Hydrate-Bearing Sediments from Deepwater GOM

Physical Properties

DE-FE0023919

Alejandro Cardona & Peter Flemings
University of Texas at Austin

U.S. Department of Energy
National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
April 2-4, 2024

Key Points

GC 955 Expedition in 2017

- International collaboration
- Test pressure core technology for material characterization

Geomechanical behavior

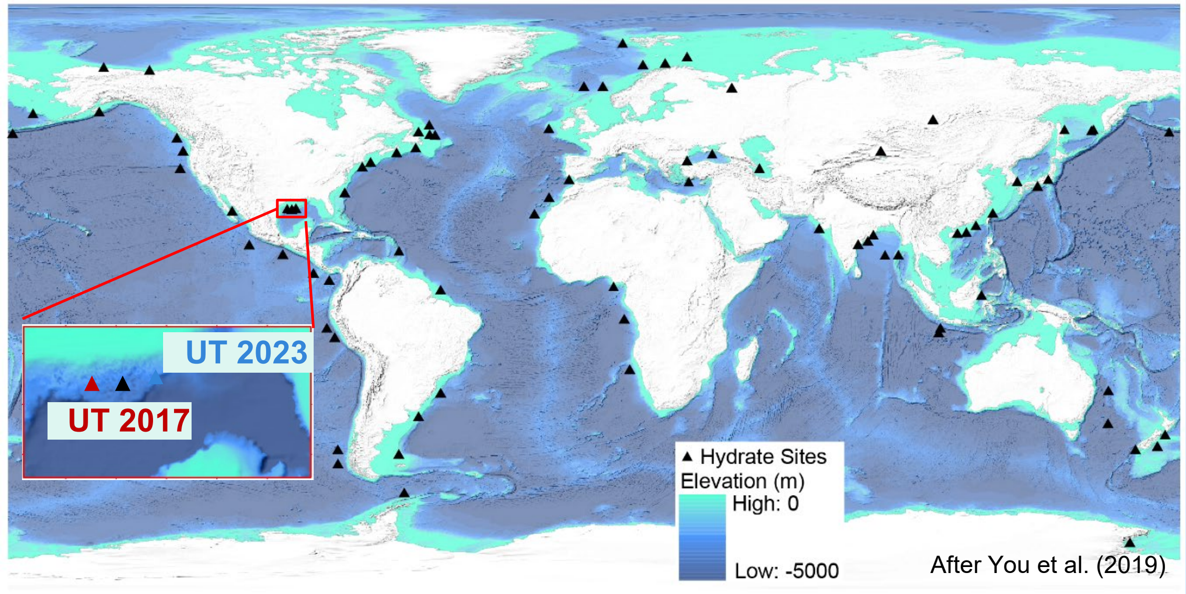
- Hydrates are visco-plastic materials
- Stress and compression are time-dependent

Water relative permeability (k_{rw})

- Pressure cores show higher k_{rw} vs. synthetic samples
- Long-term storage causes hydrate dissolution and explains k_{rw} trends

CH_4 Hydrates = ~20% of Organic Carbon

Natural hydrates - deep sea water & permafrost



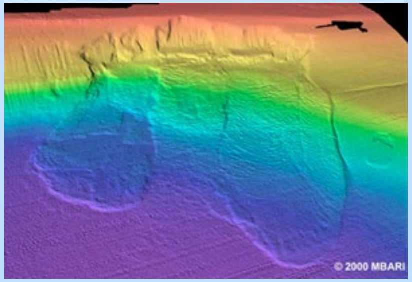
Energy

NYtimes

Global warming

USA Today

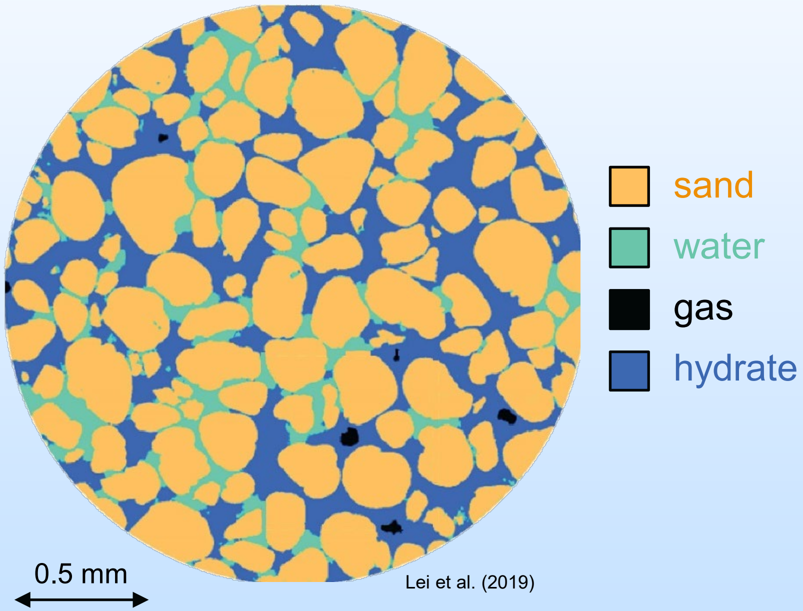
Landslides



MBARI

Hydrates – What is Special?

