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The OCEAN DRILLING PROGRAM: UNDERSTANDING THE EARTH BENEATH THE SEA

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For the past 30 years the Ocean Drilling Program (ODP), and its predecessor the Deep Sea Drilling Program, have played a critical role in providing the necessary understanding of the geological processes and events that have shaped the Earth. These programs have provided the only means available to geoscientists to sample the sediments and rocks that lie up to several thousand meters beneath the sea bed. The Ocean Drilling Program is built on and sustained by international cooperation, and provides a ready opportunity for establishing a partnership between Korea and the United States, along with its other ODP partners.

ODP Organization and Membership

The Program's membership is known collectively as the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). The JOIDES members consist of ten academic institutions from the United States (the leading oceanographic institutions, acting on behalf of all scientific institutions in the United States), plus six "international members"—major national research institutions, or funding entities, outside of the United States. Two of the six non-U.S. members are consortia of smaller funding agencies in different countries. The State Science and Technology Commission of the People's Republic of China is about to become the Program's first Associate Member.

ODP is funded by the U.S. National Science Foundation (NSF) and the other international partners. These currently include: the Australia/Canada Consortium, France, Germany, Japan, United Kingdom, and a consortium of 11 smaller European countries under the umbrella of the European Science Foundation. NSF effectively acts as the joint venture operator for all the funding institutions outside of the United States. (Since this paper was presented at the US-Korea Forum on Ocean Science & Technology in June, 1996, the Australia/Canada Consortium has expanded to include both "Chinese Taipei" and Korea.)

The basic program costs are currently just under $45 million per year. The National Science Foundation pays a little over 60 percent of the budget and each of the six non-U.S. members share the remaining costs equally. At the time of presentation of this paper, there was a shortfall of funding in the Australia/Canada Consortium. This shortfall created the opportunity for Korean scientific research agencies to join the program in October, 1996. The Korean Institute of Geology, Mining and Materials, representing Korea, and the Geological Surveys in Australia and Canada, and Universities in Taiwan have now restructured the consortium membership.

The management of the program and its organization involves an oversight office in the National Science Foundation and a prime contractor, which is the Joint Oceanographic Institutions, Inc. (JOI). JOI is a not-for-profit corporation, which was established by the ten leading U.S. oceanographic institutions to provide a vehicle for the management of the Ocean Drilling Program. JOI subcontracts certain functions, such as the science operations, to Texas A&M University, and wireline logging services to Columbia University.

A special, if not unique, feature of the Ocean Drilling Program is what is known as the "JOIDES Science Advisory Structure." The advisory structure consists of a series of eight panels and committees which provide advice to JOI on issues as diverse as technology and engineering development and pollution prevention and safety. It is supported by the Program membership in the United States and the other 19 participating countries. Representation on panels and committees is proportional to financial contribution and is provided by scientists from each member country or consortium on a volunteer basis. At the top of the advisory structure is the Scientific Committee and an Executive Committee. It is through discussions in this advisory structure that the annual science program is determined each year from a series of proposals that come from the scientific communities in each of the member countries.

Objectives and Program Delivery

ODP provides for the collection of core samples from the world's ocean basins; it provides shipboard facilities for the study of these core samples; and down-hole logging measurements and in-hole experiments. The Science Operator (Texas A&M University) provides for Program delivery through the charter of a deep water drilling platform, originally called the Sedco/BP 471, now renamed the JOIDES Resolution. Originally a petroleum exploration drilling vessel, the JOIDES Resolution was converted in 1984 solely for deep water scientific ocean drilling. It is capable of drilling in water depths of up to 7000 meters, and coring, or taking core samples, from up to 2500 meters beneath the sea bed. This vessel operates in a dedicated mode for the Program and is at sea for up to 340 days a year, which has clearly contributed to the Program's long-term success.

A particularly important aspect of the Program is the long-term archiving of a proportion of all core samples taken over the last 30 years. These archive cores are stored in various repositories around the world—there is now representative core from over 1000 drill holes from all of the world's ocean basins. There are three repositories in the United States and one in Germany. The archive is expanding all the time. It is accessible to any scientist with a valid sampling and analytical proposal from any institution in any Program member or participating country. Archive cores are still being re-sampled today, even those from the very earliest legs of the Program.

