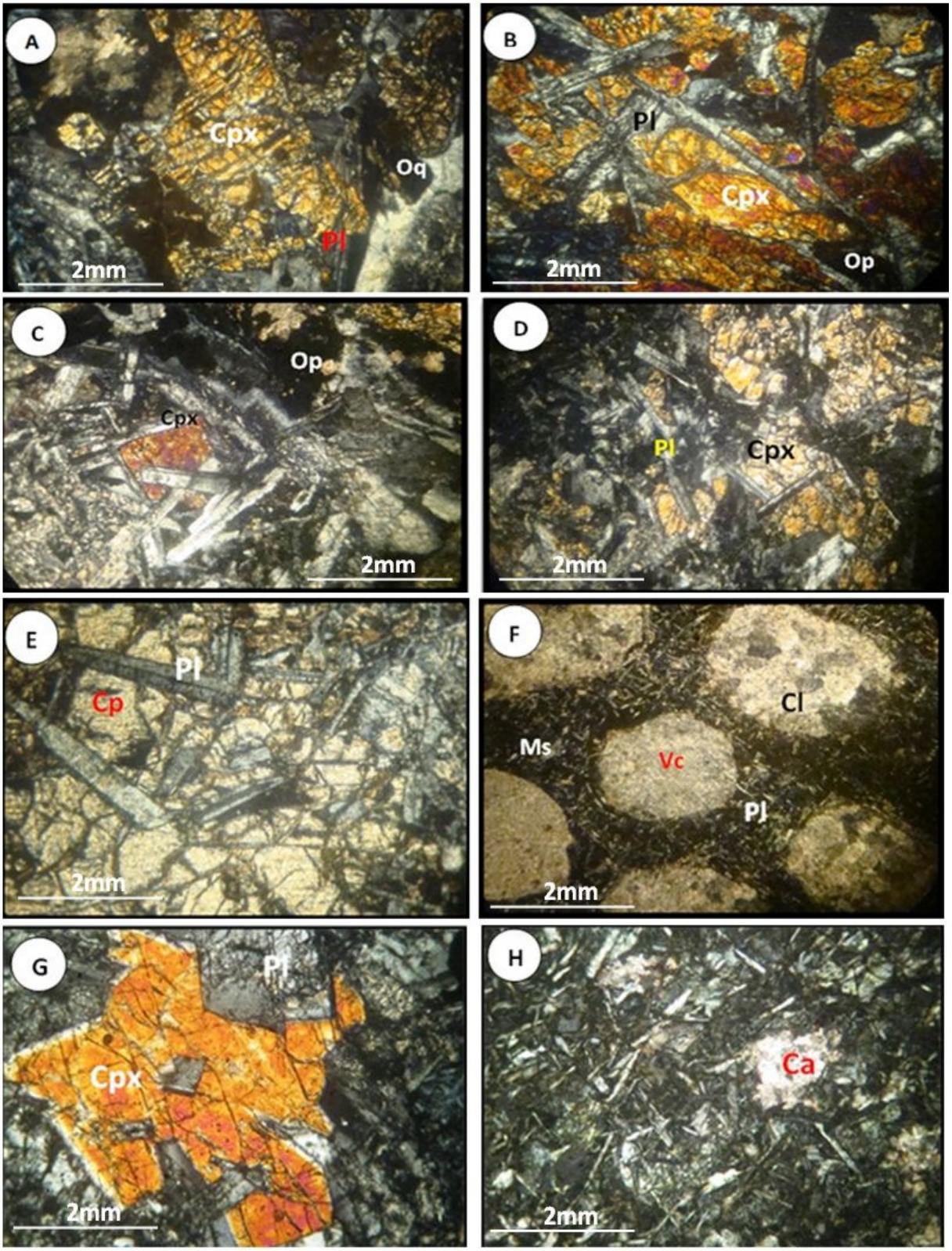

Figure-6: A) Gabbro, B) and –C and G) Dolerites showing ophitic, subophitic and intersertale texture, D, F and H) basalts showing microlithic porphyritic vacuolar textures-E) Dolerites showing ophitic texture in Lala El Gara formation Pg : Plagioclase, Cp : Clinopyroxene, Oq : Opaque, Ca : Calcite, Cl : Chlorite, Vc :Vesicles.

