WORKSHOP REPORT
Exploring deep subsurface life, sedimentation and tectonics in a young ocean: Workshop to synthesize site survey cruise data and develop new strategies for a scientific ocean drilling proposal in the Guaymas Basin

Puerto Vallarta November 6th-10th 2015

Conveners: Ivano Aiello, Andreas Teske and Christina Ravelo

Summary

A workshop, supported by the U.S. Science Support Program for IODP, was organized by Andreas Teske, Christina Ravelo and Ivano Aiello at the Bugambilias Sheraton Hotel in Puerto Vallarta, Mexico between the 6th and the 10th of November of 2015 in conjunction with the Annual Meeting of the Union Geofisica Mexicana. A multidisciplinary group of scientists was convened to create momentum in producing a drilling proposal to bring the IODP program to the Guaymas Basin in the Gulf of California (GOC). The GOC represents a singular example of interactions between tectonics, sedimentation and microbial life in a very young ocean formed by translation and oblique rifting. Drilling in the Guaymas Basin would offer a unique opportunity to understand how subsurface microbial populations intercept and process hydrothermally generated and mobilized carbon sources.

The workshop achieved two main objectives:

1) Produced an in depth panel review of the biogeochemical, sedimentological, microbiological and multichannel seismic results from two site survey cruises investigating the sedimented ridge flanks of the Guaymas Basin and the Sonoran Margin in the Gulf of California;

2) Created renewed impetus towards the formulation of a drilling proposal to bring the R/V JOIDES Resolution to the Guaymas Basin in the Gulf of California. The panel reformulated and modified the scientific objectives and the drilling priorities and created the conditions for the successful revision of pending proposal N.833.

Workshop rationale

The Guaymas Basin in the Gulf of California is a young marginal rift basin characterized by active seafloor spreading, high surface water primary productivity, influence of terrigenous sedimentation form the Sonoran mainland and rapid deposition of organic-rich sediments, characterized by extensive temperature and geochemical gradients. In this context, deeply emplaced volcanic sills originating at the spreading center indurate and alter the surrounding sediments, and shape hydrothermal circulation patterns (*Einsele et al.* 1980). Hydrothermal alteration and mobilization re-injects buried carbon into the biosphere (esp. as hydrocarbons and methane), a process that could have relevance on climate history (*Lizarralde et al.* 2011). Subsurface microbial populations can intercept and process these hydrothermally generated and mobilized carbon sources (*Teske et al.* 2014). As such, the Guaymas Basin sediments provide a model system for exploring the extent, activity, biogeography and metabolic capabilities of subsurface microbial life within extensive chemical, temperature and lithological gradients (Figure 1).

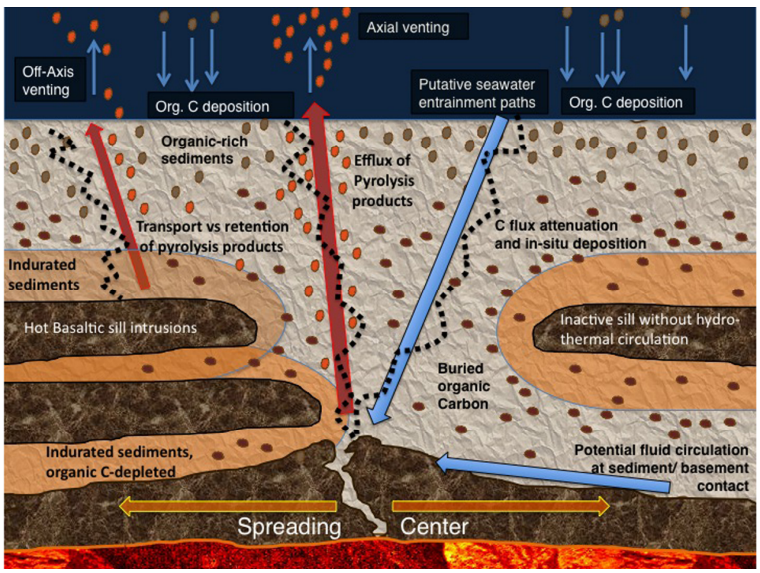


Figure 1. The Guaymas Basin subsurface with deep basement, sills, sediments, sedimentation and organic carbon input (brown drops), buried carbon in the sediment (dark-brown pellets), volatile pyrolysis products (orange drops), and hypothetical fluid flow pathways (Teske et al. 2014).

