8. IODP and ICDP drilling for scientific research: major achievements from past and current drilling initiatives

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8.1

Serpentinization and Life: IODP Drilling at the Atlantis Massif

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The Atlantis Massif, located at the inside corner high of the intersection of the Atlantis transform fault and the Mid-Atlantic Ridge at 30°N, is one of the best-studied oceanic core complexes (OCCs) and is the target of IODP drilling during Expedition 357 in late 2015. Drilling will address two exciting discoveries in ridge research: off-axis, serpentinite-hosted hydrothermal activity and carbonate precipitation, exemplified by the Lost City hydrothermal field, and the significance of tectono-magmatic processes in forming heterogeneous and variably serpentinized lithosphere as key components of slow spreading ridges. Serpentinization reactions at moderate- to low-temperatures result in alkaline fluids, which lead to precipitation of carbonate and brucite upon mixing with seawater, and are characterized by elevated concentrations of abiotic hydrogen, methane and low molecular weight hydrocarbons. These highly reactive systems have major consequences for lithospheric cooling, global geochemical cycles, carbon sequestration and microbial activity. However, little is known about the nature and distribution of microbial communities in subsurface ultramafic environments and the potential for a hydrogen-based deep biosphere in areas of active serpentinization and fluid circulation. The continuous flux of reduced compounds provides abundant thermodynamic energy to drive chemolithoautotrophy, however, carbon availability may be limited in these high pH environments and represent a challenge for microbial growth.

Here we review serpentinization processes as fundamental to understanding the evolution of oceanic lithosphere and discuss open questions related to the impact of serpentinization on the subsurface biosphere that are the motivations for IODP drilling. In particular, motivations for drilling the shallow subseafloor of the Atlantis Massif include: (1) exploring the extent and activity of the subsurface biosphere in young ultramafic and mafic seafloor; (2) quantifying the role of serpentinization in driving hydrothermal systems, in sustaining microbiological communities and in the sequestration of carbon in ultramafic rocks; (3) assessing how abiotic and biotic processes change with aging of the lithosphere and with variations in rock type; and (4) characterizing tectono-magmatic processes at OCCs and the evolution of hydrothermal activity associated with detachment faulting. Drilling will be carried out as a Mission Specific Platform (MSP) expedition and will use seabed rock drilling systems for the first time in the ocean drilling programs.

8.2

Timing of mass transport deposits at site C0018 (IODP Exp. 333)

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Submarine slides are gaining attention not only because of their catastrophic impacts, but also because their triggers (i.e earthquakes, rapid sedimentation, gas release, or clathrate dissociation etc) may represent geohazards themselves. Dating of the respective deposits, often reffered to as mass-transport deposits (MTDs) remains an important step in order to study the frequency of such large MTDs and to better understand their trigger mechanism. Although these MTDs can be imaged by seismic surveys, characterisation and dating of these deposits require scientific ocean drilling.

The aim of this study is to reconstruct the timing of five large MTDs at site C0018 (IODP Exp. 333) within a slope-basin in the outer forearc of the Nankai subduction zone, off the coast of SW Japan. The timing of the MTDs at C0018 is based on biostratigraphy and magnetostatigraphy combined with new tephrochronolgy, radiocarbon data and ^{18}O isotope-stratigraphy.

The ^{18}O data of planctonic foraminifera show a general decreasing trend above all studied MTDs. Isotope analysis of additional samples will be used to confirm this trend or not. In the case that this trend is confirmed, a relationship between MTDs, emplaced in an acitve tectonic setting, and climate cannot be excluded. The different processes/scenarios on how climate could act as trigger for these MTDs will be discussed in this study.

8.3

Uncovering a Salt Giant: Umbrella proposal of the Deep-Sea Record of Mediterranean Messinian Events (DREAM) multi-phase drilling project

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About 6 million years ago the Mediterranean Sea became an enormous saline basin where more than one million cubic kilometres of salt accumulated, locally exceeding a thickness of 3 km in the deep basins. This extreme, but geologically brief event (640 ka; the so-called Messinian salinity crisis MSC), changed the chemistry of the global ocean and had a permanent impact on both the terrestrial and marine ecosystems of a huge area surrounding the Mediterranean. Drilling the MSC salt giant represents a unique opportunity to understand the sedimentary history, stratigraphy, biosphere and fluid dynamics of a salt giant in a state close to its original depositional configuration, and to understand the responsiveness of a land-locked oceanic basin to planetary dynamics.

