Final Technical Report

U.S. Implementing Organization

Integrated Ocean Drilling Program (2003–2013)
International Ocean Discovery Program (2013–2014)

United States Implementing Organization
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Final Technical Report

Contract OCE-0352500
2003–2014

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to
The National Science Foundation

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Contents

1. Executive summary

Under U.S. National Science Foundation (NSF) Contract OCE-0352500, the U.S. Implementing Organization (USIO) operated successfully during the Integrated Ocean Drilling Program and the first year of the International Ocean Discovery Program (IODP) for the period of 1 October 2003–30 September 2014. The USIO Final Technical Report to NSF provides an overview of the operation and management of the riserless Research Vessel (R/V) *JOIDES Resolution* by the USIO and highlights 11 years of technical and scientific accomplishments.

> "You could think of [the *JOIDES Resolution*] as the oceanographic equivalent of the International Space Station. Through recovery and analysis of deep ocean sediments and rocks, the [*JOIDES Resolution*] has made possible fundamental discoveries in plate tectonics, Earth's climate history, the deep biosphere (did you know organisms live in rock miles below the ocean floor?), earthquake hazards, mineral resources, etc." —M. Raymo, Chair of the Science Advisory Structure Executive Committee

Historical perspective

The Integrated Ocean Drilling Program (2003–2013) was an international marine research program that monitored subseafloor environments and explored Earth's history and structure as recorded in seafloor sediments and rocks. Building upon the earlier successes of the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP), which revolutionized our view of Earth's history and global processes through ocean basin exploration, the Integrated Ocean Drilling Program represented the latest generation of these highly successful scientific ocean drilling initiatives, with principal research themes outlined in the program's Initial Science Plan (ISP) titled *Earth, Oceans and Life: Scientific Investigations of the Earth System Using Multiple Drilling Platforms and New Technologies*.

The Integrated Ocean Drilling Program greatly expanded on the previous programs through the use of multiple drilling platforms—a riserless research vessel, a riser drilling vessel, and mission-specific platforms—operated by three implementing organizations (IOs) to achieve its

The *JOIDES Resolution* in the Sea of Japan.

scientific goals. The riserless *JOIDES Resolution*, operated by the USIO, allowed the Integrated Ocean Drilling Program to continue to expand the global sampling coverage and disciplinary breadth that were characteristic of DSDP and ODP. The riser drilling vessel (D/V) *Chikyu*, operated by Japan's Center for Deep Earth Exploration (CDEX), allowed the Integrated Ocean Drilling Program to drill more deeply for several months at a single location. Mission-specific platforms (MSPs) operated by the European Consortium for Ocean Research Drilling (ECORD) Science Operator (ESO) allowed drilling in environments unsuitable for either the *JOIDES Resolution* or the *Chikyu*, such as locations near the shoreline in shallow-water areas and in climatically sensitive or ice-covered regions. Consistency from one expedition to the next was ensured through provision of an Expedition Project Manager/Staff Scientist from the IO responsible for operating the expedition's platform.

The Integrated Ocean Drilling Program was funded by multiple entities acting as international partners: NSF and Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) were the two lead agencies, and ECORD participated as a contributing member. Brazil joined the Integrated Ocean Drilling Program as a full member late in FY12. Over the course of the Integrated Ocean Drilling Program, associate member organizations represented the People's Republic of China, the Republic of Korea, Australia, New Zealand, and India. Commingled funds from these partners were used for the science operating costs of all Integrated Ocean Drilling Program activities. Platform operating costs were supplied directly to the IOs by their supporting national agencies. Integrated Ocean Drilling Program Management International, a nonprofit corporation with an international membership of academic institutions, served as the central management organization for the Integrated Ocean Drilling Program and was responsible for Program-wide science planning and oversight and provision of continuous performance evaluation and assessment of all elements of the Integrated Ocean Drilling Program.

The USIO comprised the Consortium for Ocean Leadership, Inc. (Ocean Leadership), and its partners, Lamont-Doherty Earth Observatory (LDEO) of Columbia University and Texas A&M University (TAMU). Ocean Leadership was the prime contractor, with ultimate responsibility for all contractual obligations entered into by the USIO. LDEO and TAMU served as subcontractors that contributed distinct but complementary capabilities that collectively supported the full range of activities necessary for implementing scientific drilling programs on the *JOIDES Resolution*. Administrative services in support of TAMU activities were provided by the Texas A&M Research Foundation (TAMRF).

In October 2013, IODP succeeded the Integrated Ocean Drilling Program. With the support of 26 nations, this new international research program brings together Earth, ocean, atmospheric, and life sciences with a common goal of understanding Earth's past, present, and future. The Program's science plan, *"Illuminating Earth's Past, Present, and Future,"* addresses pressing scientific priorities and social concerns within four themes: Climate and Ocean Change, Biosphere Frontiers, Earth Connections, and Earth in Motion.

"[W]e should all be very excited about the phenomenal series of scientific investigations that are being lined up for the new program. We're going to do nothing less than revolutionize our understanding of how the ocean and Earth work." —R. Batiza, former Section Head, Marine Geoscience Section, Ocean Sciences Division, National Science Foundation

Scientific and operational highlights

USIO operations for the Integrated Ocean Drilling Program began in June 2004. During Phase 1, the USIO completed Expeditions 301, 303–309, 311, and 312 using the *JOIDES Resolution*, a 470.5-foot-long and 70-foot-wide research vessel previously used during ODP. From 2006 to 2009, the *JOIDES Resolution* underwent extensive renovations, resulting in an improved U.S. scientific ocean drilling vessel (SODV) for Integrated Ocean Drilling Program Phase 2 operations. Laboratory space was increased by 34%, berths were added, and drilling capabilities and ship stability were enhanced. This major refurbishment period was followed by sea trials at the Ontong Java Plateau in February 2009. The *JOIDES Resolution* returned to operations with Expedition 320 in March 2009, and the Integrated Ocean Drilling Program ended with Expedition 346 in September 2013. Through a contractual modification, the USIO continued to provide services to NSF during the first year of IODP, which ended with Expedition 352 in September 2014.

Examining the Cretaceous/Paleogene (K/P) boundary.

Over the 10 year course of the Integrated Ocean Drilling Program and the first year of IODP, 858 international scientists sailed on more than 30 expeditions on board the *JOIDES Resolution*. During this time, the USIO successfully provided the drilling platform and services that helped deliver exciting and relevant science to the research community and the public, including advancements in our knowledge of the deep biosphere and subseafloor ocean; paleoclimate during times of extreme warmth, including the hyperthermal events of the Paleogene such as the Paleocene–Eocene Thermal Maximum (PETM); Antarctic glaciation and its relationship with global climatic and oceanographic change; and subduction zone magmatism.

"The sediments collected during [Expedition 320] offer an unprecedented window to the evolution of the tropical Pacific, one of the largest and most climatically important ocean regions

> on Earth. In focusing on a time period that includes some of the best analogs for abrupt climate change, extreme climate events, ocean acidification, and 'greenhouse' worlds, the results will give us insights into the potential impacts of future climate change." —Julie Morris, Director of NSF's Division of Ocean Sciences

USIO research accomplishments include establishing the first large-scale 3-D hydrologic experiment in ocean crust (Expeditions 301 and 327); conducting long-term subseafloor experiments on the extent of microbial life in ocean crust (Expeditions 327 and 336); and investigating overpressure and fluid flow processes in a deepwater Gulf of Mexico expedition involving slope stability, seeps, and shallow-water flow (Expedition 308). Significant highlights include redefining the record of the Pacific calcite compensation depth from 55 Ma to present (Expeditions 320 and 321); documenting near-tropical conditions on the Antarctic margin during the early Eocene (Expedition 318); achieving the first penetration of a fossil magma chamber through intact ocean crust (Expedition 312); documenting that the Louisville Seamount hotspot remained relatively stationary between 80 and 50 Ma (Expedition 330); breaking ocean drilling records including the deepest hole drilled on a shallow continental shelf (1,024 meters; Expedition 317), the deepest hole drilled during a single expedition (1,927 meters; Expedition 317), the deepest advanced piston corer (APC) penetration (458 meters; Expedition 323), and the most core collected during a single expedition (6,027 meters; Expedition 346); amassing the largest collection of basement rock ever collected for microbiology during 40 years of scientific ocean drilling (Expeditions 329, 330, and 336); establishing the timing and style of the opening of the Straits of Gibraltar gateway (Expedition 339); and documenting the timing of the end of seafloor spreading in the South China Sea while implementing the first Complementary Project Proposal (Expedition 349).

Additional science and operational highlights are presented in the "Scientific results" and "Engineering and operations" chapters of this report.

Technical and engineering achievements

As with the predecessor programs, technical developments during the Integrated Ocean Drilling Program were driven by scientific needs. In 2009, the USIO participated in the development of the *Integrated Ocean Drilling Program Technology Roadmap*, an evolving document designed to provide a long-term vision of priorities in engineering development during the Program. The *Integrated Ocean Drilling Program Technology Roadmap* helped guide the USIO's development of technical and engineering innovations that improved core recovery and core quality and enhanced downhole and laboratory measurements. Some of the developments that strongly influenced scientific advances during the Integrated Ocean Drilling Program are improved subseafloor observatories, improved heave compensation, upgraded downhole tools, and new drilling mud technology.

Wireline heave compensator framework.

As part of the SODV project, a wireline heave compensation (WHC) system was developed that minimized heave-related motion of logging tools during operations and enabled clear scientific interpretations of stratigraphy, structure, and geophysical properties from downhole logging data obtained in a variety of sea states.

Downhole tool development included the magnetic susceptibility sonde (MSS), a wireline logging tool that measures borehole magnetic susceptibility at two vertical resolutions and depths of investigation; the half-core APC tool, which improves core recovery by extending the utilization of piston coring in soft sediment; and the Multifunction Telemetry Module (MFTM), a wireline logging telemetry system that allows LDEO wireline tools to operate in a Schlumberger tool string and acquire data in a single logging pass. The MFTM was developed for use with third-party tools such as the Motion Decoupled Hydraulic Delivery System (MDHDS) and the Simple Cabled Instrument for Measuring In-Situ Parameters (SCIMPI).

The SCIMPI is a new observatory instrument designed to study dynamic processes in the subseafloor using a simpler and lower cost approach. The SCIMPI was developed to provide an alternative to circulation obviation retrofit kit (CORK) subseafloor observatories, which can be complex, costly, and time consuming to install in soft sediment. The MDHDS is a new downhole tool delivery system designed to decouple the downhole motion of the drill pipe from sediment temperature and pressure probes that must remain absolutely stationary in order to make useful in situ formation measurements. The USIO was involved in testing and field trials of the both SCIMPI and the MDHDS.

Additional technical and engineering achievements are described in the “Engineering and science operations” chapter of this report.

Broader impacts

One of the top priorities of the Integrated Ocean Drilling Program and IODP was to make the Programs’ cutting-edge ocean drilling science publicly accessible. The USIO helped accomplish this objective through public outreach activities and production of expedition-related publications.

The USIO developed and disseminated expedition-specific and thematic education activities and materials for elementary through post-secondary and free choice–learning audiences and promoted diversity programs and partnerships. The USIO facilitated education activities through the Deep Earth Academy (funded jointly by the USIO and the United States Science Support Program [USSSP]) in cooperation with other U.S. education and outreach groups, conducting teacher education activities; developing, testing, and disseminating educational curriculum that highlighted Integrated Ocean Drilling Program and IODP science programs; and implementing live and near-real-time programs that highlighted the *JOIDES Resolution* as a platform for education. The USIO also developed several diversity outreach initiatives that allowed minority students to pursue studies in earth systems sciences or to explore careers in scientific ocean drilling and large-scale science program management.

Documenting core on deck.

USIO public outreach activities were designed to build an easily accessible foundation of knowledge about the Integrated Ocean Drilling Program and IODP, to raise visibility of the connection between emerging scientific knowledge and its positive contribution to society worldwide, and to encourage interest in both Programs. National and international science conferences provided an excellent venue for the USIO to engage the science, education, and political communities in Integrated Ocean Drilling Program and IODP research; a Program newsletter highlighted Integrated Ocean Drilling Program and IODP successes; and press conferences, science lectures, and/or ship tours at many *JOIDES Resolution* port calls provided an excellent opportunity to conduct public outreach related to ongoing operations, while media relation activities spurred coverage of the Integrated Ocean Drilling Program and IODP by high-profile news and media publications such as *Time Magazine*, *BBC News*, *Discovery News*, *National Geographic*, *Science*, and *Nature*.

Scientific Program publications were the primary method of disseminating Integrated Ocean Drilling Program and IODP research to the scientific community and the public, and the USIO was responsible for developing, producing, delivering, and archiving these Program-wide publications. More than 650 Integrated Ocean Drilling Program and IODP publications were produced during 11 years of scientific

ocean drilling research in addition to nearly 680 Integrated Ocean Drilling Program and IODP research-related articles published in peer-reviewed journals, including more than 150 articles in the high-impact journals *Nature*, *Science*, *Nature Geoscience*, *Paleoceanography*, *Earth and Planetary Science Letters*, and *Geology*.

Additional curation, data management, and publication accomplishments are presented in the "Samples, data, and publications" chapter of this report, and additional education and outreach accomplishments are presented in the "Education and outreach" chapter.

> "All of the scientists involved enjoyed the [Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST) ship-to-shore broadcast] event and found it a rewarding experience. An event like this demonstrates the invaluable contribution that scientific ocean drilling can make to education and outreach efforts—helping the Earth sciences to come alive for audiences of all ages." —D. Teagle, Expedition 335 Co-Chief Scientist

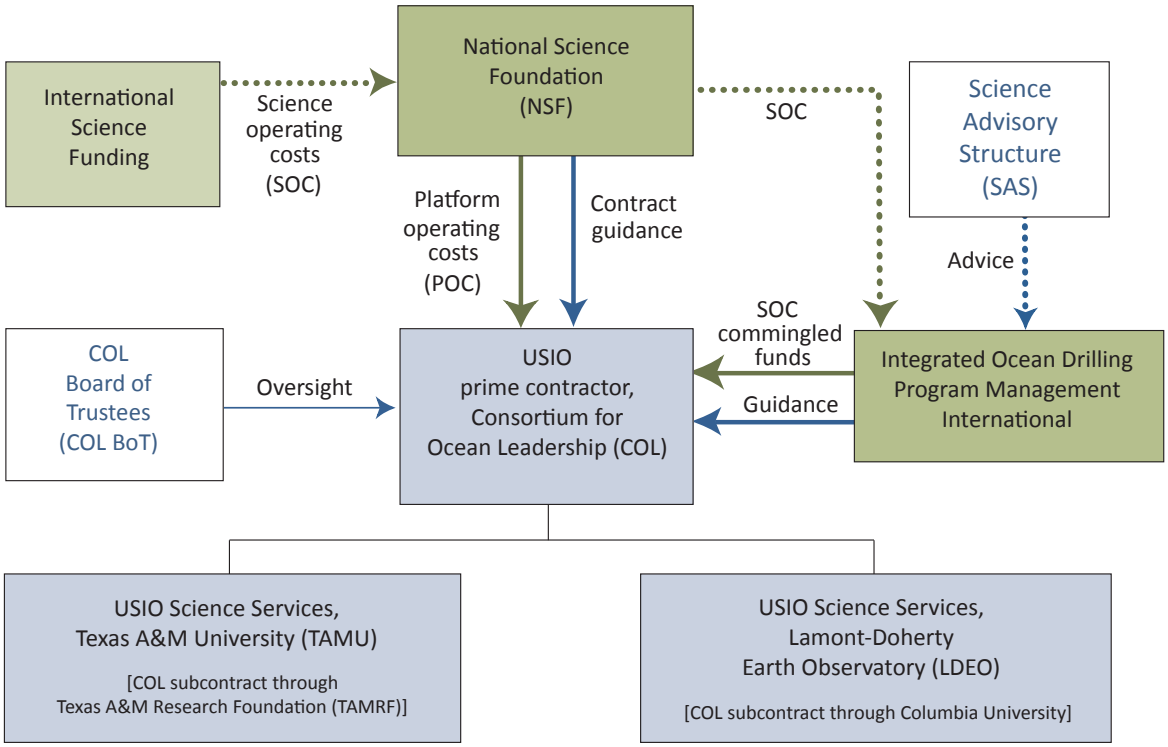
2. Management and administration

The Integrated Ocean Drilling Program and IODP were funded by several entities acting as international partners. NSF and MEXT were lead agencies, and ECORD was a contributing member. Associate members included the People's Republic of China Ministry of Science and Technology (MOST); the Interim Asian Consortium, represented by the Korea Institute of Geoscience and Mineral Resources (KIGAM); the Australian/New Zealand IODP Consortium (ANZIC) funded by the Australian Research Council (ARC) and GNS Science (New Zealand); and the Ministry of Earth Sciences (MoES), India. The Coordination for Improvement of Higher Education Personnel (CAPES), Brazil, joined the Integrated Ocean Drilling Program as a full member late in FY12.

During the Integrated Ocean Drilling Program, the USIO provided all deliverables through contracts with NSF for all system integration costs, including platform operating costs (POC), and with Integrated Ocean Drilling Program Management International for science operating costs (SOC) (Fig. 1). The commingled funds that comprise the SOC budget originated from international partners as part of their membership fees used to fund Integrated Ocean Drilling Program science. POC funding for each IO was the responsibility of the agency supplying the platform capability.

During both Programs, the USIO provided integrated management of tasks to ensure that all deliverables were met in accordance with NSF and Integrated Ocean Drilling Program Management International requirements. This effort was led by Ocean Leadership as the prime contractor in coordination with LDEO and TAMU. Management and Administration functions included planning, coordinating (with other Program-related entities), overseeing, reviewing, and reporting on IODP activities.

Figure 1. USIO management structure during the Integrated Ocean Drilling Program.



Contract and subcontract structure and roles

USIO prime contractor (program manager)

The Consortium for Ocean Leadership (Ocean Leadership) (formerly known as Joint Oceanographic Institutions [JOI]) is a nonprofit (501[c]3) oceanographic organization that was created in 1976 to help lead the U.S. effort in scientific ocean drilling. Ocean Leadership served as the prime contractor during DSDP and ODP and as the U.S. Systems Integration Contractor during the Integrated Ocean Drilling Program and the first year of IODP. As such, Ocean Leadership was ultimately responsible to NSF and Integrated Ocean Drilling Program Management International for overall program leadership; education and outreach; technical, operational, and financial management; and delivery of services for the *JOIDES Resolution* and related activities. Ocean Leadership led long-term planning development for the USIO and represented the USIO and the Program as a whole, when appropriate.

USIO subcontractors

Ocean Leadership established subcontracts with LDEO of Columbia University and with the College of Geosciences at TAMU through TAMRF to provide science services. LDEO and TAMU contributed distinct but complementary capabilities that directly supported the full range of scientific and technical activities necessary for implementing a riserless scientific drilling program.

Lamont Doherty Earth Observatory

LDEO was responsible for providing downhole geophysical measurements (logging)-related shipboard and shore-based science services and technological support. In addition, LDEO led an international logging consortium to participate in scientific ocean drilling operations. LDEO provided downhole logging equipment and engineering support through a contract with Schlumberger Technology Corporation.

