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Reading All the Pages in the Book on Climate History

By Ted Moore and Jan Backman

ABSTRACT. In recent decades, the scientific ocean drilling community has prided itself in being able to achieve the full recovery of hundreds of meters of the sedimentary section through coring, allowing scientists to decipher the history of Earth's climate in its fullest resolution. The Deep Sea Drilling Project, the Ocean Drilling Program, the Integrated Ocean Drilling Program, and the International Ocean Discovery Program provided the impetus for the rapid growth of paleoceanography as a new field of study and contributed significantly to modern-day paleoclimate studies. These new fields are based upon a long progression of technical developments over decades and hundreds of drilling expeditions. Here, we briefly review the technical and coring strategy advances that today allow us to read all the pages in the book on climate history.

THE ISSUE OF CORING SOFT SEDIMENT

At its beginning, the Deep Sea Drilling Project (DSDP) had as its ambitious goal the sampling of deep ocean sediments and upper oceanic crust using state-of-the-art offshore oil drilling technology. However, unlike drilling for oil, where the main objective is to create a hole that extends to a purported reservoir, DSDP had the primary goal of collecting core samples of sediment and rock from subsurface formations. There was one big problem with the standard oil drilling and coring bits: the ratio of the diameter of the bit face to the central opening for the core barrel was about 5 to 1. This meant that in relatively soft sediments, the bit acted like a funnel, rapidly pushing sediments into the core barrel as the drill string descended into the section. After a few sedimentary sections had been continuously cored with the intention of collecting the entire sedimentary section, biostratigraphers noted that most of their biostratigraphic boundaries fell between cores or in the catcher sample at the very base of the core (Moore, 1972). This was clear evidence that the complete core barrel had been quickly filled in the first meter or two of lowering the drill string; subsequently, sediment was simply shoved aside. Something better had to be devised.

DEVELOPMENT OF THE HYDRAULIC PISTON CORER

Toward the end of DSDP, the program's project engineers designed and built a 5 m long piston corer. Using this device, the drill pipe was pressurized, and at a given release pressure, a coring tube was shot out in front of the drill bit into the sediment. This Hydraulic Piston Corer (HPC) brought back a virtually undisturbed sample of sub-bottom sediment (Figure 1). This was a major advance in recovering deep-sea sedimentary sections that permitted observation of detailed changes in the ocean environment. Building on this success, during the

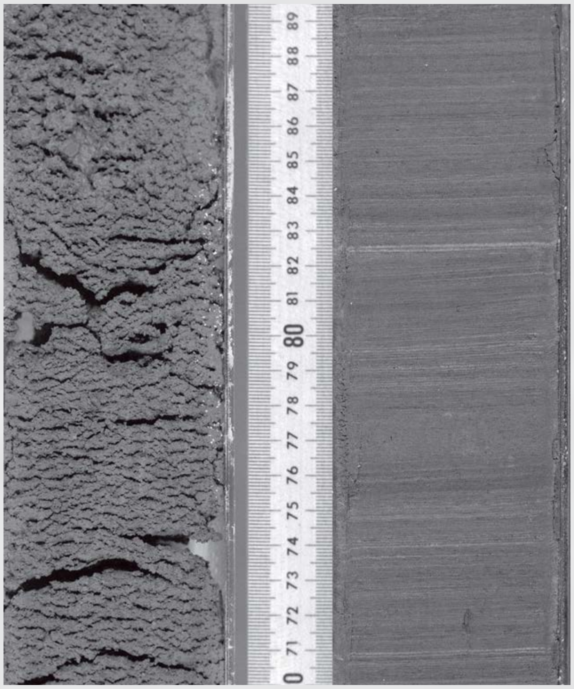
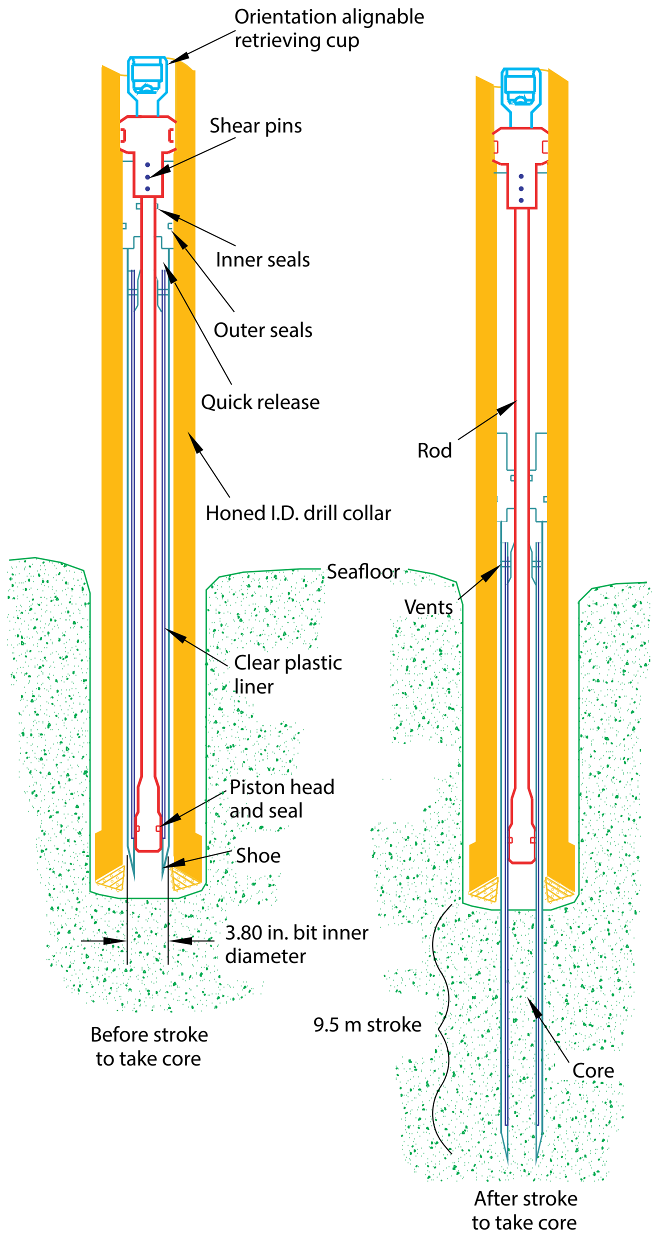


