METHANE HYDRATE
Community Workshop Report

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I. Executive Summary

The study of methane or gas hydrates in nature has been ongoing for over 40 years and the research community has made significant strides in our understanding of the occurrence, distribution and characteristics of marine methane hydrates, yet knowledge related to the role that methane hydrates may play as an energy resource, as a geologic hazard, and as a possible agent in climate change is still incomplete. More work is needed to integrate the research community's methane hydrate related research efforts while developing a more complete understanding of the critical outstanding research issues to be resolved to further understand methane hydrates in nature.

To this end, the United States Department of Energy's (DOE) National Energy Technology Laboratory (NETL) in partnership with the Consortium for Ocean Leadership (COL) initiated a new Methane Hydrate Field Research Program. The primary objective of this project is to conduct planning that will help define and enable future ocean drilling, coring, logging, testing, and analytical activities to assess the geologic occurrence, regional context, and characteristics of methane hydrate deposits along the continental margins of the United States. It is also envisioned that this effort will reach out to the international research community to develop a more global vision of methane hydrate research goals and needs. COL is leading an effort to identify the range of scientific questions and unknowns that need to be addressed within hydrate science and working inclusively within the greater hydrate research community to solicit input and develop a comprehensive "Methane Hydrate Research Science Plan" (Science Plan). COL has assembled a "Methane Hydrate Project Science Team" consisting of representatives from academia, industry, and government who are steering this effort from start to completion. To provide the foundation for the Science Plan, COL hosted the "Methane Hydrate Community Workshop" in Washington, D.C. on June 4-6, 2013 with the purpose of obtaining input from a broad section of the scientific community. This workshop provided an excellent learning opportunity, as well as a venue for the exchange of ideas among a highly interdisciplinary group of scientists. The workshop was attended by over 60 scientists and engineers from academia, industry and government with the express purpose of working together to develop the content that would be used by the Methane Hydrate Science Team to prepare a methane hydrate science plan.

This workshop report is a record of the procedures and notes generated as a result of the workshop planning and execution efforts. This report does not attempt to make any final conclusions regarding the science goals or field program targets. The Methane Hydrate Science Plan to be written by the science team in July will distill the output from the workshop and provide a clear path forward for the future methane hydrate research.

II. Workshop Planning

Workshop preparations began in January 2013 with regular conference calls to identify clear workshop goals and to develop a strategy that would ensure a successful workshop. It was decided early in the planning process that leadership from the methane hydrate community was needed to plan a coherent, meaningful, broadly attended and informative workshop. The Methane Hydrate Science Team consisting of the following members of the methane hydrate research community was assembled:

Tim Collett – Community Liaison
U.S. Geological Survey

Jang-Jun Bahk
Korea Institute of Geoscience and Mineral Resources

Matt Frye
U.S. Bureau of Ocean Energy Management

Dave Goldberg
Lamont-Doherty Earth Observatory

Jarle Husebø
Statoil ASA

Carolyn Koh
Colorado School of Mines

Mitch Malone
Texas A&M University

Craig Shipp
Shell International Exploration and Production Inc.

Marta Torres
Oregon State University

A Methane Hydrate Field Program website (www.oceanleadership.org/methane) was created as a tool to exchange information within the science team as well as the hydrate research community. Documents and reports posted on the program website included both pre - and post - workshop documents and other technical resources, such as the Historical Methane Hydrate Project Review. The historical review report includes a systematic review of the objectives and accomplishments of past Ocean Drilling Program (ODP)-Integrated Ocean Drilling Program (IODP), industry, and nationally sponsored methane hydrate research drilling expeditions, and an analysis of technical concerns that are related to both the universal occurrence of methane hydrates and specific regional concerns that are unique to a given region or hydrate accumulation. It also reviews our present understanding of the geologic controls on the occurrence of methane hydrate in nature and how these factors may impact the energy, geohazard, and climate change aspects of methane hydrate research, the report also summarizes some of the more important drilling related operational understandings and technology developments, such as pressure coring, downhole logging, and borehole instrumentation, which have contributed to our growing understanding of methane hydrates. This report concludes with a systematic review of planning documents for major methane hydrate research projects, national/international assessment reports on methane hydrate research issues and opportunities, and program peer review reports. The review report is a critical starting point for this workshop in that key unknowns about methane hydrates identified were used as “challenges” to be evaluated throughout the workshop.

III. Workshop Plan

The workshop focused on the identification and assessment of specific scientific challenges that must be dealt with to advance our understanding of methane hydrates and how these challenges can be resolved with the support of scientific drilling. In preparation for this workshop, the COL-DOE Methane Hydrate Science Team worked with other members of the methane hydrate science community to focus on an initial list of methane hydrate challenges around which the workshop was organized. This list of challenges was not intended to represent the entire range of methane hydrate research interest or limit the scope of the workshop. The initial list of challenges was considered only a starting point to help organize the workshop. As described in the workshop agenda (see Appendix A), this three-day long event featured a series of plenary presentations to introduce and explore some of the more important methane hydrate research challenges. Most of the workshop, however, was built around three topical breakout sessions developed in tandem with the initial list of methane hydrate research challenges. The breakout sessions strived to further refine our collective understanding of each of the challenges being considered and at the same time explore other challenges and opportunities. One of the key goals of the breakout sessions was the consideration and the potential proposal of specific scientific drilling expeditions that would address a particular methane hydrate science challenge or a range of challenges. The proposed expeditions are listed in section VIII.

A. Methane Hydrate Challenges

The initial challenges prepared by the Methane Hydrate Science Team around which the workshop was organized are:

1. Methane Hydrate Resource Assessment
2. Methane Hydrate Production Analysis
3. Methane Hydrate Related Geohazards

4. Methane Hydrate Role in the Global Carbon Cycle
5. Methane Hydrate Petroleum Systems
6. Methane Hydrate Laboratory and Field Characterization

The description for each challenge follows below:

1. Methane Hydrate Resource Assessment - COL-DOE Science Team Champions: Tim Collett and Matt Frye

One of the primary goals of methane hydrate research and development is the identification and quantification of the amount of technically and economically recoverable natural gas that might be stored within methane hydrate occurrences. A number of new quantitative estimates of in-place methane hydrate volumes and for the first time technical recoverable assessments have been undertaken using petroleum systems concepts developed for conventional oil and natural gas exploration. Additional work is needed to understand and compare the underlying assumptions in the various existing methane hydrate assessment methodologies. Questions and concerns about the geologic data and concepts as applied within the various completed assessments also need rigorous review and further development. Assessment approaches need to evolve with and contribute to our growing understanding of methane hydrates. It is also recognized that specialized assessment methodologies will be required to address the wide ranging characteristics of methane hydrate systems in nature.

2. Methane Hydrate Production Analysis - COL-DOE Science Team Champions: Jarle Husebø and Tim Collett

A primary goal of the U.S. national methane hydrate research program has been the determination of the viability of gas production from methane hydrate reservoirs. Today, a wealth of data gathered in the lab, during field tests, and in numerical simulation studies indicates that gas is technically recoverable from methane hydrates hosted in porous and permeable (sand or sandstone) reservoirs using existing technologies. However, what is not well understood is how long it might take to recover those volumes, from how many wells, with what water production, and what wellbore completion technologies will be required. A program of extended term field tests is needed to address these issues and move toward a better understanding of the economics of natural gas production from methane hydrates reservoirs. To be most effective, this program should feature a series of tests, utilizing different approaches, and applied over a range of geologic settings. Much more information is needed on: (1) the geology of the hydrate-bearing formations, on a large scale - the distribution of hydrates both throughout the world and on small scale – their occurrence and distribution in various host sediments; (2) the reservoir properties/characteristics of methane hydrate reservoirs; (3) the production response of various methane hydrate accumulations; (4) the environmental and economic issues controlling the ultimate resource potential of methane hydrates; and (5) the development of numerical models that represent observed phenomena in field and laboratory experiments.

3. Methane Hydrate Related Geohazards - COL-DOE Science Team Champions: Craig Shipp and Jarle Husebø (in collaboration with Charlie Paull and Brandon Dugan)

Relative to the presence of methane hydrate in nature, the term “geohazard” generally encompasses two areas of concern: “naturally-occurring” geohazards that emerge wholly from geologic processes and “operational” geohazards that represent latent natural hazards that may be triggered by human activities. It is generally believed that the presence of methane hydrate increases the mechanical strength of the sediment within which it resides. However, the dissociation of that methane hydrate releases free gas and excess pore water, which may substantially reduce the geomechanical stability of the affected sediments. The potential linkage between large-scale mass wasting events and the dissociation of methane hydrates has been a topic of interest over the past decade, but there is little agreement on the role methane hydrate plays in slope stability processes. In comparison to most conventional hydrocarbon accumulations, methane hydrates occur at relatively shallow depths and therefore as a potential “operational” geohazard could contribute to seafloor displacements over the long-term development of a methane hydrate accumulation. Methane hydrates in some cases are also considered to represent a hazard to shallow drilling and well completions. Despite the concerns associated methane hydrate related geohazards, addressing these issues with confident scientific and technical approaches remains a challenge because little data or research exist to support or refute existing theories for understanding the role of methane hydrates as a geohazard.