The MPD proposal "Uncovering a Salt Giant" originates from a series of workshops and international initiatives carried out since 2006, when riser-drilling technology was introduced in IODP in 2004. The proposal integrates in the overall objectives the goals of the MDP Proposal 798, (GOLD).

Four site-specific drilling proposals are conceived under this umbrella:
1. DREAM: Deep-Sea Records of the MSC;
2. Deformation and fluid flow in the MSC salt giant;
3. Probing the Salt Giant for its Deep Biosphere secrets;
4. Probing deep Earth and surface connections;

addressing four overarching questions:
1. What are the causes, timing and emplacement mechanisms of the MSC salt giant?
2. What are the factors responsible for early salt deformation and fluid flow across and out of the halite layer?
3. Do salt giants promote the development of a phylogenetically diverse and exceptionally active deep biosphere?
4. What are the mechanisms underlying the spectacular vertical motions inside basins and their margins?

A pre-proposal of the "Probing deep Earth and surface connections" (Rabineau et al.) proposal was approved by the SEP submitted in parallel with this MPD proposal.

Two deep basin sites (A-Sites) will be proposed, one each in the Western and Eastern Mediterranean basin, aiming at the recovery of the complete Messinian sequence. One of these, in the Western Basin, will be extended down to basement. Four intermediate basins sites are located at shallower water depths and target the recovery of MSC records to reconstruct a shallow-to-deep transect where the A-Sites are the basinal end-member.

Marginal basins sites, under consideration for ICDP, will obtain a continuous record of MSC deposits in order to provide a detailed stratigraphic correlation among a full land-deep basin transect.

Dream Project Team: Angelo Camerlenghi, Giovanni Aloisi, Sierd Cloetingh, Hugh Daigle, Gert DeLange, Rachel Flecker, Daniel Garcia-Castellanos, Zohar Gvirtzman, Christian Hübscher, Wout Krijgsman, Junichiro Kuroda, Johanna Lofi, Stefano Lugli, Agnès Maillard-Lenoir, Yizhaq Makovsky, Vinicio Manzi, Judith McKenzie, Terry McGenity, Andrea Moscariello, Marina Rabineau, Marco Roveri, Francisco Javier Sierro, Nicolas Waldmann… …….and many others.

8.4

Cold-water coral reefs along the European continental margin through the Quaternary

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Cold-water coral (CWC) reefs are marine benthic ecosystems acting as important hot spots of biodiversity and living resources. In the northeast Atlantic, the reefs form giant coral carbonate mound structures up to 300 m in height. The development of these coral carbonate mounds is controlled by environmental factors such as temperature, salinity, seawater density, current strength, food supply, sedimentation rate, and substrate availability – some of them paced by the Northern Hemisphere climate system since their development ~3 Myr ago (e.g., Freiwald, 2002; Rüggeberg et al., 2007; Raddatz et al. 2014). The aim of this study is to highlight the importance of seawater density for the CWC reefs along the European continental margin. Recent studies have shown that reefs thrive under present-day seawater densities (sigma theta, $_{\Theta}$) of ~27.5 ± 0.15 kg/m^3 (Dullo et al., 2008). This level is coherent with the position and stability of the thermocline for the carbonate mounds offshore the Irish margins (White and Dorschel, 2010). Stable and favourable environmental conditions including constant food supply by continuous or tidally controlled currents occur over longer time scales allowing CWCs to create large reef and mound ecosystems.

The possibility to reconstruct past seawater densities gives us the opportunity to determine past environmental water mass characteristics in comparison to the recent setting and interpret these in relation to CWC growth and carbonate mound development. Recent calibrations are based on salinity, temperature and stable oxygen isotope ratios of the seawater ($^{18}O_{sw}$) collected during several research cruises. The calculation of paleo-seawater densities at different time slices is based on calcitic $^{18}O_c$ values of epibenthic foraminifera (Lynch-Stieglitz et al., 1999), and has been tested for three drilled and cored coral carbonate mounds in the Porcupine Seabight, southwest off Ireland:

1. IODP Exp. 307 Site 1317 at Challenger Mound (Belgica Mound province),
2. Galway Mound (Belgica Mound province), and
3. Propeller Mound of the Hovland Mound province.

