METHANE HYDRATE NEWS

FIRE IN THE ICE

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NATIONAL ENERGY TECHNOLOGY LABORATORY

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CONTACT

John Rogers
Technology Manager
Environmentally Prudent Stewardship (EPS) and Hydrates R&D Program

(412) 979-6952
john.rogers@netl.doe.gov

U.S. DEPARTMENT OF ENERGY

NETL Machine Learning Tool Predicts Gas Hydrate Saturation and Occurrence

Evgeniy M. Myshakin, Leebyn Chong, and Yongkoo Seol
National Energy Technology Laboratory, Research and Innovation Center

Scientists at NETL's Research and Innovation Center have developed a state-of-the-art machine learning (ML) tool to estimate gas hydrate saturation and occurrence in subsurface reservoir formations using standard well log data. The tool was developed, tested, and validated using gas hydrate reservoir data from onshore sites on the North Slope Alaska and Northwest Territories, Canada (Figure 1) and offshore sites in the Indian Ocean (Figure 2 on page 3). In all test cases, the ML tool was able to estimate hydrate properties with reliable accuracy, indicating that its value as a predictive tool is likely to prove useful in other gas hydrate-bearing reservoirs.

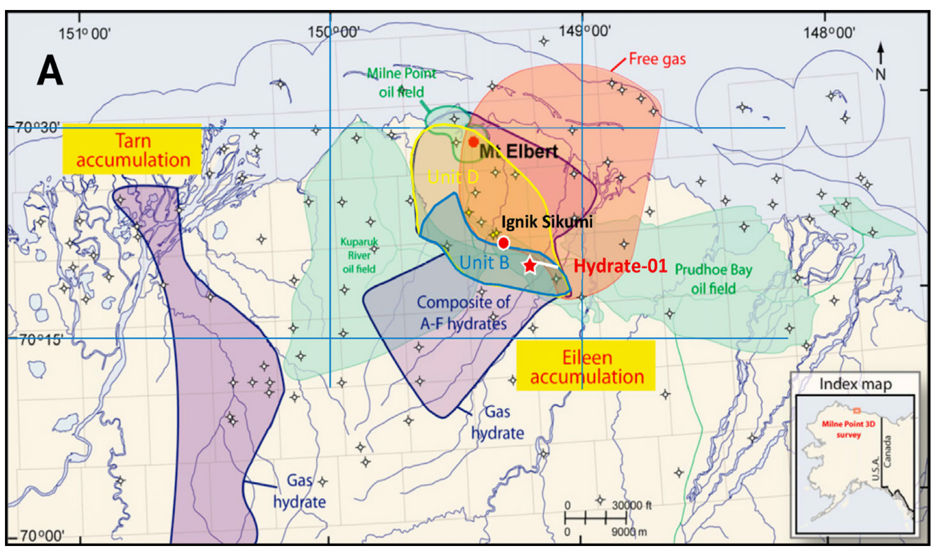


Figure 1. A) Location map of ANS regions showing Mount Elbert, Ignik Sikumi, and Hydrate-01 well locations in the Eileen gas hydrate trend. B) Page 2, location map of the Mackenzie Delta region showing the Mallik 2L-38 and 5L-38 drilling sites.

How It Works

NETL's new, supervised ML tool is based on an Artificial Neural Network (ANN) that incorporates standard well log data including density, porosity, electrical resistivity, natural gamma radiation, and compressional wave velocity. The ANN can be built as a site-specific, basin-specific, or regional

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Program staff are also located in Houston, TX and Anchorage, AK.