4. Methane Hydrate Role in the Global Carbon Cycle - COL-DOE Science Team Champions: Mitch Malone and Marta Torres

It has been shown that methane is an important component of the Earth’s carbon cycle on geologic timescales. Whether methane once stored as methane hydrate has contributed to past climate change or will play a role in the future global climate remains unclear. A given volume of methane causes 15 to 20 times more greenhouse gas warming than carbon dioxide, so the release of large quantities of methane to the atmosphere could exacerbate atmospheric warming and cause more methane hydrates to destabilize. Some research suggests that this has happened in the past. Extreme warming during the Paleocene-Eocene Thermal Maximum about 55 million years ago may have been related to a large-scale release of global methane hydrates. Some scientists have also advanced the Clathrate Gun Hypothesis to explain observations that may be consistent with repeated, catastrophic dissociation of methane hydrates and triggering of submarine landslides during the Late Quaternary (400,000 to 10,000 years ago). Considerable interest exists to understand the geologic processes associated with methane hydrate formation and decomposition, as well as the possible role of methane hydrate in global climate change.

5. Methane Hydrate Petroleum Systems - COL-DOE Science Team Champions: Matt Frye, Jang-Jun Bahk, and Marta Torres

In recent years significant progress has been made in addressing key issues on the formation, occurrence, and stability of methane hydrate in nature. The concept of a methane hydrate petroleum system, similar to the concept that guides conventional oil and gas exploration, has been developed to systematically assess the geologic controls on the occurrence of methane hydrate in nature. The methane hydrate petroleum system concept has been used to guide the site selection process for numerous recent methane hydrate scientific drilling programs. At the same time the petroleum system concept has been used to assess the impact of geologic variables, such as "reservoir conditions" or the "source" of the gas with the hydrates on the occurrence and physical nature of methane hydrate at various scales. Although there have been significant advancements in our understanding the geologic controls on the occurrence of methane hydrate our understanding how the various components of a methane hydrate system interact to form the immense range of observed hydrate types and morphologies is incomplete. It is also acknowledged that much of the methane hydrate research efforts continue to focus on describing hydrates as static deposits rather than understanding them as part of a dynamic system. There is an obvious growing need for the development of integrated time dependent models to understand the geologic controls on the formation, occurrence, and stability of methane hydrates in nature.

6. Methane Hydrate Laboratory and Field Characterization - COL-DOE Science Team Champions: Dave Goldberg, Jang-Jun Bahk, and Carolyn Koh (in collaboration with Michael Riedel)

The development of geophysical, well log, and core analysis diagnostic instrumentation and analytical methods contribute directly to the explorationist ability to locate and define hydrate-bearing reservoirs. The analysis of geophysical, well log and sediment core data have yielded critical information on the location, extent, sedimentary relationships, and the physical characteristics of methane hydrate deposits and their energy resource potential. The development of methane hydrate exploration methods and refined resource estimates is a growing focus of integrated laboratory and field geophysical, logging, and coring studies in both onshore and offshore environments. Integrated methane hydrate laboratory, field and modeling studies are needed to further characterize the geologic controls on the occurrence of methane hydrate in nature and to measure their effects on the physical, mechanical, and reservoir properties of methane-hydrate-bearing sediments. As we look to the future, methane hydrate energy assessments will require a more detailed understanding of the natural methane hydrate reservoir and its relationship to the surrounding geologic formations. This work will also provide information on hydrate production technology, sea floor stability, and other environmental issues.

B. Plenary Talks

Plenary talks were given according to 6 challenge questions as reviewed above.

- Ray Boswell - Methane Hydrate Resource Assessment
- Jarle Husebø - Methane Hydrate Production Analysis
- Craig Shipp - Methane Hydrate Related Geohazards
- Marta Torres - Methane Hydrate Role in the Global Carbon Cycle
- Matt Frye - Methane Hydrate Petroleum Systems
- Michael Riedel - Methane Hydrate Laboratory and Field Characterization
- Carolyn Koh - Methane Hydrate Laboratory and Field Characterization Research and Development (R&D)

C. Workshop Materials

Copies of the presentations and other workshop materials are available at www.oceanleadership.org/methane

D. Breakout Group Process

A total of three cross-theme breakout groups were created for the workshop. Participants in each breakout group represented diverse science and engineering disciplines, and research interests within the methane hydrate community:

Breakout group **1A** focused on challenges 1,4,5,6
Breakout group **1B** focused on challenges 2,6
Breakout group **1C** focused on challenges 3,6

The breakout groups were the workshop's primary vehicle for soliciting ideas for the methane hydrate science plan. Each breakout group was led by a "Science Team Champion" to ensure that participants took into account the following framing questions for their particular science challenge:

1. Framing Questions for each breakout group

    - What data needs to be collected to address the particular methane hydrate science challenges, both during drilling and the pre-post phases of a scientific drilling project?

    - Are there specific locations and or research areas that could be drilled to advance our collective understanding of a particular methane hydrate research challenge?

    - What laboratory (including analysis of natural and synthetic core materials) and/or modeling studies are needed to advance our collective understanding of each methane hydrate research challenge?

- What R&D requirements are needed to advance new field measurements and/or instrumentation to achieve the methane hydrate research challenges as described?

- What are the particular needs for the integration of data and models to further our understanding of the methane hydrate challenges as described in the workshop planning documents?

Additionally, each breakout session had a designated participant(s) take digital notes to document discussions during the breakouts.

E. Plenary Review and Discussions

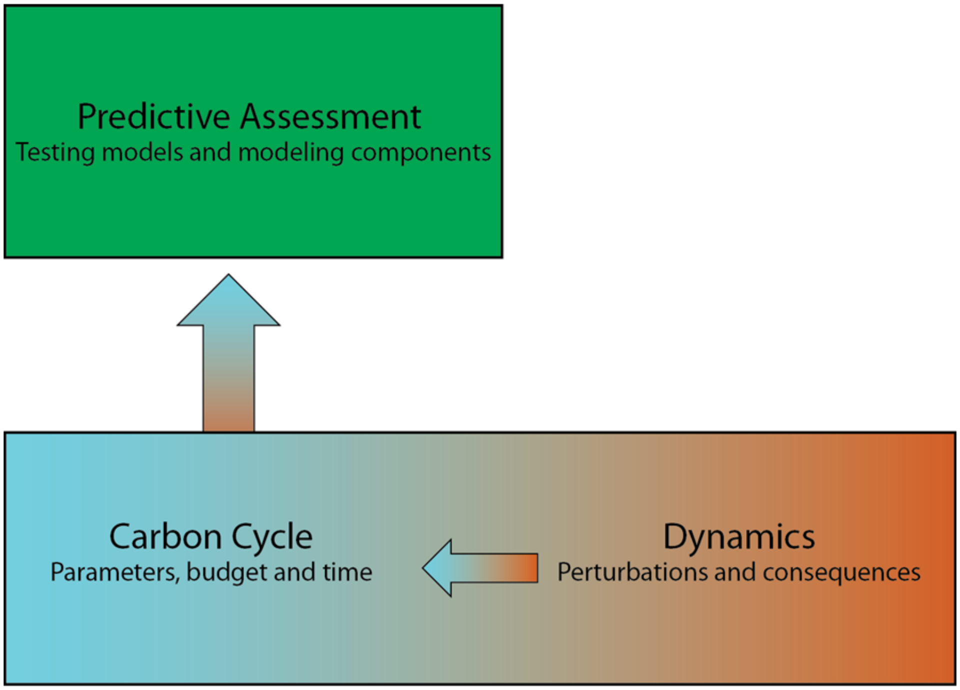
On the final day of the workshop, information collected through the two days of challenge-based breakout sessions were presented and expanded upon in a series of three final plenary discussions: (1) Methane Hydrate Science Challenges, (2) Proposed Scientific Drilling Expeditions, and (3) Methane Hydrate Laboratory and Field Characterization Research and Development. The information reviewed in the "Methane Hydrate Science Challenges" plenary discussion have been included in Section IV, V and VI below that deal with the results challenge-focused breakout discussions. The information included in the "Methane Hydrate Laboratory and Field Characterization Research" and "Development and Proposed Scientific Drilling Expedition" plenary discussion on the last day of the workshop have been included in Sections VII and VIII of this report, respectively.