It has been more than 30 years since the Glomar Challenger drilled this young basin during ODP Leg 64 (Curray et al. 1979; Curray and Moore 1982). This historical leg produced for the first time a picture of tectonics, magmatism, hydrothermal activity, organic geochemistry and sedimentation along different transects at the southern tip of Baja California (Sites 474, 475, and 476), the Guaymas Basin (Sites 477, 478, and 481), and the Guaymas Basin Slope (Sites 479 and 480). Although the drilling technology at that time imposed limitations on core recovery and sample quality, sediments and dolerite sills near the spreading center as well as off - axis sediments, have been surveyed in a multidisciplinary and comprehensive endeavor during Leg 64; this approach still serves as benchmark for Guaymas Basin subsurface research (Einsele et al. 1980, Curray and Moore 1982). However, today's scientific questions, approaches and methodologies have evolved so far that a multidisciplinary re-examination of Guaymas Basin by deep-sea drilling would be revelatory.

In April 2013, a joint US-American, Mexican and European IODP proposal (incl. Aiello, Teske and Ravelo) targeted the hydrothermally influenced deep subsurface sediments and basaltic sills of Guaymas Basin for a comprehensive study integrating the extent, activity and limits of life in this energy- rich environment with geochemical, sedimentological and

palaeoceanographic characterization. Science Evaluation Panel (SEP) reviewed the proposal (No. 833) very favorably on scientific grounds but stressed the need for a new survey of the proposed drilling sites including a comprehensive seismic survey, heatflow measurements and biogeochemical/microbial characterization. To address the site survey issue, two site survey cruises in 2014 (RV El Puma; Figure 2) and 2015 (RV Sonne) refined the seismic structure of the Guaymas Basin subsurface, and collected gravity cores for up-to-date microbial, sedimentological and geochemical analyses.

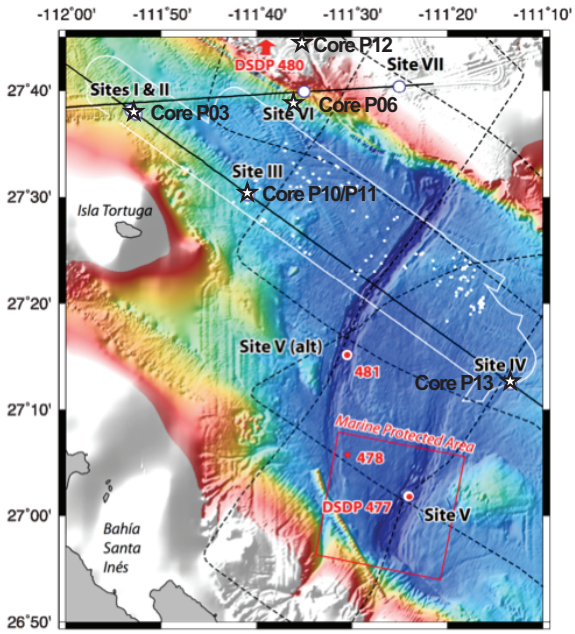


Figure 2 – Bathymetric map of the Guaymas Basin. Site I through VII were the originally proposed IODP drilling sites, and Cores P03, P06, P10, P11, P12, and C13 are the site survey cores collected by the RV El Puma in 2014.

To produce new impetus towards producing a new submission of a full proposal to drill in the Guaymas Basin, we organized a workshop to bring together junior and senior US scientists and students (directly supported by USSSP), the chief scientists, proponents, and key participants of the RV El Puma and RV Sonne site survey cruises.

The workshop took place immediately after the Annual Meeting 2015 of the Union Geofisica Mexicana (UGM) in Puerto Vallarta (including a special session on Guaymas Basin), and therefore facilitated a broad participation by our Mexican colleagues.

Workshop participants

The need to interpret the new datasets from the site survey cruises and the highly multidisciplinary character of the proposed scientific drilling to study the subsurface sediments and basaltic sills of the Guaymas Basin motivated the selection of a panel of scientists having multiple expertise including geophysics, microbiology, geochemistry, sedimentology, and palaeoceanography. The workshop participants included junior scientists and newcomers to the Guaymas Basin and Gulf of California research field, as well as more experienced, senior-level scientists who have experience working in the area or on similar research topics.

