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The Variscan Orogen in the “Souttoufides” Belt: Southwestern North Africa

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Abstract

The “Souttoufide belt” which extends from the northern Anti-Atlas fault (TZTF) to the southern Reguibat shield consists in the amalgamation of three different belts: Mauritanides to the East, Western Thrust belt (WTB) in the middle and some parts of the Appalachians, to the West. In West Africa, the Hercynian Front Thrust (HFT) is extended from the Anti-Atlas to the Southern Senegal and Northern Bissau- Guinea. This “Souttoufide belt” was first investigated by Spanish geologists to the south and by French and Moroccan geologists from geological surveys and universities. Three parts of this Souttoufide belt are outcropping: “Plage Blanche” (northern part), “Sekkem-Dhlou belt” (central part) and the “Adrar Souttoug” (or Oulad Dlim) massif (southern part). These parts were studied separately and present different structures. The northern part is limited to a tiny strip. The central part corresponds to a Paleozoic belt thrust over the Neoproterozoic and Paleozoic sediments of the Tindouf basin while the southern part exhibits several Neoproterozoic structures thrust over a thin paleozoic cover and strongly reworked by the Variscan events. During the last decades numerous radiometric dating and geochemistry data allow us to better constraint the Panafrican and Variscan geodynamic events (Late Neoproterozoic to Early Paleozoic) specially in the Adrar Souttoug massif and thus, to correlate this Souttoufide belt belts with the adjacent belts.

Keywords: Variscan Orogen, Neoproterozoic and Paleozoic Covers, Mauritanide, Appalachians and WTB Belts, Western Sahara, Morocco

Introduction

The HFT which separates the western Variscan belts from the Eastern foreland is thrust, respectively over the Tindouf Basin, the Reguibat shield, the Taoudeni Basin and the Bové basin. But, the "Souttoufide" belt which extends from the Anti-Atlas fault (TZTF) to the south of the Reguibate shield (figure.1) is capped to the West by the Meso-Cenozoic Layoune basin which separates the outcropping parts of the Souttoufide belt in three different sections: "Plage Blanche" to the North, "Sekkem-Dhlou" to the middle and the "Adrar Souttouf / Oulad Dlim" massif (ASM) to the South. Each part has a different component and structure. The central and southern parts belonged to the Spanish Sahara until 1975 and to the Moroccan Sahara since this date. The northern part was studied as a part of the Anti-Atlas belt meanwhile the central and southern parts were considered as parts the Northern Mauritanides by But, since 2010 considering that this belt consists in the northern extension of two separates belts: the central "Western Thrust belt" concealed underneath the Senegalo-Mauritanian basin and the Eastern "Mauritanide belt" reunited them in one only belt: the "Souttoufide belt" [1-6].

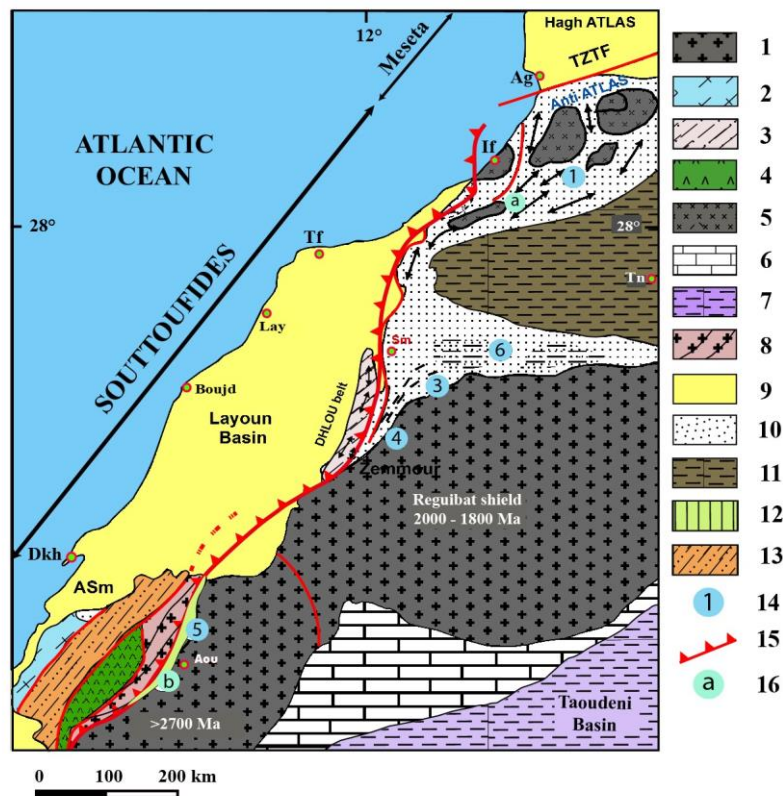


Figure 1: Location Of The Souttoufide Belt And Forelands: Reguibat Shield and Tindouf Basin To The East And The Meso-Cenozoic Layoune Basin to the West [7]. The Three Main Variscan Outcropping Areas of the Souttoufide Belt are Separated from their Foreland by the HFT (Hercynian Front Thrust)

Legend: 1- Archean and Birrimian basement, 2- Western units in the Adrar Souttouf massif, 3-Dhlou belt formations, 4- UD unit in the Adrar Souttouf massif, 5-Anti-Atlas inliers, 6-Lower Taoudeni formations, 7-Upper Taoudeni formations, 8- Eastern allochthonous units in the Adrar Souttouf massif (UB and UC), 9-Layoune basin and High-Atlas domain (post variscan), 10- Paleozoic formations (Anti-Atlas and Tindouf basin), 11- Upper Paleozoic formations in the Tindouf basin, 12- Autochthonous Paleozoic formations in the ASM (southern margin of the Tindouf basin. 13-Central unit in the Adrar Souttouf massif (UE), 14-Location of the stratigraphic successions exposed in figure.2, 15- Main thrust, 16-a= Bas Draa inlier and b=Eig formation.