The Long Range Plan

The major thrust of the program from now until 2008 has just been redefined in ODP's Long Range Plan. The new Long Range Plan has two fundamental themes. The first of these is the "Dynamics of the Earth's Environment"—the study of sediment cores in various ocean basin environments around the world with a view to analyzing the history of naturally variable climate change, sea level change, the ocean-atmosphere interaction, the paleo-oceanography of the deep sea, and also the biological and evolutionary processes that can be tracked over the past several hundred million years of earth history as reflected in the existing ocean basins.

The other major Long Range Plan theme is the "Dynamics of the Earth's Interior." It focuses on the tectonic processes that formed the Earth—its mountain belts, volcanic island arcs, deep sea trenches, ridges, oceanic plateaus, and continental margins. It provides a mechanism for looking at these processes in a long-term predictive sense. Examples include, looking at the causes of earthquakes, volcanic events, and instability and mass wasting of large volumes of sediment in the sea. The Program is also looking at the processes that form petroleum and mineral resources of the deep sea; not in the direct, or "exploration" sense, but by looking at the fundamental processes that occur in the ocean basins that lead to petroleum and mineral accumulations.

Achievements

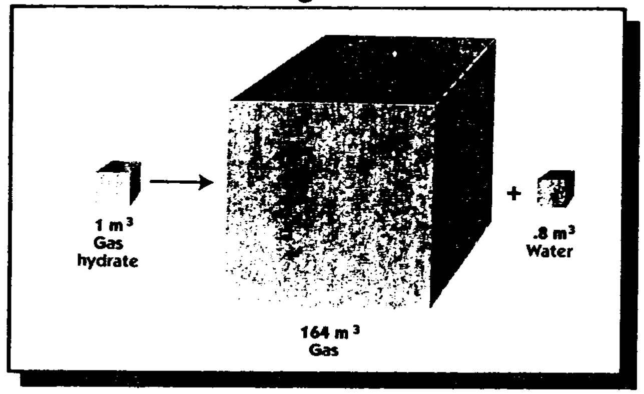
The achievements of this program over the last decade have been quite remarkable. Its earliest achievement was the recovery of cores from the South Atlantic (Leg 4; 1968) that showed that oceanic basement increased in age with distance from the mid-ocean ridge, exactly as predicted by the seafloor spreading hypothesis. Two more recent achievements will be highlighted here. They are: the formation of natural gas (methane) and resource potential of gas hydrates on the Atlantic continental margin of the United States; and hydrothermal mineralization in and along portions of the Mid-Atlantic Ridge.

Gas hydrates:

Gas hydrate is a naturally occurring hydrate of methane and water. It exists as a solid in deep sea sediments in a very specific range of pressure and temperature that exists within a few hundred meters of the sea bed and at water depths between 1000 and 4000 meters. Gas hydrates have been known to exist in these settings for many years, but it has only been through the Ocean Drilling Program that we now have our first real examples of a hydrate sampled under ambient pressure.

Figure 1 shows the ratios between methane and water in gas hydrates. One cubic meter of gas hydrate converts to 164 cubic meters of methane and 0.8 cubic meters of water. It is, therefore, a very efficient means of storing methane in sediment. Gas hydrates are known to exist on many continental margins around the world. They have been identified in many places because of a seismic anomaly created by the boundary between the hydrate and any underlying free gas in the sediment. This boundary represents a significant seismic velocity contrast, and therefore leads to a significant seismic reflection event.

Figure 1



What are current estimates of the distribution of all of the organic carbon that exists in the world? Recoverable and non-recoverable fossil fuels—that is all coal, oil and natural gas of thermogenic origin—is believed to contain on the order of 5000 gigatons of carbon. The mass of the land biota, by comparison, is a mere 850 gigatons. The resource of gas hydrates, just from locations where they have been identified from seismic reflection events alone, is believed to be well over 10,000 gigatons. It is by far the largest single resource, or reservoir, of organic carbon on this planet.

