Supplement 3. Recommendations based on deep continental drilling projects for paleoenvironmental records in Colombia.

Research objectives:

- Continental sedimentary basins are to a high degree unexplored. Results from first explorative cores should develop an understanding of basin evolution and environmental and climate dynamics. Subsequent cores should focus on specific research questions.
- In many deep basins (e.g. Biwa, Lynch Crater, Bogotá), the lowermost sediment infill does not contain fossil pollen. There, focus should be on information from abiotic proxies. Collecting the lowermost sediments consumes relatively much time.
- For long records, high-resolution (minimum sample resolution of ~100 yr) is necessary to allow the exploration of operating mechanisms and correlations with marine and ice-core records records from elsewhere. A combination of 'fast' proxies (e.g. XRF geochemistry and grain size analysis) measured at high resolution and 'slow' proxies (e.g. fossil pollen) analysed at low resolution is not optimal but may increase the feasibility of the project.

Multiple funding:

- Raising a core of undisturbed sediments with a high percentage of recovery requires high technical skills.
- Analyses of long records requires at least two PhD positions and a supervising postdoc position. A supporting team of analysts (also at distance) may speed up the analyses of slow proxies. Sampling the core should be supported by a technician. The PI should focus on a smooth progress of the project. The PI should fascilitate outreach and international and media contacts.

Site selection and permissions:

- An understanding of the bathymetry of the lake floor with hydro-acoustic sonar scanning supports site selection.
- In the preparation phase developing seismic reflectance profiles is highly recommended to identify the location with the highest chance on a most complete and undisturbed sediment sequence. Sediments that accumulated in a high energetic environment should be avoided. However, grain size and geochemical analyses of sediments devoid of fossil pollen may be helpful to develop an understanding of the sedimentary environment and sediment source areas during the earliest phase of basin infill.

- During core drilling downcore wireline logs, such as gamma ray, resistivity, and even a sonic log are valuable in correlating sediment sequences between sites and inferred climate records.
- Keep distance to (paleo)drainage systems to avoid coarse-grained sedimentary layers with poor preservation conditions for fossils of organic origin. The coring process may be disturbed by release of subterraneous water under high pressure. Methan gas might escape from buried peat layers.
- Keep distance to former lake shores to avoid gaps in the sediment archive and consequently hiatuses in the record.
- In recent decades international transport of sediment cores and sediment sample meets severe difficulties at customs and national sanitary organizations. A combined use of laboratories in the host country and international institutes may minimize international transport and strengthen international collaboration and capacity building.

<u>Technical limitations:</u>

- Technical aspects of deep drilling need careful attention: accessibility of the site, stability of site surface for heavy drilling equipment, availability of water at close distance, use of drilling liquid (benthonite) to stabilize the drilling hole, or by casing, and safety of equipment during absence; a 24-hour drilling operation may be an option.
- At latitudes close to the equator developing a paleomagnetism record requires drilling under core orientation by which the original orientation of a core cylinder in relation to the magnetic field is determined.
- Using the high-performance ICDP facilities is always to be preferred. However, national geological surveys willing to support scientific drilling may potentially raise high-quality sediment cores.

<u>Multi-proxy analyses:</u>

- Developing an age model is as crucial as challenging: use all feasible options.
- A mix of ‘rapid’ (e.g XRF geochemistry, grain size analysis) and ‘slow’ (e.g. pollen analysis) proxies is advisable to obtain quickly a stratigraphical and temporal framework of the sediment archive.
- Formation of a team of well-trained pollen analysts, optionally at distance in the host country, may boost progress in analysis of slow proxies.

