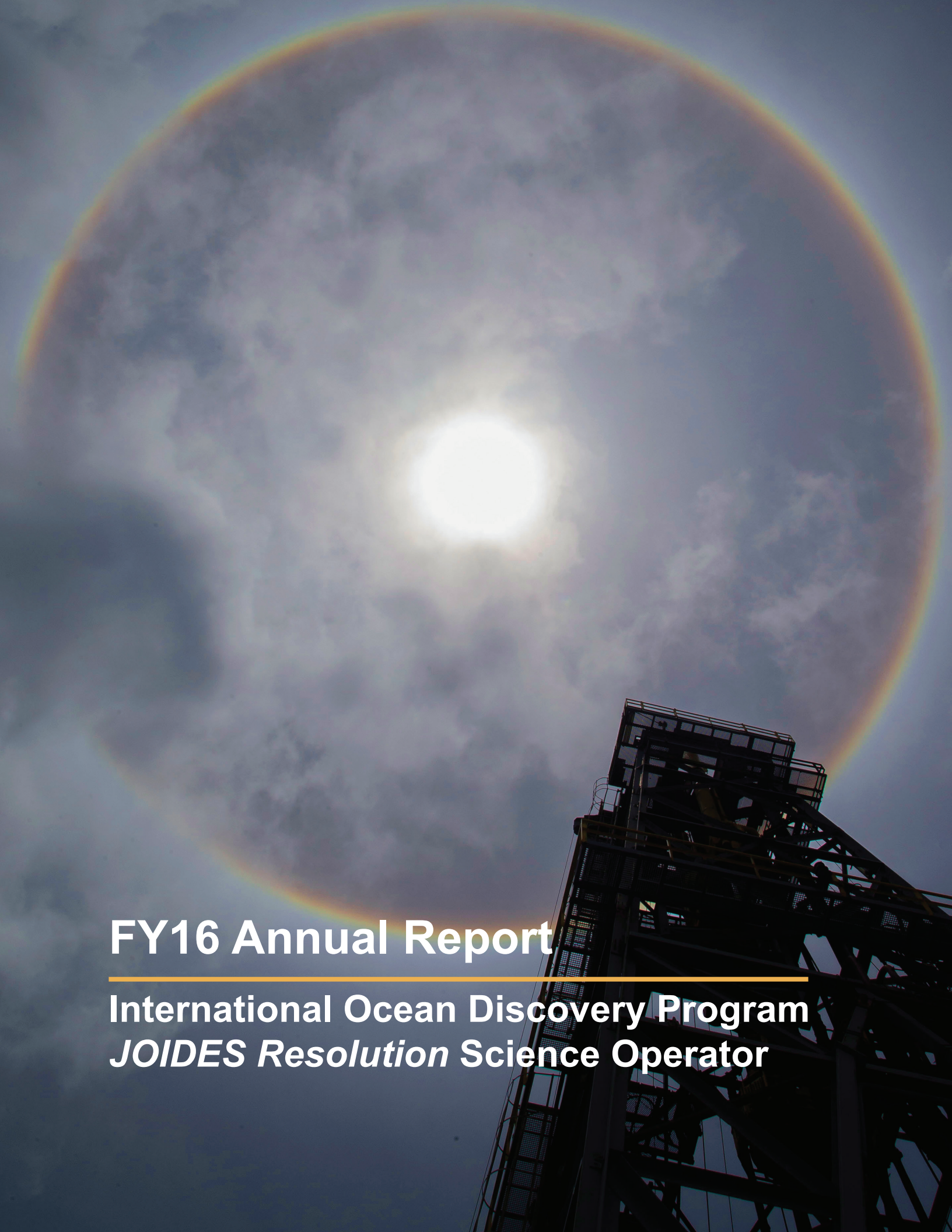

# FY16 Annual Report

## International Ocean Discovery Program
## *JOIDES Resolution* Science Operator

# FY16 Annual Report

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# *JOIDES Resolution* Science Operator

National Science Foundation

Cooperative Agreement OCE-1326927

1 October 2015–30 September 2016



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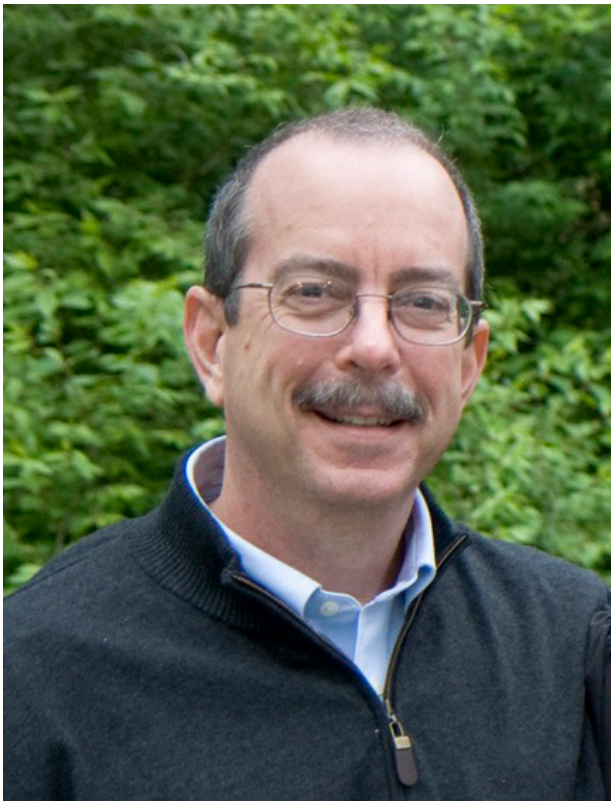
Cover photo: Sun halo over the *JOIDES Resolution* derrick during Expedition 362.



**Brad Clement**

**Director,**
**International Ocean Discovery Program,**
**Texas A&M University**

Brad Clement was appointed Director of the Integrated Ocean Drilling Program at Texas A&M University (TAMU) in August 2009. Clement previously chaired the US Advisory Committee (USAC) and has a long history of involvement with the Program, having sailed on four expeditions, worked as an Ocean Drilling Program (ODP) Staff Scientist, and served on the JOIDES Ocean History Panel. Clement earned his B.S. in Geology from the University of Georgia (1979) and his M.A. (1981) and Ph.D. (1985) in Geology from Columbia University. He previously served as Associate Program Director for the Ocean Drilling Program in the National Science Foundation's Ocean Sciences Division from 2001 to 2003, as a Professor in the Department of Earth and Environmental Science at Florida International University from 1988 to 2009, and as Adjunct Associate Professor of Geophysics at TAMU from 1984 to 1988. Clement was Associate Editor of the *Journal of Geophysical Research* and has served on several American Geophysical Union committees.

**Mitch Malone**

**Assistant Director and Manager of Science Support,**
**International Ocean Discovery Program,**
**Texas A&M University**

Mitch Malone was appointed Assistant Director of the Integrated Ocean Drilling Program at TAMU and Manager of Science Operations in 2011. Malone began working for ODP as a Staff Scientist in 1995, and after transitioning into the Integrated Ocean Drilling Program as a Staff Scientist in 2003, he held the positions of Supervisor of Science Support (2004–2006), Manager of Science Operations (2006–2011), and Acting Director (2008). During Malone's tenure, he has sailed on 10 ODP and Integrated Ocean Drilling Program expeditions. Malone earned his B.A. in Geography from the University of Texas at Austin (1986) and his M.S. (1989) and Ph.D. (1995) in Geology from Duke University. He has also been an adjunct faculty member in the TAMU Departments of Geology and Geophysics since 1996 and Oceanography since 2005. Malone was an Associate Editor of the *Journal of Sedimentary Research* from 1999 to 2004.