Texas A&M University

TAMU was responsible for providing services directly related to the scientific and engineering activities necessary to support science expeditions (vessel and drilling operations, ship- and shore-based science laboratories) and for managing expedition-related shore-based functions that included data management, core curation, and publications. Administrative services in support of TAMU activities were provided by TAMRF. TAMRF, on behalf of the USIO, contracted Overseas Drilling Limited (a subsidiary of Siem Offshore, Inc.) for the services of the riserless *JOIDES Resolution*, whose home port of registry was changed from Monrovia, Liberia, to Limassol, Cyprus, in November 2011.

Planning and reporting

Annual Program Plans

During the Integrated Ocean Drilling Program, USIO work was carried out in accordance with Annual Program Plans (APPs) that were developed by the three USIO members in consultation with the Integrated Ocean Drilling Program Management International President and the NSF Program Officer and approved in writing by the Integrated Ocean Drilling Program Management International and NSF Contracting Officers. Contractual requirements for SOC and POC funds were outlined in the APPs to Integrated Ocean Drilling Program Management International. POC and other program integration cost (OPIC) budgets were combined in the systems integration contract (SIC) costs outlined in the APP to NSF.

Based on annual mission forecasts and *JOIDES Resolution* operations schedules and shaped by the complex nature of IODP operations, APPs established priorities and allowed procurement of long–lead time equipment and services for activities that spanned multiple years. APPs addressed USIO goals, scope of USIO work for IODP deliverables, definitions of projects, scheduled ship operations, staffing, and details of required budgets that incorporated funding allocations from NSF or Integrated Ocean Drilling Program Management International for science operations and from NSF for platform operations and U.S.-sponsored tasks such as education and outreach efforts and associated management and administration support. APP preparations for each fiscal year started a year in advance; the APP was submitted to NSF and Integrated Ocean Drilling Program Management International a few months before the start of each fiscal year.

Quarterly and Annual Reports

Throughout the Integrated Ocean Drilling Program, the USIO submitted quarterly reports to NSF and Integrated Ocean Drilling Program Management International that reflected activities and progress toward deliverables that were outlined in the APP. Following the end of each fiscal year, the USIO summarized its performance in an Annual Report (AR) to Integrated Ocean Drilling Program Management International and NSF. The AR identified the accomplishments for the fiscal year, as well as strengths and weaknesses in the APP's implementation.

During the first year of IODP, the USIO was required to submit APPs, quarterly reports, and ARs only to NSF.

Contractual and financial accountability

Despite a very difficult funding environment and reduced resources, particularly during the last 4 years of the Integrated Ocean Drilling Program, the USIO managed to efficiently operate the *JOIDES Resolution* and maximize delivery of science with funding received from NSF and Integrated Ocean Drilling Program Management International (Table 1). Figure 2 highlights the challenge presented by fluctuating fuel costs.

Additionally, the USIO was able to deliver external contract agreements to utilize the *JOIDES Resolution* for non-Program work during a time when the ship would have normally been tied up. These agreements resulted in significant cost savings and platform upgrades for the Program and did not compromise the ship's normal expedition schedule.

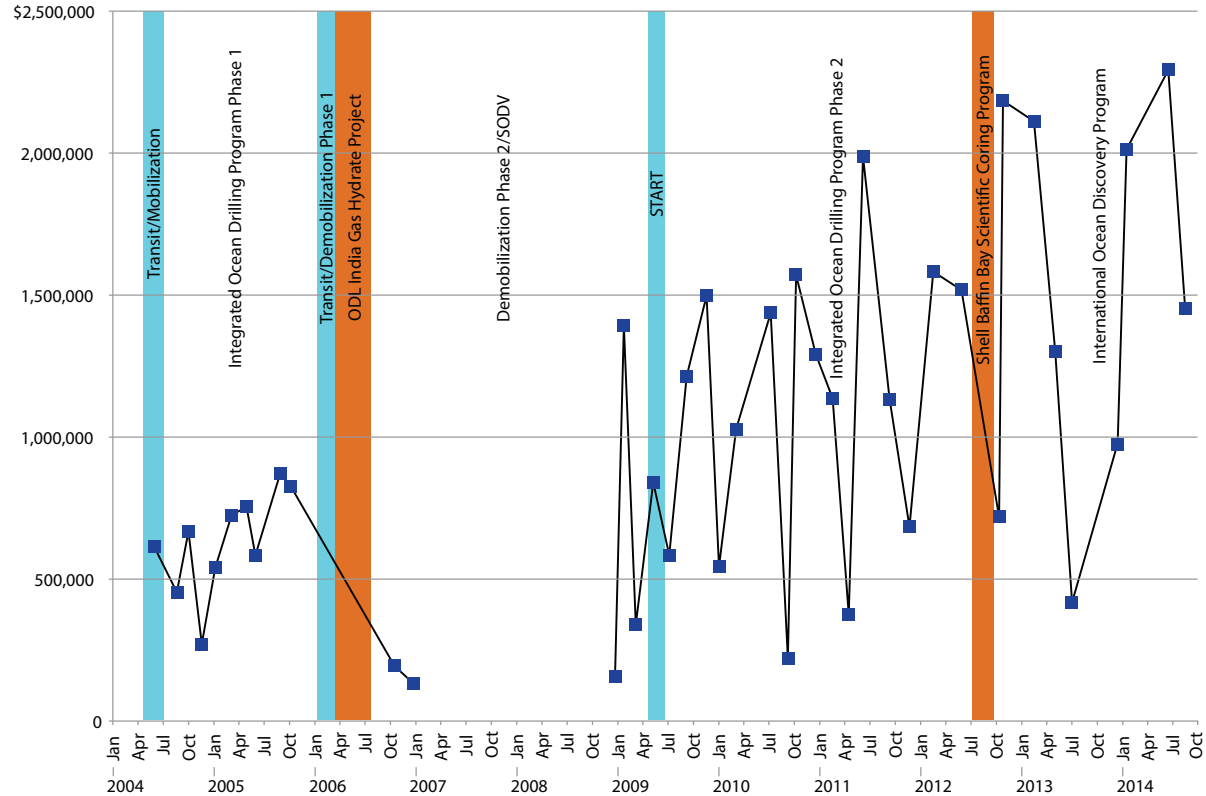
3. Remobilizing and renovating the *JOIDES Resolution*

Upon conclusion of ODP demobilization, the USIO remobilized and reoccupied the *JOIDES Resolution* in 2004 for Integrated Ocean Drilling Program Phase 1 expeditions. Remobilization efforts included

Table 1. USIO funding summary.

Year	Funding	Expenditures
FY04	25,172,752	22,441,918
FY05	43,559,364	44,863,429
FY06	17,561,797	15,748,173
FY07	8,752,985	7,564,598
FY08	37,510,191	35,391,741
FY09	50,122,565	51,720,988
FY10	38,817,381	38,069,220
FY11	64,157,334	64,747,203
FY12	61,797,059	56,125,308
FY13	62,150,418	66,214,829
FY14	63,794,889	62,109,950
Total	**$ 473,396,735**	**$ 464,997,357**

Figure 2. Fuel costs during the Integrated Ocean Drilling Program (2003–2014).



installing laboratory systems and equipping the laboratories, developing and testing new computer applications, calibrating and testing method verification on the newly installed instrument systems, assessing information technology (IT) needs and preparing the IT infrastructure, inspecting coring equipment for ship operations, and reconfiguring the very small aperture terminal (VSAT) satellite communications system.

> "This is a long-awaited day for the world of ocean research. The *JOIDES Resolution* is operational again for [Integrated Ocean Drilling Program] expeditions at an extremely important time, when our need for scientific understanding of our ocean planet—and climate and energy challenges—is at its greatest. The research pursuits of thousands of scientists around the globe will be enhanced in a major way by the future work of the *JOIDES Resolution*." —R. Gagosian, Ocean Leadership President and CEO

U.S. Scientific Ocean Drilling Vessel Project

Upon completion of the Integrated Ocean Drilling Program Phase I expeditions, the *JOIDES Resolution* spent 29 months (September 2006–January 2009) in the Jurong Shipyard in Singapore, where the ship's hotel and laboratory structure was replaced and the marine and drilling systems were completely refurbished. This major refit and modernization of the *JOIDES Resolution*, known as the U.S. SODV

Project, was funded by an NSF Major Research Equipment and Facilities Construction (MREFC) award. The USIO facilitated the SODV project, focusing on design, organization, and implementation of substantial upgrades to the *JOIDES Resolution*, including new and expansive engineering redesign and development of new analytical systems. USIO staff oversaw the refurbishment, including dockside testing of vessel equipment and systems, installation of furnishings, and replacement of all shipboard analytical systems. A Program Advisory Committee (PAC) with members from the scientific community and the drilling industry ensured community input and involvement in the project, and a dedicated website kept the community informed during the renovation.

The *JOIDES Resolution* in Ponta Delgada, Azores, before Expedition 306.

> "We are extremely pleased to see the *JOIDES Resolution* set sail once more for science—with a vastly improved capability for performing cutting-edge research into the secrets of Earth's past climate, past ocean conditions, deep biosphere and interior." —T. Killeen, NSF Assistant Director for Geosciences

Vessel refurbishment

The SODV Project replaced nearly everything inside the hull of the ship from the derrick forward, including the laboratories, accommodations, and bridge. The refurbishment included a 27% increase in overall square footage of the science facility spaces (including science offices and conference space) and a 34% increase in laboratory spaces.

Ship infrastructure and vessel systems

Hull refurbishment entailed sandblasting detritus off the hull, replacing steel where necessary, painting the hull above and below the waterline, refurbishing all thrusters, inspecting and reconditioning shafting and propellers, replacing shaft bearings, and aligning the propeller shaft. Except for the basic ship's hull, the existing structure forward of the drill rig was demolished and new steel decks, bulkheads, and a deckhouse were constructed on shore, lifted on board, and fitted to the vessel. This created a larger structure to provide increased space for laboratories, offices, accommodations, and recreational spaces.

The *JOIDES Resolution* with derrick, bridge, and labstacks removed.

Drilling equipment and infrastructure, including the derrick, were removed from the ship and refurbished; rackers were refurbished and modified to carry 6⅝ inch pipe. Vessel and drilling systems throughout the *JOIDES Resolution* were overhauled and refurbished, notably the top drive and passive heave systems and the propeller shafts, screws, and thrusters.

Dockside and at-sea testing of vessel equipment and systems included operation of the ship's generators; auxiliary equipment such as pumps and compressors; and heating, ventilation, and air conditioning (HVAC) air-handling units.

Refined and expanded accommodations

Additional berths designated for USIO staff and the Science Party were provided, bringing the total science berths to 60. New double-occupancy staterooms include shared toilets and showers, and improved noise reduction was incorporated throughout the accommodations.

Communications infrastructure

Dual VSAT units were installed to provide enhanced ship-to-shore communications for phone and e-mail service, video streaming, data file transfer, and shipboard system management from shore.

Information technology network and infrastructure

A new IT system was procured, tested, and installed, with system components that provided expanded data servers and storage systems with enhanced large file management, wireless network access throughout laboratories and living areas, a digital media management system, workstations, videoconference capability, and a video distribution system.

Logging infrastructure

Downhole logging operations were also completely renovated, including a new WHC and support systems and new wireline logging data acquisition instrumentation units. The WHC was installed near the rig floor to allow permanent wireline rig-up, thus reducing operational time and adding flexibility.

Onboard installation included a new motion reference unit (MRU) for acquiring acceleration data that control the movement of the WHC.

The logging IT system was integrated into the overall IT environment, and the logging office, telemetry laboratory, and downhole measurements laboratory were integrated into the forward deck house with the other laboratories to improve communication and facilitate greater scientific integration/exchange.

New science facilities and enhanced science system capabilities

The science laboratories were completely redesigned for better core handling, a more ergonomic workflow, and new and redesigned analytical systems. Improvements included increased bench space and chemical hoods; refrigerated storage for more than 8,000 meters of core; and an enclosed, sound-controlled core splitting and sampling room. The design also included safe, direct access to the Microbiology Isotope Laboratory container and a science conference facility capable of seating the entire science party.

Upgraded analytical systems included new data management capabilities built around an information management system, an Oracle database system, and a digital asset management system; a new sampling application that facilitates the different roles in the workflow of recording sample information; an upgrade of most of the chemistry instruments to state-of-the-art systems; a new set of core loggers built for rapid and nondestructive acquisition of images and other physical property data from whole-round and split drill cores; new instrumentation for moisture and density analysis, including a new dual-balance system and computer-controlled gas pycnometers; a new thermal conductivity instrument; a new core orientation tool system for orientation of APC cores; a new and innovative framework and application for data capture, description, and interpretation, including a database integrated into the information management system, controlled vocabularies and taxa name lists with version control, and an application with a highly configurable spreadsheet environment for data capture and visualization of context data collected with the core loggers and other instruments; and flexible and configurable data reporting and visualization using a combination of commercial and

Core description area in the core laboratory.

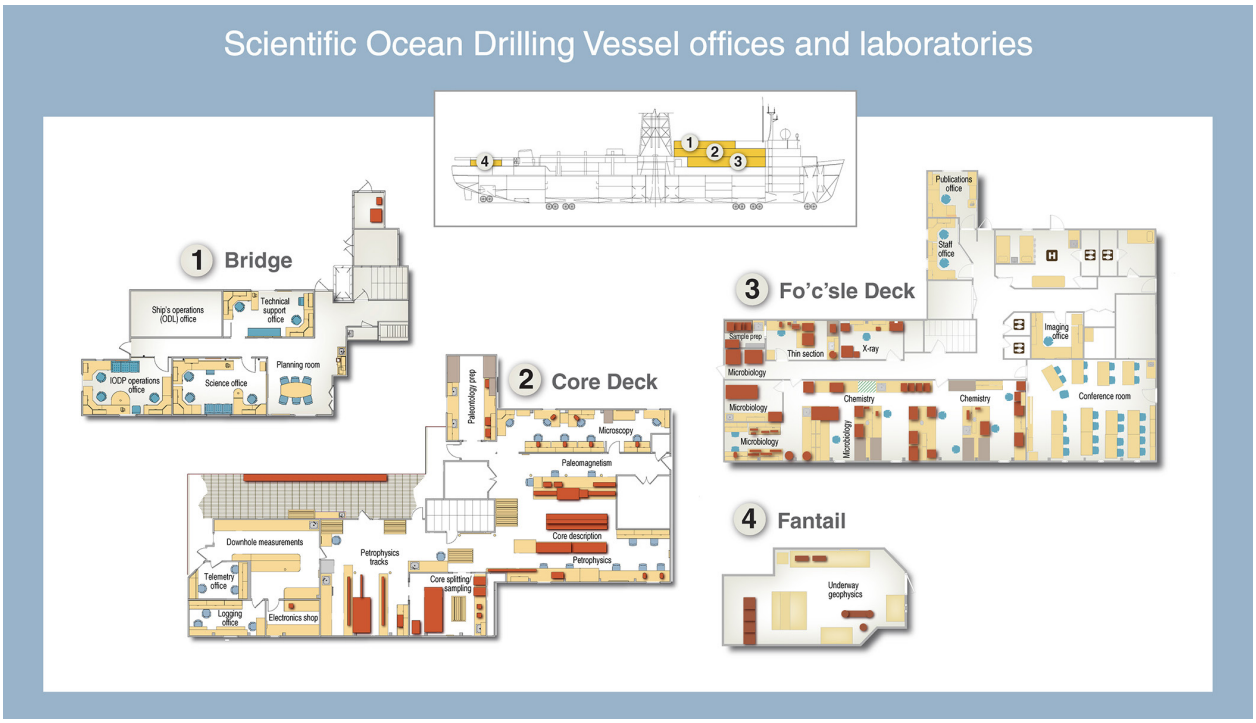
USIO-developed user applications for workflow-specific data extraction within the versatile shipboard working environment.

All laboratory equipment and systems underwent extensive testing on shore by the USIO before approval and release for shipboard installation. New analytical systems were tested by the SODV Science Systems Test-Drive Committee, an independent group of scientists from numerous institutions.

> "We found the capabilities presented in the science system computing infrastructure and the specific analytical systems we were able to review truly exciting. The systems we tested represent advances in fundamental components of the shipboard science capabilities, including petrophysics track systems, core description capabilities, uploading of chemistry data, and an integrated database structure unifying the shipboard science environment.... The science system and physical improvements result in a quantum leap in shipboard science capabilities, resulting in a truly transformative science environment." —SODV Science Systems Test-Drive Committee

Equipment and systems were shipped to Singapore and stored in warehouse facilities, and installation and onboard testing commenced as the shipyard completed outfitting of each laboratory. All shipboard personnel helped to secure equipment and instruments throughout the ship's laboratories and support facilities to ensure their seaworthiness in preparation for departure. Multidisciplinary teams focused on pre-acceptance and acceptance testing of the various systems as they came online, and equipment and

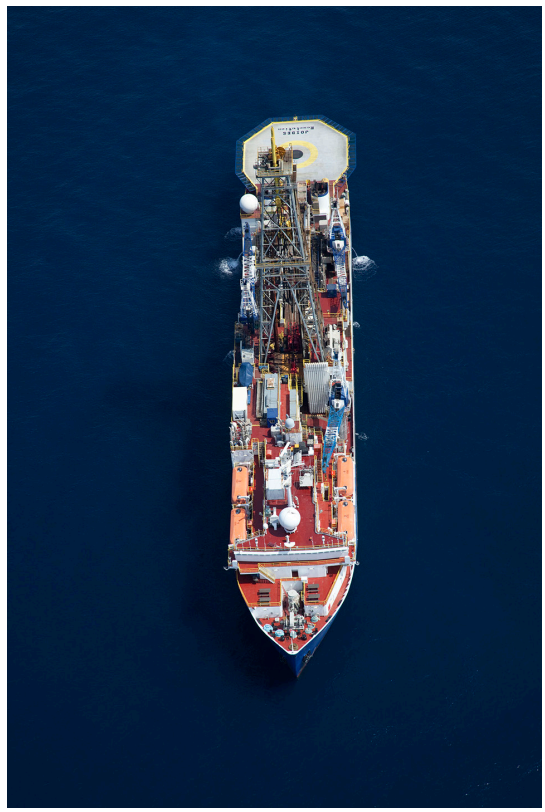
Figure 3. Diagram of ship's decks containing science spaces.



system testing satisfied the American Bureau of Shipping representatives, with a few minor adjustments required.

Sea Trials and Assessment of Readiness Transit

Following renovation of its interior spaces, operating systems, and laboratory facilities, the *JOIDES Resolution* successfully completed initial sea trials in the South China Sea during the ~6 week Sea Trials and Assessment of Readiness Transit (START) expedition conducted by the USIO to confirm the overall readiness of the refitted research vessel prior to the beginning of Integrated Ocean Drilling Program Phase 2 expeditions in 2009. During a transit that covered almost 6,000 nautical miles and included drilling a new site (U1330) in the Ontong Java Plateau near ODP Site 807, the ship's crew and USIO technical staff tested the ship's accommodations and drilling, coring, and navigation systems. USIO staff tested science and IT systems; organized collection, curation, and evaluation of core flow through the new laboratories; and uploaded all shipboard analytical measurements and descriptive observations and data to the new Laboratory Information Management System (LIMS) database. A group of seven independent scientists (the external Readiness Assessment Team [RAT]) evaluated science and IT systems and determined that the ship was ready for international scientific operations.