Visit the NETL website at:
www.netl.doe.gov

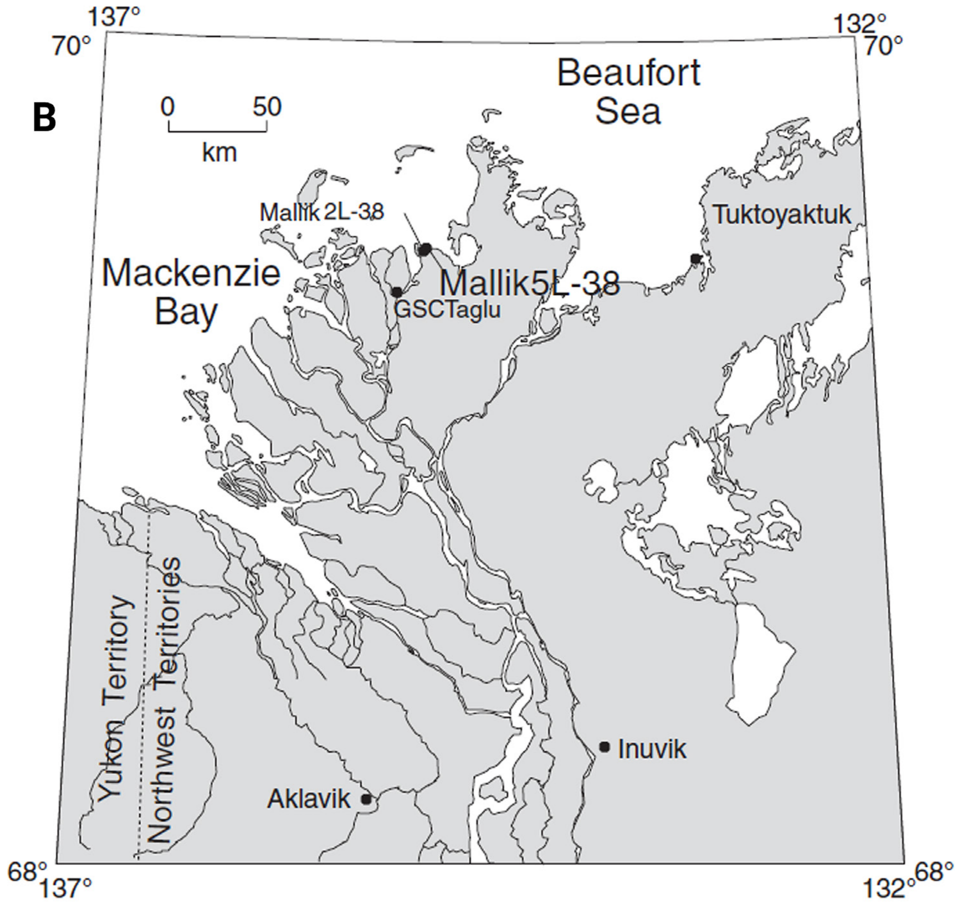
Customer Service:
1-800-553-7681

Fire in the Ice is published by the National Energy Technology Laboratory to promote the exchange of information among those involved in gas hydrates research and development.

This newsletter is available online at: https://www.netl.doe.gov/fire-in-the-ice

Interested in contributing an article to *Fire in the Ice*?

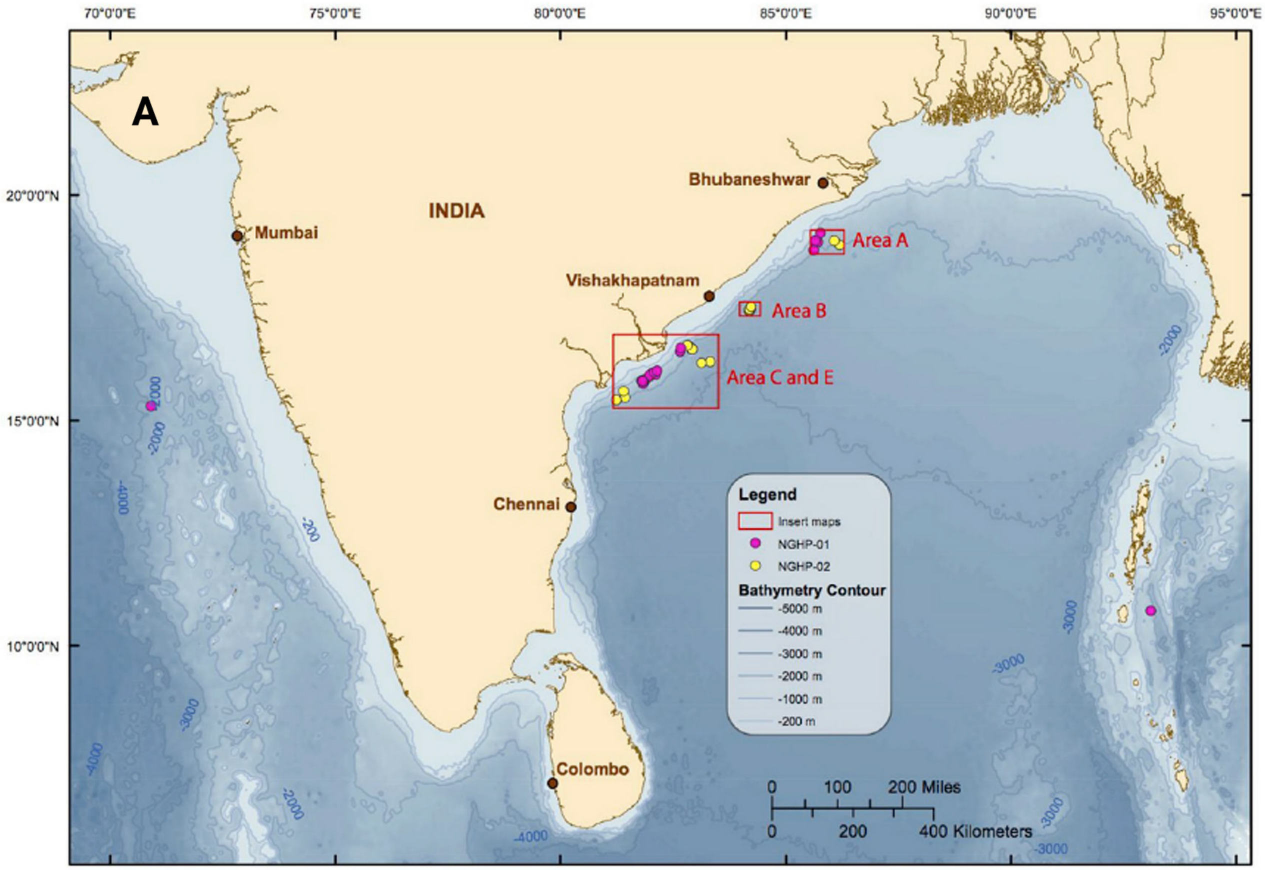
This methane hydrate newsletter now reaches 1170 individuals, representing 20 countries. If you would like to submit an article on research results likely to be of interest to the methane hydrate R&D community, please contact Karl Lang at karl.lang@keylogic.com. We look forward to hearing from you.



