TIDE-DOMINATED DELTAS RESPONDING TO HIGH-FREQUENCY SEA-LEVEL CHANGES, PRE-MESSINIAN RIFIAN CORRIDOR, MOROCCO: DISCUSSION

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INTRODUCTION

Beelen et. al. (2020) reinterpreted the late Miocene contourite depositional system of the Saiss Basin in the Rifian Corridor, Morocco (Capella et al. 2017; de Weger et al. 2020), as a tide-dominated delta environment that responded to high-frequency sea-level changes. Despite the authors stimulating a valuable discussion on the interpretation of the studied deposits, their proposed depositional system seems largely based on erroneous interpretations of the data that are misleading for the reader who is unfamiliar with the geological framework of the study area. Based on i) issues with spatial location of the outcrops they interpreted relative to known tectonic structures, ii) poor or contradictory age control that suggest that the studied outcrops are the same age, iii) evidence from faunal and sedimentary structures that better supports a deep-water setting, and iv) a lack of evidence to support the necessarily high-amplitude relative or eustatic sea-level changes, we consider that the balance of evidence recognized in these outcrops better supports a deep-water setting. With this comment we would like to address these inconsistencies and express our concerns about the train of thought used by Beelen et al. for their interpretation of shallow-marine rather than deep-marine depositional settings for the studied intervals.

SPATIOTEMPORAL LOCATION OF THE OUTCROPS

Beelen et al. provided a geological and paleogeographic framework that is mostly in line with the existing literature, reporting that a series of partially connected foreland basins formed the Rifian Corridor connection between the Atlantic Ocean and the Mediterranean Sea during the late Miocene. Furthermore, the authors address that the Rifian Corridor was probably divided into a narrower North Rifian Corridor (NRC) and a wider South Rifian Corridor (SRC), separated by an up-thrusted nappe belonging to the African continent (Capella et al. 2018). The Saiss foredeep basin, the main conduit of the SRC, is positioned in the front of this SW-ward emplaced nappe, bounded in the south, roughly 30 km south of the cities of Fes and Meknes, by the Moroccan Meseta and the Middle Atlas (Fig. 1A). Accordingly, Capella et al. (2017) and de Weger et al. (2020) argued that the frontal part of the nappe, which was already mostly emplaced by 7.8 Ma, formed the slope of the northern margin of the SRC. However, based on a misinterpretation of the geological map (Fig. 1B), Beelen et al. have erroneously considered the nappe as the Saiss Basin, and as such, assumed that the main conduit of the SRC was located on top of the nappe with its southern margin being located just north of the cities of Fes and Meknes.

Beelen et al. considered for their reinterpretation of the depositional environment three outcrops: *Ben Allou*, *El Adergha*, and *Driouate*. In the paper, Beelen et al. state that these outcrops are "broadly similar and contemporaneous." However, the deposits of the Ben Allou outcrop were deposited between 7.8 and 7.51 Ma, the El Adergha deposits between 7.35 and 7.25 Ma (Capella et al. 2017), and the Driouate deposits have not been dated by Beelen et al. but Beelen et al. considered them to be time equivalent to both Ben Allou and El Adergha. Strikingly, based on the original geological map (Chanakeb 2004) used by the Authors, as well as in Figure 1A reported here, the Driouate deposits are of middle Pliocene to upper Pleistocene in age (3.56–1.78 Ma). As such, the outcrops considered (Fig. 2) do not belong to the same stratigraphic interval and thus cannot be used for a time equivalent paleogeographic reconstruction.

The paleogeographic reconstruction provided by Beelen et al. (their Fig. 15), based on the argument addressed above, not only places the SRC north of the foredeep basin and on top of the nappe, but it also contains discrepancies with respect to their Figure 1. Figure 1 by Beelen et al. correctly shows the relative location of the Driouate outcrop with respect to the Ben Allou outcrop in the southwest, geographically located west of the city of Fes. However, in their Figure 15 the Driouate system is positioned southeast with respect to the Ben Allou system and southwest compared to the city of Fes to support their interpretation. Furthermore, the authors also used paleocurrent data derived from Capella et al. (2017) for other nearby outcrops to support their interpretations. These data from Capella et al. (2017) however, are derived from outcrops of which the interpretation does not fit with the interpretation of Beelen et al., and the authors fail to discuss these deviating interpretations. For example, the Sidi Harazem outcrop has been interpreted by Capella et al. (2017) as turbidite deposits in the axial foredeep of the SRC whilst in the Beelen et al. proposed reconstruction, this outcrop is located on the southern margin of their corridor. Moreover, the Ain Kansera outcrop is used by Beelen et al. as an argument to support the presence of wave action and a shallow marine setting after the interpretation by Capella et al. (2017). However, Beelen et al. placed this outcrop in the axis of the SRC in their reconstruction (Fig. 15 in Beelen et al.), not fitting within their interpretation of a shallow marine setting.

