Journal of African Earth Sciences 120 (2016) 181–185

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Bajocian-Bathonian (Middle Jurassic) sea-level changes in northeastern Egypt: Synthesis and further implications

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ARTICLE INFO

Article history:
Received 14 February 2016
Received in revised form
17 April 2016
Accepted 6 May 2016
Available online 13 May 2016

Keywords:
Eustasy
Relative sea level
Dynamic topography
Bajocian
Bathonian
Sinai
Gulf of Suez
Egypt

ABSTRACT

The global eustatic developments can benefit significantly from properly acquired regional information. Summarizing the available interpretations of the relative sea-level changes from two areas in northeastern Egypt, namely Gebel Maghara and Khashm El-Galala, allows better understanding of the Middle Jurassic sea-level changes. It is established that the Bajocian-Bathonian relative sea-level changes in these areas were coherent. The magnitude of changes was lower in the Bajocian than in the Bathonian. Significant sea-level rises occurred at the Bajocian-Bathonian and middle-late Bathonian transitions, and there was a clear tendency toward sea-level rise throughout the studied time interval. This evidence favors one of the two alternative global eustatic reconstructions that implies "stable" position of the shoreline in the Bajocian and general tendency to eustatic rise throughout the Jurassic. The tectonic regime of northeastern Egypt in the Middle Jurassic provided for strong eustatic control of the relative sea-level changes. The possible influence of hotspot activity is questionable. Filling the accommodation space with materials derived from the eroded continent may explain some sea-level falls that are regionally documented.

1. Introduction

The Jurassic eustatic (=global sea-level) changes have been studied for decades on both the global and regional scales, but the relevant knowledge remains incomplete and questionable to some extent (Ruban, 2015, 2016). About 30 years ago, Haq et al. (1987) proposed the well-known eustatic curve that depicted numerous global sea-level rises and falls. Immediately thereafter, an alternative eustatic curve was suggested by Hallam (1988). After a little more than a decade, the latter author updated the available knowledge and introduced a new vision of the Jurassic eustasy (Hallam, 2001). In particular, he rejected the global appearance of almost all Jurassic sea-level falls. Haq and Al-Qahtani (2005) also updated the earlier curve (Haq et al., 1987); although their work focused on the Arabian Platform, a global reconstruction was also included. As a result, there are two different alternative views of the Jurassic eustatic fluctuations, and it is really unclear which one of them is more realistic (Ruban, 2015, 2016). The broad correlation of unconformities attempted by Zorina et al. (2008) revealed the absence of global-scale sedimentation breaks during the Jurassic, which is in agreement with the suggestion of Hallam (2001). An elegant solution for this "puzzle" of opinions would be a global sea-level reconstruction based on the new plate tectonic developments (Seton et al., 2012). These reconstructions are available only for the Cretaceous–Cenozoic (Müller et al., 2008; Spasojevic and Gurnis, 2012), but regrettably they are still missing from the Jurassic (to the best of the authors' knowledge).

A powerful method for the development of eustatic knowledge is the interregional correlation of stratigraphical records, especially those well interpreted with regard to shoreline shifts and relative sea-level changes (Hallam, 2001; Miall, 2010; Ruban et al., 2010, 2012). If so, the accumulation of further data for particular regions allows a kind of methodological reflection. Unfortunately, such studies are rare, which can be explained by unwillingness of the modern research community to re-interpret the already available data ("out of fashion"), rather than to focus on collecting new facts. Hallam (2001) considered the regional Jurassic records of Europe, Greenland, Argentina, and the Himalayas. But what about Africa? The northern periphery of this continent was embraced by the Jurassic seas (Carr, 2003; Golonka, 2004; Guiraud et al., 2005;

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http://dx.doi.org/10.1016/j.jafrearsci.2016.05.002
1464-343X/

Tawadros, 2011), and really good stratigraphical records are found there. In fact, since the beginning of the 21st century, two areas with promising Jurassic sedimentary successions have been investigated in northeastern Egypt. These are Gebel Maghara (30°40′ N and 33° 23′ E) in North Sinai and Khashm El-Galala (29°34′ N and 32°20′ E) on the western side of the Gulf of Suez. In the both areas, the relative sea-level changes were reconstructed (El-Younsy, 2001; Abdelhady and Fürsich, 2015), although discussed in the context of the outdated eustatic reconstruction of Haq et al. (1987), which is so typical in the modern geoscience literature (Ruban, 2016). The main target of the present paper is to summarize the evidence of the relative sea-level changes from the noted areas and to apply this knowledge to the understanding of eustatic fluctuations on the basis of new developments. The authors wish to look back and to think deeper on the further implications of what have been found by others. However, this is not a repetition of the other authors' work; the employed method is able to bring new, original conclusions. This paper focuses on the Bajocian-Bathonian interval, which is especially well studied in the two noted areas.

