A 45 kyr laminae record from the Dead Sea: Implications for basin erosion and floods recurrence*

Yin Lu[1,2#], Revital Bookman[3], Nicolas Waldmann[3], Shmuel Marco[4]

[1]Department of Geography, University of Liege, allée du 6 août 2, 4000 Liège, Belgium

[2]Institute of Earth Sciences, Heidelberg University, Heidelberg 69120, Germany

[3]Dr. Moses Strauss Department of Marine Geosciences, University of Haifa, 3498838 Haifa, Israel

[4]Department of Geophysics, Tel Aviv University, 6997801 Tel Aviv, Israel

Lu, Y., Bookman, R., Waldmann, N.D., and Marco, S., 2020. Quaternary Science Reviews, 229 (2020), 106143.

#yin.lu@uliege.be

Homepage (Y.L.)

1. INTRODUCTION

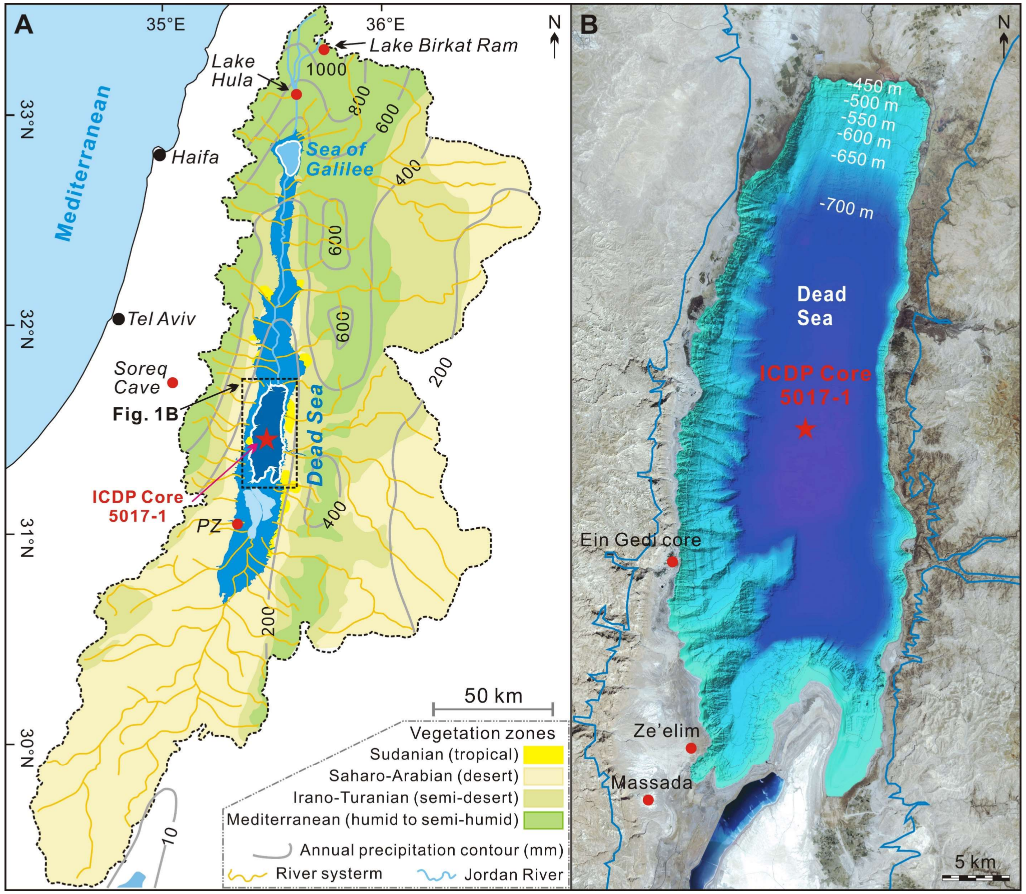
- Understanding how climate change impacts flood recurrence, basin erosion, and sedimentation is essential for future flood warning, mitigation, and hazard assessment especially in semi- to hyper-arid environments. Previous study suggests that aridification of a previously semi-humid environment may have increased the relative magnitudes of rare floods (or, conversely, increased the frequency of large floods) (Molnar, 2001).