Aerial view of the renovated *JOIDES Resolution*.

> "The people in the trenches were put into very tough positions that included moving targets and changing deadlines. We need to acknowledge the tremendous work that took place under severe time and fiscal constraints. The Integrated Ocean Drilling Program and Transocean staff we interacted with during Expedition 320T and this readiness assessment continually rose to this challenge with professionalism and a can-do attitude." —Readiness Assessment Team report

4. Scientific results

The achievements of DSDP and ODP set the stage for understanding the complex manner in which different parts of the Earth system are linked. At the conclusion of ODP, this integrated Earth view was

fundamental to the development of the Integrated Ocean Drilling Program's ISP, which outlined the Program's vision for achieving a better understanding of (1) the deep biosphere and the subseafloor ocean; (2) environmental change, processes, and effects; and (3) solid earth cycles and geodynamics.

Integrated Ocean Drilling Program expeditions

From FY03 through FY13, the USIO undertook a series of expeditions designed to address the science themes outlined in the ISP. These expeditions are summarized in Table 2. Highlights of the expeditions as they relate to ISP theme and science focus are shown below. Core recovery by expedition for each science focus is shown in Figure 2.

Deep biosphere and subseafloor ocean

Hydrogeology

Juan de Fuca Ridge

USIO expeditions at Juan de Fuca Ridge (Expeditions 301, 321T, and 327) established the first large-scale, 3-D, cross-hole hydrologic experiments in oceanic crust using a network of observatory systems known as CORKs. Four new CORKs were installed, and one was replaced (in ODP Hole 1026B). The CORKs installed were newly designed third-generation (CORK-II) wellhead completions, a complex design that included a long 4½ inch casing string, packers, multiple miniscreens, osmotic samplers, and thermistors for the multiple zones to be isolated, sampled, and monitored. In each hole, multiple isolated intervals will continue to be monitored for pressure, temperature, chemistry, and microbiology, and these intervals will serve as observatory points for planned future cross-hole experiments.

> "Expedition 327 was a challenge, but this is the kind of challenge that helps to keep IODP at the forefront of Earth and Life Science research." —A. Fisher, Expedition 327 Co-Chief Scientist

Gulf of Mexico

Drilling into the Gulf of Mexico continental slope during Expedition 308 tested a multidimensional flow model by examining how physical properties, pressure, temperature, and pore fluid composition vary within low-permeability mudstones that overlie a permeable and overpressured aquifer, revealing an active hydrodynamic environment, and provided insight into geological processes near the seafloor. This expedition was the first contemporaneous monitoring of downhole pressure and lithology (using measurement while drilling [MWD]) and the first use of weighted mud to facilitate drilling through overpressured regimes.

Gas hydrates

Cascadia margin

Building on data acquired during ODP Legs 146 and 204 on the Cascadia margin, results from Expedition 311 changed our understanding of how gas hydrates occur in nature, as their distribution proved to be much more heterogeneous in this active continental margin than was previously anticipated. Data from cores acquired during Expedition 311 yielded a better understanding of the geologic controls, evolution, and ultimate fate of gas hydrate in an accretionary prism as an important contribution to the role of gas hydrate methane gas in climate change and slope stability.

During Expedition 328, an improved permanent hydrologic borehole observatory was installed near ODP Site 889 to facilitate pressure monitoring at multiple formation levels in the frontal part of the Cascadia accretionary prism. This advanced CORK (ACORK) system facilitates pressure monitoring at multiple formation levels on the outside of a 10¾ inch casing string, documenting pressure gradients, the formation of gas hydrates, and the influence of gas hydrates and free gas on host lithologies. At a later date, proponents will add geophysical instrumentation inside the ACORK casing and the observatory will be connected to the NEPTUNE Canada fiber-optic cable for power and real-time communications from land.

Deep biosphere

South Pacific Gyre

During Expedition 329, the *JOIDES Resolution* traveled 6,655 nautical miles to the South Pacific Gyre, one of the largest, most remote, and least explored areas of the world's ocean. Cores recovered will lead to key advances in the understanding of fundamental aspects of subseafloor life, metabolic activities, and biomass in this very low activity sedimentary ecosystem and also to advances in the understanding of geological processes, including the factors that control hydrothermal circulation and chemical alteration in the ocean crust, models of regional tectonic history, geodynamo models, and models of glacial–interglacial ocean-climate change.

Preparing CORK for deployment, Expedition 336.

North Pond/Mid-Atlantic Ridge

During Expedition 336, the USIO installed two fully functional

subseafloor CORK observatories in new holes, placed an instrument and sampling string in an existing hole, and prepared a fourth hole to allow later installation of a wireline-deployed CORK, establishing a long-term subseafloor experiment to determine the extent of microbial life in oceanic crust in the North Pond region of the Atlantic Ocean. The work completed during Expedition 336 will also provide an excellent point of comparison for the borehole instrumentation studies currently under way at the Juan de Fuca Ridge.

> "It feels much like pioneering the exploration of outer space in our own 'Apollo' mission. We don't understand most of this planet. We know more about the surfaces of other planets in the solar system than we do about the ocean floor. The North Pond is perfect because it is perfectly average and has seen scientists of all stripes recording various data about it for the past 40 years. We're building on a great history of research. We're trying to find the bottom of the biosphere."
> —K. Edwards, Expedition 336 Co-Chief Scientist

Environmental change, processes, and effects

Sea level change

Canterbury Basin

Operations during Expedition 317 in the Canterbury Basin set several ocean drilling records, including the deepest hole drilled on a shallow continental shelf (1,024 meters) and the deepest hole drilled during a single Integrated Ocean Drilling Program expedition (1,927 meters). Sediment was also recovered from the shallowest scientific drilling site (85 meters water depth) ever drilled with the *JOIDES Resolution* for scientific purposes. Cores taken during Expedition 317 revealed cyclic changes in sediment type and physical properties that are believed to reflect shifts between glacial and interglacial time periods, and sedimentary records from one site provide an archive of changes in ocean circulation that occurred when movements in Earth's tectonic plates separated Antarctica from Australia. With current climate models predicting sea level rise of possibly more than 1 meter in the next 100 years, direct analysis of samples chronicling the history of rising sea levels can help us prepare for further changes to Earth's coastlines.

Paleoceanography and paleoclimate

North Pacific

Bering Sea

A continuous ~5-million-year sediment record of climate change was collected during Expedition 323 in the Bering Sea to study how sea ice accelerates climate change and how subpolar ecosystems respond to climate change. This expedition provided the first examination of subseafloor biomass and microbial processes in a high-productivity region.

Gulf of Alaska

Cores retrieved from the Gulf of Alaska margin during Expedition 341 enable examination of the paleoceanography, regional tectonics, and deep-sea sedimentary environment from the late Miocene to the present through key Neogene climatic transitional intervals, including the mid-Pliocene warm period, the early Pleistocene intensification of Northern Hemisphere glaciation, and the mid-Pleistocene transition. Expedition 341 cores provide a unique opportunity to understand the interaction of tectonics, climate, and sedimentation on a high-latitude continental margin, and the expedition's success demonstrates that scientific ocean drilling has the potential to recover similar records from other optimally located high-latitude settings.

> "We expected to find detailed records of glacial deposition that fluctuate in accordance with the advance and retreat of glaciers and ice sheets. From what we've seen so far, these core samples exceed our expectations and provide critical data that were previously unavailable." —S. Gulick, Expedition 341 Co-Chief Scientist

North Atlantic

North Atlantic climate

The *JOIDES Resolution* drilled at strategic sites that record North Atlantic Pliocene–Quaternary climate changes. Each of the sites occupied during Expedition 303 was multiple-cored, and 4,656 meters of high-quality core with mean sedimentation rates in the 5–18 centimeter/k.y. range were recovered. In the coming years, research on these cores is expected to break new ground in the fields of paleoclimatology and paleoceanography. During Expedition 306, complete sedimentary sections were drilled, recovering 2,342 meters of core, and a CORK was installed in a new borehole (Hole U1315A) close to ODP Hole 642E. In the coming years, data from this observatory will provide the first directly measured record of bottom water temperature over the last approximately 100 years from an area of the North Atlantic that is very important in terms of paleoceanography.

Splitting frozen core, Expedition 307.

Porcupine Basin

A suite of three sites (on mound, upslope, and downslope) was drilled in Challenger Mound on the eastern slope of Porcupine Seabight during Expedition 307 to test the origin of the mound,

particularly the hypothesis of the possible role of fluid venting as the trigger for mound growth, and to assess the importance of environmental forcing factors. The results of this expedition favor a hypothesis that carbonate mounds are located where currents, controlled locally by seabed morphology, supply food and nutrients to the coral ecosystem.

Newfoundland sediment drifts

During Expedition 342, Paleogene sedimentary sequences with unusually high deposition rates were recovered across a wide range of water depths. The sites were positioned to capture sedimentary and geochemical records of ocean chemistry and overturning circulation beneath the flow of the Deep Western Boundary Current in the northwest Atlantic Ocean, which will enable studies of the dynamics of past abrupt climate change, including transitions into both "greenhouse" and "icehouse" climate states, the full magnitudes of hyperthermal events, and rates of change in the carbonate compensation depth in the North Atlantic.

> "This is a site that will go down truly in history, I think. Because we have, by far and away, the most detailed record of this sort of transition into a fully glaciated world—that exists anywhere on the globe—right here.... In our hold are cores of the North Atlantic reef, a great ocean suffocation, a meteor plowing in to the Yucatan, fantastic 'died yesterday' fossils of all kinds (never seen before out in the deep blue sea), extreme global change events when the world became a hothouse, and a grand-daddy of all glaciations when Antarctica became the ice continent...a tour of the sweet spots of the ancient world over the past 120 million years." —D. Norris, Expedition 342 Co-Chief Scientist

Mediterranean outflow

During Expedition 339 in the Gulf of Cádiz, more than 4,500 meters of core was recovered from contourite deposits, providing a new marine archive to compare against ice records from Greenland and Antarctic ice sheets and with numerous land-based records. These cores included the first sediment samples ever recovered from the deep subseafloor in this region, established the timing and style of the opening of the Strait of Gibraltar gateway, confirmed contourite models of sediment deposition, and unearthed a record of climate change covering at least four major ice ages over the past 1.5 million years.

Pacific

Western Pacific

Expedition 346 cored seven sites covering a wide latitudinal range in the marginal sea between the Japan archipelago and the Korean peninsula. Drilling penetrated into Miocene sediments at two sites and the Pliocene at four sites. Three sites yielded thick Late Pleistocene sections exhibiting very high

sedimentation rates. We gathered an unparalleled archive of atmospheric-ocean linkages relating to the East Asian monsoonal system. Cores obtained during the expedition will be used to test the hypothesis that uplift of the Himalaya and Tibetan Plateau, and the consequent emergence of the two discrete modes of Westerly Jet circulation, caused amplification of millennial-scale variability of the East Asian summer monsoon and East Asian winter monsoon and provided teleconnection mechanism(s) for Dansgaard–Oeschger cycles. Expedition 346 set a new Integrated Ocean Drilling Program coring record (6,135 meters collected during a single expedition) and the record for deepest APC penetration (490.4 meters below seafloor).

High recovery, Expedition 346.

Equatorial Pacific

A series of continuous sediment records from the equatorial Pacific, one of the largest and most climatically important ocean regions on Earth, was recovered during Expeditions 320 and 321, allowing the reconstruction of extreme changes of the calcite compensation depths across major geological boundaries during the last 53 million years. Cores recovered during these expeditions provide a unique sedimentary biogenic sediment archive for several important stratigraphic intervals, such as the Paleocene/Eocene boundary event, Eocene cooling, the Eocene–Oligocene transition, the "one cold pole" Oligocene, the Oligocene–Miocene transition, and middle Miocene cooling.

> "It's truly remarkable to see 53 million years of Earth's history pulled up onto the drill ship's deck, then pass through our hands, and move past our eyes. We saw first-hand the effects of Earth's climate machine in action." —H. Pälike, Expedition 320/321 Co-Chief Scientist

Southern Ocean

Wilkes Land

Drilling in the Wilkes Land margin off Antarctica during Expedition 318 recovered a direct record of waxing and waning Antarctic ice. The Wilkes Land cores reveal details of regional tectonic history, document rifting between Australia and Antarctica, provide a direct record of severe and sudden changes in Antarctica's environment, reflect a geological history of 54 million years, and provide proof that Antarctica was once (~53 million years ago) a warm, lush, subtropical environment. Data from this

expedition will be used to create more effective global climate models and, therefore, more accurate predictions of future climate changes.

> "The new [Expedition 318] cores offer an unprecedented ability to decipher the history of glaciation in Antarctica. The climate record they preserve is immensely valuable, especially for testing how well current global climate models reproduce past history." —J. Allan, Program Director, Ocean Drilling Program, Ocean Sciences Division, National Science Foundation

Solid earth cycles and geodynamics

Seismogenesis

Middle America Trench

Complementing other deep-fault drilling (San Andreas Fault Observatory at Depth [SAFOD], the Nankai Trough Seismogenic Zone Experiment [NanTroSEIZE], and the Japan Trench Fast Drilling Project [J-FAST]), the Costa Rica Seismogenesis Project (CRISP) Program A investigated the seismogenic processes common to most faults and those unique to erosional margins and explored the only known erosional end-member of convergent margins within reach of scientific drilling. During Expedition 334, the USIO collected nearly 1,500 meters of sediment core that reveals detailed records of some 2 million years of tectonic activity along a seismic plate boundary offshore Costa Rica. The expedition also recovered ~170 tephra layers with ages ranging from middle Miocene to the present. Expedition 344 continued the CRISP project, recovering 484 meters of sediment, 96 meters of basaltic crust, and an additional ~137 tephra layers. Postexpedition analyses of the tephra will yield new insights into the evolution of Central American volcanism.

Volcanism and landslides

Lesser Antilles

During Expedition 340, the *JOIDES Resolution* drilled into marine and volcanoclastic material on the Lesser Antilles arc to explore the constructive and destructive processes related to island arc volcanism. Correlation of the chaotic deposits identified on seismic reflection profiles with sequences of turbidites or deformed marine sediment

Leaf fossil at the end of a core, Expedition 344.

recovered during the expedition will lead to a better understanding of processes related to the instabilities of the Lesser Antilles volcanoes and provide new perspectives for studies of similar volcanic settings. Development of a detailed chronology of the recovered tephras will allow characterization of the eruptive history, magmatic cycles, and long-term evolution of the arc.

Montserrat Island from the *JOIDES Resolution*, Expedition 340.

Ocean crust and plateau formation

Slow-spreading crust

Atlantis Massif

The sequence of intrusive rocks cored at Site U1309 (Expeditions 304 and 305) in the Atlantis Massif and the high recovery rates (75%) provided an unexpected wealth of information on petrologic, alteration, and structural processes that characterize the magmatic construction of young oceanic crust at slow-spreading ridges. Because the petrology and alteration of the sequence varies on the scale of meters to a few tens of meters, these cores enable study of relationships that could not be addressed with prior ODP hard rock cores. In addition, a complete set of very high quality downhole measurements was obtained, certainly the best ever recorded in igneous rocks. This, together with the high core recovery, offers a unique opportunity to establish core-log structural integration. Borehole logging of Hole U1309D during Expedition 340T enabled scientists to study geophysical properties of the dominantly gabbroic section in situ for the first time and provided measurements that will allow scientists to infer how gabbroic rocks will appear on future seismic surveys, making it easier to map subseafloor geophysical structures. Hole U1309D is a unique, open, deep hole into the oceanic crust that is viewed as an important Integrated Ocean Drilling Program legacy to the marine geosciences community.

> "Vast ocean basins cover most of the Earth, yet their crust is formed in a narrow zone. We're studying that source zone to understand how rifting and magmatism work together to form a new plate." —D. Blackman, Expedition 340T Co-Chief Scientist

Fast-spreading crust

Hess Deep

Building upon results from ODP Leg 147 as well as more recent submersible, remotely operated vehicle (ROV), and near-bottom surveys, Expedition 345 sampled lower crustal primitive gabbroic rocks that formed at the fast-spreading East Pacific Rise. The expedition recovered the first drilled sections of primitive gabbroic rocks formed at a fast-spreading ridge, provided the first confirmation of predictions that fast-spreading lower oceanic crust is layered, and revealed a diversity of layering whose characteristics have similarities and differences to both layered sequences in ophiolites and layered mafic intrusions. Moreover, the core revealed significant unexpected mineralogical and textural diversity, some of which has been rarely observed in the lower oceanic crust elsewhere or in ophiolites. The core record from Expedition 345 will be a reference section, for now the only reference section, for fast-spreading primitive ocean crust, which covers about half the Earth's surface.

> "These rocks represent one of the first reference sections for oceanic lower crust in a known tectonic setting. Future studies in other settings will be measured and compared against [Expedition 345], and past ones reassessed. These samples could not have been acquired through any other means, highlighting the importance of ocean drilling as a technique for studying the evolution of our planet." —J. Snow, Expedition 345 Co-Chief Scientist

Superfast spreading rate crust

Guatemala Basin

The multipart Superfast Spreading Rate Crust drilling project took place in a 15-million-year-old region of the Pacific Ocean that formed when the East Pacific Rise was spreading at a "superfast" rate (more than 200 millimeters per year), faster than any mid-ocean ridge on Earth today. Expeditions 309, 312, and 335 used rotary core barrel (RCB) coring to deepen ODP Hole 1256D and drill a complete section of the upper oceanic crust, extending the hole into the underlying gabbros, through the dike–gabbro transition, and into the cumulate gabbros that compose the lower oceanic crust. Although operations involved drilling into metamorphic rock as hard as any formation ever encountered during ocean drilling, the remarkable suite of heat-tempered basalts recovered

Rotary core drill bits before and after drilling, Expedition 312.

provides a detailed picture of the rarely seen boundary between magma and seawater. In addition, hole-cleaning operations recovered granoblastic and minor gabbroic rocks as large as 3.5 kilograms (~7.7 pounds) that preserve a complex history of recrystallization, hydrothermal alteration, and small-scale intrusions that could not have been observed on a core scale. The expedition series overcame significant engineering challenges, including clearing major obstructions in the previously open part of the hole and remediating and stabilizing the hole following bit failure. Expedition 335 left Hole 1256D, one of the deepest hard rock penetration sites of scientific ocean drilling, stabilized, cleared to its full depth, and primed for further deepening.

> "The formation of new crust is the first step in Earth's plate tectonic cycle. This is the principal mechanism by which heat and material rise from within the Earth to the surface of the planet. And it's the motion and interactions of Earth's tectonic plates that drive the formation of mountains and volcanoes, the initiation of earthquakes, and the exchange of elements (such as carbon) between the Earth's interior, oceans, and atmosphere." —D. Teagle, Expedition 335 Co-Chief Scientist

Large igneous provinces

Shatsky Rise

During Expedition 324, a wide range of samples was collected from Shatsky Rise that will enable scientists to address the fundamental question of whether Shatsky Rise and other large oceanic plateaus were formed by a deep-rooted mantle plume or by shallow, plate tectonic-related processes. Expedition 324 offered a unique opportunity to study the origin of supervolcanoes because Shatsky Rise Plateau formed at a rapidly spreading triple junction with characteristics that could be attributed to both the plume and the plate-tectonic origin hypotheses of ocean plateau formation and is also the only large oceanic plateau formed during a time when Earth's magnetic field reversed frequently. The magnetic reversal process created "magnetic stripe" patterns in the seafloor that will allow scientists to better understand the formation of this oceanic plateau and its relationship to the surrounding tectonic plates and triple junctions, making Shatsky Rise one of the best locations on Earth to test the plume versus plate-tectonic origin hypotheses of ocean plateau formation.

