ECORD Teachers Workshop

Exploring the Ocean Floor with the Integrated Ocean Drilling Program (IODP)

EGU General Assembly 2007
18-19, April 2007, Vienna, Austria

European Geosciences Union
ECORD Teacher's Workshop
Austria Center Vienna, 18-19 April 2007

Exploring the Ocean Floor with the Integrated Ocean Drilling Program

Dear Teacher,

Welcome to the ECORD teacher's workshop at the EGU General assembly. Our goal with the workshop is to share with you the excitement of ocean drilling research, by presenting you with some of the most recent scientific results produced by this international community of marine scientists. We also hope to demonstrate for you and your students that international cooperation between scientists with different professional skills and personal cultures is not only possible, but necessary, to discover how our planet Earth functions and how humanity can best take care of it.

We have selected ocean drilling research topics that are complementary to the natural hazard sub-theme of the Geosciences in the City GIFT workshop that you have just attended, as well as some talks about the kinds of research ships that we use to carry out our explorations. The occurrence of volcanic eruptions, earthquakes and sea-level change are all well-recognized natural hazards, originating in the Earth's plate tectonic activity that is manifested by the creation and destruction of the oceanic crust. We also look at two studies of sediments deposited in the ocean focusing on sediments stability and the potential for landslides as well as microbial communities living in the deep ocean floor – the last topic perhaps a little preview of next year's GIFT proposed workshop on the carbon cycle.

These talks are just a brief introduction to the variety of science performed by IODP. There are 21 countries participating in IODP and the specialties of the scientists sailing with IODP include geology, physics, chemistry, biochemistry, microbiology, micropaleontology, engineering….. the list goes on! IODP-related web links for both classroom material and scientific results can be found at www.iodp.org - follow the education links to find movies, posters, classroom activities and much more. You will find information which will be of specific use to you in your classroom regardless of the science discipline you teach.

We would like to thank the EGU for providing for workshop costs and logistics, and the European Commission for providing financing for the ECORD workshop via an ERA-net grant to ECORD. The EGU Committee on Education (and especially Carlo Laj for leading the GIFT effort and Barbara Donner for assistance with the hotel booking) contributed by advertising and recruiting teachers to the workshop. The Department of Geology and Geochemistry at Stockholm University provided production of the workshop volume.

Within the IODP community, we would like to thank all the scientists who agreed to make a presentation for this workshop, the ECORD managing agency (especially Patricia Maruejol) for organizing and supplying supplementary material for the teachers, IODP-MI for granting copyright permission for the Scientific Drilling article reproduced in this volume, and JAMSTEC for sending us Tadashi to talk about the Chikyu.

Eve Arnold
On behalf of the ECORD-IODP community

Teachers

GIFT-2007 Workshop List of Attending teachers

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Program

European Geosciences Union – General Assembly
ECORD Teacher's Workshop
Austria Center Vienna

Exploring the Ocean Floor with the Integrated Ocean Drilling Program

Wednesday, April 18

11.45 – 13.30 **LUNCH**

13.30 – 14.00 **INTRODUCTION TO THE OCEAN FLOOR AND IODP**
Eve Arnold
Department of Geology and Geochemistry
Stockholm University, Sweden

14.00 –15.00 **DRILLING INTO THE EARTHQUAKE ZONE IN THE NANKAI TROUGH, JAPAN**
Achim Kopf
Research Centre Ocean Margins (RCOM)
Bremen University, Germany

15.00 – 15.30 **COFFEE BREAK**

15.30 – 16.30 **IODP AND THE EARTH'S VOLCANISM**
Marco Sacchi
Institute for Coastal Marine Environment
National Research Council
Napoli, Italy

16.30 – 17.30 **CORAL REEF RECORDS OF SEA-LEVEL, CLIMATIC AND ENVIRONMENTAL CHANGES DURING QUATERNARY TIMES**
Gilbert Camoin
CEREGE
Aix-en-Provence, France

Thursday, April 19

08.30 – 09.15 **THE CHIKYU**
Tadashi Yoshizawa
JAMSTEC
Yokohama, Japan

09.15 – 10.15 **RAPID SEDIMENTATION, OVERPRESSURE AND CONTINENTAL MARGIN STABILITY IN THE GULF OF MEXICO**
Jan Behrmann
IFM-GEOMAR
Kiel, Germany

10.15 – 10.45 **COFFEE BREAK**

10.45 – 11.30 **MISSION SPECIFIC PLATFORMS**
Alan Stevenson
British Geological Survey
Ediburgh, United Kingdom

11.30 – 12.30 **EXPLORING THE DEEP SEA SUBSURFACE BIOSPHERE**
Judith McKenzie
ETH-Zurich
Zurich, Switzerland

12.30 **END OF WORKSHOP**

Speakers and abstracts

Dr. Eve Arnold
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I received my PhD in Geological Oceanography in 1996 from the Graduate School of Oceanography, University of Rhode Island, USA. My thesis research was based on mineral composition and grain size analyses of deep sea sediments from the North Pacific Ocean. The sediments in this part of the Pacific Ocean come from the deserts in Northwest China, where strong winds erode the desert soils and carry them through the atmosphere in dust storms until they are deposited in the ocean. I studied these sediments in order to determine how atmospheric circulation has changed over millions of years, and also how the deserts in northwestern China developed over time. My later research included studying dust deposits from the loess plateau in China, as well as sediments from the South China Sea, again with the purpose of understanding climate change over long geologic time scales.

After receiving my PhD, I taught oceanography at the Indiana University of Pennsylvania, USA, and in 1998 I moved to the Department of Geology and Geochemistry at Stockholm University in Sweden, where I continue to work today as a university lecturer in deep sea sedimentology. I teach courses in sediment petrology, introductory geology, marine geoscience, oceanography and deserts, and I am the director of PhD students in our department.

I have sailed on ODP deep sea drilling expeditions as part of my research work in the North Pacific and the South China Sea, and I am presently the Swedish representative for the IODP ECORD Science Support and Advisory Committee (ESSAC). This committee works to promote the scientific achievement of ocean research drilling in Europe, and one of our efforts is to communicate the results from these expeditions to the general public, teachers and students. We organize school visits and presentations in individual countries, and occasionally bring teachers along on deep sea expeditions! This workshop is part of our effort to spread the news about current and future deep ocean drilling expeditions.

INTRODUCTION TO THE OCEAN FLOOR AND IODP

Eve Arnold, Department of Geology and Geochemistry, Stockholm University, Sweden

In the early 1960's, marine geologists proved that the ocean floors are not stable rock and sediment made at the time the Earth was formed 4.6 billion years ago - instead they are regions where new oceanic crust is continuously being produced and old oceanic crust is continuously being destroyed. In fact, the oldest ocean crust is only about 200 million years old, quite young in comparison to the age of the Earth! We now know that the outer layer of the Earth is divided into tectonic plates that are always in motion. The boundaries between these tectonic plates fall into three different categories: mid-ocean ridges, subduction zones and transform faults.

New oceanic crust is created at mid-ocean spreading ridges, such as the Mid Atlantic Ridge, in a process where molten basaltic rock from the Earth's mantle rises through cracks in the ocean floor and solidifies. The ocean floor spreads apart as new crust is constantly added at spreading ridges – in the Atlantic ocean, this results in the European and African continents moving away from the North and South American continents as the ocean floor between them continuously increases in width. Oceanic crust is destroyed at subduction zones, when the old, cold and dense oceanic crust sinks back into the mantle. As the old oceanic crust sinks into the mantle, melting of rock occurs, and explosive and dangerous volcanoes are formed, sometimes on the continents, as in the west coast of South America, and sometimes they form islands in the ocean, such as the Aleutian Islands and Japan in the northern and western Pacific Ocean. Together, the subduction zones surrounding the Pacific Ocean form the well known "Ring of Fire". In addition to volcanic activity, the destruction of oceanic crust at subduction zones causes great earthquakes, as the tectonic plates are squeezed together. These earthquakes can in turn cause tsunamis and landslides. Finally, transform faults are plate boundaries where tectonic plates slide past each other – there is no formation or destruction of oceanic crust, but great earthquakes can occur as the plates grind past each other. Examples of transform faults include the San Andreas fault on the west coast of North America, and the North Anatolian Fault in Turkey.

During the time between the creation and destruction of oceanic crust, deep sea sediments are deposited on the ocean floor basalts producing an undisturbed geological record. Ocean sediments can come from soil and rock particles eroded from the continents and transported by rivers or wind to the ocean, volcanic ash produced by subduction zone volcanoes, the remains of ancient plants and animals and mineral deposits formed by hot streams of water pouring out of the mid-ocean ridges. Thus, these undisturbed sediments on the ocean floor provide detailed records of climate change, ocean circulation, river runoff and the evolution of life up to about 200 million years old.

Investigation of the deep ocean floor is thus critical for our understanding of plate tectonic processes, since the sea is the region where most of the action is taking place. By studying the rocks and sediments of the ocean floor we can learn about earthquakes, volcanoes, sea-level change and landslides, and use this information to estimate the risk to population centers so that the engineering and location of infrastructure can be optimally planned to minimize loss of human life. We can look at sedimentary marine records of climate change, the evolution of life and the types of microorganisms that exist in the deep seafloor in order to understand the relationships between the Earth's physical environment and the Earth's biosphere as presented in the IODP initial science plan, "Earth, Oceans and Life".

Ocean research drilling has and will contribute to the understanding of the processes which cause natural hazards and climate change and to predict how these processes will impact life on our planet. However, the investigation of the deep ocean floor by ocean drilling is logistically complicated and very expensive, and requires global cooperation for both financial and scientific reasons.

The Integrated Ocean Drilling Program (IODP), which started in October 2003, builds on a legacy of ocean drilling research, developed during two predecessor programs, the Deep Sea Drilling Project (DSDP, 1968-1983) and the Ocean Drilling Program (ODP, 1985–2003). The IODP differs from ODP in a significant way. Instead of the single riserless drilling platform, the D/V JOIDES Resolution operated by the USA, the international marine scientific drilling community now has access to three platforms in IODP: The riserless JOIDES Resolution; a new state of the art scientific riser drilling vessel, Chikyu, operated by Japan; and Mission Specific Platforms (MSPs) provided by Europe via ECORD. The 2 new platforms provide drilling capability in regions of the ocean floor in which the riserless JOIDES Resolution cannot operate. MSPs can drill, for example, in shallow-water and ice-covered oceans, and the riser-equipped Chikyu can safely drill over pressured and hydrocarbon-rich sedimentary deposits, as well as penetrate deep into oceanic crust. These improved access capabilities will allow scientists to address new and exciting problems in Earth history, tectonic processes and the deep biosphere.

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2001 **Habilitation**, Albert-Ludwigs-University Freiburg, Germany Thesis title: Mud volcanism on the Mediterranean Ridge accretionary prism
1995 **PhD** Geology (*'magna cum laude'*), Justus-Liebig-University, Germany Thesis title: Mass balance of sedimentary accretion and subduction combined with computer-based modelling of balanced cross sections across the Chile Margin
1992 **MSc** Geology, Justus-Liebig-University, Germany **BA** Art History, German Literature, Justus-Liebig-University, Germany
1990 **BSc** Geology, Justus-Liebig-University, Germany
1989 **BSc** Biology, Justus-Liebig-University, Germany

From the start of my career, the main thrust of my research focused on complex dynamic processes at ocean margins. Since then, both compressional. extensional and passive margins have been studied. Much of the work covered the field of marine structural geology, sediment processes, and geohazards. During research projects at active convergent margins in the Pacific and Mediterranean, I participated in 4 ODP cruises. Much of the research focused on mud volcanism as well as seismogenesis, involving geophysical and geochemical approaches, analog and numerical modelling, geotechnical laboratory testing, and mass balance calculations. In addition, seagoing equipment for in situ measurement of sediment physical parameters was developed in my working group at RCOM Bremen and used in national and international campaigns including academia and NATO expert system tests. Most recent work concerns natural hazards such as landslides, earthquake nucleation, and mud extrusion at ocean margins, but also ICDP studies such as the SAFOD project (USA) and marine scientific IODP drilling in the framework of the NanTroSEIZE project (Japan).