Figure 2

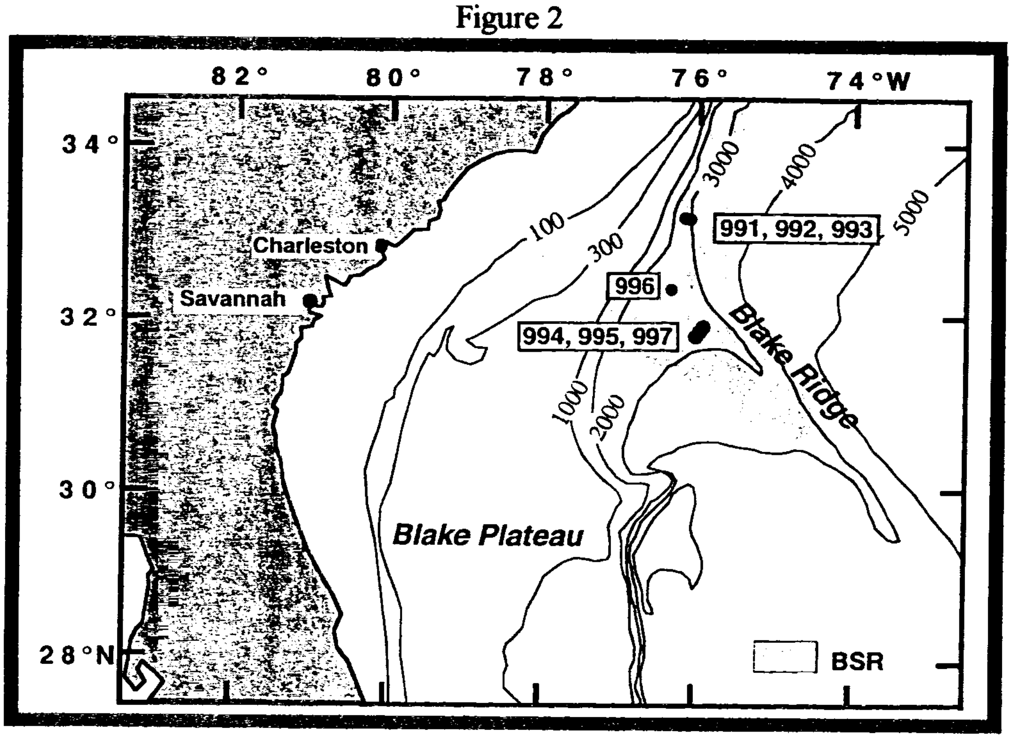


Figure 2 shows the distribution of the gas hydrate deposit off the coast of South Carolina, identified in ODP drill holes in water depths of around 2000 meters, drilled to just over 300 meters sub-sea bed. In this location, the hydrate is in a stable temperature and pressure environment. Figure 2 is a typical cross section. The gas hydrate layer exists at a fixed depth beneath the sea bed. It forms a impervious cap, preventing the escape of any underlying free gas. That underlying free gas is generated by a break down of the hydrate, caused by increasing temperature with depth. It is this velocity contrast between the hydrate filled sediment and the methane filled sediment which causes the "bottom simulating" seismic reflector that allows distribution of the hydrate to be mapped. The significant contribution made by ODP to understanding the magnitude of the hydrate resource off of South Carolina was the discovery of just how widespread the hydrate regime is. It is, in fact, much broader than the seismic anomaly alone. The thickness of gas hydrate is known to be around 200 meters thick. Therefore, the current estimate of gas hydrate resource in this one area alone is at least 35 gigatons of carbon as methane. To put that in context, it contains sufficient natural gas, if it could be produced, to supply all demand in the United States for over 100 years!

Processes of Mineralization:

For many years, the existence of vents, or "black smokers," consisting of very hot, metal-rich fluids being expelled from the ocean crust at mid-ocean ridges have been known through both submersible dives and deep sea camera work. Until now, however, the geological setting beneath a black smoker had not been examined. That was the purpose of an ODP operation on the mid-Atlantic ridge in 1994.

Black smokers develop when cold sea water is drawn into the flanks of a mid-ocean ridge and pumped out at the crest. This convection is driven by the thermal anomaly caused by molten lava directly beneath the axis of the mid-ocean ridge. As sea water passes through the ocean crust, it scavenges minerals, including base metal sulfides, and pours these out in plumes of super-heated water at temperatures up to 300 degrees Celsius. By drilling through the mounds—a technological achievement in itself due to the harsh physical regime—ODP scientists have been able to map the structure of what has turned out to be a base metal ore deposit in the process of formation. This is illustrated in Figure 3. Figure 4 shows base metal mineralization in a core taken beneath the thermal mounds at the Mid-Atlantic Ridge. If this photograph were shown to an on-shore explorationist, he or she would probably think that it came from a conventional ore body in a section somewhere on land, whereas the core actually came from 2500 to 3000 meters beneath the middle of the Atlantic Ocean. This is such a significant discovery that mineral exploration companies operating on land could potentially apply this model in their exploration strategies.