USSSP invited a total of 11 scientists, 6 seniors and 5 juniors (out of which 4 PhD students or post-Docs). The group of scientists sponsored by USSP, including the 3 conveners and our host Carlos Mortera was representative of the following fields: geophysics (5), microbiology (2), bio-geochemistry (4), sedimentology-paleoceanography (3): Ashley Cohen (SBU), Dan Lizzaralde (WHOI), Simon Brassel (Indiana University, Bloomington), Luke MacKay (Montana State), Doug LaRowe (USC), Robert Harris (OSU), Joann Stock (Caltech Pasadena), Konstantin Choumiline (UC Riverside), Marta Torres (OSU) and Andrew Fowler (UC Davis). Other non USSSP-sponsored participants included: Andrew Buckley (UNC-CH), Christian Berndt (Geomar), Jessica Whiteside (National Oceanography Centre Southampton).

The location and timing of the Workshop allowed for a larger participation of Mexican colleagues collaborating and interested in working in the Gulf of California as well as the participation of the Chief Scientists of the geophysical surveys conducted in the Guaymas Basin by the R/V Sonne and the R/V El Puma. As a result, at any time the workshop was attended by a relatively large group of scientists ranging between 15 and 25 attendees.

Figure 3 - Guaymas Basin Workshop: the picture includes the workshop participants (including non USSSP participants): Ashley Cohen, Dan Lizarralde, Simon Brassel, Luke MacKay, Doug LaRowe, Robert Harris, Konstantin Choumiline, Marta Torres, Andrew Fowler, Andrew Buckley, Carlos Mortera, Christina Ravelo, Andreas Teske and Ivano Aiello.

The criteria used for the selection of the panelist sponsored by USSSP resulted to be extremely successful, and the mix of expertise and levels of familiarity with the Guaymas Basin science allowed for vibrant discussions and major achievements towards the next phase of planning of drilling proposal. The conveners are especially thankful for the active participation and inspiration of the younger, early career scientists who have been instrumental in driving many of the panel discussions. The workshop could not have happened without UNAMS's (Universidad Nacional Autónoma de México) geoscientist Dr. Carlos Mortera who has been a wonderful host and tremendous help with both organizing the event and making the panel discussions very productive.

Workshop Timeline

The workshop occurred over 3-days and followed a three-fold agenda:

1) During Day 1, the conveners and some of the participants previously involved in the Guaymas Basin drilling proposal or the site survey cruise outlined IODP proposal 833 and presented new site survey results. 2) 2) During Day 2 the new results were discussed and synthesized during break out sessions, and the sub-groups formulated data-driven responses to the IODP watchdog concerns and criticisms about proposal 833. 3) Day 3 was a plenary session during which more focused science objectives, revised drilling site priorities and drilling depths were formulated.

Day 1 - Saturday Nov. 7th: New site survey results presentation

The first part of the day included short presentations that offered an overview of the multidisciplinary aspects of the science of the GOC and specifically of the Guaymas Basin

and a review of the available site survey data. Then the panel discussed drilling proposal Full-833 and the previous feedback from the Science Evaluation Panel (SEP).

The second half of the day focused on reviewing the preliminary results of a site survey cruise of the UNAM's research ship *El Puma* in Fall 2014, in particular the geochemical, microbiological and sedimentological data from the gravity cores collected in the Guaymas Basin at the proposed IODP drilling locations (Figure 2).

Then, the panel discussed the results of the site survey cruise of the German RV Sonne in the Guaymas Basin, presented by GEOMAR scientist Christian Berndt. This cruise produced crucial 2D seismic and heath flow data as well as extended gravity cores in areas of the Guaymas Basin not previously studied. The results of these cruises were fundamental at reshaping the drilling proposal, re-focusing the science objectives and prioritizing the drill sites that will be included in a future proposal.

Day 2 - Sunday Nov. 8th: Charting a new drilling strategy for the Guaymas Basin

While day 1 was focused at reviewing the existing science, science objectives and preliminary datasets available from the site surveys, during day 2 the panel concentrated on two major tasks:

1) Redrawing the scientific objectives for a new drilling proposal in the Guaymas Basing.