Appointments, Awards and Fellowships:
1990-1995 Graduate Research Assistant, Justus-Liebig-University Giessen
1995-1997 Postgraduate Research Assistant, Albert-Ludwigs-University, Freiburg
1997 Fellowship by the European Union, Brussels, Belgium
1997-1998 Post-doc researcher, GEOMAR, Kiel
1998 Fellowship by BASF/Studienstiftung des Deutschen Volkes
1998-2000 Post-doc researcher, Géosciences Azur, Villefranche-sur-Mer, France
2000 Post-doc researcher, GEOMAR, Kiel
2000-2002 Fellowship by Alexander von Humboldt foundation, SCRIPPS Institution of Oceanography, La Jolla, U.S.A.
2001 Hans-Cloos-Award by the German Geological Union (Geol. Vereinigung)
2003 Heisenberg-Fellowship by DFG, SCRIPPS Institution of Oceanography, La Jolla, U.S.A.
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Teaching Interests: Subduction zone dynamics, Marine geotechnology, Soil Mechanics, Continental Margin Resources, Structural Geology

Drilling into the earthquake zone in Nankai Trough, Japan

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Subduction zones account for 90% of global seismic moment release, generating damaging earthquakes and tsunamis, with potentially disastrous effects on heavily populated coastal areas. Understanding the processes that govern the strength of earthquakes, and nature and distribution of slip along these plate boundary fault systems, are crucial steps toward evaluating and mitigating geohazards, including tsunamis. More generally, characterizing fault behaviour at all plate boundary types through direct sampling, near field geophysical observations, and measurement of in situ conditions at depths of coseismic slip is a fundamental and societally relevant goal of modern Earth science. Toward that end, several recent and ongoing drilling programs have targeted portions of active plate boundary faults that have either slipped co-seismically in large earthquakes or nucleated smaller events; these efforts include the San Andreas Fault Observatory at Depth (SAFOD), the Taiwan-Chelungpu Drilling Project (TCDP), and the IODP drilling campaign NanTroSEIZE.

The foremost goal of the NanTroSEIZE (Nankai Trough Seismogenic Zone Experiment) Project is to understand the mechanics and dynamics of seismogenesis and rupture propagation along the active plate boundary faults of a subduction zone, in terms of direct *in situ* sampling and instrumentation at depth. The Nankai Trough is a unique place to study the mechanism and energy budget of great earthquakes in the subduction zone. Advantages include a long historical earthquake record, extensive DSDP and ODP drilling efforts further to the west, a wealth of pre-site survey data, a huge seismological data set by the Japanese scientists, etc. Also, a cabled observatory network in the Kumano Basin area has just been funded to carry out long-term observation in shallow sediments, into which borehole observatories may be incorporated.

NanTroSEIZE is a multi-expedition, multi-platform IODP complex drilling project with scientific drilling vessels 'Joides Resolution' and 'Chikyu'. Penetrations at a depth range from ~1 km below sea floor to the seismogenic zone (ca. 6 km bsf) are critical in testing many of the key hypotheses related to (a) progressive down-dip and along-strike changes in fault mechanical state and frictional properties, (b) fault strength and the role of fluids, (c) temporal changes in strain, micro-seismicity, pore pressure and temperature within the fault zone, (d) the partitioning of slip between seismic and aseismic periods along faults at different pressure-temperature conditions within the system, and (e) processes of earthquake and tsunami generation.

The Nankai margin is a sediment-dominated subduction zone, much as the East Aleutian and Cascadia systems, characterized by repeated occurrence of great earthquakes of ~M_w 8.0. Although the causative mechanisms remain poorly documented, the up-dip limit of the seismogenic zone at these margins is thought to correlate with a topographic break along the outer rise. At Nankai, 3D high-resolution seismic-reflection data of the outer rise clearly document a large out-of-sequence-thrust (OOST) fault system that branches from the plate boundary décollement within the coseismic rupture zone of the 1944 (M 8.2) Tonankai earthquake. Two of the first-order goals of targeting the seismogenic zone are to document the role of the mega-splay fault in accommodating plate motion, and to characterize its mechanical and hydrologic behavior over the earthquake cycle. The drilling results will be used to evaluate a set of core hypotheses through a combination of riser and non-riser drilling, long-term borehole observatories, and associated geophysical, laboratory, and numerical modeling efforts.

NanTroSEIZE transect of boreholes penetrating various depth levels of the frontal subduction zone in map view (Fig. 1) and cross section (Fig. 2):

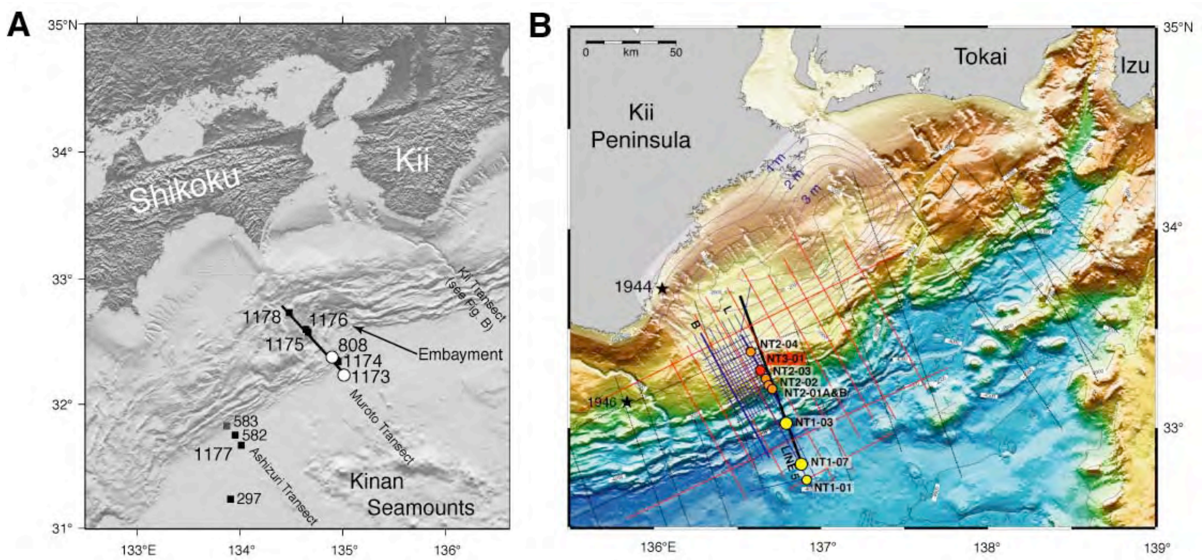

Figure 1: Location map showing locations of previous DSDP and ODP Nankai Trough drilling and planned NanTroSEIZE drillsites. **A**) Map of western (Cape Ashizuri transect) and central (Cape Muroto transect) Nankai drilling including site numbers. The open circles show present CORK installations. **B**) Map of eastern Nankai proposed drilling (Cape Kii transect). Contours on the map show coseismic slip during the 1944 M 8.2 Tonankai EQ. Proposed drilling phases are denoted by drillsites shown in yellow (Phase 1), orange (Phase 2), and red (Phase 3); the CORKs proposed here are highlighted by larger circles.

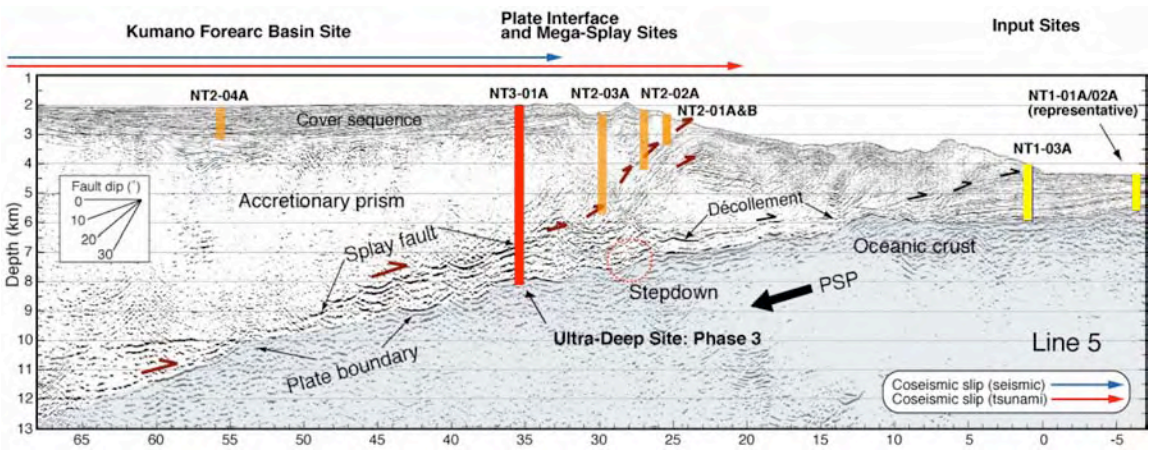

Figure 2: Seismic reflection profile across the Kii segment of the Nankai Trough accretionary complex showing locations of planned NanTroSEIZE drillsites. The extent of coseismic rupture are shown above the seismic line by red and blue arrows. Proposed drillsites shown are in yellow/orange (Phases 1 and 2), and red (Phase 3).

Related WWW links:

http://www.ees.nmt.edu/**NanTroSEIZE**
http://www.iodp.org/**nantroseize**
http://www.iodp.org/**nantroseize**-stage-1-scientific-prospectus
http:// w3.jamstec.go.jp/chikyu/ eng/Expedition/**NantroSEIZE**/index.html
http:// www.**nantroseize**.com/

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Marco Sacchi is senior researcher at the Institute for Coastal Marine Environment of the Italian Research Council (CNR) where he has been on staff since 1990. He specializes in research and teaching in the study of sedimentary rocks, particularly the sedimentology of siliciclastic-volcaniclastic environments. He has a special interest in the study of seismic and sequence stratigraphy of both marine and nonmarine sediments, and in recent years has also written a series of articles dealing with the Late Miocene chronostratigraphy of the continental record of Central Europe. He is author of more than 50 papers in international and national journals and has participated as chief and co-chief scientist in more than 35 oceanographic cruises in the Mediterranean Sea, Atlantic Ocean, and mission specific cruises on lakes (e.g. Lake Balaton, Hungary; Lake Cheko, Siberia, Russia).

Marco Sacchi was born in Naples, Italy, in 1960, and graduated at the Federico II University, Naples, in 1984, with a degree in geology. He was Research Associate at the Department of Geology and Geophysics of Rice University, Houston, TX ,USA in 1986 and worked as consultant geologist for a number of companies in south Italy, for three years after completing his education. In 1990 he joined the CNR Marine Geology Institute of Naples as Research fellow, studying regional geology of the Southern Apennines and the peri-Tyrrhenian and Pannonian basin systems. He was Research Associate at the Department of Geophysics of the Eötvös University of Budapest Hungary, in 1995 and earned a PhD in geology from the same University in 2001.

Sacchi now coordinates the offshore mapping of five sheets of the Geological Map of Italy, 1:50.000 scale and is engaged in several projects on Quaternary stratigraphy of the continental shelf of South Italy investigating deltaic architecture, sequence stratigraphy and the offshore volcaniclastic sediments of the Vesuvius and Campi Flegrei. He is principal proponent of IODP pre-proposal # 671: Drilling through an active caldera, offshore Campi Flegrei, Eastern Tyrrhenian margin.

Committee Memberships

2001-2003: Member of the CNR Commission for the Italian participation in the Integrated Ocean Drilling Program (IODP); Italian observer in the IODP International Working Group (IWG)

2004-2006: Vice-chair of the Committee for the Italian participation in the IODP; Italian Alternate to ECORD Science Support and Advisory Committee

2006-2007: Chair of the Committee for the Italian participation in the IODP; Italian Delegate to ECORD Science Support and Advisory Committee

Research experience

1984-1989: Geological mapping of Southern Apennines and carbonate microfacies analysis; Neogene extensional tecnonics of Southern Apennines

1989-1993: Sesimic stratigraphy of the Eastern Tyrrhenian Margin

1994-2000: Sesimic and sequence stratigraphy of the Western Pannonian Basin; High-resolution stratigraphy and correlation of Mediterranean and Paratethys Miocene

2000-2007: Geological Mapping of Italy (offshore areas) 1:50.000 scale; Geomorphology, sedimentology, event stratigraphy, tephrostratigraphy and volcanism of the Eastern Tyrrhenian margin.

Teaching experience

1998: Marine Geology (third-year course) Federico II University, Naples

2000: Stratigraphy (fourth-year course) Federico II University, Naples

2001-2005: Cultural Geology (third/fourth-year course) Suor Orsola Benincasa University, Naples

IODP AND THE EARTH'S VOLCANISM

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Few people realize that the majority of volcanic activity on Earth actually takes place beneath the ocean. The volcanic eruptions we see on television show only the tip of the crater. What goes on beneath the surface of the ocean is just as spectacular and explosive, but much more frequent.