# Historical perspective

From October 2015 through September 2016, the international marine research collaboration called the International Ocean Discovery Program (IODP) monitored subseafloor environments and explored Earth's history and dynamics as recorded in seafloor sediments and rocks. IODP built on the earlier successes of the Deep Sea Drilling Project (DSDP), Ocean Drilling Program (ODP), and Integrated Ocean Drilling Program, which revolutionized our view of Earth's history and global processes through ocean basin exploration.

IODP expanded on the predecessor programs through the use of multiple drilling platforms operated by three implementing organizations (IOs) to achieve the Program's goals. The riserless research vessel *JOIDES Resolution*, a research facility managed for IODP by Texas A&M University (TAMU) as the *JOIDES Resolution* Science Operator (JRSO), continues to expand the global sampling coverage and disciplinary breadth that were characteristic of DSDP, ODP, and the Integrated Ocean Drilling Program. The riser drilling vessel *Chikyu*, operated by Japan's Center for Deep Earth Exploration (CDEX), allows extended drilling for several months at a single location. Mission-specific platforms operated by the European Consortium for Ocean Research Drilling (ECORD) Science Operator (ESO) allow 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 is ensured through provision of an Expedition Project Manager/Staff Scientist from the IO responsible for operating the expedition's platform.

Each IODP platform provider utilizes a Facility Board to make decisions on the effective use of its drilling facility in fulfilling the objectives of the IODP Science Plan, "Illuminating Earth's Past, Present, and Future," and each of the IOs provides liaisons with appropriate expertise to interact with the Facility Boards and other Program working groups and task forces. The *JOIDES Resolution* Facility Board (JRFB) is informed by advisory panels—the *JOIDES Resolution* Facility (JRF) Science Evaluation Panel (SEP) and the JRF Environmental Protection and Safety Panel (EPSP)—to evaluate the science, sites, environmental protection, and safety of hypothesis-driven science expedition proposals aligned with principal research themes outlined in the IODP science plan.

IODP facilities are funded by three platform providers (the US National Science Foundation [NSF], Japan's Ministry of Education, Culture, Sports, Science and Technology [MEXT], and ECORD) with financial contributions from the People's Republic of China Ministry of Science and Technology (MOST); the Coordination for Improvement of Higher Education, Brazil; the Interim Asian Consortium, represented by the Korea Institute of Geoscience and Mineral Resources (KIGAM); the Australian and 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. Together, these agencies represent 26 participating nations whose scientists are selected to staff IODP research expeditions conducted throughout the world's oceans.

The *JOIDES Resolution* docked in Colombo, Sri Lanka.

# Contents

# 1. Executive summary

The *JOIDES Resolution* Science Operator (JRSO) successfully completed four full-length expeditions this fiscal year that will advance the global understanding of Earth systems and processes. Postexpedition research on the collected sediments from these expeditions will improve our understanding of mechanisms that play critical roles in current and future climate change in monsoonal regions and deep Earth dynamics and their impact on surficial processes.

During Expedition 359, carbonate platforms and drifts in the Maldives were drilled to better understand changing current systems through time and the effects of global monsoon evolution in the Indo-Pacific realm. Deposits recovered document a dramatic shift in development of the carbonate platform system from sea level–controlled to predominantly current-dominated, a transition that appears to be directly linked to the evolving Indian monsoon.

As the first leg of a multiphase drilling program designed to drill through the Mohorovičić seismic discontinuity (Moho), Expedition 360 drilled into the Atlantis Bank to establish a pilot hole for ultradeep drilling, achieving the deepest igneous rock penetration from the seafloor during a single 2-month *JOIDES Resolution* expedition. Lower crust gabbro recovered from Hole U1473A is similar to that exposed on the surface of the Atlantis Bank oceanic core complex and recovered in nearby Ocean Drilling Program (ODP) Holes 735B and 1105A, enabling assessment of the spatial and temporal scales of variability of igneous lower crustal accretion for the first time. Remediation operations and stabilization of Hole U1473A for future use took place during Expedition 362T.

Expedition 361 drilled into the southeast African margin and in the Indian-Atlantic ocean gateway, southwest Indian Ocean, to recover sediment that will help to reconstruct the history of the greater Agulhas Current system over the past ~5 My by generating complete spliced stratigraphic sections detailing decadal- to millennial-scale climatic records for the area.

Expedition 360 scientists holding record-length Expedition 360 core.

Expedition 362 drilled into the Indian oceanic plate to collect input materials of the North Sumatran subduction zone, the origin of the 2004 earthquake and tsunami in the Indian Ocean region, and examine the role of

seafloor sediments and their potential effect on seismogenesis and tsunamogenesis. Findings suggest the input materials are key to driving shallow earthquake generation and influencing the long-term forearc structure.

A third-quarter ship maintenance period allowed completion of programmatic projects, improvement of *JOIDES Resolution* facilities and laboratory infrastructure, and cross-training of technical staff in support of future International Ocean Discovery Program (IODP) expeditions.

The JRSO produced and published IODP scientific publications including *Scientific Prospectuses*, *Preliminary Reports*, and expedition *Proceedings* volumes containing expedition site reports, expedition research results data reports, and synthesis papers online to disseminate IODP research to the scientific community and the public; tracked IODP expedition science publications in the outside literature and maintained bibliographies of expedition publications; and illustrated the impact of IODP science through program and external publications in the 2016 Scientific Ocean Drilling Bibliographic Database Report. JRSO staff members provided technical support to Onboard Education Officers who used the *JOIDES Resolution* as a platform for education and promoted JRSO expeditions and IODP science through social media tools and live ship-to-shore broadcasts. JRSO staff also assisted with planning and conducting port call outreach, hosted workshops at the Gulf Core Repository (GCR), and made the IODP core collection available for Program outreach.

A Co-Chief Scientist review and a National Science Foundation (NSF) review panel and site visit early in the second quarter culminated in positive feedback, concluding that the JRSO is managing the *JOIDES Resolution* facility well and receiving effective oversight by the *JOIDES Resolution* Facility Board (JRFB) and NSF. The JRSO responded to panel recommendations and NSF guidance by increasing satellite communication bandwidth on the ship, increasing science community participation in laboratory working groups, and making plans for additional staffing.