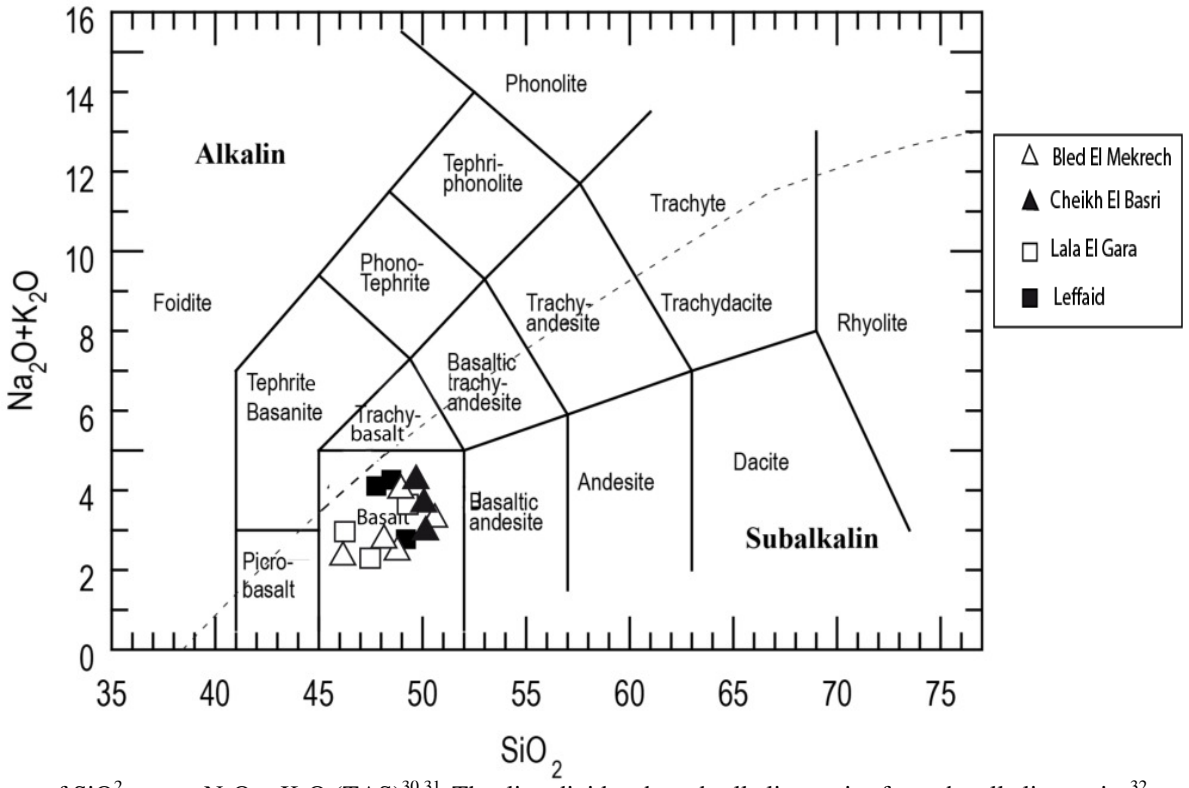

Figure-7: Diagram of SiO^2 versus $N_2O + K_2O$ (TAS)[30,31]. The line divides the sub-alkaline series from the alkaline series[32].