Geological Framework

The Foreland

The foreland includes the metamorphic basements and the sedimentary covers of the Tindouf basin. Two metamorphic basements are distinguished: the Panafrican Anti-Atlas belt to the North and the Reguibat shield to the South. The Pan-African Anti-Atlas belt outcrops in several inliers and was studied by many geologists meanwhile the Reguibat shield composed of Archean to Birrimian terranes was only studied by. The Tindouf basin has been stratigraphic investigated in many places located in Figure 1 and presented in Figure 2. The stratigraphic successions are made by Palaeozoic sediments mainly presents in the southern flank of the Anti-Atlas. They were investigated successively by [8-17].

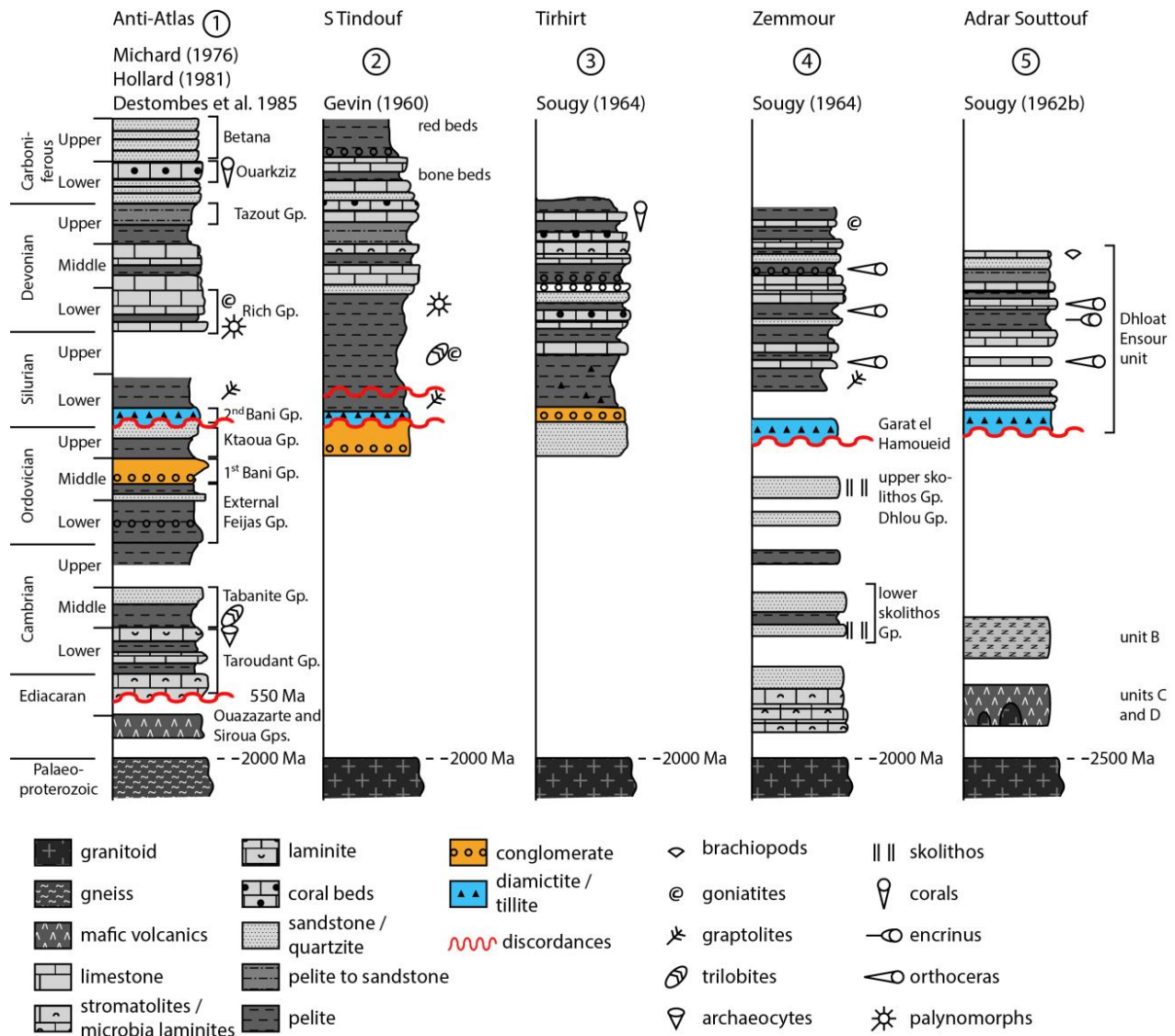


Figure 2: Stratigraphic Successions of Sediments In The Foreland Tindouf Basin [7]

Logs 1 to 5 are located in figure 1.

The Belts

The Souttoug belt is outcropping in three separate areas: Plage Blanche area, Dlhoul-Sekkem belt and the Adrar Souttoug massif.