- However, the scarcity of long and reliable terrestrial archives of floods, which encompass at least the latest Holocene/Pleistocene climate transition at high-resolution, hinders our further understanding of this issue.

- Previous records are too short of representing paleoflood sequences occurring through a glacial-interglacial transition. Extending the time series of reliable paleoflood records to cover at least the last glacial-interglacial transition is a key for understanding the impact of long-term climate change on flood recurrence and basin erosion in hyper-arid environments prone to flash-floods.

- The deposition of aragonite-detritus laminae couplets in the lacustrine sequences deposited during the Quaternary in the Dead Sea Basin has been considered as resulting from climate-controlled runoff processes. Therefore, these laminae couplets represent seasonal variations and thus can serve as hydrologic gauges.
- We aim to exploit this “gauge” by analyzing the aragonite-detritus laminae couplets spanning the last 45 kyr (MIS3-MIS1) as identified in the ICDP Core 5017-1 from the Dead Sea depocenter.
- We discuss (i) forcing factors for the change in basin erosion and detritus lamina thickness, and (ii) implications of lamina thickness-frequency distribution for floods magnitude-frequency distribution during the last glacial and Holocene periods.

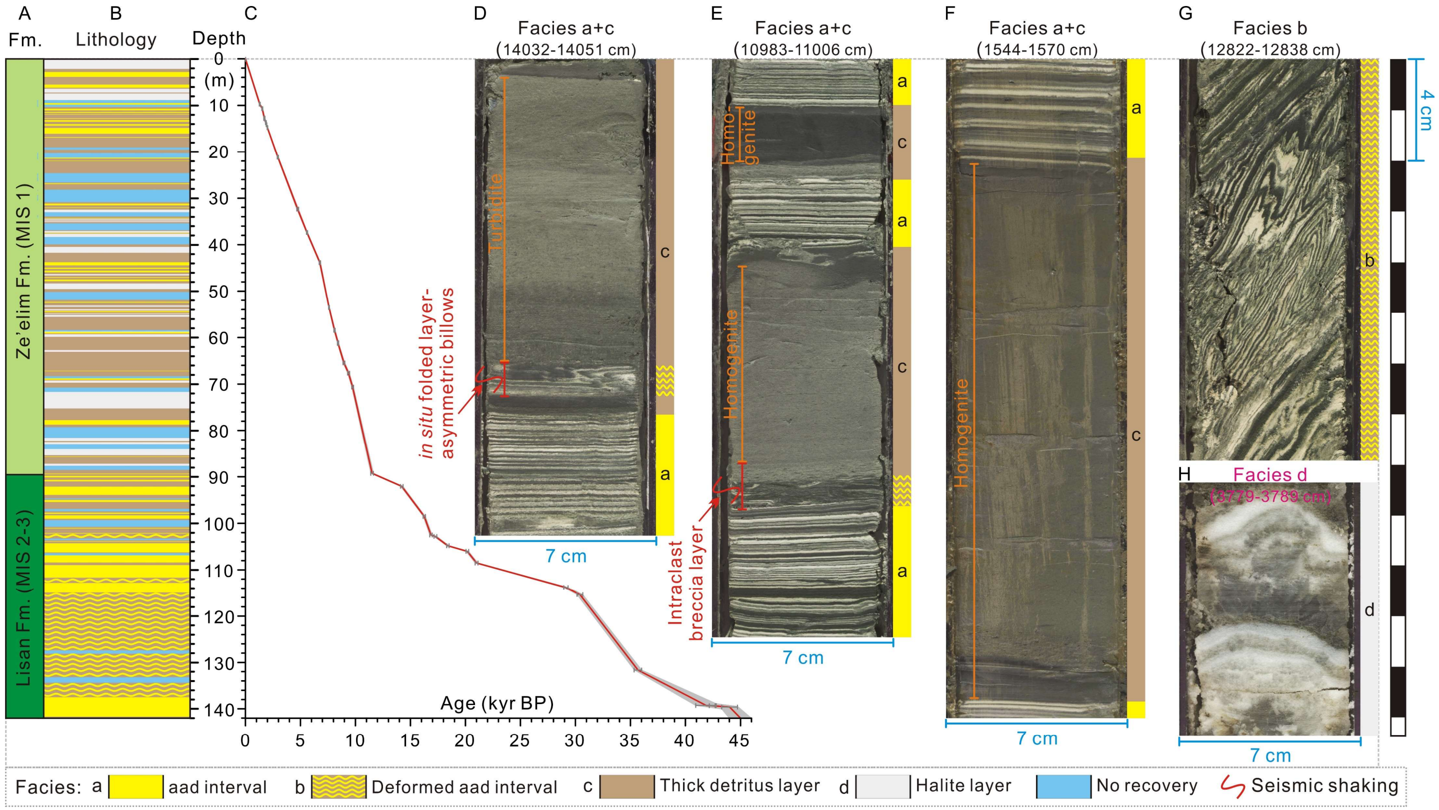
2. GEOLOGICAL SETTING



ICDP Core 5017-1:
a 457 m-thick
sedimentary sequence
from the Dead Sea center

Fig. 1. Geological setting of the Dead Sea drainage. A: Current precipitation (gray isohyet lines, in mm yr-1) (Enzel et al., 2003), vegetation zones (shaded areas) (Langgut et al., 2014), and Dead Sea tributaries (yellow lines) (Greenbaum et al., 2006) in the drainage basin; the blue shaded area within the drainage basin represents maximum extent of Lake Lisan (Bartov et al., 2002); PZ, Perazim Valley. B: Dead Sea bathymetric map (Sade et al., 2014); the blue lines mark the maximum extent of Lake Lisan; the red points mark places referred to this study.

3. MATERIALS & CHRONOLOGY



We focus on the uppermost 142 m of the core. The sedimentary sequence spans the last ~45 kyr (Fig. 2).

Fig. 2. Age-depth plot and basic facies of the studied interval in the ICDP Core 5017-1. A: Marine isotope stage (MIS) and formation (Fm.) of the studied core section. **B:** Generalized lithology column of the core section. **C:** Age-depth, which was plotted with thirty-two ^{14}C ages with 1σ error (Kitagawa et al., 2017) and one U-Th age with 2σ error (Torfstein et al., 2015). **D:** A combination of alternating aragonite and detritus laminae (*aad*) interval (bottom), seismic deformed *aad* (middle), and turbidite (top). **E:** A combination of aad interval, seismic deformed *aad*, and homogenite. **F:** A combination of *aad* interval and homogenite. **G:** Seismic deformed *aad* interval. **H:** Halite layer.