2) Revising the location and number of proposed drill sites based on the new science focus and in consideration of the results of the site surveys, especially the one done by the RV Sonne.

Importantly, to accomplish both tasks 1 and 2 the feedback received from SEP on the earlier submittal of proposal Full-883 was taken in full consideration.

To make the discussion more productive and focused, the panel was divided into two sub-groups organized by broader disciplinary topics:

1 – tectonics/sedimentology/paleoceanography; 2- geochemistry/microbiology. However the participants (many of which have multidisciplinary expertise) moved from one group to another insure flow of information and to update the different groups on progress.

The panel met again in plenary session during the second half of the day to start a plenary discussion on tasks 1 and 2, which continued during the 3rd day of the meeting.

Day 3 - Monday Nov. 9th: Strategies to develop collaborations and address IODP watchdog concerns. Developing new site priorities.

The plenary discussion during day 3 was extremely prolific and the results of this work form the basis for a new version of a drilling proposal to the Guaymas Basin.

The panel achieved a consensus concerning both the focus of the scientific objectives of the proposal and the number and location of drill sites. These topics are discussed in more detail in the following paragraphs.

Guaymas Basin revised priority drill sites

Following the suggestions of the SEP watchdogs, and taking into account the new survey data and the re-prioritization of the scientific objectives (see later), the panel discussed how to improve the chances of a successful drilling proposal by removing, changing and adding sites to the original list proposed in Full-883.

Following is a new site list, which has 7 priority sites and 3 alternate sites (Table 1 includes also a tentative operation plan). A map with the new site location is also provided (Figure 4).

1) Site 1A was chosen to represent undisturbed, non thermogenically altered sediments next to a sill intrusion and provide information on background hemipelagic sedimentation characterized by normal diagenetic processes. The panel suggested that the site should be drilled deeper the one proposed earlier to ca. 700m. A deeper site will allow reaching a lower sill which will illustrate the longer-term history of thermally altered sediments. Moreover, the site is the deepest undisturbed sediment pile that we could find in the Guaymas Basin (observation supported by crossing seismic lines).

TOP PRIORITY PLAN

Site Name	Lat (deg)	Lat (min)	Long (deg)	Long (min)	Water Depth (m)	Expected Penetr'n (m)	Location	Operations	Transit 10.5 kt (days)	Coring Time (days)
Port	32	39.100	-117	-13.600			San Diego	none		
GUAYM-01A	27	38.074	-111	-53.093	1600	600	NW basin, background bio sed, deep sill	APC/XCB HOLE A, APC HOLE B, APC/XCB and LOG HOLE C	4.28	9.3
GUAYM-02A	27	37.697	-111	-52.503	1600	1300	NW basin, bio sed, shallow sill	APC/XCB Hole A; APC Hole B; RCB and LOG Hole C	0.00	12.3
GUAYM-03A	27	30.087	-111	-40.622	1750	150	NE of MOR, active shallow cooking	APC Hole A, B, C; RCB and LOG Hole C	0.05	5.8
GUAYM-04A	27	12.297	-111	-13.056	1850	650	SE basin, terrig sed, deep sill	APC Hole A and B; APC/XCB and LOG Hole C	0.12	6.6
GUAYM-04B	27	12.297	-111	-13.056	1850	450	SE basin, terrig sed, deep sill	APC Hole A and B; APC/XCB and LOG Hole C	0.00	5.5
GUAYM-06A	27	15.300	-111	-30.767	2000	150	High heat flow, active shallow sill	APC/XCB Holes A, B; APC and LOG Hole C	0.06	4.9
GUAYM-10A	27	33.301	-111	-32.883	1845	200	shallow gas hydrate	APC Holes A, B; APC and LOG Hole C	0.07	3.8
Port	32	39.100	-117	-13.600			San Diego		4.24	

LIST OF ALTERNATE SITES

Site Name	Lat (deg)	Lat (min)	Long (deg)	Long (min)	Water Depth (m)	Max Penetr'n (m)	Location	Operations (mbsf)	Transit 10.5 kt (days)	Coring Time (days)
GUAYM-03B	27	28.181	-111	-28.379	1843	400	NE of MOR, active shallow cooking	APC Hole A, B, C; RCB and LOG Hole C		6.4
GUAYM-04B	27	12.297	-111	-13.056	1850	450	SE basin, terrig sed, deep sill	APC Hole A and B; APC/XCB and LOG Hole C		6.3
GUAYM-01A	27	38.074	-111	-53.093	1600	700	NW basin, background bio sed, deep sill	APC/XCB HOLE A, APC HOLE B, APC/XCB and LOG HOLE C		10.4

Table 1 – List of new Priority and Alternate Site for the Guaymas Basin drilling.