Plage Blanche Area

Recent works extend the main « Variscan Front Thrust » (HFT) until "Plage Blanche", which is located to the West of the Ifni inlier. But unfortunately, this part HFT is concealed. However, a W-E cross-section shows a succession of shales, quartzites and argillites locally deformed and oriented from N-S to NE-SW with a deep to the West. These sediments ascribed to the Ordovician exhibits many thrusts deeping to the West and ascribed to the Variscan tectonic event. Such thrusts have been observed in the Ifni Inlier. The meridian orientation of the Paleozoic formations is not surprising since have demonstrated a N-S Variscan (or Cadomian) belt cross cutting the E-W Pan-African Anti-Atlas belt in this area. A Variscan reworking of parallel Late Ediacarian structures is possible [18-20].

Dhlou-Sekkem Belt

The Dhlou and Sekkem belt consist in parts of the Tindouf basin sediments folded and sheared which are thrust over the western part of the Tindouf basin (Figure.3). The sedimentary pile starts with the Ediacaran limestones and includes every period of the Lower Palaeozoic, from the Cambrian to the upper Devonian (Frasnian). The Dhlou-Sekkem belt was studied by and while the stratigraphy of the foreland Zemmour area comes from the thesis. Then proposed a stratigraphic succession for both, the Sakiet el Hamra and Zemmour areas. These observations were completed by [17,18,21-23].

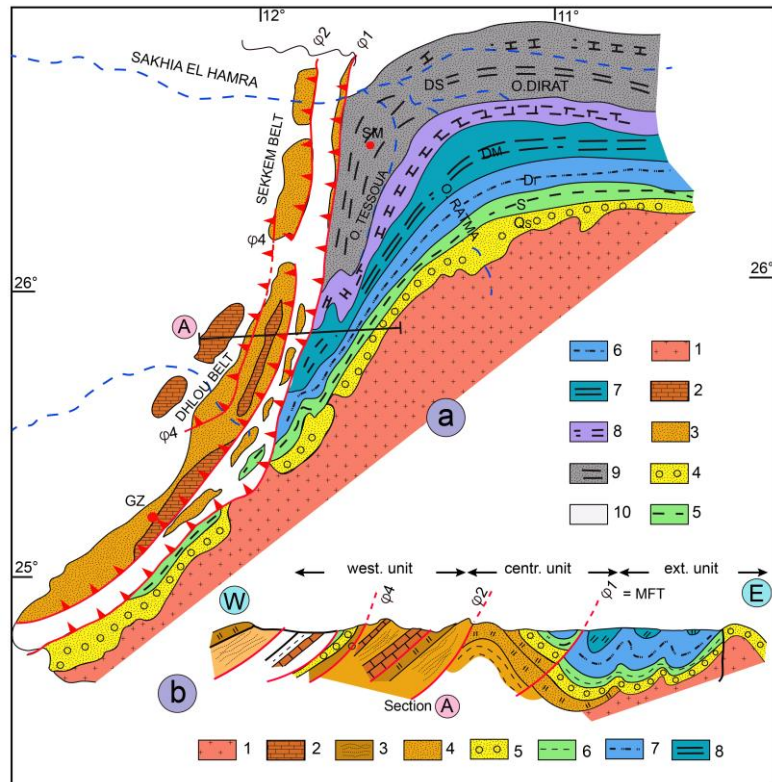


Figure 3: Geological Scheme And Cross-Sections Of The Zemmour-Smara Areas (Southwestern Tindouf basin) [7]

Legend: A-Geological scheme of the Dhlou-Zemmour area, b-Geological cross-section.

Legend Figure 3a: 1- Reguibat basement, 2 - El Thlethyate limestones, 3 - Lower Ordovician shales, 4- Scolithus sandstones, 5- Hirnantian tillite, 6- Silurian shales, 7-Couvinian limestones, 8-Gedinnian sandstones, 9-Siegenian, 10-Frasnian limestones.

Adrar Souttoug Massif (or Oulad Dlim Massif)

This large area was studied by many geologists since 1949. In the contrary of the Dhlou-Sekkem belt, the Adrar Souttoug massif suffers different interpretations. In contrary of who ascribe the metamorphic units to the Reguibat basement and who separated both basements by a vertical fault, shows that the main metamorphic units of the Adrar Souttoug were thrust over the Reguibat shield and its thin Palaeozoic cover, during the Variscan tectonic event [22,29]. Then, consider the metamorphic massif as a pile of sheets with the gabbro sheet on top. But, argued for a succession of sheets stacked from the West to the East and given rise to seven main units (UA to UG) thrust to the East upon the Reguibat basement (Figure.4). These units named UA to UG, from the East to the West, are then subdivided [3,7]. Geophysical investigations show a thin sedimentary layer (less than 1km) on top of the Reguibat basement. But, more recently [32,33]. Considered five zones with an SSW-NNE trending. With the rapid development of radiometric investigations since 2001, these units indicate a more complex history beginning by the Pan-African orogen and termed by a large reworking during the Variscan tectonic event [6,7,24-33] .