4. RESULTS & OBSERVATIONS

Lamina thickness and occurrence frequency during the past 45 kyr

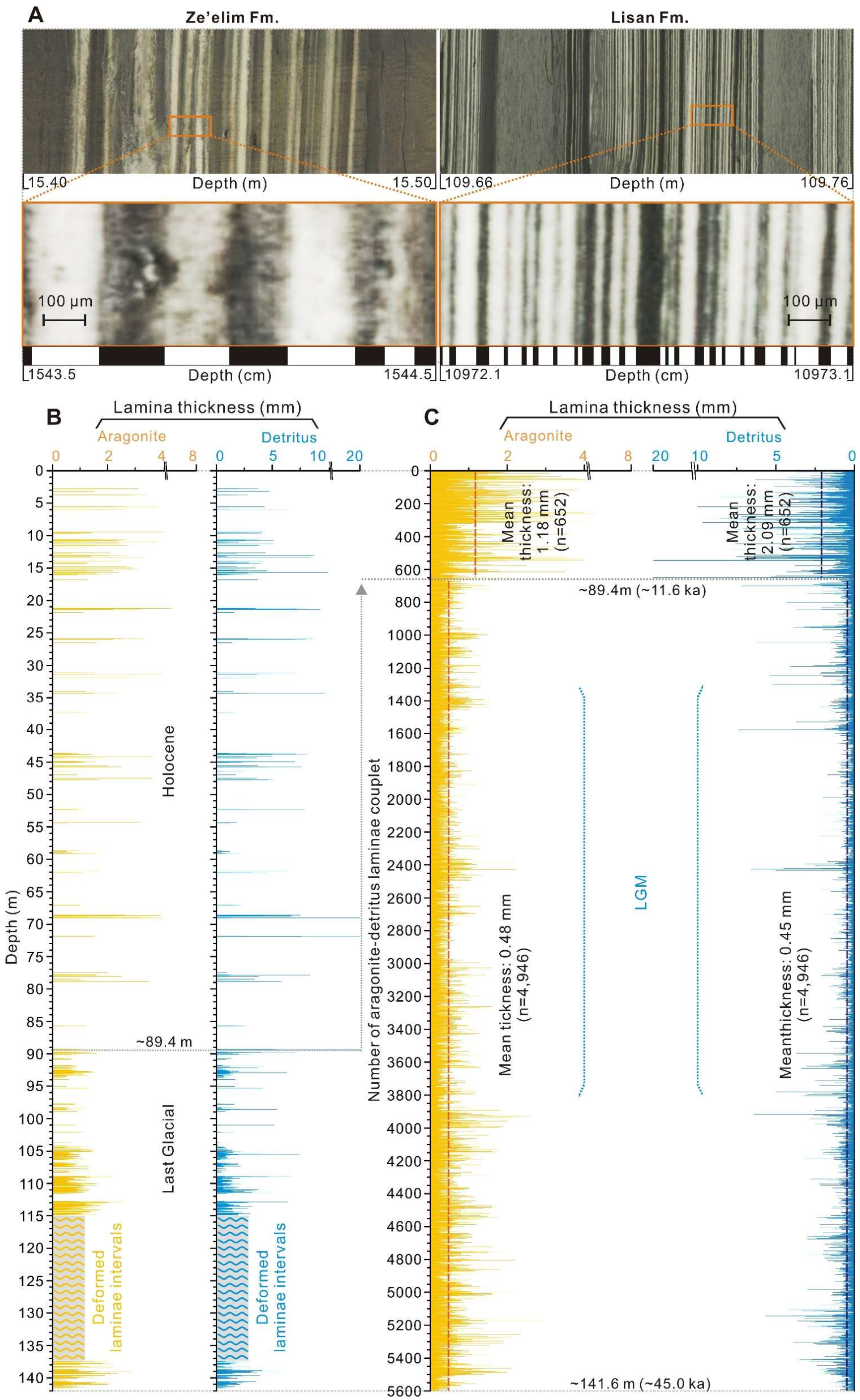


Fig. 3. The thickness of aragonite and detritus laminae in the studied section (~141.6-0 m, ~45.0 ka-Present) of the ICDP Core 5017-1. A: Thickness difference of aragonite and detritus laminae between the two different Fms. The white bars represent aragonite laminae; the black ones represent detritus laminae. **B:** Depth