Hotspot motion

Louisville Seamount Trail

Expedition 330 drilled into an extinct 4,300-kilometer-long volcanic chain (Louisville Seamount Trail) built over the past 80 million years as the Pacific plate moved over a hotspot, obtaining results that indicate the Louisville Seamount hotspot remained relatively stationary between 80 and 50 million years ago in contrast to the Hawaiian mantle plume, suggesting that flow in the mantle behaves regionally rather than globally. Core recovery during Expedition 330 was outstanding, with an average of 72.4%,

which included a record-breaking 88% of basement recovery at Site U1374 on Rigil Guyot. In addition, the combined recovered sample material from Expeditions 329, 330, and 336 comprises the largest collection of basement rock ever collected for microbiology research during 40 years of scientific ocean drilling.

Discussing sampling, Expedition 330.

> "Submarine volcanic trails like the Louisville Seamount Trail are unique because they record the direction and speed at which tectonic plates move.... The challenge is that no one knows if hotspots are truly stationary—or if they somehow wander over time. If they wander, then our calculations of plate direction and speed need to be re-evaluated. But even more importantly, the results of this expedition will give us a more accurate picture of the dynamic nature of the interior of the Earth on a planetary scale." —A. Koppers, Expedition 330 Co-Chief Scientist

International Ocean Discovery Program expeditions

In FY14, the USIO conducted the first four expeditions to address science themes outlined in *Illuminating Earth's Past, Present, and Future*, the 2013–2023 science plan for the International Ocean Discovery Program (IODP). This science plan outlines the vision for achieving a better understanding of (1) climate and ocean change, (2) biosphere frontiers, (3) Earth connections, and (4) Earth in motion. These expeditions are summarized in Table 3, and highlights of the expeditions as they relate to the Earth Connections theme of the science plan are discussed below.

Earth connections

South China Sea

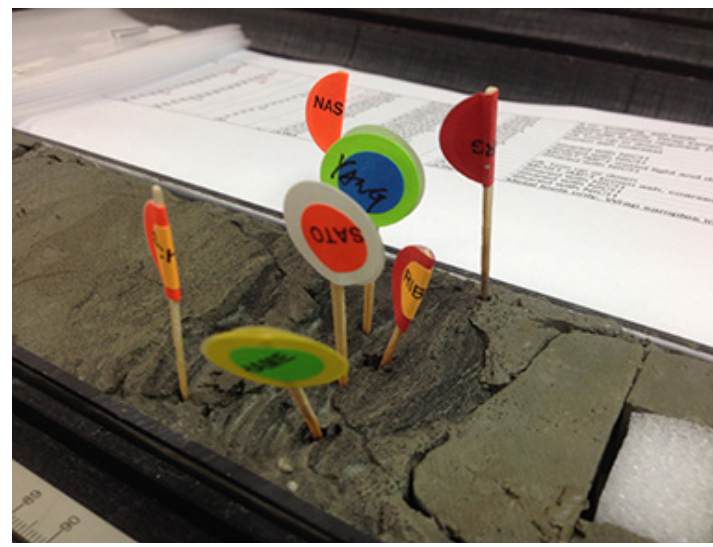
Five sites were drilled in the deep basin of the South China Sea during Expedition 349, recovering a total of 1,524 meters of sediment/sedimentary rock and 78 meters of oceanic basalt. Based on shipboard results, oceanic basement rocks are typical mid-ocean-ridge basalts, and biostratigraphic ages of the sediments immediately above the basaltic basement suggest preliminary age for the cessation of spreading to be early Miocene (16–20 Ma). There appears to not be a large difference in spreading age between the subbasins. Postexpedition dating of the basalt will be required to verify preliminary

shipboard results. Recovery of an unconformity at ~33 Ma between overlying deep marine and shallow near-shore marine sediments at Site U1345 is interpreted to be the approximate age of initiation of seafloor spreading.

Izu-Bonin-Mariana arc system

Izu-Bonin-Mariana rear arc

Expedition 350 Site U1437, situated in the Izu-Bonin-Mariana (IBM) rear arc, was located to characterize "the missing half of the subduction factory." Five holes were occupied at Site U1437, one of which included installation of the longest casing deployed from the *JOIDES Resolution* (1,085.6 meters) that reached the total depth of 1,804 meters below seafloor (Hole U1437E). Site U1437 appears to provide a complete tephra record, including (1) Miocene to present "hot fingers" magmatism, which produced the volcano-bounded basin drilled at Site U1437, and (2) Oligocene–Eocene(?) rear-arc magmatism, which is interpreted to have produced most of the Izu arc middle crust but has never been recovered in the IBM rear arc. The Oligocene–Eocene(?) rear-arc record will allow comparison with the previously drilled fore-arc magmatic record and determination of across-arc geochemical variation throughout the history of the arc system, which is fundamental to understanding subduction zone magmatism.



Ash layers flagged for sampling, Expedition 350.

Izu-Bonin-Mariana arc origins

Expedition 351 successfully accomplished its primary and most of its secondary objectives at Site U1438, penetrating the uppermost oceanic igneous basement. The voluminous volcaniclastic materials recovered from the Eocene through Oligocene sediment sequence contain sufficiently fresh glass and igneous minerals to allow comprehensive petrological and geochemical studies to determine the IBM arc compositional evolution during the Paleogene. The fundamentally important discoveries of the age and composition of the oceanic basement at Site U1438, such as variably altered and veined sheeted lava flows, provide critical constraints on the inception of the intra-oceanic IBM arc. It appears that major motion changes of the Pacific plate following subduction of the Izanagi-Pacific Ridge along East Asia led to reorganization of equatorially located networks of island arc systems in the region between the Australian and Asian plates. The Philippine Sea plate developed in this region and experienced

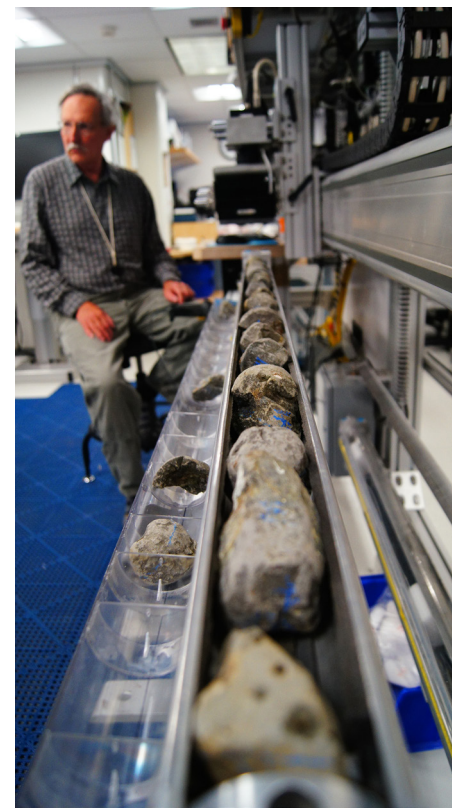
trench roll-back at one or more of its bounding plate margins. The oldest magmatic basement of the IBM arc is extensive, both latitudinally and longitudinally, developed in a seafloor spreading regime, and is dominated by tholeiitic magmas.

Izu-Bonin-Mariana fore arc

Expedition 352 successfully cored 1.22 kilometers of igneous basement and 0.46 kilometers of overlying sediment, providing diverse, stratigraphically controlled suites of fore-arc basalts (FABs) and boninite related to seafloor spreading and earliest arc development. FABs were recovered at the two deeper water sites (U1440 and U1441) and boninites at the two sites drilled upslope to the west (U1439 and U1442). The presence of dikes at the base of the sections at Sites U1439 and U1440 provides evidence that boninitic and FAB lavas are both underlain by their own conduit systems, and that FAB and boninite group lavas are likely offset more horizontally than vertically. We thus propose that seafloor spreading related to subduction initiation migrated from east to west after subduction initiation and during early arc development. Initial spreading was likely rapid, and an axial magma chamber was present. Melting was largely decompressional during this period, but subducted fluids affected some melting. As subduction continued and spreading migrated to the west, the embryonic mantle wedge became more depleted and the influence of subducted constituents dramatically increased, causing the oceanic crust to be built of boninitic rather than tholeiitic magma. The general decrease in fractionation upward reflects the eventual disappearance of persistent magma chambers, either because spreading rate was decreasing with distance from the trench or because spreading was succeeded by off-axis magmatism trenchward of the ridge.

Summary

Integrated Ocean Drilling Program and IODP USIO expeditions significantly expanded the scope of the predecessor programs and made fundamental contributions to our understanding of Earth. More than 825 international scientists sailed on USIO expeditions that retrieved 9,413 cores—more than 62,000 meters of sediment and rock—leading to more than 600 Program publications and nearly 680 peer-reviewed scientific publications.



Imaging a whole round basalt core, Expedition 352.

Table 2. Integrated Ocean Drilling Program USIO expedition summary.

Exp	Start date	End date	Port	Sites	Region	Staff Scientists (TAMU, LDEO)	Co-Chief Scientists
301	27-Jun-04	21-Aug-04	Astoria, Oregon (USA)	1026, U1301	Juan de Fuca Ridge	A. Klaus, G. Iturrino	A. Fisher, T. Urabe
301T	21-Aug-04	25-Sep-04	Astoria, Oregon (USA)	1253, 1255	Middle America Trench	NA	M. Kastner
303	25-Sep-04	17-Nov-04	St. John's, Newfoundland (Canada)	U1302–U1308	North Atlantic	M. Malone, S. Robinson	J. Channell, T. Sato
304	17-Nov-04	8-Jan-05	Ponta Delgada, Azores (Portugal)	U1310, U1311	Atlantis Massif	J. Miller, F. Einaudi	D. Blackman, B. John
305	8-Jan-05	2-Mar-05	Ponta Delgada, Azores (Portugal)	U1309	Atlantis Massif	J. Miller, H. Delius	B. Ildefonse, Y. Ohara
306	2-Mar-05	26-Apr-05	Ponta Delgada, Azores (Portugal)	U1312–U1315	North Atlantic	C. Alvarez Zarikian, S. Higgins	T. Kanamatsu, R. Stein
307	26-Apr-05	31-May-05	Dublin, Ireland	U1316–U1318	Porcupine Basin	T. Williams, P. Gaillot	T. Ferdelman, A. Kano
308	31-May-05	10-Jul-05	Mobile, Alabama (USA)	U1319–U1324	Gulf of Mexico	C. John, G. Iturrino	P. Flemings, J. Behrmann
309	8-Jul-05	28-Aug-05	Cristobal, Panama	1256	Guatemala Basin	N. Banerjee, F. Einaudi	D. Teagle, S. Umino
311	28-Aug-05	29-Oct-05	Astoria, Oregon (USA)	U1325–U1329	Cascadia Margin	M. Malone, G. Guerin	M. Riedel, T. Collett
312	29-Oct-05	29-Dec-05	Acapulco, Mexico	1256	Guatemala Basin	N. Banerjee, M. Reichow	J. Alt, S. Miyashita
320	5-Mar-09	5-May-09	Honolulu, Hawaii (USA)	U1331–U1336	Equatorial Pacific	A. Klaus, H. Evans	H. Pälike, H. Nishi
321	5-May-09	5-Jul-09	Honolulu, Hawaii (USA)	U1337, U1338	Equatorial Pacific	K. Gamage, A. Malinverno	M. Lyle, I. Raffi
321T	22-Jun-09	5-Jul-09	San Diego, California (USA)	U1301	Juan de Fuca Ridge	K. Gamage	A. Fisher
323	5-Jul-09	4-Sep-09	Victoria, British Columbia (Canada)	U1339–U1345	Bering Sea	C. Alvarez Zarikian, G. Guerin	C. Ravelo, K. Takahashi
324	4-Sep-09	3-Nov-09	Yokohama, Japan	U1346–U1350	Shatsky Rise	J. Geldmacher, G. Iturrino	W. Sager, T. Sano
317	4-Nov-09	3-Jan-10	Townsville, Australia	U1351–U1354	Canterbury Basin	P. Blum, A. Slagle	C. Fulthorpe, K. Hoyanagi
318	3-Jan-10	8-Mar-10	Wellington, New Zealand	U1355–U1361	Wilkes Land	A. Klaus, A. Fehr, T. Williams	C. Escutia, H. Brinkhuis
327	5-Jul-10	5-Sep-10	Victoria, British Columbia (Canada)	U1362, U1363, U1301, 1027	Juan de Fuca Ridge	K. Petronotis, S. Mrozewski	A. Fisher, T. Tsuji
328	5-Sep-10	18-Sep-10	Victoria, British Columbia (Canada)	U1364	Cascadia Margin	M. Malone	E. Davis
329	9-Oct-10	13-Dec-10	Papeete, Tahiti	U1365–U1371	South Pacific Gyre	C. Alvarez Zarikian, H. Evans	S. D'Hondt, F. Inagaki
330	13-Dec-10	11-Feb-11	Auckland, New Zealand	U1372–U1377	Louisville Seamount Trail	J. Geldmacher, L. Anderson	A. Koppers, T. Yamazaki
334	13-Mar-11	13-Apr-11	Puntarenas, Costa Rica	U1378–U1381	Middle America Trench	N. Stroncik, A. Malinverno	P. Vannucchi, K. Ujiie
335	13-Apr-11	3-Jun-11	Puntarenas, Costa Rica	1256	Guatemala Basin	P. Blum, G. Guerin	D. Teagle, B. Ildefonse
336	16-Sep-11	19-Nov-11	Bridgetown, Barbados	395, U1382–U1384	North Pond, Mid-Atlantic Ridge	A. Klaus, L. Anderson	K. Edwards, W. Bach
339	19-Nov-11	19-Jan-12	Ponta Delgada, Azores (Portugal)	U1385–U1391	Gulf of Cadiz and West Iberian Margin	C. Alvarez Zarikian, T. Williams	F. Hernandez-Molina, D. Stow
340T	15-Feb-12	2-Mar-12	Lisbon, Portugal	U1309, U1392	Atlantis Massif	A. Slagle, G. Guerin	D. Blackman
340	2-Mar-12	17-Apr-12	Lisbon, Portugal	U1393–U1401	Lesser Antilles	A. Klaus, A. Slagle	A. Le Friant, O. Ishizuka
342	2-Jun-12	1-Aug-12	St. George, Bermuda	U1402, U1403–U1411	J-Anomaly and Southeast Newfoundland Ridges	P. Blum, A. Fehr	R. Norris, P. Wilson
344	23-Oct-12	11-Dec-12	Balboa, Panama	U1380, U1381, U1412–U1414	Middle America Trench	K. Petronotis, A. Malinverno	R. Harris, A. Sakaguchi
345	11-Dec-12	12-Feb-13	Puntarenas, Costa Rica	U1415	Hess Deep	A. Klaus, G. Guerin	K. Gillis, J. Snow
341S	19-May-13	29-May-13	Victoria, British Columbia (Canada)	858, U1416	Juan de Fuca Ridge and Cascadia Margin	A. Klaus, G. Iturrino	I. Kulin, M. Riedel
341	29-May-13	29-Jul-13	Victoria, British Columbia (Canada)	U1417–U1421	Southern Alaska Margin	L. Schneider, A. Slagle	J. Jaeger, S. Gulick
346	29-Jul-13	27-Sep-13	Valdez, Alaska (USA)	U1422–U1430	Japan Sea, Northern East China Sea	C. Alvarez Zarikian, J. Lofi	R. Tada, R. Murray

Figure 4. Thematic map of Integrated Ocean Drilling Program USIO expeditions and recovery

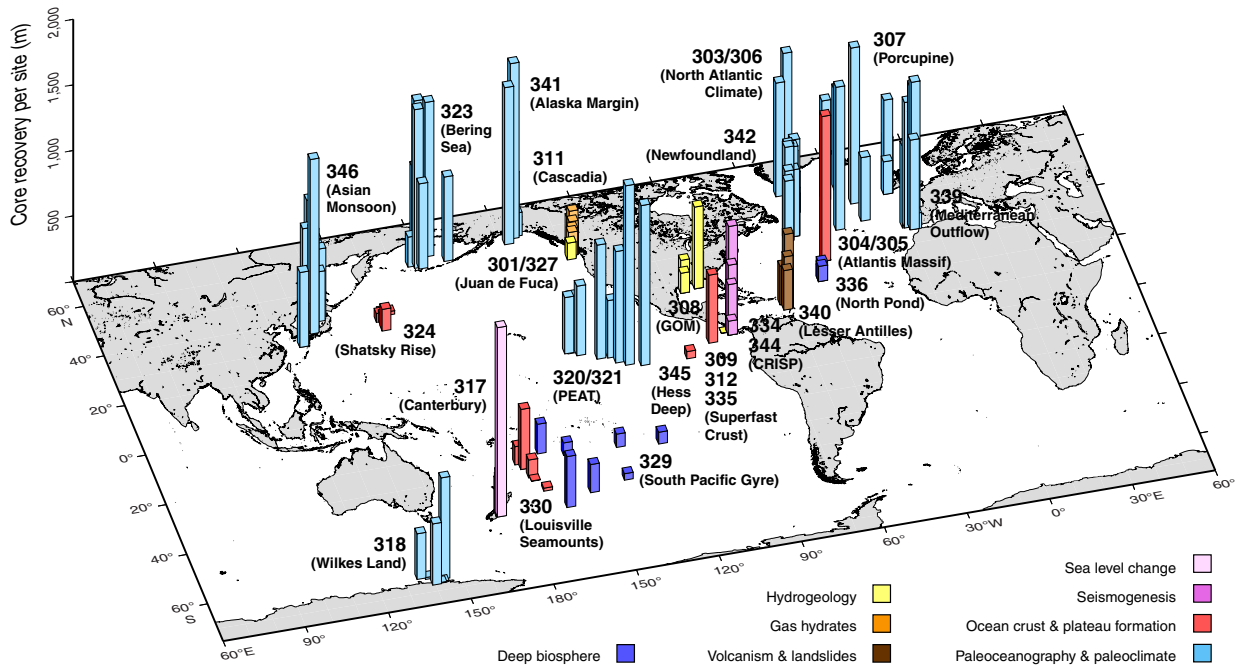


Table 3. International Ocean Discovery Program USIO expedition summary.