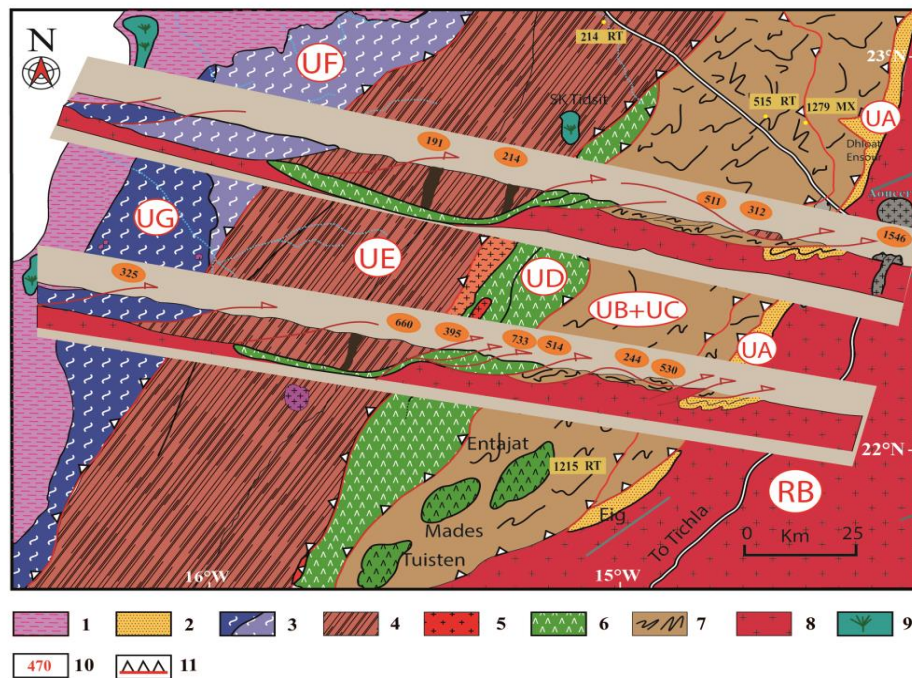


Figure 4: Geological Scheme of the Adrar Souttoug Massif and Cross-Sections

Legend: 1-Coastal basins, 2-UA (Unit A: Dhlout Ensour Unit), 3-UF & UG (Unit F: Oued Togba Unit, Unit G: Oued Fadrat al Garod Unit); 4-UE (Unit E: Sebkha Gezmayet Unit), 5-Granites in UD, 6-UD (Unit D: Dayet Lawda Unit), 7-UB & UC (Unit B: Eastern Sebkha Matallah Unit, Unit C: Western Sebkha Matallah Unit), 8-Reguibat basement, 9-Sebkhas, 10-. Circled numbers on cross-sections correspond to the ages in Ma of samples dated by Zircons. Numbers with RT correspond to samples dated by K/Ar on whole rocks, 11-Main thrusts. Names of the various units are from [7].

Geochronology and Geochemistry

In the "Dhlou-Sekkem belt" the stratigraphy is mainly supported by fossils and in our knowledge, no radiometric measurements have been performed. In the contrary, in the Adrar Souttoug massif, at least more than hundred radiometric dating have been performed since 2001 mainly with LA-ICP-MS or SHRIMP methods on zircons. Owing to these measures, several clusters of ages have been distinguished on granites, metabasites or sediments. These clusters are: Archean (3100-2500 Ma), Ediacaran, (610 to 550 Ma), Early Palaeozoic (420 to 405 Ma) and Late Palaeozoic (370 to 214 Ma). These radiometric clusters correspond to different orogens: Archean, Pan-African, Taconic and Variscan. Only the latest cluster (Variscan orogeny) is considered here. In another hand very few geochemical investigations have been published to support the different interpretations [5,4,7,33-35].

The Variscan Orogen

Classically an orogen includes three main stages: pre-collisional, collisional and post-collisional. Pre-collisional stage corresponds to the sedimentary deposition and oceanic formations. Collisional stage corresponds to tectonic deformations and associated magmatic and metamorphic events meanwhile the post-collisional stage corresponds to the molassic emplacement and post-magmatic events. Thus, a period between the Early Devonian (Emsian) and the Middle Trias (Anisian) should be related to the Variscan Orogen, in this country. The pre-collisional stage varies in age depending on the area investigated. In the western part of the Adrar Souttoug the evidence of Taconic orogen began this pre-collisional stage by the Early Devonian (Frasnian) but in other parts, where the Taconic orogen is lacking, this stage began by the Cambrian. The collisional stage could be extended from the Fammenian to the Moscovian and the post-collisional stage could be extended until the Early Triassic. The dykes of dolerites starting at 244 Ma (Anisian) could be considered as an extensive event at the beginning of a new orogen.

Tectonic and Magmatic Events

The Variscan deformations are mainly made by thrust and local recrystallizations in every part of the Saharan belts. However, in many places, sinistral strike-slips have been recorded along the NNE-SSW faults. The Variscan tectonic imprints are evident in the "Plage Blanche" and "Dhlou-Sekkem" section where, on the western side of the HFT, Paleozoic sedimentary or metamorphic formations have been deformed and thrust. But in the Adrar Souttoug section, the Variscan tectonic imprint is not limited to the eastern Paleozoic stripe. It can be evidenced by radiometric data in every sheet and particularly at the limits of sheets. We don't know exactly the number of tectonic events but four clusters of radiometric ages are evidenced by Ar/K, Ar/Ar or Sm/Nd method on samples D3 to D160.

- cluster 1 : 350 Ma (D160), 345 and 333Ma [4], 325 Ma (D6), 312 (Derramane gneiss)
- cluster 2 : 288Ma (D66), 287 (D 18), 274 (D75b), 271 Ma (D30).
- cluster 3 : 251 Ma, 246 (D75)
- cluster 4 : 226 Ma (D12), 214 Ma (D3), 190 Ma (D22).

