Journal of African Earth Sciences 80 (2013) 48–59

Contents lists available at SciVerse ScienceDirect

Journal of African Earth Sciences

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

Significance of Detrended Correspondence Analysis (DCA) in palaeoecology and biostratigraphy: A case study from the Upper Cretaceous of Egypt

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ARTICLE INFO

Article history:
Received 5 July 2012
Received in revised form 28 November 2012
Accepted 30 November 2012
Available online 20 December 2012

Keywords:
Palaeoecology
Biostratigraphy
Detrended Correspondence Analysis (DCA)
Cenomanian–Turonian
Sinai Peninsula
Egypt

ABSTRACT

The Cenomanian–Turonian macrofauna from the Sinai Peninsula, Egypt offers an excellent opportunity to test the applicability of gradient analysis in palaeoecology and biostratigraphy. Detrended Correspondence Analysis (DCA) is a simple multivariate technique for arranging species and samples along environmental gradients. In order to reconstruct palaeoecological patterns and biostratigraphy, 42 samples, 4564 individuals, and 132 species from three sections of eastern Sinai were subjected to DCA. Compared with other multivariate techniques such as cluster analysis, the macrobenthic associations (obtained by DCA) fall fully within or deviate only slightly from associations obtained by cluster analysis. However, DCA makes it possible to arrange these associations from completely random distribution (as tested by cluster analysis) to a temporal gradient. Therefore, it is possible to use this multivariate technique also as a useful tool in biostratigraphy. The first detrended correspondence axis (DC1) reflects a water-depth gradient from onshore to offshore, higher scores being typical of onshore samples from the southernmost section and lower scores being typical of offshore samples from the northern section. Overprinted on the DC1 axis is also a gradient of life and feeding modes, as samples with low scores are dominated by epifaunal species and samples with high scores display a higher proportion of shallow-infaunal taxa. With respect to the second detrended correspondence axis (DC2), substrate composition and water energy are overprinted on this axis as samples with low scores predominantly are coarse-grained carbonates (e.g., reefal rudstone), while samples with high scores primarily are mixed-siliciclastics/carbonates (e.g., marl), which are dominated by low-energy taxa. Because the substrate conditions are closely related to the water energy, the coarse-grained substrates were deposited under high water energy, while the marly facies was deposited under low-energy conditions. Excursions in DC2 scores, reflecting substrate composition and water energy, are used to reconstruct the macrobenthic associations; eight associations and two assemblages were recognized. High stress environments (low DC2 scores) were occupied by less diverse associations such as the *Chondrodonta joannae* association and the *Pchelinsevia coquandiana–Praeradiolites biskraensis* association. The latter association is stratigraphically followed by high-diversity associations such as the *Ilymatogyra africana–Rhynchostreon suborbiculatum* association, which preferred less-stressed environments (high DC2 scores).

1. Introduction

The most recent development in multivariate techniques is Detrended Correspondence Analysis (DCA) (e.g., Tuckey and Anstey, 1989; Miller et al., 2001; Scarponi and Kowalewski, 2004; Huntley, 2011). According to Huntley (2011), DCA is a multivariate ordination whose purpose is to identify taxonomic groupings of samples distributed across environmental gradients. A significant distinction of DCA from other multivariate ordinations is that it assigns scores to species as well as samples. The result is that taxa which commonly co-occur in samples plot near to one another in the DC-defined space. Moreover, samples have scores similar to those of their constituent taxa. DC-axes are often interpreted to represent environmental gradients controlling the distribution of taxa. For instance, in marine settings the first DCA axis has been interpreted in some cases as a function of water depth (Holland et al., 2001; Miller et al., 2001; Bonelli and Patzkowsky, 2008). Thus, sample DC1 scores can be used to estimate relative changes in sea level. Scarponi and Kowalewski (2004) were the first to quantify the relationship between DC1 scores and water depth by regressing Pleistocene – Holocene mollusc scores on the

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1464-343X/$ - see front matter
http://dx.doi.org/10.1016/j.jafrearsci.2012.11.012