There are three types of volcanism or volcanic settings in the ocean basins:

1. Ocean spreading ridge volcanism
2. Trench related volcanism; island arcs and mountain chains
3. Mantle Plume (hot spot) volcanism

Oceanic spreading ridges are the most active volcanic zones on earth, continually producing new oceanic lithosphere. The best known volcanoes are in Subduction Zones, in part because these tend to be explosive, deadly volcanoes. But some rift volcanoes are well known (Mt. Kilamanjaro), as are hotspots (Iceland, Hawaii, Tahiti). If we consider the major volcanic eruptions of the world, 15% are in continental rifts, 80% in subduction zones, and 5% in hotspots, but these numbers apply only to the subaerial (above ground) eruptions. Far more volcanic activity occurs under the oceans. There are from 15-20 large subaerial eruptions each year.

The mixing of red hot lava and cold seawater produces a broad spectrum of dynamics and interactions on the seafloor. In the deep ocean the heat from submarine volcanoes sustains exotic biological communities in normally inhospitable conditions. These communities are able to flourish despite the lack of light and extreme pressure. Closer to the surface, the mixing of magma and water can become extremely violent as new islands emerge above sea level or existing islands sink into the abyss.

Early in DSDP and ODP, it was discovered that explosive volcanism is highly episodic on Earth, however, the cause of this episodicity remains an enigma. Silicic volcanic ash layers are widespread in the ocean basins, often several tens of centimeters thick and thousands of kilometers from their source, but their temporal distribution in the sedimentary record is very uneven. These ash layers have the characteristics of co-ignimbrite ash fallout, and their sources are in major ignimbrite-forming explosive eruptions, primarily in volcanic arcs at continental margins.

In the past decades, with a few exceptions, ODP and DSDP have realized only a limited exploration of volcanic continental margins. However, since the advent of Mission Specific Platforms, in 2003, IODP has broadened its range of strategies and actions and offshore drilling has expanded to fully include continental margins, which are among the principal loci of the populated Earth for natural resources and geohazards. In particular, knowledge of volcanic hazards has become a dominant issue for the scientific and social community worldwide.

Future IODP research and science planning calls for a more expansive, ambitious approach to ocean drilling to study the many active geologic processes, such as volcanic eruptions, earthquakes, landslides that will affect the future of humankind on Earth in the next centuries. Offshore drilling at specific sites such as Eastern Caribbean – Lesser Antilles (Montserrat volcano), off the Japanese volcanoes (e.g. Mt. Unzen, or Tokyo area near Mount Fuji) or the Campi Flegrei Caldera near Naples, is likely to provide a significant source of information to substantially improve our understanding of the interaction between volcanism and large-scale tectonics, as well as our capability to predict the onset, styles of evolution, and cessation of volcanic eruptions.

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Gilbert Camoin was born in Marseille (France) in 1958. He graduated from the University of Provence (Marseille) in 1982. He is a senior research scientist at the C.N.R.S. (Centre National de la Recherche Scientifique) and currently works at the C.E.R.E.G.E. (Centre Européen de Recherche et d'Enseignement de Géosciences de l'Environnement) Institute in Aix-en-Provence, France. His expertise covers carbonate sedimentology (depositional settings and diagenesis) and reef geology, including a good background and experience in geophysics (seismics and downhole measurements) and geochemistry (stable isotopes).

During his career, his major scientific interests research activities are mainly devoted to the records of sea level and environmental/climatic changes by reefs and carbonate platforms and the impact of such changes on the processes controlling : a) the architecture and evolution of carbonate systems, and b) the development of potential reservoirs (diagenetic processes). To achieve those objectives, his research has been mainly conducted though the integration of sedimentological, geophysical and geochemical data.

His research activities have been focused both on Cretaceous and Miocene carbonate platforms from North Africa, Italy, Spain and the NW Pacific (ODP Leg 144) and on Quaternary to modern reef systems from the Indian and Pacific (IODP Expedition 310) oceans. Methods used in the field and at sea are the following : reef drilling, coral coring, scuba diving, seismics, multibeam bathymetry, dredging, submersible dives, downhole measurements.

During his career, he has maintained close collaborations with industry (TOTAL, SHELL, ELF-Aquitaine, TEXACO) through research contracts, grants and consulting activities on Carboniferous, Permian, Triassic, Cretaceous, Eocene and Miocene carbonate reservoirs.

He has been (and is still) deeply involved in the Ocean Drilling Program (ODP) and the Integrated Ocean Drilling Program (IODP) as scientist (ODP Leg 144), co-chief scientist (Expedition #310 « Tahiti Sea-Level ») and as member of various committees of those programs.

He is the author of more than 100 papers and publications.

Coral reef records of sea-level, climatic and environmental changes during Quaternary times

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Shallow water carbonate systems store fundamental information about the Earth's response to changes in sea level, climate and tectonics that are responsible for temporal and spatial fluctuations in sediment supply, in sediment types, oceanographic current regimes, subsurface fluids, nutrients and biota. Massive and rapid accumulations of shallow-water carbonates at low latitudes also themselves in£uence the global climate through the feedback that they exert on biogeochemical cycles.

The increasing importance of reefs and carbonate platforms in paleoceanology and paleoclimatology is a reflection of their extreme sensitivity to climatic and environmental changes and their capacity to monitor such changes at a variety of time scales, of increasing resolution. They form archives that may be used to understand the long-term behavior of the tropical ocean/atmosphere system in response to anthropogenic and natural forcing.

Coral reefs are sensitive recorders of past sea-level, climatic and environmental changes.

Sea-level changes

Coral reefs provide the most accurate records of sea-level changes as corals are excellent sea-level indicators and can be accurately dated by mass spectrometry ; their study helps, therefore, in the understanding of the mechanisms driving the glacial-interglacial cycles during Quaternary times. The reconstructed sea-level fluctuations based on coral reef records provide therefore the most direct estimates of changes in ice volume during the Quaternary. So far, the most useful coral reef records of past sea-level changes are related to the Holocene (i.e. the last 10,000 yrs) and the last interglacial period, approximately 125 ka ago. U/Th ages for older isotopic stages are limited due to the scarcity of datable material arising from diagenetic alteration and post-depositional migration of U and Th isotopes. The most complete records of sea levels for the last glacial cycle and/or stage 7 (reefs of the penultimate Interglacial) have come from coral reef terraces exposed on the Huon Peninsula, New Guinea, Barbados and Sumba that generally coincide with major sea level highs predicted by the astronomical theory of climate change ; data concerning reef units formed during glacial periods are fewer. Valuable coral reef records have been also obtained on mid-oceanic atolls that include reef sequences formed both during sea-level highstands and lowstands.

The last deglaciation (i.e. the last 20,000 yrs) is of special interest because it is generally seen as a potential recent analog for the environmental changes that our Planet may face in the near future as a consequence of ocean thermal expansion and the melting of polar ice-sheets related to the greenhouse effect.

Climatic changes

Coral skeletons carry a diverse suite of isotopic and chemical indicators that track water temperature, salinity, and isotopic composition as well as site-specific features including turbidity, runoff, and upwelling intensity. There has been a concerted effort during the last decade to identify new climatic tracers in corals and develop more sophisticated techniques for data extraction and measurement. As a result, a multi-proxy approach to coral-based paleoclimatology emerged and yielded new insights into high-resolution records of tropical paleoclimates that are of prime importance to investigate ocean/atmosphere variability. Accordingly, coral records provide a subseasonal resolution at a variety of time scales over the past several centuries and in well-dated windows spanning decades to centuries throughout the late Quaternary. So far, only few data have been obtained on the past glacial cycles either due to the inaccessibility of these coral reef records or to the diagenetic alteration of coral skeletons.

Environmental changes

Changes in other environmental parameters such as light conditions, water energy and nutrient levels are usually reflected in variations in the composition of reef communities, as reef-dwelling organisms are sensitive to subtle ecological changes affecting their environment.

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In front of the permanent exhibition of the Chikyu at Miraikan Museum, Tokyo

Tadashi Yoshizawa joined the Center for Deep Earth Exploration in July 2005. Before that, Tadashi worked for the Japan Aerospace Exploration Agency as an associate project coordinator for 5 years, promoting an international research project on arctic earth observations using satellites. During this project, he travelled to Fairbanks, Alaska more than 15 times and was bewitched by beautiful northern lights. Tadashi graduated from the University of Tsukuba in 1998 and majored in political science, especially public relations and learned advertising. Tadashi also studied a teacher-training course in civics and is a licensed high school teacher. Since 2006, Tadashi has been responsible for the Education and Outreach program for the Integrated Ocean Drilling Program (IODP) in Japan, organizing educational projects, planning exhibitions, producing PR publications and managing the *Chikyu* web site at www.jamstec.go.jp/chikyu/. Recently, IODP Japan launched the program, "*Sand for Students*" which is a "hands-on" outreach program for junior and senior high school students. The program provides classroom lectures along the local rivers and streams, as teachers and students collect sand samples and analyze them. The program organizers selected sand as the teaching medium because sands evoke the story of the crust's evolution and development and convey data such as the age of mountains, mineral composition of the hinterlands, and more. It is expected that the experiential learning gained through *Sand for Students* will instill a better understanding of the natural environment among students. Sample analyses are to be carried out in coordination with IODP research institutes. The sand data will be correlated with core sample data collected by IODP drilling expeditions. Using classroom results, the new program plans to present students' experimental results on the Web and at academic conferences. In March, in collaboration with Japan's National Science Museum and high school teachers, lectures and fieldwork along the *Fuji* and *Abe* Rivers in *Shizuoka* Prefecture were held and Tadashi worked as the program coordinator. Photos and details are online at www.sand4students.net. An English-language version of the program web is currently in development. The program plans to roll out globally and seeks international partners. Please contact Tadashi if you have interest!

SAND FOR STUDENTS
www.sand4students.net

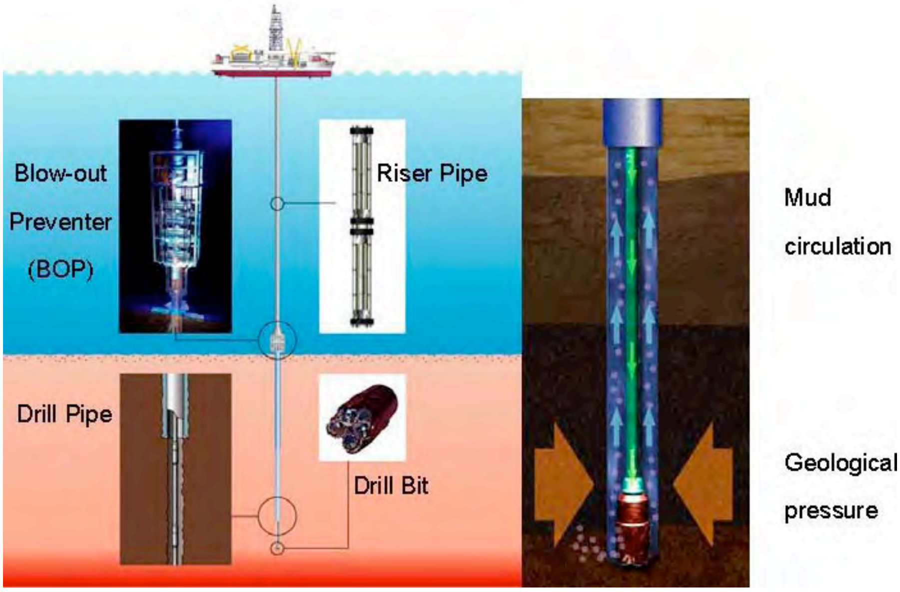
The *Chikyu*: the long-cherished dream of geoscientists is finally a reality

Tadashi Yoshizawa
Center for Deep Earth Exploration
Japan Agency for Marine-Earth Science Technology

The *Chikyu* is the name of the only dedicated scientific deep-sea drilling vessel which can explore the interior of the Earth using riser drilling technology. The *Chikyu* was planned and built by Japan and provided to the ambitious international science program, the Integrated Ocean Drilling Program (IODP, www.iodp.org). The scientific drill ships of past few decades used only non-riser technology to perform drilling, and circulated seawater through the drill pipe to push the rock cuttings out of the borehole and on to the seafloor. The advantage of the non-riser drilling method is that many boreholes can be drilled in a short time, although the borehole wall can become unstable due to geological formation pressures. It is also difficult to drill without a riser through potential oil and gas formations because of the risk of environmental and operational damage. At present, the world depth record for non-riser scientific drilling is about 2,000 meters below the sea floor. However, the *Chikyu* will eventually be capable of drilling up to 7,000 meters below the sea floor with the ultimate aim to reach the Earth's mantle as well as fault zones which have never before been directly explored by ocean drilling.

