Development of a precise age–depth model for the varved record of Lake Butrint (Albania): a reconstruction of environmental change in the central Mediterranean region during the last millennium

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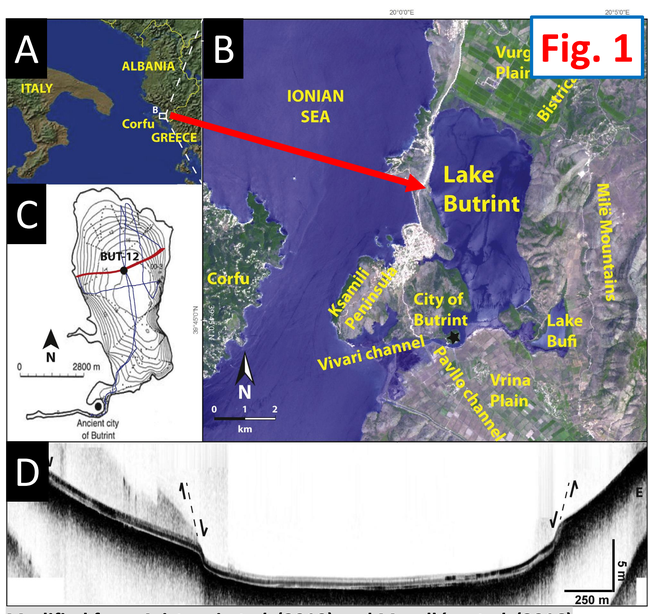
1. INTRODUCTION: The varved record of Lake Butrint



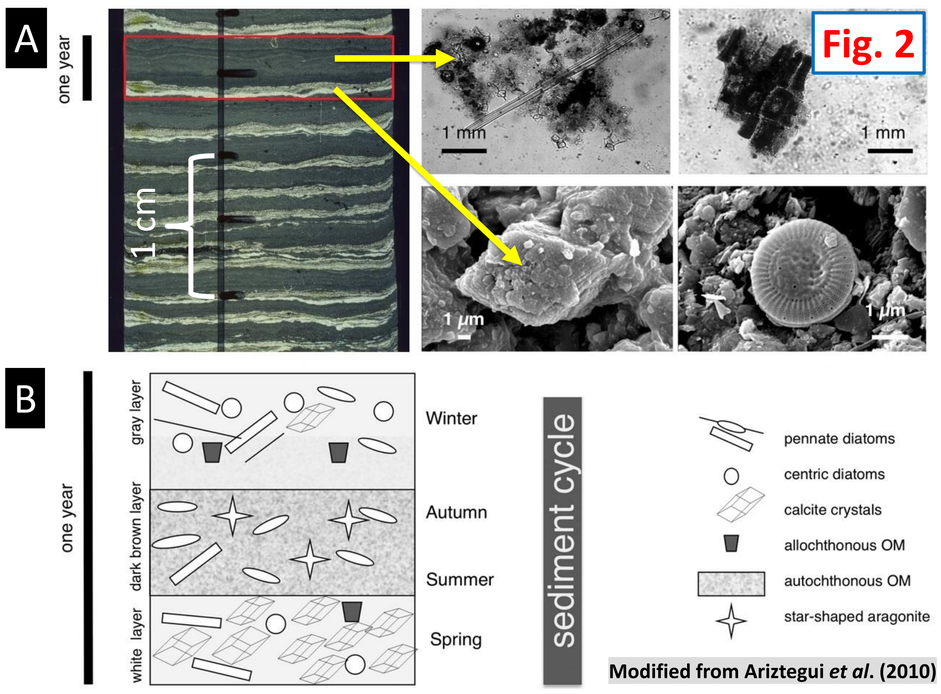
Modified from Ariztegui *et al.* (2010) and Morellón *et al.* (2016)

***FIGURE 1**: A) Regional setting of the study area; (B) Close-up of Lake Butrint; (C) bathymetric map with the location of the coring site BUT-12 (black dot), with the surveyed seismic grid (blue lines) and indication of the seismic profile displayed below (red line) and (D) W-E seismic profile of the lake basin.*

STUDY SITE:

Lake Butrint (39°47 N, 20°1 E) is a lagoon of tectonic origin located on the southern Ionian Sea coast of Albania (**Fig. 1**). The lake basin occupies a N-S extending graben structure formed during the Pleistocene, which has experienced subsidence until recent times and was invaded by Mediterranean Sea water during the Holocene transgression.

