ICDP project DeepCHALLA: reconstructing East African climate change and environmental history over the past 250,000 years

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Summary

Sediments on the bottom of Lake Challa, a 92-meter deep and meromictic crater lake on the border of Kenya and Tanzania near Mt. Kilimanjaro, contain a uniquely long and continuous record of past climate and environmental change. The near-equatorial location close to the Indian Ocean coast and exceptional quality of this natural archive provide great opportunities to study tropical climate variability at both short (inter-annual to decadal) and long (glacial-interglacial) time scales, with the latter relatively unaffected by the history of northern high-latitude glaciation (**Figures 1-3**); and the influence of this climate variability on the region's freshwater resources, terrestrial ecosystem functioning, fire regimes and the history of the East African landscape in which modern humans (our species, *Homo sapiens*) evolved and lived ever since.

Supported by the International Continental Scientific Drilling Programme (ICDP) and by funding agencies and universities in 12 countries including Kenya and Tanzania (see logo's below), the DeepCHALLA project has now recovered the sediment record of Lake Challa down to 214.8 meter below the lake floor, with 100% cover of the uppermost 121.3 meter (~160,000 years BP to present) and ~85% cover in the lower part of the sequence, down to the lowermost distinct reflector in the seismic stratigraphy (**Figures 4-6**). This reflector represents a layer of volcanic sand and silt deposited ~260,000 years ago, and overlies still older but largely unsampled silty lacustrine clays deposited during early lake development. Down-hole logging produced continuous profiles of in-situ sediment composition that confer an absolute depth scale to both the recovered cores and their three-dimensional representation in seismic stratigraphy.

Lake Challa sediments are finely laminated throughout most of the recovered sequence, up to the present-day sediment-water interface (**Figures 7-8**), implying that even during past episodes of extreme drought (e.g., the Last Glacial Maximum, Heinrich events and MIS5 'African megadroughts'), Lake Challa was sufficiently deep to maintain a (near–permanently) anoxic lake bottom. In its sediment record, long sections with distinct regular varves alternate with less repetitive and/or more wavy lamination. They are occasionally interrupted by event deposits such as turbidites reflecting failure of basin-peripheral slopes, more local sediment slumping; as well as by multiple tephra horizons and fish carcasses (**Figure 9**).

The continuity and exquisite time resolution of the Lake Challa sediment record combined with good prospects for absolute dating (**Figure 6**) promises to greatly increase understanding of tropical climate and ecosystem dynamics, creating a long-awaited equatorial counterpart to the high-latitude climate records extracted from the ice sheets of Greenland and Antarctica.

