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# Tectonics

## REPLY

10.1029/2020TC006165

This article is a reply to a comment by Michard et al. (2020) <https://doi.org/10.1029/2019TC006004>.

### Key Points:

- Opening of the Maghrebian Tethys during a major Middle Jurassic rifting phase
- Late Triassic to Early Jurassic CAMP-related magmatism
- Non-oceanic nature of the Mesorif Gabbroic Complex and absence of an overlying oceanic sequence

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## Reply to comment by Michard et al. on “The Mesozoic Margin of the Maghrebian Tethys in the Rif Belt (Morocco): Evidence for Polyphase Rifting and Related Magmatic Activity”

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### 1. Introduction

Our contribution (Gimeno-Vives et al., 2019) proposed a new tectono-sedimentary evolution of the North African Mesozoic rifted margin exposed in the External Rif in Northern Morocco (Figure 1). In this reply, we firmly maintain our interpretation and further show its agreement with available data and current knowledge. Despite their praises on the quality of our work, Michard et al. (2020) question the significance of the lithostratigraphic associations and structures of the Senhadja Nappe (Mesorif Domain; Figure 1b) and the implications for the evolution of the North African Mesozoic rifted margin. In particular, opposite interpretations of the Mesorif Gabbroic Complex (MGC) led to two distinct models, proposing either of the following:

1. an emplacement within the continental crust during the Late Triassic to Early Jurassic and a subsequent exhumation and tectonic juxtaposition against the Lower Jurassic carbonate platform during a major Middle Jurassic rifting phase (our work) or
2. an emplacement within the mantle in relation with a speculative Early Jurassic oceanic domain represented by the Mesorif Suture Zone (MSZ; Michard et al., 2018, 2020).

This reply provides us the opportunity to further explain and discuss the differences between the successive models proposed by Michard et al. (2014, 2018, 2020) and ours. Their comment focuses on three main points regarding (1) the general structure and paleogeographic meaning of the Senhadja Nappe, (2) the geochemical characteristics and petrography of the MGC, and finally (3) the interpretation of geochronological data. Detailed answers to the major points discussed in the comment are provided and discussed below.

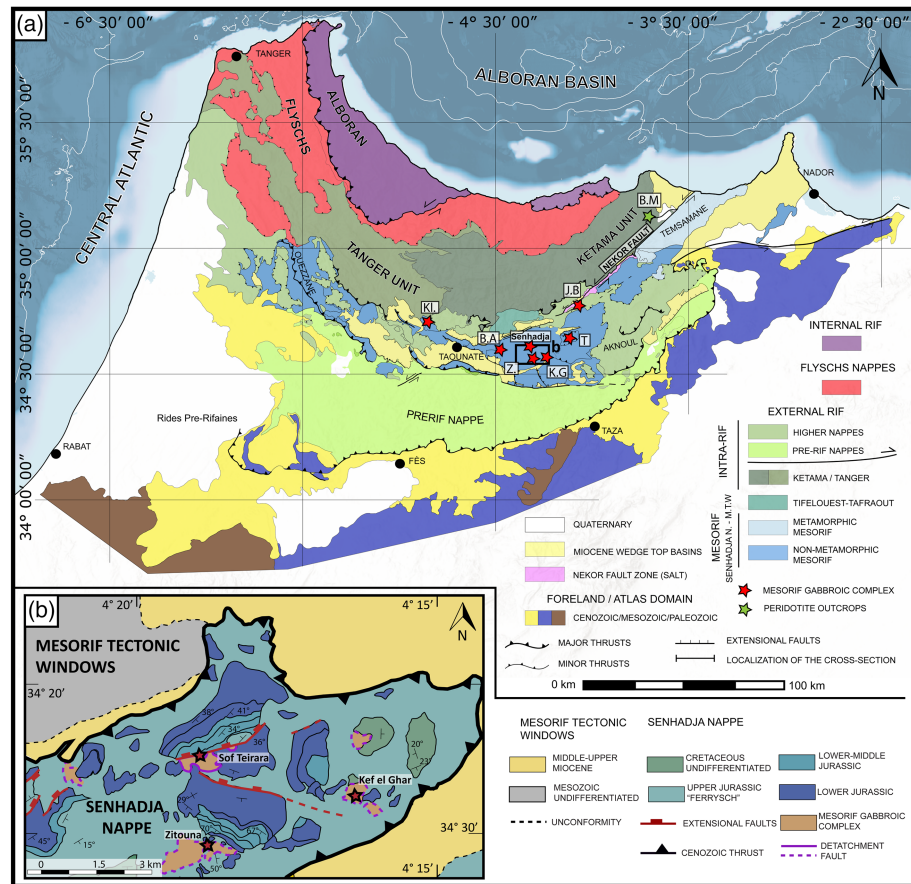
Eventually, in the light of our observations and results, we will show that the alternative model tentatively proposed by Michard et al. (2020) should be simply abandoned.

### 2. Lithostratigraphy and Structure of the Senhadja Nappe

The structure of the Senhadja Nappe was extensively described in Gimeno-Vives et al. (2019), recognizing, after the pioneer work of Favre et al. (1991), the remnants of the North African rifted margin. We recall here our main observations but also provide additional and original data, such as field pictures and thin section descriptions, confirming our initial results.