Scientific riser drilling was planned in the 1990's, and the Chikyu was built in 2005. The photo shows the Chikyu carrying out test drilling in 2006.

The *Chikyu* has a "riser drilling system", which is commonly used in industry. The riser forms a closed connection with the seafloor, so that drilling mud is pumped from the ship down inside the drill pipe and then up in between the drill pipe and the riser or hole casing back to the ship where it is cleaned and then re-used. "Mud", which is an artificial drilling fluid, has higher density than water, and the pressure in the borehole can be maintained to prevent the borehole from collapsing as the pressure increases with increasing depth. In addition, the Blow-Out Prevention (BOP) system ensures safe drilling conditions even when there are unexpected high pressure layers of gas, oil or other formation fluids within the hole.



Riser Drilling Technology

Another name for the *Chikyu* could be "Floating High-Tech Laboratory". A sediment or rock core taken from a geological layer can provide us with much information about tectonic processes or Earth history. The laboratory building on board is equipped with dozens of instruments for analyzing the rock, sediment and pore waters. The science party is able to analyze the physical and chemical properties, paleomagnetism and microorganisms soon after the core arrives on deck.

The microbiology lab provides various equipment such as anaerobic glove boxes, freezers and incubators for quick and uncontaminated sampling and storage of subsurface microorganisms.

The Earth has experienced a number of great tectonic and environmental changes over time, and the evidence for these changes is preserved under the deep seafloor. Scientific deep sea drilling opens a new frontier of Earth and life science by revealing the systems of major earthquakes, global changes and origin of life. For example, investigating earthquake mechanisms requires surveys, direct observations, samples and monitoring under the Earth's surface at tectonic plate boundaries. The *Chikyu*, because it can drill through the seismogenic (fault) zones, is a primary tool for obtaining these crucial pieces of information for the first time in the history. In addition, laboratory studies have indicated that the origin of life may have been formed in the primitive Earth under high temperature, high pressure and no oxygen conditions, an environment similar to some parts of the subseafloor of the present Earth. Research into these microbes in extreme environments may resolve the origin and evolution of life on Earth. Finally, one of the main objectives of the *Chikyu* is to drill through the Earth's crust and reach the mantle, where no one has ever explored before. The Earth has been continuously changing its aspect due to tectonic activity, largely driven by mantle processes. Direct mantle exploration will open the door for direct understanding of the relationship between global-scale environmental change and mantle processes. The *Chikyu* was built in 2005 and will debut in the scientific challenges in September this year. The long-cherished dream of not only geoscientists but human beings will be realized very soon.

P.S. The name *Chikyu* means planet Earth in Japanese.

Chikyu Specifications

Main Spec.		*The same as…*
Length	210 meters	8 cars of express train
Breadth	38 meters	The width of a soccer court
Height	130 meters (from bottom)	Building with 30 floors
Gross Tonnage	57,087 tons	
Max cruising speed	12 knots About 22 km/h	Almost same as the speed of a bicycle
Length of drill string	10,000 meters	3 times the height of Mt. Fuji
Max water depth	2,500 meters (Riser drilling)	
Derrick (Drilling Tower)	Height: 70.1meters, Width: 18.3 meters, Length: 21.9 meters, Hanging capacity: 1,250 tons	
Staff	150 people Crew: 100, Scientist: 50	
Dynamic Positioning on the ocean	Against; 23 meter/sec wind speed, 3-4 knots surface current and 4.5 meters wave height	

You can understand how big and tall the Chikyu is, in order to explore the deep Earth. Look at the gentleman on the lower left.

Chikyu Hakken (Portal site of *Chikyu* information)

http://www.jamstec.go.jp/chikyu/

To go on tour outside/inside the *Chikyu,*

CHIKYU TOUR

http://www.jamstec.go.jp/chikyu/eng/CHIKYU/tour.html

To see movies and photos of the *Chikyu,*

CHIKYU IMAGE

http://www.jamstec.go.jp/chikyu/eng/ChikyuImages/index.html

To read the newsletter and brochures,

CHIKYU LIBLRARY

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Or search by keyword “*Chikyu*” in Google, Yahoo, or any major internet browser.

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I studied geology at the Universities of Erlangen (Germany) and Oxford (U.K.), and received a D.Phil. at Oxford in 1982. After working as a project geologist in uranium and gold exploration with Exxon and BP Minerals International in the late seventies and early eighties, my career path in research and teaching started at the Universities of Tübingen and Giessen (Germany). From 1995 I held the Chair in Geology at Freiburg University (Germany) for eleven years, before taking over my present position at IFM-GEOMAR.

I was always fascinated by the geology and tectonophysics of plate margins, from the deep sea trenches to the summits of the highest mountain chains on Earth. My main aim is to help understand the deformation mechanics of rocks. For example, this is a major requirement to find out how earthquakes form, and what governs the stability of sediments on continental margins. Geographically, most of my research was in the Alps, the Betic Cordilleras of Spain, the Variscan Mountain Belt of Europe, the continental rift zones of Europe and East Africa, and, of course, much lesser known oceanic areas, as the northwest and southeast Pacific plate margins, the Antilles, the Gulf of Mexico and the Mediterranean. I have sailed on three ODP/IODP cruises (Barbados, Chile Triple Junction, Gulf of Mexico Hydrogeology), leading the last two as Co-Chief Scientist.

At present, I am serving on the Science Planning Committee and the Operations Task Force of the Integrated Ocean Drilling Program (IODP), and in the Science Advisory Group of the International Continental Drilling Program (ICDP).

Rapid sedimentation, overpressure and continental margin stability, Gulf of Mexico. An account of IODP Expedition 308

by Jan H. Behrmann[1], Peter B. Flemings[2], Cédric John[3] and IODP Expedition 308 Shipboard Scientific Party[3]

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Integrated Ocean Drilling Program (IODP) Expedition 308 was dedicated to the study of overpressure and fluid flow on the Gulf of Mexico continental slope. The scientific programme examined how sedimentation, overpressure, fluid flow, and deformation are coupled a passive continental margin setting. Expedition 308 tested a multidimensional flow model by examining how physical properties, pressure, temperature, and pore fluid compositions vary within low-permeability mudstones that overlie a permeable and overpressured aquifer. A reference location, Brazos-Trinity Basin IV, located 200 km due south of Galveston (Texas) was drilled and logged at three sites and *in situ* measurements of pressure were performed where little overpressure was deemed to be present. These measurements were contrasted with experiments performed in a region of very rapid late Pleistocene sedimentation where overpressure was known to be present: the Ursa region of the northern Gulf of Mexico, south of the modern Missisippi Delta. Drilling there documented severe overpressure in a zone about 165 meters below the seafloor. This abrupt jump in formation pressure lies directly beneath a zone of large submarine landslides that span hundreds of square miles. Our measurements document a model wherein sedimentation above a confined aquifer drives flow laterally and induces slope failure. This process is like stepping on a wet sponge: rapid sedimentation acting as the 'heel of the foot' drives water towards the 'toe' where the high pressure destabilizes the sediment and causes large, kilometer-size blocks to slide downhill. Only a few 10's of thousands of years ago, this process may have set loose significant submarine landslides around the world. Submarine landslides generate tidal waves, and thus pose a major threat to coastal communites and industrial installations. Ultimately these studies may allow us to predict in what locations around the world submarine landslides are more likely and hence what populations are at greater risk from tidal waves caused by these events.

Initial scientific results of IODP Exp. 308 are published on the Internet at: http://iodp.tamu.edu/publications/exp308/308title.htm

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Published by the Integrated Ocean Drilling Program with the International Continental Scientific Drilling Program

Rapid Sedimentation, Overpressure, and Focused Fluid Flow, Gulf of Mexico Continental Margin

by Jan H. Behrmann, Peter B. Flemings, Cédric M. John, and the IODP Expedition 308 Scientists

doi:10.2204/iodp.sd.3.03.2006

Abstract

Expedition 308 of the Integrated Ocean Drilling Program (IODP) was the first phase of a two-component project dedicated to studying overpressure and fluid flow on the continental slope of the Gulf of Mexico. We examined how sedimentation, overpressure, fluid flow, and deformation are coupled in a passive margin setting and investigated how extremely rapid deposition of fine-grained mud might lead to a rapid build-up of pore pressure in excess of hydrostatic (overpressure), underconsolidation, and sedimentary mass wasting. Our tests within the Ursa region, where sediment accumulated rapidly in the late Pleistocene, included the first-ever *in situ* measurements of how physical properties, pressure, temperature, and pore fluid compositions vary within low-permeability mudstones that overlie a permeable, overpressured aquifer, and we documented severe overpressure in the mudstones overlying the aquifer. We also drilled and logged three references sites in the Brazos-Trinity Basin IV and documented hydrostatic pressure conditions and normal consolidation. Post-expedition studies will address how the generation and timing of overpressure control slope stability, seafloor seeps, and large-scale crustal fluid flow. The operations of Expedition 308 provide a foundation for future long-term *in situ* monitoring experiments in the aquifer and bounding mudstones.

Introduction

Rapid sedimentation at rates >1 mm·yr^{-1} generate overpressure in many sedimentary basins around the world (Rubey and Hubbert, 1959; Fertl, 1976). When low-permeability sediments are rapidly loaded, pore fluids cannot escape, and the fluids bear some of the overlying sediment load. In this situation a pore pressure exceeding the hydrostatic pressure (overpressure, P*) develops. Recent work has focused on the coupling of rapid sedimentation and stratigraphic architecture to produce two- and three-dimensional flow fields. If, for example, permeable sand is rapidly buried by low-permeability mud of laterally varying thickness (Fig. 1), fluids flow sub-horizontally through the sand layer to regions of thin overburden before they are expelled into the overlying sediment. This creates characteristic distributions of sediment properties, fluid pressure, effective stress, temperature, and fluid chemistry in the aquifers and the bounding mud (Fig. 1). This simple flow-focusing process can cause slope instability near the seafloor (Dugan and Flemings, 2000; Flemings et al., 2002). In the deeper subsurface, overpressures created by focused flow can drive fluids through low-permeability strata to vent

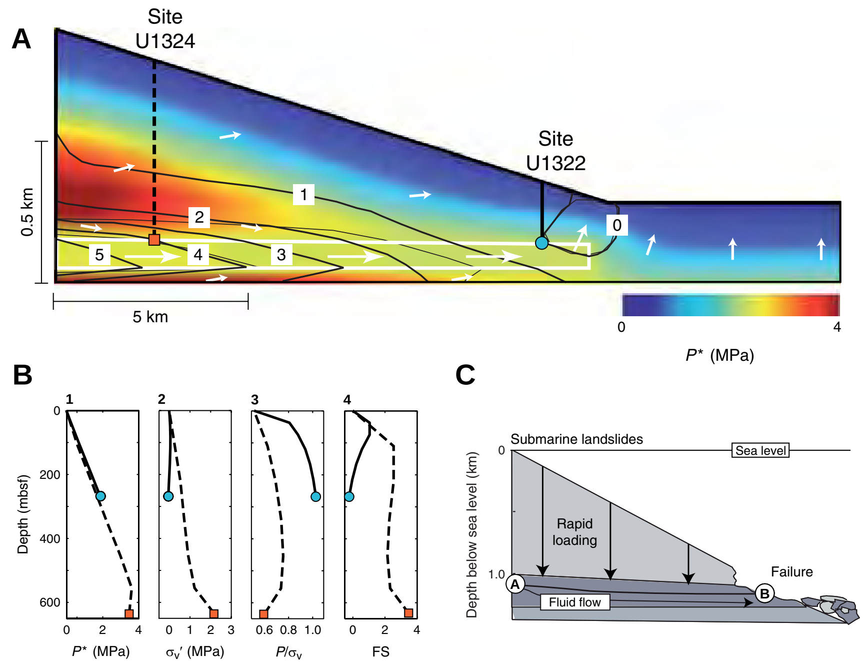

Figure 1. Flow-focusing model approximating conditions in Ursa Basin. [A] Low permeability sediments are rapidly deposited on a high permeability aquifer (outlined in white). Sedimentation rate decreases from left to right, resulting in final wedge-shaped geometry. Rapid sedimentation generates overpressure (P*; color contours) that is greatest on the left (red) side of the picture. Flow is driven laterally (left to right) along the aquifer and is expelled at the toe of the slope where the aquifer ends (white arrows). Vertical effective stress (black contours) is lowest on the right side of the picture. [B] Predicted overpressure profiles where overburden is thick (Site U1324) and thin (Site U1322). (1) Overpressure at Site U1322 is slightly greater than at Site U1324 for equivalent depths. (2) Vertical effective stress (σ_v') is much lower at Site U1322 than at Site U1324. (3) Pore pressures (P) equal overburden stress (σ_v) at Site U1322. (4) Slope failure is predicted by infinite slope analysis near Site U1322 for FS < 1. FS relates failure-driving stress to available shear strength for shallow failures. [C] Model parameters: low permeability mudstone $k_v < 5 \times 10^{-8}$ m^2 and $k_h < 5 \times 10^{-16}$ m^2; aquifer permeability $k_h = k_v\ 5 \times 10^{-14}$ m^2; maximum sedimentation rate = 3.5 mm·y^{-1}; minimum sedimentation rate = 0.8 mm·y^{-1}. [C] Drawing of how flow focusing drives slope instability.