SHALLOW vs DEEPWATER

Based on the dominant occurrence of benthic foraminiferal genera indicative of shallow water environments, *Ammonia*, *Elphidium*, and *Cibicides*, Beelen et al. indicate deep-middle to inner-neritic water depths
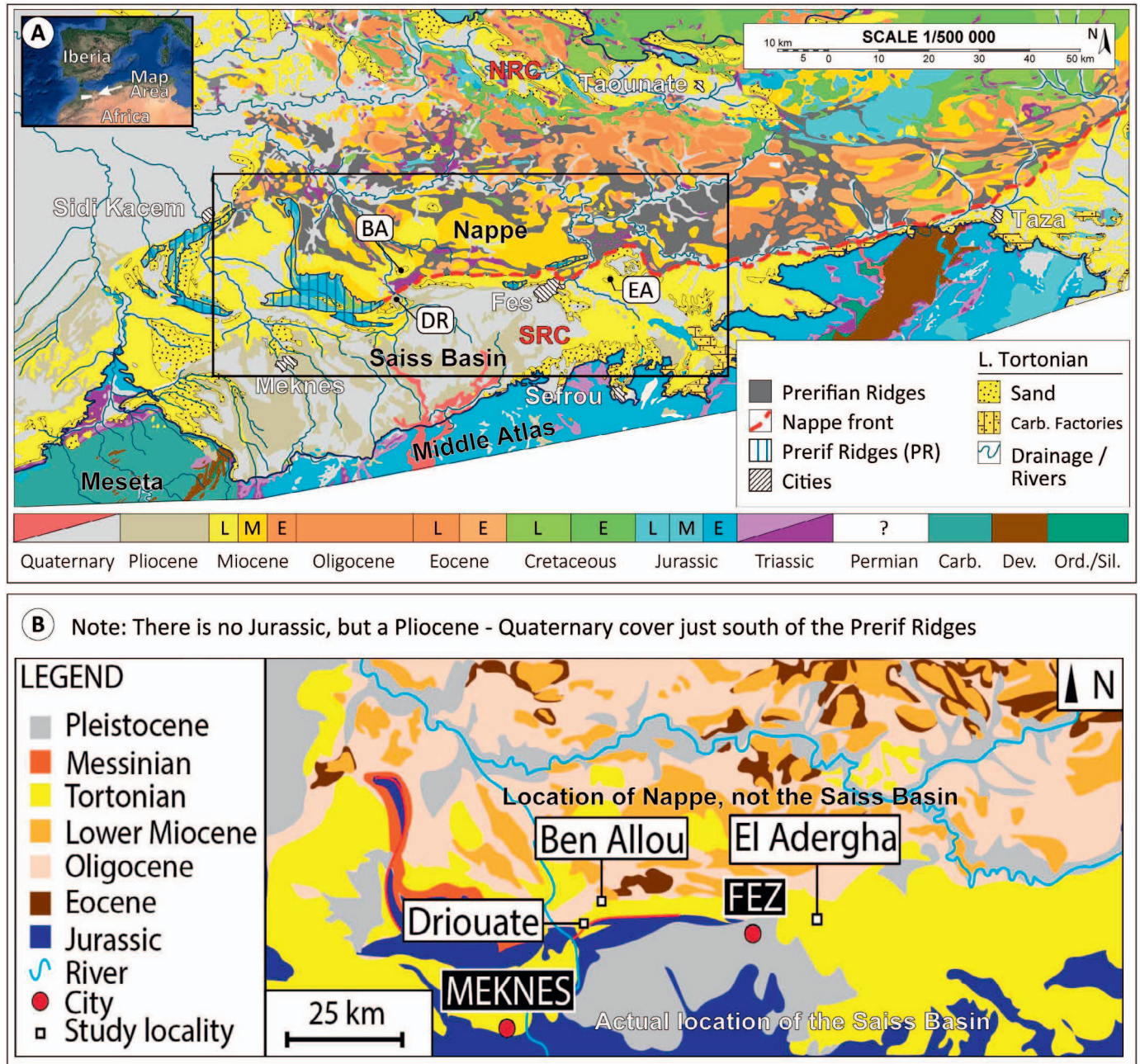
Fig. 1.—**A)** Regional geological map of the study area including the locations of the studied upper Miocene outcrops, Ben Allou (BA) and El Adergha (EA), as well as the Pliocene Driouate (DR) outcrop. The South Rifian Corridor (SRC) was limited northwards by the nappe and southwards by both the Moroccan Meseta in the southeast, and the Middle Atlas to the south. The North Rifian Corridor (NRC) is located north of the nappe. The square outlines the location of Part B. Carb. Factories is short for Carbonate factories; L, late; M, middle; E, early (modified after Saadi et al. 1980). **B)** The geological map wrongly modified by Beelen et al. after Chanakeb 2004. Note that the Jurassic cover south of Fes and Meknes or south of the Prerif Ridges is not present in the Saiss Basin but is related to the Middle Atlas.