model that uses these reference logs as input features. Gas hydrate saturation and occurrence, whether pore-filling or fracture-filling type, are then predicted as response variables from the ML models trained on these features. Note that ML models trained with all five reference logs yield higher accuracy predictions; however models trained with three or four reference logs also yield reliable results. This is significant because in the real world many sites, especially legacy wells, do not have all five reference logs available and individual log records may have data gaps. In addition, NMR logs, which are often used to calculate gas hydrate saturation, and Resitivity-at-Bit (RAB) images are often not available at a given well or site of interest.

Alaska North Slope and Mallik Gas Hydrate Reservoirs

The ML tool was first tested using onshore permafrost-associated gas hydrate reservoir data from the Eileen gas hydrate trend on the Alaska North Slope (USA) and the Mallik hydrate trend in the Beaufort-Mackenzie Basin, Northwest Territories (Canada) (Figure 1). Both basins have gas hydrate-bearing reservoirs that have been verified and tested via logging-while-drilling (LWD), wireline logging, and core sampling. Well log data from three wells in the Eileen trend (Mount Elbert, Ignik Sikumi, and Kuparuk 7-11-12) and two in the Mallik trend (2L-38 and 5L-38) were used to train the ML model. Physics-based gas hydrate saturation values, and observations of gas hydrate as a pore-filling or fracture-filling occurrence in reservoir sediments, were used to validate and test the ML models.



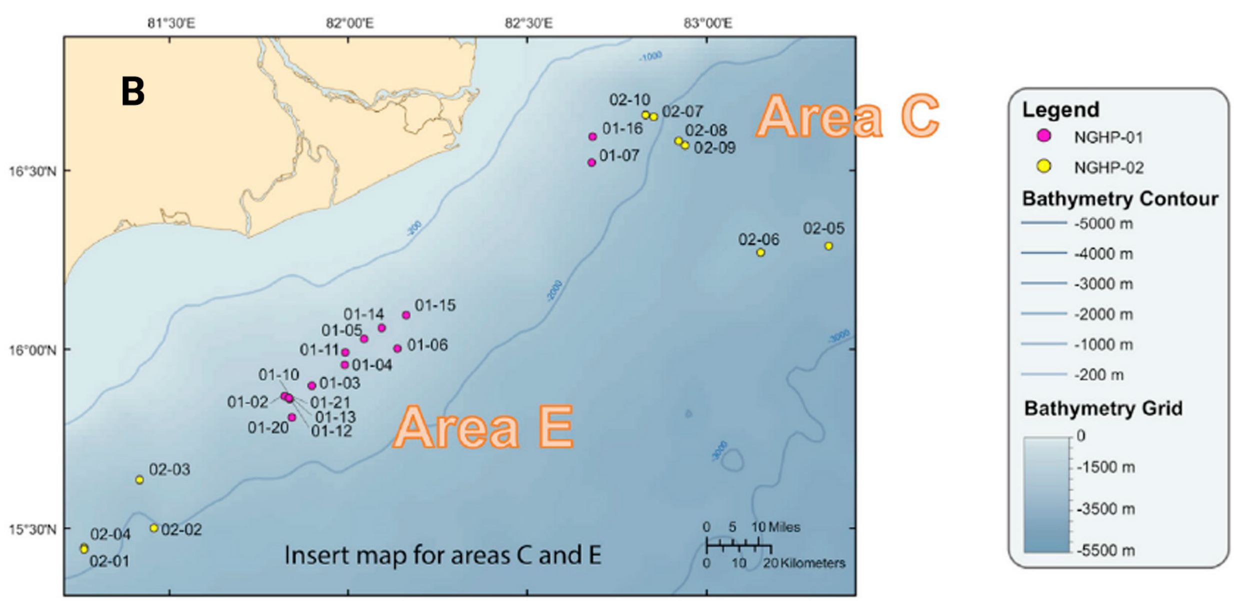


Figure 2. A) National Gas Hydrate Expedition 01 (NGHP-01) and NGHP-02 site maps showing the locations of wells drilled during the expeditions in the Krishna-Godavari (Area B, Area C, and Area E) and Mahanadi (Area A) offshore areas of India. B) Expanded view of Area C and Area E showing names of individual sites.

The log data used for ML model training included density, porosity, electrical resistivity, natural gamma radiation, and acoustic wave velocity measurements. NMR- or Archie-derived saturation (Sgh) and occurrence recognition based on RAB image processing were used as reference data for training purposes. The reference (or "ground truth") data were utilized to assess the accuracy of ML model predictions through regression analysis for Sgh prediction and categorical analysis for occurrence.