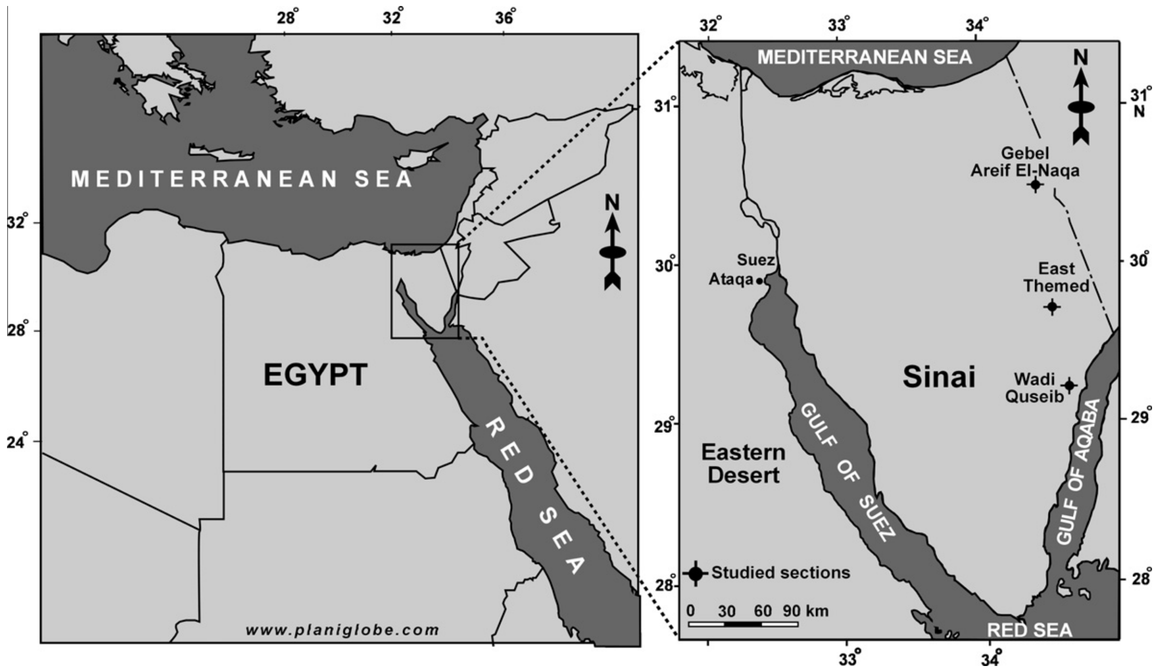

Fig. 1. Locality map showing the position of the three studied sections on the Sinai Peninsula, Egypt.

preferred water depth of modern con-specifics. This in turn allowed them to produce a water depth curve for each stratigraphic column based on DC1 scores of their samples, which was used to confirm and refine sequence stratigraphic interpretation. Subsequent DC axes typically represent other environmental gradients which affect the biotic distribution (e.g., salinity, water energy, substrate type).

Considering previous studies (e.g., Miller et al., 2001; Scarponi and Kowalewski, 2004), the applications of DCA have yet to be tested on certain types of field data and their full potential as analytical tool has yet to be fully explored. The purpose of this paper is to demonstrate the applicability of this technique to palaeoecology and biostratigraphy. To reach the above-mentioned goal, we applied Detrended Correspondence Analysis (DCA) to a matrix of macrofossil species occurrences (primarily environmental indicators) from three Cenomanian–Turonian sections (Wadi Quseib, East Themed, Gebel Areif El Naqa) of the Sinai Peninsula, Egypt (Fig. 1) representing shallow-marine conditions. The collected benthic fauna from the studied sections consists of altogether 4564 individuals, belonging to 132 taxa distributed among bivalves, gastropods, echinoids, corals, and coralline sponges (see Appendix A). The main target of this paper is to use the macrobenthos (in data-intensive multivariate analyses) for estimating the structure of fossil community relicts and predicting habitats and other environmental variables of the ecosystem. In addition, results from DCA (macrobenthic associations and assemblages) and those from classical cluster analysis are compared. Another aim is to explore to what extent water depth and associated environmental variables are depicted by DCA. Commonly the first DC axis is explained as a function of water depth. However, this function must be justified rather than assumed. The last goal is to confirm that DCA is potentially a useful tool in biostratigraphy by arranging the fauna along a time axis.

2. Lithostratigraphy

The Cenomanian–Turonian succession of Gebel Areif El-Naqa (northern section) is 457 m thick and has been subdivided into three formations, which from older to younger are the Halal Formation (Upper Albian–Cenomanian, 301 m), the Abu Qada Formation (Lower-?Middle Turonian, 96 m), and the Wata Formation (Upper Turonian, 60 m). The Halal Formation has been subdivided into three informal members (Ayoub-Hannaa, 2011). The formation is composed mainly of carbonate rocks (about 65% of the total thickness of the formation; Fig. 2) and is fossiliferous containing bivalves such as *Nayadina gaudryi* Thomas and Peron, *Ceratostreon flabellatum* (Goldfuss), and *Rhynchostreon suborbiculatum* (Lamarck), and the echinoids *Pedinopsis desori* (Coquand), *Tetragramma variolare* (Brongniart), *Heterodiadema libycum* (Agassiz and Desor), and *Coenholectypus larteti* (Cotteau) (see Appendix A for a detailed faunal list). The Abu Qada Formation is easily distinguished by its characteristic green fossiliferous marls and shales containing the ammonite *Choffaticeras* (*Ch.*) *segne*, which are interbedded with limestone and marly limestone. The Wata Formation differs from the underlying Abu Qada Formation by its cyclic, thick-bedded, cliff-forming chalky limestones with chert nodules, dolomitic limestones, and hard limestones (Fig. 2).

In the East Themed section (east-central section), the Cenomanian–Turonian succession is 239 m thick and has been subdivided into four formations which, from older to younger, are the Galala (Middle–lower Upper Cenomanian), Abu Qada (Upper Cenomanian–Lower Turonian), Buttum (Middle Turonian), and Wata formations (Upper Turonian). The Galala Formation is composed mainly of grey to yellowish grey, hard, fossiliferous limestone (floatstone to rudstone) with intercalations of shales and marls. The Abu Qada Formation attains a thickness of 70 m and is composed mainly of shale with limestone and marly intercalations. The lower 17 m of the formation consist of greyish-green, soft, glauconitic shale with oysters such as *Ilymatogyra africana* (Lamarck) and *Costagyra olisiponensis* (Sharpe) (Fig. 3). The middle part of the Abu Qada Formation consists of yellowish-white, moderately hard, fossiliferous limestone rich in ammonites such as *Choffaticeras* (*Ch.*) *securiforme* (Eck) and *Choffaticeras* (*Ch.*) *segne* (Solger). This ammonite bed contains also other faunal elements such as the bivalves *Nuculana* (*N.*) sp., *Pseudolima itieriana* (Pictet and Roux), and *Granocardium* (*G.*) *productum* (Sowerby), the gastropods *Campanile*? sp., *Tylostoma* (*T.*) *pallaryi* (Peron and Fourtau),