The sedimentary record of Lake Butrint provides an unique record of past hydrological changes in the Central Mediterranean region during the last millennia.



Modified from Ariztegui *et al.* (2010)

VARVED RECORD:

The relatively high water depth of the lake (ca. 21 m) and its progressive isolation from the sea has led to permanent water stratification, allowing the deposition of varved sediments formed by seasonal laminae (Zolitschka, 2007):

- endogenic calcite
- organic matter
- clay

during the last millennia (**Fig. 2**). Occasionally, the white carbonate pure component is missing.

***FIGURE 2**: A) High-resolution photograph of a thin section with crossed nicols showing a laminated section. The main components of each lamina are amorphous and refractive organic matter (top left and right images, respectively); and SEM microphotographs exhibiting a crystal of an authigenic carbonate and a centric diatom (bottom left and right images, respectively). B) Schema showing the interpreted annual cycle as recorded in each ideal varve for the most recent sediments.*

2. METHODS AND RESULTS: An annually-resolved age-depth model

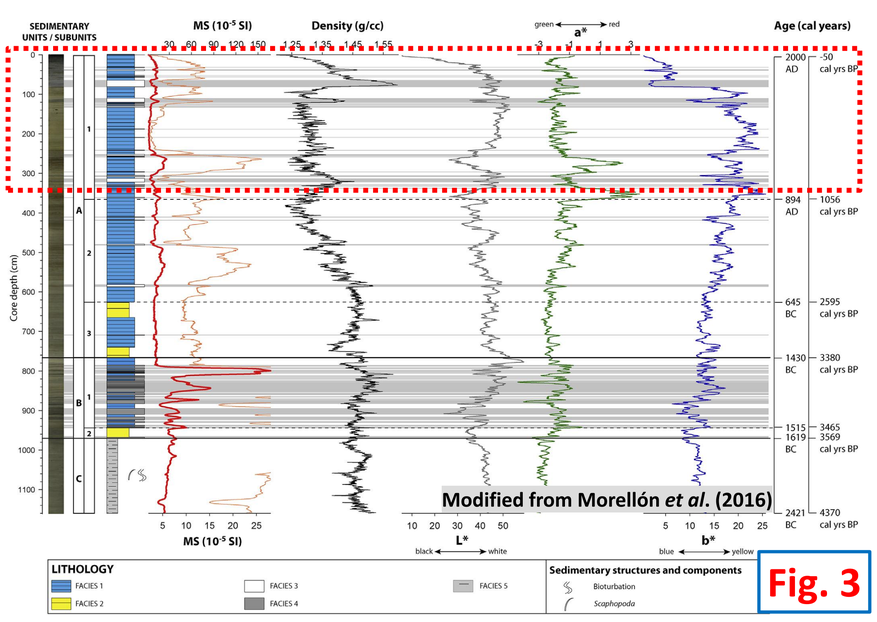


***FIGURE 3**: Physical properties and chronological scale (in cal years AD/BC) for the composite sequence of the Lake Butrint record.*