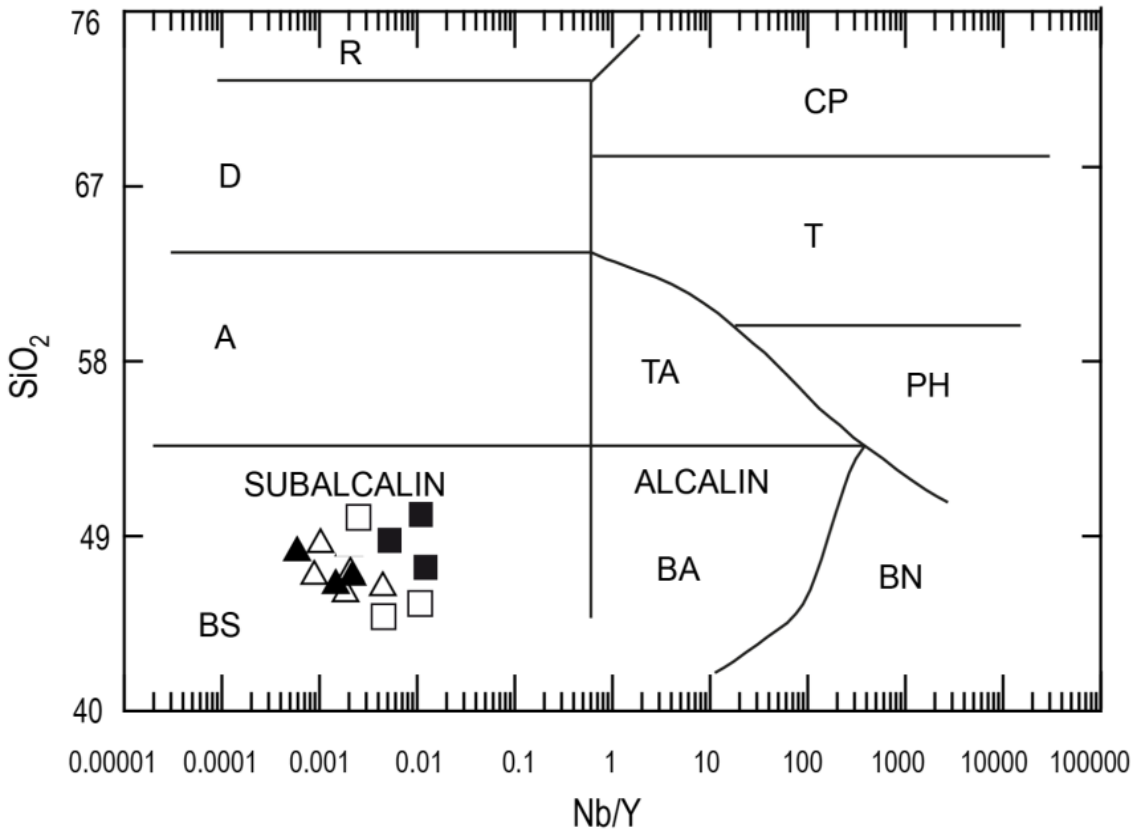

Figure-7: SiO_2 –Nb/Y classification diagram[33].

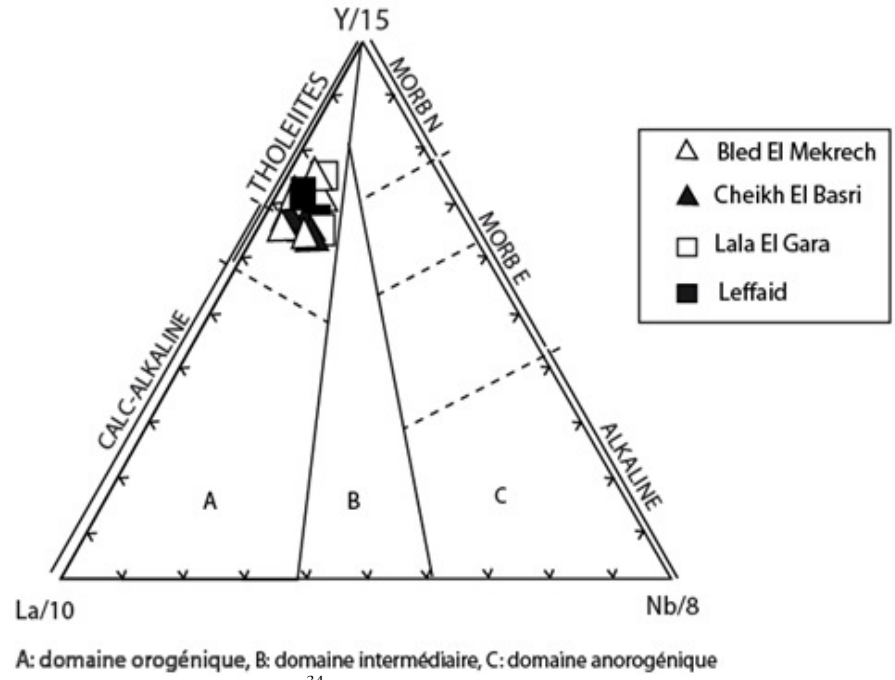

Figure-8: La-Y-Nb diagram[34] for the magmatic basic rocks of the Mechraa Basin.