The 3 first clusters which correspond to rejuvenations of rocks could belong to the Variscan collisional or post-collisional stages but the last one which is coeval to the dolerite dykes could belong to another orogen. However, no molasses deposits related to this Variscan orogen have been evidenced in any section of these Variscan belts.

Variscan Metamorphism

Apart some recrystallizations on biotites and feldspars, no specific metamorphism has been registered.

Geodynamic Model

As well as age in "Plage Blanche" as in the "Sekkem-Dhlou belt", no geodynamic interpretation has been done taking in consideration that the inner parts of the belts are concealed by the Atlantic coastal basins. Only the Adrar Souttouf section better exposed can be interpreted. In accordance with thin-skin geophysical interpretation in the Adrar Souttouf formations and the hypothesis of a Reguibat shield imprint in the Appalachian (North American Craton) we postulated that the different units of the Adrar Souttouf are thrust and stacked over the Reguibat apron [5,35-37].

But concerning the geodynamic interpretation of these thrust units onto the Reguibat Shield, there is no consensus in the geodynamic models developed by the authors particularly concerning the Pan-African orogens. Gärtner et al. (2014, 2015) and Guillou et al. (2026) support an island arc model linked to the WANO Ocean meanwhile Bea et al. (2020) favoured an Ediacaran graben linked to a Rift process. More investigations, particularly in geochemistry, will allow us to better understand the right geodynamic model. In its present state, the rift model is not consistent with the Mauritanides interpretation where two Pan-African orogenic events with subduction zones, Island arcs and Back-arc basins, were considered [6,38]. But the geodynamic model linked to the Variscan orogen which is related to the collision between the NAC (North American Craton) and the WAC (West African Craton) has long ago been accepted. The suture between NAC and WAC is concealed under the post variscan coastal basins and most of authors consider the "Brunswick anomaly" as a witness of this suture (Alleghanian suture). The 320-340 Ma periods considered in Figure.4 correspond to the thrusting of Western units and to the reworking of ancient thrusts in the UB1, UB2 and UC units [33,35].

Correlations

The Souttoufide belt is a part of the whole Variscan system owing to the collision between Laurentia and Gondwana continents which led to the Pangea supercontinent, by the Carboniferous time. This system includes the Mauritanide belt to the South, the Appalachian belt to the West and the Variscan European belts to the North. Correlations with the areas located to the North of the TZTF (Anti-Atlas fault zone) were developed by other authors. But correlations with the Mauritanide and Appalachian belts are exposed in Villeneuve et al. (2015b) [40].

A recent interpretation of the whole Variscan system involving the West and North African belts on one side and the Appalachians, in another hand, has been published [38]. This model presented in Figure.5 takes in consideration the play of the Reguibat shield when moving to the West with the Gondwana continent. At first, this motion is imprinting the Neoproterozoic (Pan-African I and II) Mauritanide belt and its extension to the Souttoufides and the WTB (Western Thrust Belt) and its extension in the Souttoufide belt. Finally, several authors are ascribing the "arcuate" form in the middle of the Appalachians to this Reguibat shield motion [5,35-38].

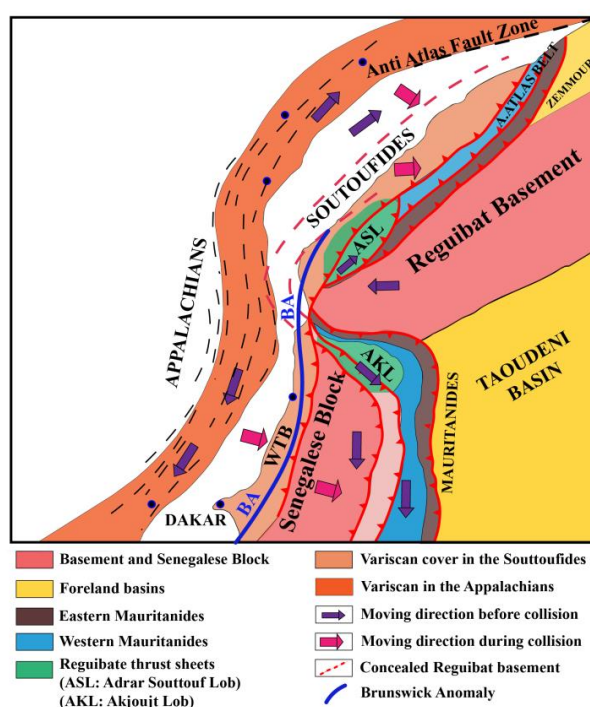


Figure 5: The Eastern American and the Western West African Belts by the Carboniferous and Permian Times

Discussion

According to this Figure.5, the Eastern units UA, UB, UC and UD evidenced in Figure.4 belong to the Neoproterozoic belts included in the Mauritanide belt and their extension into the Souttoudide belt. But unit UE is correlated to the WTB and unit UF could be a sheet of the Reguibat basement included in the Variscan belt during the carboniferous tectonic event according to Bea et al, 2020.[38] Unit UG could belong to the Appalachian belt. Figure 6 attempt to represent these interpretations with a pile of sheets thrust, from the West to the East, over the Reguibat basement (or Reguibat shield). According to the seismic interpretation of Fateh (2008) units UE, UF and UG are very thin with respect to the Unit UD which corresponds to a lobe of Pan-frican belts from the Mauritanide belt. Thus, the interfingering of sheets from the Reguibat basement within the WTB and Appalachians cover could be explained by this process. However, there is no evidence to understand the shape of UA underneath the Units UB and UC [32].