Alaska and Canada Results

Figure 3 is a plot of NMR-based Sgh values (x-axis) vs ML model-predicted values (y-axis) for the Eileen and Mallik gas hydrate reservoirs. Overall, the ML tool succeeded in predicting gas hydrate saturations with 80-90% accuracy when compared with NMR-derived values. The Sgh predicted values against the reference data show an excellent match for Sgh > 50%, whereas the predicted saturation values are underestimated for Sgh < 50%. This systematic underestimation may be attributed to a limitation of the NMR-log based technique. The reported ML models are expandable, meaning that as more data become available for training, the accuracy of predictions is expected to increase for other onshore basins.

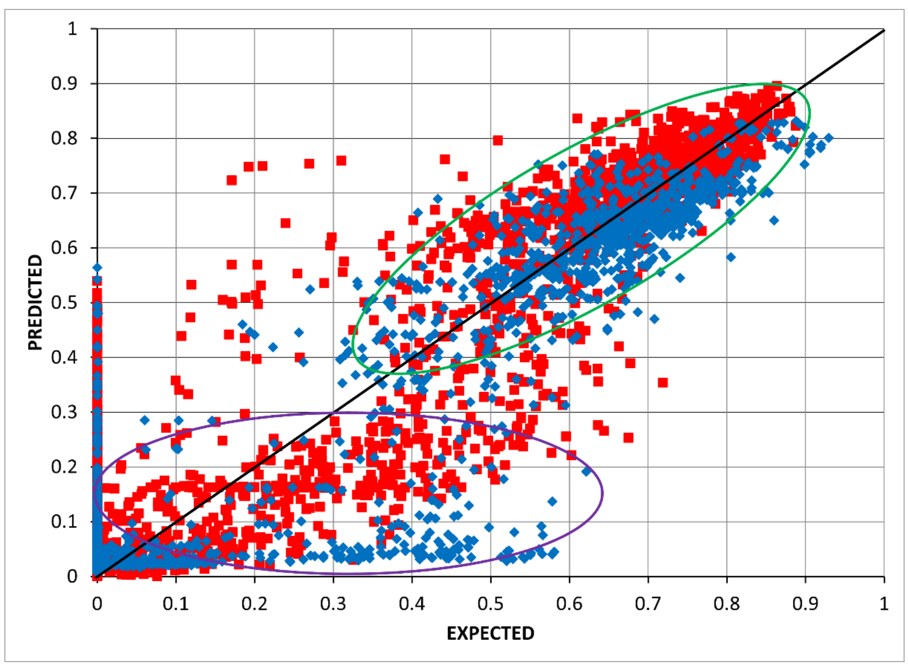


Figure 3. Graph showing NMR-derived (horizontal axis) vs. Ml-predicted (vertical axis) hydrate saturation values at the Mallik (red squares) and Alaska North Slope wells (blue diamonds).

Indian Ocean Basins

The ML models for the Krishna-Godavari sites in the Indian Ocean were trained using log data from six wells drilled in 2015 as part of India's National Gas Hydrate Program NGHP-02 expedition (Figure 2). As with the onshore, permafrost-associate hydrates in Arctic Alaska and Canada, the ANN model for these offshore hydrate deposits was trained with conventional well log data, including density, porosity, electrical resistivity, natural gamma radiation, and acoustic wave velocity. For the marine sediments offshore India, the ML models were used to predict not only gas hydrate saturation but also gas hydrate occurrence as pore-filling or fracture-filling in sediments of the host reservoir. Pore-filling methane hydrate is typically found in coarse-grained, sand-rich deposits with high porosity, high intrinsic permeability, and high gas hydrate saturation. On the other hand, gas hydrate occurring in fractures and veins is often associated with mud- and clay-rich sediments with low porosities, low intrinsic permeabilities, and low hydrate saturation values. Thus, pore-filling gas hydrate in sand-rich reservoirs presents an attractive resource compared to fracture-filling gas hydrate in mud- and clay-rich sediments. The trained ML tool was designed to distinguish the more desirable pore-filling hydrate from the less economically viable fracture-filling type.

Indian Ocean Results

In the Indian Ocean case, the ML models predicated gas hydrate morphology with accuracies of 79-86% and gas hydrate saturation with accuracies of 68-92%. These accuracy scores validate the usefulness of this ML tool to predict critical gas hydrate reservoir characteristics in marine environments. The results indicate that ML models like these can be used to augment physics-driven methods or as an independent tool to predict gas hydrate saturation and occurrence.

Conclusions

Based on these examples, it is evident that the ML tool developed at NETL can provide reliable predictions of gas hydrate saturation in onshore and offshore reservoirs, as long as standard well log data are available to train the ML models. In addition, this modeling strategy can predict the type of gas hydrate occurrence in a reservoir, e.g., whether it occurs as a pore filling or a fracture filling.

Acknowledgments

The authors would like to thank Timothy S. Collett of the U.S. Geological Survey and C. Gabriel Creason of NETL, who were co-authors on the source material for this article. The authors also express gratitude to Frances Toro for helping prepare the article.

