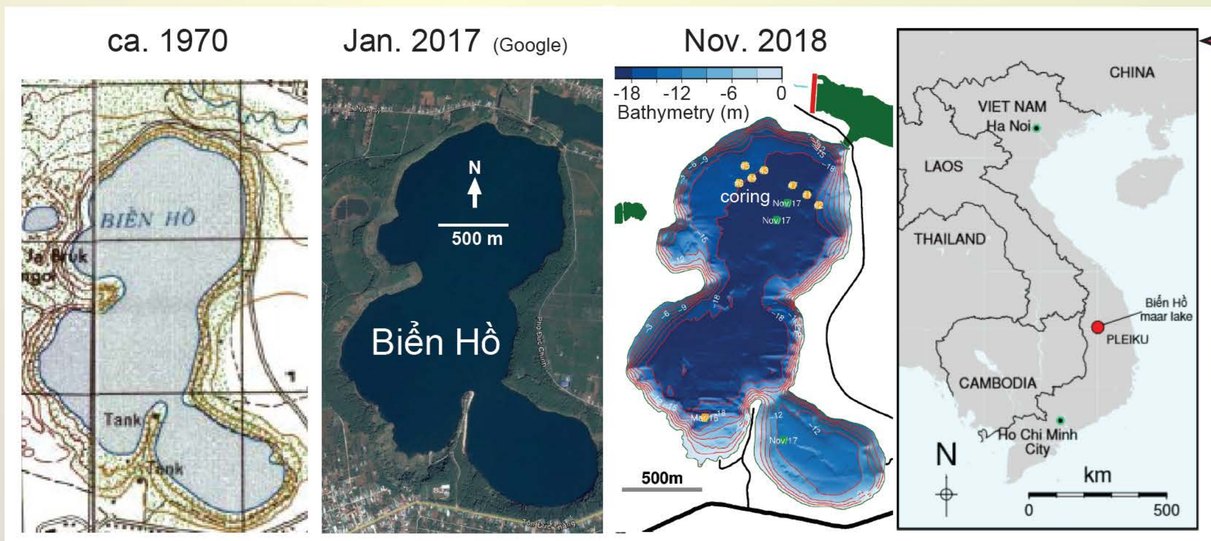
Laminated sediment archives from Biển Hồ maar lake in the Central Highlands, Vietnam, as a recorder of Holocene hydroclimatic variability

Arndt Schimmelmann[1], Hướng Nguyễn-Văn[2], Dương Nguyễn-Thùy[2a], Ingmar Unkel[3], Jan P. Schimmelmann[4], Kelsey Doiron[1], Antti E.K. Ojala[5], Peter E. Sauer[1], Agnieszka Drobniak[6], Thái Nguyễn-Đình[2], Dương Nguyễn-Thùy[2b], Nguyệt Thị Ánh Nguyễn[2], Quốc Đỗ-Trọng[2], Hồng Nguyễn-Thị[2], Hoàng Vũ[2], Minh Ngọc Schimmelmann[1]

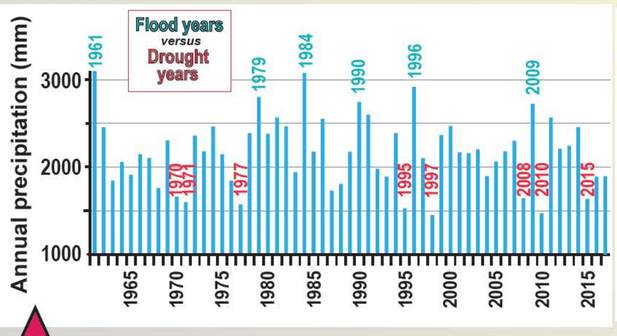
[1] Indiana University, Department of Earth and Atmospheric Sciences, 1001 10th Street, Bloomington, Indiana 47405, USA
[2] EOS Research Group, Faculty of Geology, [a] Mineralogy, [b] Palynology, VNU University of Science, 334 Nguyễn Trãi Street, Hà Nội, Việt Nam
[3] Institute for Ecosystem Research, Christian-Albrechts-Universität zu Kiel, D 24118 Kiel, Germany
[4] University of Bremen, Institute of Geography, Celsiusstrasse 2, D 28359 Bremen, Germany
[5] Geological Survey of Finland, Betonimiehenkuja 4, FI 02150 Espoo, Finland
[6] Indiana Geological and Water Survey, Indiana University, 611 N. Walnut Grove Avenue, Bloomington, IN 47405-2208, USA

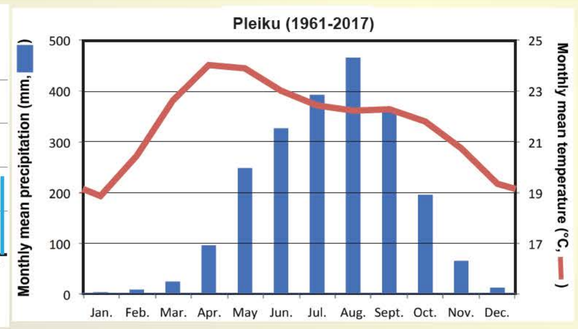


① Introduction

Global warming increases atmospheric humidity and will likely affect the East-Asian monsoon system across Vietnam. It is essential to understand the long-term regional climatic variability to properly evaluate present and potential future trends along global climate change. Sediments from maar lakes can provide long-term paleoenvironmental records. Biển Hồ maar in central Vietnam offers an archive of erosion from a small catchment that had been limited to the interior of volcanic craters until in 1983 a dam (red bar on bathymetric map) established a reservoir to the northeast.