2) The location of Site 2A (site chosen to study disturbed sediment over a recently emplaced sill) was shifted to the south than suggested previously, to the location of crossing

seismic lines. The new site location offers a window to the basement and will allow sampling deeper in the sediment pile where sediments have experienced multiple episodes of thermal alteration.

3) The panel suggested to keep Site 3A in the originally proposed location as an example for an attenuated off-axis seep site. Concerning this site, the panel discussed the opportunity to run new crossing line with a future cruise of the RV Alpha Helix of CICESE. Based on the discussion during the workshop, Dan Lizarralde applied for funding to pay for the seismic data collection by the Alpha Helix, and these seismic data have just recently been collected on a cruise in May 2016.

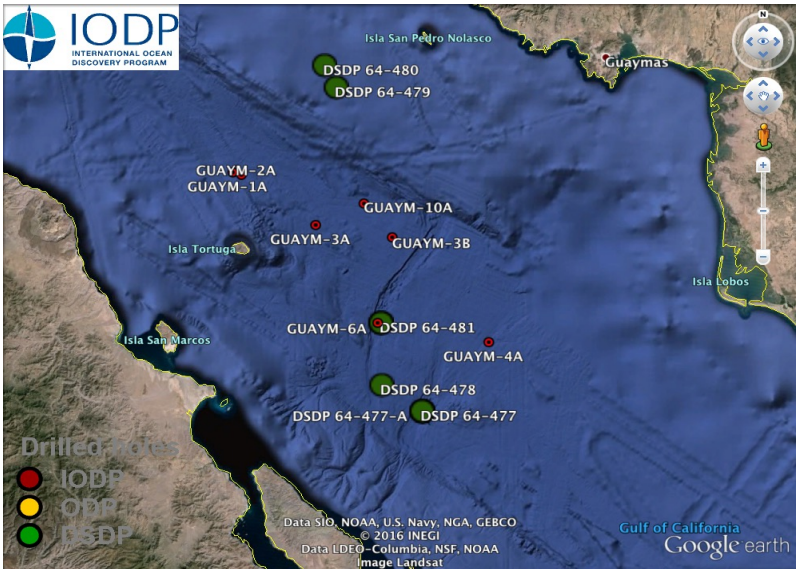


Figure 4 – Google Earth image of the Guaymas Basin showing the sites listed in Table 1 and the Sites drilled during DSDP Leg 64.

4) A new Site 3B was introduced as alternate for Site 3A which was originally situated to study sediments and microbial activity is in the “bull’s eye’ of a vent. As observed during the Sonne cruise this is a central vent site which resembles to Site 03 (e.g. loss of sediment stratification indicating gas upflow, and seafloor images indicating seep communities); however the sill at Site 03B is deeper than at the originally proposed location.

5) The panel proposed to retain the original Site 4A on the southeastern edge of the Guaymas Basin also in consideration of a new crossing line from the RV Sonne cruise. The panel also considered moving Site 04 from the center of the saucer-shaped sill (imaged my the MCS) to its edge to study the upflow of fluids/gasses/sediment disturbance at its margin. However this potential shift would require a new crossing line (carried out by the Alpha Helix cruise). This site would provide an important lithological counterpart to the northern side of the mid-ocean ridge. Specifically, it would allow to study how hydrothermal systems affect different sedimentary sequences that have higher terrigenous content and different types and concentrations of organic matter.

6) Site 5A (V in Figure 2) in the southern side of the basin was removed since it is in the Guaymas Biosphere reserve.

7) The panel suggested to keep Site 6A (old DSDP Site 481) as the hot reference site on the Northern Graben of the Guaymas spreading center as site with the highest heatflow. A seismic line (not a crossing line) is present nearby although of poor quality. The panel suggested to contact the SEP watch dogs to question whether the old information related to DSDP Site 481 is sufficient to justify drilling at this site.