SOURCE MATERIAL AND SUGGESTED READING

Chong, L., Collett, T.S., Creason, C.G., Seol, Y. and Myshakin, E.M., IN REVIEW, Machine learning application to assess occurrence and saturations of methane hydrate in marine deposits offshore India, Computers and Geosciences.

Chong, L., Singh, H., Creason, C.G., Seol, Y., and Myshakin, E.M., 2022, Application of machine learning to characterize gas hydrate reservoirs in Mackenzie Delta (Canada) and on the Alaska North Slope (USA), Computational Geosciences, v. 26, pp. 1151-1165. https://doi.org/10.1007/s10596-022-10151-9

National Energy Technology Laboratory, 2022, Machine learning tool predicts hydrate saturation and morphology in onshore and offshore basins, in MACHINE LEARNING TOOL PREDICTS HYDRATE SATURATION AND MORPHOLOGY IN ONSHORE AND OFFSHORE BASINS, p. 92, published online, https://netl.doe.gov/sites/default/files/publication/2022%20NETL%20Annual%20Accomplishments%20Book.pdf

World Atlas of Submarine Gas Hydrates in Continental Margins – A Review

David Goldberg
Lamont-Doherty Earth Observatory

Gas hydrate is widespread at concentrations of a few percent to as much as 70% or more of available pore space in the shallow sediments of marine continental margins and oceanic areas around the globe. However, gas hydrates are not present in all such sediments, and understanding the variations in the nature of gas hydrates is essential for understanding why, both for research and exploration purposes. In the *World Atlas of Submarine Gas Hydrates in Continental Margins*, J. Mienert, C. Berndt, A. M. Trehu, A. Camerlenghi, and C-S Liu provide a state-of-the-art examination of gas hydrates compiled from geophysical measurements and "ground truth" observations from a variety of submarine settings, aggregated across 43 chapters depicting worldwide examples in an atlas format. Given that the editors have each published extensively on gas hydrates, they could easily have banked enough expertise to do this quite effectively among themselves. Instead, these chapters are organized regionally – co-authored by more than 100 researchers and colleagues from international universities and esteemed research laboratories – and grouped into 14 sections by ocean basin and area.

Each chapter presents subsurface geophysical images of a given region, expert interpretations, analyses, photos, and when available, sample and borehole measurements which tie research results together at each location. The sequence of chapters in the *Atlas* essentially circumnavigates the Earth, spanning the continental margins of the northern Atlantic, western Pacific, Arctic, southern Atlantic, Indian, and Southern Oceans. Other submarine settings include the Mediterranean and Black Seas, Lake Baikal, and more. The compilation results in a unique volume that will be a useful resource for exploration and research of marine gas hydrates on Earth (and potentially some extra-terrestrial locations as well), making site-by-site comparisons possible and informing global topics on climate change, marine geohazards, natural ecosystems, and carbon resources.

The *World Atlas of Submarine Gas Hydrates in Continental Margins* (Figure 1) captures the massive advances in technology and geophysical information collection over the last 15-20 years, which has resulted from decades of international investment in gas hydrate research. Early chapters explain the basic principles of gas hydrate occurrences in submarine settings, the history of hydrate discovery through geophysical and drilling exploration, oil and gas production and pipeline applications, and some of the fundamental principles behind the geophysical tools used for gas hydrate measurements (for example, elastic and electromagnetic methods, pore-scale modeling). Overall, these chapters assume quite a lot of background knowledge and understanding by the reader in terms of geophysical processes and techniques, and geological representations. Although some chapters may be challenging for novices, the volume is potentially useful as a teaching tool for graduate level courses in marine geology and geophysics, and related subjects.

Many chapters approach each region from a conventional "exploration plan" perspective. That is to say, visualizing and interpreting gas hydrates in the subsurface using modeling and remote geophysical methods such as reflection seismology and other surveys, followed by drilling studies that often include geophysical well logging, coring, and laboratory sample analyses. Unlike other textbooks and monograph series on this subject, most chapters in the *Atlas* do not extrapolate findings to estimate the static hydrate concentration in a given accumulation or reservoir, nor do they predict the potential reserves of natural gas in a particular region. Excluding this from the scope of the *Atlas*, the editors have