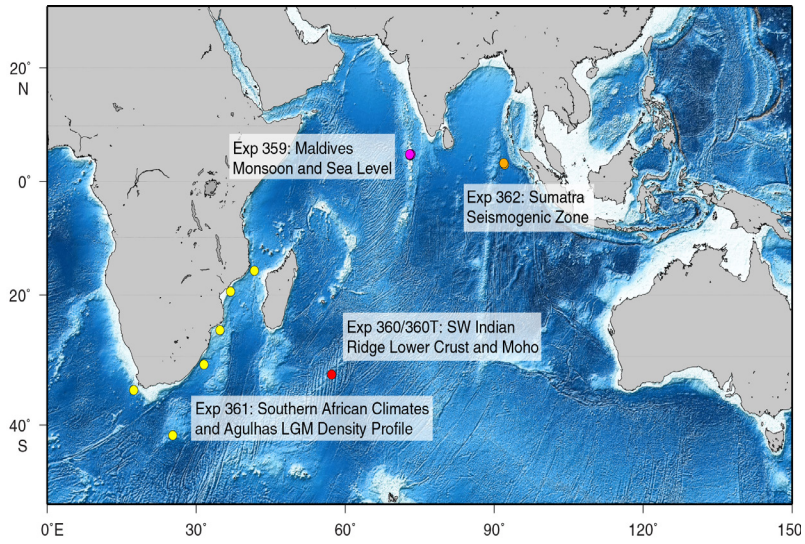
This IODP JRSO FY16 Annual Report details these accomplishments and other activities undertaken in support of NSF Cooperative Agreement OCE-1326927 during the period from 1 October 2015 to 30 September 2016.

# 2. IODP JRSO FY16 expeditions

## Expedition 359

Expedition 359 (Maldives Monsoon and Sea Level; 30 September–30 November 2015) was designed to address changes in sea level and currents, as well as monsoon evolution in the Indian Ocean. The tropical marine record from the Maldives area is key for better understanding the effects of this global evolution in the Indo-Pacific realm. The bank geometries of the growing carbonate archipelago provide a physical

record of changing sea level and ocean currents. Bank growth occurs in pulses of aggradation and progradation controlled by sea level fluctuations during the early and middle Miocene, including the mid-Miocene Climate Optimum. A dramatic shift in development of the carbonate edifice from a sea level–controlled to a predominantly current-controlled system appears to be directly linked to the evolving Indian monsoon. This phase led to a twofold configuration of bank development: bank growth continued in some parts of the edifice, whereas in other places, banks drowned. Drowning steps seem to coincide with onset and intensification of the monsoon-related current system and deposition of contourite fans and giant sediment drifts. Expedition 359 cores will be used to reconstruct the changing current system through time that is directly related to the evolution of the Indian monsoon. As such, the drift deposits will provide a continuous record of Indian monsoon development in the region of the Maldives.



FY16 expedition sites.

The expedition had two main objectives. The first was to date precisely the onset of the current system that is potentially in concert with the onset or the intensification of the Indian monsoon and coincides with the onset of the modern current system in the world's ocean. The second was groundtruthing the hypothesis that the dramatic, pronounced change in style of the sedimentary carbonate sequence stacking was caused by a combination of relative sea level fluctuations and ocean current system changes. These questions were directly addressed by the shipboard scientific data.


Expedition 359 Co-Chief Scientists with the first core on the catwalk.

In addition, Expedition 359 cores will provide a complete Neogene $\delta^{13}C$ record of the platform and

platform margin sediments and a comparison with pelagic records over the same time period. This comparison will allow assessment of the extent to which platform carbonates record changes in the global carbon cycle and whether changes in the carbon isotopic composition of organic and inorganic components covary and the implications this has on the deep-time record. This determination is important, as such records are the only type that exist in deep time.

## Expedition 360

Expedition 360 (Southwest Indian Ridge Lower Crust and Moho; 30 November 2015–30 January 2016) was the first leg of Phase I of the SloMo Project (shorthand for "the nature of the lower crust and Moho at slower spreading ridges"), a multiphase drilling program that proposes to drill through the outermost of the global seismic velocity discontinuities, the Moho. The Moho corresponds to a compressional wave velocity increase, typically at ~7 km beneath the ocean floor, and has generally been regarded as the boundary between crust and mantle. An alternative model, that the Moho is a hydration front in the mantle, has recently gained credence upon the discovery of abundant partially serpentinized peridotite on the seafloor and on the walls of fracture zones, such as at Atlantis Bank, an 11–13 My old elevated oceanic core complex massif adjacent to the Atlantis II Transform on the Southwest Indian Ridge.

During Expedition 360, Hole U1473A was drilled on the summit of Atlantis Bank, 1–2 km away from two previous ODP holes: Hole 735B (drilled during Leg 118 in 1987 and Leg 176 in 1997) and Hole 1105A (drilled during Leg 179 in 1998). A mantle peridotite/gabbro contact was traced by dredging and diving along the transform wall for 40 km. The contact is located at ~4,200 m depth at the drill sites but shoals considerably 20 km to the south, where it was observed in outcrop at 2,563 m depth. Moho reflections have been found, however, at ~5–6 km beneath Atlantis Bank and <4 km beneath the transform wall, leading to the suggestion that the seismic discontinuity may not represent the crust/mantle boundary but rather an alteration (serpentinization) front. This suggestion raises the interesting possibility that a whole new planetary biosphere may thrive due to methanogenesis associated with serpentinization. The SloMo Project seeks to test the two hypotheses for the Moho reflections at Atlantis Bank and evaluate carbon sequestration in the lower crust and uppermost mantle.


Expedition 360 scientist holding core fresh from the drill floor.

The primary broad-scale objective of Expedition 360 was to establish a pilot hole for ultradeep drilling. At Site U1473, we were successful in achieving the deepest igneous rock penetration from the seafloor ever during a single 2-month expedition with the *JOIDES Resolution* (789.7 meters below seafloor [mbsf]). Hole U1473A is open and viable to be substantially deepened; moreover, an unprecedented 96% core recovery in the lowermost 200 m of the hole was achieved by the end of the expedition. As anticipated, a section of lower crustal gabbro similar to that exposed on the surface of the Atlantis Bank oceanic core complex and recovered in nearby Holes 735B and 1105A was drilled. Mantle lithologies were neither expected nor encountered during the first leg of the first phase of the SloMo Project. From the Hole U1473A cores and full suite of downhole logs, most of the major expedition-specific scientific objectives will be fully addressed.

One major objective was to establish whether or not the stratigraphy encountered and processes documented in Hole 735B are representative of the enormous 400 $km^2$ gabbro massif mapped over Atlantis Bank and whether they can be reasonably considered as representative. Both seem to be the case on the basis of three holes drilled there, from which the spatial and temporal scales of variability of igneous lower crustal accretion were assessed for the first time. Equally important is the comparison between Atlantis Bank and its counterpart the Atlantis Massif oceanic core complex on the Mid-Atlantic Ridge, where the stratigraphy differs profoundly in several aspects. A major long-term objective of the SloMo Project is to establish a seismic laboratory at which the properties of the lower crust and upper mantle can be directly measured at seismically appropriate scales. Expedition 360 shows that Atlantis Bank is a (probably uniquely) suitable location for such an endeavor.