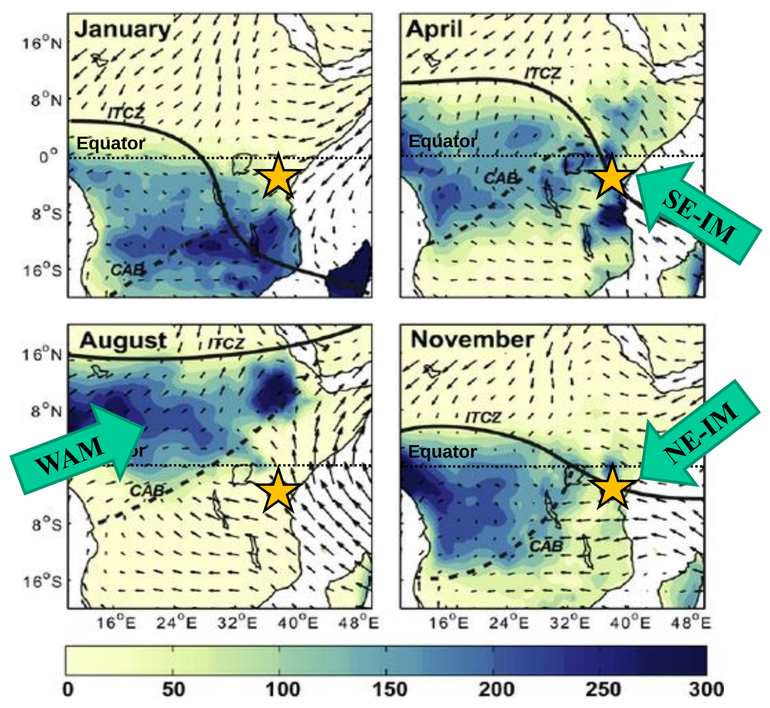

Figure 1. Present-day synoptic climatology. Lake Challa is located in easternmost equatorial East Africa, always east of the Congo Air Boundary (CAB) and therefore starved of westerly flow bringing moisture derived from the tropical Atlantic Ocean (WAM = West African Monsoon). Seasonal migration of the Intertropical Convergence Zone (ITCZ) between the NH and SH covers 33° latitude, resulting in two rain seasons (MAM and OND) and two dry seasons (JJAS and JF). SE-IM and NE-IM are the southeasterly and northeasterly Indian Monsoon, respectively. Modified from Tierney et al.(2011) *Quat. Sci. Rev.*

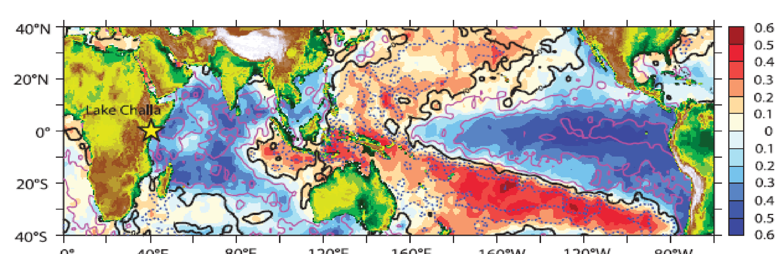

Figure 2. Correlation between November NCEP–NCAR wind-speed anomalies at Lake Challa and November Hadley Centre sea-surface temperature (HadISST1) anomalies in the tropical Indo-Pacific oceans (1948-2011). Positive/negative wind/rainfall anomalies near Lake Challa are significantly correlated with La Niña and a negative Indian Ocean Dipole. From Wolff et al. (2011) *Science.*

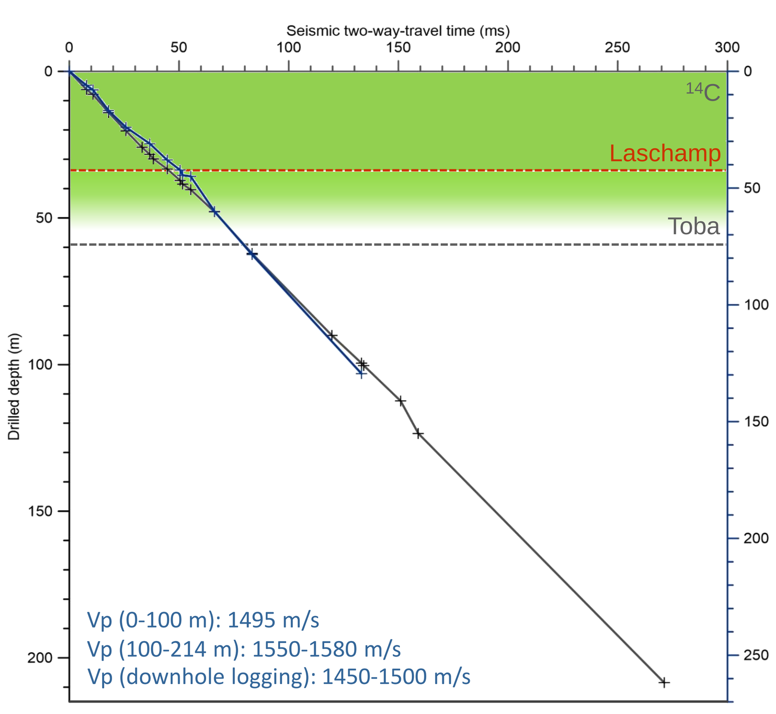

Figure 6. Preliminary age model for the DeepCHALLA composite core based on i) tie points between sedimentary features (mostly turbidites) and the age model for the 140-ka period based on seismic stratigraphy (Moernaut et al. 2011 *EPSL*); and ii) the near-constant sonic velocity (Vp) implied by that cross-correlation and measured in down-hole logging, both indicating very little compaction with increasing depth.