in the core to lamina thickness. **C:** Running number of laminae to thickness. n: number of measured laminae.

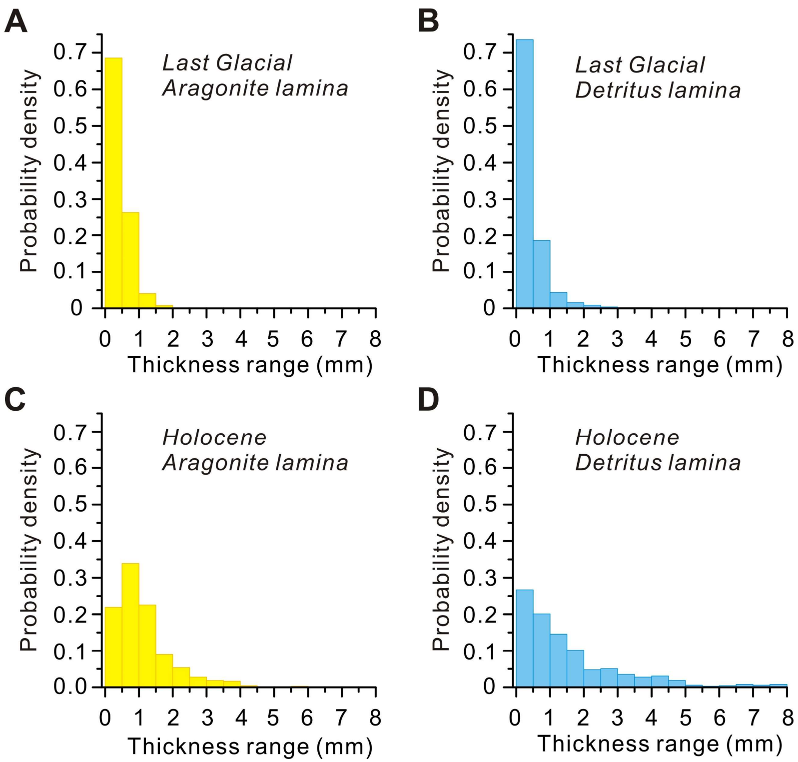


Fig. 4. Frequency of aragonite and detritus laminae with different thickness ranges in the ICDP Core 5017-1. A and B: Histograms for the occurrence of aragonite and detritus laminae during the last glacial. **C and D**: Histograms for the occurrence of aragonite and detritus laminae during the Holocene.