- Organic matter input (abundance aquatic vegetation) serves lake-level reconstructions and charcoal analysis is helpful to document the regional fire history.
- In a pre-analysis the variety of pollen taxa in the sediments should be explored. Routine analysis of pollen samples may be speed up by counting a selection of taxa. Document ecological ranges in an informative table and select the most informative taxa to be analysed (in the Fúquene records ~50 taxa out of the ~150 present; in the tropics a significant part of the pollen taxa occur as singletons). However, this practice may cause the data set is not feasible for certain research questions, such as changing temporal taxa diversity.
- Visualize all taxa-to-be-analyzed in a poster and place the poster as a helpful attribute next to the microscope of all team members.
- Diatom analysis is helpful to support the interpretation of ‘local’ proxies (aquatic pollen, grain size analysis, organic matter content)
- Molecular markers may serve as independent proxies, with respect to temperature in particular.
- Each proxy preferably needs the support of a specialist participating in the team.
- A minimum standard expertise for each proxy should be reached in shortest time in order to prevent in the records a visible increase of expertise (the 357-m long Funza-1 core was first analysed at 100-cm distance, later at 20-cm distance; a frequency analysis of the total data set identified an 1-m frequency). However to speed up first (preliminary) publications analyses of the sediment core in intervals is advisable to let growing expertise settle in the team. At least one proxy should be analysed along the full sediment core to serve stratigraphical understanding and to prevent the risk that the last interval receives less time, finance and attention.

<u>Data access and core access:</u>

- Long delays in making data open access is harmful for letting results percolate into the scientific community. A period of ‘privileged data use’ or ‘restricted data use’ should be as short as possible and may proceed data have the status of full open access. The dilemma of team investment *vs.* team profit *vs.* the general interest in open access to data needs thoughtful decisions.
- From the viewpoint of data producers of long continental records of environmental and climate change it is suggested data bases accept temporary uploading secondary time series (such as arboreal pollen vs non-arboreal pollen counts/percentages as a reflection

of openness of the landscape or, in mountain areas, temperature-driven altitudinal migrations of the upper forest line) to support rapid use of results in multi-site studies.

- Availability of a cold room (4°C) is essential to keep sediment cores over decades in good condition allowing resampling. Sediment cores in half-pvc tubes should be covered by plastic foil, wrapped in a sealed plastic tube, and stored in a pvc-tube on both sides covered with a taped plastic capsule (3 levels of protection against drying out). On the longterm special core archives (as available for deep-sea cores and ice-cores) are more reliable than small institute-bound cold facilities.
- Any resampling needs a careful documentation of objectives, sample report and list of collected samples to keep the project history transparent. Mind the difference between ‘core depth’ and ‘composite core depth’ and include a conversion instruction in each pvc-tube.

Outreach & Visualization:

- Using a logo and/or acronym for a project is helpful in teambuilding and communication.
- Outreach during progress of a project should avoid the release of premature information with a high risk of requiring correction in the near future. Practice learns that ages models are most frequently subject to change.
- Thinking on long time-scales is difficult for the layman and needs special attention. A vizualisation how climate-driven changes during multiple Pleistocene ice ages have repeatedly changed the environment brings much understanding and might be distributed through youtube and potentially also submitted to film festivals with focus on the environment.

Relevant references

[1] Bronk Ramsey et al.: Oh no, not another timescale...: the view from Lake Suigetsu, Japan (oral presentation). INTIMATE Workshop, De Lutte, The Netherlands, 2012.

[2] Cohen, A.S., 2011, Scientific drilling and biological evolution in ancient lakes: lessons learned and recommendations for the future: Hydrobiologia 682, 3–25, doi: 10.1007/s10750-010-0546-7, 2011.

Abstract: Scientific drilling to recover sediment core and fossil samples is a promising approach to increasing our understanding of species evolution in ancient lakes. Most lake drilling efforts to date have focused on paleoclimate reconstruction. However, it is clear from the excellent fossil preservation and high temporal resolution typical of lake beds that significant advances in evolutionary biology can be made

through drill core studies coordinated with phylogenetic work on appropriate taxa. Geological records can be used to constrain the age of specific lakes and the timing of evolutionarily significant events (such as lake level fluctuations and salinity crises). Fossil data can be used to test speciation and biogeographic hypotheses and flesh out phylogenetic trees, using a better-resolved fossil record to estimate timing of phylogenetic divergences. The extraordinary preservation of many fossils in anoxic lake beds holds the hope of collecting fossil DNA from the same body fossils that improve our understanding of morphological character evolution and adaptation. Moreover, fossils allow calibration of molecular clocks, which are currently largely inferential. Lake Malawi Drilling Project results provide some guideposts on what might be expected in a drilling project for studies of evolution. The extreme variability in lake level and environmental history that most ancient lakes experience (exemplified by the Lake Malawi record) demonstrates that no one drilling locality is likely to provide a complete record of phylogenetic history for a radiating lineage. Evolutionary biologists should take an active role in the design of drilling projects, which typically have interdisciplinary objectives, to ensure their sampling needs will be met by whatever sites in a lake are ultimately drilled.