IV. Breakout Group 1A Discussions - Petroleum Systems, Resource Assessment, Global Carbon Cycle

Breakout session 1A consisted of a series of robust challenges that included Methane Hydrate (MH) Petroleum Systems, MH Resource Assessment and MH role in the Global Carbon Cycle. The challenges were further clarified into the following three challenges:

1. Predicative assessment of MH and production (resource assessment)
2. Budgets and controls of carbon over time (carbon cycle) - Local and global
3. Dynamics - Temporal evolution of MH systems Response to forcing and consequences

Extensive discussions began with the collection of initial comments that helped lead the organization of the thoughts and ideas into possible site and locations for future methane hydrate expeditions. A graphic depicting the relationships between the challenges that were developed during the breakout session is shown below.



To move the workshop breakout group 1A toward suggestions for potential drill sites, a list of fundamental unanswered questions were developed, followed by data requirements that would help provide answers to the questions.

A. Fundamental unanswered questions

1. What is the origin, character and chemical composition of the organic material (OM) reaching the seafloor? How fast was it deposited? How is it available to the microbes? How do these factors translate to methane hydrate accumulations?
2. What critical parameters (nature and amount of OM, sedimentation rate, specific microbial communities, etc.) affect OM conversion to methane?
3. What is the relative contribution of biogenic versus thermogenic sources to gas hydrate formation? How does it change over time? How does it change in space? What percentage of biogenic gas would make an economic source? What is our predictive capability for gas hydrate assessment in biogenic vs. thermogenic systems?
4. Monitoring a hydrate system that is well-studied already to address: What is the magnitude of fluxes in and out of the system? How much is generated and consumed by microbes? How much arrives at sulfate-methane transition zone (SMTZ) from deeper sources? How much escapes the system through seafloor vents? What is the contribution of methane hydrate to the shallow methane carbon budget? What are the kinetics controlling the various processes?
5. How does hydrate-grain interaction, pore space size, and lithologic host determine methane hydrate accumulations? How does MH form in small pores, how important are fractures, and how does MH act to seal available permeability paths?

6. What roles do lithology, structure, tectonics, hydrogeology, play on methane migration from source term to current locations vs. accumulation below GHSZ? What are the main transport mechanisms and relative contributions of diffusive and advective methane transport as a dissolved phase vs. gas phase?

7. How gases move through the system (allochthonous and autochthonous sources)? How much of it is trapped in the system? To what extent does the water vs. gas ratio affect gas migration, methane hydrate formation and venting?

B. Potential high level objectives

1. Predictive modeling for formation and accumulation of methane hydrate
2. Vertical and horizontal methane flux: diffusive vs. advective vs. free gas contributions
3. Carbon source assessment: biogenic vs. thermogenic; origin, transport, accumulation and MH formation
4. Properties of evolution of MH in coarse vs. fine systems; in organic rich vs. organic poor
5. Temporal scales of MH system: kinetics, geology, proximity to MH stability field
6. Physiological and metabolic capabilities of microbes that are directly and indirectly involved in the production and consumption of methane

C. Data Needs – Pre-Drilling

1. Site survey
    a) Frequency selection is important
        200Hz – best for methane hydrates
        30Hz – excellent for tectonics
    b) Data of opportunity at target sites
    c) 3D seismic and/or P-cable with Ocean Bottom Seismometer (OBS)
    d) Backscatter and bathymetry
    e) Controlled Source Electromagnetic (CSEM)
    f) Shallow piston coring
    g) Heat flow probes
    h) Satellite data
    i) Water column imaging

D. Data Needs – During Drilling/Coring/Logging Operations

Specific data needs for specific issues are for key parameters and issues:

1. Microbial vs. Thermogenic
    a) Isotopes for hydrocarbons and CO_2
    b) Cavity Ring Down Spectroscopy (CRDS)
2. Transport: diffusive, advective, gas

    a) High resolution core imaging, CAT scan, X-rays (pressure and conventional cores)
    b) High resolution geochemical sampling
    c) Downhole pressure, temperature, resistivity
    d) Pressure cores for gas saturation and composition
    e) Downhole in situ fluid sampling – Modular Formation Dynamics Tester (MDT)
    f) Physical properties (permeability, resistivity, velocity as a function of methane hydrate/gas and water saturation)

3. Gas venting
    a) Installation of borehole monitoring systems
    b) Video while drilling
    c) Seafloor flux meters
4. Role of water
    a) Isotopic composition of water
    b) Nuclear Magnetic Resonance (NMR) and resistivity logs
    c) NMR logging of pressure cores
    d) Fluid chemistry
5. Lithologic host
    a) Track lithologies in hydrate whole round samples (mineralogy, grain size, physical properties)
    b) Infrared guided sampling
    c) Triaxial measurements in pressure cores
    d) Geochemical logging tools
6. Structural controls (migration and accumulation)
    a) High resolution core imaging, CAT scan, X-rays (pressure and conventional cores)
    b) Borehole imaging
    c) Structural analyses of cores
    d) Core-log seismic integration
    e) Synthetic seismics
    f) Reservoir characterization
    g) Acoustic and electrical measurements – anisotropic analysis
    h) Upscaling from cores/logs/field data
7. Type and amount of organic matter
    a) Pyrolosis
    b) Isotopes, molecular biomarkers (e.g., intact polar lipids, PMEs)
    c) Dissolved organic carbon- amount, type, compound specific
    d) All phases of carbon in the system
    e) Heavy element isotopes
    f) CHNS and nitrogen and sulfur isotope

8. Role of microbes
    a) Laboratory vs. in-situ
    b) Geochemical modeling
    c) Tie geochemical and microbiological rates
    d) Sampling from targeted zones
    e) Laboratory studies (e.g., bioreactors for methane production and oxidation)
    f) Continuous sampling plus targeted zones
        - Temperature increases
        - Phase changes
        - Grain size and interfaces
    g) Gene probes – Fluorescence In Situ Hybridization (FISH), active probes
9. Sedimentation rate
    a) Biostratigraphy
    b) Paleomagnetics
    c) Radiometric dating (^{14}C, U-Th)
10. Tectonic controls

E. Data Needs – Post-Drilling

1. 4D seismic – time lapse experiments
2. Borehole and seafloor instrumentation for continuous monitoring
3. Water column surveys

F. Where to drill

The suggested strategy is to frame the challenge and then identify the location where the issue can best be addressed.

1. Coarse vs. fine grained systems
2. Active vs. passive margin
3. Advective vs. diffusive systems; dissolved vs. gas transport
4. High vs. low organic matter systems
5. Over (and not over) active petroleum systems
6. Upper limit of methane hydrate stability
7. Vent system
8. Producing site

G. Data and Model Integration

There is a critical need to better integrate field and modeling efforts. All simulations should include some data and all data collection should be informed by models. To this aim, we recognize the challenges associated with scaling (at all levels) and integration of large scale heterogeneity (e.g., salt bodies). Possible approaches include drilling transects and arrays of cores/data collection.

V. Breakout Group 1B Discussions - Production

Breakout group 1B was focused on the production of methane hydrate and chose two primary issues as the scope of work, (1) what are the major challenges within the different topics? and (2), what can scientific drilling add to this issue? To answer these primary questions, the following 5 subtopics were discussed.

- Methane Hydrate reservoir setting
- Key reservoir parameters
- Challenges – Production rates
- Challenges – Production method
- Challenges – Well and completion design

A. Methane Hydrate reservoir setting

1. Sand Reservoir is ideal
2. Ideally a Class 3 reservoir (hydrate between impermeable layers)
    a) Alternatively with water below for added heat to the system
    b) Avoid gas contact
        Perhaps thinly interbedded reservoir for heat
3. Deeper water, deeper relative to seafloor:
    a) Formation will be warmer
    b) Formation will have higher pressure
        Stronger depressurization (driving force)
        Able to produce longer without added complexities
    c) Better seal
    d) More stable reservoir (cemented, compacted)
    e) Possible to do horizontal drilling
4. Close to existing infrastructure is likely prerequisite for long-term test
    a) GC781 Mad Dog has infrastructure in-place
5. A site with broad scientific value (e.g. long term occupancy and a pre-drilling/post-drilling science program)
    a) A site that has been studied extensively already such as one of the JIP sites (WR313) or other sites that have a similar knowledge basis

B. Key reservoir parameters

1. Reservoir properties/characteristics
2. Pure methane
3. Near GHSZ
4. High Permeability
    a) Identify Hydrate saturation effect on Relative Permeability
        Scientific drilling, NMR-logging, Logging While Drilling (LWD)

C. Challenges – Production rates

1. Relative permeability and how it is controlled by hydrate saturation
    a) What can we do to study this effect?
        Laboratory study and modeling
2. Heat transfer likely to impact in the long-term
    a) Fundamental modeling
    b) Laboratory work
        Imaging (CT, MRI) of pore systems/ hydrate distribution
        Developing new techniques for characterizing hydrate reservoirs, and potential need for new lab facility/acquisition

D. Challenges – Production method

1. Depressurization
    a) Laboratory and multi scale modeling to investigate key parameters impacting production
    b) Clay content (effects on relative permeability, Reservoir water saturation)
    c) Grain size distribution
    d) Geomechanical studies in parallel with production studies
2. What about operational issues? Sand production.
    a) Target rates to ensure we see more than near-well effects, balance rate vs. pressure
    b) Plan to manage production for a year? Short-term test has limited value.
    c) Evolving production strategy: inhibitors, heating, other stimulation, etc.
    d) Potential to use N_2 for flow assurance and stimulation?