2. Geologic setting

The geology of northeastern Egypt, including the stratigraphy of the sedimentary successions and the geological history, is well described (Said, 1962, 1990; Keeley et al., 1990; Keeley and Wallis, 1991; Wycisk, 1994; Wilson et al., 1998; Issawi, 2002, 2005; Carr, 2003; El Kelani et al., 2003; Guiraud et al., 2005; Tawadros et al., 2006; Issawi et al., 2009; Tawadros, 2011; Gaina et al., 2013; Abdelhady and Fürsich, 2015). Large-scale reconstructions have allowed an insight into the Jurassic palaeogeography (Stampfli and Borel, 2002; Golonka, 2004; Seton et al., 2012). The geological structures of northeastern Egypt, including the Sinai Peninsula, are generally complex (Fig. 1). During the Middle Jurassic, this region was a passive continental margin, characterized by some tectono-magmatic activity. The sea did not extend far into the continent relative to its present-day shoreline, although marine sedimentation of siliciclastics and carbonates persisted over large areas. River systems developed on the nearby land.

The Bajocian-Bathonian deposits are well represented in several sections at Gebel Maghara in North Sinai, where carbonate rocks prevail over sandstones and shales (Fig. 2), and these sections are well documented by Shahin (2000), Orabi (2001), El Kelani et al. (2003), Ghandour et al. (2003), and Abdelhady and Fürsich (2014, 2015). Depositional environments were diverse; shelfal conditions dominated, although alluvial facies did also exist. The Bajocian-Bathonian siliciclastics-dominated deposits (with some carbonates) crop out in several sections at Khashm El-Galala

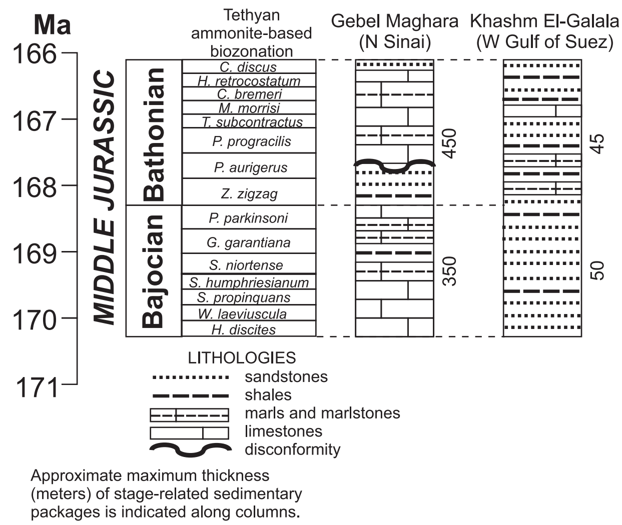

Fig. 2. Simplified composite Bajocian-Bathonian sections of North Sinai and the West Gulf of Suez (based on El-Younsy, 2001; El Qot et al., 2009; Abdelhady and Fürsich, 2015). Columns are given for only general comparison, and direct correlation should be done with serious caution. The geologic time scale follows the recommendation of the International Commission on Stratigraphy (stratigraphy.org), and the biozonation is given according to Gradstein et al. (2012).