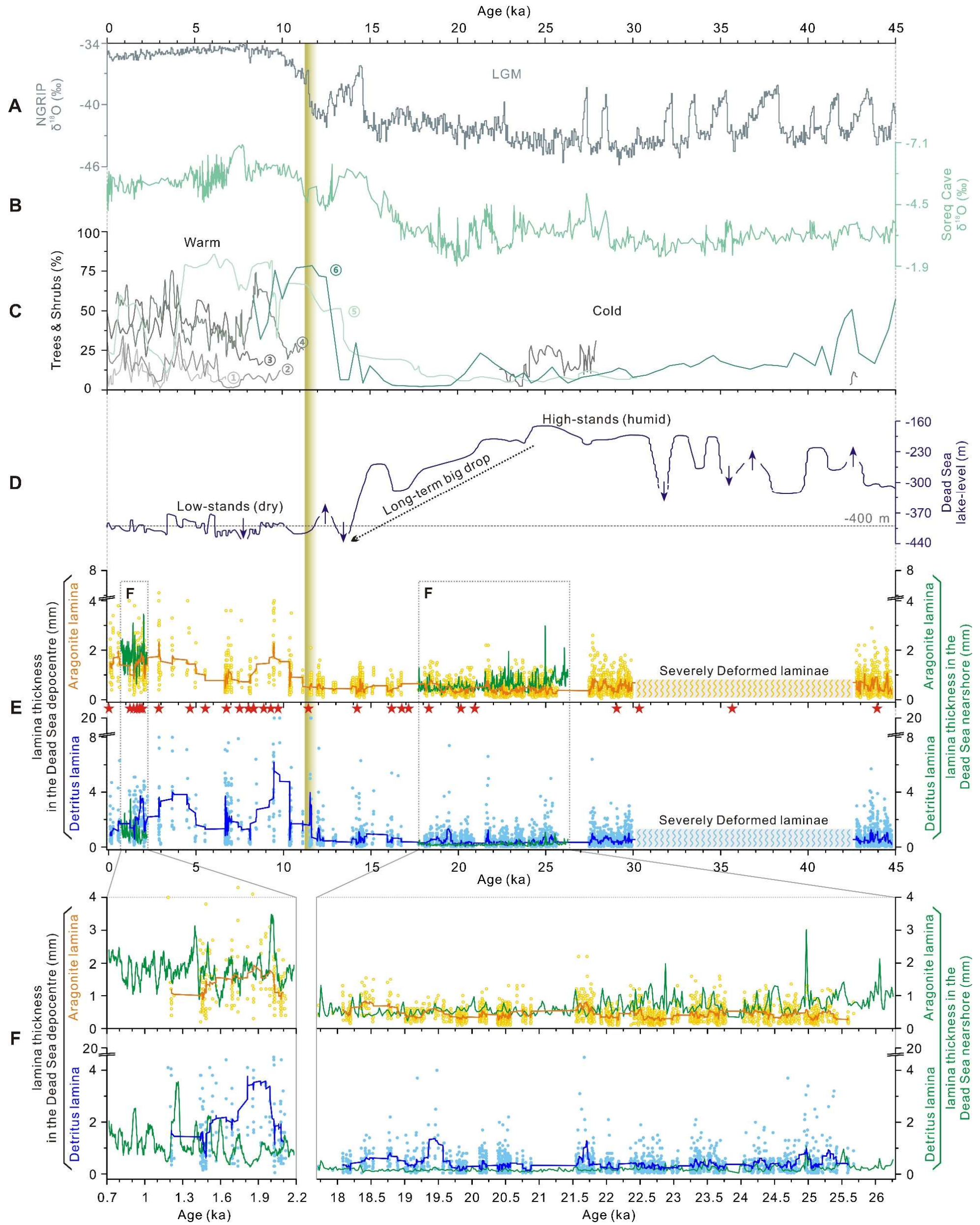
The aragonite-detritus laminae couplets are:

thinner and occur at high frequency during Last Glacial;

while they are much thicker and less frequent during the Holocene.