for the fine-grained deposits and inner-neritic to littoral water depths for the calcarenites. The presence of these genera is indeed consistent with inner-neritic settings, but the authors fail to explain how genera indicative of deeper settings (*Pullenia*, *Dentalina*, *Oolina*, *Planulina*, and others) were transported to the interpreted coastal environments. García-Gallardo et al. (2017) and van der Schee et al. (2016) have observed the abundant presence of shelf foraminifera in sandy deposits associated with the early Pliocene contourite deposits in the Gulf of Cadiz, in water depths exceeding 400 m. These allochthonous assemblages contain similar specimens as reported by Beelen et al., containing also abundant *Ammonia*

and *Elphidium*. Garcia-Gallardo et al. (2017) and van der Schee et al. (2016) argued that these shelfal foraminifera were transported down the slope by turbidity currents to be redistributed along slope by contour currents, similarly as was proposed by Capella et al. (2017). All of this suggests that a shallow depositional setting cannot be affirmed by the foraminiferal assemblages. Furthermore, the Driourate section was interpreted as a lagoon deposit; however, most of the species found are incompatible with a lagoon setting. Although *Ammonia* and *Elphidium* can be found in lagoons, as well as in the inner shelf, *Pullenia*, *Oolina*, *Amphicoryna*, *Dentalina*, *Planulina*, and the planktonic genera, referred to
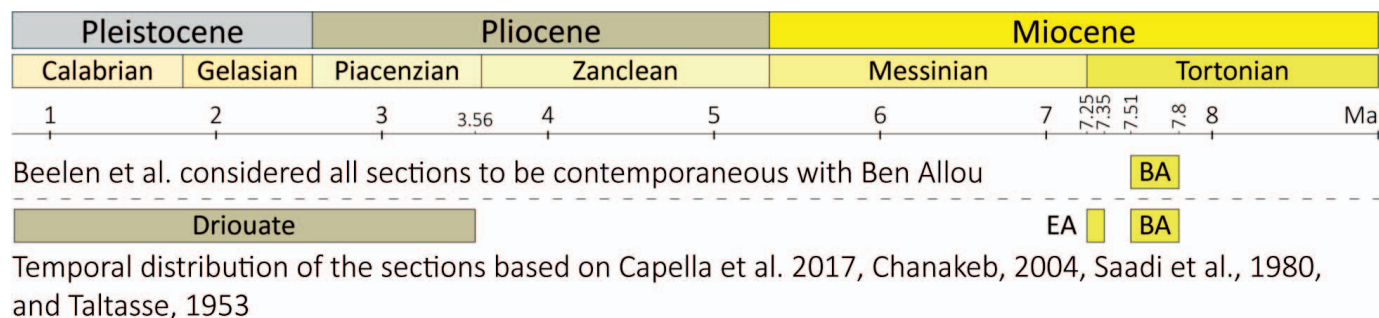
Fig. 2.—Temporal distribution of the studied outcrops used by Beelen et al. and based on other sources such as Capella et al. (2017), Chanakeb (2004), Saadi et al. (1980), and Taltasse (1953). BA, the Ben Allou outcrop; EA, El Adergha.

in Table 2 of the authors' supplemental information, are characteristic of open, deeper-marine waters.

Contourites are associated with bottom currents that transport and accumulate sedimentary particles. The type of particles transported by currents depends on the geological setting, and only a minority of these particles are formed on the slope. The vast majority are siliciclastic, supplied by, for example, rivers, or bioclastic (mostly calcareous fossils), formed on the shelf or from a pelagic settling (planktonic foraminifers, coccoliths) (e.g., de Castro et al. 2021b; Hüneke et al. 2021). The presence of largely fragmented macrofossils, such as barnacles, bryozoan, mollusks, calcareous algae, and others, which live in shallow-water environments, as such, cannot be considered as indicators of paleo–water depth. Bioclasts derived from these macrofossils are very commonly the main components of deposits associated with bottom currents (e.g., Longhitano et al. 2014; de Castro et al. 2021). Ostracods have, for example, been identified on the upper continental slope (at water depths of 501 m) and were used to evaluate their relationship with variability in bottom-water conditions and the control of the Levantine Intermediate Water current benthic faunas (Minto'o et al. 2015). Beelen et al. particularly regard the abundant occurrence of barnacles as an indicator of the shallow-water origin of the calcarenites as they argue that some of them appear to be in life position. Barnacles, however, are sessile crustaceans living attached to a substrate. We never found barnacles in life position and apparently neither have the authors, as they did not find the hard substrates on which these barnacles were fixed. To support their ideas, Beelen et al. speculated that these barnacles were probably attached to tidewrack or wood that was not preserved.