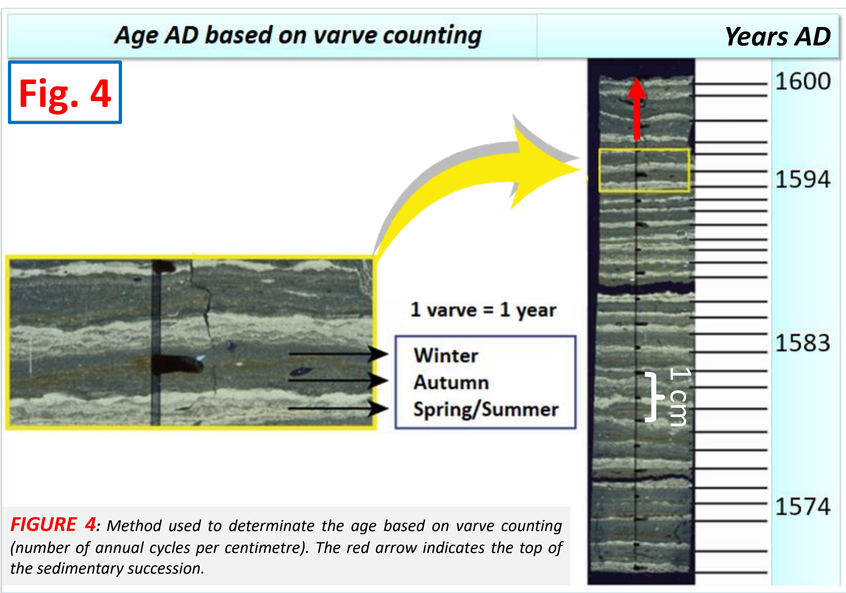


***FIGURE 4**: Method used to determinate the age based on varve counting (number of annual cycles per centimetre). The red arrow indicates the top of the sedimentary succession.*

VARVE COUNTING:

- The uppermost 350 cm of core BUT-12 (**Fig. 3**) was selected for this high-resolution study due to the good preservation of the laminae. Large format thin sections (100×15×35 mm) were prepared using the freeze-drying technique and subsequent impregnation with epoxy resin (Araldite®) under vacuum conditions (Brauer and Casanova, 2001).
- The varve counting of the uppermost ca. 3.5 m of a 12 m long sediment core, through the petrographic analysis of thin sections (**Fig. 4**), enabled the construction of an annually-resolved age-depth model (**Fig. 5**) for the last millennium, supported by radiocarbon and ^{137}Cs dating (**Fig. 6**), as well as the location of homogenites formed by mass-wasting activity associated to well-dated, historical earthquakes. The comp. depth doesn't consider the homogenites to be associated to instantaneous events.

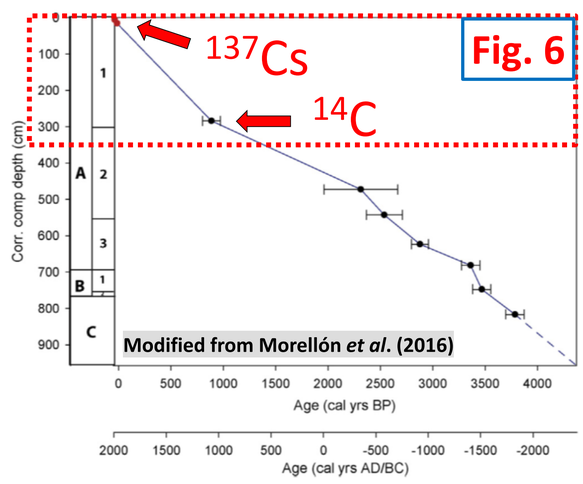


***FIGURE 6**: Chronological model for the event-corrected (i.e., without homogenites) depth scale of the sequence, based on the linear interpolation of calibrated radiocarbon dates and maximum ^{137}Cs peaks. Sedimentary units and subunits are represented at the left side of the figure.*