The Senhadja Nappe is characterized by a complex lithostratigraphic association with significant lateral variations (Figures 1 and 2). An idealized lithostratigraphy from bottom to top consists of the MGC overlaid by Upper Triassic evaporites, Lower Jurassic carbonate platform, and Middle Jurassic to Lower Cretaceous detrital sequences (Favre, 1992; Gimeno-Vives et al., 2019; Papillon, 1989).

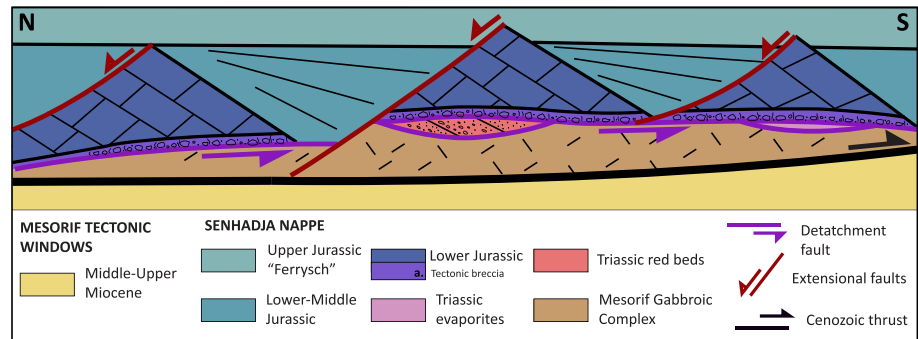
The contact between the overlying Mesozoic cover and the underlying MGC is of critical importance and is described in Gimeno-Vives et al. (2019). In that respect, the following statement by Michard et al. (2020)



**Figure 1.** (a) Structural map of the Rif belt in the north of Morocco (after Suter, 1980a, 1980b, and Chalouan et al., 2008). (b) Detailed geological map of the Senhadja Nappe (compiled from the geological maps of the External Rif at 1/50,000 Vidal, 1983, and local maps of Papillon, 1989). The main Mesorif Gabbroic Complex outcrops are indicated in both maps as well as the location of the main peridotite outcrop in the Eastern External Rif. B.A. = Bou Adel; B.M = Beni Malek; J. B = Jebel Baïo; K.G = Kef el Ghar; Kl = LaKlaaia; M.T.W. = Mesorif Tectonic Windows; T = Taïnest; Z = Zitouna.

“Gimeno-Vives et al. do not present convincing data in support of their claim that the Senhadja Mesozoic units are the stratigraphical cover of the Mesorif gabbros” does not correspond to our observations. In fact, we never claimed that the Mesozoic cover was in a stratigraphic contact with the MGC: through all our manuscript, we documented and illustrated the reverse, showing that the contact between the Mesozoic sedimentary cover and the “MGC” is always of tectonic origin. Our interpretation is based on the following lines of evidence: (1) a brittle fault zone characterized by tectonic breccias is always observed at the contact (Figure 2); (2) the absence of contact metamorphism in the overlying Jurassic sediments, precluding any direct contact at the time of emplacement of the MGC; and (3) the magmatic textures of the MGC suggest an emplacement at depth (e.g., cumulitic texture). Eventually, we are glad that now Michard et al. (2020) concur with our interpretation of a tectonic contact, which they previously erroneously interpreted as stratigraphic in Michard et al. (2014, 2018). In our view, this tectonic contact is interpreted as a detachment fault responsible for the exhumation of the MGC up to the surface during the Middle Jurassic rifting. In the hanging wall of the detachment fault, the Lower Jurassic carbonate platform is dismembered along the Upper Triassic evaporites and forms typical “rafts.” In between these “rafts,” Middle to Upper Jurassic sediments are directly resting over the tectonically exhumed MGC (Figure 2).

The occurrence of a typical Mesozoic oceanic type sequence well documented in the Alps and Apennines as the remnants of the Ligurian Tethys (Lemoine et al., 1986; Stampfli et al., 1998) is not observed in the Senhadja Nappe. Indeed, the MGC is locally associated with carbonate veins (i.e., referred as opicalcites



**Figure 2.** Idealized sketch of the structure observed in Senhadja Nappe, showing the main lithostratigraphic associations characterizing the North African distal margin. The dismembered Lower Jurassic carbonate platform is overlaying the Mesorif Gabbroic Complex along a major detachment fault characterized by tectonic breccias. Triassic sandstones and evaporites are locally preserved along the detachment fault. Fluid rock interactions between the Lower Jurassic carbonates and the Mesorif Gabbroic Complex are generally observed at the contact.

