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Using palynology to re-assess the Dead Sea laminated sediments – Indeed varves?

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ABSTRACT

Lacustrine laminated sediments are often varves representing annual rhythmic deposition. The Dead Sea high-stand laminated sections consist of mm-scale alternating detrital and authigenic aragonite laminae. Previous studies assumed these laminae were varves deposited seasonally. However, this assumption has never been robustly validated. Here we report an examination of the seasonal deposition of detrital-aragonite couplets from two well-known Late Holocene laminated sections at the Ze'elim fan-delta using palynology and grain-size distribution analyses. These analyses are complemented by the study of contemporary flash-flood samples and multivariate statistical analysis. Because transport affects the pollen preservation state, well–preserved (mostly) air-borne transported pollen was analysed separately from badly-preserved pollen and fungal spores, which are more indicative of water transport and reworking from soils. Our results indicate that (i) both detrital and aragonite laminae were deposited during the rainy season; (ii) aragonite laminae have significantly lower reworked and fungal spore concentrations than detrital and flash-flood samples; and (iii) detrital laminae are composed of recycling of local and distal sources, with coarser particles that were initially deposited in the Dead Sea watershed and later transported via run-off to the lake. This is in line with previous carbon balance studies that showed that aragonite precipitation occurs after the massive input of TCO_2 associated with run-off episodes. Consequently, at least for the Holocene Ze'elim Formation, laminated sediments cannot be considered as varves. Older Quaternary laminated sequences should be re-evaluated.

1. Introduction

Fine-laminated lacustrine sequences have commonly proven to be annually deposited. Thus, varve-based chronologies of these sequences can be obtained (e.g. Ojala and Alenius, 2005; Zolitschka et al., 2015). Large portions of the Dead Sea Basin (DSB) Late Quaternary sediments are laminated (Neev and Emery, 1967; Begin et al., 1974), i.e. the Lisan Formation (70–13 ka BP; Stein and Goldstein, 2006; Torfstein et al., 2013) and the Ze'elim Formation (<10 ka BP; Migowski et al., 2006). These laminated sections consist of mm-scale alternating detrital and authigenic aragonite laminae. Based on age-depth models and lamina counting, these laminae were assumed to be varves in most studies, i.e. rainy season-detrital *versus* summer-aragonite deposition (Neev and Emery, 1967; Begin et al., 1974; Heim et al., 1997; Migowski et al., 2004; Prasad et al., 2004; Neumann et al., 2009; Leroy et al., 2010; Neugebauer et al., 2015). However, the exact seasonal character of the Dead Sea laminae has not been confirmed in a robust manner. This is of extreme importance for the accurate use of the DSB laminated sediments as palaeoenvironmental and palaeoclimate archives. Therefore, the aim of this paper is to re-address the nature of these laminated sediments in order to aid accurate interpretations of environmental change in the region.

Dead Sea detrital laminae are composed of a mixture of regional dust inputs and local run-off erosion products from the catchment area (Belmaker et al., 2011; Haliva-Cohen et al., 2012). In numerous lakes, carbonate deposition is closely related to biological activity

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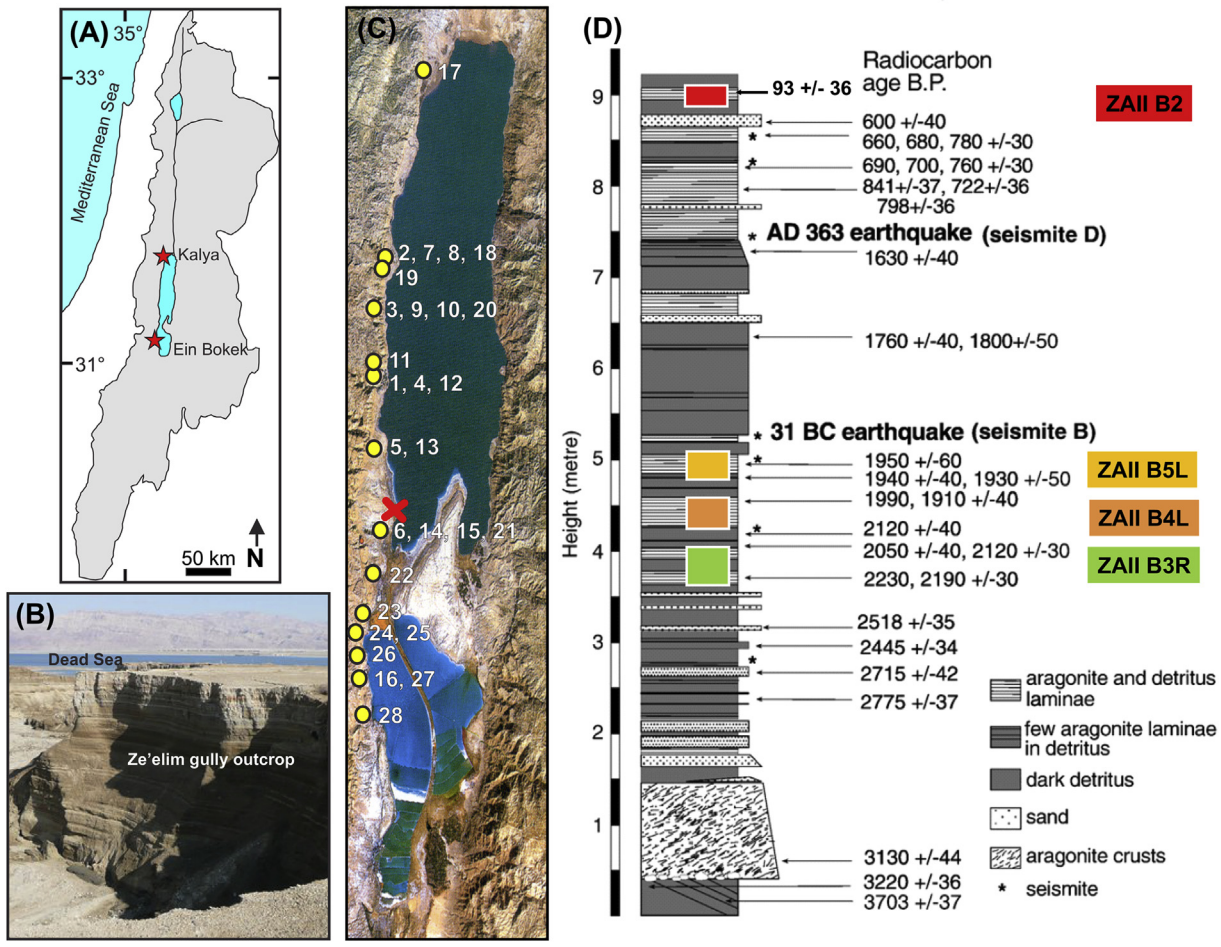

