

Breakout group Water Mass Tracers: W Curry, T Marchitto, E. Michel, M Sarnthein, C Wunsch, R Zahn,

A wide variety of palaeo-proxies is used in palaeo-circulation studies including novel proxies that have become available over the past 5-10 years and are being used to various degrees by the palaeoceanographic community. Temperature proxies probably are the ones that are most widely used and encompass the range of approaches from quantitative micropalaeontology (foraminiferal/diatom/radiolarian census counts); biomarkers from marine nannoflora (Uk37); temperature sensitive trace element ratios (Mg/Ca); calcium isotope ratios in marine carbonate ($\delta^{44}\text{Ca}$). It must be noted that these proxies and approaches are used to the largest extent “only” in sea surface temperature reconstructions. Mg/Ca is about the only temperature proxy that is being tested in benthic foraminifera, with some degree of success. As such, development and calibration of deep ocean temperature proxies are an immediate urgency for reconstructing ocean THC. Traditionally, deep/bottom water T is inferred from benthic d18O. Without independent benthic T estimators this approach is not convincing. As for the surface ocean procedures in place for temperature reconstructions largely are acceptable and are currently being improved in accuracy (calibration), compatibility and spatial coverage by the international community (GLAMAP, MARGO). However, there is need for high-resolution SST records in conjunction with an improved chronology to map amplitude and timing of abrupt SST swings across different latitudes.

Deep ocean circulation patterns are almost entirely being mapped using benthic foraminiferal d18O and d13C. Both are the workhorse of deep ocean palaeoceanography reflecting advances over the past 15 years to fully automated instrumentation enabling large and reasonably fast sample throughput. Substantial progress has been made towards a fuller understanding of the variables influencing both isotope ratios (pH, air-sea gas exchange etc.). Cd/Ca is the only other benthic proxy that has advanced to a reasonably well understood proxy but remains underutilized because of its intricate analytical procedure. Promising new benthic palaeo-proxies are elemental Zn/Ca and Ba/Ca ratios that are coupled to marine nutrient cycling. They also suffer from intricate sample preparation procedures and are not anticipated to make it to the forefront of preferred proxies any time soon. It is to be noted most deep-ocean proxies currently in use trace non-conservative, nutrient-related properties. There is an urgent need for proxies of conservative properties that trace ocean mixing only and are not influenced by “secondary” processes such as nutrient cycling. Nd isotopes show great promise in that their application is based on discrete basin-to-basin signal difference between the Pacific, Atlantic and Indian Ocean. Excess $^{231}\text{Pa}/^{230}\text{Th}$ is evolving as another promising proxy to study changes in the rate of ocean MOC. Both need to be advanced into a reliable proxy that bears potential to complement and expand existing data bases from the other proxies. To develop an independent salt proxy is another obvious urgency. Extraction of palaeo-salinity from oxygen isotope palaeotemperature equations, even in conjunction with independent benthic T estimators, will remain circumstantial because of uncertainties related to the spatial and temporal variability of the seawater $\delta^{18}\text{O}$ – salinity couple.

The sortable silt size index (SS) has been in use for a while now and is about the only calibratable proxy from which to infer physical flow speeds in the near-bottom water layer. While this proxy is used by several laboratories, it likewise appears underutilized. Laboratory protocols involved with SS do not seem overly demanding so that the SS index deserves greater attention by the community. Magnetic parameters are considered another viable tracer/proxy for magnetic material transports from which to infer near-bottom current direction.

In terms of data density and regional coverage the data base of foraminiferal $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and to some extent Cd/Ca in the Atlantic has reached the extent and quality to call on a basin-scale synthesis. This then will provide the data basis for modeling exercises to test for quantitative changes in MOC. Parameters notably critical in this exercise are e.g., response times of the proxies involved (e.g., Pa/Th vs $\delta^{13}\text{C}$), and changing air-sea exchanges and isotope fractionation ($\delta^{13}\text{C}$).

Data quality and density appears reasonable in the Pacific and Southern Ocean for the LGM period and should be synthesized with an outlook towards further improvement. A high-priority conceptual task must focus on the integration of proxies, including proxy testing in paired-sample exercises that employ multi-proxy (chemical, faunal) approaches e.g., opal vs carbonate based, and numerical proxy modelling. A strategic focus is needed on the Southern Ocean (meridional, zonal gradients) where the sedimentary carbonate domain borders the non-carbonate domain making it an exciting task to compile complementary and, importantly, compatible quantitative palaeo-databases to assess palaeo-circulation and water mass production.

It was noted that PACE has the potential to evolve into a platform to help making progress on these issues by organizing and overseeing inter-laboratory calibration exercises e.g., development of laboratory standards (DIC!), and inter-proxy calibration.