8) Sites 7 and 8 (VII and VIII in Figure 2) on the Sonora Margin have been removed since they are not directly related to the main focus of the drilling proposal (deep hot biosphere).

9) A new, second-priority site (Site 10, 1800m water depth) was proposed by the panel. This is a site will allow studying hydrate-rich sediment on the northern section of the NW ridge flank of the spreading center. Seismic data for this site are high-quality and the RV Sonne cruise retrieved long gravity cores at the same location. Further scientific questions that can be studied at this site include: geochemical changes through the gas hydrate stability zone and below it in the sediment above a sill which is about 700m deep. Finally this could be an important site for carbon sequestration that can be connected to the Guaymas hydrothermal system to calculate carbon budgets within the basin.

Guaymas Basin drilling: revised scientific objectives

Much of the panel discussions during the afternoons of day 2 and 3 were focused at reformulating and, in same case, completely rethinking the science objectives and the hypotheses to be tested by the new drilling proposal. During the discussion, several flow-charts and conceptual diagrams were developed (e.g. Figures 5 and 6).

The following paragraphs list scientific hypotheses on the extent and mechanisms controlling deep subsurface life in relation to geochemistry, sedimentation and tectonics in the Guaymas Basin. The list includes potential strategies to test these hypotheses and at which of the proposed drill sites (Table 1). Note that the hypotheses that concern directly the microbiology of the system are labeled “Bio”, while the hypotheses related to the geochemistry/solid phase components of the system are labeled “Abio”. The sites that are relevant to the specific hypotheses are shown in parenthesis.

1) Understanding the chemical and physical factors that shape the temporal and spatial development of microbial communities and their contribution to the C cycle in the deep biosphere of the GB

H1Bio (all sites): Do microbes attenuate carbon mobilization out of the system (“microbial gauntlet”)?

- The taxonomy and the biomarkers can help predict the usage of C.
- Production, amount and composition of CH4 vs precipitation of authigenic carbonates.
- Pore fluids geochemistry (electron donors, acceptors and activity inhibitors).
- Organic (molecular and isotopic) composition and analysis in solids, fluids and gases (TOC, DOC, TON, POC, recovery of core sample in situ pressure; PCS)
- Use of IPLs, 16SrRNA, activity assays (to determine whether microbes are dead, alive or ‘zombies’).

H2Bio (all but Site 10; especially Site 2A vs. Site 1A): Is microbial contribution to carbon speciation (volatiles, DIC) dependent on proximity to the ridge axis (e.g. Site 3A vs. 4A)? Does high temperature in the deep biosphere affect the ability of microbes to survive as they need constant supply of C and energy (the higher T the higher energy demand to repair molecules). What are the limits of the deep hot life?

- Same approach as for H1 but in different T settings.

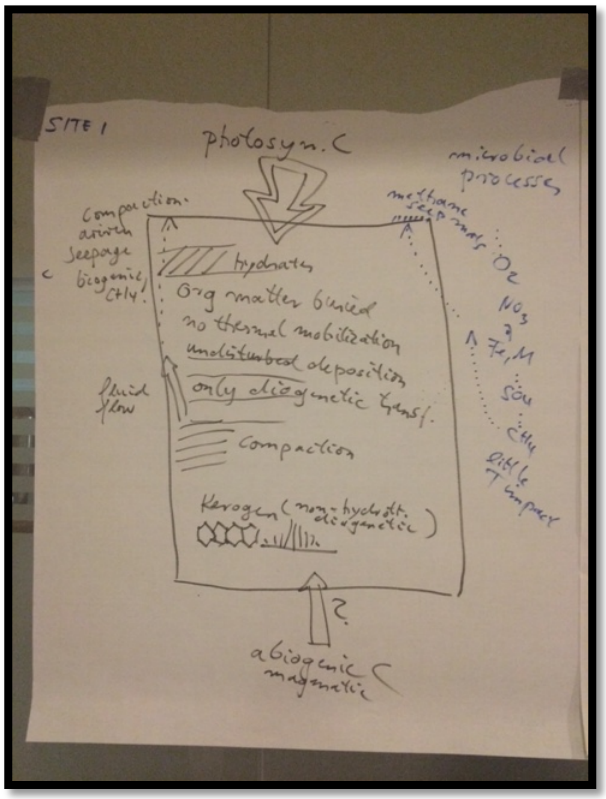


Figure 5 – Snapshot of the meeting's whiteboard. This is an example of the conceptual models used to identify the main hypotheses to be tested. This example is about the location of proposed drill site 1 in relation to 2 sill intrusions (a younger at the top and older at the bottom) and the potential interaction between solid geochemistry of the sediments, fluid flow, carbon types and microbial activity.