E. Challenges – Well and completion design

1. We should propose a longer time for scientific drilling to be able to test and investigate drilling and completion solutions
    a) Sand control method
    b) Flow assurance solution

        c) Down-hole pump solution (electric submersible pump, jet-pump)
        d) Well architecture (horizontal,
    2. Identify minimum depth requirements where you are able to drill more complex wells:
        a) Horizontal well

VI. Breakout Group 1C Discussions - Geohazards

Breakout Group 1C charge was to focus on methane hydrate geohazards and it became clear that this topic includes six related subtopics listed below. Considerable effort was spent to explore each subtopic and a summary for each follows:

- Public Opinion
- Occurrence
- Characterization
- Stability
- Production
- Environmental

A. Public Opinion

1. Overall, the methane hydrate community must address the public perception of geohazards related to methane hydrate, particular catastrophic gas release and widespread mass failure if we are to expect the public acceptance of MH as a safe energy resource.

2. To address the issue of public opinion, the community must define which geohazards are not a risk and why they are not. Be direct about which ones are a potential a risk such as production-related subsidence, and how these are being studied. The community must also be clear about which issues are not "catastrophic" issues and why?

B. Occurrence

1. Need to look at geohazards related to hydrate habit/morphology in different lithologies. They will respond differently and must be studied differently.

2. We need to know more about how geohazards are expressed in permafrost-hydrate-water systems. Most existing work is limited and has been focused on water-hydrate systems. What impact does permafrost have on seal capacity, pressure buildup and on strength?

3. Geohazards are seen at various scales with differing amounts of heterogeneity:

    a) At the borehole scale, we see different fracture orientations - why and how does this relate to geohazard issues?

    b) At the continental margin scale, we see different shelf-edge failure morphologies in geologically similar margins.

    c) Why or how do methane hydrate and/or perturbation influence these morphologies? Or is the control geological (e.g., plumbing, heat flow)?

C. Characterization

1. Geohazards understanding can be learned by piggy backing on other studies (e.g., production tests, carbon cycling projects) as long as we get the appropriate monitoring and measurements in space and time. Specific measurements to be considered are:
    a) Pressure
    b) Temperature
    c) Strain
    d) Resistivity
    e) 4D Seismic data
    f) Water column measurements – several
    g) Sonar sensing
2. Much can be done with existing data and data integration. An assessment should be conducted to determine what data sets are near-complete for geohazard studies, work with them, and identify what we need to complete them.
3. Operational geohazards - What do we know about operational and natural occurring geohazards in the last 100 years? During the Holocene?
    a) Storegga, Grand Banks, Shell/Fugro anecdotal experience – failures over drape is debris flow-like, thin, and are confined, not rotational
    b) Big slide scars are of multiple ages, evolving in a variety of ways
    c) Earthquakes triggering mass failures and tsunami in last 100 years
    d) Gulf of Mexico Campeche expulsion feature could be related to dissociation
    e) Natural cracks/giant pockmarks (like offshore Virginia or upslope of Storegga) as insipient failure zones
    f) Zones with creep, incipient failures, can see in morphology it may fail but failure not yet happened (e.g., permafrost, Hikurangi)
    g) There are complications based on horizontal and upward flux and thickness of hydrate zone between biogenic and thermogenic hydrates.
    h) Different hydrate types have different stability zones
    i) More complicated that we have considered in the past.
4. Sands are the most likely first candidate for additional exploration and production efforts given their location at the top of the occurrence pyramid, and therefore studies should begin there. Need to include multi-phase (before, during, post) monitoring of key measurements with observatories, geophysics (shear wave) and maybe electromagnetic surveys.
5. Fractured clays will respond to production from sands below. We need to understand how flow and strength of clays will change as this could result in failure (sliding, slip, more fractures) or enhanced permeability and potentially release of gas to the water column.
6. Naturally occurring geohazards are a more difficult of an issue to address. It is unclear how to run a reasonable experiment in scale and time. Monitoring of methane hydrates in accretionary prisms and earthquake-prone may provide an opportunity to monitor a natural perturbation.

7. Upscaling of laboratory to field to production or to natural perturbation is difficult and unconstrained. There is no clear way forward here without focused preparation.

8. Physical impacts of a production test must be carefully measured to understand the conditions of the production area before, during, and after the test.

9. Fundamental understanding the actual consequence of methane hydrate dissociation is needed. The key parameters in understanding the short-term response to hydrate dissociation are being able to measure strength and permeability changes over time.

10. Consider using the relief well (monitoring well) strategy to investigate the impact of production that has been used at *Mallik.*

D. Stability

1. There are no documented examples of hydrate dissociation induced instability and thus seafloor instability caused by methane hydrate dissociation remains an outstanding question. Can it be said conclusively that since we have no known examples, this is not an issue? Some thoughts on this issue are:
    a) Arctic warming could be moving out of a period of stability into one of instability.
    b) Challenge is to get robust information to see where methane hydrate may cause instability.
    c) Understanding of basic mechanics and processes of failure still needed – despite efforts, not much progress has been made.
    d) No good examples exist of methane hydrate related mass failure, however, that doesn't mean there are not any.
2. How do bulk sediment properties (flow and strength) behave in three phase systems (gas/water/hydrate)? Especially what do we know about failure in gaseous systems? In unloading systems?
    a) Failure relates to the weak link in a system that is at the scale of the dominant heterogeneity
        - How can this be addressed that at the laboratory scale?
        - What is the key heterogeneity (e.g., grain size, lithology)? Lab testing provides ability to control the heterogeneity, but there is always a need for the lab sample to be much larger than the scale of heterogeneity.
    b) More information is needed about bulk in-situ properties
        - Need more lab work on fractured clay strength to expand on history of sand work
        - Triaxial tests on cores via systems such as the Pressure Core and Analysis and Transfer System (PCATS) to observe degradation from in situ conditions to conditions after depressurization
        - In situ tests to needed to measure material strength

E. Production

1. Monitoring before, during, and after production tests can inform what the geohazard risk is associated with long-term production.
    - a) AUV site survey with the proper slope geotechnical testing.
    - b) Properly located samples.
    - c) Modeling of subsidence and response to production
    - d) Gravity (non-seismic) monitoring of CO2 injection for subsidence, could be done for hydrates
    - e) Does it make sense to study and test a site that is near local failure conditions to demonstrate limit before which failure occurs?
2. Impact of seafloor subsidence associated with methane hydrate production
    - a) Subsidence is an issue that is known and must be studied yet a method for how to assess this as a hazard is still needed. The method must establish a baseline on variety of parameters.
    - b) It is postulated that withdrawal at a shallow zone (e.g., 150 m) has a bigger risk than deep (1000 m). Can this be proven? Perhaps through micro-seismicity that can occur during subsidence and its impacts.
    - c) Time delay from initial production and reservoir compaction followed by seal consolidation
    - d) Will subsidence be a ductile process (large smooth depression) or brittle (drop down fault blocks).
    - e) Passive monitoring of seismic (OBSs), fluid flow, pressure sensors before, during, and after production/perturbation experiment.
    - f) 4D seismic surveys, can be done non-standard (leave out a cable and a source) and at the kHz range.
    - g) Small cubes can be done this way in standard surveys at kHz range.
3. Need to assess the portion of gaseous fluid that will escape to the seafloor during shallow subsurface methane -hydrate production
    - a) Collect water and gas samples during production tests to look at how gas concentrations and/or isotopic composition changes.
    - b) How much gas is in the hydrate stability zone? Do we sample in the correct way to understand? One method could be to sample a volume around the well.
    - c) To assess hazard of gas in GHSZ, normal field assessment with seismic (look for conduits and gas anomalies)
    - d) How is production in the permafrost zone affected?
    - e) How do you track fluid flow in the environment within and above the reservoir? Is CSEM a possible tool?