The results indicate that the development of CWCs building those carbonate mounds is closely linked to mid-depth bottom water densities. Thriving coral growth during the past 3 Myr is predominantly found at seawater densities (sigma-theta, $_{?}$) between 27.2 and 27.7 kg/m^3. In comparison to present-day conditions, the reconstructed $_{\Theta}$-values can be interpreted as the pycnocline at around 27.5 kg/m^3 serving as boundary layer on which horizontal currents develop to carry nutrients and possibly coral larvae.

To verify past seawater stratification at intermediate water depths, a compilation of existing $^{18}O_c$ data from DSDP, ODP and IODP sites combined with data from sediment cores are used to reconstruct paleo-seawater densities. At three latitudinal depth-transects (37°N, 51°N and 65°N) paleo-seawater densities of different periods in the Pleistocene have been determined for the upper 3000 m of water column. As example, using PMIP 2 Had-CM3M2 modelled temperature and salinity data of the Last Glacial Maximum, when no coral growth is reported at 51°N and 65°N, paleo-seawater densities for the latitudinal transects were determined. In comparison to the present-day data the Had-CM3M2 model data indicate a general freshening and cooling of the water masses resulting in slightly heavier $_{\Theta}$-values – confirming calculated $_{\Theta}$-values from $^{18}O_c$ data.

The determination of past seawater densities has great potential in paleoceanographic reconstructions of intermediate water mass dynamics. More time slices will be investigated to understand the cold-water coral carbonate mound development of the past 3 Myr in more detail. It also provides a tool to study the sensitivity of CWC ecosystems with respect to environmental changes and highlights the importance of pycnoclines as a controlling factor favoring CWC growth on carbonate mounds.

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P 8.1

IODP Exp. 351 Izu-Bonin-Mariana (IBM) Arc: Scientific Objectives and Lithostratigraphy of Site U1438

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Arc initiation and subduction inception are fundamental processes leading to arc magmatism and continental crust genesis. Within the past few decades, extensive investigation of the Izu-Bonin-Mariana (IBM) intraoceanic arc in the northwestern Pacific has helped constrain the age (~52 Ma) and site of subduction initiation along the Kyushu-Palau Ridge (KPR). The International Ocean Discovery Program (IODP) Expedition 351 (June-July 2014) targeted the Amami Sankaku Basin, adjacent to the KPR, where the pre-arc and nascent arc basement could be accessed by drilling. Two primary objectives of the expedition were to recover the sedimentological record overlying the oceanic crust as well as the oceanic crust itself in order to i) constrain the petrological and geochemical characteristics of the mantle prior to subduction ii) constrain the petrological and geochemical evolution of the nascent arc and iii) resolve the processes of subduction initiation and arc formation.

IODP Site U1438 recovered 160m of Neogene terrigenous, biogenic and volcanogenic mud and ooze interspersed with well-preserved vitric- and crystal-rich ash layers most likely related to the Ryukyu, Honshu and IBM volcanic arcs. These sediments overlie 1300m of volcaniclastic sedimentary rock dominated by tuffaceous sandstone and tuffaceous mudstone with minor tuffaceous breccia-conglomerate incorporating preserved basaltic to rhyolitic pebbles and pumice. The sedimentological record of Site U1438 provides an unprecedented look at the waxing and waning patterns of volcanogenic output of the IBM arc, particularly through the Paleogene from arc initiation (~52 Ma) through maturation and demise (~25 Ma) related to the eastward migration of the IBM arc and cessation of volcanic activity at the KPR. Underlying these arc-derived sediments is 150m of oceanic crust made up of well-preserved plagioclase-clinopyroxene aphyric to sparsely microphyric basaltic flows.