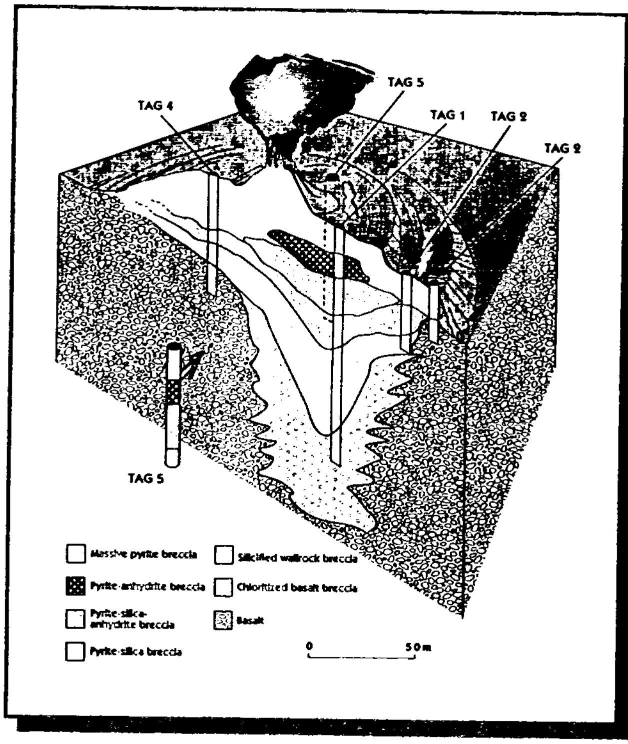


Figure 3
Modified from Humphris, Herzig, Miller et al., 1995. The internal structure of an active sea-floor massive sulphide deposit. Nature, 377, 713-716

Figure 4

Technology Development

For ODP to remain a dynamic program operating at the cutting edge of the science, we need to find better, more creative and innovative ways of doing science in the deep sea. Two examples illustrate ways in which we are approaching innovation. The first involves using the drill hole for more than just the recovery of core. In several places, ODP will place long-term observatories in drill holes in the deep ocean crust. Sensor strings will hang off a recording unit that is inserted in a re-entry cone above the hole. The re-entry cone will have a port which will allow submersibles or devices from surface ships to tap in periodically to the data recorded by the sensors. Sensors include magnetic observatories, earthquake seismic observatories, and fluid flow observatories. Data access will be periodic at first, but access to some of the disused analogue telephone cables is being explored as a means of avoiding expensive external interdiction.

The second example of innovative ODP technology involves improving core recovery in difficult sediment and rock sections. This is being tackled by the installation of a new system of active primary heave compensation coupled with higher speed, smaller diameter diamond coring bits. As with all oil exploration drilling vessels, heave compensation attempts to keep the weight on the drilling bit fairly constant as the ship goes up and down in the ocean swell. Large variations in weight on bit caused by large heave and poor heave compensation, leads to poor core recovery. The solution is a computer-driven active heave compensation system, coupled with high speed diamond coring. ODP will install such a system in October, 1997. It promises to keep a much more accurate weight-on-bit which will allow much better recovery of whole cores in brittle rocks.

Partnerships

Partnership relations between ODP and other scientific programs, such as the Inter-Ridge Program—a multifaceted approach to the study of mid-ocean ridges—are now under development. These scientific partnerships aim to increase the scientific dimension of, and participation in, the

Program. ODP is also exploring the development of cooperative technology research and development agreements with private enterprises and with government agencies aimed at improving our technology development. ODP is also seeking new countries, such as Brazil and Russia, to participate in the Program.

Conclusion

The community returns from major frontier science programs such as the Ocean Drilling Program goes well beyond the expansion of scientific knowledge and understanding. The collaboration and opportunities to send young scientists on board the drill ship to work in a team environment for two months at a time has proved an outstanding contribution to graduate-level scientific training. It also produces related educational benefits—for example, follow-on science through access to core material after the cruise is completed. There is a huge regional data base that has arisen now out of 30 years of ocean drilling, and a major spin-off has been the indicative resource potential in many areas, particularly on continental margins. With the UN Convention on the Law of the Sea now in force, ODP stands as a model of international and open scientific cooperation in research.