View from NNE over the maar (**A**). A peninsula (**B**) separates two sub-basins. Dam (**C**) caused the filling of the reservoir (**D**) that seasonally spills turbid water through a breach (**E**) into the maar. Water can exit through an emergency overflow (**F**), a hydroelectric power plant (**G**), an overflow channel (**H**), and pumping stations near (**B**) and (**I**).



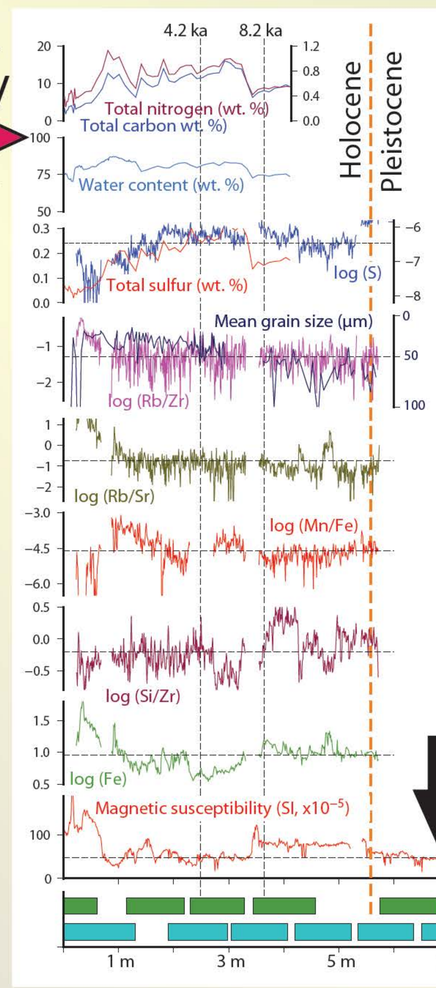


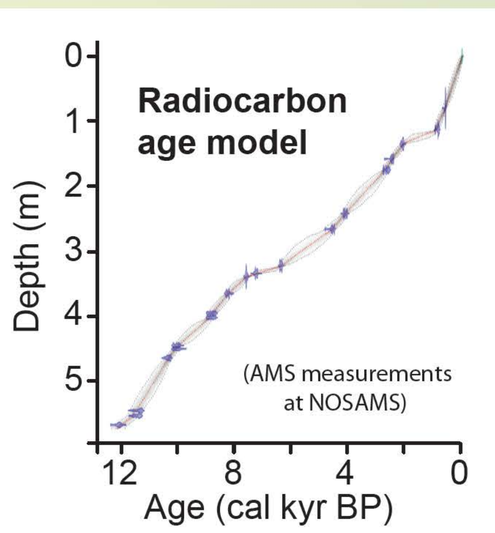
② Local climate time-series

Instrumental records from Pleiku from 1961 to 2017 indicate seasonal monsoonal rainfall peaking in August, and strong interannual variability in rainfall. Historical floods and droughts date back to 1961.

③ Prelimin. sedimentary records

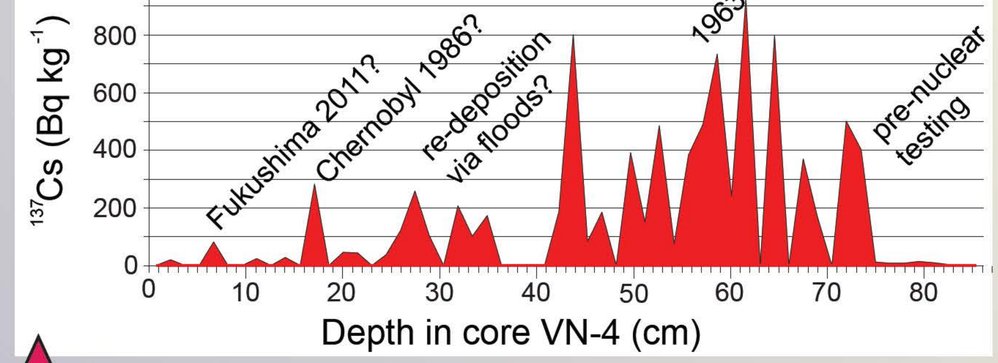
Preliminary data series mainly cover the top 6 m, whereas data for deeper sediment and repeat data from parallel cores are in progress. Modern and pre-1900 AD sediment differs in many ways due to recent changes in land use. The Holocene record documents significant changes in chemical composition that require additional data for interpretation. Biomarker, pollen, and thin-section data are expected for 2019. Sediment trap data with semi-annual resolution (wet *versus* dry parts of the year) have been collected since late 2017 to help interpreting the laminated sediment record.