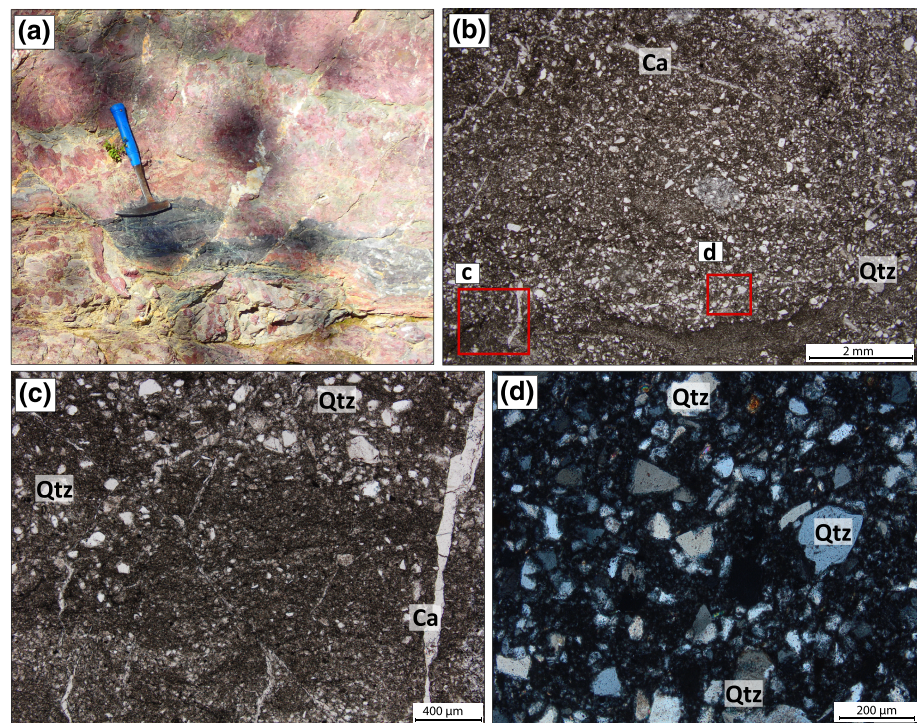
by Benzaggagh et al., 2014, and Benzaggagh, 2016). However, these rock associations are markedly different from the well-documented oceanic sequence of the Ligurian Tethys in the Western Alps (Lemoine et al., 1987). In the case of the Senhadja Nappe, they are related to structurally controlled fluid-rock interactions between the underlying MGC and the overlying shallow marine Lower Jurassic carbonate platform and/or Middle Jurassic turbiditic sequences. In this tectonic scenario, the Upper Triassic evaporites, sandwiched in between (Figure 2), likely played a major role. The structural framework is also markedly different from the ophiolitic sequence reported elsewhere in the Ligurian Tethys realm. In addition, it is worth noting the complete lack of serpentinized mantle either as a basement or reworked in the Mesozoic sediments of the Senhadja Nappe.

For Michard et al. (2020), a major point for the proposition of an “oceanic-type” sequence, and an oceanic origin for the “MGC,” relies on the presence of radiolarites. Several field pictures of these red colored rocks have been published before by the authors. In that respect, Figure 2a in Michard et al. (2020) is an enlarged version of Figure 9 in Benzaggagh et al. (2014), with a different interpretation. Nevertheless, no single evidence and description of radiolarian fauna has ever been provided in these former contributions. Even the statement of the authors of the comment sounds ambiguous: “explicit mention of radiolarian fossils (unfortunately undeterminable).”

In this reply, we show new field and microtextural evidence of these red rocks from the “type locality (i.e., Kef el Ghar)” indicated in the comment of Michard et al. (2020; Figures 1 and 3). Microscale observations reveal that these rocks are not radiolarite but poorly sorted sandstone (Figure 3b), essentially made of monocrystalline quartz grains and oxides forming distinct layers. This sandstone shows alternating shale and sand layers (Figure 3c). The size of the quartz grains varies from (0.07 to 0.1 mm) in the coarse-grained parts of the sandstone. The shape of the quartz grains is subangular to subrounded (Figure 3d). Grain size distribution of the fine-grained parts range from 0.03–0.05 mm (rare) to <0.01 mm (common).

We refer these red sandstones to the Triassic Buntsandstein facies, already documented in others parts of the External Rif (Figures 1 and 3a). Therefore, these sediments are not oceanic “radiolarites” deposited directly on top of the “MGC.” To our present knowledge, no radiolarites of Early Jurassic age have yet been unambiguously reported in the Senhadja Nappe. Radiolarites have been documented instead in other domains of the Rif belt such as the Flysch domain (Andrieux, 1971), dated as latest Middle Jurassic in that case, and related to the opening of the Maghrebian Tethys.

Finally, Michard et al. (2020) built their interpretation from observations taken from different localities and corresponding to different rifting events (Upper Triassic and Middle Jurassic, respectively). The occurrence of basalt clasts or lava flows within the Late Jurassic to Early Cretaceous sediments has already been reported by Benzaggagh (2011). Since these basalts occur locally as lava flows within the Early Cretaceous sediments (Benzaggagh, 2011), they cannot be directly related to a former Early Jurassic Ocean.