F. Environmental

1. Enhanced methane flux altering benthic ecology, geomorphology, and chemistry
    - a) Opportunities to return to previous holes and see if communities have occupied previous sites that had flow
    - b) Industry does go back to previous wells and monitor and doesn't appear (anecdotally) that communities have not grown but other wellheads have been populated by chemosynthetic communities.
    - c) There are numerous ROV video surveys over wells to serve as a baseline
    - d) By producing methane hydrates:
        - Are we going to create new communities or shut off existing communities? This will be important for permitting?
        - Will there be an alteration of flow paths related to subsidence and related processes?
        - Will there be energy flux changes for communities?
        - Will there be geomorphic impacts (e.g., sediment removal)?
    - e) The environmental baseline is important because systems could be highly dynamic on their own, so how would the producer/regulator know if change is natural or induced
    - f) Having a control site far away from drilling site could be helpful in establishing a baseline
2. Tools to quantify enhanced flux
    - a) Potential for EM monitoring, but the lack of lab measurements could hinder this approach (e.g., resistivity during dissociation)
    - b) 4D monitoring could benefit with seabed cable left in place, coordinated with seismic
    - c) Seismic – differentiate between reflection, refraction, and passive; attenuation can be valuable for gas assessment
    - d) Repeat surveys with sniffers, (methane, salinity, oxygen, chemical profiles vertical and aerially) to look at hydrate forming or gas/fluids passing through GHSZ into water column
    - e) Support science projects to continually monitor currently instrumented sites (e.g., Neptune Canada monitoring around hydrate mounds)
    - f) Sea-surface monitoring (radar sat monitoring) to see what reaches atmosphere or how this changes and evolves

VII. Methane Hydrate laboratory and field characterization research and development

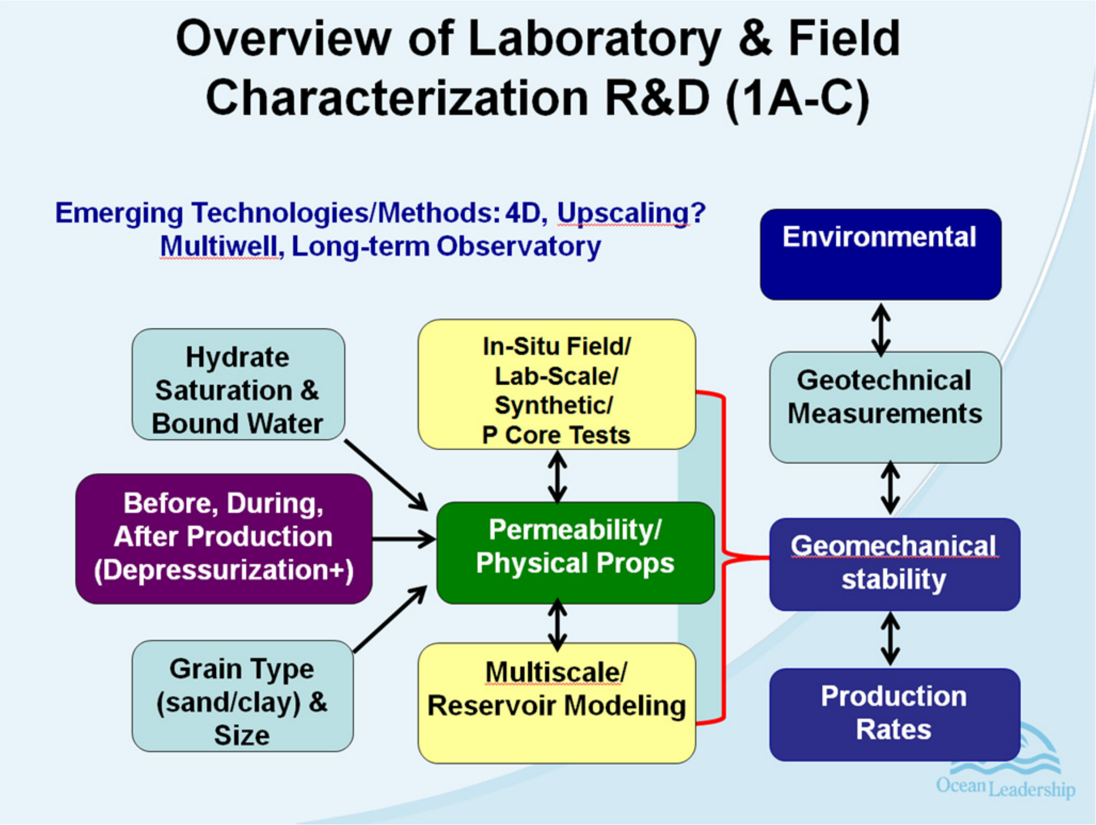
In order to meet the science objectives associated with methane hydrate exploration, tools and equipment both for laboratory and downhole measurements must be identified. Each breakout group was asked to address the following questions that were intended to develop a working list of what research and development tool/method is missing or needs to be developed.

- What laboratory (including analysis of natural and synthetic core materials) and/or modeling studies are needed to advance our collective understanding of each methane hydrate research challenge?

- What R&D requirements are needed to advance new field measurements and/or instrumentation to achieve the methane hydrate research challenges as described?

- What are the particular needs for the integration of data and models to further our understanding of the methane hydrate challenges as described in the workshop planning documents?

Through the discussions in each breakout the group, the several flow charts were created to illustrate the data needs and how the data could be acquired.



Overview of Laboratory & Field Characterization R&D (1A-C)

Emerging Technologies/Methods: 4D, Upscaling?
Multiwell, Long-term Observatory

Figure created during the workshop displaying the vital relationships between data needed on the left, how they might be measured and areas on the right that require/utilize the data

From the three breakout groups, the following list captures the lab and field characterization need along with a brief description.

- ***Monitor water column, seafloor, boreholes and 4D seismic surveys to better understand or quantify***
    - “Timing issues” related to dynamic aspects of MH system
    - Input/output fluxes of methane
    - *Improve “upscaling” of core measurements to log-seismic integration*

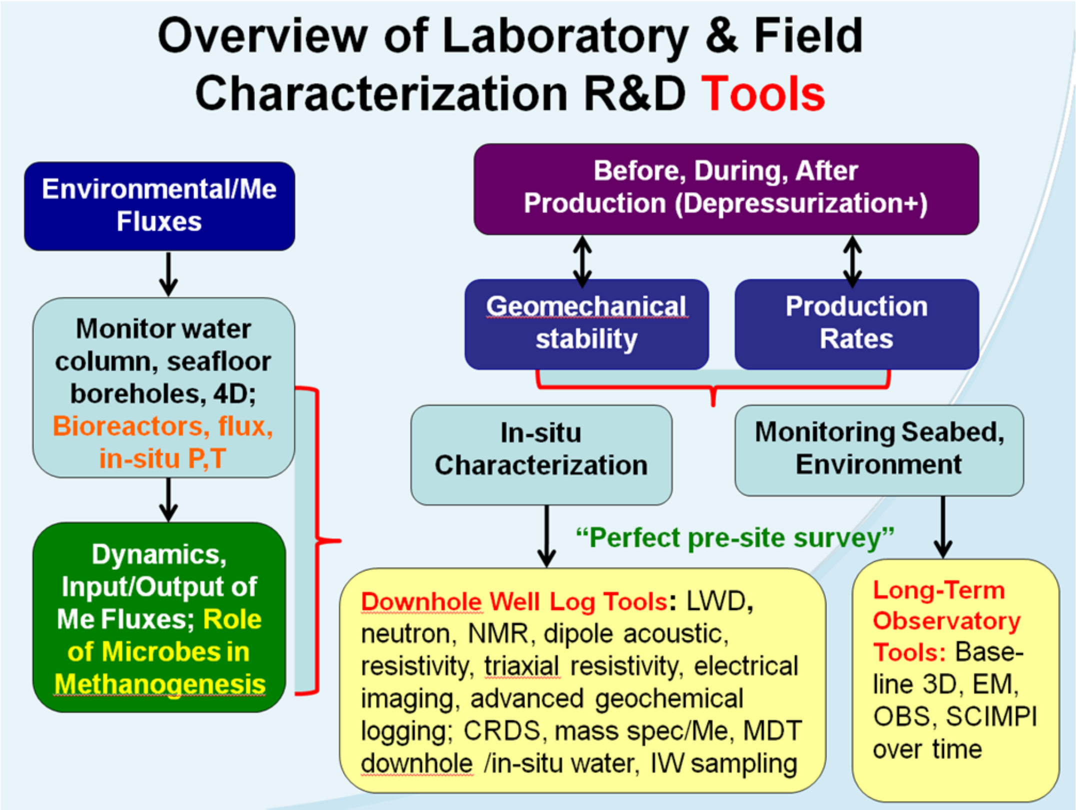
- ***Improve understanding of microbes role on methanogenesis***
    - Bioreactors with different substratum, flux, in-situ PT conditions