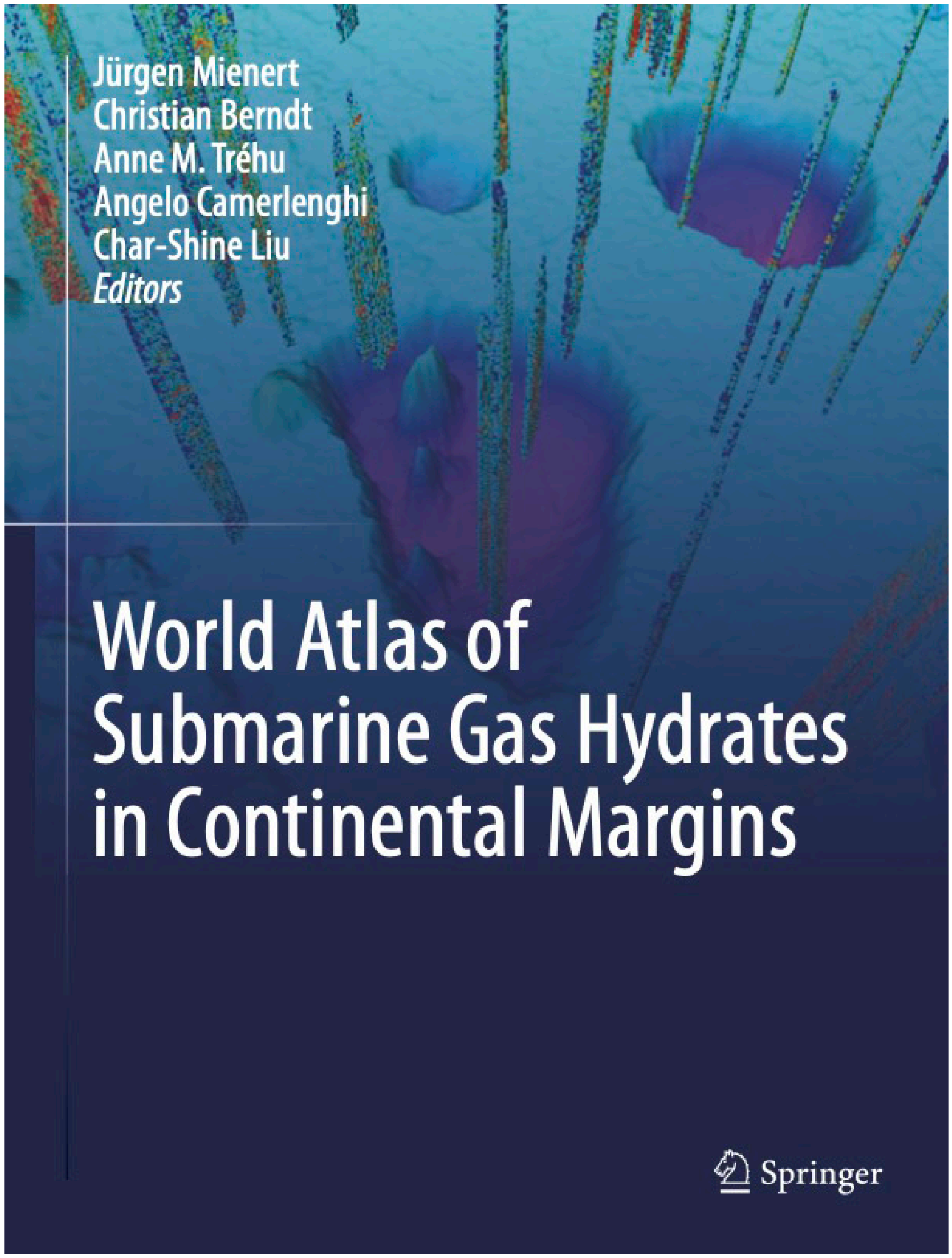


Figure 1. Atlas cover, Source: Springer Nature, Switzerland AG.

skillfully been able to compile a vast resource of technical information, subsurface images, and current results from world-renowned gas hydrate researchers that will have a broader impact on future studies. The volume will become increasingly important as the impacts of climate change continue and we seek to expand our understanding of the dynamic processes underway along our continental margins.

Perhaps most importantly, the *Atlas* presents a comprehensive catalog of the characteristic "Bottom Simulating Reflectors" (BSR) that, while one of the most common seismic expressions of the presence of gas hydrate, come in many shapes and sizes. This catalog offers a global comparison of geophysical exploration in nearly all marine regions where gas hydrates have been studied to date. For example, the images below from the *Atlas*