- Incubation experiments at different T and volatile concentrations.
- Sequencing to reconstruct community structure (e.g. methanogens vs. metanothrophs vs. other remineralizers) in relation to hydrothermal activity.
- Biomarkers for microbial identity.

H3Bio (Site 2A vs. 4A): Hemipelagic vs terrigenous sediments, microbial variability in turbidite sequences;

- Same approach as H1 but in different lithologic settings.

H4Bio (Sites 2, 3, 4, 6): Successional aspects and microbial recolonization of indurated sediments after sill intrusion;

- Same approach as H1 but in sediments having different physical properties and having different times of sill emplacement and thermal history.

H5Bio (Sites 2 vs. 1 and 6 vs. 1): Compare sediment with fresher organic matter unaltered by sill intrusion (Site I) with sediments affected by sill intrusion currently (Sites 2 and 6).

- Release/assimilation experiments (e.g. Wellsbury, 1997).

2) Abiotic properties and processes that govern storage of C in the subseafloor of the GB

H1Abio (Sites 2A, 3A, 4A, and 6A): How does sill emplacement affect the 'physics' of the carbon storage and transport in the system?

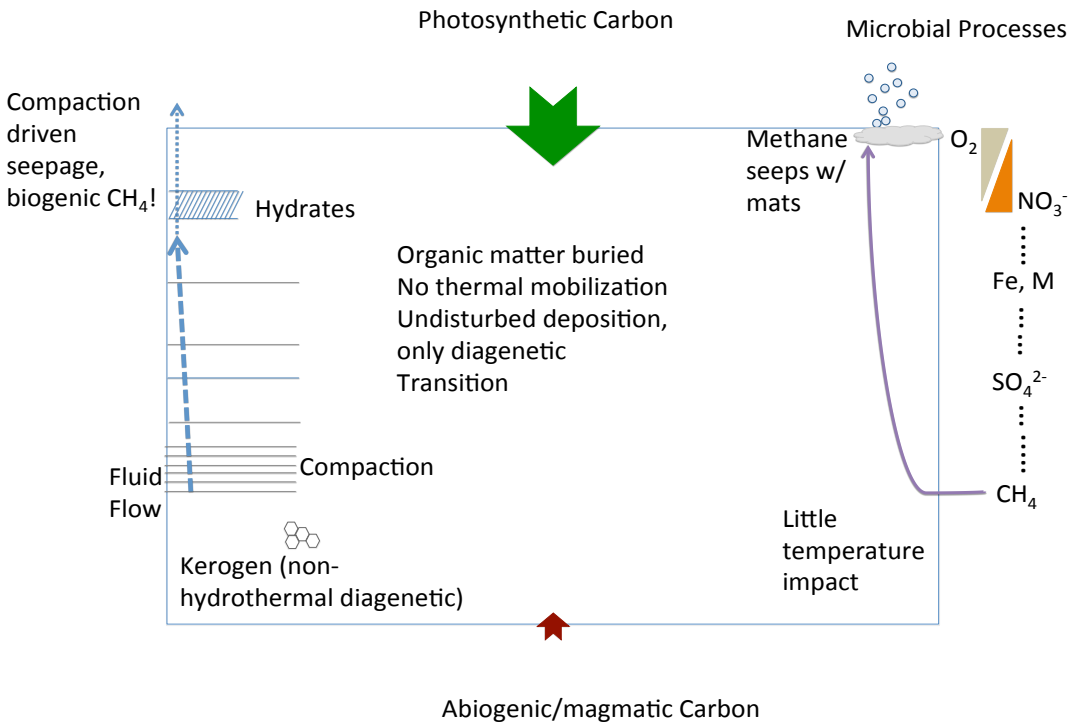
Measure changes in physical properties (porosity, permeability, grain size, recrystallization, clay minerals, metamorphism/alteration, fracturing).

Pore fluids geochemistry and comparison between sites having different levels of hydrothermal activity (tracers of fluid flow and hydrothermal activity).