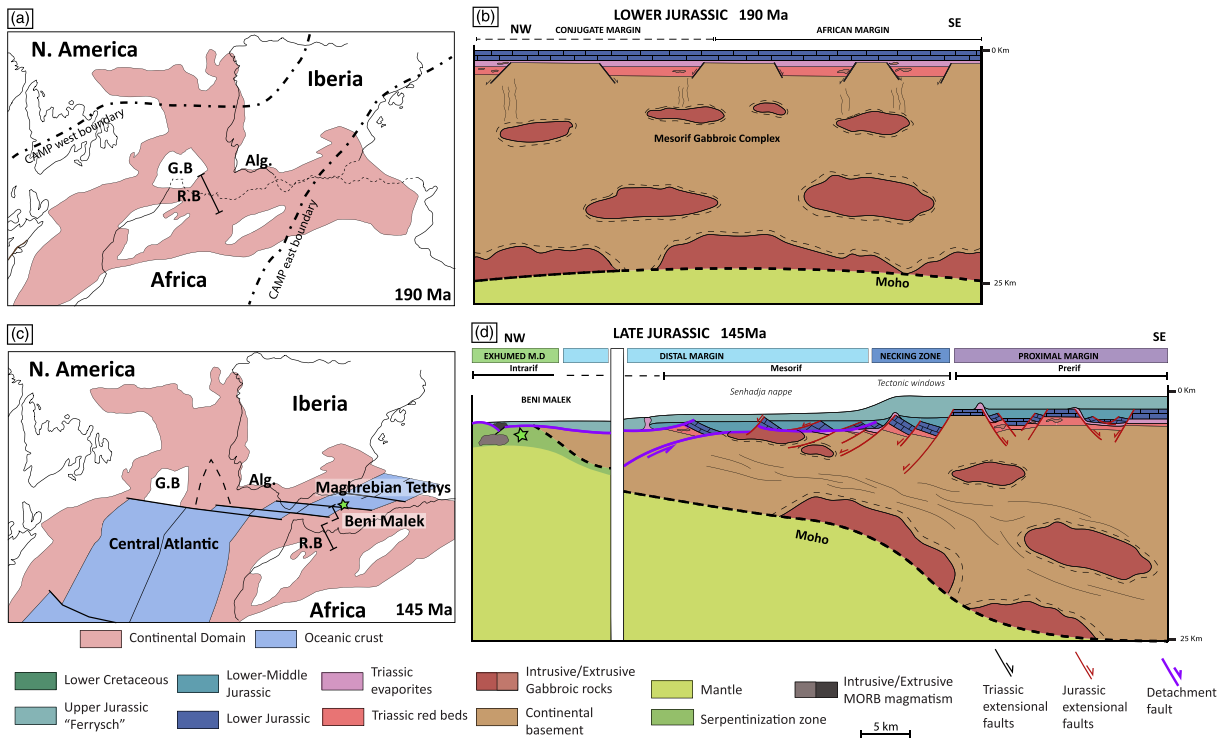
**Figure 3.** (a) Field picture of the Kef el Ghar red sandstone ( $34^{\circ}31'061''\text{N}/-4^{\circ}15'895''\text{E}$  (see location in Figure 1 b)). Microphotographs of the red sandstone: (b) poorly sorted sandstone (plane polarized light), (c) detail of the fine-grained zones (plane polarized light; see location in b), and (d) detail of the coarse-grained areas, showing sub-angular quartz grains (cross polarized light; see location in b).

Furthermore, the correlation with the Beni Malek serpentinitized massif is inconsistent with previous works showing that the serpentinitized mantle was exhumed during the Upper Jurassic at the Continent-Ocean transition of the North African rifted margin in relation with the opening of the Magrebian Tethys and not during the early Jurassic (Michard et al., 1992, 2007).

### 3. Age and Geodynamic Significance of the MGC

The MGC has been dated in several localities through U-Pb zircon dating by Michard et al. (2018; one sample) and Gimeno-Vives et al. (2019; four samples). The ages range from  $200 \pm 4$  to  $192 \pm 4$  Ma. Nevertheless, the data obtained from the zircons in both studies display an unusual high Th/U ratios with a mean value of 2.7 and ranging from 0.2 to 12.7 (Gimeno-Vives et al., 2019). This contrasts with the mean value of  $<0.5$  in igneous zircons (Hoskin & Schaltegger, 2003). Such ratios suggest a low retention of the radiogenic Pb. The zircons with low Th ( $\sim 50$  ppm) and U ( $\sim 100$  ppm) contents yield consistently the oldest ages, while younger ages, likely disturbed with Pb loss, presents high Th ( $\sim 10,000$  ppm) and U ( $\sim 4,000$  ppm) contents. It is the reason why we favored the oldest ages obtained for the emplacement of the MGC.

The age interval (200–192 Ma) found in our samples matches perfectly with the radiometric data of CAMP rocks reported and compiled from literature (Marzoli et al., 2018, and references therein). Ages as young as 196 Ma have already been found in Eastern North America (e.g., Sutter, 1988; Hames et al., 2003) and Western Africa (Deckart et al., 1997). Younger ages (as found in the leucocratic segregations in mafic intrusions by Michard et al., 2018, and Gimeno-Vives et al., 2019) of about 190 Ma were also reported from different parts of the CAMP (Deckart et al., 1997; Jourdan et al., 2009; Knight et al., 2004; Marzoli et al., 1999, 2004; Nomade et al., 2007; Sebai et al., 1991; Verati et al., 2007). All these data indicate an early peak of magmatic activity, followed by late protracted low-volume magmatism until  $\sim 192$  Ma (Marzoli et al., 2018, and references therein). Comparing more precisely with the Moroccan CAMP, they plot in the same age interval,



**Figure 4.** (a) Paleogeographic reconstruction and (b) schematic cross section of the Rif basin during the Early Jurassic (190 Ma). (c) Paleogeographic reconstruction and (d) schematic cross section of the Rif basin during the Upper Jurassic (145 Ma). Paleogeographic reconstructions are modified after Fernandez (2019) and cross sections illustrating the geodynamic evolution and architecture of the Rif basin during the Mesozoic are modified from Gimeno-Vives et al., 2019. Localization of the cross sections is indicated in the paleogeographic reconstructions as well as the boundaries of the CAMP (after Marzoli et al., 2018). Alg. Algarve, G.B. Grand Banks, and R.B. Rif Basin.