## Expedition 361

Expedition 361 (South African Climates [Agulhas LGM Density Profile]; 30 January–31 March 2016) drilled six sites on the southeast African margin and in the Indian-Atlantic ocean gateway, southwest Indian Ocean. The sites, situated in the Mozambique Channel at locations directly influenced by discharge from the Zambezi and Limpopo River catchments, the Natal Valley, the Agulhas Plateau, and

IODP JRSO FY16 expedition summary.

| Expedition | Operations time (days) | Distance traveled (nmi) | Sites (number) | Holes (number) | Meters cored | Cores recovered (number) | Core recovery (%) | Holes logged (number) |
|---|---|---|---|---|---|---|---|---|
| 359: Maldives Monsoon and Sea Level | 37.88 | 4,269 | 8 | 22 | 5,428.8 | 658 | 57 | 5 |
| 360: SW Indian Ridge Lower Crust and Moho | 36.19 | 4,907 | 1 | 1 | 742.7 | 88 | 63 | 1 |
| 361: South African Climates | 29.74 | 6,772 | 6 | 35 | 5,080.4 | 601 | 102 | 0 |
| 362: Sumatra Seismogenic Zone | 40.51 | 3,885 | 2 | 8 | 1,952.9 | 229 | 54 | 2 |
| **Totals** | **144.32** | **19,834** | **17** | **66** | **13,204.8** | **1,576** | **74** | **8** |

Cape Basin, were targeted to reconstruct the history of the greater Agulhas Current system over the past ~5 My. The Agulhas Current is the strongest western boundary current in the Southern Hemisphere, transporting some 70 Sv of warm, saline surface water from the tropical Indian Ocean along the East African margin to the tip of Africa. Exchanges of heat and moisture with the atmosphere influence southern African climates, including individual weather systems such as extratropical cyclone formation in the region and rainfall patterns. Recent ocean model and paleoceanographic data further suggest a potential role of the Agulhas Current in controlling the strength and mode of the Atlantic Meridional Overturning Circulation (AMOC) during the Late Pleistocene. Spillage of saline Agulhas water into the South Atlantic stimulates buoyancy anomalies that act as control mechanisms on the basin-wide AMOC, with implications for convective activity in the North Atlantic and global climate change.

Expedition 361 scientists collecting Rhizon samples from the core.

The main objectives of the expedition were to establish the sensitivity of the Agulhas Current to climatic changes during the Pliocene–Pleistocene, to determine the dynamics of the Indian-Atlantic gateway circulation during this time, to examine the connection of the Agulhas leakage and AMOC, and to address the influence of the Agulhas Current on African terrestrial climates and coincidences with human evolution. Additionally, the expedition collected samples to fulfill the needs of the Ancillary Project Letter, consisting of high-resolution interstitial water samples that will constrain the temperature and salinity profiles of the ocean during the Last Glacial Maximum.

The expedition made major strides toward fulfilling each of these objectives. In total, 5,175 m of core was recovered with an average recovery of 102%. The recovered sequences allowed generation of complete spliced stratigraphic sections that span from 0 to between ~0.13 and 7 Ma. This sediment will provide decadal- to millennial-scale climatic records that will answer the paleoceanographic and paleoclimatic questions set out in the drilling proposal.

## Expedition 362T

During the transit from the April–June 2016 tie up in Cape Town, South Africa, to the Expedition 362 port call in Colombo, Sri Lanka (4 July–6 August 2016), the JRSO conducted Hole U1473A remediation operations to remove the mechanical bit release retainer sleeve (MBR-RS) left at the bottom of the hole at the end of Expedition 360, cement multiple fault zone intervals to stabilize them, obtain a borehole temperature log across the fault zones (at the beginning of operations), and deepen the hole by coring an interval of no more than ~20 m.

The planned temperature logging run at the beginning of Expedition 362T operations was only partially successful because the logging tool could not be lowered below a ledge at 276 mbsf. Subsequent reaming using two tricone bit runs established a clean hole free of debris to the total depth of 789.7 m drilling depth below seafloor (DSF) established during Expedition 360. The fishing run with the reverse circulation junk basket (RCJB) deepened Hole U1473A by 0.5 m, but no junk was present at the bottom of the hole; this result was interpreted to indicate the retaining sleeve had been recovered during the last fishing run during Expedition 360 but fell out of the basket while pipe was being tripped to the surface. To verify that the hole was clean, the hole was advanced by coring 19.7 m with five rotary core barrel (RCB) cores, recovering 16.9 m of gabbro. The final remediation operation was to cement as much of the identified fault zone horizons between ~580 and 160 mbsf as possible. The first zone (~574–509 mbsf) was cemented with 50 barrels, the top of which was tagged at ~500 mbsf. Three attempts to cement the second zone (484–409 m) were made using 152 barrels of cement, with the top of the cemented zone tagged at 434 mbsf. The third attempt did not add to the height of the cement plug, indicating that the borehole in the fault zone was enlarged enough to accommodate the 55 barrels of cement slurry laterally. The last attempt consumed the cement available for the remedial effort, concluding operations.

## Expedition 362

Expedition 362 (Sumatra Seismogenic Zone; 6 August–6 October 2016) was designed to groundtruth the material properties causing unexpectedly shallow seismogenic slip and a distinctive forearc prism structure by drilling the input materials of the North Sumatran subduction zone, part of the 5,000 km Sunda subduction zone system and the origin of the Mw ~9.2 earthquake and tsunami that devastated coastal communities around the Indian Ocean in 2004. This intriguing seismogenic behavior and forearc structure are not well explained by existing models or by relationships observed at margins where seismogenic slip typically occurs farther landward. The input materials of the North Sumatran subduction zone are a distinctive, thick sequence of primarily Bengal-Nicobar Fan–related sediments. The correspondence between the 2004 rupture location and the overlying prism plateau, as well as evidence for a strengthened input section, suggests the input materials are key to driving the distinctive

slip behavior and long-term forearc structure.

Expedition 362 scientists at the sampling table.

During Expedition 362, two sites on the Indian oceanic plate ~250 km southwest of the subduction zone, Sites U1480 and U1481, were drilled, cored, and logged to a maximum depth of 1,500 mbsf. The sediment/rocks that will develop into the plate boundary detachment and drive growth of the forearc were sampled, and their progressive mechanical, frictional, and hydrogeological property evolution will be analyzed through postexpedition experimental and modeling studies. Large penetration depths with good core recovery and successful wireline logging in the challenging submarine fan materials will enable evaluation of the role of thick sedimentary subduction zone input sections in driving shallow slip, as well as the resulting amplified earthquake and tsunami magnitudes, at the Sunda subduction zone and globally at other subduction zones where submarine fan-influenced sections are being subducted.

Drilling into Hole U1481A, which reached a total penetration depth of 5,678 meters below sea level, required one of the top six longest drill strings used by a riserless vessel in scientific ocean drilling history and the third longest used by the *JOIDES Resolution*.

# 3. Program review

## Facility performance assessment

The JRSO hosted two meetings during the second quarter of FY16 to assess the JRSO's performance. The first meeting, held 22 and 23 February 2016, was a Co-Chief Scientist review chaired by Craig Fulthorpe (University of Texas at Austin, USA), during which seven of the eight FY15 expedition Co-Chief Scientists assessed the JRSO's performance in implementing FY15 Expeditions 353–356. Their findings were compiled in a report that was presented at the second meeting, an NSF Proposal Review Panel for Ocean Sciences site visit held 24–26 February to assess the JRSO's performance as a facility in meeting the needs of the International Ocean Discovery Program in fulfilling its Science Plan. The international review panel found that "the facility is being managed exceptionally well by the JRSO, and that it is also being overseen effectively by the JRFB and NSF to meet the IODP Science Plan."

