GEOLOGY OF MOROCCO: WHAT'S NEW?

Omar SADDIQI[1]

[1]*Géosciences Laboratory, Hassan II University of Casablanca. Morocco.* omarsaddiqi@yahoo.fr

Morocco is one of the most fascinating lands the world over for geology. It is located at the triple junction between a continent (Africa), an ocean (the Atlantic) and a plate collision zone (the Alpine belt system). This results in a rough topography with a wide range of outcropping terranes spanning from Archean to Cenozoic in age, as well as varied tectonic systems, from sedimentary basins to fold belts. Finally, it is worth emphasizing that natural resources extracted from the Moroccan subsoil are important for the national economy (phosphate, Ag, Pb, Zn, barytine, fluorine, etc.). At the moment, there is active exploration for oil and gas fields offshore.

Topography and major geological domains

At first sight, the topography of Morocco is comparable with that of the neighbouring countries of North Africa. To the north, the Rif Range extends along the Mediterranean coast (Alboran Sea), ensuring the continuity of the Kabylian-Tellian belts (Maghrebides) up to the Gibraltar strait. South of these coastal ranges, a domain of elevated plateaux or mesetas occur (Algerian High Plateaux and Oran Meseta, Moroccan Meseta), including intramontane basins. Then the Atlas system rises up, providing a northern boundary to the extended, and generally low-elevation Sub-Saharan and Saharan domains. However, Morocco differs from Algeria and Tunisia in several ways. On the one hand, the elevation of most of the country (except the Rif and Atlantic areas) is particularly high **[1]**. The High Atlas displays several massifs close to 4000 m high, including the highest peak of northern Africa (Jebel Toubkal). A branch of the Atlas system extends obliquely across the Mesetan domain, namely the Middle Atlas, which exceeds 3000 m in elevation. The northern border of the Sub-Saharan domain also rises and forms a massive mountain belt, the Anti-Atlas, up to 2700 m high in J. Saghro, and even higher in the case of the J. Sirwa volcano (3300 m). The elevation decreases westward away from the Middle Atlas mountains to the Central Massif of the Moroccan Meseta, towards the Atlantic coastal basins, and eventually to the Atlantic abyssal plains. South of Anti-Atlas and Saghro mountains, the plateaux (hamadas) elevation decreases southward from c. 1000 m to less than 400 m (Tindouf basin), and westward to less than 200 m, close to the Atlantic (Tarfaya basin).

It has been demonstrated, based on geophysical data that this specific topography results from a hot mantle anomaly (asthenosphere uplift) extending SW-NE from western Anti-Atlas to eastern Rif. This anomaly is also outlined by the scatter of recent alkaline volcanoes along the Siroua-Middle Atlas-Eastern Morocco trend (Moroccan Hot Line).

The successive fold belts

Morocco includes large parts of the orogenic systems that formed around the 2 Ga-old continental nucleus of northwestern Africa, i.e. the West African Craton (WAC). These successive belts are the Pan-African, Variscan (Hercynian), and Alpine belts **[2,3]** (Fig. 1).

The WAC extends in the Sahara desert. Its crystalline basement crops out in the Reguibat shield or arch, whereas it is hidden beneath undeformed sediments in the Tindouf, Reggane and Taoudenni basins. The western part of the Reguibat Arch records Archean episodes of continental crust formation. Some gneisses were dated at 3.5 Ga, but most granites yielded 3.0 and 2.7 Ga dates. After 2.92 Ga there is no trace of magmatic activity until the intrusion of the Awsard feldspathoidal (kalsilite and nepheline) syenites at 2.46 Ga. This reveals that, for reasons that are not yet well understood, the Archean crust in this sector of the Reguibat Rise stabilised long before than any other surrounding cratonic area **[4,5]**. By contrast, the eastern part of the arch formed at about 2.1 Ga (Paleoproterozoic) during the Eburnian orogeny, and collided with the Archean part around 1.7 Ga ago. The overlying sedimentary deposits span the whole Neoproterozoic-Cenozoic times, with not any internal unconformity, which defines a typical cratonic area. The Neoproterozoic onlap is exposed on the southern border of the Reguibat shield consisting of quartzites and stromatolitic limestones, 1000-700 Ma in age. By contrast, at the southern border of the Tindouf basin, the base of the sedimentary succession is made up of Cambrian and Ordovician sandstones.

The *Variscan belt* is again a major orogen, formed during the Pangean collision. Only the southern, external parts of the belt, devoid of ophiolite and high-pressure metamorphism, are preserved in Morocco. East-vergent thrusts reworking Precambrian material emplaced during the Carboniferous upon the western margin of the Reguibat Arch (Adrar Souttouf), in the northern continuation of the Mauritanide belt. Late Paleozoic deformation remains quite moderate in the Moroccan Anti-Atlas and Algerian Ougarta around the WAC border. By contrast, a strongly deformed, metamorphic Variscan segment, intruded by granitic massifs crops out in the western High Atlas-Meseta domain. The Late Permian or, more generally, Triassic unconformity marks the end of the Variscan evolution.