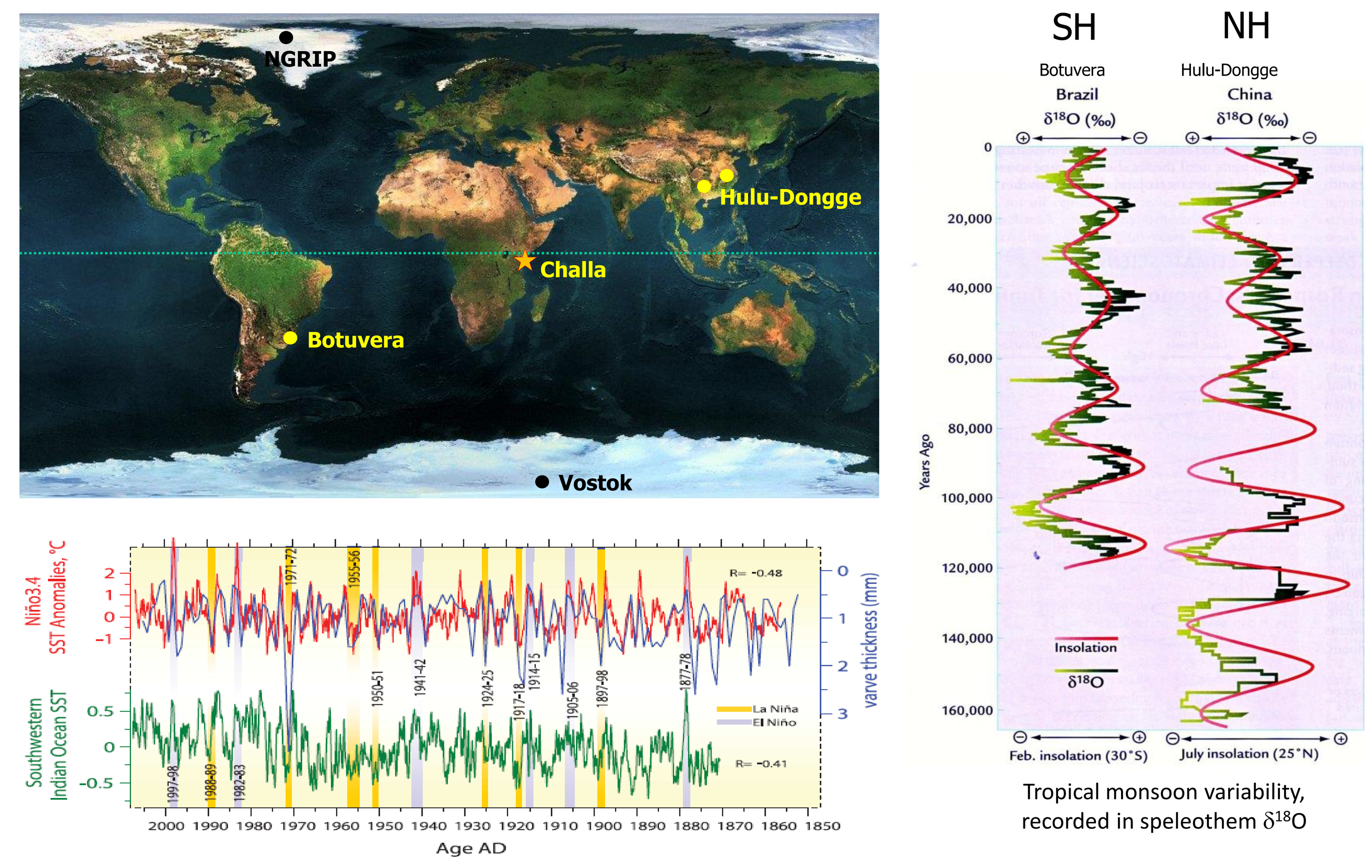

Figure 3. Long- and short-term paleoclimate context. **Top panel**: Given the region's relative isolation from Atlantic Meridional Overturning Circulatio (AMOC; cf. Figure 1) and strongly bimodal rainfall regime, Lake Challa is ideally located to document how equatorial climate history is shaped by the interaction between NH and SH monsoon systems (**right panel**), with minimum imprint of long-term variation in northern high-latitude glaciation. Expanded from Ruddiman (2007) *Earth's Climate: Past and Future.* **Bottom panel:** Inverse correlation between Lake Challa varve thickness (blue line) and both averaged western Indian Ocean HadISST anomalies (green line) and the Niño3.4 index (red line; cf. Figure 2). From Wolff et al. (2011) *Science*.