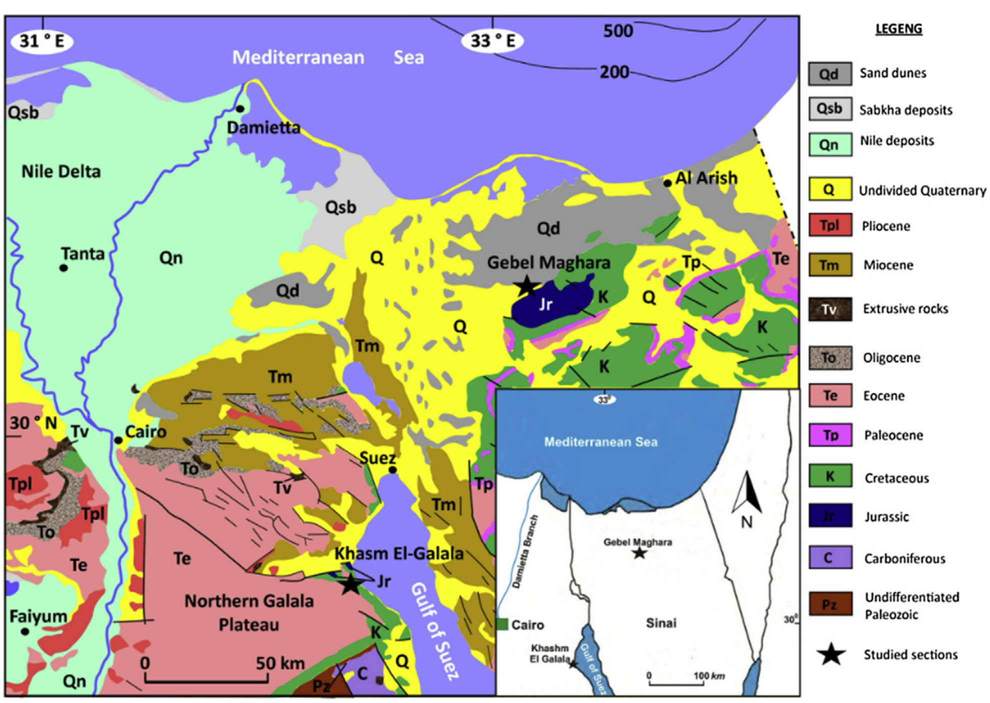

Fig. 1. Location of the areas discussed in the present paper. Geological map is modified from Geological Survey of Egypt (1981).

(Fig. 2), among which Ain Sukhna and Ras El Abd sections (Fig. 3) are the most important ones. These sections were appropriately described by El-Younsy (2001), Abu El-Hassan and Wanas (2003), Hegab and Aly (2004), Salem et al. (2006), and El Qot et al. (2009). Facies are alluvial, shallow-marine, and transitional. The Bajocian-Bathonian sedimentary succession is much thicker at Gebel Maghara section (Fig. 2).

The age of the deposits at Gebel Maghara was established on the basis of diverse fossils, including ammonites, bivalves, brachiopods, foraminifers, etc. (Orabi, 2001; Abdelhady and Fürsich, 2014, 2015). At Khashm El-Galala, the age was also established on the basis of fossils, among which brachiopods and foraminifers are especially important (El-Younsy, 2001; Hegab and Aly, 2004; El Qot et al., 2009). The available stratigraphical information permits correlation between these areas (i.e., Gebel Maghara and Khashm El-Galala) with an error of about half of a substage (first of all, because of the still insufficient knowledge on the Khashm El-Galala sections). This degree of error is not big relative to the modern eustatic knowledge (Ruban, 2016), and thus, acceptable (and even inevitable). Therefore, the direct comparison of the sections is possible. It also appears that the stages as defined by the authors of the original studies discussed here correspond well with the stratigraphical limits established by Gradstein et al. (2012).

3. Coherence of relative sea-level changes

The high-resolution reconstruction of the Middle Jurassic palaeoenvironmental changes at Gebel Maghara proposed by Abdelhady and Fürsich (2015) provided valuable information about the relative sea-level changes during the Bajocian-Bathonian (Fig. 4). According to these authors, weak fluctuations during the Bajocian were followed by prominent fall at the beginning of the Bathonian and then immense rise in the middle part of this stage. Sea level fell again by the advent of the late Bathonian. The reconstruction of the Middle Jurassic relative sea-level changes in Khashm El-Galala (El-Younsy, 2001) is of the same resolution. It reveals a marked sea-level rise throughout the Bajocian, peaking up near its end, and more significant fluctuations in the Bathonian with a peak in its midst (Fig. 4).

By integrating the above-mentioned reconstructions, a conclusion about the significant coherence of the Bajocian-Bathonian relative sea-level changes in northeastern Egypt can be reached, despite the large distance between North Sinai and west Gulf of Suez (Fig. 1). The possible error of about half of a substage (as mentioned above) was taken into consideration when making such conclusion. All major events are visible on both curves (Fig. 4). It should be noted that the earliest Bathonian sea-level rise at Gebel Maghara corresponds to the latest Bajocian rise at Khashm El-

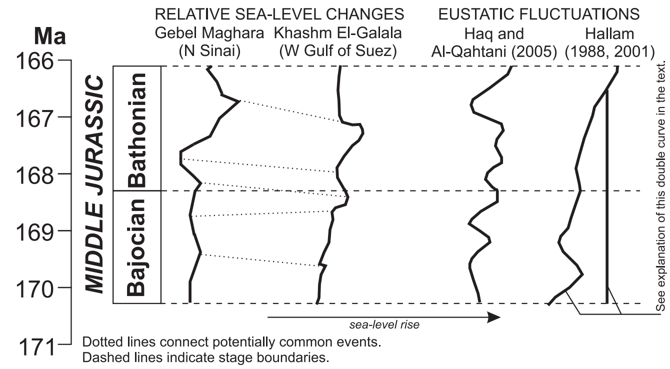

Fig. 4. Relative sea-level changes interpreted in Egypt (modified from El-Younsy, 2001; Abdelhady and Fürsich, 2015) and global eustatic fluctuations (after Hallam, 1988, 2001; Haq and Al-Qahtani, 2005; adapted from Ruban, 2015). The available stratigraphical information allows only general comparison, and direct correlation should be done with serious caution. The magnitude of events is shown out of any common scale and cannot be compared for the curves.