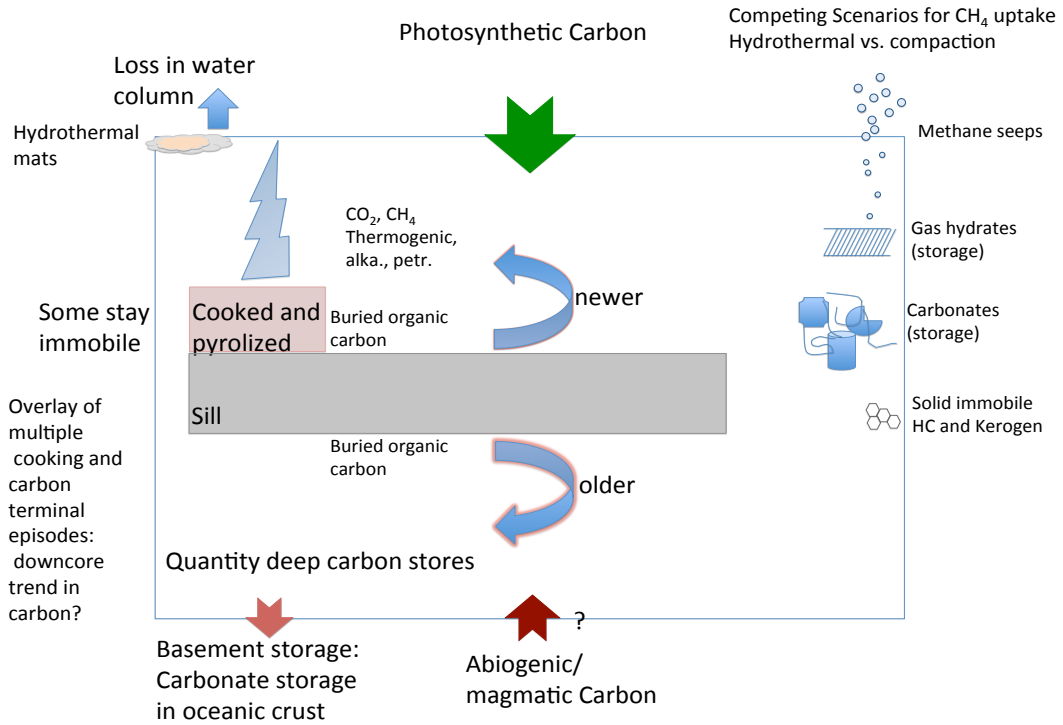
Molecular and isotopic composition of organic and inorganic carbon; analysis in solids, fluids, gases and fluid inclusion (TOC, DOC, TON, POC, in situ pressure; PCS).

H2Abio (Sites 2A, 3A, 4A, and 6A): What are the effects of sill characteristics (age, composition, depth of intrusion, timing of emplacement, sill size, volume, thickness shape, initial T, composition of fluids) on the physical and hydrogeologic properties of the sediment?

Same as H1 but for different sills.



A)



B)

Figure 6 – Conceptual diagrams developed during the meeting. The top diagram (A) shows the expected geo-microbiological interactions in a 'cold' region with no hydrothermal activity. In contrast, bottom diagram (B) shows how the same sediment affected by one of more sill intrusions produces a much more complex system characterized by the re-mobilization, storage and recycling of different types of carbon.

H3Abio (Site 2A vs. 4A): How do the differences in composition (e.g. terrigenous vs. biogenic), texture, physical properties and mode of deformation (brittle vs. ductile) of the sediments affected by sill emplacement control C storage and mobilization?

- Test the physical effects (compaction, porosity change) and the C distribution and speciation in the sediment in relation to sill emplacement (e.g. distance from sill).

H4Abio (Sites 2A, 3A, 4A, and 6A): Do the hummocky layers embedding the sills in the MCS correspond to hydrothermally altered sediments? How does their thickness affect C distribution and speciation?

H5Abio (Site 10A): How does sill intrusion affect destabilization of gas hydrates and its role in the carbon budget in the GB system.

- Correlation of the present distribution of gas hydrates with the modern thermal regime as result of sill emplacement.
- Characterization of gas hydrates to infer the carbon source(s).
- Amount and composition of CH4 (PCS).

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