Exp	Start date	End date	Port	Sites	Region	Staff Scientists (TAMU, LDEO)	Co-Chief Scientists
349	26-Jan-14	30-Mar-14	Hong Kong, China	U1431–U1435	South China Sea	D. Kulhanek, T. Williams	C.-F. Li, J. Lin
350	30-Mar-14	30-May-14	Keelung, Taiwan	U1436–U1437	Izu-Bonin-Mariana Rear Arc	P. Blum, G. Guerin	Y. Tamura, C. Busby
351	30-May-14	30-Jul-14	Yokohama, Japan	U1438	Izu-Bonin-Mariana Arc	K. Bogus, L. Drab	R. Arculus, O. Ishizuka
352	30-Jul-14	29-Sep-14	Yokohama, Japan	U1439–U1442	Izu-Bonin-Mariana Fore Arc	K. Petronotis, S. Morgan	J. Pearce, M. Reagan

5. Engineering and Science Operations

USIO drilling, coring, and logging operations

The USIO planned, staffed, and completed 34 *JOIDES Resolution* expeditions and 4 single-purpose mini-expeditions during transits. Expedition shipboard staff ensured smooth, safe vessel and drilling operations; working laboratories; and databases and provided the experience and skills necessary to enable the shipboard Science Parties to maximize science delivery. By the end of Expedition 352 in the fourth quarter of FY14, the *JOIDES Resolution* had traveled ~110,874 nautical miles and occupied 154 sites, drilling 460 holes. The northernmost hole (U1345A) was located at 60°9.1917'N, 179°28.2036'W in the Bering Sea and the southernmost (U1357C) at 66°24.8013'S, 140°25.4651'E was in the Adélie Basin off the Wilkes Land margin of Antarctica. Coring operations were successfully conducted in water depths ranging from 84.2 meters (~276 feet) to 5,696.6 meters (~18,689 feet) below sea level. The deepest hole drilled extended 1,927 meters (~6,322 feet) below the seafloor. A total of 9,413 cores were collected,

Table 4. *JOIDES Resolution* FY04–FY14 expedition coring and logging summary.

Exp	Meters cored	Cores recovered (number)	Core recovered (m)	Core recovery (%)	Meters logged
301	455.40	61	254.53	55.89	528.80
301T	0.00	0	0.00	0.00	0.00
303/306	6,968.50	754	6,998.90	100.44	1,148.40
304/305	1,551.20	326	1,107.93	71.42	1,517.30
307	1,529.40	181	1,384.92	90.55	622.50
308	1,386.20	166	1,300.20	93.80	2,036.60
309/312	755.30	158	229.13	30.34	2,691.10
311	1,615.90	180	1,190.10	73.65	3,139.50
317	4,505.20	555	2,338.68	51.91	3,425.80
318	3,071.90	331	1,972.60	64.21	990.20
320T	111.30	12	103.26	92.78	555.00
320/321	6,322.40	712	6,140.82	97.13	1,208.90
321T	0.00	0	0.00	0.00	0.00
323	5,896.50	669	5,740.90	97.36	2,288.30
324	923.30	113	363.50	39.37	1,083.80
327	337.70	46	169.97	50.33	528.00
328	0.00	0	0.00	0.00	0.00
329	1,321.80	194	1,168.80	88.42	115.10
330	1,113.71	161	806.31	72.40	704.80
334	1,761.90	221	1,492.88	84.73	1,419.70
335	14.50	5	1.64	11.31	1,521.60
336	645.50	80	359.40	55.68	1,145.00
339	6,301.60	681	5,446.66	86.43	3,542.40
340T	0.01	1	0.01	100.00	1,415.50
340	3,487.50	434	2,384.25	68.37	878.20
342	5,741.90	657	5,412.52	94.26	0.00
344	2,017.60	253	1,471.10	72.91	608.00
345	300.50	45	55.17	18.36	0.00
341S	0.00	0	0.00	0.00	0.00
341	5,474.40	682	3,239.73	59.20	2,285.00
346	6,045.90	815	6,135.29	101.50	1,478.00
349	2,506.30	273	1,602.83	64.00	1,317.00
350	2,123.20	264	1,359.81	64.05	963.00
351	1,706.30	189	1,225.84	71.80	2,206.00
352	1,684.60	194	561.23	33.30	1,042.00
Total	**77,677.42**	**9,413**	**62,018.91**	**79.84**	**38,642.50**

yielding 62,019 meters (~203,474 feet) of core material for study. The coring and logging summaries for each expedition are available in Table 4, and details of the operational data for each expedition are available in Table 5.

USIO operational and laboratory advancements

Operational and engineering advancements

During the Integrated Ocean Drilling Program and the first year of IODP, improvements were made in operational and engineering techniques, tools, hardware, and systems as financial constraints allowed.

Table 5. ***JOIDES Resolution*** FY04–FY14 operational days/on-site breakdown.

Exp	Coring, drilling, tripping (days)	Logging & downhole tools (days)	Reentry, casing, cementing (days)	Remedial action (days)	Engineering, completion, CORK (days)	Lost time [weather, breakdown] (days)	Other (days)	Total days on site
301	14.57	4.35	19.75	2.97	9.79	0.16	0.70	52.29
301T	0.00	0.00	0.00	0.00	0.00	0.00	3.98	3.98
303	31.07	0.50	0.00	0.00	0.00	0.99	0.24	32.80
304	26.73	2.23	1.40	0.07	9.94	0.04	0.49	40.90
305	35.37	4.19	0.64	0.00	0.00	0.00	0.15	40.35
306	13.26	1.66	2.70	0.00	0.80	8.31	1.48	28.21
307	9.78	1.88	0.00	0.00	0.00	0.00	0.23	11.89
308	21.52	1.91	0.78	0.00	0.00	0.19	0.90	25.30
309	34.95	3.54	0.13	0.00	0.00	0.00	0.48	39.10
311	21.16	12.46	0.00	0.00	0.00	1.66	1.38	36.66
312	22.54	3.63	0.53	3.14	0.00	0.00	4.72	34.56
320T	4.07	2.01	0.05	0.00	0.00	0.00	0.94	7.07
320	33.94	1.16	0.19	0.65	0.00	1.07	0.10	37.11
321	21.64	3.72	0.00	0.00	0.00	0.17	1.15	26.68
321T	0.47	0.00	0.78	0.00	0.00	0.00	3.06	4.31
323	31.22	3.30	0.00	0.00	0.00	0.59	0.00	35.11
324	26.96	4.45	0.39	0.00	0.00	0.92	0.13	32.85
317	38.76	4.68	0.00	0.00	0.00	0.81	0.52	44.77
318	27.22	3.11	0.20	0.00	0.00	4.86	0.22	35.61
327	37.57	2.86	3.30	0.99	5.89	0.19	5.15	55.95
328	3.14	0.00	3.20	0.00	0.73	0.16	0.11	7.34
329	31.42	0.68	0.00	0.00	0.00	1.48	0.10	33.68
330	37.15	3.95	1.81	1.59	0.00	0.00	0.19	44.69
334	17.46	6.29	0.00	0.00	0.00	0.20	0.99	24.94
335	35.89	1.42	2.22	0.70	0.00	0.35	0.85	41.43
336	33.01	3.66	4.10	0.00	5.20	1.57	0.64	48.18
339	45.93	3.60	1.30	0.11	0.00	0.00	0.21	51.15
340T	1.39	2.82	0.32	0.00	0.00	0.22	0.19	4.94
340	31.56	3.82	0.17	2.80	0.00	0.03	0.17	38.55
342	44.24	1.18	0.18	0.00	0.76	0.82	0.36	47.54
344	37.52	3.34	3.39	0.55	0.00	0.54	0.16	45.50
345	36.76	0.65	6.41	0.47	0.00	0.41	1.21	45.91
341S	2.51	0.00	3.31	0.00	0.48	0.00	1.11	7.41
341	47.64	4.83	0.13	0.00	0.00	0.30	0.23	53.13
346	27.73	2.10	0.35	0.00	0.00	0.00	0.86	31.05
349	43.32	2.57	3.42	1.14	0.00	0.13	0.73	51.30
350	42.27	1.04	4.68	0.50	0.00	0.28	1.56	50.33
351	37.22	3.15	3.25	0.46	0.00	3.41	2.13	49.60
352	40.27	2.66	3.19	0.16	0.00	1.54	0.04	47.85
Total	**1,049.23**	**109.40**	**72.27**	**16.29**	**33.59**	**31.39**	**37.86**	**1,119.89**

Third-generation advanced piston corer temperature tool

The APCT-3 tool was developed by a third party, tested, and incorporated as a routine Integrated Ocean Drilling Program tool, leading to improvements in reliable downhole temperature measurements collected in conjunction with APC cores.

Metrology laboratory

To address long-standing community issues with tool calibration and reliability of downhole measurements that were not being met by commercial companies, the USIO established an in-house metrology laboratory. CDEX temperature tools were also calibrated at the USIO metrology laboratory.

Common data acquisition system for downhole tools

The USIO developed a common downhole data acquisition system (CDAQ) using upgraded data acquisition boards to standardize data systems in most of the downhole tools. Most notably, the CDAQ was integrated with the Davis-Villinger Temperature Probe (DVTP) and the Davis-Villinger Temperature-Pressure Probe (DVTPP), resulting in significantly shorter tool profiles that are easier to maintain and operate than previous versions of the tools. These tools are now referred to as the Sediment Temperature (SET) and SET Pressure (SETP) tools, respectively.

Working on the rig floor.

Borehole test facilities

The Simulated Borehole Test Facility (SBTF) at TAMU was designed and constructed to test and analyze the performance of downhole tools that sample fluids and measure pressure, temperature, and other parameters in formations at the bottom of the hole. In addition, the existing Lamont Borehole Test Facility was significantly enhanced for the Integrated Ocean Drilling Program. This facility provides pressure and temperature capabilities for both USIO-developed and third-party downhole tools, as well as a 1,500 foot test well drilled through igneous and sedimentary units that allows calibration and performance assessment of downhole tools.

Rotary core barrel bits

Addition of backreaming buttons to the upper body shoulder of RCB bits increased the ability to backream out of problematic unstable formations, reducing stuck pipe and incidents of pipe severing.

Drilling equipment

JOIDES Resolution drilling equipment underwent service life extension refurbishment during the SODV project. In particular, the active heave compensator used during ODP was removed, the passive heave compensator was extensively refurbished, and a modern rig instrumentation system was installed.

Wireline heave compensation system

The WHC, an “active” heave compensation system designed to counter the vertical motion (heave) of the ship caused by waves, minimized heave-related motion of logging tools during operations. A new wireline heave compensator was developed for use during Integrated Ocean Drilling Program operations

and was installed near the rig floor to allow permanent wireline rig-up, reducing operational time and adding flexibility. Experiments were conducted during several expeditions to assess the performance of the wireline heave compensator and to further tune the system.

Operations Planner software

A significant improvement in the expedition planning process was realized with the deployment of a modern, purpose-designed Operations Planner software application that allowed operational plans, cost estimates, and operational scenarios to be developed much more efficiently. In addition, the software tool was used to manage the operational schedule in real time on board the ship, allowing the USIO to respond more nimbly to ever-changing operational events during expeditions.

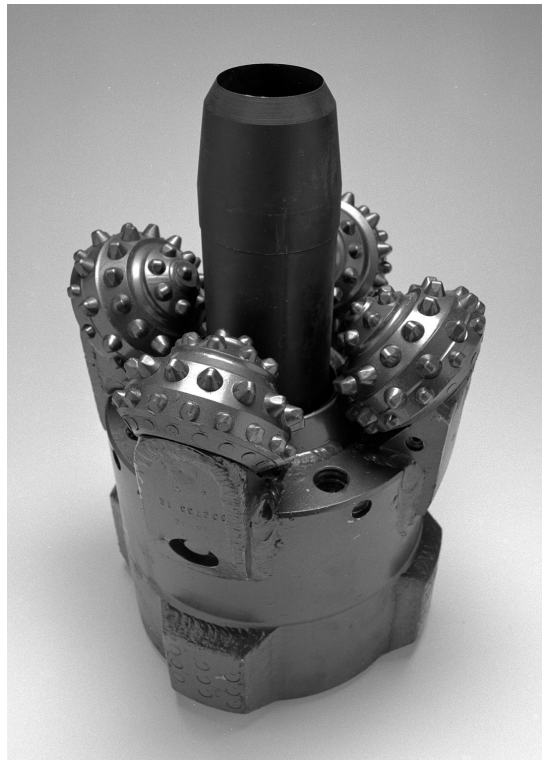
Drilling over stuck APC barrels/APC coring depth record

Routine implementation of drilling over stuck APC core barrels to increase APC penetration depths, combined with optimal coring conditions, led to breaking the APC coring depth record repeatedly since 2009, reaching 458 meters below seafloor during the Bering Sea expedition. Consistently drilling over stuck APC barrels also led operations and engineering staff to develop a new half-length APC tool (see below), which further enhanced the ability to push APC technology to its limits.

Half-length APC tool

The half-length APC tool (HLAPC) was designed to shoot a short piston core (4.7 meters) to improve core quality during drillover conditions and deepen APC penetration. The HLAPC also will allow the driller to more effectively target soft sediments in and around intervals of indurated layers or chert. Deployed successfully during Expedition 341 for the first time, half-core drilling information was used effectively to make corrections in the position of core breaks based on input from stratigraphic correlators. During Expedition 346, the HLAPC was used extensively to deepen APC penetration after reaching drillover conditions, which led to breaking the APC record again (490.4 meters below seafloor).

> "I believe that the half-APC system will be a 'game changer' for paleoceanographic and paleoclimatological research....
> [I]t will allow IODP to recover records of climate

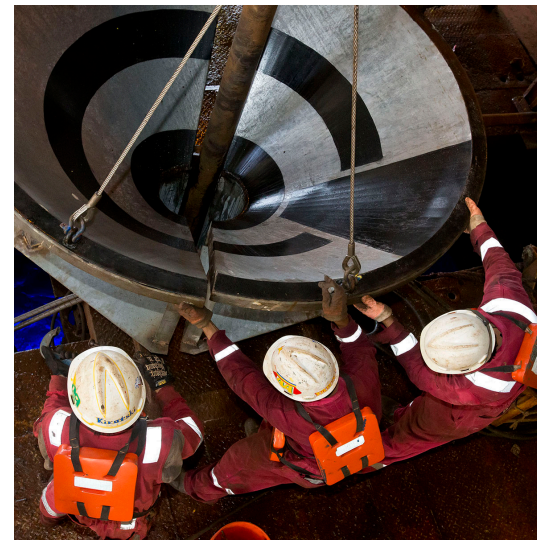


APC piston shoe extending through APC/XCB bit (shown upside down).

> change under a variety of different natural conditions that we could only dream of prior to its implementation. The half-length APC system worked beautifully during Expedition 346, and it was—without exaggeration—essential for our success.... In general, we were able to penetrate TWICE as deeply as "regular APC".... We were able to recover Miocene aged (10–12 Ma) laminated intervals from deep in the stratigraphic sections (many 100's of [meters below seafloor]) that looked similar in quality to the very soft, shallowly buried laminated intervals of the Cariaco Basin, one of the premier Pleistocene climate archives of the world. That we were able to do so in deeply buried, Miocene-aged sediments is an incredibly impressive engineering feat. —R. Murray, Expedition 346 Co-Chief Scientist

Free-fall funnels

The traditional free-fall funnel (FFF) was modified to incorporate deployment of surface casing of various sizes where full-size reentry cones and casing systems could not be deployed. These modifications offered the option to nest a second FFF with smaller diameter casing inside surface casing to extend a short casing string if needed.



Assembling a free-fall funnel.

Subseafloor observatories

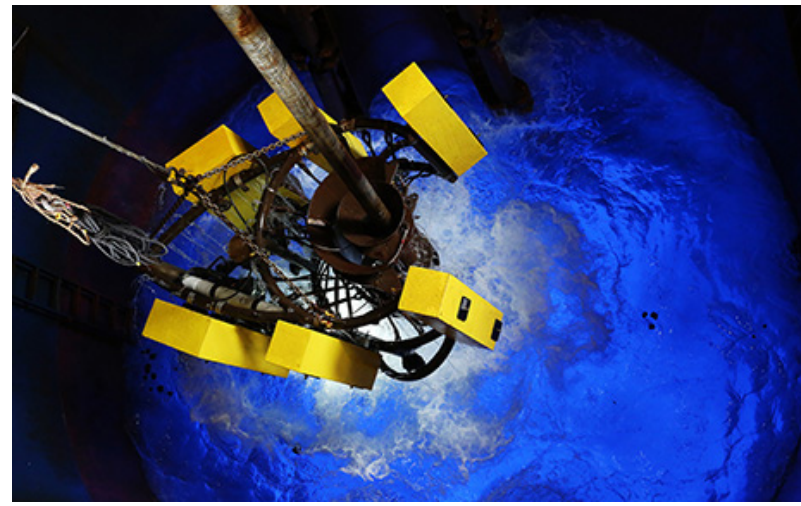
The USIO worked with proponents to implement technical improvements in subseafloor observatories or CORKs. The use of swellable casing packers provided long-term redundancy for zone isolation, eliminating problems caused by deflation of inflatable packers over time. Deployment of fiberglass casing in lieu of steel (or coated steel) in the borehole instrumentation system reduced potential contamination that could have impacted microbiological studies. Finally, use of "blended" cement (addition of celloflake lost circulation material) led to improved cement jobs around critical casing strings installed in fractured formations, leading to more reliable zone isolation in subseafloor observatories.

Vibration-isolated television camera system

The 30-year-old subsea camera and sonar system (vibration-isolated television [VIT]) was replaced with a modern fiber-optic cable, camera, sonar, and gyro system. In addition, the downhole network node design will allow addition of other subsea equipment in the future.

Magnetic Susceptibility Sonde

The USIO developed the Magnetic Susceptibility Sonde (MSS), a wireline logging tool that measures borehole magnetic susceptibility at two vertical resolutions and depths of investigation. A single-coil sensor provided high-resolution measurements (~10 centimeters) of borehole magnetic susceptibility. Data from the MSS were useful in investigating stratigraphic changes in mineralogy and lithology, constructing accurate and complete stratigraphic frameworks in areas of imperfect core recovery, resolving astronomical cyclicity of sedimentary changes, and correlating between holes on a regional scale.



The Vibration Isolated Television (VIT) frame suspended over the moonpool.

Multifunction Telemetry Module

The MFTM, a wireline logging telemetry system that transmits third-party tool downhole data to the surface in real time, allowed third-party tools to be run in combination with tool strings with Schlumberger tools. The USIO developed the MFTM to support other projects such as the Deep Exploration Biosphere Investigative Tool (DEBI-t), MDHDS, and SCIMPI.

Modular Temperature Tool

The Modular Temperature Tool (MTT), a flexible, general-purpose third-party temperature logging tool, was developed to replace two previous temperature logging tools: (1) the Temperature-Acceleration-Pressure probe (TAP), which was limited to maximum borehole temperatures of 85°C and operated only in memory mode, and (2) the High Temperature Tool (HTT), which could be deployed only in stand-alone mode. The MTT uses two temperature sensors—a fast-responding thermocouple and a highly accurate resistance temperature detector (RTD)—and has two sensor sondes to either store log data in flash memory for later recall or to send real-time data to the surface via Schlumberger's telemetry system. The tool was deployed during a number of expeditions, primarily in hard rock formations, to meet geothermal gradient and fluid flow scientific objectives.

Laboratory infrastructure/project management advancements

JOIDES Resolution *laboratory infrastructure*

All laboratory infrastructure on the *JOIDES Resolution* was custom built and fitted by the Integrated Ocean Drilling Program technical staff during the SODV project. During every ship maintenance period since SODV, the technical staff worked to implement revisions to laboratory infrastructure suggested by expedition Science Parties, successfully demonstrating the modular laboratory design that was an integral part of SODV planning and development.