Beelen et al. furthermore mentioned that trace fossils recognized in the Ben Allou and El Adergha outcrops are indicative of the *Glossifungites* Ichnofacies. However, two of the most abundant trace fossils recorded by Beelen et al. (*Scolicia* and *Macaronichnus*) are not included in this archetypical ichnofacies (MacEachern et al. 2007, 2012). Moreover, the ichnological information (i.e., *Rhizocorallium*, *Skolithos*, and *Phytoplasma*), presented to justify the *Glossifungites* Ichnofacies, is poorly documented. As such, any interpretation based on the recognition of the *Glossifungites* Ichnofacies is weak and should be reconsidered. Additionally, *Rosalina* is not an ichnogenus *per se* as this term only refers to small foraminiferans that produce small boreholes (Bromley 1981; Neumann and Wisshak 2006). Thus, the appearance of the "*Rosalina*" ichnogenus cannot be used to support that El Adergha was deposited in shallower waters compared to the gray marlstones in Ben Allou.

Beelen et al. explain the alternating occurrence of "shallow-marine" and "deep-marine" fine-grained deposits by roughly 70–80 m fluctuations of high-frequency eustatic sea-level rise to support their interpretation of a tide-dominated delta. Although the authors claim that these high-magnitude sea-level fluctuations are supported by previous work, the references cited either do not cover the studied interval (Liebrand et al.

2011) or do not support such high-magnitude and high-frequency sea-level variations (Westerhold et al. 2005; Kominz et al. 2008). Westerhold et al. (2005) and Kominz et al. (2008) reported sea-level fluctuations for the late Tortonian of not more than 30 meters. Consequently, sea-level fluctuations with a magnitude sufficient to explain shallow-marine to deep-marine transitions are not supported, and in fact are contradicted by the references cited, making the interpretation of a deep-water depositional setting more suitable.

DEPOSITIONAL SETTING: SEDIMENTOLOGICAL DATA AND INTERPRETATION

Beelen et al. mention the presence of bidirectional sedimentary structures eleven times throughout the manuscript, but do not provide any data to support the interpretation of bidirectional tidal flow. Furthermore, the authors stated: "Overall, our combined measurements of paleocurrent directions across the calcarenite layers agree with those published by Capella et al. (2017) and show a dominance of southwestward-oriented, omnidirectional flow." However, the authors failed to provide their own paleocurrent data; the data used (Fig. 16 in Beelen et al.) is derived from Capella et al. (2017), which does not show a bidirectional trend. Moreover, what has been reported as bidirectional cross stratification and potentially herringbone cross stratification (Fig. 4C in Beelen et al.) is an example of "false herringbones" showing a section which is not parallel to the paleo-flow. As such, we found the interpretation of the existence of bidirectional currents a somewhat "forced" interpretation.

Beelen et al. mention that hummocky cross-stratification was found in the El Adergha outcrop (p. 1652), but this is not supported by any evidence. Moreover, the authors even mention a lack of sedimentary structures associated with waves, such as symmetrical ripples, hummocks, and swales (p. 1655).

The presence of mudcracks, highly relevant for the interpretation of subaerial exposures, has been mentioned but is not strongly supported by evidence in the manuscript (their Fig. 6C). Furthermore, dewatering structures are used to support a periodic subaerial exposure (p. 1656), not considering that these structures are usually related to loosely packed and rapidly deposited sediment, independent of water depth. Plant rootlets (their Fig. 10B) have also been used to support the interpretation that the deposits have been subaerially exposed. However, the supporting material (their Fig. 10A and B) suggests that they are just as likely to be Anthropocene rather than Miocene roots growing in the strata and forcing them to break apart producing the photographed exposure (Fig. 10B). Furthermore, insect-larva burrows reported for the Driouate outcrop (their Fig. 10G), despite this outcrop not being relevant to their interpretation of the late Miocene, are also more probably the product of recent biological activity.

Finally, the Ben Allou and El Adergha outcrops are composed of marls and sand bodies that, particularly in the Ben Allou outcrop, show large concave-up features. Although Beelen et al. argue to have found facies related to depositional sub-environments of a tide-dominated delta, evidence for a delta plain and a time-equivalent (7.8–7.25 Ma) proximal fluvial feeder system have not been documented.

CONCLUSION

In conclusion, based on issues with spatial locations of the outcrops and the use of erroneous data, we find that the observations and interpretations provided by Beelen et al. are not adequate to challenge the current interpretations of the studied deposits as being formed in deepwater by the paleo-Mediterranean Outflow Water.

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