- ***Characterize in-situ geochemistry, lithology, and physical properties***
    - Downhole tools and sampling: *e.g*. downhole tools for mass spec/CH4, geochemical sensors, MDT for downhole fluid sampling and in-situ water sampling of shallow part
    - In situ interstitial water (IW) sampling and vertical flux meter for pressure cores

- ***Is there a link between slope instability and man-made dissociation during production?***
    - *Measure geomechanical props of synthetic hydrate bearing sediments (HBS) & in-situ natural HBS during depressurization*

- ***Which rock-physics model represents natural HBS?***
    - Cementing grains, pore filling
    - Use controlled range of synthetic HBS (S_H, grain-hydrate contacts; CT) to calibrate field data
    - Measure Vs. EM (lab) during dissociation, Direct geotechnical (CPS, well testing)

- ***Test geohazard hypotheses; potential environ seabed changes***
    - Measure P, T, conductivity, strain, fluids geochemistry, water column, sonar & seismicity with spatial and temporal coverage (4D)
    - Extensive pre-/post-drilling remote operating vehicle (ROV)/AUV surveying
    - Routine core index property measurements
    - Exploit vast existing and near-complete data sets
- ***Assess stability and environmental effects for shallow (150 mbsf) vs. deep (1000 mbsf) targets?***
    - Reservoir and geomechanical modeling needed
    - Non-seismic monitoring for subsidence around well before, during, and after perturbation
- ***Monitoring seabed environmental & biological systems***
    - CSEM, seabed cable, water column, sea-surface (radar satellite), camera survey around well at control site far away from drilling site



Overview of Laboratory & Field Characterization R&D Tools

Environmental/Me Fluxes

Monitor water column, seafloor boreholes, 4D; Bioreactors, flux, in-situ P,T

Dynamics, Input/Output of Me Fluxes; Role of Microbes in Methanogenesis

Before, During, After Production (Depressurization+)

Geomechanical stability

Production Rates

In-situ Characterization

Monitoring Seabed, Environment

"Perfect pre-site survey"

Downhole Well Log Tools: LWD, neutron, NMR, dipole acoustic, resistivity, triaxial resistivity, electrical imaging, advanced geochemical logging; CRDS, mass spec/Me, MDT downhole /in-situ water, IW sampling

Long-Term Observatory Tools: Base-line 3D, EM, OBS, SCIMPI over time

Figure illustrating the desired outputs and requisite tools to create the perfect pre-drilling site survey.

A. Perfect Pre-drilling Site Survey

The concept of a perfect pre-drilling site survey recognizes that not all data will be available prior to site selected and subsequent spudding of a well. However, some or most of the data may be available and it is critical that operation planners consider existing data and critical missing data. The outline below includes datasets the workshop attendees consider part of the ideal dataset.

1. Remote
   a) Conventional 3D survey of region to locate target area
   b) Hi-res 3D to focus in on prospect and sites
   c) Multi-component seismic data, OBSs (broadband)
   d) Sub-bottom profiling (chirp)
   e) Multi-beam bathymetry and backscatter collected at 25-cm grid interval
   f) Water column anomalies (echo sounder, multi-frequency systems)
   g) EM, microgravity
   h) 100% seafloor video coverage
   i) Sea-surface observations (slicks, gas at surface)
2. Near-seafloor Sampling and Investigation

a) Fluid flux meters
b) Gas flux coming out of the system – sniffers, diffusion detectors
c) Infaunal sampling with spatial resolution – box cores
d) SMTZ– piston cores
e) Tiltmeters and bottom pressure sensors
f) Heat flow
g) Geotech coring, cone penetrometers (CPT), discrete temperature measurements

VIII. Proposed Scientific Drilling Expeditions

Through the work of the breakout groups, example expeditions were discussed and outlined in a standardized format. These by no means represent the full extent of the possible expeditions. The following entries below represent specific challenges that may be addressed and how scientific drilling expeditions could address the outstanding methane hydrate related challenges. The specific operational or scientific details are not included in these proposed expeditions and thus these are intended only to show what may be possible.

A. Response of MH system to perturbations operating at the upper edge of gas hydrate stability

1. General geologic setting– Updip limit of hydrate stability zone
2. Specific Locations – Beaufort Shelf; Cascadia Margin; Cape Fear; Hikurangi Margin; Northern Europe (Svalbard); Cape Hatteras
3. Location geologic conditions – well defined upper limit of methane hydrate stability, evidence of gas hydrate occurrence, venting, evidence of temperature changes in water column (present and past), evidence of altered MH stability field
4. Scientific objectives – reconstruct paleo changes in thinning; understand response of system to change/forcing – present and past; consequences of change (gas flux rates, seafloor stability, geomechanics); interpret present thermodynamic state; ground truth existing acoustic data; rate of dissociation; response of microbes; shallow sediment carbon cycle
5. Drilling strategy - transect, or multiple transects (including reference site)
6. Required technology
    a) Downhole tools - formation temperature/pressure measurement and thermal conductivity
    b) Logging - LWD
    c) Coring – high res fluid chemistry, physical props, sedimentology (paleo proxy), biostratigraphy, paleomagnetism
    d) Pressure coring
    e) Instrumentation – monitoring
7. Has the location been previously drilled, what did we learn? Not previously drilled
8. Other: consider what industry is doing in this challenge area; reconstruct sea level; tectonics (relative sea-level); other external influences/consequences; gas composition; synergies with geohazard challenges

B. High methane hydrate concentrations in sand reservoirs (related to resource assessment and global carbon cycle)

1. Geologic setting– deep water fans; turbidites
2. Specific Locations – GOM (WR 313, GC 955); New Jersey margin; Mackenzie delta; SW Taiwan; Hikurangi Margin; Ulleung Basin, Nankai Trough
3. Scientific objectives – MH saturation; understand mechanism of formation of high concentration MH in deep marine sand deposits; inform predictive models and assessments
4. Site survey requirements – existing industry seismic data; nearby well control is desirable; facies and depositional models
5. Drilling strategy – twin existing wells if available; transect to test migration mechanism; (exploration risk vs. development options)
6. Required technology
    a) Logging – LWD and/or wireline
    b) Coring – standard IODP suite
    c) Pressure coring - essential
    d) Instrumentation – standard IODP suite
7. Has the location been previously drilled, what did we learn? – Some sites under this description have been drilled; depth, thickness, and likely areal extent of reservoir (petrophysical measurements, acoustic properties) have been established
8. Pre and post laboratory and modeling requirements – extensive pressure core analysis

C. Global carbon cycle in high flux settings

1. Geologic setting– vent/chimney locations to evaluate mechanism of formation and evolution of high flux systems
2. Specific Locations – Many examples exist around the globe, some well-studied examples are in the Gulf of Mexico, Cascadia, Black Sea, North Slope, etc.
3. Scientific objectives – understand mass flux, methane flux to water column, gas flux to GHSZ, impact on microbiology, kinetics of rapid formation of hydrate and dissociation, spatial variation of shallow sediment carrying capacity (AOM)
4. Site survey requirements – leverage existing data sets (multibeam and backscatter, water column, seismic data, monitoring stations)
5. Drilling strategy – adapt to local conditions; collect an array of correlative data to fully characterize the MH system and external forcings (e.g. tides, water temperature, seismicity, etc.)
6. Required technology
    a) Logging - standard
    b) Coring - standard
    c) Pressure coring
    d) Instrumentation - observatory

7. Has the location been previously drilled, what did we learn? – 164 diapirs, Hydrate Ridge, Bullseye Vent, Site 10 NGHP, AT 13/14 JIP Leg I

8. Pre and post laboratory and modeling requirements

D. Fully parameterize global carbon cycle using wells of opportunity

1. Geologic setting– all margins; target thermogenic vs. microbial gas environments, focused flow vs. basin-centered accumulations, passive vs. active margins, low vs. high organic matter etc.
2. Specific Locations – global, full gamut of conditions and settings
3. Scientific objectives – defining metrics that control global carbon cycle budget over time (including microbes); establish thresholds, informing global/local assessment models; understand the lifecycle components of carbon to methane over time
4. Site survey requirements – piggyback with other programs if possible
5. Drilling strategy – wells of opportunity, establish a consistent protocol, and requires a management team
6. Required technology
   a) Logging – LWD/wireline
   b) Coring – sampling/analysis within defined protocols
   c) Pressure coring – when possible
   d) Instrumentation

Has the location been previously drilled, what did we learn? In concept, yes, in multiple locations, but without an integrated process-oriented focus

7. Pre and post laboratory and modeling requirements – microbial gas generation models; migration, timing, and cycling; etc.