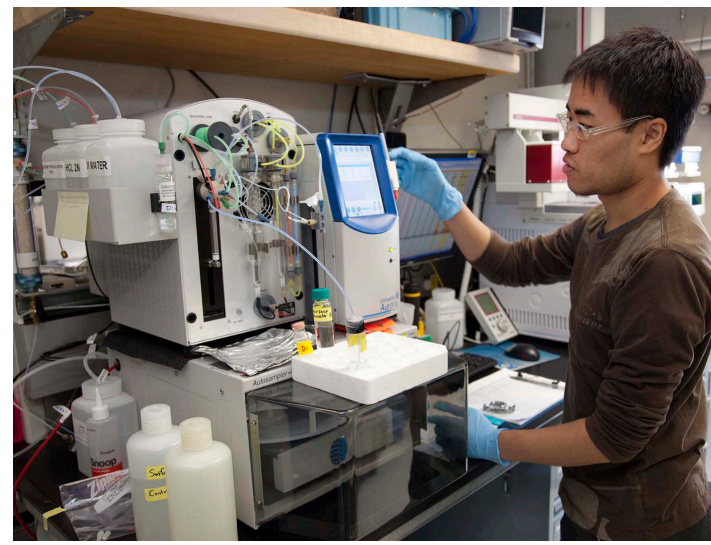
Shipboard laboratory modular design

The modular design developed for the shipboard laboratory spaces allowed reconfiguration and adaptation for optimal use during each expedition. This design was tested most rigorously during Expedition 329. The USIO technical staff reconfigured the entire chemistry facility during the port call in advance of Expedition 329 to meet the requirements of a full-on shipboard microbiology program. For subsequent expeditions, the technical staff reconfigured other shipboard laboratory spaces and made adjustments to meet scientific objectives, including modifying long-tempered sampling practices, assisting with installation of custom seafloor instrumentation, and implementing innovative measurement systems and protocols.

Project portfolio management

The USIO handled major cross-departmental tasks and projects through implementation teams using a formal project portfolio management (PPM) approach, which provided the framework, workflow, and tools for managing projects of all types. Most importantly, this process minimized ad hoc approaches to project investment decision making and focused limited resources on the highest priorities and those projects that had the highest probability of maximizing scientific research delivery.

The PPM team included a cross-functional mix of managers, supervisors, and staff scientists who identified, categorized, reviewed, evaluated, selected, and prioritized proposed projects. The PPM process resulted in the early selection and accelerated completion of several major interdepartmental developments including the design, testing, and implementation of the LIMS Reports and



Working in the chemistry laboratory.

Data Review and Editing Tool applications and multiple DESCLogik application enhancements. A Shore Web Architecture Update and the *JOIDES Resolution* Microscope Laboratory Infrastructure Renovation project were completed in the third quarter of FY14 for implementation in FY15, and as of the fourth quarter of FY14, LIMS On-line Report Environment and Stratigraphic Correlation Enhancements projects were ongoing.

Laboratory working groups

The USIO established laboratory working groups (LWGs) for geochemistry, geology, geophysics, and curation and core handling. The technical staff participating in these groups responded enthusiastically to feedback from scientists sailing on the *JOIDES Resolution* and used LWG meetings after each expedition as an opportunity to review and assess critical scientist reviews of laboratory performance. The LWGs provided the opportunity to brainstorm effective solutions and developments to fulfill the goal of exceeding the expectations of the scientific ocean drilling community.

Shipboard and shore laboratory equipment advancements

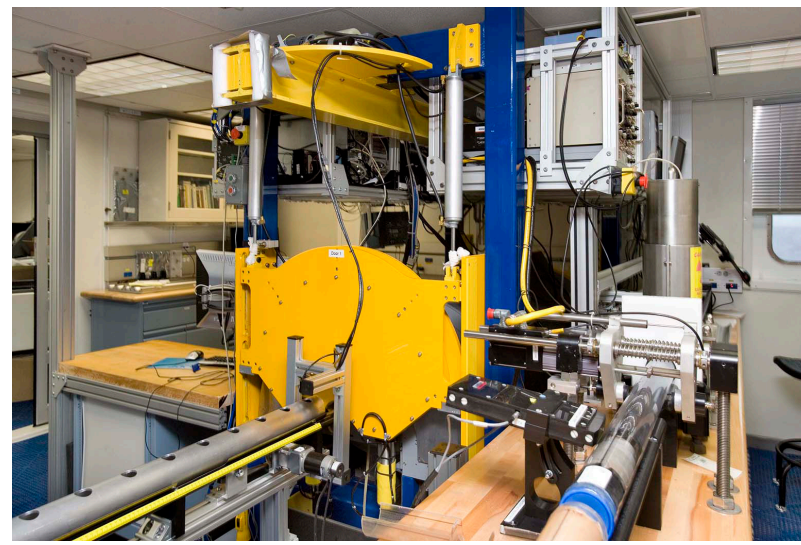
Prior to 2009, USIO developmental efforts were dedicated toward planning for SODV enhancements. During and after the SODV project, several new or vastly modified scientific measurement systems were installed on the *JOIDES Resolution*.

Natural gamma ray emission measurement enhancement

The USIO installed modular whole-core measurement tracks and a new core logger that, for the first time, allowed scientists to acquire natural gamma ray emission data (a volume-sensitive measurement) from cores at the same resolution that can be acquired using the much larger and more common downhole logging tools.

Magnetic susceptibility core logger

In response to the Expedition 303 and Expedition 306 requirement for a dedicated, rapid core logging system to support the stratigraphic correlation process, the USIO assembled and configured existing equipment in a customized



Natural gamma ray (NGR) logger.

magnetic susceptibility core logger, which was deployed for the first time on the *JOIDES Resolution* in 2004.

Digital imaging systems development

Digital imaging systems were developed that completely replaced film photography, with specially designed lighting systems that overcame the reduced dynamic range of digital systems as compared to film counterparts. This development provided real-time feedback to expedition Science Parties during visual core description.

Enhanced physical properties measurements

A unique, high-resolution color spectrophotometer and multitasking physical properties systems provided a higher depth of resolution to data types recorded during the predecessor programs to the Integrated Ocean Drilling Program (i.e., DSDP and ODP).

Microimage capture and archiving

In-house systems were developed and, where available and affordable, commercial solutions were adapted to microimage capture and archive, including a one-of-a-kind imaging/display/teaching system for thin sections. Microimaging capability was expanded to include a scanning electron microscope (SEM) for high-magnification paleontology requirements, and microanalysis capability was enhanced by the acquisition of a hand-held X-ray fluorescence (XRF) spectrophotometer.

> "The state-of-the-art microscopes were a real pleasure to work on. I especially appreciated [working on] the SEM…. It is very easy to use and provides suitable images of microfossils (radiolarians) in a relatively short time. For [E]xpedition 351, this was crucial as it allowed us to identify relatively poorly preserved radiolarians and to give an age to the basal sediments above the basement." —A. Bandini, Expedition 351 paleontologist

Visual core description process enhancements

Recognizing that no commercial product exists to simultaneously utilize all the instrumental and visual-based data types collected on a daily basis during any Integrated Ocean Drilling Program expedition, the USIO developed software applications in-house (DESCLogic and LIMSpeak) that allowed scientists to sequentially or simultaneously view, enter, download, and interpret Earth materials observations (see "Data Management" improvements).

Petrographic image capture and archiving tool

USIO staff constructed a system to facilitate easy and efficient capture of thin section images in transmitted light, polarized light, and cross-polarized light. The petrographic image capture and archiving

tool (PICAT) allowed users to see the live image on screen before capturing and uploading the image to the database along with key metadata. One PICAT was deployed on the *JOIDES Resolution* and one was installed in the Gulf Core Repository (GCR) for imaging the archive thin sections and making those images available to researchers.

> "[By coming] on the ship...you get an appreciation of the value of the data...that you would never get if you just sat in your chair and received this data, for example, through a computer. So, in a way, by coming here, we see the measurements come alive." —A. Malinverno, Logging Staff Scientist

ODASES geosciences laboratory

Texas A&M University's Ocean Drilling and Sustainable Earth Science (ODASES) geosciences laboratory was housed in the GCR, where the USIO installed an XRF core scanner and constructed a Section-Half Image Logger (SHIL) and a Whole-Round Multisensor Logger (WRMSL) with magnetic susceptibility, density by gamma ray attenuation, and *P*-wave velocity capabilities. These loggers provided a testbed for improvements before they were deployed to the operational environment and, when not being used for development, were available for use by visiting scientists.

Safety and Environment

Drilling operations on the *JOIDES Resolution* followed offshore industry best practices, as reflected in the drilling subcontractor's company policies and procedures. Although operations routinely pushed drilling technology to the limit, an extremely low equipment failure rate was achieved. Between 2009 and the last quarter of FY14, only ~26 hours of operational time were lost; only a fraction of that lost time was caused by failure of the ship or drilling equipment. A rigorous maintenance and equipment upgrade program limited rig time lost because of equipment failure during logging operations.

Deploying survival suits during a shipboard safety drill.

In addition, the USIO maintained an accident rate only a fraction of the average rate found in commercial industries as a result of careful adherence to safe

operating practices on the part of both the USIO and the drilling subcontractor. There were no lost-time accidents from 2004 through 2014.

Protocols were developed as needed for sophisticated wireline tools (e.g., MWD and logging while drilling [LWD]). Because the *JOIDES Resolution* is a riserless platform with no blowout prevention equipment, the USIO addressed environmental safety and pollution prevention issues in a comprehensive Programmatic Environmental Impact Statement (PEIS). The PEIS provided an evaluation of the potential impacts of proposed operations and USIO research activities on the human or natural environment and informed decision makers and the public of reasonable alternatives that would avoid or minimize adverse impacts or enhance the quality of the environment.

The Environmental Protection and Safety Panel (EPSP) and the TAMU Safety Panel carefully evaluated proposed drill sites and provided advice with regard to safety and environmental issues that may be associated with general and specific geologic circumstances of proposed drill sites. The EPSP also provided advice on appropriate drilling technologies for avoidance of drilling hazards and protecting the environment.

Environmental assessments were done as needed to determine the risk to marine mammals from seismic (air gun) operations from the ship. The USIO followed a rigorous marine mammal policy designed to minimize the impact of drilling operations and, to address the direct risk to marine life from expeditions, worked with the appropriate authorities to develop specific operating guidelines acceptable to all parties involved.

Table 6. USIO core curation activity.

Phase/	Integrated Ocean Drilling Program Phase 1		Core Redistribution Project JR demobilization and SODV			Integrated Ocean Drilling Program Phase 2				
calendar year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
USIO postmoratorium sample requests	159	193	174	162	160	125	169	186	209	220
Postmoratorium samples taken at the GCR	29,474	19,539	41,204	26,323	23,114	18,626	26,229	26,650	15,921	22,190
Postmoratorium samples taken at the ECR	8,593	8,647	6,894	3,080	1,340	0	0	0	0	0
Postmoratorium samples taken at the WCR	3,358	1,808	2,146	1,846	514	0	0	0	0	0
Samples taken during USIO expedition sampling parties at the GCR	0	3,337	0	0	0	25,675	22,791	0	9,269	23,000
Samples taken during USIO expedition sampling parties at the KCC and BCR						~40,000	0	0	~40,000	~35,000
Total USIO samples taken	**41,425**	**33,331**	**50,244**	**31,249**	**24,968**	**~84,301**	**49,020**	**26,650**	**~65,190**	**~80,190**
Sections pulled from the GCR for XRF scanning at the ODASES laboratory						0	0	2,096	2,136	867

JR = ***JOIDES Resolution***; SODV = the U.S. Scientific Ocean Drilling Vessel project; GCR = Gulf Coast Repository; ECR = East Coast Repository; WCR = West Coast Repository; KCC = Kochi Core Center; BCR = Bremen Core Repository; ODASES = Ocean Drilling and Sustainable Earth Science; XRF = X-ray diffraction.

Documentation and Training

USIO procedures were extensively documented to help standardize shipboard operations, train new staff, and facilitate later interpretation of the scientific results of Integrated Ocean Drilling Program and IODP expeditions. The USIO maintained an archive of Technical Notes developed during ODP and developed detailed user guides to provide shipboard scientists and technicians with step-by-step instructions for use of tools and hardware.

Working in the Gulf Core Repository.

> "The scientists were supported by the highest quality technical, drilling and ship's personnel. The camaraderie and careful nurturing of personal relationships by the TAMU laboratory officers was at world-best-practice level." —B. Carter, Expedition 317 Scientist

6. Samples, data, and publications

The USIO curated more than 62,000 meters of core recovered during the Integrated Ocean Drilling Program and the first year of IODP. Ongoing scientific study of these cores provides a wealth of information to researchers around the world and is invaluable to developing a better understanding of Earth's history. Scientists are able to access core material through IODP repositories, where the cores are sampled and preserved. Scientific data generated from USIO cores were made publicly available through LIMS and the Log Database and in scientific publications produced by the USIO.

Core curation and repository management

In addition to Integrated Ocean Drilling Program and IODP cores, the GCR houses DSDP, ODP, SAFOD, and New Jersey margin cores. During the Integrated Ocean Drilling Program and the first year of IODP, the USIO maintained the GCR core collection archive (more than 131 kilometers of core), which includes curated and preserved permanent archive halves, working halves, processed sample residues, thin sections, smear slides, evaporate cores, frozen microbiology samples, frozen whole rounds, frozen whole-round gas hydrate samples, and pressurized gas hydrate samples. USIO staff responded to more

than 528,000 sample requests, loaned out cores for museum exhibits, and hosted more than 3,300 visitors between FY03 and FY14.

Shipboard analyses of cores and core samples collected during each USIO expedition provide the primary source of data archived by the USIO. Data were also archived from postexpedition analyses, for which careful preservation of cores and core material was critical. In order to best preserve these materials, the USIO continually improved on shipboard and shore-based handling and curation procedures and made situation-specific improvements as needed.

Core curation achievements

Updated routine core-preservation protocol

The USIO established an improved routine core-preservation protocol that dictates sealing all new split cores in moisture- and oxygen-barrier shrink film. The film has a very low water vapor and oxygen transmission rate; with this new method, cores only need to be resealed if opened for sampling. GCR staff wrapped the entire GCR core collection (except hard rock cores) in the film and established a standard procedure to wrap cores as soon as they arrive from the ship and to rewrap each core section after sampling in the repository. This new process is relatively inexpensive and fast, eliminating the need for a full-time position dedicated to minimizing core degradation and dehydration using the old protocol.

Program-wide legacy core redistribution project

The USIO completed a multiyear, integrated cooperative effort that relocated and consolidated DSDP and ODP legacy core from four ODP repositories to three Integrated Ocean Drilling Program core repositories according to the geographic distribution model for the core collection, effectively rearranging two-thirds of the legacy core collection. The geographic distribution model assigns cores to one of three core repositories (GCR, Kochi Core Center [KCC], and Bremen Core Repository [BCR]) according to the sample's origin, regardless of which platform acquired the sample. The BCR at University of Bremen, Germany, houses core collected in the Atlantic and Arctic Oceans north of the Bering Strait; the KCC houses core collected from the Pacific Ocean (west of the western boundary of the Pacific plate), the Indian Ocean (north of 60°S), and all of the Kerguelan Plateau; and the GCR houses core collected from the Pacific Ocean (Pacific plate east of western boundary), the Caribbean Sea and Gulf of Mexico, and the Southern Ocean (south of 60°S, except the Kerguelan Plateau). This redistribution project secured the Program's core legacy and resources and enabled scientists to concentrate their efforts at specific Program repositories and shore-based laboratories.

Table 7. Integrated Ocean Drilling Program and IODP USIO data.

Ocean Leadership data storage	
PDF documents in Dspace asset storage	40.0 GB
Unstructured data on file server	1.8 GB
Total Program storage used by Ocean Leadership	**41.8 GB**
TAMU data storage (starting Phase 2)	
Structured data (data stored in a database)	210.3 GB
Unstructured data (data files and low resolution imagery stored in folders, outside a database)	3,080.36 GB
High resolution imagery (TIFF files)	5,877.85 GB
Total Program storage used by TAMU	**9.17 TB**
TAMU unstructured data formats (starting Phase 2)	
pdf	Portable document format
cfg	Configuration file
zip	Compressed archive
ini	Configuration file
cr2	Camera raw image format
raw	Camera raw image format
dat	Data file
dwl	Downhole temperature file
erg	Evaluation parameter for TK04 file
jpg, jpeg	Compressed imagery file
png	Compressed bitmap imagery file format
xls, xlsx, csv	Spreadsheet files
gra	Graph file
mdb	Database file
ms, pwc, pwl, rsc, srm	Logger files
roi	Image cropping parameter file
summary	NGR file
tiff	Tagged image file format (high-resolution imagery)
uxd	X-ray diffraction file
lvm	LabVIEW file

Record-setting core sampling

After Expeditions 304 and 305 (2005), nearly 1.5 kilometers of continuous hard rock core was laid out in the GCR and sampled by more than 50 scientists. Since the *JOIDES Resolution* refit was completed in 2009, more than 35 kilometers of core has been curated by USIO staff, and nearly 300,000 samples have been taken and delivered from the vessel to scientists around the world. During the first ship tie-up period (2010), the USIO orchestrated a shipboard sampling party of cores from Antarctica that resulted in more than 11,000 samples delivered to scientists, complementing another 11,000 samples delivered to scientists during a nearly coincident sampling party at the GCR. In addition to expedition sampling parties coordinated at the GCR, USIO staff coordinated and participated in sampling parties of *JOIDES Resolution* cores at the other two repositories (KCC and BCR) for Expeditions 303, 306, 323, 338, 342, and 346. Sampling parties for Expeditions 323 (Bering Sea) and 339 (Mediterranean Outflow) both resulted in more than 40,000 samples distributed to their respective Science Parties.

Improved postmoratorium sample request processing time

The USIO improved sampling efficiency and significantly decreased the amount of time needed to meet postmoratorium sample requests. Overall postmoratorium sample processing times since 2009 are 30%–40% faster than processing times during ODP and Integrated Ocean Drilling Program Phase 1.

Data management

USIO staff implemented a database infrastructure and systems overhaul during the first post-refit ship maintenance period based on feedback received during the first six expeditions (see "Data Management achievements"). Throughout the Integrated Ocean Drilling Program and the first year of IODP, the USIO continued to implement advances in scientific analysis and visualization tools to enable advances in scientific ocean drilling research. Integrated Ocean Drilling Program and IODP data stored by the USIO is summarized in Table 7 and below.

Scientific databases

Janus

The USIO continued to maintain the ODP legacy Janus database, which contains paleontological, lithostratigraphic, chemical, physical, sedimentological, and geophysical data from more than 2 million ODP core samples. There were 546,000 data downloads from the Janus database from FY03 through FY14.

Laboratory Information Management System

The LIMS database is a laboratory systems inventory and document management database customized by the USIO for use with planning activities, laboratory reports, and access to laboratory documents. After release from moratorium, expedition data are also sent to the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) for long-term archival access. There were 109,000 data downloads from the LIMS database from its implementation in FY09 through FY14.