with the youngest ages (196 Ma) fitting probably even better with those from the recurrent basalts of the Central High Atlas. Essentially, the debates are related to the geodynamic context of the emplacement of the MGC (continental vs oceanic). We documented numerous indirect observations, pointing out for an emplacement of the MGC into the continental basement:

1. No lithostratigraphic evidence suggesting the occurrence of an Early Jurassic oceanic basin is reported from the External Rif. The time range for the emplacement of the MGC is coeval with a period of tectonic quiescence in the External Rif during the Upper Triassic and Lower Jurassic times (Bulundwe Kitongo, 1986; Favre, 1992; Papillon, 1989). This period is associated with shallow marine carbonate platform deposition, which developed not only in the North African margin (preserved in the External Rif) but also in the South Iberian margin (preserved in the Gulf of Cadiz and the External Betics; Ramos et al., 2017; Terrinha, 1998) and in the Grand Banks (Newfoundland) conjugate margin (OETR (Offshore Energy Technical Research Association), 2011; Figures 4a and 4b).
2. Postdating the MGC emplacement, a major Middle Jurassic rifting occurred and is described in detail in Gimeno-Vives et al. (2019). This rift event shows a general deepening of the depositional environment associated with the development of extensional faults with the deposition of synrift sequences. This phase was associated with the exhumation of the MGC and its tectonic juxtaposition with the Lower Jurassic carbonate platform. This rift event led ultimately to the mantle exhumation documented in Beni Malek section and the opening of the Maghrebian Tethys (Michard et al., 1992, 2007; Figures 4c and 4d).
3. Furthermore, the occurrence of two inherited zircons over 98 zircons dated in total (7 for Michard et al., 2018, and 91 for Gimeno-Vives et al., 2019), although not entirely conclusive, supports the crustal contamination of the MGC and its emplacement in the continental basement. Emplacement of mafic intrusions during this period in close relation with the CAMP is not new and has already been described in distinct localities such as the Southern Alps (Denyszyn et al., 2018).

Concerning the geochemical data, the authors of the comment propose a series of arguments to disprove the CAMP affinity of the MGC. These arguments essentially rely on the absence of a negative Nb-Ta anomaly “characteristic feature of the CAMP rocks.” Even though the geochemical analyses of the Bou Adel and Kef el Ghar locality do not display the negative Nb-Ta anomaly, in others such as in Zitouna, Laklaaia, and Taineste, a clear anomaly is observed (supporting information, Figure S2, in Gimeno-Vives et al., 2019). It is worth noting that these two groups have the same age, the same lithostratigraphic association, and are in a similar structural position within the Senhadja Nappe, especially the Zitouna and Kef el Ghar massifs separated by only 4 km. Furthermore, the “characteristic” Nb-Ta anomaly is not always observed in mafic rocks related to the CAMP area, as for example in Cassipore and Manranhao in Brazil (see De Min et al., 2003, and Merle, 2011) or in the French Guyana and Suriname (see Bertrand et al., 1999, and Nomade et al., 2002). We attribute these differences to geochemical heterogeneities of the mantle sources as well as crustal contaminations as emphasized in many previous contributions (Verati et al., 2005; Bensalah et al., 2011; Marzoli et al., 2018). Such contaminations are in any case expected for mafic magmatic rocks emplacing into the continental basement (Petri et al., 2016).

#### 4. Is the Alternative Scenario of Michard et al. (2020) Convincing?

Michard et al. (2020) concluded with the proposition of an alternative scenario based on an analogy with the North Iberian Mesozoic paleo-margin preserved in the Pyrenees. One can note that the same analogy has previously been proposed by Vázquez et al. (2013) and commented by Michard et al. (2015). For the understanding of this “alternative scenario,” it is useful to trace the historical origin of the MSZ. Michard et al. (1992, 2007) recognized exhumed subcontinental mantle within the North African rifted margin (the Beni Malek Massif) of the Maghrebian Tethys. The MSZ was interpreted as the vestige of a small rim basin, element of the North African rifted margin. Subsequently, Benzaggagh (2011) recognized the abundance of Upper Jurassic-lowermost Cretaceous volcanic rocks in the Mesorif (see mostly Benzaggagh et al., 2014, and Benzaggagh, 2016). In the same zone, the MGC, previously interpreted as basement rocks (Leblanc, 1979), was recognized as gabbroic bodies and assigned to the Middle Jurassic ( $166 \pm 3$  Ma) on the basis of a single whole rock K-Ar age (Asebriy, 1994). It was consequently tempting to associate all these elements to reinforce the concept of MSZ (Benzaggagh et al., 2014; Michard et al., 2014). The presence of the presumed radiolarites (excluded in this reply) in stratigraphic contact with the MGC at Kef el Ghar was an additional strong argument. However, a first modern zircon U-Pb dating of the MGC indicates an Early Jurassic age (Michard et al., 2018). Given this new age, the authors changed their interpretation: the MSZ became a secondary branch of the Central Atlantic and not anymore of the Maghrebian Tethys. However, this new interpretation was clearly in conflict with the age of the Beni Malek Massif exhumation on the one hand (Michard et al., 1992) and the age of the associated volcanic rocks on the other hand (Benzaggagh, 2011). This discrepancy led the authors to introduce a new concept: the Mesorif Basalt Breccia lineament superimposed to the MSZ. As result, the “alternative scenario” proposed in Michard et al. (2020) is in fact a new version of the previous one (Michard et al., 2018) introducing only a tectonic contact between the “radiolarite” and the MGC. Moreover, the gravity gliding of such prerift sequence in the speculative Early Jurassic oceanic basin is in contradiction with the previous reported field observations (Gimeno-Vives et al., 2019, and this reply).