## Panel recommendations and NSF guidance

The JRSO received panel recommendations from NSF on 8 March 2016 with guidance for implementation; some of the recommendations were addressed during FY16 and others in the JRSO FY17 Annual Program Plan.

### Additional staffing

The review panel proposed that the JRSO request additional staffing within either a FY16 Annual Program Plan Addendum or in the FY17 Annual Program Plan to (1) ensure the ability to quickly address unexpected complications in obtaining clearance, (2) ensure that backup is in place for the loss of a JRSO employee without compromise of facility operations, and (3) add staff sufficient to meet the needs of 10 months of facility operations per year. In response to this recommendation, the JRSO began reviewing possible additions to the staffing model to provide assistance in the Science Operations department with the episodic requirements of research clearance and environmental assessments and to provide some degree of redundancy in the management structure. In preparing for implementing five expeditions per year, the JRSO added one curatorial representative and two marine technical specialists to the roster of positions supported by the cooperative agreement.

### Increased satellite communication bandwidth

The review panel proposed adoption of increased satellite communication bandwidth aboard the *JOIDES Resolution* to be included in either a FY16 Annual Program Plan Addendum or in the FY17 or FY18 Annual Program Plans. In response, the JRSO implemented and tested wide area network (WAN) acceleration, negotiated an increase in service with RigNet that resulted in an additional 1 Mbps of downlink bandwidth, and added 384 kbps of uplink and downlink bandwidth that was previously allocated to SIEM Offshore. Total JRSO bandwidth currently available aboard the *JOIDES Resolution* is 1 Mbps up (out from the ship) and 2 Mbps down (to the ship).

### Increased community participation

The review panel recommended an increase in community participation in the Laboratory Working Groups (LWGs) and the visibility of LWG activities to

Siem Offshore crew pulling core from the drill pipe.

the broader science community, to be implemented in FY16. In response, the JRSO worked to increase community participation in the LWGs and requested travel funds in the FY17 Annual Program Plan for external members of two LWGs to attend *JOIDES Resolution* port calls to assess the laboratories, protocols, and documentation. During FY16, external members participated in Geology, Geophysics, and Geochemistry LWG meetings.

### Port call outreach

The review panel recommended that the JRSO discuss with NSF the advisability and cost for providing JRSO personnel support for conducting ship tours by appropriate local/regional/national groups during port calls and tie-up periods. Adding budgetary support for this activity would require modification to the existing Cooperative Agreement. In response, the JRSO proposed in the FY17 Annual Program Plan to work with NSF to revise the Cooperative Agreement to reflect efforts by JRSO staff to support outreach at port calls of the *JOIDES Resolution*.

### Other panel discussion topics

The JRSO also pursued the following items discussed by the review panel.

#### *Nondestructive elemental scanning*

The JRSO continued to evaluate nondestructive elemental scanning of individual core samples by both portable X-ray fluorescence (XRF) and new laser methods. A portable handheld XRF will be deployed on Expedition 366. At this time, the laser-induced breakdown spectroscopy (LIBS) method does not appear to be mature enough for shipboard deployment.

#### *Data discoverability*

The JSRO began collaborating with a group of Principal Investigators (Doug Fils [Consortium for Ocean Leadership], Kerstin Lenhert [Lamont-Doherty Earth Observatory], and Anders Noren [University of Minnesota]) to develop Open Core Data (OCD), a project that will define a graph-based data model for scientific ocean drilling data and continental scientific drilling data. The result will provide a repository for data that is persistent and machine discoverable.

## 4. Operational and technical support

The JRSO provided operational and technical support for four complete *JOIDES Resolution* expeditions during FY16 and improved shipboard laboratory infrastructure, completed programmatic projects, and cross-trained technical staff during the maintenance period in Colombo, Sri Lanka.

## Expedition planning

The JRSO coordinated science staffing to fulfill specialized needs, made shipboard berths available to accommodate education and outreach efforts, and acquired and shipped operational and laboratory supplies for restocking during all FY16 expedition port calls.

Science staffing was completed this year for FY17 Expeditions 363 (Western Pacific Warm Pool) and 366 (Mariana Convergent Margin). Pre-expedition planning meetings were held in College Station, Texas (USA), for FY17 Expeditions 366, 367 and 368 (South China Sea Rifted Margin), and 369 (Australia Cretaceous Climate and Tectonics), along with a CORK design meeting for Expedition 375 (Hikurangi Subduction Margin). In addition, JRSO expedition scientists and proponents met to discuss changes in the Expedition 362 operational plan and FY18 Expedition 375 planning and issues during the American Geophysical Union (AGU) Fall Meeting.

The JRSO received a special permit to carry explosives during Expedition 359 while in Maldivian waters, which was not included in the previously obtained clearance. The South African government granted consent for Expedition 361 proposed research; however, because of issues with paperwork in Mozambique, the JRSO had to resubmit the clearance agreement and the *JOIDES Resolution* had to divert and start work in South African and international waters while awaiting formal approval. The US State Department obtained verbal permission from the Mozambique government for the *JOIDES Resolution* to start operations in Mozambique waters on 7 March 2016, 6 weeks after the start of the expedition. After 6 months of effort to resolve Expedition 362 clearance hurdles, the decision was made to focus only on international water sites and forego pursuing clearance for sites in Indonesian waters. The JRSO offered Indonesia two guest scientific berths. Australia, Papua New Guinea, and the Federated States of Micronesia issued authorizations to conduct Expedition 363 proposed research. Authorization from the Philippines was still pending at the end of the fiscal year. The JRSO also submitted a clearance application to the US State Department and addressed follow-up queries from Taiwan and the US embassy in Beijing for Expeditions 367 and 368, requested depth extensions for some Expedition 366 sites, and sent initial queries to the Navy

Siem Offshore crewman at work.

(Commander, Submarine Force, US Pacific Fleet [COMSUBPAC]) concerning deconflicting operations at Expedition 366 Site 1200.

NSF reviewed environmental evaluations and approved the use of acoustic sources to conduct zero-offset vertical seismic profiles (VSPs) during Expeditions 360, 361, and 362. Outside of its annual meeting, the Environmental Protection and Safety Panel (EPSP) and the Texas A&M University (TAMU) Safety Panel recommended approval of depth extensions for two Expedition 359 sites, operations within a clarified coordinate box for Expedition 360, two new Expedition 361 sites, two new Expedition 363 sites, and depth extensions for five Expedition 366 sites.

## Shipboard and laboratory improvements

### Laboratory working groups

The Geochemistry, Geology, Geophysics, and Curation and Core Handling LWGs comprise technical and science staff members and external participants who review expedition evaluations, expedition technical reports, and issues management communications to develop advice on corrective actions and potential developments on the *JOIDES Resolution* and on shore. The LWG technical and science leads attend Issues Management Team meetings to help management better prioritize the LWG efforts. The four LWGs advised equipment acquisition and upgrades, process improvements, maintenance period activities, and ongoing quality assurance work during FY16.