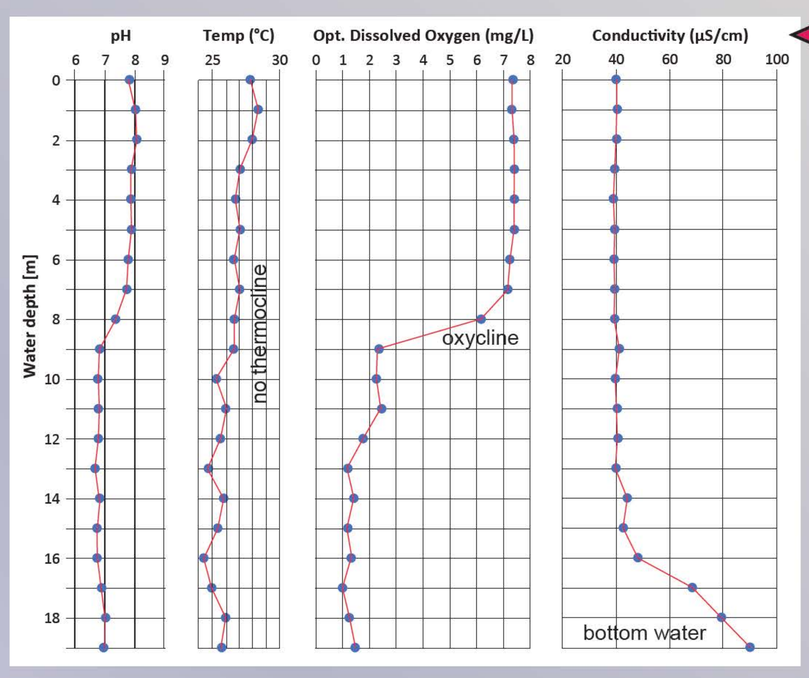
Fossil leaves yielded ^{14}C dates, e.g. 12 ka cal BP at ca. 6 m depth. Dates from up to 15 m are pending.

Since 2016, we recovered many gravity, piston, and freeze cores that reach as deep as ca. 15 m.



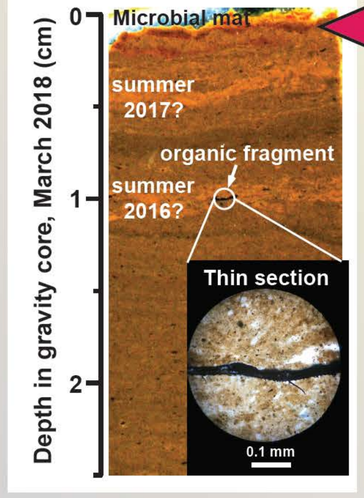
④ ^{137}Cs dating

Despite limited airborne fallout in Vietnam from nuclear testing and accidents, we tentatively identified events. Low ^{137}Cs below ca. 75 cm depth dates to the 1950s before nuclear testing. Some later peaks may result from monsoonal erosion along the crater rim and redistribution of ^{137}Cs during environmental degradation and high sedimentation.



⑤ Water column

In November 2018, analytical profiling of the water column did not identify a thermocline, but marked an oxycline at ca. 8 m water depth. Water at 19 m depth contained traces of hydrogen sulfide. Bottom water was turbid and dark (viewed with a GoPro underwater camera) and showed elevated conductivity. Euxinia excluded macrobenthos and preserved lamination. Inspection of the benthic environment with a GoPro in January 2017 indicated that light could reach the lake bottom. We suspect that annual nepheloid layers from the monsoon season deposit their particulates by year's end.



⑥ Spurr-epoxy-impregnated slab

A short slab from a March 2018 core was embedded in Spurr epoxy resin, milled and polished. Orange laminae are iron (III)-rich summer deposits. Ages are preliminary.

⑦ Recent environmental changes

Images from the 1960s show exposed terraces at low water level in the southeastern part of the maar. In 1983, a new reservoir to the northeast began spilling into the maar lake and raised the maar's water level. Reforestation and protection improved the maar's environment after 1990.

⑧ Conclusions

The sedimentary archive in Vietnam's Biển Hồ maar extends deep into the Pleistocene. Maar lakes with suboxic bottom waters may offer well-preserved laminated sediments with paleoenvironmental information, including a record of monsoon-related flood layers. The anthropogenically influenced last few decades of lake history can provide proof-of-concept when interpreting earlier flood layers of similar composition. Similarly, the recent reforestation efforts around the maar crater's rim offer a test case for evaluating vegetation dynamics and pollen accumulation in relation to rapid environmental change. In addition to Biển Hồ maar, the region offers many other maars with potentially valuable paleoenvironmental records.