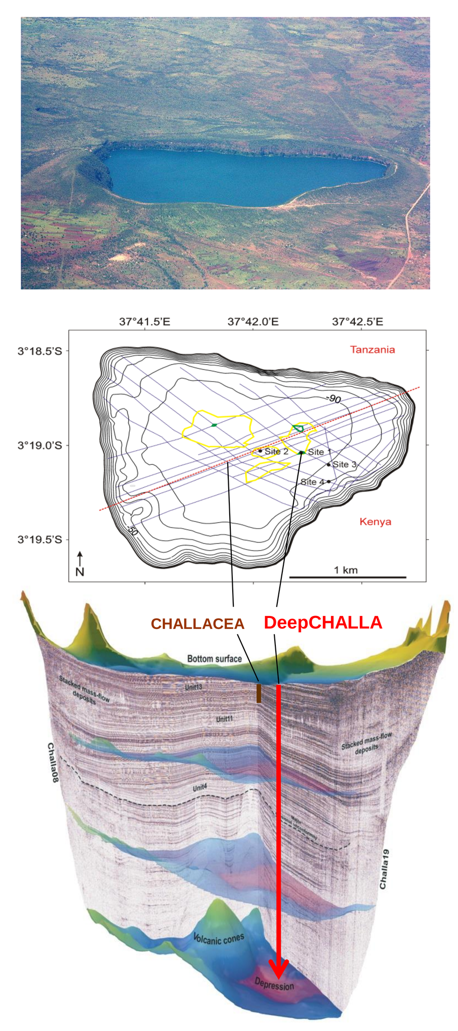

Figure 4. **Top to bottom**: Oblique aerial view of Lake Challa and its steep-sided crater basin from the south. Bathymetry with Geopulse 3.5-khz seismic-profiling grid and core sites of the CHALLACEA and DeepCHALLA projects. Drill depths of both projects set in a 3-D reconstruction of the crater basin infill based on seismic profiling.