The *Cenozoic Alpine belt* is mostly superimposed onto the Variscan belt. The broad organisation of these young mountain belts is directly visible in the topography. The High and Middle Atlas are autochthonous, intracontinental belts, developed by inversion of Triassic-Jurassic aborted rifts. By contrast, the Maghrebides include both parautochthonous, external units originating from the African Mesozoic passive margin, and allochthonous terranes originating from the Maghrebian-Ligurian Tethys and from a continental block "Alboran-Kabylia-Calabria". In both the Atlas and Maghrebide systems, mountain building spans the Late Eocene to Present times, i.e. the last 40 My.

The Pan-African Belt formed at ~660 Ma, with the latest magmatic and tectonic events being dated at 610-560 Ma. The unconformity beneath the Anti-Atlas Cambrian formations records the end of the Pan-African evolution. By contrast with the eastern WAC border in Algeria and Mali, the Pan-African belt is poorly exposed as isolated inliers in the Moroccan Anti-Atlas, and only displays low-pressure metamorphic units. However, it is currently admitted that collision tectonics also occurred in this region, i.e. on the northern "metacratonic" boundary of the WAC.

Active tectonics

Due to its position at the northwest border of the African plate, Morocco still offers significant tectonic activity, especially in its younger parts.

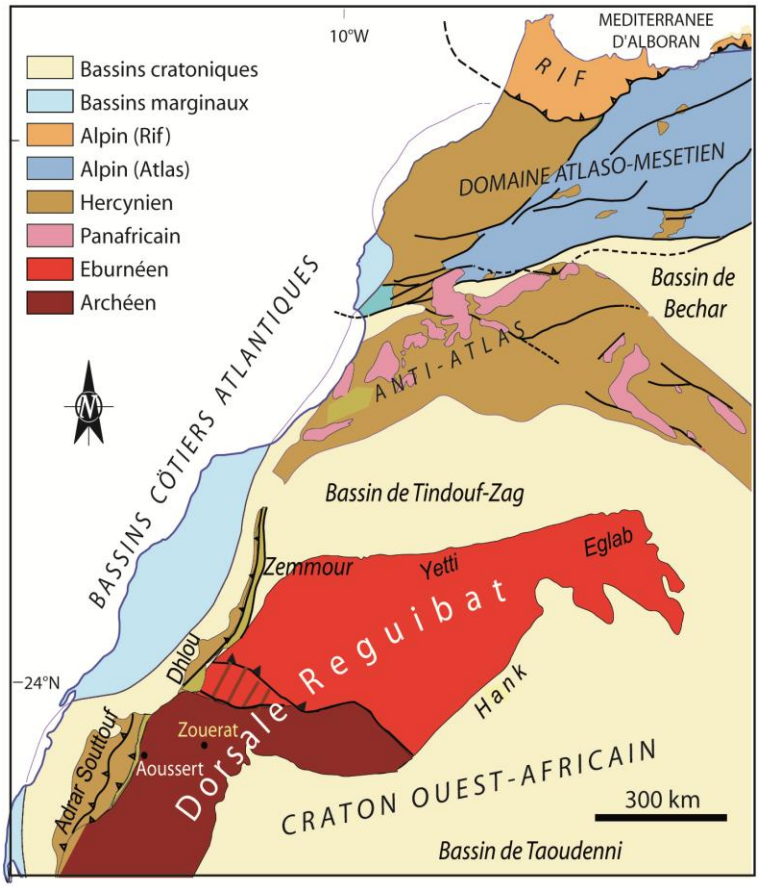

Fig. 1: Geological domains of Morocco.

The most seismic zone corresponds to the eastern Rif and Alboran Sea. The present-day Africa-Eurasia relative movement is broadly directed SE-NW, i.e. oblique to the African margin. The convergence rate decreases from 6 to 4 mm/year from the longitude of Tunisia to that of Morocco, due to the anti-clockwise rotation of Africa. Moreover, the overall converging movement is combined with a regional extension in the Alboran area, trending E-W to ENE-WSW, and responsible for the building of the Gibraltar Arc since ~20 Ma.

References :

[1] Frizon de Lamotte D., Leturmy P., Missenard Y., Khomsi S., Ruiz G., Saddiqi O., F. Guillocheau. 2009. Mesozoic and Cenozoic vertical movements in the Atlas system (Algeria , Morocco , Tunisia): An overview. *Tectonophysics*, 475, p. 9-28.

[2] Frizon de Lamotte D., Michard A., Saddiqi O. 2006. Some Recent Developments on the Maghreb Geodynamics : An Introduction. *C. R. Géosciences*, 338, p.1-10.

[3] Michard A., Saddiqi O., Chalouan A., Frizon de Lamotte D. (Eds.), Continental Evolution: The Geology of Morocco. Structure, Stratigraphy, and Tectonics of the Africa-Atlantic-Mediterranean Triple Junction, *Springer Verl*., Berlin, Heidelberg (2008), 420 p., 235 figs. ISSN 0930-0317.

[4] Bea, F., Montero, P., Haissen, F., El Archi, A. 2.46 Ga kalsilite and nepheline syenites from the Awsard pluton, Reguibat Rise of the West African Craton, Morocco. Page 27 of 5027 of 27 Generation of extremely K-rich magmas at the Archean–Proterozoic transition. *Precambrian Research* 224, 242-254. 2013.

[5] Montero, P., Haissen, F., Archi, A.E., Rjimati, E., Bea, F.,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* (2014), http://dx.doi.org/10.1016/j.precamres.2013.12.013