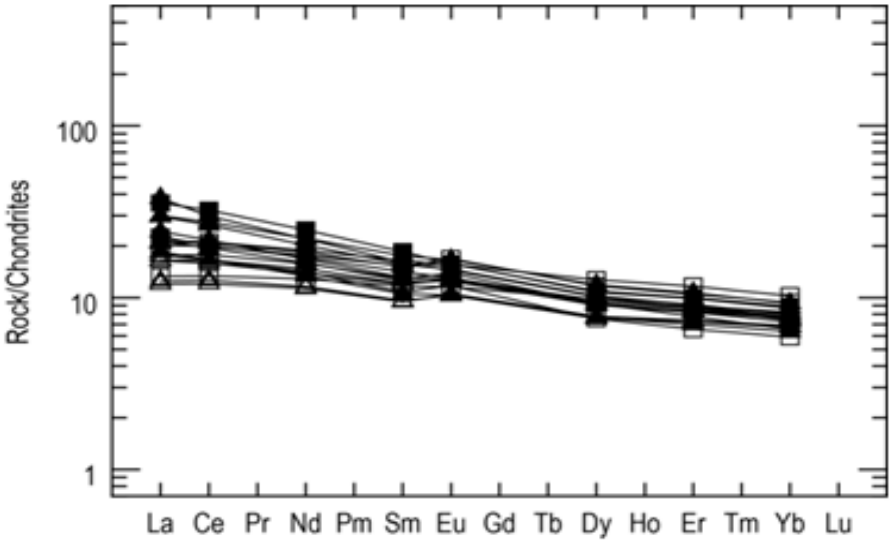

Figure-9: Chondrite-normalized[35] REE patterns for the studied tholeiitic rocks.

Discussion: The geodynamic evolution of the Moroccan Meseta during the Late Carboniferous is generally related to transtensive[28,36] or compressive setting[10].

The proposed models explain the geodynamics of the Moroccan Hercynian orogeny design that would have been a continental-continental subduction[13,6], or generally fossil continental subduction[38,10].

Piqué[4] suggested the model indicates subduction toward East. While, Roddaz et al.[14] proposed a subducted continental slab toward the West. Recently, Rheiic subduction toward the East was suggested as new mode[10,24,41]. The integration of the Mechraa Ben Abbou Basin into the geodynamic evolution of the Moroccan Meseta during the Late Carboniferous considered here further evidences to support the transtensive setting[28,36] more than compressive context[10].

If this is accepted, the basic magmatism of Mechraa Ben Abbou Basin is intraplate tholeiitic type and orogenic, that would be completely different from the magmatism of Moroccan Meseta. Thus, in Central Jebilet, the Visean outcrops are intruded by

basic magmatism consisting of gabbro and dolerite attributed to the tholeiitic series[6] while in the Eastern Jebilet the basalts are of type alkaline to tholeiitic affinity[11].

More in the north, several authors highlighted the presence of Doleritic sills of Alkaline to Tholeiitic affinity in Oued Korifla as well as in Fourhal basin in central Morocco[6,8,11,12]. Furthermore, Kharbouch et al.[6] and Remmal et al.[39] reported gabbro, porphyritic dolerite dykes and pillow lavas of tholeiitic to transitional affinity.

In the Sidi Bettache basin, the basic rocks are represented by spilitised lavas of tholeiitic to transitional nature. In Azrou Khenifra basin, East of central Massif, the basic igneous rocks consist of dolorites and gabbros of alkaline to calc-alkaline affinity[40]. The Eastern Meseta is characterised by a bimodal volcanism, mostly explosive, pre-dominated by andesitic or acid with ignimbritic features of calc-alkaline affinity wich indicates an orogenic setting[6].

The pre-dominated tholeiitic gabbroic to basaltic volcanism has developed in the Spanish Central System[41] and pre-dominated tholeiitic dolerite to basalt in the North East of the Armorican Basin in Laval Basin[42]. Through the previous geochemical studies on the magmatic rocks intruded into Visean deposits of Moroccan Meseta, the series are either calc-alkaline or tholeiitic with anorogenic features.