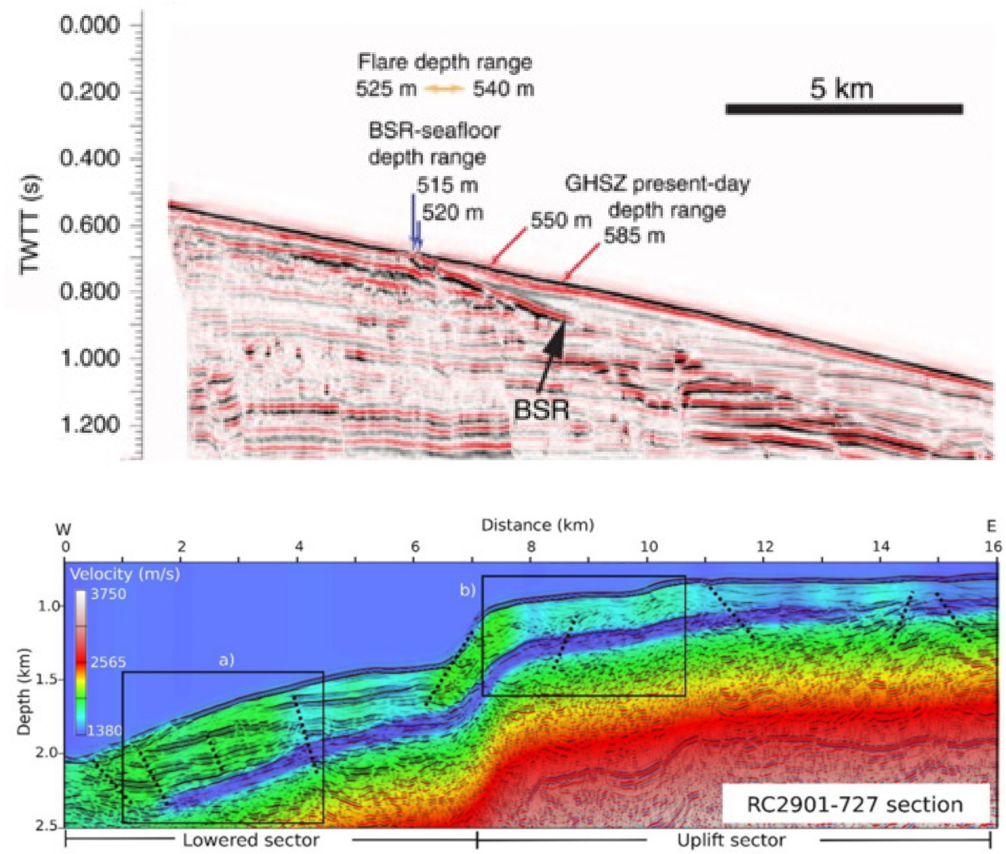


Figure 2. Comparison of BSR images from Brazil (top) and Chile (bottom).

show how the characteristics of a BSR observed in Brazil (top), a passive margin where it intersects the seafloor, differs from one observed in Chile (bottom), an active margin where tectonic faults and fractures intersect it at depth. In Brazil, a combination of climate-driven sea level rise and ocean warming may cause the dissociation of shallow gas hydrates and the release of methane at the point where the BSR intersects the seafloor and the gas hydrate stability zone shallows (from *Atlas*, Chap. 29, Fig. 29.7; after Ketzer et al., 2020). In Chile, methane seeps through fractures to the seafloor and into the ocean (from *Atlas*, Chap. 34, Fig. 34.4; after Vargas-Cordero et al., 2017).

Other chapters depict "pingo-like" hydrate structures, seafloor deposits, and seeps where unique biological communities currently flourish on the seabed in association with hydrates. The image in Figure 3 shows a layered gas hydrate complex recovered from the floor of the Barents Sea (from *Atlas*, Fig. 3.2, credit: Arctic University of Norway).

The *Atlas* thus sets a baseline of current knowledge against which we may be able to observe changes in a warming world and that will support future assessments of these dynamic systems over time. Together, the images, analyses, and research results offer visually striking, and authoritative, source materials that underpin our overall understanding of gas hydrate systems on both active and passive margins.

Figure 3. Image from Atlas illustrating a layered gas hydrate complex recovered from the floor of the Barents Sea

Undoubtedly, geophysicists and researchers searching for a comprehensive reference on gas hydrates will all benefit from *World Atlas of Submarine Gas Hydrates in Continental Margins*. The *Atlas* is available in both hardbound and e-book form.

World Atlas of Submarine Gas Hydrates in Continental Margins

by J Mienert, C Berndt, A M Trehu, A Camerlenghi, C-S Liu, Eds. 2022

Springer Nature Switzerland AG, Gewerbestrasse 11, 6330 Cham, Switzerland

14 sections, 43 chapters, 514 pages ($279.99, hardbound) ISBN 978-3-030-81185-3

(e-book also available) https://link.springer.com/book/10.1007/978-3-030-81186-0

Foraminifera Fossils Hold Key to Timing of Ancient Hydrate Dissociation Events

A team of scientists led by Brown University's Dr. Steven Clemens, has developed a new method for monitoring when deep sea methane deposits convert to gas and rise toward the seafloor in amounts that were previously too small to detect. In a paper published in May 2023 in *Earth and Planetary Science Letters* titled *"Indian margin methane hydrate dissociation recorded in the carbon isotopes of benthic (Miliolida) foraminifera,"* by S.C. Clemens and K. Thirumalai of Brown, and D. Oppo of University of Louisiana at Lafayette's School of Geosciences, the authors describe how fossils of benthic foraminifera have a unique ability to record both the location and timing of methane hydrate dissociation, even in small amounts.

In the study, the researchers' analysis of 372 individual Miliolida fossils revealed previously unrecorded dissociation events that have been occurring in the Bay of Bengal in the northern Indian Ocean for the past 1.5 million years, but were too small to detect through the usual signs of hydrate dissociation that are preserved in the sediment record and detected by the formation and presence of large carbonate nodules and chemosynthetic communities of organisms that develop at sites of methane release.

The analysis shows that dissociation events have been largely driven by increasingly warming waters in the region. These findings underscore the effects that climate change can have on ancient methane deposits and show that hydrates may transition from solid to gas more often than previously understood. This research was supported by the National Science Foundation. The paper can be accessed here: https://www.sciencedirect.com/science/article/pii/S0012821X23001140?via%3Dihub

Japan's MODEC Developing Methane Hydrates Harvester for Shallow Subsea Deposits

MODEC, Inc., a Japanese supplier and operator of offshore floating platforms, announced that it has been participating in the development of shallow methane hydrate harvesting technology commissioned by the Japanese Ministry of Economy, Trade and Industry (METI). The envisioned technology will employ vertical drilling equipment coupled with disk-shaped, large diameter drill bits (see Figure).