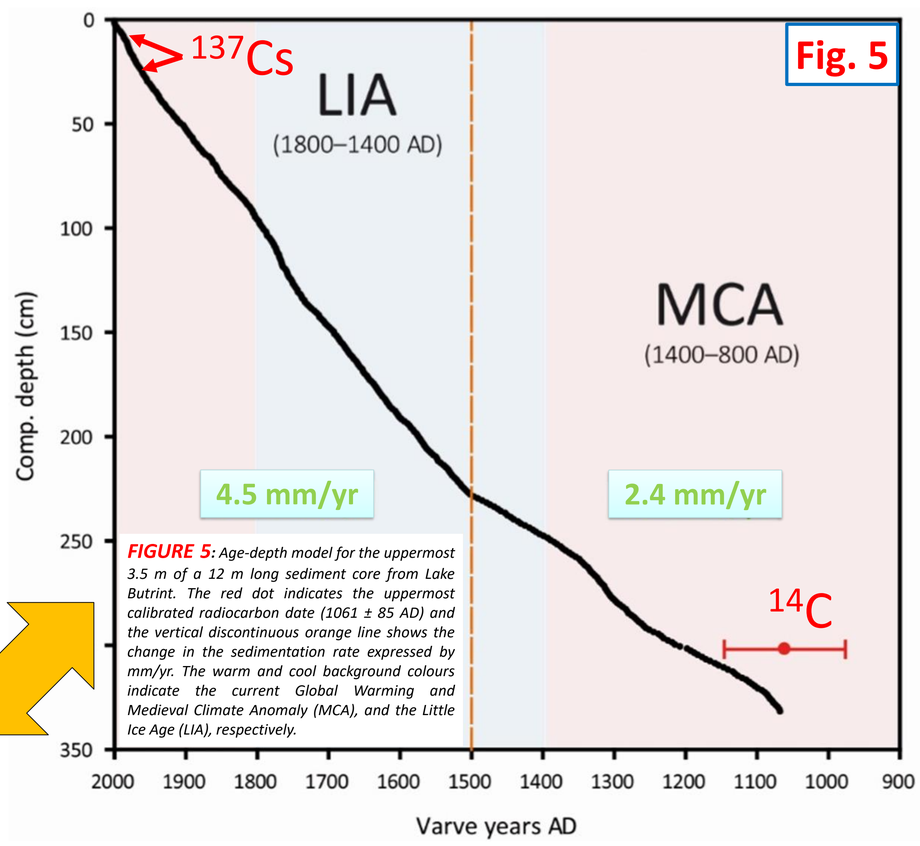


***FIGURE 5**: Age-depth model for the uppermost 3.5 m of a 12 m long sediment core from Lake Butrint. The red dot indicates the uppermost calibrated radiocarbon date (1061 ± 85 AD) and the vertical discontinuous orange line shows the change in the sedimentation rate expressed by mm/yr. The warm and cool background colours indicate the current Global Warming and Medieval Climate Anomaly (MCA), and the Little Ice Age (LIA), respectively.*

AGE-DEPTH MODEL:

- **Lower sedimentation** rate (**2.4 mm/yr**) between 1000 and 1500 AD:
  - Continuous presence and relatively high thickness of calcite laminae
  - Arid conditions (maximum water salinity and higher bioproductivity)
  - Medieval Climate Anomaly (800-1400 AD)
- **Higher sedimentation** rate was (**4.5 mm/yr**) between 1500 and 2000 AD:
  - Thicker clay-rich and thinner calcite laminae
  - More humid conditions (lower salinity and higher runoff)
  - Little Ice Age (1400-1800 AD)
- The **highest sedimentation rates** (**4.7 mm/yr**) after 1800 AD:
  - It may be due to an increasing human activity

3. CONCLUSIONS

CONCLUSIONS:

- The **annually-resolved age-depth model** for the last millennium enables discussion on the **changes** of **microfacies** in relation with **hydrological variability**.
- **Variations** in the **presence and/or thickness** of **different laminae** indicate **fluctuations** in water salinity, bioproductivity, and runoff, **resulting** from the **interplay** of **climate variability** and **fluctuating human activity**.
- The **annually-resolved sedimentary record of Lake Butrint** provides a detailed **reconstruction of the climatic evolution** of the **Central Mediterranean** region during the **last millennium**.

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