Galala. Consequently, it is possible to tell that a relative sea-level rise in northeastern Egypt occurred at the Bajocian-Bathonian transition. Similarly, the late Bathonian peak at Gebel Maghara corresponds to the mid-Bathonian peak at Khashm El-Galala, and, therefore, one would assume that a relative sea-level rise in northeastern Egypt took place at the middle-late Bathonian transition. Generally, the palaeoenvironmental space of northeastern Egypt was rather homogenous, as one can deduce from the established coherence of the relative sea-level changes in the two investigated areas.

4. Relative sea-level changes versus eustatic fluctuations

The global curve of Haq and Al-Qahtani (2005), which is an update of the earlier proposed curve of Haq et al. (1987), demonstrates a series of global sea-level changes of the same magnitude throughout the Bajocian-Bathonian. The number of eustatic cycles is a bit larger than registered in northeastern Egypt. Although some regional events (e.g., the sea-level rises at the Bajocian-Bathonian and middle-late Bathonian transitions) can be brought in correspondence with those global, it would be tricky to establish any correspondence between the regional and global curves (Fig. 4). Moreover, the data from Gebel Maghara and Khashm El-Galala suggest that the magnitude of sea-level changes increased greatly in the Bathonian relative to the Bajocian, which is not observed on the curve proposed by Haq and Al-Qahtani (2005).

The global curve by Hallam (1988) indicates some eustatic rises and falls, but his later conclusion about the absence of the truly

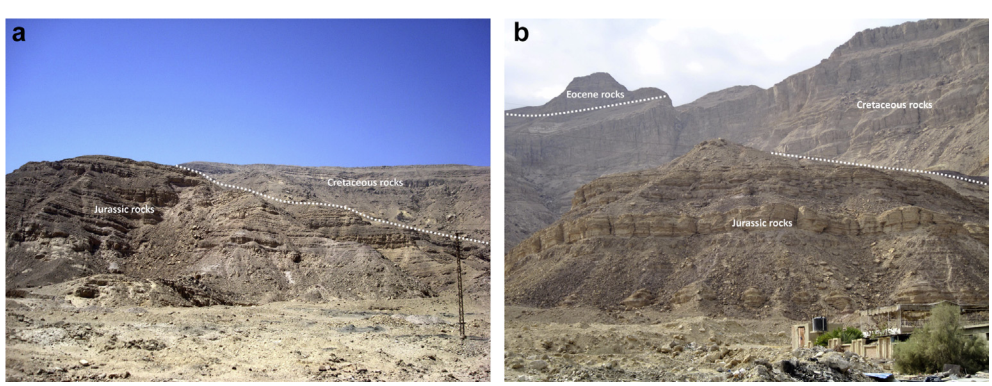

Fig. 3. General views of the representative outcrops in the Khashm El-Galala: a – Ain Sukhna section, b – Ras El Abd section.

global falls and the general tendency of eustatic rise throughout the Jurassic (Hallam, 2001) warranted for a modification by Ruban (2015) so to outline a long-term "stable" position of the sea level in the Bajocian followed by some rise in the late Bathonian. This differs from the relative sea-level changes established in northeastern Egypt (Fig. 4), although two important observations should be noted. First, the relatively small magnitude of regional sea-level changes in the Bajocian corresponds rather well to the hypothesized "stable" position of the global sea level during this stage. Second, the regional fluctuations demonstrate a clear tendency toward sea-level rise throughout the two stages considered in the present paper, which is in agreement with both the earlier curve of Hallam (1988) and its later modification by Ruban (2015) on the basis of suggestions by Hallam (2001). The eustatic reconstruction of Haq and Al-Qahtani (2005) also shows a tendency toward sea-level rise, although much weaker. As for the relative sea-level falls, these are expected because of the common regional alterations of global sea-level changes by tectonic activity and/or transformation of accommodation space.