Log Database

USIO expedition downhole logging data obtained through wireline logs and LWD were collected digitally and processed using GeoFrame software from Schlumberger. Logging data are archived in a Web-searchable Log Database that contains downloadable original and processed files from DSDP, ODP, the Integrated Ocean Drilling Program, and IODP (including ESO and CDEX). The Log Database received ~848,000 data requests from FY04 through FY14.

Data management achievements

The USIO data management team continually sought opportunities to maximize value in the products and services offered to science community customers. Some of the resulting data management achievements are highlighted in the sections below.

Working in the computer server room.

Log Database improvements

During the Integrated Ocean Drilling Program, the Log Database was transitioned to a relational database to allow links from the logging metadata directly to each logging file. A stand-alone logging operations database schema was also developed for internal use on the *JOIDES Resolution*, from which details of logging operations are transmitted to shore and stored in a master operations database. Relevant information from this master operations database is exported and included within the new Log Database to enable more complicated searches; the schema from the two databases (operations and log) were aligned to allow better organization of the various operations reports, development of a web-based data entry form for Logging Scientists, and search capabilities that navigate better between databases. A mirror copy of the shore-based Log Database was installed on board the *JOIDES Resolution* to provide a local asset that scientists could use to search for logging data, with automatic synchronization of data between ship and shore.

Improved array of services based on scientist feedback

Responding to frank, constructive feedback received from scientists who sailed on Expeditions 320, 321, 323, and 324, the USIO embarked on an aggressive plan to select and implement data management best practices with the strongest potential to progressively yield improvements in data service quality while placing the most useful tools in the hands of science customers. This resulted in an overall decline in shipboard data collection and processing problems since Expedition 320 in 2009. Change management, PPM, and configuration management programs have realized several compelling benefits thus far and continue to mature. For example, the practice of formally introducing, reviewing, and approving software application changes has virtually eliminated time wasted on problem identification and enabled the development staff to reclaim 40% of a programmer full-time equivalent (FTE), permitting more time for important projects and initiatives.

Regional Test and Integration Facility

In FY10, the USIO constructed a Regional Test and Integration Facility (RTIF) to provide a consolidated facility for testing USIO-developed software and successfully moved the RTIF to an off-site location in FY13. In addition to test and integration capability, the RTIF now offers better options for responding to a catastrophic event should USIO-TAMU lose services in the main building in College Station, Texas.

Core description software for descriptive data capture

The USIO developed and stabilized an innovative, flexible, database-integrated, descriptive and interpretive information archive and reporting software (DESClogik). This unique tool combines a tabular format for input and review of descriptive information with user-defined multiformat data extraction and presentation tools. In one of the premier applications of our PPM process, the USIO collected, categorized, prioritized, and implemented bug fixes and user-requested enhancements to this software. As a result of this effort and the continued increase in understanding and confidence of our technical support staff, the software has reached a stable development plateau. The USIO envisions continued development of this critical element of our science delivery package, and recent expeditions have continued the trend of user acceptance and vitally important feedback.

DESC Reports

DESC Reports provides online access to all descriptive data, including macroscopic and microscopic core descriptions, paleontological investigations, and stratigraphic unit definitions that were collected aboard the *JOIDES Resolution* since May 2009. The primary objective is to report the data collected using the DESClogik data capture application, but other spreadsheet or form-based data captured outside of DESClogik are also included in DESC Reports (secondary objective). Data are accessed from links on the LIMS Reports interface, where the USIO provides access to numerous reports of instrumental data.

LIMS database tools

The suite of LIMS tools (LIMSpeak, LIMS Reports, and LIMS Overview) introduced between 2010 and 2012 offer scientists simple, intuitive web service capability for extracting relevant data and generating special reports for scientific analysis. LIMSpeak provides rapid graphic web viewing of LIMS information in barrel-sheet style to enhance the core description process. Feedback on LIMS Reports and LIMS Overview from science customers suggests both tools provide easy-to-use, comprehensive search, retrieval, and display capability, which previous applications lacked. Seeking to improve data quality and reduce overhead, the USIO successfully completed the LIMS data review and editing tool that enables expedition Science Party members and other technical staff to correct sample and data errors in the database without developer assistance.

Inventory Asset Management System

The USIO developed a customized Inventory Asset Management System (AMS) to track and maintain federal property and Integrated Ocean Drilling Program inventory from acquisition to disposal. The AMS operates as a single, fully integrated ship- and shore-based system that performs requisitioning, inventory control, and shipping functions.

Publications

The USIO Publication Services Department coordinated activities involved in developing, producing, delivering, and archiving all required reports and publications for the USIO.

Expedition publications

Precruise plan

The USIO published a *Scientific Prospectus*, a detailed precruise plan, for each Integrated Ocean Drilling Program and IODP expedition several months before each cruise. This report outlined and described the scientific objectives and operational strategies established for the expedition and provided a valuable resource for scientists to plan their cruise participation, research goals, and sample requests.

Preliminary Report

A *Preliminary Report* for each Integrated Ocean Drilling Program and IODP expedition was published online within 2 months of completion of each cruise. This report summarized the preliminary scientific and operational results of the cruise and evaluated fulfillment of the original scientific objectives.

Proceedings of the Integrated Ocean Drilling Program

During FY05, following the Integrated Ocean Drilling Program Management International Publications Task Force recommendation, the USIO played a leading role in developing the new IODP *Proceedings* series. Efforts included design of new PDF and HTML layouts, development of a new DVD product, and production of the initial volumes. Each volume of the *Proceedings of the Integrated Ocean Drilling Program* includes expedition results, postexpedition data reports and synthesis papers, and a bibliography of related publications. The initial science results for each expedition are published at the end of the 1-year moratorium in a *Proceedings* volume for that expedition. The *Proceedings* volume is posted with open access on the web, data reports are published online throughout the postmoratorium research period, and the online expedition-related bibliography is continually updated with postexpedition results published in peer-reviewed journals and books, related articles that rely partly on expedition data, and expedition-related presentations at conferences.

Technical documents

The USIO published a series of technical documents for use primarily by Integrated Ocean Drilling Program and IODP shipboard science party members and staff, comprising ~70 advanced user guides, user guides, and quick start guides. These documents and other vendor documentation are available online via a web-based digital asset management system.

Reports

During the Integrated Ocean Drilling Program and the first year of IODP, the USIO produced 15 APPs (with multiple iterations), 10 Annual Reports, 43 quarterly reports, 11 annual citation studies, and multiple special-request reports.

Bibliographic databases

The Integrated Ocean Drilling Program collaborated with the American Geological Institute (AGI) to continue compiling the collection of DSDP- and ODP-related citations in the Ocean Drilling Citation Database, a subset of the AGI GeoRef database. The USIO solicited the ocean drilling community for additional DSDP-, ODP-, Integrated Ocean Drilling Program–, and IODP-related citations for inclusion in GeoRef and the Ocean Drilling Citation Database. The database contained nearly 30,000 citations related to DSDP, ODP, Integrated Ocean Drilling Program, and IODP research as of the third quarter of FY14. AGI provided an annual update of the Ocean Drilling Citation Database to the USIO; this data was used to produce annual studies that documented the number and venue of publications generated from each expedition, the number of publications authored by scientists from various member countries, and other information valuable to Program members.

Expedition-related publication statistics

Since the start of the Integrated Ocean Drilling Program in 2003, USIO Publication Services has produced and published 71 *Scientific Prospectuses* and *Scientific Prospectus Addendums*, 53 *Preliminary Reports*, 42 *Proceedings* volumes comprising 287 chapters, and 146 Expedition Research Results chapters (data reports and synthesis chapters)

Working in the Publications Specialist office.

Table 8. Integrated Ocean Drilling Program and IODP expedition-related publications overview.

	Program publications				Non-Program publications			
Exp	*Scientific Prospectus*	*Preliminary Report*	*Proceedings* chapters	Other	Serials	Meeting abstracts	Misc.	Total
301T	1	1	0	0	0	0	0	2
301	1	1	12	2	41	47	0	104
302	1	1	9	2	96	122	9	240
303/306	2	2	28	5	56	63	6	162
304/305	1	2	10	9	54	76	4	156
307	1	1	13	1	51	37	3	107
308	1	1	22	3	32	70	4	133
309/312	1	2	8	5	30	51	5	102
310	1	1	14	3	36	58	1	114
311	2	1	22	5	43	39	4	116
313	1	1	6	2	20	43	0	73
314/315/316	6	3	41	5	71	181	3	310
317	1	1	12	2	5	26	1	48
318	1	1	9	4	18	91	0	124
319	1	1	8	6	20	50	0	86
320T	0	1	0	0	0	0	0	1
320/321	2	2	27	6	37	26	1	101
321T	1	1	0	0	0	0	0	2
322	1	1	12	5	17	48	0	84
323	1	1	12	3	21	70	0	108
324	1	1	14	3	10	38	0	67
325	1	1	6	3	10	11	1	33
326	1	1	0	2	0	1	0	5
327	1	1	10	3	8	21	0	44
328	1	1	0	3	0	0	0	5
329	1	1	13	4	22	26	1	68
330	1	1	10	3	5	9	0	29
331	1	1	7	3	5	8	0	25
332	1	1	6	3	5	9	0	25
333	1	1	8	3	12	29	0	54
334	1	1	6	5	1	19	1	34
335	1	1	5	3	3	11	0	24
336	1	1	12	3	2	16	0	35
337	2	1	3	1	2	4	0	13
338	1	1	7	1	0	2	0	12
339	2	1	9	5	8	10	0	35
340T	1	1	0	2	1	4	0	9
340	1	1	11	2	5	8	0	28
341	2	1	0	0	7	3	0	13
341S	1	1	0	1	0	0	0	3
342	1	1	12	2	0	0	0	16
343/343T	1	1	3	2	10	54	0	71
344	1	1	7	2	0	6	0	17
345	1	1	15	2	1	3	0	23
346	2	1	0	1	0	0	0	4
347	1	1	0	3	1	2	0	8
348	1	0	0	1	0	3	0	5
349	1	1	0	0	1	0	0	3
350	1	0	0	0	0	0	0	1
351	1	0	0	0	0	0	0	1
352	1	0	0	0	0	0	0	1
Total	**58**	**47**	**429**	**132**	**577**	**802**	**41**	**2,086**

Misc. = Miscellaneous non-serial maps, videos, books, CD-ROM/DVD-ROM, monographs, and theses.

based on Integrated Ocean Drilling Program and IODP expeditions. In addition, more than 570 articles based on expedition science have been published in peer-reviewed scientific journals, and more than 800 presentations of Integrated Ocean Drilling Program science have been made at national and international conferences. All of these publications are included in online expedition-related bibliographies maintained by the USIO Publication Services. Table 8 presents a summary of Integrated Ocean Drilling Program and IODP expedition-related publications.

Website statistics

The cumulative USIO websites (iodp-usio.org, iodp.ldeo.columbia.edu, and iodp.tamu.edu) received more than 2.5 million site visits since 2003. Through FY14, Program science was accessed more than 1 million times through the Program's Publications website (iodp.tamu.edu/ publications). In addition, Google Scholar records show that primary Integrated Ocean Drilling Program and IODP expedition research has been cited in scientific publications more than 9,500 times since 2003.

Publications achievements

Successful international collaboration

One of the most successful integrations of the Integrated Ocean Drilling Program has been the seamless and timely publication of expedition science from the three implementing organizations. Working at the direction of Integrated Ocean Drilling Program Management International, Publication Services built on its experience producing publications for ODP to produce a *Scientific Prospectus*, a *Preliminary Report*, and a *Proceedings of the Integrated Ocean Drilling Program* volume for all Integrated Ocean Drilling Program expeditions. Despite the physical distance between the implementing organizations, Expedition Project Managers and expedition participants have delivered shipboard reports to the publications team for editing and formatting. Final publications are then delivered online on a common Program web server. This approach has enabled Program science to be presented in a unified fashion to science community in a cost-efficient manner. The collaboration has been so successful that both CDEX and ESO have expressed interest in continuing the Integrated Ocean Drilling Program publication model on a contract basis during IODP.

Integrated Ocean Drilling Program publications move to web-only distribution

The Integrated Ocean Drilling Program *Proceedings* evolved from hard-cover volumes produced during ODP that contained initial reports and scientific results to a combination CD-ROM and booklet format, and, finally, during the Integrated Ocean Drilling Program, to web-only publication. DVDs of Integrated Ocean Drilling Program expedition reports, distributed worldwide to libraries, scientists, and program affiliates from FY05 through FY12, are now produced as ISO disc images and distributed online.

New ways of doing business

During the Integrated Ocean Drilling Program and the first year of IODP, the USIO Publication Services provided shipboard publications support during both *JOIDES Resolution* and *Chikyu* expeditions and at ESO onshore Science Party meetings. At sea and at the onshore meetings, USIO Publications Specialists coordinated the collection of shipboard reports and, since 2009, used database export tools and plotting software programs to prepare summary core descriptions for publication in the *Proceedings of the*

Integrated Ocean Drilling Program. In 2009 and 2010, the USIO trained a Marine Works Japan technician to support Chikyu expeditions in the role of Publication Assistant.

When practical, Publication Services has taken advantage of new technologies and introduced operational efficiencies. For example, since the start of the Integrated Ocean Drilling Program, digital object identifiers (DOIs) have been incorporated into Program publications to assure persistent identification and access online. Through CrossRef's free "Cited-by Linking" service, which utilizes publisher-provided metadata, links were provided from Integrated Ocean Drilling Program publications table of contents pages to scientific articles or books that cite the Program publication. Aided by online search engines, USIO Publication Services staff invested significant effort to document the impact of the Integrated Ocean Drilling Program and IODP through the capture of postexpedition research citations in peer-reviewed literature. In addition, during postexpedition editorial meetings, participating scientists and Publication Services staff now use an electronic work flow for text editing that is considerably more efficient than editing and proofing on hard copy.

Summary

USIO curation of the Program legacy and core collection archive enabled many hundreds of scientists to access samples from more than 170 miles of core. The USIO maintained Program legacy data, adapted a robust database for Integrated Ocean Drilling Program and IODP expedition data and developed tools that made these data easily accessible online, and improved the accessibility of log data. Throughout the Integrated Ocean Drilling Program and the first year of IODP, the USIO generated and archived a wealth of data, scientific publications and reports, and expedition-related outreach and educational materials designed to make Integrated Ocean Drilling Program and IODP science publicly accessible.

7. Education and outreach

USIO education and outreach activities built an easily accessible foundation of knowledge about the Integrated Ocean Drilling Program and IODP, raised the visibility of the connection between the emerging scientific knowledge and its positive contribution to society worldwide, raised awareness of the Program's areas of scientific inquiry, and encouraged interest in both Programs.

Education and outreach activities

Congressional outreach

Throughout the Integrated Ocean Drilling Program, the USIO worked to increase awareness among members of the U.S. Congress of the value of scientific ocean drilling and the scientific endeavors possible with an advanced drillship. Science communitywide events such as annual Congressional Visits Day events and the Annual Coalition for National Science Funding Exhibition and Reception on

Capitol Hill in Washington, D.C., enabled USIO staff and scientists to present exhibits and meet with their congressional delegations to talk about the importance and impact of scientific ocean drilling. Beginning in 2008, the Geosciences Congressional Visits Day enabled U.S. scientists to visit congressional offices and underscore the importance of geoscience research to America's competitiveness in the global marketplace given the tremendous challenges arising from a rapidly changing climate. As scientists actively involved in the Integrated Ocean Drilling Program and IODP, they were able to deliver those messages through stories about individual accomplishments within scientific ocean drilling.

Caroline Kennedy, U.S. Ambassador to Japan, learning about Expedition 351.

Port call outreach

Throughout the Integrated Ocean Drilling Program and the first year of IODP, press conferences, science lectures, and/or ship tours at many *JOIDES Resolution* port calls provided an excellent opportunity to conduct public outreach related to ongoing operations. Port call activities in 10 countries included media releases and news conferences; ship tours for more than 3,000 local students, educators, scientists, community leaders, industry representatives, VIPs, and government representatives; and, in some cases, science lectures, workshops, and receptions.

Conference representation

Forums such as the American Geophysical Union (AGU) Fall Meetings, the Geological Society of America (GSA) Annual Meetings, the European Geosciences Union (EGU) General Assemblies, and the National Science Teachers Association (NSTA) National Conferences, as well as, occasionally, the Society for Advancement of Chicanos and Native Americans in Science (SACNAS), provided the opportunity for the USIO to engage the science, education, and political communities in scientific ocean drilling research. USIO staff, scientists, and School of Rock/Education Officer alumni (see "School of Rock" below) represented the Integrated Ocean Drilling Program and IODP at these and other regional and national science conferences, educational conferences, and meetings through presentation of lectures, hands-on education, workshops, share-a-thons, distribution of educational materials, and presentation of highly

interactive and innovative museum-style booths.

Professional development for educators

School of Rock

School of Rock participants, Expedition 321T.

In 2005, the pilot professional development initiative named "School of Rock: An Ocean-Going Research Expedition for Earth and Ocean Science Teachers" kicked off a series of workshops that have since reached hundreds of educators and tens of thousands of students. School of Rock workshops provided participants with hands-on experience on board the *JOIDES Resolution*, where they were introduced to all facets of ship operations on a typical expedition, or in the GCR in College Station, TX, or other shore-based partner institutions. Participants conducted laboratory work using cores and published data from previous expeditions, received science lectures from Integrated Ocean Drilling Program and IODP scientists, communicated with students through blogs and videoconferences, and learned about the scientific legacy of ocean drilling as well as major topics that ocean drilling continues to investigate today (e.g., global climate change, discovery of methane hydrates, etc.). In addition, participants translated their new knowledge as well as Integrated Ocean Drilling Program and IODP data sets into easily accessible classroom and laboratory activities that could be used by themselves and others. The School of Rock generated an extensive suite of teaching materials related to ocean drilling research, and School of Rock alumni have disseminated Integrated Ocean Drilling Program and IODP science education through a wide range of local, regional, and national outreach efforts (Table 9).