In conclusion, the observations and data developed in Gimeno-Vives et al. (2019) and in this reply show that the MSZ concept is currently obsolete. The main reasons are as follows:

1. the nonoceanic nature of the MGC;
2. the absence of “oceanic sequence” (the presumed radiolarites are sandstones, and the contact between the MGC and the overlying rocks is everywhere of tectonic nature); and
3. the Intrarif Domain belongs to the Maghrebian Tethys distal margin or oceanic domain and does not form an isolated continental ribbon as proposed in the Figure 4 of Michard et al. (2020).

Therefore, we reiterate our conclusions and proposed model (Figure 4), which are supported by the available observations and data from the External Rif. The model of the MSZ was historically useful but must be now abandoned.

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## References

- Andrieux, J. (1971). La structure du Rif central: Étude des relations entre la tectonique de compression et les nappes de glissement dans un tronçon de la chaîne alpine. In *Notes et Mémoires du Service Géologique*, (Vol. 235, p. 155). Rabat, Morocco: Service géologique du Maroc.
- Asebriy, L. (1994). Evolution tectonique et métamorphique du Rif central (Maroc): Définition du domaine subriftain. (PhD Thesis). Université Mohammed V, Rabat 283p.
- Bensalah, M. K., Youbi, N., Mahmoudi, A., Bertrand, H., Mata, J., El Hachimi, H., et al. (2011). The Central Atlantic Magmatic Province (CAMP) volcanic sequences of Berrechid and Doukkala basins (Western Meseta, Morocco): Volcanology and geochemistry/As sequências vulcânicas da província magmática do Atlântico Central (CAMP) das bacias de berrechid. *Comunicacoes Geologicas*, 98(1), 15–27.
- Benzaggagh, M. (2011). Activités volcaniques sous-marines à la limite Jurassique-Crétacé dans le Rif externe (Maroc). Age et relation avec la sédimentation et la paléogéographie du sillon rifain externe. *Comptes Rendus Geoscience*, 343(4), 302–311. <https://doi.org/10.1016/j.crte.2010.12.009>
- Benzaggagh, M. (2016). Tholeiitic basalts and ophiolitic complexes of the Mesorif Zone (External Rif, Morocco) at the Jurassic-Cretaceous boundary and the importance of the Ouerra Accident in the palaeogeographic and geodynamic evolution of the Rif Mountains. *Boletín Geológico y Minero*, 127, 389–406.
- Benzaggagh, M., Mokhtari, A., Rossi, P., Michard, A., el Maz, A., Chalouan, A., et al. (2014). Oceanic units in the core of the External Rif (Morocco): Intramargin hiatus or South-Tethyan remnants? *Journal of Geodynamics*, 77, 4–21. <https://doi.org/10.1016/j.jog.2013.10.003>
- Bertrand, H., Féraud, G., Haller, M., Luais, B., Martínez, M., Alric, V., & Fornari, M. (1999). The Mesozoic silicic large igneous province of Patagonia: chronology and origin evidenced by 40Ar-39Ar and Sr-Nd isotopes. 2° Simposio Sudamericano de Geología Isotópica, Actas 167-169, Córdoba.
- Bulundwe Kitongo MK. (1986). Stratigraphie des «sofs» jurassiques du Pré-rif interne, Maroc: Publications du Département de Géologie et de Paléontologie, Université de Genève, 4, 326 p.
- Chalouan, A., Michard, A., El Kadiri, K., Negro, F., Frizon de Lamotte, D., Soto, J. I., & Saddiqi, O. (2008). The Rif belt. In A. Michard (Ed.), *The geology of Morocco*, (pp. 203–302). Berlin: Springer.
- De Min, A., Piccirillo, E. M., Marzoli, A., Bellieni, G., Renne, P. R., Ernesto, M., & Marques, L. (2003). The Central Atlantic Magmatic Province (CAMP) in Brazil: Petrology, geochemistry, 40Ar/39Ar ages, paleomagnetism and geodynamic implications. In W. E. Hames, J. G. McHone, P. R. Renne, & C. Ruppel (Eds.), *The Central Atlantic Magmatic Province: Insights from Fragments of Pangea*, AGU Geophysical Monographs, (Vol. 136, pp. 91–128). Washington, DC: American Geophysical Union.
- Deckart, K., Féraud, G., & Bertrand, H. (1997). Age of Jurassic continental tholeiites of French Guyana, Surinam and Guinea: Implications for the initial opening of the Central Atlantic Ocean. *Earth and Planetary Science Letters*, 150, 205–220.
- Denyszyn, S. W., Fiorentini, M. L., Maas, R., & Dering, G. (2018). A bigger tent for CAMP. *Geology*, 46(9), 823–826.
- Favre, P. (1992). Géologie des massifs calcaires situés au front S de l'unité de Kétama (Rif, Maroc). Publications du Département de Géologie et Paléontologie, Univ. Genève, 11, 138.