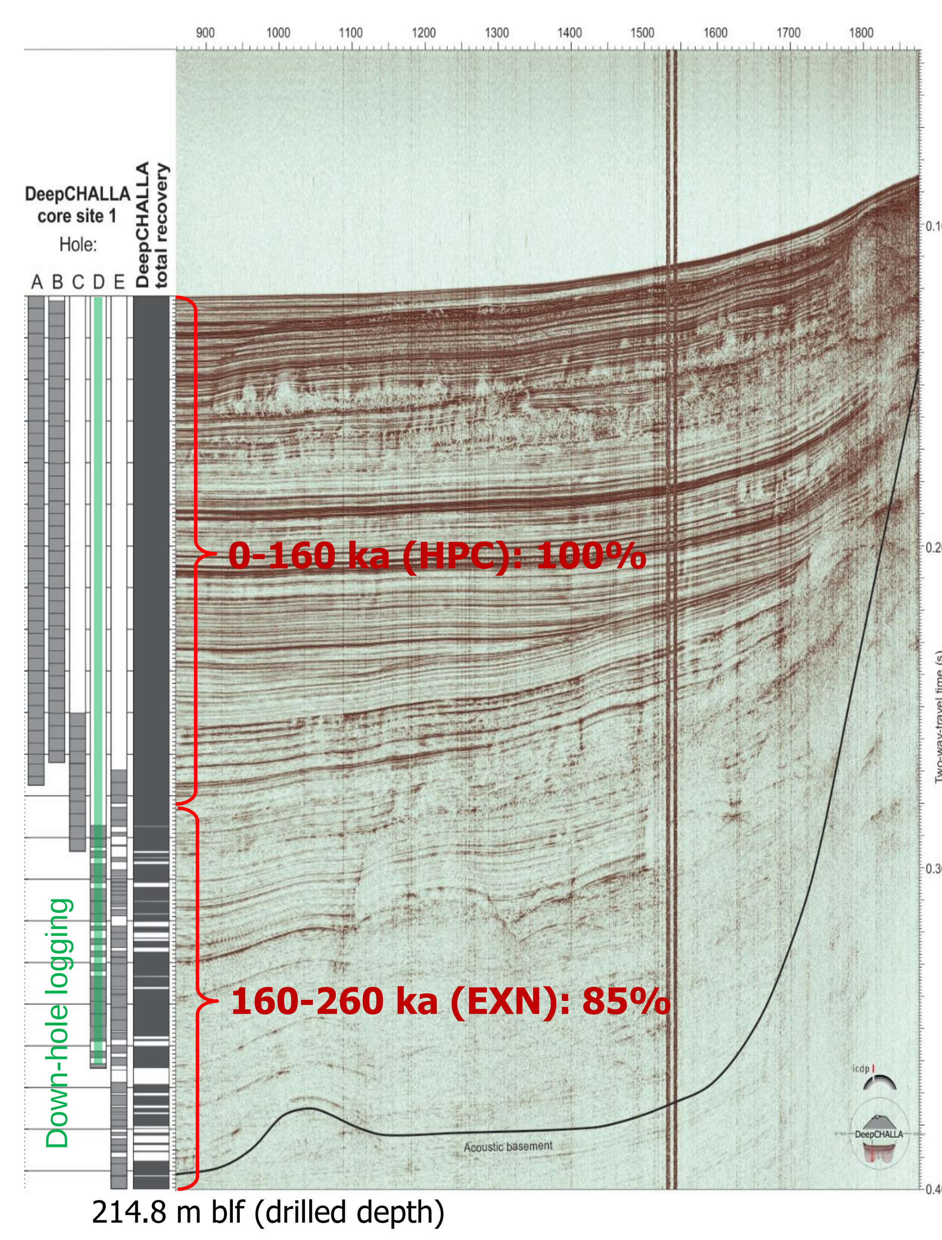

Figure 5. Seismic stratigraphy along a cross section running ENE from core site 1 towards the basin periphery, with indication of successive section depths drilled in holes A-B (HPC) and C-E (EXN), the down-hole logging performed in hole D, and total composite recovery.

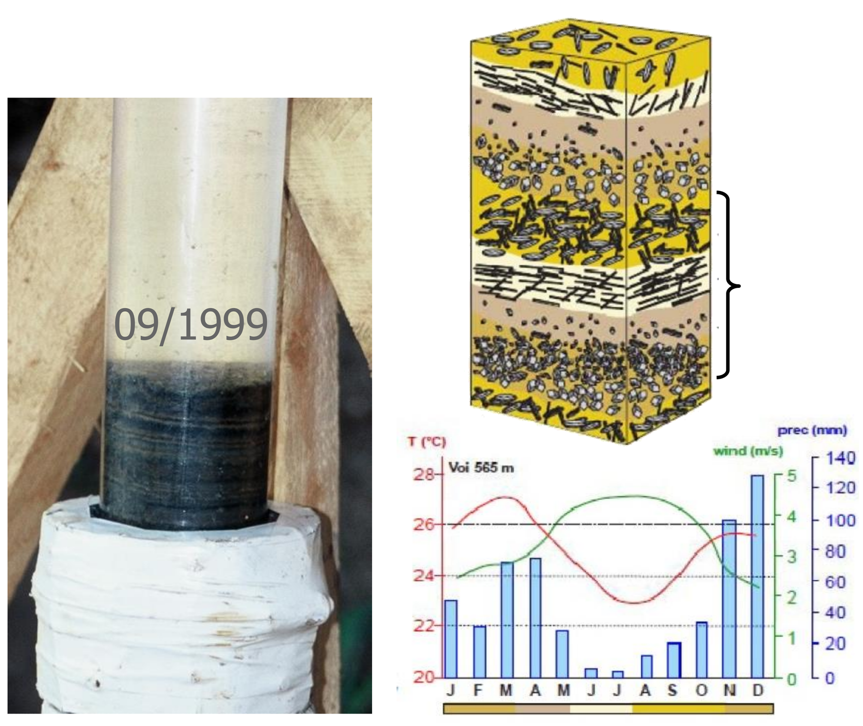

Figure 7. **Left**: Sediment-water interface of gravity core CH99-1G, recovered in September 1999. **Top right**: Schematic representation of 4-layered varve structure comprised of calcite crystals (orange), clay with aquatic (algal and cyanobacterial) organic matter (mustard), *Nitzschia* diatoms (beige) and *Afrocymbella* diatoms (yellow). **Bottom right**: Seasonal variation in mean temperature, rainfall (mm/month) and wind plotted above the seasonal succession in settling particles, as recorded in a sediment trap; colour codes as in top right panel.