Performance tests conducted on land in October 2022 using a simulated soft mud ground with the same strength as shallow methane hydrate, confirmed that the concept would enable the efficient harvesting of methane hydrate, even in sediments that are essentially 100% hydrate. In the previous tests, the equipment was able to efficiently harvest granular hydrate from soft mud with 20% methane hydrate content, designed to simulate accumulations several tens of meters below the seabed.

Based on the data collected from the two drilling performance tests, MODEC plans to characterize the optimum combination of drill bits and associated equipment for a variety of target areas and subsea conditions, and then conduct simulations to determine the required power and drilling capacity necessary to profitability deploy this harvesting technology.

Photo courtesy of MODEC, Inc.

MODEC aims to provide technologies for the manufacturing and operation of offshore production facilities for methane hydrate, a seabed resource that lies in seafloor deposits in the seas around Japan, by applying the technologies the company has cultivated through the construction and operation of FPSOs. For more details see https://www.modec.com/news/2023/20230227_pr_MH.html

China Spuds Third Methane Hydrate Well in South China Sea

According to *upstream*, China's Ministry of Natural Resources (MNR) is pushing ahead with plans to spud a third gas hydrate well in the South China Sea, in anticipation of planned commercial development by 2030. Over the past year the MNR has completed seismic and environmental surveys in targeted waters of the South China Sea as well as geological engineering for the new well. MNR did not say when drilling would start. China drilled two successful gas hydrate wells in 2017 and 2020, respectively. The second well, drilled at the Shenhu trough in the South China Sea, flowed at an average 28,700 cubic meters per day (1014 Mcfd) during a month-long test. The previous well, also drilled in the same area, flowed a total of 309,000 cubic meters (10.9 MMcf) of gas from hydrates over 60 days of testing, averaging 5150 cubic meters per day (182 Mcfd).

China had planned to start pilot production of gas hydrates as early as 2023. However, officials decided that further appraisal drilling is needed before the country can begin commercial development of the unconventional gas resource, which is now scheduled for 2030. China's government has classified gas hydrates as a new mineral resource, distinct from conventional hydrocarbons, which has provided the legal basis for subsidizing its future production, according to *upstream* sources. China's offshore waters hold estimated gas hydrate reserves of 80 billion metric tonnes (584 million barrels of oil equivalent). Full article is available to subscribers at https://www.upstreamonline.com/exploration/china-ready-to-spud-third-gas-hydrate-well-in-south-china-sea/2-1-1388773

Spotlight on Research

JOHN ROGERS

NETL Technology Manager

NETL is excited to welcome back John D. Rogers in a new role as Technology Manager of DOE's Environmentally Prudent Stewardship (EPS) and Hydrates research programs in the Science & Technology Strategic Plans & Programs Division at the Laboratory's Houston, Texas, office. Rogers previously worked at NETL in the Laboratory's Strategic Center for Natural Gas and Oil in Morgantown, W.Va., as a project manager. He holds a Ph.D. and B.S. in Chemical Engineering from New Mexico State University, as well as an M.S. in Petroleum Engineering from Texas Tech University Lubbock. John is also a licensed Professional Engineer (PE).

John's career spans a wide range of roles in federal and local government, university R&D, sustainable energy non-profit efforts, and the energy industry sector where he primarily focused on environmentally responsible resource recovery. He has held a wide variety of positions, from Senior Production Operations Engineer, to Reservoir Engineer, to Industrial Wastewater Control Supervisor, to Project/Program manager, to Vice President of Operations. Asked about his current career objectives, John responds, "I am committed to the development of sustainable clean energy supplies, and dedicated to fostering team success in creating and utilizing cutting edge technology to develop technically sustainable energy resources."

In his new role as the Technology Manager for the EPS and Hydrates programs, Rogers will be leading a cross-functional, interdisciplinary technical team within NETL to execute FECM's Advanced Remediation Technologies research efforts. As a Technology Manager, Rogers oversees the strategic and technical direction and implementation of the R&D in the Hydrates program at NETL and ensures government funding is obligated in a timely and fiscally responsible manner.

DOE's Hydrates Program research is broadly focused on advancing our technical understanding of naturally occurring hydrates in Alaska and in moderately deep areas of the Gulf of Mexico. "The DOE Hydrates Program has contributed significantly to the vast amount of scientific data, analytical products and research tools developed over the past few decades, all of which have expanded our knowledge of clathrates and the potential safety and environmental issues associated with them," says Rogers. "The most important question now, in my view, is determining if methane can be produced from hydrates sustainably, economically, and environmentally responsibly. Should they be produced or should we let nature keep them safely locked up as it has for millions of years? Is it prudent to try and harvest these technically-difficult-to-produce assets?" John will be leading DOE's efforts to answer these questions, and others, through its Hydrates research program.

If you or someone you know would like to be the subject of the newsletter's next "Spotlight on Research," please contact Karl Lang (karl.lang@keylogic.com) Thank you!