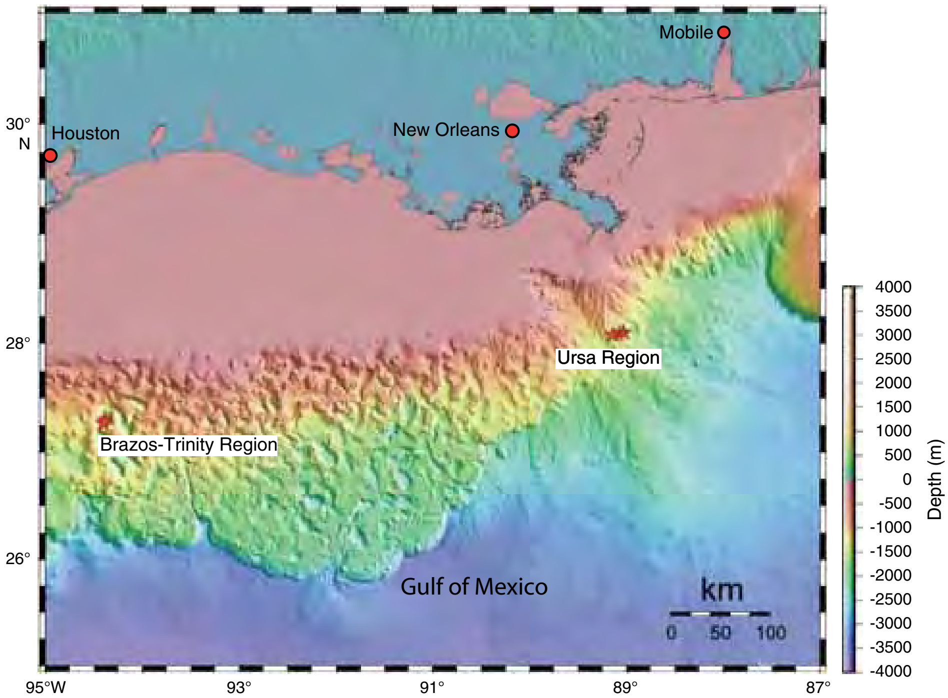

Figure 2. Bathymetric image of continental slope of Gulf of Mexico. Drilling took place in Brazos-Trinity (reference sites) and Ursa (overpressured sites) regions.

ultimately at the seafloor (Boehm and Moore, 2002; Davies et al., 2002; Seldon and Flemings, 2005). This is a potentially important mechanism for the transfer of fluids from the solid earth to the hydrosphere and the atmosphere.

Brazos-Trinity Reference Sites

Brazos-Trinity Basin IV is located 200 km due south of Galveston, Texas (U.S.A.) in ~1400 m of water (Fig. 2). As one of a chain of five basins that are separated by interbasinal highs, it is a classic area for analysis of turbidite depositional environments, and it is a modern analog to describe the formation of deep-water turbidite reservoir deposits (e.g., Badalini et al., 2000; Winker, 1996; Winker and Booth, 2000). The primary data used to evaluate the borehole locations comprise a high-resolution, two-dimensional (2-D) seismic survey conducted by Shell Exploration and Production Company to image the turbidite stratigraphy. The three drilling sites are shown on dip seismic Line 3020 (Fig. 3). Site U1320 is located where the turbidite deposits are thickest, whereas Site U1319 lies along the southern flank of Basin IV where turbidite deposits are more condensed. Site U1321 was a logging-while-drilling and measurement-while-drilling (LWD/MWD) site and was not cored. This is the first time in the history of scientific ocean drilling that a hole was drilled exclusively for logging purposes.

Integration of core, downhole measurement, and seismic data enabled a detailed lithostratigraphic (Fig. 4) and physicochemical characterization of the basin and dating of key surfaces. The data provide the basis to estimate sediment fluxes over time across a source-to-sink system. A 175-m-thick sequence of sand-rich turbidite fans, mass-transport deposits, and hemipelagic sediment has accumulated within the last ~120,000 years in Brazos Trinity Basin IV. Pre-fan deposits form a conformable sequence dominated by terrigenous clays transported by dilute turbidity currents and river plumes. The two sequences are separated by a thin (~1 m) layer of microfossil-rich clay, interpreted to represent the sea-level highstand during Marine Isotope Stage 5e. The basin infill is marked by two main pulses of mass-gravity flow deposition, separated by a pause in turbidity current activity. The pause lasted as much as 45 ky, starting at ~90 ka. The microfossil-rich clays in this interval contain the Los Chocoyos ash layer (Y8), a physical correlation marker across Basin IV and adjacent basins. The lower part of the basin contains mostly thin-bedded, muddy turbidites. The upper part contains muddy slump deposits derived from the basin margin and sand-rich turbidites that form several packets of very fine to fine sand beds that are

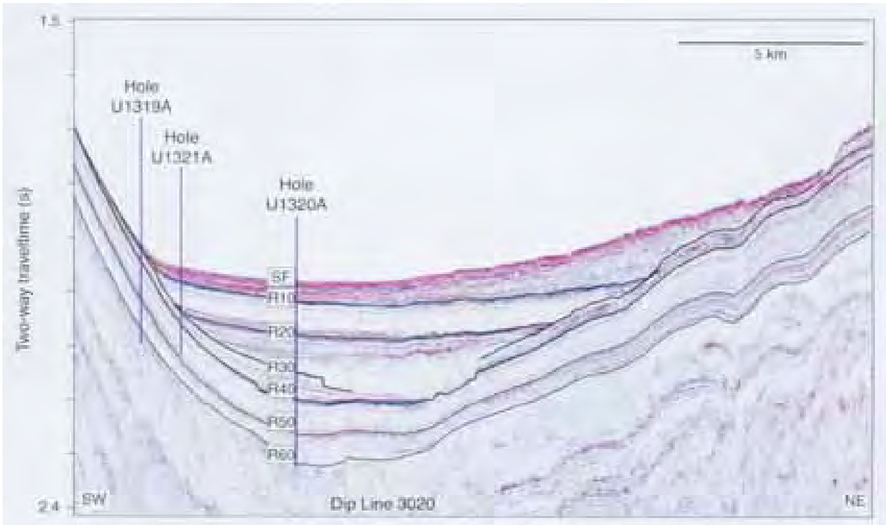

Figure 3. Reflection seismic section (Dip Line 3020) across Brazos Trinity Basin IV. Specific drill sites are located at cross-tie with strike Line 3045 (Site U1320), strike Line 3055 (Site U1321), and at southern limit of this line (Site U1319). R10–R60 = major seismic reflectors correlatable between drill holes. SF = seafloor.

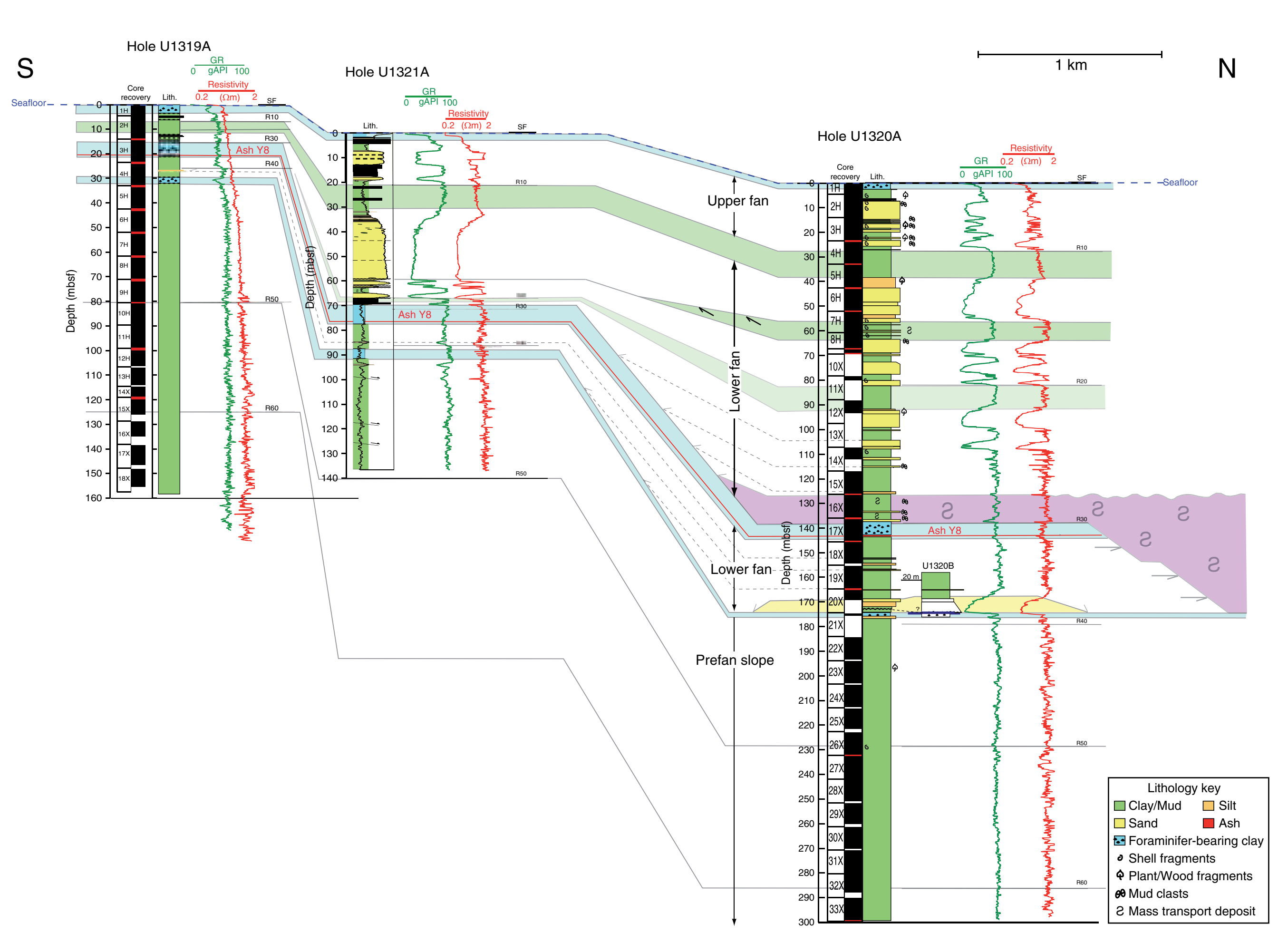

Figure 4. Stratigraphic cross-section of Brazos-Trinity Basin IV. Data of core and well logs are at sea level. Stratigraphic ties between sites are based on seismic, lithology, log signature, and biostratigraphy. Each column contains depth scale, schematic lithology, gamma ray (GR) and resistivity logs (from LWD data), and depth of key seismic surfaces. In core recovery diagram, black = cored, red = overlap due to core expansion, and white = no recovery. mbsf = meters below sea floor.

5–25 m thick (Fig. 4). Rates of basin subsidence, sea-level change, and average sediment accumulation or erosion are of similar magnitude in this system, resulting in a complex interaction between (a) sea level changes and deltaic dynamics, which affect the delivery of sediment in the source area, (b) salt tectonics, which affects the basin configuration and topographic gradients over time, and (c) the dynamic interaction between turbidity currents and the underlying topography.