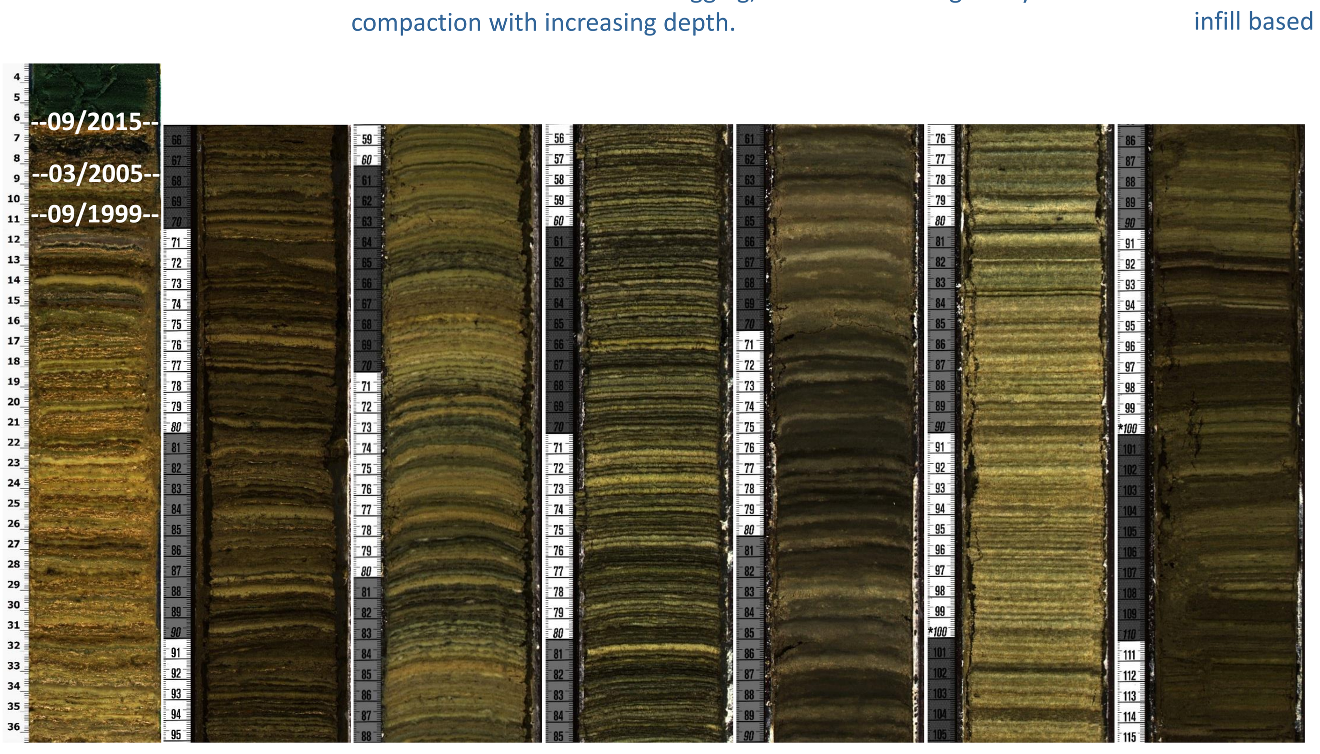

Figure 8. Representative selection of a gravity core (G) and six core sections recovered using the HPC (H) or ETN (E) coring tool, showing continuous fine lamination of either clear annual varves (1B-15H-1, 1D-17E-2) or less repetitive wavy layering (1A-30H-3) or a combination of both (1B-12H-3). 'CD' = approximate composite depth; 'ka' = 1000s of years BP.