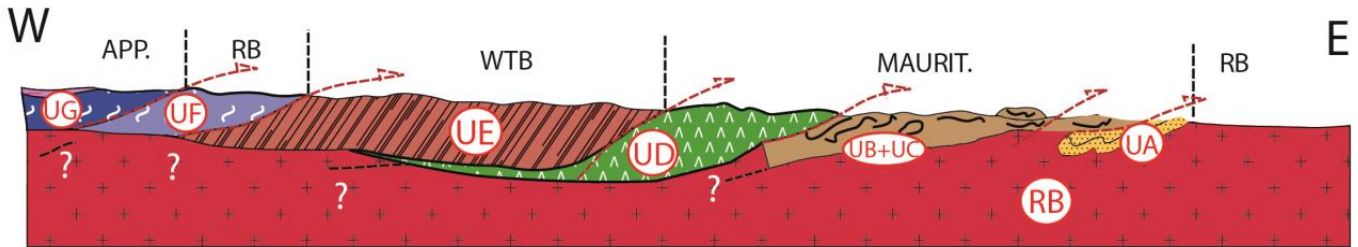


Figure 6: Interpretation Of Stacking Of Units Onto The West African Craton, In The Adrar Souttoud Massif

The ascribing of Unit E to the WTB (Western Thrust Belt) is enhanced by the magnetic anomaly (NSWL) separating the Unit E in two parts: E1 and UE2. However, the relationships between the WTB and the Appalachians are not clearly understood. Direct comparisons are not possible owing to the covering of this WTB by the Mesozoic Senegalo-Mauritanian basin. But considering the location of the "Brunswick anomaly" (BA in Figure.5) which is linked to the "Alleghanian suture" both in the WTB and the Southern Appalachians (North Florida) we favour the gathering of the WTB with the Southern Appalachians, in a single belt [7,40].

Conclusions

In conclusion, the "Souttoudide" belt is a geological masterpiece for the whole Variscan system leading to the Pangea supercontinent. But in contrary of studies in the Appalachians and European Variscan belts, this part of the African Variscan system was poorly investigated in the second half of the 20th century. It is now more investigated specially in radiochronology. These new studies pointed out the major effect of the Reguibat shield and allow us to distinguish the Variscan orogeny from the Neoproterozoic ones. New interpretations consider the "Souttoudide" belt as an amalgamation of three different belts: the Neoproterozoic belts included in the Mauritanide and reworked during the Variscan tectonic event, the poorly known WTB concealed underneath the Mesozoic coastal basin and the Appalachians largely reworked by the Variscan tectonic event. The link of the WTB with the Appalachians is strongly suspected. To the moment, this part of the Variscan system should be taken in consideration for a global interpretation of the entire Variscan system. However, new field, geochemistry and geophysical studies are still necessary in order to compare this "Souttoudide" belt with the adjacent belts [41-50].

References

1. Sougy, J. (1962). West African fold belt. *Geological Society of America Bulletin*, 73(7), 871-876.
2. Sougy, J. (1962). Contribution a l'etude geologique des guebels Bou Leria (region d'Aoucert, Sahara Espagnol). *Bulletin de la Société Géologique de France*, 7(3), 436-445.
3. Bronner, G., Marchand, J., & Sougy, J. (1983). Structure en synclinal de nappes des Mauritanides septentrionales (Adrar Souttoud, Sahara occidental). In *12e Colloque de géologie africaine, Bruxelles* (p. 15).
4. Le Goff, É., Guerrot, C., Maurin, G., Johan, V., Tegye, M., & Zerga, M. B. (2001). Découverte d'éclogites hercyniennes dans la chaîne septentrionale des Mauritanides (Afrique de l'Ouest). *Comptes Rendus de l'Académie des Sciences-Series IIA-Earth and Planetary Science*, 333(11), 711-718.
5. Villeneuve, M., Bellon, H., El Archi, A., Sahabi, M., Rehault, J. P., Olivet, J. L., & Aghzer, A. M. (2006). Événements panafricains dans l'Adrar Souttoud (Sahara marocain). *Comptes rendus. Géoscience*, 338(5), 359-367.
6. Villeneuve, M., El Archi, A., & Nzamba, J. (2010). Les chaînes de la marge occidentale du Craton Ouest-Africain, modèles géodynamiques. *Comptes Rendus. Géoscience*, 342(1), 1-10.
7. Villeneuve, M., Gärtner, A., Youbi, N., El Archi, A., Vernhet, E., Rjimiati, E. C., ... & Paquette, J. L. (2015). The southern and central parts of the "Souttoudide" belt, Northwest Africa. *Journal of African Earth Sciences*, 112, 451-470.
8. Sougy, J. (1972). Etat des connaissances sur la partie mauritanienne de la dorsale Reguibat précambrienne. *Notes et mémoires du Service Géologique du Maroc, Rabat*, 236, 95-103.
9. Maurin G., Bronner G., Le Goff E., Chardon D., 1997. Chami : Notice explicative de la carte a` 1/200000, 469, Documents Service Géologique Mauritanie, Nouakchott, 32p.
10. Chardon, 1997. Les déformations continentales, modélisation thermomécanique, mémoire de Geosciences, Rennes.

Exemples naturels et modélisation thermo-mécanique. Mémoires de Géosciences, Rennes, 76, 300p.