The observations presented above permit to conclude that the reconstruction of the relative sea-level changes by El-Younsy (2001) and Abdelhady and Fürsich (2015) prove the validity of the eustatic developments of Hallam (1988, 2001), and if so, these regional changes were significantly controlled (but, of course, not fully) by global changes. This inference is sensible because the areas considered in the present paper were located on a passive continental margin in the Middle Jurassic (Stampfli and Borel, 2002; Golonka, 2004; Guiraud et al., 2005; Seton et al., 2012; Gaina et al., 2013), where tectonic "stability" would permit a good signature of long-term events. The reconstruction of Gaina et al. (2013) implies that the considered areas of northeastern Egypt were located in proximity to the spreading axe that stretched between the African-Arabian margin and Adria. The young age of the crust implies that the oceanic branch along the noted axe was not deep, and the older-aged flanks of this ocean (Seton et al., 2012) and the continental periphery were slowly subsiding. Such conditions are almost ideal to document the global eustatic influences in this region. It also appears that the Middle Jurassic activity of faults noted by Guiraud et al. (2005) which were linked to basin evolution on Sinai (Abdelhady and Fürsich, 2015) did not mask this signature of eustasy in northeastern Egypt.

5. Regional factors of relative sea-level changes

When a region is said to be "stable" because of being part of a passive margin, this does not mean the sea-level changes are not influenced by forces linked to mantle dynamics, ridge push, and other relevant phenomena. The mechanisms of dynamic topography are well described by Moucha et al. (2008), Müller et al. (2008), Conrad and Husson (2009), Lovell (2010), Jones et al. (2012), Spasojevic and Gurnis (2012), and Conrad (2013) (see also Ruban, 2016). Although we do not have appropriate reconstructions of mantle-induced vertical motions during the Jurassic in Africa, like those available for later stages of its geological history (Spasojevic and Gurnis, 2012), attention should be paid to the possible activity of hotspots.

Golonka and Bocharova (2000) indicated that the Gebel Mara hotspot in the Middle Jurassic, close to the territory of what is now northeastern Egypt, was responsible for seafloor spreading between the African-Arabian margin and Adria. Seton et al. (2012) placed a hotspot (most probably, this is the same Gebel Mara hotspot) to the north of the northeastern African margin, and it appears that continent movement placed this hotspot directly beneath Sinai at 120 Ma. If these ideas are valid, this means the noted hotspot did not affect significantly the relative sea level changes in Gebel Maghara or Khashm El-Galala, but it "fed" the ocean spreading to the north. Pirajno and Santosh (2015) did not recognize the Gebel Mara hotspot in their reconstruction, but recorded the Cameroon hotspot on the territory of present-day Libya. They also delineated the area with the relevant crustal uplift, although this area seems to be too small in comparison to the spatial extent of the Gebel Mara volcanism (Golonka and Bocharova, 2000). Anyway, if Pirajno and Santosh (2015) are right, the noted hotspot was responsible for certain uplift of the African continental margin, although this effect might have been minimal in northeastern Egypt.

The other regional factor that should be taken into account is the transformation of the accommodation space. The slow subsidence of the continental margin (noted above and also stated by Abdelhady and Fürsich (2015)) coupled with an evident flux of clastic material by riverine systems from the eroded continent permitted easy filling of the basin with sediments. This was enough to decrease the water depth. When considering the lithologies and stratigraphic architecture of sedimentary complexes (Fig. 2, see also El-Younsy (2001) and Abdelhady and Fürsich (2015)), such a scenario seems to be very plausible for explanation of the early and late Bathonian relative sea-level falls. However, it was anyway the regional tectonic regime that allowed the basin filling to occur.

6. Conclusions

Consideration of the available interpretations of the Bajocian-Bathonian relative sea-level changes in northeastern Egypt permits to judge this territory well suitable for discussions on the Middle Jurassic eustasy. The implications are as follows:

1) the Bajocian-Bathonian relative sea-level changes in Gebel Maghara (North Sinai) and Khashm El-Galala (West Gulf of Suez) were coherent, and this fact reveals a kind of homogeneity of the marine basin located there;
2) the Bajocian-Bathonian relative sea-level changes in northeastern Egypt prove the validity of the eustatic reconstruction of Hallam (1988, 2001), and, if so, these regional changes were controlled significantly by the global fluctuations of the sea level;
3) both the regional tectonics and the transformation of the accommodation space (large amounts of sediment supply cannot be excluded) affected the Bajocian-Bathonian relative sea-level changes in northeastern Egypt, and the possible mantle influences are questionable.

Acknowledgements

The authors gratefully thank the journal editor, S. Jain (India), and H. Zerfass (Brazil) for their constructive suggestions, M.K. Zobaa (USA) for linguistic correction, and C.P. Conrad (USA), G.M. El Qot (Egypt), and S.O. Zorina (Russia) for discussions and literature support.

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