Fig. 1. (A) Location map of the Dead Sea and its watershed. Red stars indicate the location of the two aeropalynological stations. (B) Photo of the Ze'elim gully outcrop sampled in this study (Photo by L. López-Merino). (C) Location map of the laminated sediment blocks at Ze'elim and flash-flood sampling sites. Red cross indicates the location of the Ze'elim outcrop. Yellow circles indicate flash-flood sampling locations (numbers as in Supplementary Table S3 (D) Sedimentary scheme of the Ze'elim outcrop profile and radiocarbon chronology (modified from Bookman (Ken-Tor) et al., 2004). ZA11B2 sediment block represent the late 19th – early 20th centuries high-stand. ZA11B3R, ZA11B4L and ZA11B5L sediment blocks represent the Hellenistic-early Roman high-stand. Aragonite crusts were deposited in a coastal to terrestrial environment, while the aragonite laminae (discussed in this study) were deposited in a lacustrine environment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(e.g. Thompson et al., 1997; Salmaso and Decet, 1998). In contrast, carbonate deposition in the Dead Sea is inorganic and results from the interaction between freshwater run-off and Dead Sea hypersaline brine (Katz and Kolodny, 1989; Stein et al., 1997). The primary origin of aragonite from the diluted upper water mass is confirmed by the excellent state of preservation of the crystals and their concentration within specific layers in the laminated sequences. This supports non-overlapping times of deposition between aragonite and detrital laminae (Heim et al., 1997; Stein et al., 1997). The commonly presumed season for aragonite precipitation is summer. The trigger is attributed to evaporation and warming of the high bicarbonate surface waters that entered via run-off during the wet season ("whitening" events) (Neev and Emery, 1967; Stein et al., 1997). On the other hand, Barkan et al. (2001) measured carbonate system parameters in the upper water mass that formed after the heavy flooding during the extreme winter of 1992 and showed that, at least in the modern Dead Sea, aragonite precipitation occurs just after the massive input of TCO_2 during the wet season. Research so far, on geochemical and palaeolimnological parameters, has not established the exact timing of the aragonite deposition and its relation to detrital input events.

Based on the observations of Barkan et al. (2001), we hypothesise that aragonite may have not been deposited during summer as is commonly interpreted, but instead the detrital-aragonite couplets may represent flash-flood events rather than an annual cycle. Thus, laminated sequences could be formed by flash-flood events delivering sediments into the lake followed by aragonite deposition in a climate-controlled lacustrine environment, i.e. precipitation in the drainage basin. To examine this hypothesis we performed grain-size and palynological analyses of detrital-aragonite couplets from two well-dated high-stand laminated sequences in the Ze'elim Formation: the Hellenistic-early Roman and the late 19th – early 20th centuries (Bookman (Ken-Tor) et al., 2004). Grain-size distribution provides information on sediment source (i.e. dust or watershed erosion), while palynology provides information on both seasonality (well-preserved, air-borne pollen) and sediment transport (reworked, water-borne pollen). In addition, palynological analysis was carried out on fine mud deposits collected immediately after modern flash-flood events, assuming that these deposits represent flood suspended matter.

2. Materials and methods

2.1. Study area and selected laminated sediments

The Dead Sea (Fig. 1A) is a closed, inland hypersaline lake (e.g.