11. Bea, F., Montero, P., Haissen, F., & El Archi, A. (2013). 2.46 Ga kalsilite and nepheline syenites from the Awsard pluton, Reguibat Rise of the West African Craton, Morocco. Generation of extremely K-rich magmas at the Archean-Proterozoic transition. *Precambrian Research*, 224, 242-254.
12. Montero, P., Haissen, F., El Archi, A., Rjmati, E., & Bea, F. (2014). Timing of Archean crust formation and cratonization in the Awsard-Tichla zone of the NW Reguibat Rise, West African Craton: A SHRIMP, Nd-Sr isotopes, and geochemical reconnaissance study. *Precambrian Research*, 242, 112-137.
13. Montero, P., Haissen, F., Mouttaqi, A., Molina, J. F., Errami, A., Sadki, O., ... & Bea, F. (2016). Contrasting SHRIMP U-Pb zircon ages of two carbonatite complexes from the peri-cratonic terranes of the Reguibat Shield: Implications for the lateral extension of the West African Craton. *Gondwana Research*, 38, 238-250.
14. Gevin, P. (1948). Série Paléozoïque d'Aouinet Legra (Sahara occidental). *Bulletin de la Société Géologique de France*, 5(6-7), 369-381.
15. Borroco, J., & Nyssen, R. (1955). Mission de pre-reconnaissance BRP La région du Zemmour. *SN Repal, Alger*, 22p.
16. Sougy, J. (1961). *Les formations paléozoïques du Zemmour noir (Mauritanie septentrionale): étude stratigraphique, pétrographique et paléontologique* (Doctoral dissertation).
17. Ratschiller, L.K., 1971. Lithostratigraphy of the Northern Spanish Sahara. Instituto di Geologia, Università Trieste, Italia, 88, 78p.
18. Belfoul, M. A. (2005). Cinématique de la déformation hercynienne et géodynamique de la marge NW du Gondwana (Anti-Atlas Sud-Occidental, Sahara Marocain: Zemmour, Ouled Dhlou et Mauritanides septentrionales). [Kinematics of the Hercynian deformation and geodynamics of the NW Gondwana margin (South Western Anti-Atlas, Moroccan Sahara, Zemmour, Ouled Dhlou and northern Mauritanides)]. *State Dissertation, Ibn Zor University*.
19. Ennih, N., Liegeois, J.P. (Eds.), The Boundaries of the West African Craton. Geological Society London, Special Publications, 297, pp. 433-452.
20. Villeneuve, M., Vernhet, E., & El Archi, A. (2012, September). Is there two «Neoproterozoic» orogens in the Moroccan Anti-Atlas belt. In *29th IAS Meeting of Sedimentology* (pp. 10-13).
21. Dacheux, A. (1967). *Etude photogéologique de la chaîne de Dhlou (Zemmour-Mauritanie septentrionale)* (Vol. 22). Laboratoire de géologie de la faculté des Sciences de l'Université de Dakar.
22. Sougy J., 1964. Les formations paléozoïques du Zemmour noir (Mauritanie septentrionale). *Etude stratigraphique, Pétrographique et Paléontologique*. Annales Faculté Sciences Université, Dakar, 12, 695p.
23. Rjmati, E., Zemmouri, A., Benlakhdim, A., Id Sahara, M., Amzarhrou, M., Haimouk, M., & Mustaphi, H. (2002). Carte Géologique du Maroc, 1: 100000, feuille Smara. *Notes et Mémoires du Service Géologique*, (438).
24. Alia-Médina, M. (1949). El Sahara español, 2e part. *Estudio geológico, Instituto de Estudios Africanos, Madrid*, 201-414.
25. Alia Medina, M. (1949). Contribución al conocimiento geomorfológico de las zonas centrales del Sáhara español. *Contribución al conocimiento geomorfológico de las zonas centrales del Sáhara español*.
26. Medina, M. A. (1958). *Esquema geológico del Sahara español*. Instituto de Estudios africanos.
27. Alia, M. A. N. U. E. L. (1960). La tectonica del Sahara español. *Rep. 21th Int. Geol. Congr. Norden, Copenhagen*, 18, 193-202.
28. de la Viña, J., de Alvarado Medina, A., & Cabezón, C. M. (1958). *Mapa geológico del Sahara Español y zonas limítrofes...* Instituto Geológico y Minero de España.
29. Arribas, A. (1960). Las formaciones metamórficas del Sahara Español y sus relaciones con el Precámbrico de otras regiones africanas. In *Report 21th International Geological Congress Norden, Copenhagen, Denmark, Part IX* (Vol. 9, pp. 51-58).
30. Arribas, A. (1968). El Precámbrico del Sahara español y sus relaciones con las series sedimentarias más modernas. *Boletín Geol. Minero*, 84, 445-480.
31. Gärtner, A., Villeneuve, M., Linnemann, U., El Archi, A., & Bellon, H. (2013). An exotic terrane of Laurussian affinity in the Mauritanides and Souttoudides (Moroccan Sahara). *Gondwana Research*, 24(2), 687-699.
32. Gärtner, A., Villeneuve, M., Linnemann, U., Youbi, N., & Gerdes, A. (2015). The Adrar Souttoud Massif (Moroccan Sahara)—a key to the Avalonia and Meguma conundrum.
33. Gärtner, A., Villeneuve, M., Linnemann, U., Gerdes, A., Youbi, N., & Hofmann, M. (2016). Similar crustal evolution in the western units of the Adrar Souttoud Massif (Moroccan Sahara) and the Avalonian terranes: Insights from Hf isotope data. *Tectonophysics*, 681, 305-317.
34. Gärtner, A., Villeneuve, M., Linnemann, U., Gerdes, A., Youbi, N., Guillou, O., & Rjmati, E. C. (2016). History of the west African Neoproterozoic ocean: key to the geotectonic history of circum-Atlantic peri-Gondwana (Adrar Souttoud massif, Moroccan Sahara). *Gondwana Research*, 29(1), 220-233.
35. Gärtner, A., Youbi, N., Villeneuve, M., Sagawe, A., Hofmann, M., Mahmoudi, A., ... & Linnemann, U. (2017). The zircon evidence of temporally changing sediment transport—the NW Gondwana margin during Cambrian to Devonian time (Aoucert and Smara areas, Moroccan Sahara). *International Journal of Earth Sciences*, 106(8), 2747-2769.
36. Gärtner, A., Youbi, N., Villeneuve, M., Linnemann, U., Sagawe, A., Hofmann, M., ... & Boumehdi, M. A. (2018). Provenance of detrital zircon from siliciclastic rocks of the Sebkhah Gezmayet unit of the Adrar Souttoud Massif (Moroccan Sahara)—Palaeogeographic implications. *Comptes Rendus. Géoscience*, 350(6), 255-266.
37. Fateh, B. (2008). Modélisation de la propagation des ondes sismiques dans les milieux visco-élastiques: Application