The three drilling sites in the Brazos-Trinity Basin IV provided evidence of progressive and punctual downhole changes in physical properties as measured onboard the *JOIDES Resolution*, especially at Site U1319. Basin in-fill sediments (down to reflector R40) and underlying hemipelagic drape sediments (below reflector R40) are essentially non-slumped, normally consolidated muds that provide an excellent reference for materials found within the basin (Site U1320) and at Ursa Basin (Sites U1322 and U1324). The sediment porosity at Site U1319 decreases exponentially downhole from 80% to 50%. In comparison, Site U1320 has a section of underconsolidated muds and clays below Reflector R40; this was not anticipated but is explained by rapid sediment loading precluding fluid drainage and consolidation of muds of the basin interior.

Overpressured Ursa Basin Sites

Ursa Basin lies approximately 150 km south-southeast of New Orleans, Louisiana (U.S.A.) in ~1000 m of water (Fig. 2). The region is of economic interest because of its prolific oilfields that lie >4000 meters below the seafloor (mbsf; e.g. Mahaffie, 1994). We were interested in the sediments from 0 to 1000 mbsf (e.g., Pratson and Ryan, 1994; Pulham, 1993). Four three-dimensional (3-D) seismic data sets were used to constrain stratigraphy within Ursa Basin. The high-resolution surveys were conducted by Shell Exploration and Production Company for the purpose of shallow hazards analysis. Figure 5 shows the seismic transect along which Sites U1322, U1323, and U1324 were drilled. The sand-dominated Mississippi Canyon Blue Unit (Fig. 5) is a late-Pleistocene “ponded fan” deposited in a broad topographic low. The Blue Unit is overlain by a mud-dominated levee-channel assemblage. The most spectacular feature is the

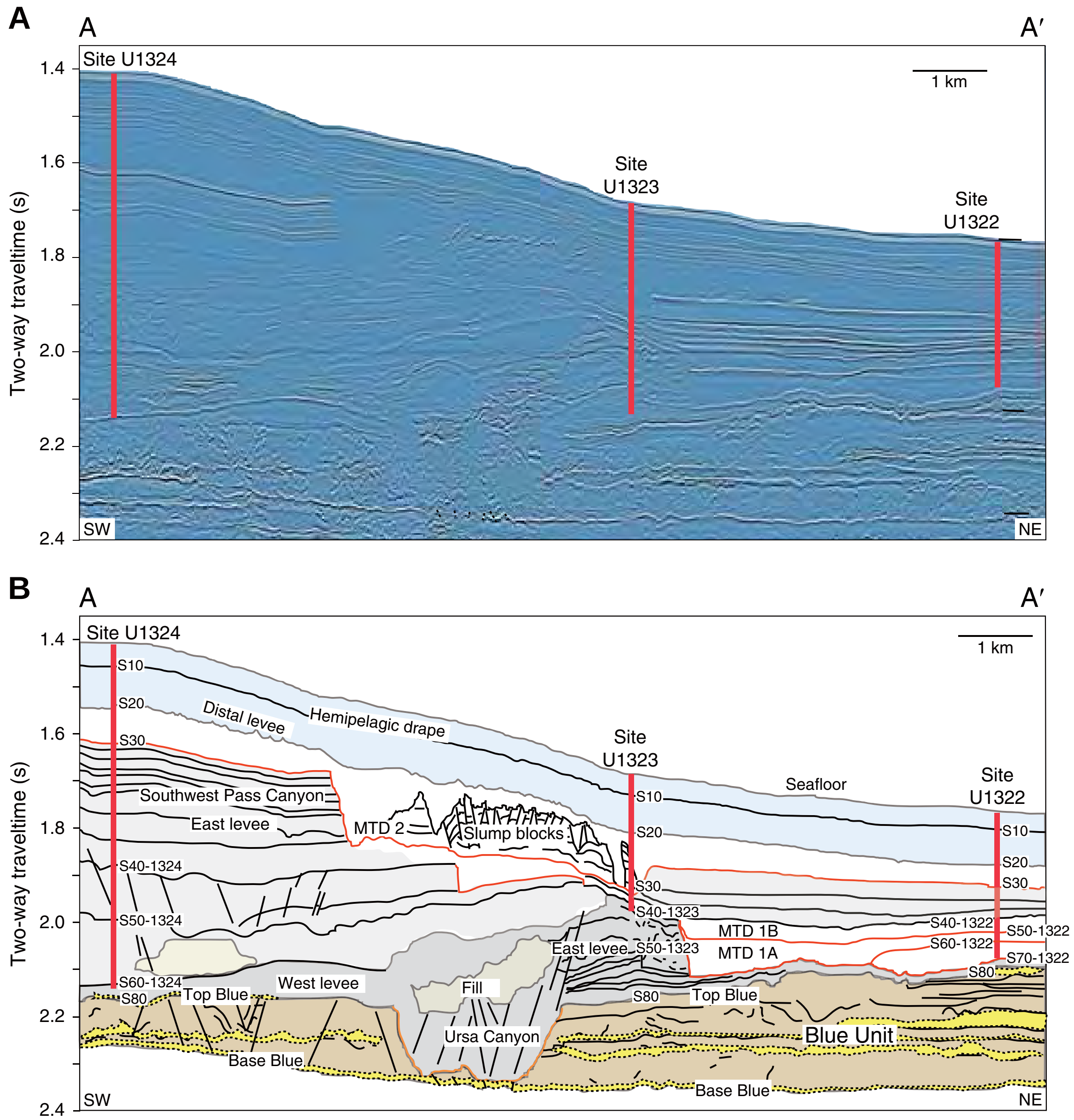

Figure 5. [A] Seismic cross-section A–A' from Ursa Basin. [B] Interpreted cross-section A–A'. Sand-prone Blue Unit has been incised by channel-levee complex and then overlain by thick and heavily slumped hemipelagic mudstone wedge that thickens westward (left). Blue Unit sands correlate to distinct seismic facies. Thickness of hemipelagic mudstone above Blue Unit does not change significantly in north-south direction. Seismic reproduced with permission of Shell Exploration and Production Company.

sand-cored levee-channel of the Ursa Canyon, overlain by the muddy eastern levee deposits of the Southwest Pass Canyon and a hemipelagic drape cover. The mudstone package lying above the Blue Unit has numerous detachment surfaces that record slumping and mass transport deposits.

The Ursa Basin sites provided a west-east transect that tested the flow-focusing model of differential loading on a permeable aquifer. Overburden was drilled and sampled to 608 m depth at Site U1324 (thick overburden) and to 234 m at Site U1322 (thin overburden). We used a penetrometer (Fig. 6) to measure overpressure below 100 m at both sites. Normalized overpressure of approximately 0.6 was determined at the base of each site (i.e., the pore pressure lies 60% of the way between hydrostatic pressure and lithostatic pressure). The temperature gradient is 18°C·km^{-1} at Site U1324 and 26°C·km^{-1} at Site U1322. Thermal conductivities at the two locations are similar (1.15–1.2 W·m^{-1}·K^{-1}), implying a vertical conductive heat flow of ~22 mW·m^{-2} at Site U1324 versus ~30 mW·m^{-2} at Site U1322.

Sedimentation has accumulated more rapidly at Site U1324 (10 mm·y^{-1}) than at Site U1322 (3.8 mm·y^{-1}). In spite of the almost three-fold difference in sedimentation rate, the similar overpressure gradients present at these two sites imply a component of lateral flow between them. This lateral flow drives fluids from Site U1324 toward Site U1322, increases the pressure at Site U1322 relative to a system with only vertical fluid migration, and decreases pressure at Site U1324 relative to a system with only vertical migration. The

Blue Unit, composed of interbedded sheet sands and mudstones, is interpreted to facilitate the lateral transfer of fluids from Site U1324 to Site U1322, making the regional pressure field diverge from a simple one-dimensional, compaction system. Core, log, and seismic interpretations document numerous scales of slumping, faulting, and soft-sediment deformation with increased occurrence at Site U1322. This deformation is consistent with predictions of the flow-focusing model. The dramatic difference in sedimentation rates between the sites also helps to explain the difference in observed thermal gradients. These results suggest that at the basin scale, this type of lateral fluid flow may be the prime factor for the distribution and occurrence of cold seeps, mud volcanoes, and repeated submarine landslides generating major mass transport deposits.

Expectations and Achievements of IODP Expedition 308

A fundamental achievement of IODP Expedition 308 is that the overpressure profile as a function of depth at Sites U1322 and U1324 in Ursa Basin could be directly measured. These measurements were difficult, and we experienced a high rate of failure; however, we ultimately acquired enough data to constrain the overpressure field above the Blue Unit. Preliminary interpretations suggest that flow focusing is occurring in this basin and contributing to deformation and failure of sediments where overburden is thin. This is the first time in the history of scientific ocean drilling that the spatial variation of the pressure field has been documented at such resolution. We also acquired an extraordinary data set documenting a striking difference in temperature gradients between Sites U1322 and U1324.

We wanted to establish reference logging and core properties where overpressure is not present at a range of effective stresses in Brazos-Trinity Basin IV. Coring and logging were successful at all locations there, resulting in a high-resolution recontruction of basin architecture and lithostratigraphy, in part below the level of individual lithostratigraphic subunits.

Our data on pore pressure, sediment properties, and overburden stress (Fig. 7) will provide a basis to assess the potential for slope failure, especially in Ursa Basin, and to estimate the conditions that drove previous slope failures. A major component of the ongoing post-expedition research is the integration of the stratigraphic geometry, physical properties, timing, and pressures associated with these mass-wasting processes.

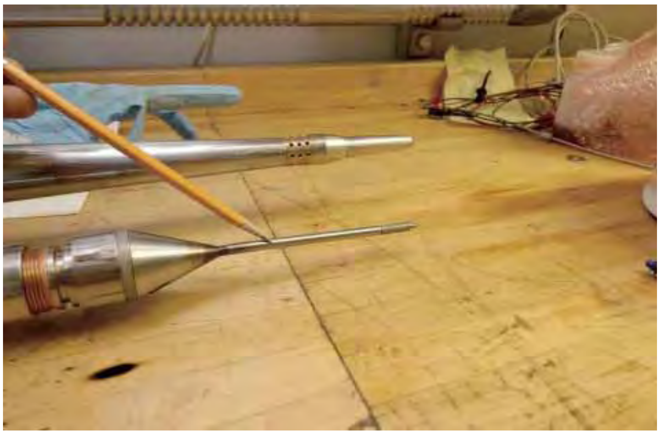

Figure 6. Temperature Two Pressure probe (T2P, foreground) and Davis-Villinger Temperature-Pressure Probe (DVTPP, background). Both tools measure formation pressure by being forced into formation by drill string.

IODP Expedition 308 monitored downhole pressure and lithology in real time using the MWD approach and for the first time used weighted mud as a tool to drill and core

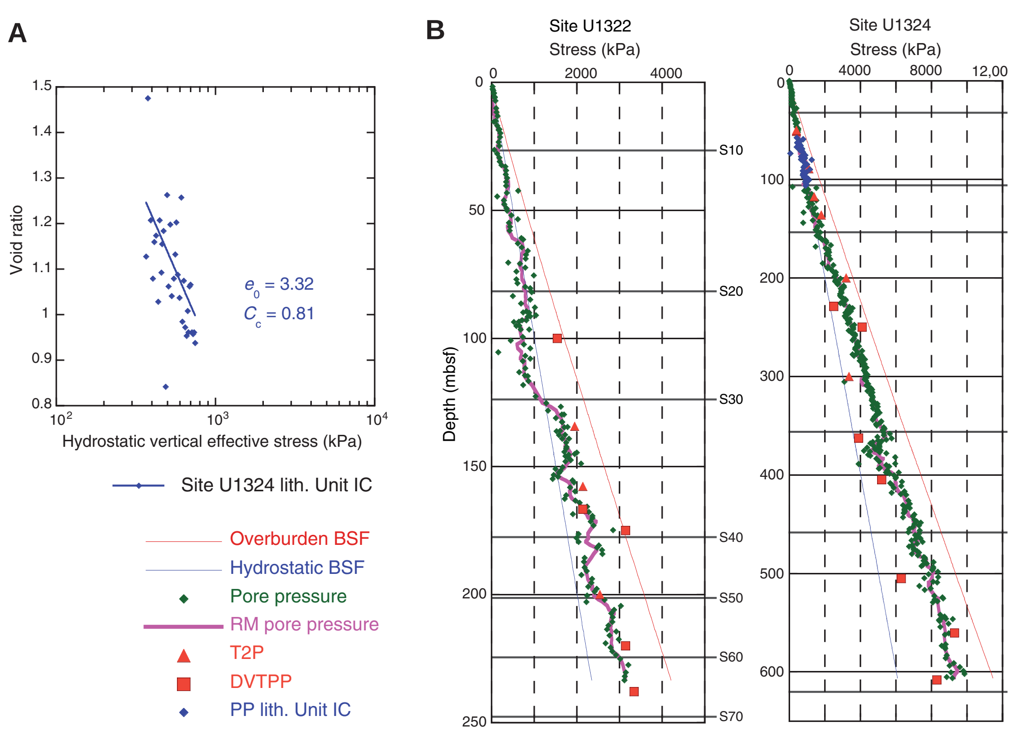

Figure 7. [A] Void ratio (e) versus hydrostatic vertical effective stress (σ_{vh}) for lithostratigraphic Subunit IC at Site U1324. Reference void ratio (e_0) and compression index (C_c) are derived from fit of type $e = e_0 - C_c \ln(\sigma_{vh})$. [B] Pore pressures for Site U1322 and U1324 are derived from parameters derived in [A] assuming that lithostratigraphic Subunit IC (blue dots) at Site U1324 is hydrostatically pressured. Pore pressures recorded at end of temperature and dual pressure probe (T2P) (red triangles) and DVTPP (red squares) deployments are also shown. BSF = below seafloor, RM = running mean, PP = pore pressure.

overpressured regimes. Real-time monitoring allowed us to observe shallow-water flow and to respond to this incident by raising the mud weight to retard flow into the borehole, thereby proving the feasibility of this technique for long-term, *in situ* monitoring experiments in the aquifer and bounding mudstones.