Conclusion

The present paper highlights for the first time in the Western Meseta a tholeiitic magmatism of an orogenic setting. These evidences confirm the results reported in the Eastern Meseta on the calc-alkaline magmatism. This magmatic activity was probably triggered by lithospheric extension in post-collision times, and, thus, is interpreted as being related to the subduction of the Rheic ocean during Late Devonian. The SE convergence of the sheets suggests subduction of the continental margin towards the NW, however, on the transverse of the Meseta, the NW dominant convergence suggests an oceanic subduction (Rheic Ocean) under the Gondwana margin[43] (Figure-10).

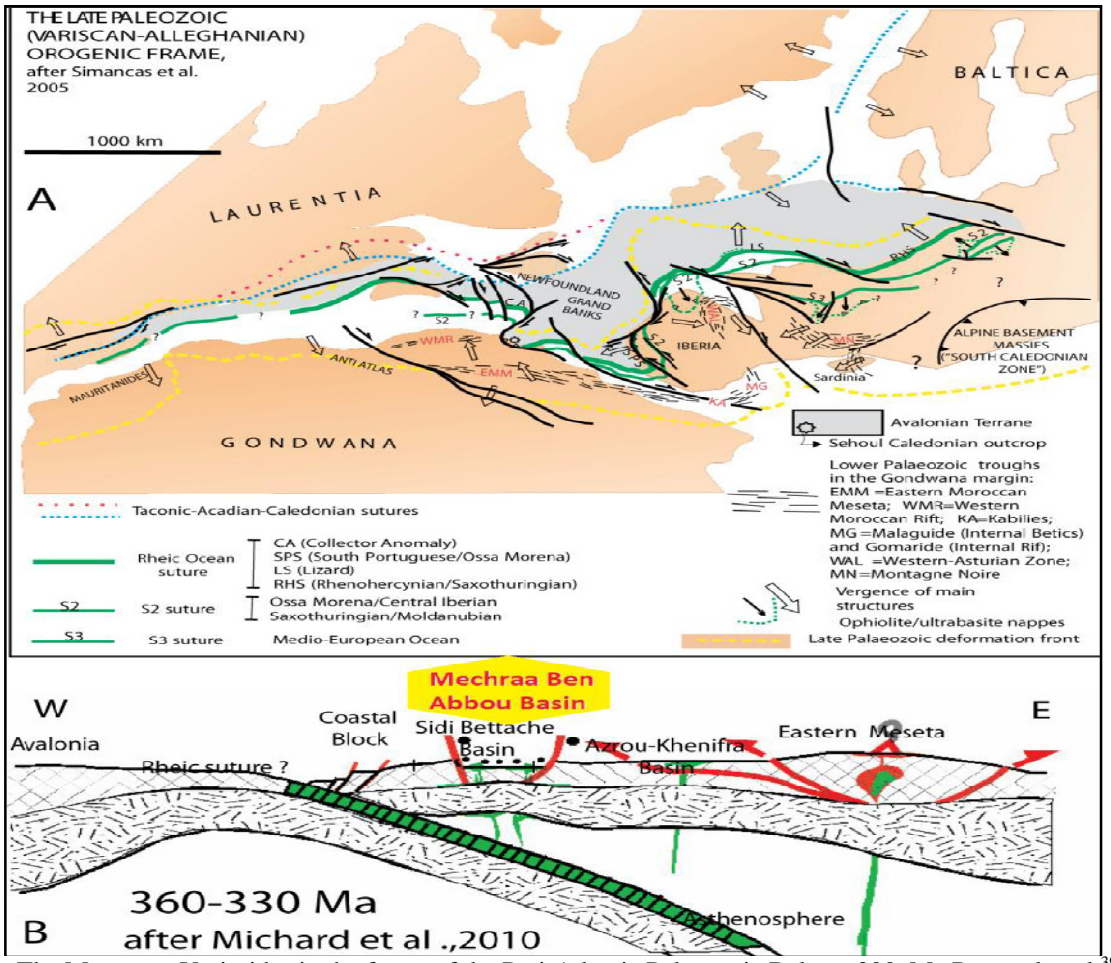

Figure-10: A: The Moroccan Variscides in the frame of the Peri-Atlantic Palaeozoic Belts at 300. Ma Remmal et al.[39] modified in Michard et al.[24]. B, Geodynamic interpretation of the Meseta Variscan orogeny during the Early Carboniferous, position of Mechraa Ben Abbou basin Michard et al.[24], Simancas et al.[43], Simancas et al.[44], Simancas et al.[45] modified.

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