à la détermination de l'atténuation des milieux sédimentaires. *These, Université de Bretagne Occidentale, Brest, 181p.*

38. Bea, F., Montero, P., Haissen, F., Molina, J. F., Lodeiro, F. G., Mouttaqi, A., ... & Chaib, M. (2020). The Archean to Late-Paleozoic architecture of the Oulad Dlim Massif, the main Gondwanan indenter during the collision with Laurentia. *Earth-Science Reviews*, 208, 103273.
39. Molina, J. F., Bea, F., Montero, P., Haissen, F., González-Lodeiro, F., Errami, A., ... & Mouttaqi, A. (2018). High-P amphibolite-facies metamorphism in the Adrar-Souttoug Metamafic Complex, Oulad Dlim Massif (West African Craton margin, Morocco). *Comptes Rendus. Géoscience*, 350(6), 245-254.
40. Villeneuve M., Guillou M., Gaertner A., EL Archi A., Aghzer A., Bellon H., Mueller P.A., Ndiaye P.M., Youbi N., Linnemann U., Corsini M. 2026. Imprint of the Reguibat Promontory (West Africa) in the Appalachians, Mauritanide and Souttougide belts during the assembly of Pangea. *Geosciences*, 16, 14, 15p.
41. Lefort, J. P. (1988). Imprint of the Reguibat uplift (Mauritania) on to the central and southern Appalachians of the USA. *Journal of African Earth Sciences (and the Middle East)*, 7(2), 433-442.
42. Lefort, J.P., 1989. Basement Correlation across the North Atlantic. Springer Verlag, Berlin 148p.
43. Vauchez, A., Kessler, S. F., Lécorché, J. P., & Villeneuve, M. (1987). Southward extrusion tectonics during the Carboniferous Africa-North America collision. *Tectonophysics*, 142(2-4), 317-322.
44. Villeneuve, M., Bellon, H., Guillou, O., Gärtner, A., Mueller, P. A., Heatherington, A. L., ... & Youbi, N. (2025). Evolution of the West African fold belts: Review, new geochronological data, new correlations and new geodynamic hypothesis. *Journal of African Earth Sciences*, 223, 105484.
45. Villeneuve, M., Fournier, F., Cirilli, S., Spina, A., Ndiaye, M., Zamba, J., ... & Ngom, P. M. (2015). Structure of the Paleozoic basement in the Senegalo-Mauritanian basin (West Africa). *Bulletin de la Société Géologique de France*, 186(2-3), 193-203.
46. Villeneuve M., A. Gaertner A., Mueller P.A., Guillou, O., Linnemann U. 2024. Colliding cratons: linking the Variscan Orogeny in West Africa and North America. Geological Society of London, special publications. 542. (1), 359-377.
47. Guillou, O., El Janatti M., Youbi, N., Gärtner, A., Villeneuve, M., Mata, J., Bodinier, J. L., ... & Linnemann, U. (2026). Geochemical and isotopic signature of a rift-to-arc transition in the Neoproterozoic Adrar Souttoug Massif, Moroccan Sahara. *Geochemistry*, 86(2), 126410.
48. Haissen, F., Montero, P., Cambeses, A., Bea, F., Molina, J. F., Mouttaqi, A., ... & Errami, A. (2018). Petrogenesis of Derraman peralkaline granite (Oulad Dlim massif, west African Craton margin, Morocco): New constraints from zircon Hf and O isotopic compositions. *Comptes Rendus. Géoscience*, 350(6), 236-244.
49. Leprêtre, R., Villeneuve, M., Chopin, F., Gärtner, A., Houicha, M. E., Aghzer, A. M., ... & Ghienne, J. F. (2024). The Variscides in the NW Corner of Africa. In *The Geology of North Africa* (pp. 145-185). Cham: Springer International Publishing..
50. Schofield, D. I., Horstwood, M. S. A., Pitfield, P. E. J., Gillespie, M., Darbyshire, F., O'connor, E. A., & Abdouloye, T. B. (2012). U–Pb dating and Sm–Nd isotopic analysis of granitic rocks from the Tiris Complex: New constraints on key events in the evolution of the Reguibat Shield, Mauritania. *Precambrian Research*, 204, 1-11.