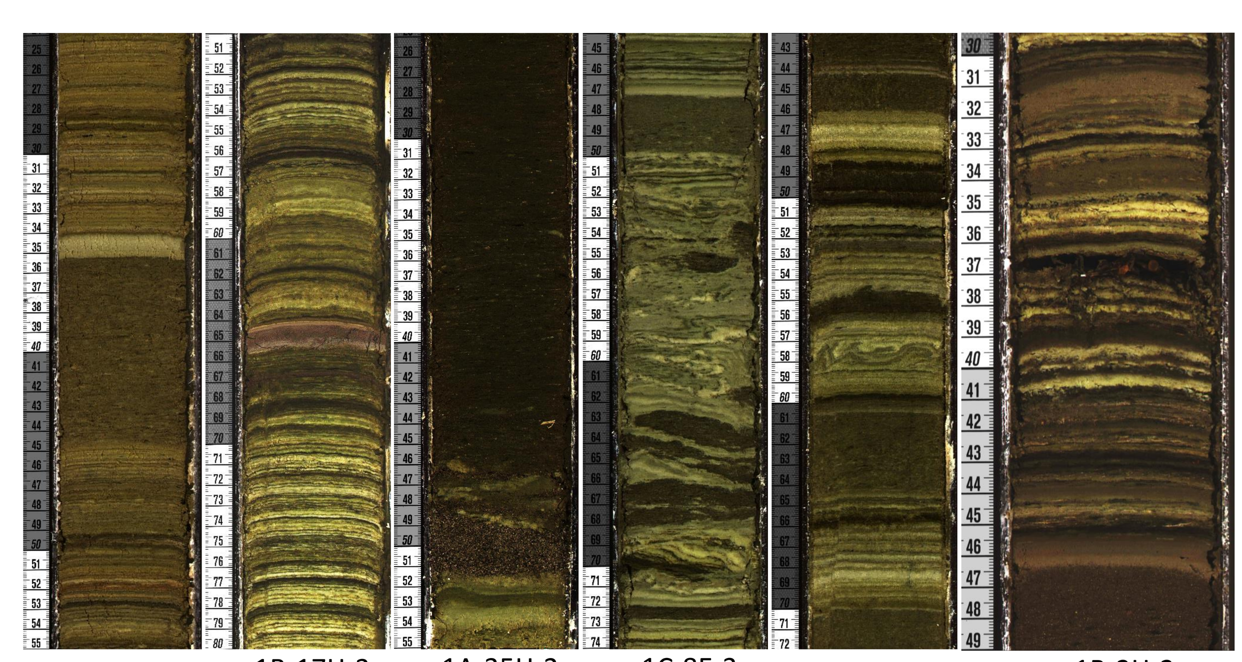

Figure 9. Core sections with event deposits. **From left to right**: non-erosive turbidite (34-44.5 cm) capped by a layer of pale-colored diatoms; tephra horizon (64-65 cm); coarse sand (49-51.5 cm) at the base of erosive mega-turbidite; local slump deposit (50-71 cm) capped by non-erosive turbidite (46.5-50 cm); thin local slump deposit (57-58.5 cm) between non-deformed varves and unrelated turbidites; fish carcass (36.5-37.5 cm) sandwiched between varves.

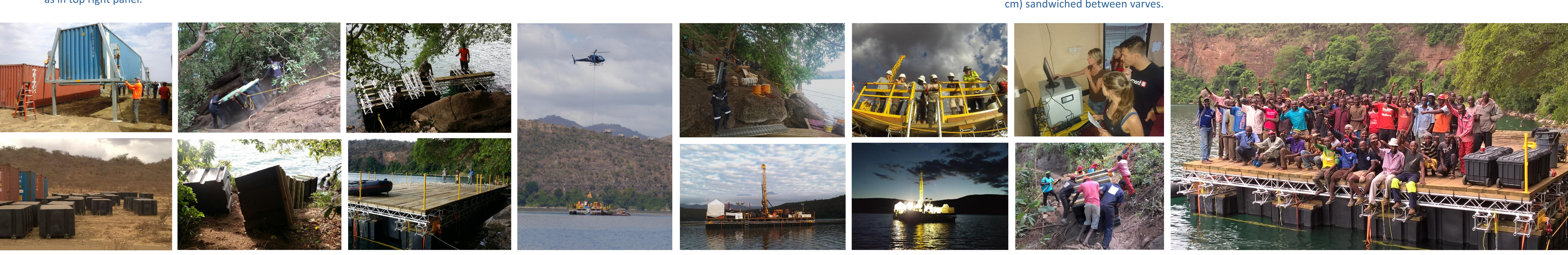

Figure 10. **Top to bottom, then left to right**: time sequence of activities during mobilization, drilling and demobilization phases of the fieldwork. Far right: part of the 97-person strong local support crew of porters, watchmen, cooking ladies and drivers under the command of personnel manager Peter Goi (left, wearing Chelsea shirt).

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