FIGURE 1. Comparison of sediment core quality between rotary drilling and piston coring.

latter days of DSDP and the early days of the Ocean Drilling Program (ODP), engineers improved the HPC design and increased the length of the core barrel to 9 m. This Advanced Piston Corer (APC) is still in use today (Figures 2 and 3). In addition, the newer Extended Core Barrel (XCB) can cut through semi-lithified sediments that are too hard to be cored with the APC (Figure 3). With these new and innovative tools, scientists could be assured of collecting a nearly undisturbed sedimentary section down several hundred meters into the deep-sea blanket of sediments.

ENSURING FULL RECOVERY

But was this recovered section really complete? Cores were taken sequentially in 9 m steps, but suspicious stratigraphers feared that there still might be gaps between cores caused by inaccuracies in positioning the drill string. By coring multiple holes a few tens of meters apart at each site and by offsetting the core intervals in each hole, two things were achieved. First, this practice demonstrated that indeed there were gaps between successive cores, even in continuously cored sections. Second, it allowed the scientists to construct a composite section that was demonstrably complete, based on physical property data. This combination of improvements in hardware and drilling strategy opened the door to the most detailed investigation of paleoceanographic and paleoclimatic changes that the resolution of the sediment itself would allow.



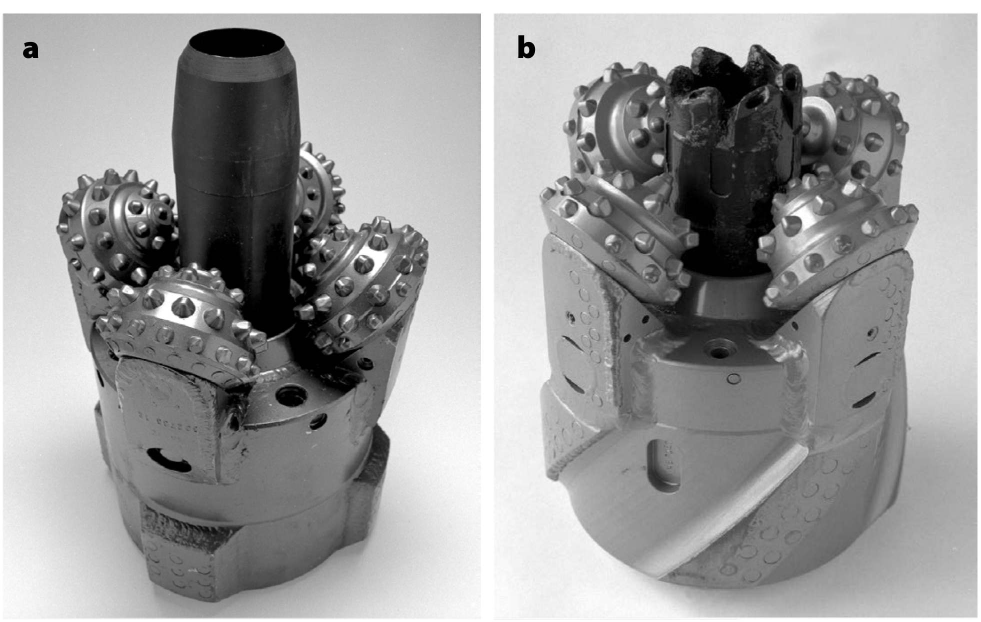


FIGURE 2 (above). Schematic of the Advanced Piston Corer (APC) before and after stroking out the inner core barrel to take a core. Pump pressure inside the drill string severs the shear pins and allows the inner core barrel to stroke out 9.5 m in 2–3 seconds with ~27,000 lb of force.