5. DISCUSSION

Fig. 5. Comparison of laminae record from the Dead Sea center with global (A) and regional climate proxies (B, C), Dead Sea lake-level (D), and laminae record from the lake margin (E, F). A: Greenland (NGRIP) (Andersen et al., 2004) ice core δ18O. B: δ18Ospeleo record (Grant et al., 2012) from Soreq Cave, Israel. C: Pollen data within and near to the Dead Sea watershed; the numbers of ① to ⑥ represent locations from south to north along the Dead Sea Rift: Ze'elim (Neumann et al., 2007), Ein Gedi (Litt et al., 2012), Sea of Galilee (Miebach et al., 2017; Schiebel and Litt, 2017), Lake Hula (van Zeist et al., 2009), Lake Birkat Ram (Schiebel, 2013) and Yammouneh, Lebanon (Gasse et al., 2011); the total percentage of trees & shrubs and herbs are 100%. D: Dead Sea lake-level (Torfstein et al., 2013). E: Comparison of lamina thickness from the Dead Sea center sedimentary sequence (yellow and blue colors, Core 5017-1) with nearshore sections (green color); the late Holocene (2.2-0.7 ka) and last glacial (26.2-17.7 ka) nearshore laminae records were recovered from Dead Sea Ein Gedi core (Migowski, 2001) and Massada outcrop (Prasad et al., 2004), respectively; the red stars mark the dated ages. F: Comparison of lamina thickness between the Dead Sea margins and center in both glacial (26.2-17.7 ka) and interglacial (2.2-0.7 ka) time periods.



Increase of erodible materials in the watershed during the last deglaciation (~22-11.6 ka)

- The aragonite-detritus laminae from the lake margins show the same thickness distribution pattern as in the lake depocenter (Fig. 5), which reflects a much higher sedimentation rate in the Dead Sea during the Holocene than during the last glacial.

- The source-to-sink process-linked sedimentation in the Dead Sea Basin depends mainly upon (1) availability of erodible materials and (2) capacity of fluvial transportation/rainfall intensity/discharge (e.g., Zhang et al., 2019).

- Significant lake-level drops, enhanced dust input, and low vegetative cover in the drainage basin during the last deglaciation (22-11.6 ka) have considerably increased erodible materials in the Dead Sea watershed.