Data from the ponded turbidite system in Brazos Trinity Basin IV and the channelized systems present in Ursa Basin are of great interest for further studies by academic and industry researchers. They will likely break new ground, especially in the field of geotechnical and hydrogeological analysis of continental slopes along passive and active continental margins. We have also shown that *in situ* measurements of pore pressure in fine-grained sediments can be performed with overall success and that drilling into overpressured formations with riserless technology can be managed using heavy mud. Future drilling in a variety of settings might benefit from the controlled use of weighted mud to stabilize the borehole.

Acknowledgements

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IODP Expedition 308 Scientists

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References

Badalini, G., Kneller, B., and Winker, C.D., 2000. Architecture and processes in the late Pleistocene Brazos-Trinity turbidite system, Gulf of Mexico continental slope. Deep-Water Reservoirs of the World: *Proc. GCSSEPM 20th Annu. Res. Conf.*, pp.16–34.

Boehm, A., and Moore, J.C., 2002. Fluidized sandstone intrusions as an indicator of paleostress orientation, Santa Cruz, California. *Geofluids*, 2(2):147–161, doi:10.1046/j.1468-8123.2002.00026.x.

Davies, R., Bell, B.R., Cartwright, J.A., and Shoulders, S., 2002. Three-dimensional seismic imaging of Paleogene dike-fed submarine volcanoes from the northeast Atlantic margin. *Geology*, 30:223–226.

Dugan, B., and Flemings, P.B., 2000. Overpressure and fluid flow in the New Jersey Continental Slope: implications for slope failure and cold seeps. *Science*, 289:288–291, doi:10.1126/science.289.5477.288.

Fertl, W.H., 1976. *Abnormal Formation Pressures: Implications to Exploration, Drilling, and Production of Oil and Gas Resources*: Amsterdam (Elsevier).

Flemings, P.B., Stump, B.B., Finkbeiner, T., and Zoback, M., 2002. Flow focusing in overpressured sandstones: theory, observations, and applications. *Am. J. Sci.*, 302:827–855, doi:10.2475/ajs.302.10.827.

Mahaffie, M.J., 1994. Reservoir classification for turbidite intervals at the Mars discovery, Mississippi Canyon Block 807, Gulf of Mexico. *In* Bouma, A.H., and Perkins, B.G. (Eds.), *Submarine Fans and Turbidite Systems: Proc. GCSSEPM 15th Annu. Res. Conf.*, pp.233–244.

Pratson, L.F., and Ryan, W.B.F., 1994. Pliocene to recent infilling and subsidence of intraslope basins offshore Louisiana. *AAPG Bull.*, 78:1483–1506.

Pulham, A.J., 1993. Variations in slope deposition, Pliocene–Pleistocene, offshore Louisiana, northeast Gulf of Mexico. *In* Posamentier, H., and Weimer, P. (Eds.), *Siliclastic Sequence Stratigraphy: Recent Developments and Applications.* AAPG Mem., 58:199–233.

Rubey, W.W., and Hubbert, M.K., 1959. Role of fluid pressure in mechanics of overthrust faulting, Part 2. Overthrust belt in geosynclinal area of western Wyoming in light of fluid-pressure hypothesis. *Geol. Soc. Am. Bull.*, 70:167–205.

Seldon, B., and Flemings, P.B., 2005. Reservoir pressure and seafloor venting: Predicting trap integrity in a deepwater turbidite reservoir. *AAPG Bull.*, 89(2): 193-209, doi:10.1306/09170403122.

Winker, C.D., 1996. High-resolution seismic stratigraphy of a late Pleistocene submarine fan ponded by salt-withdrawal mini-basins on the Gulf of Mexico continental slope. *Proc. 3rd Annu. Offshore Technol. Conf.*, 28(1):619–628.

Winker, C.D., and Booth, J.R., 2000. Sedimentary dynamics of the salt-dominated continental slope, Gulf of Mexico: integration of observations from the seafloor, near-surface, and deep subsurface. *Deep-Water Reservoirs of the World: Proc. GCSSEPM 20th Annu. Res. Conf.*, pp.1059–1086.

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Related Web Link

http://iodp.tamu.edu/scienceops/expeditions/exp308.html

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I am a Principal Researcher based at the British Geological Survey (BGS) in Edinburgh, Scotland where I currently manage our Marine and Coastal Geology projects. I was educated at the University of St. Andrews and joined the BGS in London in 1978, where I started my career making geochemical and environmental maps of the UK. After 8 years collecting rocks and sediments from rivers and streams in the Scottish highlands and islands, I decided it was time to change career direction. It seemed a natural progression to move from rivers to the sea, so in 1986 I moved to Edinburgh to work on marine geology projects.

Initially I mapped sediments deposited by glaciers during the last major ice age to affect the UK from about 22,000-10,000 years ago. As sea level has risen since the ice melted, much of the evidence for the extent of glaciation around the British Isles is found on the sea floor. Using my previous experience as a geochemist, I was also involved in producing an atlas of the sea bed describing the natural concentrations of metals in sediments, information that is used as a baseline against which to measure pollution in the marine environment.

Since the mid-1990's I have worked mainly on international projects, which is particularly important to marine geologists, as the processes that shape the sea bed (e.g. currents) do not stop at national boundaries. During the last 10 years I have been involved in 7 projects funded by the European Commission, in which I have collaborated mainly with colleagues from other European geological surveys. This work has extended from the Atlantic Ocean to the Caspian Sea and in our most recent project I was Co-ordinator of a group of scientists from over 20 countries developing a database of geological information from the European seas.

In recent years my main interest has been in the use of geological information to help manage the marine environment and resources in a sustainable way. This includes working with scientists in industry, universities and government organisations with a wide range of interests, such as oceanographers and biologists researching the habitats of marine animals to inform management of the European fishing industry.

In all of these roles I have been actively involved in promoting the value of geological information to the public, so in November 2005 I was pleased to have the opportunity to join the Integrated Ocean Drilling Program (IODP) team as the Outreach Manager for the European Consortium for Ocean Research Drilling (ECORD) Science Operator. In this role I am responsible for helping scientists involved in mission-specific platform expeditions to convey their research results to as wide an audience as possible.

Mission-specific platforms for the Integrated Ocean Drilling Program

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Since the start of the Deep Sea Drilling Project (DSDP) and during the Ocean Drilling Program (ODP), scientific ocean drilling has taken place mainly in deep waters (more than a few hundred metres water depth), and there was no capability to drill in shallow or ice-covered seas. Consequently, a wide range of environments were inaccessible to scientists, even though there was a clear demand to obtain cores from these new targets. There was therefore a need to provide a range of coring platforms in order to achieve new and exciting scientific goals.

During planning for the Integrated Ocean Drilling Program (IODP), the inclusion of mission-specific platforms (MSPs) was an important new development. Within the IODP structure, MSPs are provided by the European Consortium for Ocean Research Drilling (ECORD), a group of 16 European countries as well as Canada. To implement the drilling on their behalf, ECORD appointed an ECORD Science Operator (ESO) comprising a consortium of the British Geological Survey, the University of Bremen and the European Petrophysics Consortium, led by the University of Leicester.

As the name implies, MSPs are contracted specifically for each expedition dependent on the requirements to achieve its scientific goals. Although shallow-water drilling is new to the international academic community, industry and other scientific institutes had long carried out this type of coring, so that considerable expertise exists in this field. However, drilling in ice-covered waters had not been successfully accomplished, perhaps largely because there was no infrastructure or funding to mount a concerted effort.

To date, two MSP IODP expeditions have been carried out demonstrating that shallow-water and coring in ice-covered waters can be achieved, whilst further expeditions are planned for the future.

Arctic Coring Expedition (ACEX)

The first MSP expedition was IODP Expedition 302, known as the Arctic Coring Expedition (ACEX), which posed a considerable logistical and technical challenge. Planning had determined that it was necessary to put together a fleet comprising 3 vessels; a powerful lead icebreaker, the Russian vessel *Sovetskiy Soyuz*, the Swedish icebreaker *Oden* that served as another powerful icebreaker and as the main base for the scientific party, and a third vessel, the *Vidar Viking* capable of drilling in Arctic ice. To help assemble the fleet and assist with other logistics such as helicopters and ice management, ESO enlisted the help of the Swedish Polar Research Secretariat (SPRS), and this expedition took place during 2004.

A particular challenge was the mobilisation of the drilling vessel, for there were no icebreakers equipped for drilling. The *Vidar Viking*, an anchor-handling vessel that also serves as a Baltic icebreaker in winter, required substantial modification to act as a drillship, however this was achieved in just 6 days. At the end of the successful expedition, the vessel was returned to its former condition.

The cores collected during the ACEX expedition have revealed exciting new insights into the history of the Arctic Ocean during the last 65 million years

Tahiti Sea Level

The next MSP expedition (IODP Expedition 310) was to the tropics to drill the coral reefs in shallow water around the island of Tahiti. The drilling vessel employed was the *DP Hunter*, a ship normally used for diving support. Again, a drilling rig and equipment had to be assembled onto a bare deck. A particular system for coring (known as ‘piggy-back drilling’) was installed for this expedition as this was considered the optimum set-up for obtaining good recovery of corals.

The expedition was carried out in October-November 2005, and excellent core recovery (>90%) was achieved at 37 holes on different sides of the island. A total of 632 m of reef cores were retrieved from between 40 and 120 m water depth; these probably cover most of the last deglacial sea-level rise from about 20 to 6 ka before present, the scientific target for this expedition.

Future drilling

The first two MSP expeditions have clearly demonstrated the value of the addition of this new IODP coring facility to the scientific community, and a high level of refinement to the global post-glacial sea-level curve and related environmental changes in the Tahiti region can be anticipated.

An expedition to study sea-level changes during the period between 24 and 14 million years ago and their influence on the development of the shelf off New Jersey, USA is planned for the summer of 2007. Other highly ranked proposals that may be implemented are further coral drilling in the Great Barrier Reef, and a study of the hydrogeology off the New England coast of the United States. These expeditions will require a range of different platforms and drilling techniques, and MSPs have the flexibility to use the most appropriate methods for each project.

With the combination of the *Chikyu,* the SODV and MSPs, Scientists now have the facility within IODP to drill targets in any depth of water and in any marine environment, thus opening exciting new possibilities for understanding earth systems.