E. Preconditioning of areas for slope failure with high methane hydrate saturations

1. General geologic setting or model – toe of the slope, looking for downdip edge of future retrogressive failure
2. Specific Locations – north wall of Storegga slope, northwest Svalbard, Cape Fear slide
3. Location geologic conditions – 1-3^{o} slope, high methane hydrate saturation in a stable environment; hydrates with free gas
4. Scientific objectives – understanding of strength at toe of slope and potentially how/what causes retrogressive failure; impacts of dissolution and dissociation
5. Drilling strategy- shallow, riserless drilling transects
6. Required technology
   a) Logging
   b) Coring
   c) Pressure coring
   d) Instrumentation

7. Has the location been previously drilled, what did we learn?

F. Production related geohazards with a deepwater, deep sand

1. General geologic setting or model – deepwater, deep sand reservoir as selected by the production group
2. Specific Locations – determined by the production group
3. Location geologic conditions
4. Scientific objectives – understand how strength and stress state around the producing interval (reservoir and seal) change with production of methane hydrate; subsidence issues, brittle or plastic deformation, fluid flow changes in reservoir and seal; associated benthic and seafloor geomorphology changes
5. Drilling strategy - controlled production test; geohazard evaluation and monitoring wells; cabled observatories
6. Required technology
    a) Logging
    b) Coring
    c) Pressure coring
    d) Instrumentation
7. Has the location been previously drilled, what did we learn?

G. Production related geohazards with a shallow reservoir; how is it different from a deeper reservoir

1. General geologic setting or model – shallow reservoir with controlled perturbation
2. Specific Location – Southern Hydrate Ridge
3. Location geologic conditions
4. Scientific objectives – understand how strength and stress state around the producing interval (reservoir and seal) change with production of methane hydrate; subsidence issues, brittle or plastic; deformation, fluid flow changes in reservoir and seal; associated benthic and seafloor geomorphology changes; comparison of difference between perturbation of shallow and deep hydrate systems; fate of gas formed during shallow dissociation
5. Drilling strategy- production test either by thermal stimulation or pressure depletion; geohazard evaluation and monitoring wells; cabled observatories
6. Required technology
    a) Logging
    b) Coring
    c) Pressure coring
    d) Instrumentation
7. Has the location been previously drilled, what did we learn? Yes

H. What is fate of water and gas produced from methane hydrate permafrost?

1. General geologic setting or model – Arctic permafrost site
2. Specific Location -
3. Location geologic conditions – where top of GHSZ is within the permafrost zone
4. Scientific objectives – see how freezing of water produced impacts seal capacity, how pressure below may increase below seal
5. Drilling strategy – transect across the permafrost-hydrate boundary
6. Required technology
   a) Logging
   b) Coring
   c) Pressure coring
   d) Instrumentation – pressure, temperature more important than usual
7. Has the location been previously drilled, what did we learn?

I. Methane hydrate response to earthquakes to assess natural perturbation

1. General geologic setting or model – rapid response after a large earthquake in a hydrate-bearing region
2. Specific Locations – Chile, Japan, Cascadia
3. Location geologic conditions
4. Scientific objectives
5. Drilling strategy
6. Required technology
   a) Logging
   b) Coring
   c) Pressure coring
   d) Instrumentation
7. Has the location been previously drilled, what did we learn?

J. Understanding relation of BSR to free gas beneath; relation to saturations (FG, MH) and geology/lithology

1. General geologic setting or model
2. Specific Locations – wells of opportunity with some very selected geophysical measurements (e.g., VSP) to get at MH and FG saturations at BSR
3. Location geologic conditions
4. Scientific objectives

5. Drilling strategy
6. Required technology
    a) Logging
    b) Coring
    c) Pressure coring
    d) Instrumentation
7. Has the location been previously drilled, what did we learn?

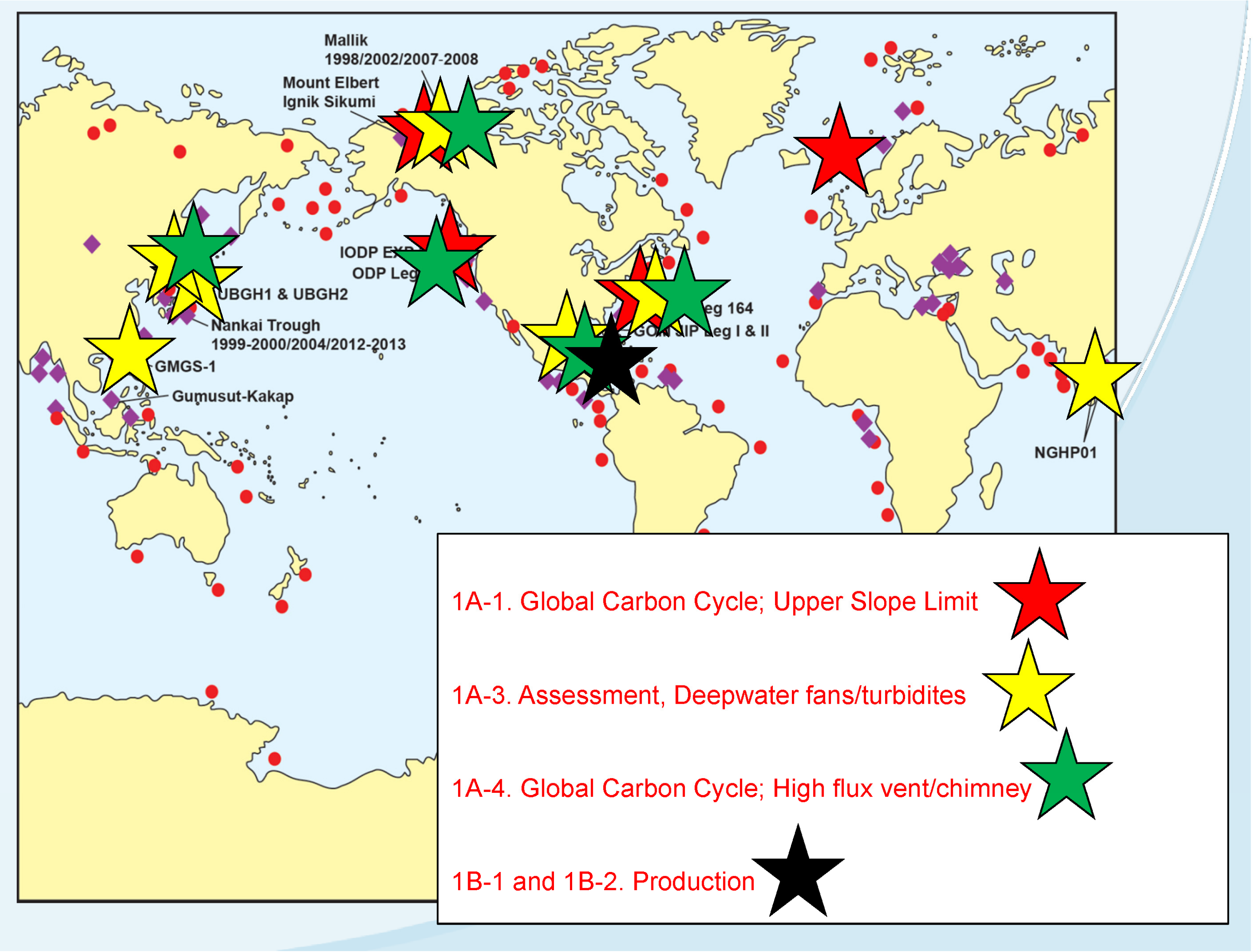
K. Basic characterization of things that are identified as geohazards (wipe-out zone, mounds, pingo-like features); what do these features represent? How fast do these features evolve?