FIGURE 3 (left). (a) APC piston shoe extending through APC/Extended Core Barrel (XCB) drillbit. (b) XCB cutting shoe extending through APC/XCB drillbit.

ACHIEVING ORBITAL TUNING

During this time of improvements in section recovery, there were parallel improvements in continuous logging of the physical and chemical properties of the recovered sediments, revealing the often pervasive cyclicity that could be correlated not only from hole to hole, but also from site to site within large regions of the ocean. Once tied to a robust biostratigraphy and a paleomagnetic timescale, these cycles were found to have concentrations of variance (spectral power) at frequencies very close to the Milankovitch orbital frequencies. Scientists then used this concordance to "tune" cyclic sedimentary records to the calculated orbital frequencies (Shackleton et al., 1995). The result is a chronostratigraphy that allows us to compare the rates of environmental change in 30 million year old sediments with the same precision as in 3 million year old sediments, something unheard of when we depended solely on interpolations and extrapolations of biomagnetostratigraphic data. The cyclostratigraphic "tuning" approach provides independent age estimates that do not rely on linear interpolation within single geomagnetic chrons (Hays et al., 1976).

RESULTING SCIENTIFIC ACHIEVEMENTS

These tools and techniques, when paired with our growing ability to decipher the nature of changes in the ocean environment, have led to a steadily increasing understanding of these changes. With multiple measurements on the core samples that approximate ocean productivity, seawater temperature, bottom water source area, the chemical "age" of bottom waters, and the changing biogeography of the ocean's flora and fauna, we have learned:

- How major changes in ocean gateways have affected ocean environments and global climate
- How the meridional overturning of the ocean has varied with time
- How the links between tectonics, ocean chemistry, and atmospheric CO_2 have driven our climate system
- How the cyclic changes in the ocean environment give evidence of the feedback processes between the ocean and the atmosphere
- How some large changes in the global climate system can occur very rapidly (e.g., the Paleocene-Eocene Thermal Maximum and the Eocene-Oligocene transition)

Initiation of the Integrated Ocean Drilling Program (IODP) brought scientists the ability to sample new regions of the oceanic environment. In addition to deep drilling, the use of specialized, mission-specific drilling platforms allows us to sample sedimentary records in shallow, nearshore areas and in ice-covered polar oceans. The former represents a dynamic region of the ocean where biologic productivity is high (and highly variable), where chemical and physical exchanges between the land and the ocean occur, and where changes in sea level have the largest environmental impact. The ice-covered oceans, particularly the Arctic Ocean as the only true polar ocean, remain mysterious. Today's climate conditions in both high southern and northern latitude regions are changing rapidly, and scientific ocean drilling in both these areas have clearly shown that Earth's climate was radically different over the past millions of years.

LOOKING INTO THE FUTURE AND GAPS IN OUR KNOWLEDGE

Now that we are able to obtain complete, undisturbed sections of marine sedimentary records from nearly all ocean areas, we are well on the way to understanding the broad outlines of ocean history for at least the last 100 million years (Zachos et al., 2001). In addition, we also are able to delve into the details of how sudden cataclysmic changes (e.g., the Cretaceous-Paleogene bolide impact; see Lowery et al., 2019, in this issue) as well short-term cyclic changes (e.g., the multiple Eocene hyperthermals) affect the ocean environment and, in turn, global climate. There are still key regions of the ocean basins that have yet to be adequately sampled and studied. Certainly, the Arctic and Southern Oceans are such areas. Understanding the history of continental ice sheets is another allied area. There is also a need for a better understanding of the role of intermediate ocean waters. These are the source waters for both coastal and equatorial upwelling, yet their history and origins have yet to be fully documented. Detailed study of these waters would involve coring the shallow oceanic plateaus and rises (e.g., Manihiki, Magellan, Rio Grande) that contain records of late Mesozoic as well as Cenozoic paleoclimate. As we bring to light any further details of the marine record, we can hope to better understand how the ocean-atmosphere climate system works now, how it has worked in the past, and how the system might change in the future.

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AUTHORS

Ted Moore (tedmoore@umich.edu) is Professor Emeritus, Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI, USA. **Jan Backman** is Professor Emeritus, Department of Geological Sciences, Stockholm University, Stockholm, Sweden.

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