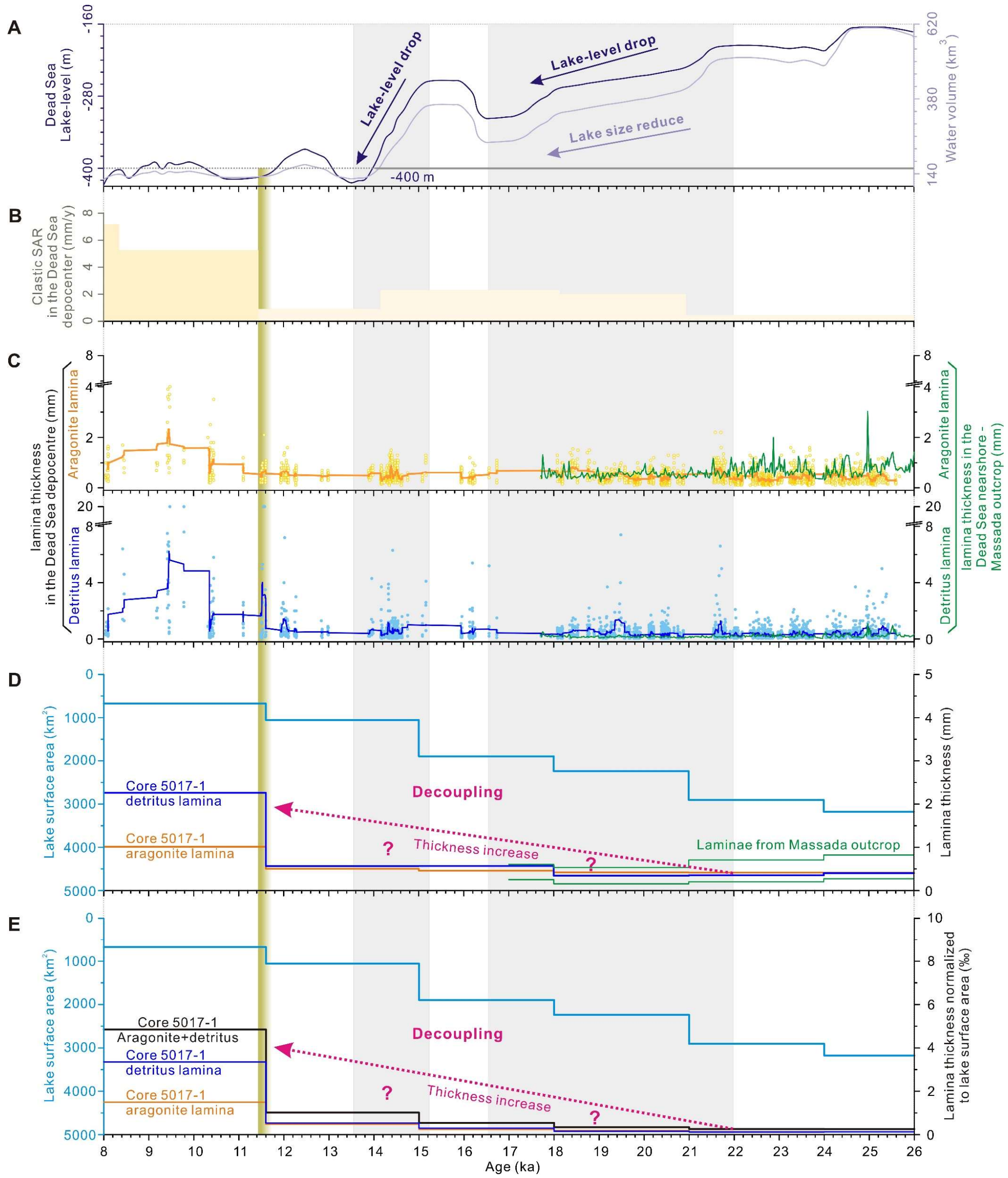


Fig. 6. Comparison of Dead Sea center and marginal laminae records (B-E) with Dead Sea lake-level and size changes (A) during 26-8 ka. A: The most significant lake-level drop and lake size reduction in the Dead Sea drainage basin during the past 45 kyr (Torfstein et al., 2013; Hall, 1996). B: Clastic (detritus laminae plus detritus layers) sediment accumulation rate (SAR) in the Dead Sea depocenter, based on Core 5017-1 (Lu et al., 2017b). C: Comparison of lamina thickness (21-points running average) change with significant lake-level and size changes during 26-8 ka; yellow and blue curves represent aragonite and detritus laminae from Core 5017-1, respectively; green curves represent aragonite and detritus laminae from the Dead Sea margin. D: Comparison of lamina thickness change with lake surface area change. E: Normalize lamina thickness to lake surface area. The “?” in (D) and (E) indicates no significant increase in lamina thickness during the two intervals of most significant lake-level drop/lake size reduction; the dashed magenta lines in (D) and (E) represent the expected change trend of lamina thickness if the thickness controlled by lake-level/size changes.

The lamina thickness is not controlled by lake level/size change

- It seems that the distribution pattern of lamina thickness and lake-level at glacial/interglacial timescale is in line with most literature have claimed that lake-level/size changes controlling the thickness of detritus lamina (Schramm, 1997; Prasad et al., 2004; Neugebauer et al., 2015; López-Merino et al., 2016).

- However, no apparent increase in lamina thickness is visible during the most significant lake-level drop and lake size reduction between ~22-11.6 ka (Fig. 6).

- Moreover, at the same time period, the change in lamina thickness does not follow the general trend of the lake-level/size changes.

- A gradual increase in lamina thickness from ~22 ka to 11.6 ka instead of only after ~11.6 ka should be noted if the lake-level/size changes controlling the lamina thickness (Fig. 6D, E).