### Shipboard systems and laboratories

During the third-quarter maintenance period, the JRSO focused laboratory activities on refurbishing worn equipment, completing programmatic projects, and cross-training technical staff to improve coverage of laboratory facilities within the current staffing model. Tasks performed during the maintenance period included removing and replacing damaged floors in the core splitting room,

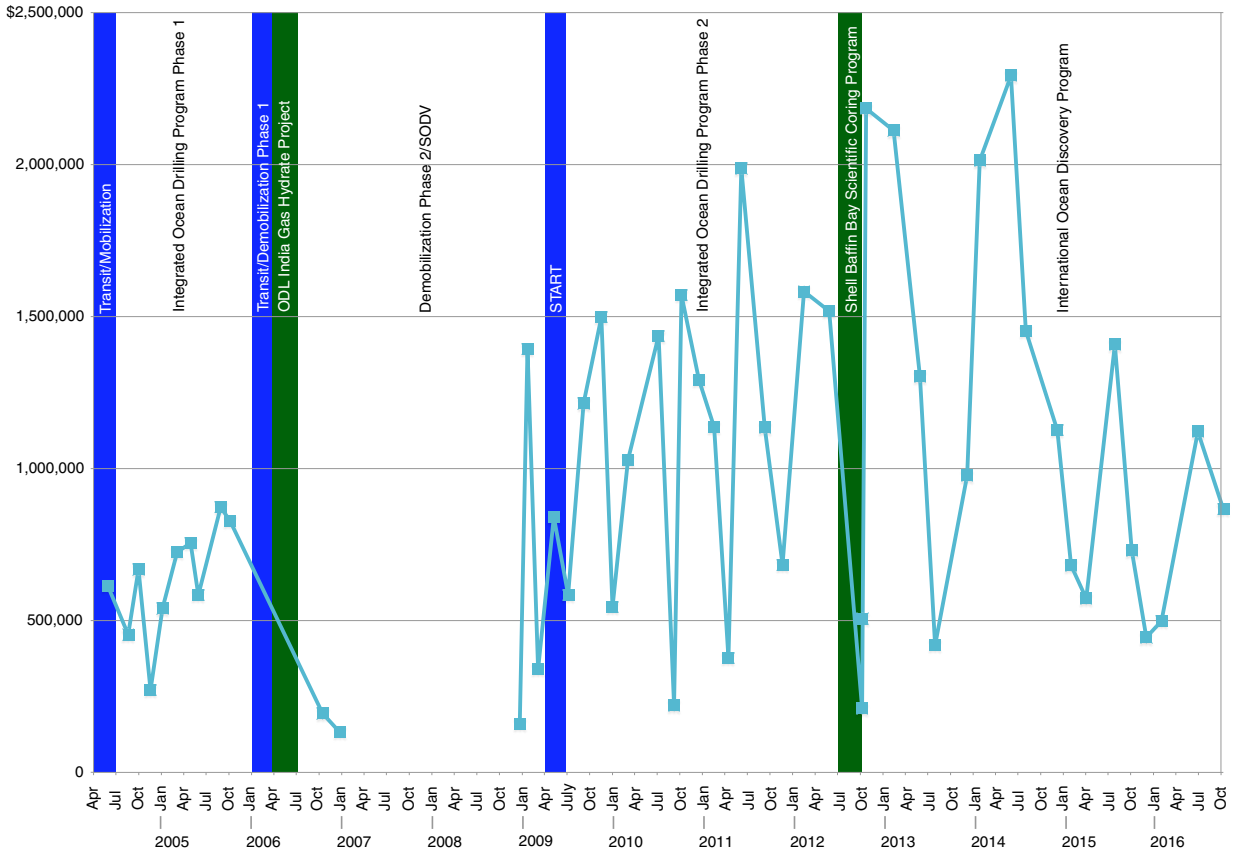
IODP JRSO FY16 expedition science staffing breakdown.

| Member country/consortium | Expedition | | | | Total |
|---|---|---|---|---|---|
| | 359 | 360 | 361 | 362 | |
| United States Science Support Program (USSSP) | 9 | 10 | 9 | 9 | 37 |
| Japan Drilling Earth Science Consortium (J-DESC) | 4 | 4 | 3 | 4 | 15 |
| European Consortium for Ocean Research Drilling (ECORD) | 10 | 9 | 10 | 10 | 39 |
| Korea Integrated Ocean Drilling Program (K-IODP) | 1 | 1 | 0 | 1 | 3 |
| IODP-China | 2 | 2 | 2 | 3 | 9 |
| Australia/New Zealand IODP Consortium (ANZIC) | 1 | 1 | 2 | 2 | 6 |
| India Ministry of Earth Science (MoES) | 1 | 1 | 1 | 1 | 4 |
| Coordination for Improvement of Higher Education (IODP-Brazil) | 1 | 1 | 1 | 1 | 4 |
| **Total Science Party participants** | **29** | **29** | **28** | **31** | **117** |

replacing the air-conditioning unit on the radioisotope van, dismantling and refurbishing all rock saws, fabricating new rock saw enclosures, and refinishing countertops. Laboratory equipment was sent for repair (Icefield MI-5 orientation tools and Agilent 7890 gas chromatographs), and new equipment was installed in the shipboard laboratories (new color reflectance spectrophotometers and a second imaging logger, which was returned to shore to become a testbed for program improvements and upgrades). JRSO staff began rebuilding the superconducting rock magnetometer (SRM) software, evaluated potential replacements for the Thermo Niton XLt3 handheld energy-dispersive XRF (ED-XRF) spectrometer, and created a new inductively coupled plasma spectroscopy (ICP) data reduction program, which will be tested alongside the existing data reduction software (ICP Analyzer) for possible implementation.

More than 8,700 core sections were processed through the shipboard laboratories during the four FY16 expeditions, and over 40,000 samples were taken, more than 3,500 of which were catwalk samples. Shipboard technical staff and expedition scientists made well over 3,260,000 shipboard measurements on FY16 samples and placed more than 19,800 images (sections, close-ups, and microimages) in the database archive.

Actual fuel costs FY04–FY16.



## Shore-based geosciences laboratory

The TAMU Geosciences XRF Core Scanner facility housed at the GCR hosted scientists for XRF scanning projects throughout the fiscal year, using the facility an average of 80% of available days. More IODP scientists continue to request postexpedition XRF time; the majority of requests for scanner use at the end of the fiscal year were from scientists from recent expeditions, with only 2 weeks of the first quarter of FY17 reserved for analyzing legacy cores.

The scanner's X-ray source failed in early January, and the detector no longer functioned properly, so the XRF manufacturer, Avaatech, made their next generation of detector available, along with the existing software modifications to use it. The new detector is roughly three times faster than the old detector and has higher spectral resolution. Over the past few years, there has been increasing demand for scanning XRF data to refine splices, guide sampling, and determine downhole elemental trends. In support of adding XRF scanning to our programmatic measurement portfolio, the JRSO purchased a new XRF core scanner, which will be delivered in FY17 to operate in conjunction with the existing system. The JRSO also began developing guidelines for the support of postexpedition XRF scanning and plans to fold the TAMU College of Geosciences XRF scanning system into JRSO management and control.

# Core curation

The JRSO provides services in support of IODP core sampling and curation of the core collection archived at the GCR. The GCR refurbishment project was completed in time for the GCR to host the United States Science Support Program (USSSP) Antarctic Workshop, which was attended by ~80 scientists.