P 8.2

Microbial influence on organic proxy in the Dead Sea sediment at the beginning of the Holocene

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Paleoenvironmental reconstruction is among the main targets of the International Continental Drilling Program (ICDP)-sponsored Dead Sea Deep Drilling Project (DSDDP). During drilling of the Dead Sea in the winter 2010-2011, around 450 meters of core were retrieved and currently several multi-disciplinary studies are being performed to illuminate this almost continuous sedimentary record. Careful attention has been directed to understanding the microbial communities living in the hypersaline sediment and the potential impact they might have on biogeochemical cycles both in the lake and in the Dead Sea precursors. Studies have highlighted the potential for microbial activity in the lake, in spite of its hypersalinity, and the putative influence of microbial communities on the geochemical record, especially with respect to reconstruction of the carbon and sulfur cycles (Luz et al., 1997; Torfstein et al., 2005; Kolodny et al., 2005). More recently, geomicrobiological and geochemical studies with samples obtained during the DSDDP have revealed the potential for methane production (methanogenesis) in the subsurface; this can greatly impact the carbon isotope record in the subsurface and could skew any paleoenvironmental interpretation (Thomas et al., submitted). By combining carbon, sulfur and oxygen isotopes from the interstitial pore water and the surrounding sediment, including a lithological facies study and biomarker analysis, we highlight that the period following massive gypsum precipitation in the Dead Sea, at the onset of the Holocene, has been subject to major changes. At this time, variations in the level of the lake, accompanied by water mixing, have supposedly initiated intense microbial activity in the paleo-water column and probably within the sediment after its burial, as indicated by specific authigenic Fe-S mineralizations. Sulfur isotope evidence from the pore fluids suggests that these Fe-S precipitations may be microbial in nature. While no DNA could be extracted from this interval to allow a microbial diversity study, the retrieval, among other, of non-isoprenoid macrocyclic glycerol diethers potentially calls for the presence and influence of extremophiles involved in sulfur cycling (Baudrand et al., 2010). Current work will help unravel the extent of the biological impact on proxies that could be used for paleoclimatic studies. Additionally, this work highlights the importance of routinely implementing geobiological studies within the ICDP framework.

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P 8.3

Drilling modern to ancient continental spring carbonates – Comparison of facies and petrophysics from travertine cores in the Ballik area (Pleistocene, Denizli, Turkey) and Mammoth Hot Springs (Holocene, Yellowstone, USA)

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Continental microbial carbonate deposits gained recently interest due to their potential as reservoir rocks, e.g. for hydrocarbons. Travertine is a particular type of continental carbonate deposit that forms at hot springs. In these settings, the strong interplay of physico-chemical processes and micro-organisms along the downstream flow path influences the fast-precipitating carbonate fabric and its petrophysical properties. Diagenetic overprinting may, in addition, drastically affect the primary fabric and pore network.

The combined study of drill cores and time-equivalent, high-quality exposures in the ancient Faber quarry (Pleistocene, Denizli, Turkey) and the modern Mammoth Hot Springs system (Yellowstone, USA) allow direct 1D to 3D up-scaling. This offers a unique setting (1) to interpret depositional system evolution in terms of changing biological, physical, and chemical conditions and diagenetic imprints (cementation, alteration), and (2) to evaluate (facies-specific) parameters controlling the petrophysical and acoustic properties of these rocks.

This study used drill cores with a total length of 120 m from the Faber quarry, located in the northern flank of the Denizli Basin and incorporates preliminary observations of the Y-10 core (total length of 113 m; USGS, 1969; Chafetz and Guidry, 2003) transecting the modern to Holocene Mammoth Hot Spring (MHS) deposits. Core sections were described in detail and travertine fabrics were placed within a geobiological facies context. Representative sections of the Faber cores (+/- 60 m) have been logged for P-wave velocity and gamma ray density with a resolution of 1 cm (GEOTEK MSCL). Both cores were subsampled for microscopic observations and poroperm analyses.

In agreement with earlier observations, this study demonstrated the broad applicability of the five-fold travertine facies framework, proposed by Fouke (2011) both for modern and ancient deposits. Core sections from both areas documentthe presence of large-scale subhorizontally bedded facies intercalated with different levels of alluvial conglomerates and marly deposits at Faber and with volcanoclastic layers at MHS. Both travertine systems evolve into a domal build-up with increasingly more proximal deposits and repeated facies shifts.

For the Faber cores, porosity and permeability analyses on plugs (1.5 inch diameter) allowed calibrating porosity estimations based on the logged parameters. In agreement with Soete et al. (subm.) acoustic velocity variations in continental carbonates relate to geobody boundaries, in which the seismic expression is in function of porosity and pore types. In general, the results suggest that specific core transects allow to deduce the main vertical facies succession and evolution in spring carbonates. Acoustic and petrophysical properties, measured by physical logging of the calcitic Faber travertine cores provide a first measure for changes in the porosity and suggest a relation to pore structure and pore structure modifications.

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