Websites for further information

Integrated Ocean Drilling Program – www.iodp.org
European Consortium for Ocean Research Drilling – www.ecord.org
ECORD Science Operator – www.eso.ecord.org

The *Vidar Viking* drilling in the Arctic ice, with the Russian icebreaker *Sovetskiy Soyuz* in the distance. Photo taken from the *Oden*. Photo: D McInroy© IODP/ECORD

The *DP Hunter* coring off Tahiti. Photo: I Pheasant© IODP/ECORD

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Judith A. McKenzie was appointed Professor of Earth System Sciences in the Geological Institute at the Swiss Federal Institute of Technology (ETH) Zurich in 1996. The Earth System Sciences Group under her direction includes the Stable Isotope, Limnogeology and Geomicrobiology laboratories of the Geological Institute, ETH. Over the years, she has been very active in the international Ocean Drilling Program (ODP) in both a research and advisory capacity and is now involved in the management of Swiss participation in the new Integrated Ocean Drilling Program (IODP). She was a shipboard participant in 5 ocean drilling campaigns, once sailing as a Co-chief Scientist. She is an active member of several professional societies, serving currently as the Past President of the International Association of Sedimentologists (2006-2010). She was elected a Fellow of the American Geophysical Union in 1999, a foreign member of the Royal Danish Academy of Sciences and Letters in 2006 and, most recently, a Geochemistry Fellow of the Geochemical Society and the European Association for Geochemistry in 2007. Prof. McKenzie received the 2006 Jean Baptiste Lamarck Medal of the European Geosciences Union.

Prof. McKenzie completed her doctoral thesis at the ETH in 1976 based on a study of modern dolomite formation beneath the coastal sabkhas (salt flats in Arabic) of Abu Dhabi, U.A.E. Afterwards, as a senior researcher in the Geological Institute, she established the Stable Isotope Laboratory and taught courses in chemical sedimentology and limnogeology. From 1985-87, she was associate professor at the University of Florida, Gainesville. Her research has concentrated on the study of evidence for past climate and environmental change as recorded in chemical sediments from both lacustrine and marine systems. The study of important modern environmental systems, such as the Great Barrier Reef in Australia or hypersaline lagoons in Brazil or geochemical cycles in lakes in Switzerland, is emphasized in her research along with an evaluation of anthropogenic influences on these environments. Since 1997, her research has taken a new direction into the field of geomicrobiology or biomineralization in an attempt to understand the influence of microbes on carbonate precipitation, particularly related to the occurrence of dolomite throughout Earth's history. With this new focus, her research has come full circle with a return to the arid sabkhas of Abu Dhabi, where she and her colleagues are investigating the microbial community mediating modern dolomite precipitation, as well as microbial dolomite formation in the deep-sea sediments of the Peru Margin (ODP Leg 201).

Abstract
Exploring the Deep Sea Subsurface Biosphere

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Fifty years ago, the deep ocean was thought to be a dark and quiet environment vastly depleted in known life forms. In particular, all life, even bacterial life, was thought to disappear only 7 m beneath the seafloor (mbsf), and this depth represented the lower limits of the biosphere. Since then, the introduction of modern coring techniques combined with ocean research drilling has delivered intact sediment cores from the deep sea to be examined in a nearly *in situ* state. Geochemists and sedimentologists studying these cores recognized that the deep-sea sediments cannot be barren of life because they contain distinctive geochemical signals in the sediment pore water, which are indicative of microbial activity. With the addition of microbiologists to the research teams, the presence of living cells has fundamentally been demonstrated at greater and greater depths in the deep-sea subsurface over a broad range of temperatures and pressures. The old paradigm that deep-sea sediments are sterile below 7 mbsf has now been overturned. Rigorous cell counts in sediment cores obtained by the Ocean Drilling Program (ODP) have demonstrated that microbes occur at depths greater than 750 mbsf (Parkes et al. 2000). It has been variously estimated that the subseafloor microbial biomass could represent from 10% to up to 30% of the Earth's microbial populations, which would be a significant component of the global carbon budget. An exciting new research emphasis to establish the exact lower limits of the deep-sea biosphere and to explore this entirely new ecosystem in sedimentary sequences, as well as in submarine basalts, using ocean drilling is now underway with the Integrated Ocean Drilling Program (IODP).

What is so unique about the microbial world beneath the seafloor? Firstly, this world is dominated by prokaryotes, *Bacteria* and *Archaea*, with the "higher" organisms, the plants and animals, being excluded. Most *Bacteria* and *Archaea* are between 500 nanometers (nm) and 2 micrometers (μm) in diameter, with a volume between 1 and 3 μm^3 and a wet weight approximating 10^{-12} grams. Obviously, this very small size permits these microorganisms to occupy the pore spaces between sediment particles, which are often only micrometers in scale. Secondly, although the metabolic processes employed by the subsurface microorganisms may be similar to those of surface species, the lack of light at depth excludes photosynthesis. The subseafloor microbial life is, therefore, dependent on energy sources that have been buried in the sediment or influxes of dissolved components with circulating fluids. Thirdly, because oxygen is rapidly depleted near the seafloor, anaerobic processes must dominate at depth. These processes can be followed with depth by changes in the chemical species measured in the pore waters recovered from drill cores. Fluxes of metabolic reactants and products within the sedimentary column clearly show that a very diverse microbial activity exists in the subseafloor anoxic sediments. Figure 1 illustrates subseafloor microbial processes with associated reactions as a function of depth. Each of the reactions introduces CO_2 or HCO_3^- with very characteristic carbon isotope compositions ($\delta^{13}C$ values), which are recorded in

diagenetic carbonates, such as dolomite [$CaMg(CO_3)_2$] or siderite ($FeCO_3$), precipitating with the sediments. These $\delta^{13}C$ values are useful as a signal of paleo-microbial activity.

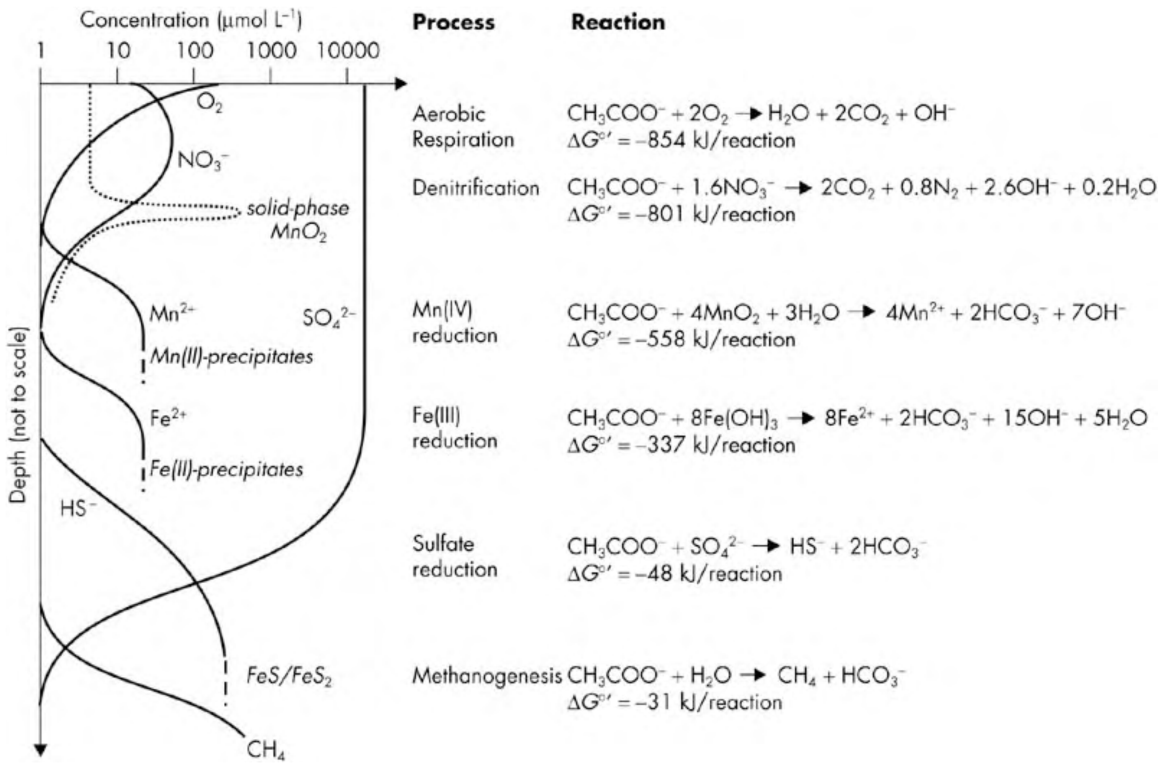

Fig. 1. Idealized pore water and solid-phase profiles based on the successive utilization of terminal elector acceptors during the decomposition of marine sedimentary organic matter. (From Kornhauser, 2007.)

In order to study the microbial communities in deep-sea sediment cores, great care must be taken to avoid contamination by microbes found in seawater, which is the commonly used drilling fluid. Using a combination of dye injected into the drilling fluid and fluorescent beads, it has been demonstrated that it is possible to retrieve cores with little to no detectable seawater intrusion. Based on the study of pristine cores, cell abundances with depth in sediments have been determined using acridine orange direct counts (AODC) (Parkes et al., 200). Because acridine orange fluoresces when bound to nucleic acid, DNA-bearing cells become microscopically visible when the sediment is stained and can, thus, be counted. Cell abundance is typically on the order of 10^8-10^9 cells/cm^3 near the sediment/water interface and declines exponentially with depth in the sediment column to values of around 10^5 cells/cm^3 at ~750 mbsf. The linear regression line shown in Figure 2 illustrates that the cell count at depth in the sedimentary column can vary considerably with significantly higher or lower counts depending on the location of the drill site (continental margin vs. open ocean) and the content of buried sedimentary organic matter. This variability was succinctly tested during ODP Leg 201, which was a dedicated geomicrobiology drilling campaign to the eastern Equatorial Pacific and the Peru Margin (D'Hondt et al., 2004).

Besides counting the number of living cells present at depth in the sediment, in an attempt to estimate the subseafloor biomass, geomicrobiologists are also interested to learn exactly which microorganisms are present, what they are doing and how do they survive. In other words, attempts are underway to determine the microbial diversity and functionality in the sediments buried deep below the seafloor using increasingly more sophisticated molecular tools and techniques. ODP Leg 201 proved to be a groundbreaking experiment to examine the diversity and functionality in the deep-sea subsurface biosphere (Smith & D'Hondt, 2006). In particular, the application of the fluorescence in situ hybridization (FISH) method, which targets ribosomal RNA using oligonucleotide probes designed to identify different phylogenetic levels, led to the identification of both *Bacteria* and *Archaea* in the sedimentary column demonstrating that a large fraction of the cells observed using AODC are truly alive and active. How these microbes interact and survive living in very close proximity in pore spaces over long periods in a diffusion-based economy remains an exciting topic for future research.

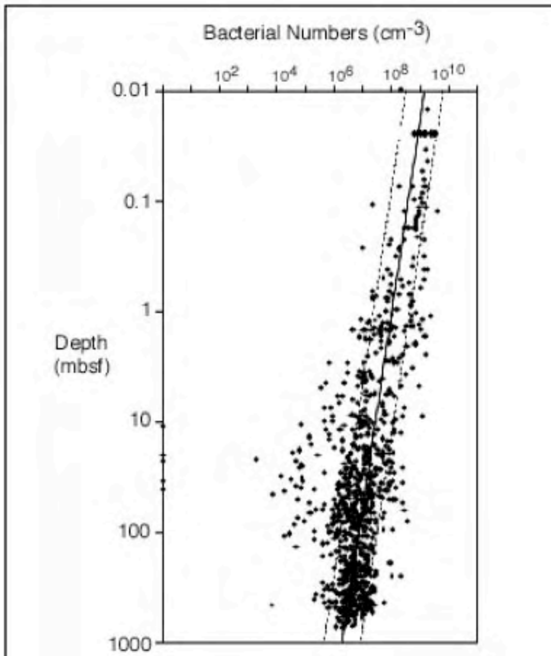

Fig. 2. Bacterial abundances as a function of sub-bottom sediment depth as seen in ODP boreholes down to ~750 mbsf. (From Parkes et al., 2000.)

References:

D'Hondt, S., Jørgensen, B.B., Miller, K.J. and ODP Leg 201 Shipboard Scientific Party (2004). Distributions of microbial activities in deep subseafloor sediments. *Science*, v. 306, p. 2216-2221.

Konhauser, K. (2007). *Introduction to Geomicrobiology*, Blackwell Publishing, 425p.

Parkes, R.J., Cragg, B.A. 7 Wellsbury, P. (2000). Recent studies on bacterial populations and processes in subseafloor sediments: a review. *Hydrogeol. J.*, v. 8, p. 11-28.

Smith, D.C. & D'Hondt, S. (2006). Exploration of life in deep subseafloor sediments, *Oceanography*, v. 19, p. 58-70.