1. General geologic setting or model
2. Specific Location
3. Location geologic conditions
4. Scientific objectives
5. Drilling strategy
6. Required technology
    a) Logging

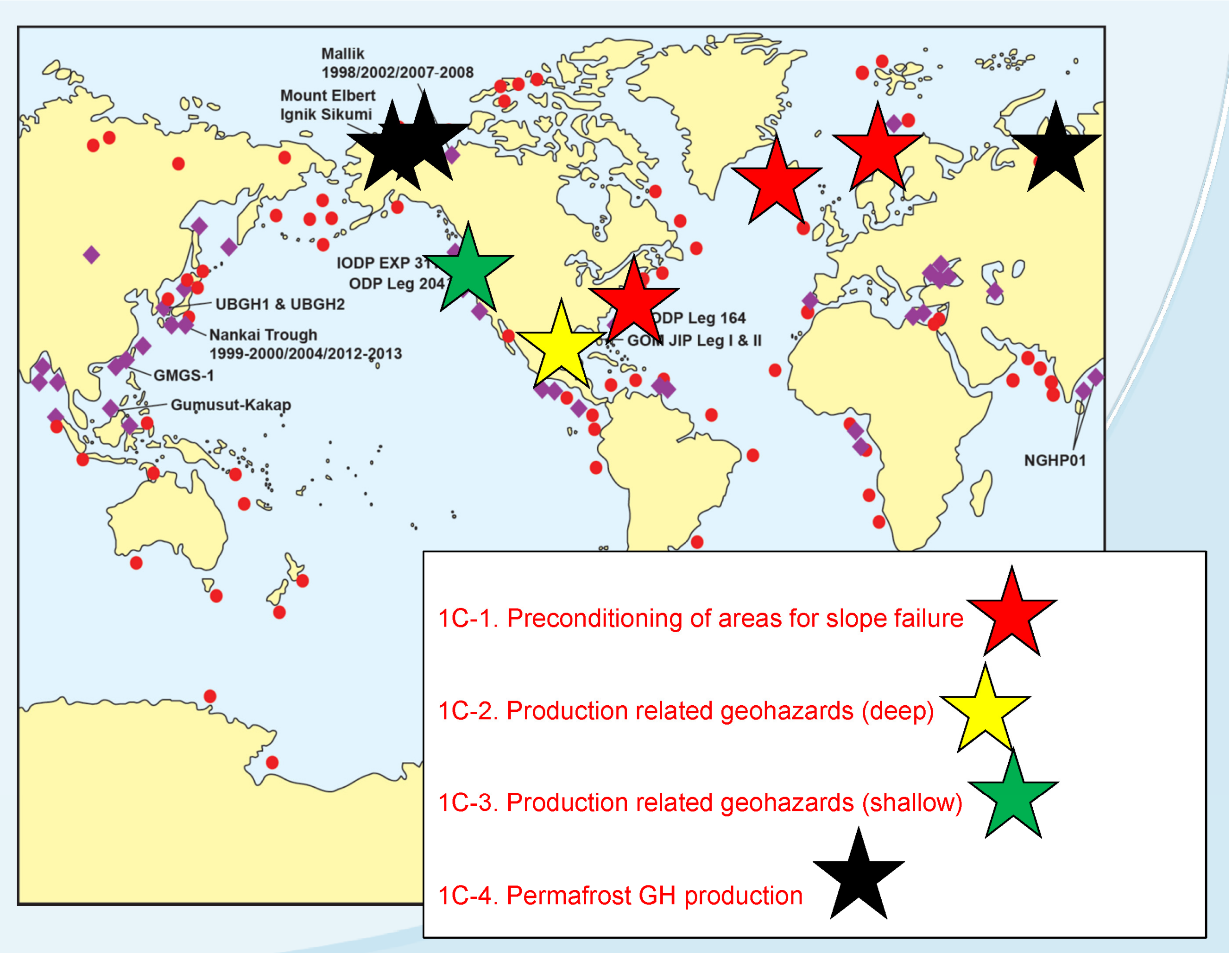
       MWD/LWD in first hole for safety, wireline, standard tools, 3-component resistivity, checkshot/VSP, shear waves for matrix; MDT, XPT, NMR for fluids - CPT, downhole foundational tools (fluid pressure, resistivity, strength, fluid sampling, temperature), seismic cone; interspersed with coring/pressure coring
    b) Coring standard physical props, sedimentology, structure, porewater
    c) Pressure coring PCATS and PCCTs together, controlled depressurizations
    d) Instrumentation long-term observatory with sensors for P, T, X, etc.
7. Has the location been previously drilled, what did we learn?

IX. Possible Drill Site Locations Maps

Locations discussed in section VIII above have been incorporated into two summary maps, one for sites considered by breakout groups 1A and 1B and the second map summarizes the potential sites considered by breakout group 1C.



The map above depicts the possible drillsites that address the challenges discussed in breakout groups 1A and 1B which dealt with resource assessment, global carbon cycle, petroleum systems and production respectively.



The map above depicts the sites that address the challenges discussed in breakout groups 1C, methane hydrate related geohazards.

X. Next Steps – Generation of a Methane Hydrate Science Plan

A number of important discussions and datasets came from the workshop including a list of potential expeditions that could drilled in the future. The methane hydrate science team will convene in July 2013 to begin drafting the methane hydrate science plan using the discussions and commentary generated during the workshop. The science plan is the primary project deliverable.

The following outline will serve as the starting point for the methane hydrate science plan. Once the science plan is finalized in September 2013, it will be available for download at http://www.oceanleadership.org/scientific-programs/methane-hydrate-field-program/:

a) Marine Methane Hydrate Science Plan
  - Executive Summary
  - Approach
  - Goals

b) Challenges
  - MH Resource Assessment and Global Carbon Cycle
    - (a) Description and discussion
    - (b) Drilling program requirements
      - (i) Site Identification
      - (ii) Site Characterization and systems analysis
      - (iii) Drilling and sampling program
      - (iv) Tools and equipment
  - MH Production Analysis
    - (c) Description and discussion
    - (d) Drilling program requirements
      - (i) Site Identification
      - (ii) Site Characterization and systems analysis
      - (iii) Drilling and sampling program
      - (iv) Tools and equipment
  - MH Related Geohazards
    - (e) Description and discussion
    - (f) Drilling program requirements
      - (i) Site Identification
      - (ii) Site Characterization and systems analysis
      - (iii) Drilling and sampling program
      - (iv) Tools and equipment

c) Cross cutting relationships between challenges
  - MH Systems
  - MH Laboratory and Field Characterization
  - Upscaling

d) Recommendations

X. Acknowledgements

The COL and DOE-NETL would like to thank all participants as well as the science team members for their active participation and for bringing their ideas and expertise to the workshop. Michael Riedel who gave a plenary talk; Charlie Paul, Brandon Dugan, Rick Colwell and Joel Johnson who helped the COL-DOE Science Team Champions lead the breakout group discussions; and to Rick Colwell and Joel Johnson who served as note takers/scribes and ensured that the participants' ideas were recorded during the fast-paced discussions.

Appendix A – Agenda

Day One - Tuesday June 4, 2013 (09:00-17:00 hr)

9:00-9:30 Workshop Check-In and Breakfast

9:30-10:30 Opening Session

-Introductions
-Project Overview and Meeting Goals (G. Myers)
-DOE Program Perspective (R. Boswell)
-Project Science Team Contributions (T. Collett) – *Historical Review and Science Planning*

10:30-12:30 Invited Plenary Presentations

(1) Methane Hydrate Resource Assessment
(2) Methane Hydrate Production Analysis
(3) Methane Hydrate Related Geohazards
(4) Methane Hydrate Role in the Global Carbon Cycle
(5) Methane Hydrate Petroleum Systems
(6) Methane Hydrate Laboratory and Field Characterization

12:30-13:30 Lunch (at Ocean Leadership)

13:30-17:00 Breakout Session (1)

-Development and Tasking Breakout Groups for Breakout Session (1)

-Breakout Discussions (1) - *Methane Hydrate Science Challenges*

- *Breakout 1.A. Methane hydrate petroleum systems with considerations of methane hydrate resource assessment and global carbon cycle analysis*
- *Breakout 1.B. Methane hydrate production analysis*
- *Breakout 1.C. Methane hydrate related geohazard characterization and assessment*

-16:30: Breakout Reporting (1) – *Methane Hydrate Science Challenges*

Day Two - Wednesday June 5, 2013 (09:00-17:00 hr)

9:00-9:30 Breakfast

9:30-12:30 Breakout Session (1) - Continued

-Breakout Discussions (1) - *Methane Hydrate Science Challenges*

- *Breakout 1.A. Methane hydrate petroleum systems with considerations of methane hydrate resource assessment and global carbon cycle analysis*
- *Breakout 1.B. Methane hydrate production analysis*
- *Breakout 1.C. Methane hydrate related geohazard characterization and assessment*

-11:30: Breakout Reporting (1) - *Methane Hydrate Science Challenges*

12:30-13:30 Lunch (at Ocean Leadership)

13:30-17:00 Breakout Session (2)

-Breakout Discussions (2) – Proposed Scientific Drilling Expeditions as Developed from the Science Challenges

- *Breakout 1.A. Methane hydrate petroleum systems with considerations of methane hydrate resource assessment and global carbon cycle analysis*
- *Breakout 1.B. Methane hydrate production analysis*
- *Breakout 1.C. Methane hydrate related geohazard characterization and assessment*

- 16:30: Breakout Reporting (2) – *Proposed Scientific Drilling Expeditions*

Day Three - Thursday June 6, 2013 (09:00-13:00 hr)

9:00-9:30 Breakfast

9:30-13:00 Plenary Review and Discussion

(1) Methane Hydrate Science Challenges
(2) Proposed Scientific Drilling Expeditions
(3) Methane Hydrate Laboratory and Field Characterization Research and Development

-Science Plan Development and Path Forward

Appendix B – Attendees

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