In FY16, the GCR processed a total of 13,631 sample requests and hosted sampling parties for Expeditions 356 and 359, during which 15,726 and 29,618 samples, respectively, were taken. JRSO staff also worked with the Kochi Core Center curator to create integrated sample lists before and resolve further sampling issues during the Expedition 353 sampling party, during which more than 40,000 samples were taken.

Siem Offshore crew preparing the free-fall funnel for use.

# Data management

The JRSO manages data in support of IODP activities, including expedition and postexpedition

data; provides long-term archival access to data; and supports JRSO information technology services. Upgrades of the *JOIDES Resolution* satellite system were implemented this year, along with planning and work toward several high-priority development projects.

## Laboratory Information Management System

During expeditions, laboratory work aboard the *JOIDES Resolution* produces a vast amount of data that are stored in the Laboratory Information Management System (LIMS). LIMS data collected during JRSO Expeditions 356, 359–361, and 362T were successfully transferred to shore, merged with the cumulative LIMS database, and made available online to participating scientists. More than 24,800 downloads were made from the LIMS database during FY16.

## JOIDES Resolution satellite services

The JRSO worked closely with RigNet, its Very Small Aperture Terminal (VSAT) vendor, to resolve a problem with internet service degradation, which caused intermittent outages and poor performance on the *JOIDES Resolution*. The problem was determined to be a faulty fiber modem in the Fuchsstadt, Germany, land earth station and interference by a strong carrier near the *JOIDES Resolution*'s satellite operating frequency. JRSO negotiations with RigNet and Siem Offshore resulted in increased available bandwidth aboard the *JOIDES Resolution,* now 2 Mbps down (to the ship) and 1 Mbps up (out from the ship). In addition, the JRSO successfully implemented and tested WAN acceleration during Expedition 361, which improved network throughput. The new WAN accelerator will be used for all future expeditions.

## Development projects

Teams were assigned through JRSO's project portfolio management process, and planning began for projects to install a new liquid helium–free magnetometer aboard the *JOIDES Resolution* and test the new Integrated Measurement System (IMS)-based SRM software running the system; replace the current LIMSpeak application with a set of applications that will improve the user interface and experience and adopt some user-requested improvements; and implement installation, data handling processes, quality assurance guidelines, and staff training for a second Avaatech XRF core scanner to be used on shore along with an existing Avaatech scanner to facilitate postexpedition XRF scanning.

Work on the Extending IMS to Whole-Round Multisensor Logger (WRMSL) and Special Task Multisensor Logger (STMSL) project was completed during FY15, and operational testing and documentation were completed during FY16. With completion of the SRM software and the new WRMSL, all core loggers on the *JOIDES Resolution* except the natural gamma ray logger will have the same fundamental software architecture. Other major projects assigned in FY15 that were completed in FY16 include Improve Web

Services, 360 Degree Images to LIMS, and JR-6A Spinner Magnetometer Uploader.

*Improve Web Services*

The Improve Web Services project improved functionality and maintainability of web services for data input and output to LIMS by fixing and replacing existing web services with newer versions while implementing secure authentication for all services that use accounts and passwords (part of meeting a TAMU security requirement).

*360 Degree Images to LIMS*

The 360 Degree Images to LIMS project improved support for capture, retrieval, and management of Whole-Round Line Scan (WRLS) images and their composites. Successful integration entailed revisions to data storage definitions, LIMS Reports, the data upload facility, and the Section Half Image Logger (SHIL).

RGB color calibration standards on the Section Half Image Logger.

*Thin Section Form Report Follow-up*

The Thin Section Form Report Follow-up project improved the appearance of reports generated by the Report Writer application, particularly relating to pagination, in response to repeated user requests, and improved user friendliness of the Report Builder, which should improve task efficiency and report quality for personnel defining reports and shorten the learning curve for new personnel assigned to that role.

*JR-6A Spinner Magnetometer Uploader*

The JR-6A Spinner Magnetometer is the primary instrument used in the paleomagnetism laboratory to measure discrete samples. In response to requests the Geophysics LWG received from expedition scientists, the JRSO developed an uploader that will accept JR-6A Spinner Magnetometer files and make the data available in the LIMS database.

## Program integration and planning for the future

The JRSO produced Integrated Ocean Drilling Program *Proceedings* volumes for expeditions that concluded by the end of FY14, including Center for Deep Earth (CDEX) expeditions. In addition, the *Chikyu* and European Consortium for Ocean Research Drilling (ECORD) Facility Boards each include

a JRSO liaison, and the JRFB includes liaisons from ECORD and CDEX. This year, JRSO representatives participated in the JRFB meeting in May, Science Evaluation Panels in January and June, *Chikyu* IODP Board meeting in March, ECORD Facility Board meeting in June, EPSP meeting in July, and US Advisory Committee (USAC) meeting in February.

Senior JRSO staff attended the USSSP leadership meeting on 15 December 2015 at the AGU Fall Meeting, and JRSO Director of Science Services Brad Clement presented a keynote presentation at the Australian Earth Science Convention held 27 June 2016 in Adelaide, Australia. The talk presented the initial results of the *JOIDES Resolution*'s expeditions in the Indian Ocean to date and was part of a special session organized by the Australian and New Zealand International Ocean Discovery Program Consortium (ANZIC) to highlight ANZIC's role in the International Ocean Discovery Program. Clement also attended the IODP Forum meeting held 21–23 September 2016 in Buzios, Brazil.

# 5. Broader impacts

The JRSO publishes Integrated Ocean Drilling Program and IODP science on an ongoing basis and provides technical support for shipboard and port call education and outreach efforts to expand the visibility of IODP as a societally relevant, cutting-edge international Earth science research program.

## Publications

IODP Publication Services produces publications from Integrated Ocean Drilling Program and IODP riserless, mission-specific, and riser drilling expeditions and provides editing, production, and graphics services for required Program reports, technical documentation, and scientific publications as defined in the JRSO cooperative agreement with NSF. Publications from IODP mission-specific expeditions are produced under contract with the British Geological Survey on behalf of ECORD and the ECORD Science Operator (ESO).

### Publishing IODP science

IODP scientific publications are the primary method of disseminating Program research to the scientific community and the public. This year, IODP Publication Services produced and published nine *Scientific Prospectuses* for JRSO, CDEX, and ESO expeditions; four *Preliminary Reports* for JRSO and ESO expeditions; and three *Proceedings* volumes for JRSO expeditions. *Proceedings* volumes include expedition reports and postexpedition research data reports and synthesis contributions. During FY16, IODP Publication Services coordinated postexpedition publications and worked on *Proceedings* content for 19 expeditions, including 35 data reports, and shipboard reports from 9 expeditions.

The JRSO facilitates production of IODP *Proceedings* volumes by sailing Publications Specialists on JRSO expeditions to coordinate shipboard reports and hosting postexpedition editorial meetings. During

these meetings, Publications staff coordinate science reviews of all expedition reports content and assist meeting participants with editing prior to publication. In FY16, Publications Specialists sailed during all JRSO expeditions, and JRSO staff in College Station hosted postexpedition meetings for three JRSO expeditions and one ESO expedition.

Student group from Mauritius touring the *JOIDES Resolution*.