Decoupling between significant lake level/size change and detritus lamina thickness during the last deglaciation

- Erodible materials in the Dead Sea watershed have considerably increased during the last deglaciation (~22-11.6 ka).
- However, the total clastic SAR remained low and no apparent increase in the thickness of detritus laminae during the time period.
- A decoupling existed between significant lake-level drop/lake size reduction and detritus lamina thickness during the last deglaciation (22-11.6 ka).
- A response lag cannot account for the decoupling.
- The decoupling implies the (suspended load) transport capacity of flash-floods is low and might be saturated by the oversupply of erodible materials during the time period. We suggest that this decoupling indicates a transport-limited regime.

Implications to floods recurrence

- Relative humid conditions in the region during the last glacial, as was denoted by high-stands of Lake Lisan (Stein et al., 1997; Bartov et al., 2002; Bookman et al., 2006; Rohling, 2013).

- Enzel et al. (2008) proposed that the three- to five-fold increase in inflow during the last glacial could have resulted from doubling mean annual rainfall in the Lake Lisan drainage area.

- Modeling response of soil erosion to changes in precipitation reveals that changes in rainfall intensity will likely have a greater impact on land surface erosion than simply changes in rainfall amount alone (Nearing et al., 2005).

- Field experiments in the Jordanian Plateau (Ziadat and Taimeh, 2013) and laboratory modeling (Defersha and Melesse, 2012) confirmed that sediment yield increased with rainfall intensity augmentation.

- Late Pleistocene erosion and deposition studies by Enzel et al. (2012) in Nahal Yael (southern Israel) also reveal that the intensity/frequency of extreme storms is a key factor for pulses of sediment delivery at millennial time scale.

Implications to floods recurrence

- Present-day meteorological data show that the frequency of rare floods in arid regions is much higher than in humid regions in the Dead Sea watershed (Ben-Zvi, 1988; Greenbaum et al., 1998).
- On a century time scale, late Holocene paleohydrological reconstructions for the western watershed of the Dead Sea reveals an increased frequency of large floods during eastern Mediterranean droughts (~2.9-2.6 ka) (Ahlborn et al., 2018).
- Moreover, in the southern watershed of the Dead Sea, observations show that higher intensity rainfall is associated with increased aridity during the late Holocene (Bull and Schick, 1979; Greenbaum et al., 2000).
- The increased frequency of high intensity rainfall, which are associated with increased aridity, most probably result from increased frequency of extreme localized Active Red Sea Trough associated rainstorms (Greenbaum et al., 2000; Ahlborn et al., 2018).
- In the Dead Sea region, high rain intensities with long recurrence intervals are more frequent as the climate becomes drier (Morin et al., 2009).
- Field observations in the Negev Highlands, southern Israel reveal that the significant climate shift during the Late Pleistocene/Holocene transition led to higher rainfall intensity, and thus generating stronger floods and extensive soil erosion since ~12 ka (Avni et al., 2006; Faershtein et al., 2016).

Implications to floods recurrence

- The higher occurrence frequency of aragonite-detritus laminae couplets during MIS2-3 (~45-11.6 ka) compared to the MIS1 (~11.6 ka-present) can be explained by the twofold mean annual rainfall and four to six times larger amount of annual runoff during the last glacial than the Holocene (Enzel et al., 2008).
- Therefore, we propose the thickness-frequency distribution of aragonite-detritus laminae couplets may indicate small-magnitude and high-frequency floods during a more humid last glacial period, and low frequency but large-magnitude floods during the arid Holocene.

5. CONCLUSIONS

- ✓ In the Dead Sea, the aragonite and detritus laminae are thinner and occur at high frequency during the Last Glacial, while they are much thicker and less frequent during the Holocene.
- ✓ The significant lake-level drops, enhanced dust input in the drainage system, and low vegetative cover in the drainage basin during the last deglaciation (22-11.6 ka) have considerably increased erodible materials in the Dead Sea watershed.
- ✓ A decoupling existed between the significant lake level/size change and lamina thickness change during the last deglaciation, and the lamina thickness is not controlled by the lake-level/size change during the last glacial and the Holocene. We interpret this decoupling implying the transport capacity of flash-floods is low and might be saturated by the oversupply of erodible materials during the time period.
- ✓ We suggest that the observed thickness-frequency distribution of aragonite-detritus laminae reflects the small-magnitude and high-frequency floods during the humid last glacial, and low frequency but large-magnitude floods during the arid Holocene.