- Favre, P., Stampfli, G., & Wildi, W. (1991). Jurassic sedimentary record and tectonic evolution of the northwestern corner of Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 87(1–4), 53–73. [https://doi.org/10.1016/0031-0182\(91\)90130-J](https://doi.org/10.1016/0031-0182(91)90130-J)
- Fernandez, O. (2019). The Jurassic evolution of the Africa-Iberia conjugate margin and its implications on the evolution of the Atlantic-Tethys triple junction. *Tectonophysics*, 750, 379–393. <https://doi.org/10.1016/j.tecto.2018.12.006>
- Gimeno-Vives, O., Mohn, G., Bosse, V., Haissen, F., Zaghloul, M. N., Atouabat, A., & Frizon de Lamotte, D. (2019). The Mesozoic margin of the Maghreb Tethys in the Rif belt (Morocco): Evidence for poly-phase rifting and related magmatic activity. *Tectonics*, 38, 2894–2918. <https://doi.org/10.1029/2019TC005508>
- Hames, W., McHone, J. G., Renne, P., & Ruppel, C. (2003). *Introduction. The Central Atlantic magmatic province: Insights from fragments of Pangea*, Geophysical Monograph, (Vol. 136). Washington, D.C: AGU.
- Hoskin, P. W. O., & Schaltegger, U. (2003). The composition of zircon and igneous and meta-morphic petrogenesis. In J. M. Hancher, & P. W. O. Hoskin (Eds.), *Reviews in mineralogy and geochemistry*, (pp. 53, 27–62). America: Mineralogical Society of America. <https://doi.org/10.2113/0530027>
- Jourdan, F., Marzoli, A., Bertrand, H., Cirilli, S., Tanner, L. H., Kontak, D. J., et al. (2009). 40Ar/39Ar ages of CAMP in North America: Implications for the Triassic–Jurassic boundary and the 40K decay constant bias. *Lithos*, 110, 167–180.
- Knight, K. B., Nomade, S., Renne, P. R., Marzoli, A., Bertrand, H., & Youbi, N. (2004). The Central Atlantic Magmatic Province at the Triassic–Jurassic boundary: Paleomagnetic and 40Ar/39Ar evidence from Morocco for brief, episodic volcanism. *Earth and Planetary Science Letters*, 228(1–2), 143–160. <https://doi.org/10.1016/j.epsl.2004.09.022>
- Leblanc, D. (1979). Etude géologique du Rif externe oriental au Nord de Taza (Maroc). Notes et Mdm. Serv. gdol. Maroc, Rabat, n° 281.
- Lemoine, M., Bas, T., Arnaud-Vanneau, A., Arnaud, H., Dumont, T., Gidon, M., et al. (1986). The continental margin of the Mesozoic Tethys in the Western Alps. *Marine and Petroleum Geology*, 3(3), 179–199. [https://doi.org/10.1016/0264-8172\(86\)90044-9](https://doi.org/10.1016/0264-8172(86)90044-9)
- Lemoine, M., Tricart, P., & Boillot, G. (1987). Ultramafic and gabbroic ocean floor of the Ligurian Tethys (Alps, Corsica, Apennines): in search of a genetic model. *Geology*, 15(7), 622–625.
- Marzoli, A., Bertrand, H., Knight, K., Cirilli, S., Buratti, N., Verati, C., et al. (2004). Synchrony of the Central Atlantic magmatic province and the Triassic–Jurassic boundary climatic and biotic crisis. *Geology*, 32, 376–379.
- Marzoli, A., Callegaro, S., Corso, J. D., Davies, J. H. F. L., Chiaradia, M., Youbi, N., et al. (2018). *The Central Atlantic Magmatic Province (CAMP): A review*. Cham: Springer.
- Marzoli, A., Renne, P. R., Piccirillo, E. M., Ernesto, M., Bellieni, G., & De Min, A. (1999). Extensive 200-million-year-old continental flood basalts of the Central Atlantic Magmatic Province. *Science*, 284(5414), 616–618. <https://doi.org/10.1126/science.284.5414.616>
- Merle, O. (2011). A simple continental rift classification. *Tectonophysics*, 513(1–4), 88–95. <https://doi.org/10.1016/j.tecto.2011.10.004>
- Michard, A., Chalouan, A., Negro, F., & Saddiqi, O. (2015). Comment on “Evidence of extensional metamorphism associated to Cretaceous rifting of the North-Maghreb passive margin: The tanger-ketama unit (external rif, Northern Morocco)” by Vázquez et al., *geologica acta* 11 (2013), 277–293. *Geologica Acta*, 13(1), 69–76. <https://doi.org/10.1344/GeologicaActa2015.13.1.5>
- Michard, A., Feinberg, H., El-Azzab, D., Bouybaouène, M., & Saddiqi, O. (1992). A serpentinite ridge in a collisional paleomargin setting: The Beni Malek Massif, external Rif, Morocco. *Earth and Planetary Science Letters*, 113(3), 435–442. [https://doi.org/10.1016/0012-821X\(92\)90144-K](https://doi.org/10.1016/0012-821X(92)90144-K)
- Michard, A., Mokhtari, A., Chalouan, A., Saddiqi, O., Rossi, P., & Rjimat, E. C. (2014). New ophiolite slivers in the External Rif belt, and tentative restoration of a dual Tethyan suture in the western Maghrebides. *Bulletin de la Société Géologique de France*, 185(5), 313–328. <https://doi.org/10.2113/gssgfbull.185.5.313>