> "Participating in the School of Rock on the *JOIDES Resolution* was an experience beyond my expectations.... I learned many aspects of the whole scientific operation which complement and enhance each other including: oceanography, micropaleontology, plate tectonics, ocean-floor hydrology, analytical and instrumental methods for core analysis, the process of conducting large scientific endeavors, the lives of scientists and crew and tangential skills that are necessary for large scientific endeavors to operate. As a scientist, often I don't see how these things connect, but they become very apparent while on board the *JOIDES Resolution*. I think the Integrated Ocean Drilling Program and Deep Earth Academy offer a once-in-a-lifetime opportunity for earth science educators to immerse themselves in [scientific] ocean drilling [research] operations and marine science. The experience brings a sense of excitement and wonder for the world around

them, which will certainly translate into an engaged classroom." —P. Cleary, Assistant Professor of Geosciences (University of Wisconsin-Parkside) and 2009 School of Rock Alumnus

Education Officer initiative

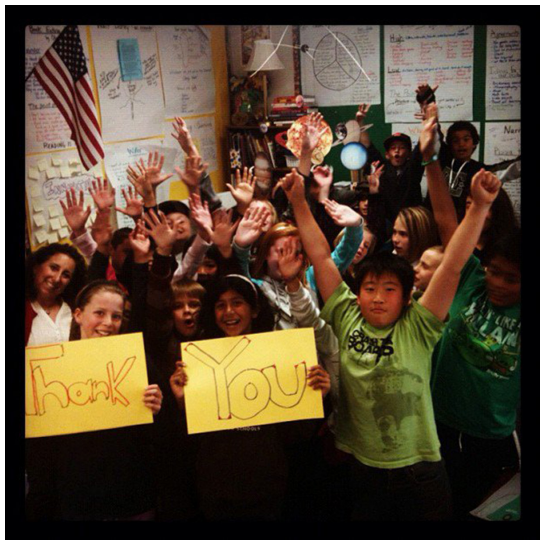
In FY04, the USIO launched the Education Officer pilot program through which formal and informal educators (e.g., university faculty, K–12 educators, museum educators, scientific illustrators, videographers, etc.) sailed on board the *JOIDES Resolution* to chronicle expeditions and develop projects that would make ocean drilling science accessible to educators and other nonscientist shore-based audiences. The role of Education Officers expanded over time to promote Integrated Ocean Drilling Program and IODP science to a broader audience with the addition of such tasks as managing website content; blogging and facilitating blog entries from expedition participants; conducting video broadcasts with classrooms and museums; and posting photos, comments, and video entries to social networking sites.

"The experience as Education Officer on the *JOIDES Resolution* changed me...I am more sensitive to communicating science to others and understand the communication gap between scientists and the public...I am more eager to experiment with ideas that haven't been tried before and realize real science takes longer and is often more complicated than is presented in school. I believe my experience has impacted my students through my attitude and because I have been able to help them expand their horizons for career opportunities and helped them see science differently." —J. Kane, Expedition 327 Onboard Education Officer

Table 9. Education and outreach statistics.

Initiative	SOR	EO
Alumni	169	34
Participating states	38	12
Participating countries	5	6
Activities/publications developed	200	25
Workshops/presentations given	250	
Workshop/presentation participants	30,000	
Participating states*	38	
Participating countries*	5	
Ship-to-shore video broadcasts		840
Video broadcast participants		33,000
Participating states		40
Participating countries		20

SOR = School of Rock, EO = Education Officer. * = SOR alumni gave presentations and workshops in their home states.



"LIVE Aboard the JR" Skype session.

Live ship-to-shore video broadcasts

Beginning in FY09, the USIO provided regular ship-to-shore programming (video broadcasts) to schools, universities, professional development workshops, and museums. Interest in live video broadcasting from the *JOIDES Resolution* grew dramatically over the years, culminating in an average of 40 video events per expedition reaching thousands of viewers in the U.S. and other countries (Table 9). Broadcasts presented tours of the ship's laboratories and engineering spaces, tableaus of life at sea, shipboard safety, the careers of scientists and technicians on board, science conducted on board the *JOIDES Resolution*, and opportunities for questions and answers with scientists and staff on board.

> "The video conference really made me rethink what science is to me. In my experience, most sciences don't seem very applicable in the real world, but I was reminded how many people are employed for the purpose of discovery, and learning about the universe we live in. I also realized how diverse the science community is. There are so many people on the [*JOIDES Resolution*], and each of them has a different job and purpose on the ship. I have always thought that I wanted to go into science when I get older, and this has reminded me of how many options I have." — Madeline, Grade 11–12 Honors Physics student

Diversity initiatives

USIO diversity initiatives were primarily designed to provide minority undergraduate and graduate students with opportunities for increased exposure to, interaction with, and participation in the Earth system science community (www.oceanleadership.org/education/diversity/).

Through the Minorities Striving and Pursuing Higher Degrees of Success (MS PHD'S) in Earth System Science Initiative, the USIO supported travel for minority students to observe the 2005–2008 Integrated Ocean Drilling Program Science Steering and Evaluation Panel meetings, where the students were mentored regarding scientific proposal development and evaluation and how science can serve a diplomatic function in the international sphere.

From FY05 through FY10, the Historically Black Colleges and Universities (HBCU) Fellowship provided students attending HBCUs with an opportunity to pursue studies in Earth Systems Science (or complementary fields), or to explore a broad range of careers in scientific ocean drilling and large-scale

science program management. Of the nine fellowships awarded from 2005 to 2010, one was awarded in 2010 to an undergraduate student to sail on Expedition 327 as part of the Education and Outreach team. An HBCU Educator at Sea sailed in 2009 on Expedition 324 to help the USIO reach out to HBCU institutions and minority-serving teachers and their students (8th grade and high school). Through educational outreach activities that included live videoconferences to HBCU institutions, the HBCU Educator at Sea raised the profile of the HBCU Fellowship and career opportunities in scientific ocean drilling for HBCU students and promoted Integrated Ocean Drilling Program science and the *JOIDES Resolution* as ideal vehicles for Earth systems science education. Although the USIO explored a number of mechanisms to improve the recruitment of faculty/research mentors and students at HBCUs, the level of interest remained low. To address this issue, the USIO redesigned its diversity initiatives and launched new programs that helped to broaden and increase the level of participation of minority groups in scientific ocean drilling, particularly those not represented in the HBCU student population.

HBCU fellow and scientist working on board the *JOIDES Resolution*.

Beginning in FY11, USIO diversity initiatives included two separate programs for undergraduate and graduate students of ethnic and racial groups currently underrepresented in scientific ocean drilling. The Minorities in Scientific Ocean Drilling Fellowship provided a mechanism for graduate students enrolled full-time in a U.S. geoscience or engineering program to complete research in topics related to scientific ocean drilling or develop technology that would help advance science or engineering in a scientific ocean drilling research setting. The first Minorities in Scientific Ocean Drilling Fellowship was awarded in 2012 to a PhD minority student from Brown University; due to lack of funding, this initiative was canceled the following year. The USIO Diversity Internship, developed for students enrolled full-time at (or recently graduated from) a U.S. university or college and with a significant interest in the ocean and/or Earth sciences, exposed minority students to careers in scientific ocean drilling by providing them with a 10–12 week educational and career-building experience at one of the USIO institutions. From 2011 to 2014, a total of seven internships were awarded, two at the Ocean Leadership Office with a focus in science communications and five at LDEO with a focus in scientific research using data or cores from DSDP, ODP, and the Integrated Ocean Drilling Program.

> "This experience has tested me in more ways than I will ever be able to express; the education and connections I am taking away from this are priceless. The fact that I was able to experience

first-hand one of the ways that my major is applicable in real life made the experience invaluable." —B. Richardson, 2009 HBCU Fellow/Expedition 327 E&O Team Member

"My time as an intern with the USIO has been an invaluable experience; the opportunity to work with professionals and scientists in so many different fields at such a preeminent international organization has really enriched my thinking about science, and galvanized my interest in scientific ocean drilling!" –A. Sutton, 2011 USIO Diversity Intern

The USIO has successfully raised awareness about the Program and capacity-building opportunities available in the Program for minority groups by exhibiting and presenting at professional society and education conferences, particularly those with a diversity focus, and advertising via listservers targeting Minority Serving Institutions, professional association websites, publications, and mailings.

Strategic partnerships

Many USIO education and some diversity-enhancing activities were developed in conjunction with USSSP education activities, and USIO staff continually pursued supplemental funding for USIO-related educational projects. The USIO also invested considerable effort to broaden existing ties and develop new ties with other U.S. Earth and marine science education and outreach groups and fostered partnerships and alliances with national and international museums and science partners with synergistic goals and objectives.

National Science Teachers Association

In August 2005, the USIO hosted the annual dinner for the NSTA National Congress for Science Education, which was attended by 150 NSTA state and affiliate organization delegates and the NSTA Council and Board. USIO presentations indelibly branded the Integrated Ocean Drilling Program in the minds of the nation's most influential science educators and decision makers, resulting in numerous requests for materials, workshops, partnerships, and involvement in future conference events. The USIO continued its relationship with NSTA with strong representation at annual conferences.

The USIO also became a partner in Building a Presence for Science, a network sponsored by the NSTA and NSF that promotes professional development and science education tools to 43,000 kindergarten through 12th-grade students from campuses in 26 states. This partnership allowed the USIO to link into one of the most efficient communication channels for reaching science teachers.

Complementary educational grants

Center for Dark Energy Biosphere Investigations

In FY11, the USIO established a partnership with the Center for Dark Energy Biosphere Investigations (C-DEBI) through which C-DEBI funded materials development and outreach efforts and also awarded

grants for USIO coordination of educational components during two R/V *Atlantis* expeditions that collected samples and data from subseafloor observatories installed during Integrated Ocean Drilling Program Expedition 327. C-DEBI also funded the development of an e-book about subseafloor biosphere research from the *JOIDES Resolution*.

Ship-to-Shore Science—the *JOIDES Resolution* as a Platform for Education

An NSF Informal Science Pathways grant funded the Ship-to-Shore Science program, through which four pilot projects were funded including a Girl Scouts project, a Core Stories serious interactive game, a *JOIDES Resolution* Hub Network to support regional *JOIDES Resolution* events, and publication of an e-book titled *Uncovering Earth's Secrets: Science and Adventure on the* JOIDES Resolution. This project has resulted in numerous partnerships with informal science institutions such as museums and libraries.

School of Rock: Enhancing Diversity in the Geosciences

The second 2012 School of Rock held at the GCR was partly funded through the NSF Opportunities for Enhancing Diversity in the Geosciences program grant for faculty members of minority-serving institutions. The USIO collaborated with the American Meteorological Society, James Madison University, and Los Angeles Valley College to guide School of Rock participants through laboratory exercises and collected feedback for a full-scale implementation proposal for use of the *JOIDES Resolution* as a platform for education.

Museum outreach partnerships

Japan/U.S. Public Understanding of Research

The Japan/U.S. Public Understanding of Research pilot program took place during Integrated Ocean Drilling Program Expedition 312 with the shipboard participation of an American informal educator and a Japanese museum educator who broadcast real-time expedition-related education and outreach activities in English on the Science Museum of Minnesota's Science Buzz Web page and in Japanese on Japan's National Museum of Emerging Science and Innovation (Miraikan) website.

Smithsonian's National Museum of Natural History: The Sant Ocean Hall

The USIO collaborated with Integrated Ocean Drilling Program Management International and exhibit developers from the Smithsonian's National Museum of Natural History to create comprehensive exhibit text, a video highlighting ocean drilling, and a display including ocean drilling cores and the history of the Integrated Ocean Drilling Program as well as its predecessor, ODP, in The Sant Ocean Hall, which opened in 2008.

Table 10. Educational website statistics.

Educational website	Site visits	Page views
www.oceanleadership.org/education/deep-earth-academy	222,829	329,237
www.joidesresolution.org	321,206	1,128,943
Total	**544,035**	**1,458,180**

Traveling exhibit: Getting to the Core: the *JOIDES Resolution*

In FY11 and FY12, a traveling exhibit called "Getting to the Core: the *JOIDES Resolution*" toured museums in Texas and Pennsylvania. The exhibit featured large-scale banner graphics, real sediment cores, drilling artifacts, video clips, a 3-D model of the *JOIDES Resolution*, a montage of photos and images, and a series of exhibit-related activities including a "guide-by-cell" phone tour, live ship-to-shore events, and a children's spring-break science camp.

Education and outreach tools and products

Media relations tools

USIO communications staff developed tools for use at port calls and in press conference settings, including a frequently asked questions (FAQ) document; a set of media "Key Talking Points" designed to tell an expedition's story in clear and compelling language to a wide audience; media advisories, including customized advisories released to local news media organizations in the hometowns of participating educators; and press releases, some of which included links to videos to help readers better understand an expedition's mission. These tools and other USIO media relations activities spurred coverage of the Integrated Ocean Drilling Program and IODP by high-profile news and science publications, including *Time Magazine*, *BBC News*, *Discovery News*, *National Geographic*, *Science*, and *Nature*.

Web presence and social networking

In FY06, the USIO developed an educational website to give science educators and outreach professionals easy access to educational materials related to the drilling platform and drilling technology. The *JOIDES Resolution*: Exploring Beneath the Ocean Floor (joidesresolution.org) website was introduced in FY09 to showcase the renovated ship and serve as a hub for promoting USIO expeditions and Program social networking (Table 10). The site's target audience of teachers, students, and families was able to virtually tour the *JOIDES Resolution*, track the ship's position during transit, and follow expedition progress through blogs, photos, and engaging videos. Interactive features enabled visitors to participate in games and polls and to comment on blogs or send questions to scientists. During FY14, content from the educational website was transferred to joidesresolution.org to centralize all Integrated Ocean Drilling Program and IODP educational content on one site.

Social networking was initiated in FY08 with the *JOIDES Resolution* Facebook page and an education-focused Twitter account (@theJR) that provided expedition-related updates and science news. Ocean Leadership also established a YouTube channel in FY08 where expedition-related videos were published. The "IODP Science News" Twitter account, @SeafloorSci, was launched in FY12 to target the geoscience media and blogging community, augmenting the efforts of the *JOIDES Resolution* account. A *JOIDES Resolution* Tumblr page was initiated during the last quarter of FY12 to further expand visibility of the Program through social media, and a *JOIDES Resolution* Instagram account was created in FY14.

Educational materials

New expedition-specific and thematic learning materials were produced throughout the Program for educating students at the K–12 and undergraduate level, including lesson plans, teaching kits and core models, classroom activities and learning modules for use in shore-based classrooms, online interactive games and puzzles, and DVDs on topics such as climate change, ocean drilling highlights, and more. The USIO distributed hundreds of thousands of educational materials during the Integrated Ocean Drilling Program and the first year of IODP including DVDs, bookmarks, pencils, posters, sticker pages, inflatable globes, papercraft models of the *JOIDES Resolution*, and more at conferences and outreach activities and through requests to the educational website.

Animations, videos, and documentaries

Shipboard digital visualization specialists created a computer animation of ocean floor drilling and CORK installation and operation and a series of "JR in a Minute" animations about the ship and how it works. Professional videographers sailed during expeditions to provide footage for "webisodes" and to film general-audience documentaries that educated a broad audience about science objectives, the drilling process, core flow on the ship, observatory technology, downhole logging on the *JOIDES Resolution*, life at sea, postexpedition sampling and core handling, and more. By the end of FY14, there were more than 200,000 views for all of the IODP videos available on YouTube.

Brochures, graphic novels, and newsletters

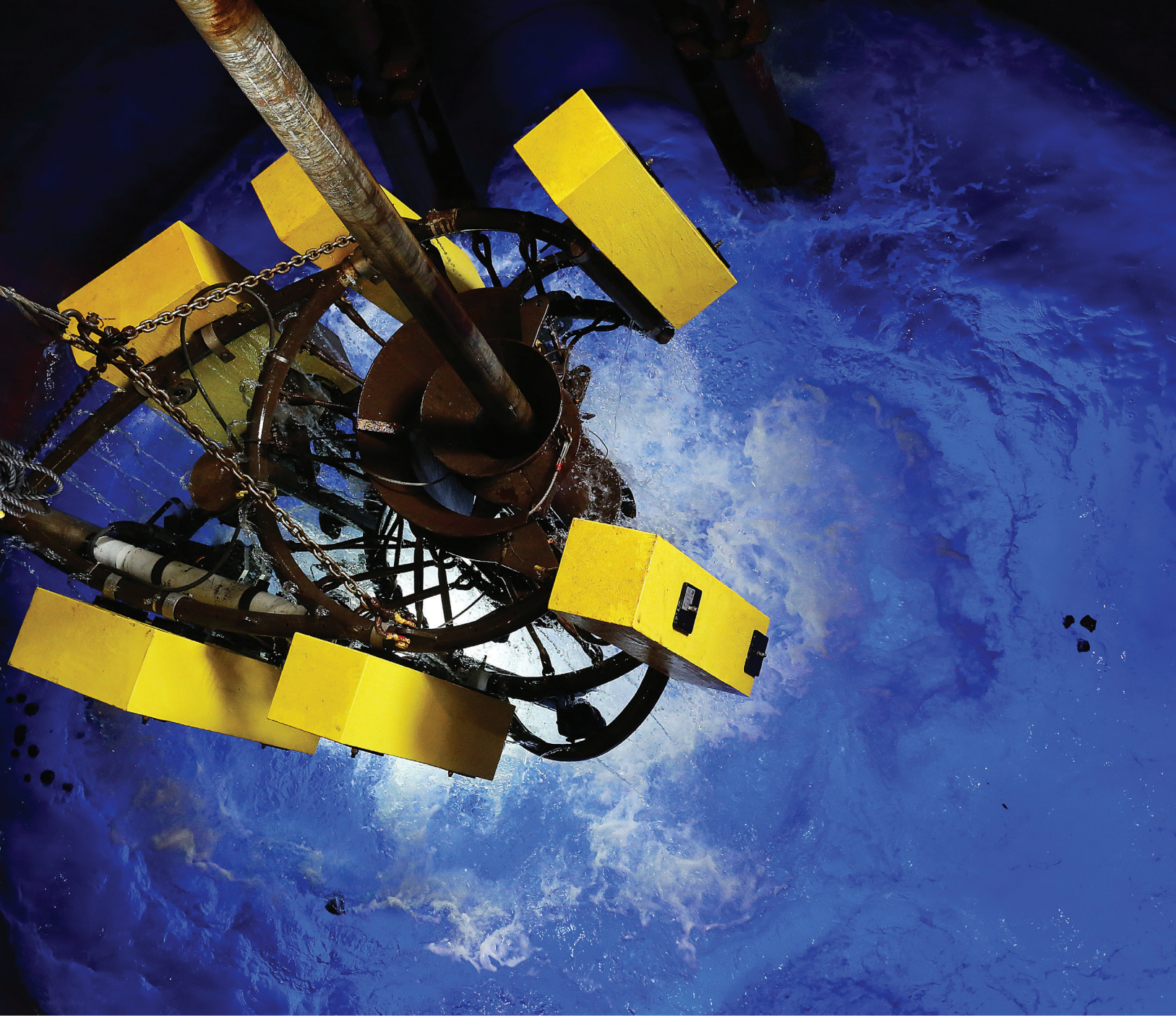
The *IODP Phase 1 Riserless Vessel* brochure, which included information on the *JOIDES Resolution* and the first five Integrated Ocean Drilling Program USIO expeditions, was distributed at conferences and port calls worldwide in FY04 and FY05.

In FY09, the USIO introduced a graphic novel series titled *Tales of the Resolution!*, which provided an engaging format for all ages, covering topics such as operations of the *JOIDES Resolution*, refurbishment and redeployment of the ship, shipboard jobs, and the science of the Pacific Equatorial Age Transect and Louisville Seamount Trail expeditions.

Since 2009, a monthly *JOIDES Resolution* newsletter distributed by e-mail has updated educators on ship expeditions and happenings, directed them to new website features, and alerted them to upcoming opportunities, including open application periods for School of Rock or Education Officer opportunities.

A full-color U.S. Integrated Ocean Drilling Program Community newsletter—*Core Discoveries*—was introduced in FY11 for distribution to the U.S. scientific community and funding agency representatives. The newsletter, which was funded by the USIO and USSSP and published three times a year, highlighted Integrated Ocean Drilling Program and IODP successes, provided readers with timely expedition updates and information on USIO and USSSP activities, and encouraged Program participation.

Core Discoveries newsletter.



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