## Making IODP publications accessible

All DSDP, ODP, Integrated Ocean Drilling Program, and IODP scientific publications are accessible online at the IODP Publications website (http://publications.iodp.org). Zip volumes are available so users can download the expedition reports portion of any IODP *Proceedings* volume. Program scientific publications are also easily accessible through CrossRef, an official digital object identifier (DOI) registration agency for scholarly and professional publications, and the Scientific Ocean Drilling Bibliographic Database (http://iodp.americangeosciences.org/vufind). The database is a subset of the American Geosciences Institute's (AGI's) GeoRef database and includes more than 32,000 entries related to IODP and the preceding scientific ocean drilling programs, representing nearly a half century of scientific ocean drilling research.

AGI launched a new version of the Scientific Ocean Drilling Bibliographic Database on 30 September 2016. This redesigned web interface utilizes VuFind software and replaces the Inmagic interface AGI developed 15 years ago for ODP. With the new interface, users can set up accounts to customize their experience by making publication lists, adding notes to records, and saving favorite searches. Interface search and support is offered in multiple languages, and users will find expanded search fields; suggested keywords and categories based on search; and options for filtering results, browsing, conducting geographic searches, and exporting bibliographic records in multiple formats.

IODP Publication Services staff continued to explore options for a permanent electronic archive solution for legacy Program expedition publications.

### Measuring Program publication impact

IODP Publication Services tracks the number of times Program publications are accessed through available online resources to derive an indication of the level of interest in IODP scientific publications. There were 83,862 visits to the IODP Publications website during FY16. Program publications accessed through CrossRef numbered more than 59,000 DOI resolutions for Integrated Ocean Drilling Program and IODP publications and more than 153,000 DOI resolutions for DSDP and ODP publications. More than 8,700 queries were run on the Ocean Drilling Citation Database, and additional records for more than 16,000 citations were viewed.

2016 TAMU GeoX camp touring the GCR.

The annual Scientific Ocean Drilling Bibliographic Database Report documents how postexpedition Program-related research is disseminated into the scientific community through publications. The 2016 report looks at publications from highly ranking peer-reviewed journals, publications by authors from current IODP member countries, and publications by IODP expedition and Science Plan theme and also illustrates through "cited-by" data from Google Scholar how often scientific ocean drilling program publications are cited in other research articles. This report was published on 30 September and is available online at http://iodp.tamu.edu/publications/AGI_studies/AGI_study_2016.pdf.

IODP Publication Services uses CrossRef's "Cited-by Linking" service, which utilizes publisher-provided metadata to provide links from all Integrated Ocean Drilling Program and IODP publications table of contents pages to scientific articles or books that cite the Program publication.

## Supporting education and outreach

### Promoting IODP science

JRSO staff provided technical support for Onboard Education Officers' live ship-to-shore broadcasting, helped plan and execute public relations and outreach activities during port calls for FY16 Expeditions 359–362, and assisted with planning FY17 Expedition 363 port call activities. JRSO scientists mentored TAMU students this year through Staff Scientist science engagement activities, which culminated in presentations of the students' work at the TAMU Student Research Week on 30 March 2016. One

of these mentored students won first place at the TAMU Geology & Geophysics Student Research Symposium on 31 March.

## Using IODP core collections for education

The GCR core collection was used for Program outreach through materials provided for display at meetings and museums, tours of the repository, and educational programs. The GCR hosted the USSSP Antarctic Workshop (9–11 May) and the Minority-Serving Institution–Reconstructing Earth's Climate History (MSI-REaCH) Program Faculty Development Workshop (1–5 August) and gave repository tours to 359 visitors, including workshop participants, university faculty and students, and 120 middle school students from the Summer Science Safari Program from Houston, Texas.

# URL list

*Illuminating Earth's Past, Present and Future: The Science Plan for the International Ocean Discovery Program* 2013–2023: http://iodp.org/Science-Plan-for-2013-2023

IODP funding agencies: http://www.iodp.org/funding-agencies

*JOIDES Resolution* Facility Board and Panels: http://www.iodp.org/facility-boards

IODP JRSO website: http://iodp.tamu.edu

IODP JRSO FY16 Annual Program Plan: http://iodp.tamu.edu/publications/PP/IODP_JRSO_FY16_APP.pdf

IODP JRSO FY16 Quarterly Reports: http://iodp.tamu.edu/publications/reports.html

IODP expedition schedule: http://iodp.tamu.edu/scienceops/index.html

IODP expedition information: http://iodp.tamu.edu/scienceops/expeditions.html

Gulf Coast Repository: http://iodp.tamu.edu/curation/gcr/index.html

Core database: http://iodp.tamu.edu/tasapps

LIMS Reports: http://web.iodp.tamu.edu/LORE

Sample requests: http:/iodp.tamu.edu/curation/samples.html

IODP scientific publications: http://publications.iodp.org

*Proceedings of the International Ocean Discovery Program*: http://iodp.tamu.edu/publications/proceedings.html

Expedition-related citation lists: http://iodp.tamu.edu/publications/citations.html

Scientific Ocean Drilling Bibliographic Database: http://iodp.americangeosciences.org/vufind

2016 Scientific Ocean Drilling Bibliographic Database Report: http://iodp.tamu.edu/publications/AGI_studies/AGI_study_2016.pdf

# Acronyms

| | |
|---|---|
| AGI | American Geosciences Institute |
| AGU | American Geophysical Union |
| AMOC | Atlantic Meridional Overturning Circulation |
| ANZIC | Australian and New Zealand IODP Consortium |
| CDEX | Center for Deep Earth Exploration |
| DOI | digital object identifier |
| DSF | drilling depth below seafloor |
| ECORD | European Consortium for Ocean Research Drilling |
| ECS | extended continental shelf |
| ED-XRF | energy-dispersive XRF |
| EPSP | Environmental Protection and Safety Panel |
| ESO | ECORD Science Operator |
| GCR | Gulf Coast Repository |
| ICP | inductively coupled plasma spectroscopy |
| IMS | Integrated Measurement System |
| IODP | International Ocean Discovery Program |
| JRFB | JOIDES Resolution Facility Board |
| JRSO | JOIDES Resolution Science Operator |
| LIBS | laser-induced breakdown spectroscopy |
| LIMS | Laboratory Information Management System |
| LWG | laboratory working group |
| MBR-RS | mechanical bit release retainer sleeve |
| mbsf | meters below seafloor |
| Moho | Mohorovičić seismic discontinuity |
| NSF | National Science Foundation |
| OCD | Open Core Data |
| ODP | Ocean Drilling Program |
| RCB | rotary core barrel |
| RCJB | reverse circulation junk basket |
| SHIL | Section Half Imaging Logger |
| SloMo | the nature of the lower crust and Moho at slower spreading ridges |
| SRM | superconducting rock magnetometer |
| STMSL | Special Task Multisensor Logger |
| TAMU | Texas A&M University |
| USAC | US Advisory Committee |
| VSAT | Very Small Aperture Terminal |
| VSP | vertical seismic profile |
| WAN | wide area network |
| WRLS | Whole-Round Line Scan |
| WRMSL | Whole-Round Multisensor Logger |
| XRF | X-ray fluorescence |