- Michard, A., Mokhtari, A., Lach, P., Rossi, P., Chalouan, A., Saddiqi, O., & Rjimati, E. C. (2018). Liassic age of an oceanic gabbro of the External Rif (Morocco): Implications for the Jurassic continent–ocean boundary of Northwest Africa. *Comptes Rendus Geoscience*, 350(6), 299–309. <https://doi.org/10.1016/j.crte.2018.05.006>
- Michard, A., Negro, F., Frizon de Lamotte, D., & Saddiqi, O. (2007). Serpentine slivers and metamorphism in the Externa Maghrebides: Arguments for an intracontinental suture in the African paleomargin (Morocco, Algeria). *Revista de La Sociedad Geológica de España*, 20, 173–186.
- Michard, A., Saddiqi, O., Chalouan, A., Chabou, M. C., Lach, P., Rossi, P., et al. (2020). Comment on « The Mesozoic Margin of the Maghrebien Tethys in the Rif Belt (Morocco): Evidence for Polyphase Rifting and Related Magmatic Activity” by Gimeno-Vives et al. *Tectonics*, 39, e2019TC006004. <https://doi.org/10.1029/2019TC006004>
- Nomade, S., Knight, K. B., Beutel, E., Renne, P. R., Verati, C., Féraud, G., et al. (2007). Chronology of the Central Atlantic Magmatic Province: Implications for the Central Atlantic rifting processes and the Triassic–Jurassic biotic crisis. *Palaeogeography Palaeoclimatology Palaeoecology*, 244, 326–344.
- Nomade, S., Pouclet, A., Chen, Y. (2002). The French Guyana doleritic dykes: Geochemical evidence of three populations and new data for the Jurassic Central Atlantic Magmatic
- OETR (Offshore Energy Technical Research Association). (2011). Play fairway analysis atlas—offshore Nova Scotia. Nova Scotia department of energy report, NSDOE records storage file no. 88-11-0004-01, 349. <http://energy.novascotia.ca/oil-and-gas/offshore/play-fairway-analysis>.
- Papillon, R. (1989). Stratigraphie des Sofs Lias-Dogger des massifs des Senhadja et de l’Azrou Akchar (Rif, Maroc). Publications du Département Géologie et de Paléontologie de l’Université de Genève, 8, 217.
- Petri, B., Mohn, G., Štípská, P., Schulmann, K., & Manatschal, G. (2016). The Sondalo gabbro contact aureole (Campo unit, Eastern Alps): Implications for mid-crustal mafic magma emplacement. *Contributions to Mineralogy and Petrology*, 171(5), 1–21. <https://doi.org/10.1007/s00410-016-1263-7>
- Ramos, A., Fernández, O., Torne, M., Sánchez de la Muela, A., Muñoz, J. A., Terrinha, P., et al. (2017). Crustal structure of the SW Iberian passive margin: The westernmost remnant of the Ligurian Tethys? *Tectonophysics*, 705, 42–62. <https://doi.org/10.1016/j.tecto.2017.03.012>
- Sebai, A., Féraud, G., Bertrand, H., & Hanes, J. (1991). 40Ar/39Ar dating and geochemistry of tholeiitic magmatism related to the early opening of the Central Atlantic rift. *Earth and Planetary Science Letters*, 104, 455–472.
- Stampfli, G. M., Mosar, J., Marquer, D., Marchant, R., Baudin, T., & Borel, G. (1998). Subduction and obduction processes in the Swiss Alps. *Tectonophysics*, 296(1–2), 159–204.
- Suter, G. (1980a). Carte géologique de la chaîne rifaine a 1/500 000. Notes et Mém. Serv. géol. Maroc, n° 245a.
- Suter, G. (1980b). Carte structurale de la chaîne rifaine h 1/500000. Notes et Mém. Serv. géol. Maroc, n° 245b.
- Sutter, J. F. (1988). Innovative approaches to the dating of igneous events in the early Mesozoic basins of the eastern United States. In studies of the Early Mesozoic basins of the eastern United States, edited by A. J. Froelich and G. R. Robinson, Jr., U.S. *Geological Survey Bulletin*, 1776, 194–200.
- Terrinha, P. (1998). Structural geology and tectonic evolution of the Algarve Basin, South Portugal. Unpublished PhD thesis. University of London.
- Vázquez, M., Asebriy, L., Azdimousa, A., Jabaloy, A., Booth-Rea, G., Barbero, L., et al. (2013). Evidence of extensional metamorphism associated to Cretaceous rifting of the north-Maghrebien passive margin: The Tanger–Ketama unit (external Rif, northern Morocco). *Geologica Acta*, 11, 277–293.
- Verati, C., Bertrand, H., & Féraud, G. (2005). The farthest record of the Central Atlantic Magmatic Province into West Africa craton: Precise 40Ar/39Ar dating and geochemistry of Taoudenni basin intrusives (northern Mali). *Earth and Planetary Science Letters*, 235, 391–407.
- Verati, C., Rapaille, C., Féraud, G., Marzoli, A., Marzoli, H., Bertrand, H., & Youbi, N. (2007). Ar–Ar ages and duration of the Central Atlantic magmatic province volcanism in Morocco and Portugal and its relation to the Triassic–Jurassic boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 244(1–4), 308–325. <https://doi.org/10.1016/j.palaeo.2006.06.033>
- Vidal, J. C. (1983). Carte géologique du Rif, feuille de Dhar Souk au 1/50.000. Notes et Mémoire du Service géologique du Maroc, 298.