[3] PAGES: Continental drilling for paleoclimatic records. Recommendations from an international workshop. Workshop Report, Series 1996-4, 104 pp, GeoForschungsZentrum, Potsdam, June 30-July 2, 1995. ISBN 3-9521078-3-2, 1996.

Introduction: The impetus for this Workshop came from a growing need for long continental paleoclimate records with the Past Global Change (PAGES) Project of the International Geosphere-Biosphere Programme (IGBP), together with the development of the International Continental Drilling Program (ICDP) and its Earth History and Climate Theme. In particular the needs of the continental-scale, pole-equator-pole (PEP) transects of PAGES for long, high-resolution climate records provided a strong incentive for the Workshop.

Progress in global change research has come from many fronts in recent years. Much better understanding of the processes involved in the earth's climate system is now available, but along with this understanding has come a renewed awareness of the incredible complexity of this system. Much attention is deservedly given to climate-simulation models, most recently coupled ocean-atmosphere models, because of their ability to forecast. Such models, however, are just beginning to produce realistic simulations of human impact on the climate system that are comparable to those observed in the instrumental record. In addition to difficulties with accurately representing climatically important processes, models have problems in dealing with non-equilibrium conditions and non-linear processes. The record of the past shows that climate is constantly evolving, that 'equilibrium' is relative to time scales, that sudden and unexpected events occur, and that earth systems may have internal, non-linear properties (such as 'mode switches' in oceanic circulation). Thus, even as our understanding of climate processes grows, and our ability to model those processes increases, we are more dependent than ever on the record of past climate changes for true understanding of the climate system.

Finally, as important as it is to reconstruct climate changes of the past and to forecast them for the future, ultimately, it is the *impact* of those changes that are important to humanity. The continental paleoclimate record provides evidence of the impacts of past climate changes that are on a spatial and temporal scale that is relevant to human activity.

A wide variety of archives of continental paleoclimate records exist. These include historical records, tree rings, ice cores, relict geomorphic features, and sediments. The scope of the Workshop was restricted to records from sediment archives. Although records from all types of continental sediments are valuable and were considered within the scope of the Workshop, attention focused on lake sediments, because of their relative continuity, time resolution, and sensitivity of climate change, and because of the general ability to compare ancient lake sediments with their modern counterparts in the same lake. However, most of the discussion that follows applies to other continental sedimentary records as well, such as continuously accumulating loess in China.

[4] Schnurrenberger, D., Kelts, K., Johnson, T.C., Shana, L., Ito, E.: National lacustrine core repository (LacCore). J. Palaeolim. 25, doi: 10.1023/A:1008171027125, 2001.

Abstract: This paper announces the launch of the first National Lacustrine Core Repository (LacCore) in the United States under the sponsorship of the National Science Foundation, Earth Systems History program, in cooperation with the University of Minnesota, Limnological Research Center (LRC) and Large Lakes Observatory (LLO). Policies are being developed in consultation with a national External Advisory Group (EAG), with requested input from the international paleolimnological community. The dynamic growth of national and international coring programs brings exciting new developments in paleolimnology and also brings a growing need for multi-proxy, cost-efficient usage of core material, similar to practices common in the marine sciences. The goals of this shared program and repository are to: (1) curate cores as a material documentation of scientific analysis and basin archives; (2) increase the quality and scope of paleoecological science by developing procedural standards and by facilitating interdisciplinary interaction among scientists; (3) provide community access to cores; and (4) create web-based access to an ongoing, developing data base.LacCore is a community venture and input is welcome in these early stages. The central idea is that curation of lake cores is significantly more than storage. A curation repository requires professional expertise and advice to assure consistent and coherent conventions for Initial Core Descriptions (ICD), data management, sample oversight, and pro-active dissemination of information on opportunities. Careful curation of cores allows maximum core utilization because maintained and documented cores are available for re-sampling, for comparative, interdisciplinary investigations, for application of new proxy techniques, and for correlation of proxies of environmental change across the continents.

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