

Geochemical, isotopic, and physical evidence for vigorous meridional overturning circulation at mid-depth in the Atlantic Ocean at the LGM

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Geochemical, isotopic, and physical evidence reveals that the Atlantic meridional overturning circulation (AMOC) was structured differently during the last glacial maximum (LGM) than in the modern ocean. Yet the driving forces for this overturning circulation are persistent, and were likely to be even greater in the ice-age ocean. A number of numerical and conceptual models invoke a role for the ocean's large-scale circulation in past and potential future climate changes. We discuss new and existing evidence that supports both the contrasting organization of glacial and modern AMOC and also the presence of a strong overturning cell that reached to intermediate depths in the LGM Atlantic.

Our results include additional $^{231}\text{Pa}/^{230}\text{Th}$ time series and sediment composition measurements from multiple sites in the east, west, and north sectors of the North Atlantic, as well as from the central Mid-Atlantic ridge. At locations from 1-3 km water depth, the Pa/Th burial ratios are not only well below the production ratio from uranium dissolved in seawater, they are also lower than Holocene burial ratios at the same sites. By contrast, deeper sites have higher Pa/Th at the LGM than in the Holocene. These results suggest an enhanced lateral removal of Pa from the basin's intermediate depths, despite the fact that scavenging by increased particle and opal fluxes may have been greater at the LGM. The simplest explanation for these observations is that Pa was exported from mid-depth in the North Atlantic by a vigorous AMOC. This interpretation is supported by other geochemical, physical, and isotopic data including multi-proxy results from the same sediment cores. An alternative explanation, that of enhanced lateral transport by increased eddy diffusion, is less likely given the evidence for a generally higher basin-wide scavenging and the absence of a boundary-scavenging signal in our cores from sites near the basin margins.

Rapid, *in situ*, Portable, and Minimally Destructive Analysis by Laser-Induced Breakdown Spectroscopy: A New Paradigm in Geochemistry

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Many geochemical analysis scenarios could benefit from rapid, *in situ* analysis in field situations. Laser-Induced Breakdown Spectroscopy (LIBS) is a relatively new technique with analytical capabilities that represent a new paradigm in geochemical analysis. A microanalysis technique, LIBS collects the UV-VIS-IR spectrum (200 – 1000 nm) of photons emitted from a cooling plasma formed by ablating a small amount of material with a focused laser. The spectrum contains a rich chemical fingerprint of the material because most elements emit in this range. No sample preparation is required; the maximum sample size is limited only by the configuration of laser, lenses, and optic fiber. Stand-off LIBS is performed by collecting the photon spectrum by telescope. Backpack LIBS is under development, making geochemical analysis and mapping a reasonable and reliable field technique.

LIBS will not compete with the accuracy and precision of lab-based techniques. Concentrations are not calculated using peak heights or areas; instead, hundreds of entire spectra are used in chemometric techniques such as principal component analysis or partial least squares regression. Use of the information-rich spectra permits use of asking questions that are impossible with lab-based techniques.

The NMSU LIBS lab has been working on LIBS applications on many geomaterials. Whole-rock analysis is achieved by combining hundreds of analyses from a grid on the surface of the material. This allows rapid field-based analysis of geologic materials for such applications as correlation of ash flow tuffs and whole-rock analysis in volcanic fields. Detailed maps of large samples, such as petrified wood, can be constructed; analysis of precious materials, such as gem stones is also possible. Rapid analysis of petroleum could enhance petroleum exploration; experiments to determine methods for liquid analysis with minimal sample preparation are underway.