Composite porous media
grains + water + gas + hydrate



Pressure cores
needed for representative properties

Pressure core
in-situ sediment fabric

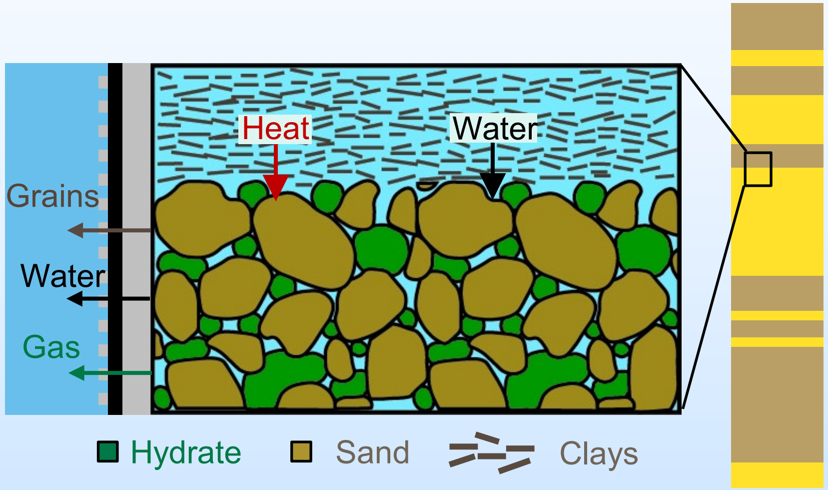
Conventional core
mousse-like texture

- **Measurements?** → challenging (high pressure & low temperature)
- **Typical models?** → not realistic for hydrates
- **Gas production?** → complex THCM processes

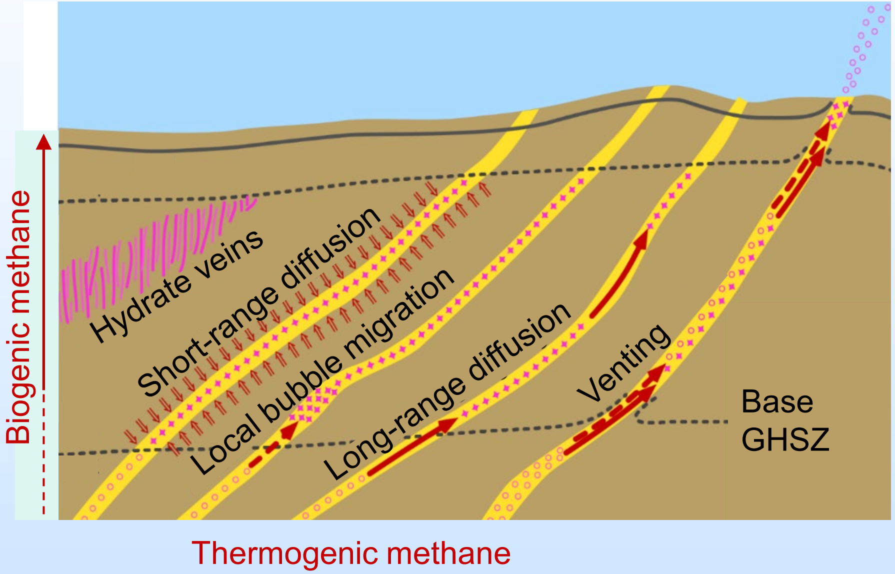
THCM: thermo-hydro-chemo-mechanical

UT-GOM2: Reservoir & Carbon Cycle

Reservoir System



Basin System



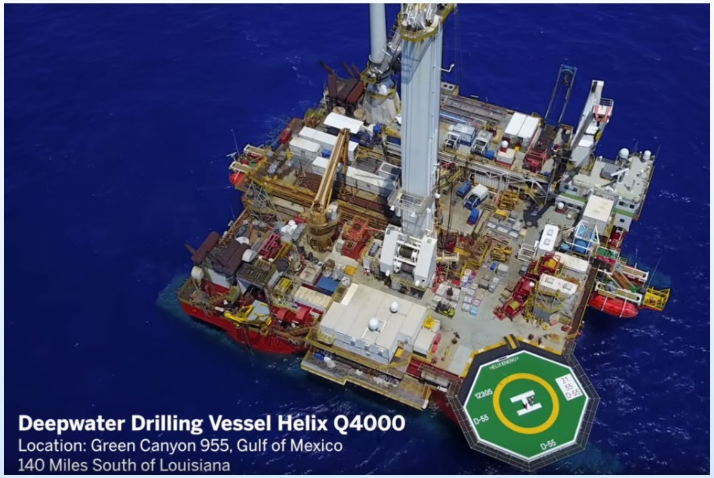
Production - reservoir models

Interpretation - microbial factory & transport
- carbon cycle

Characterization: saturation, composition, age, texture, pore chemistry
Material behavior: permeability, compression, strength

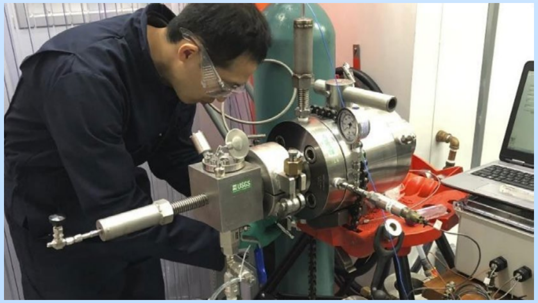
UT-GOM2-1 - 2017 Expedition

Green Canyon 955



Technology

International collaboration



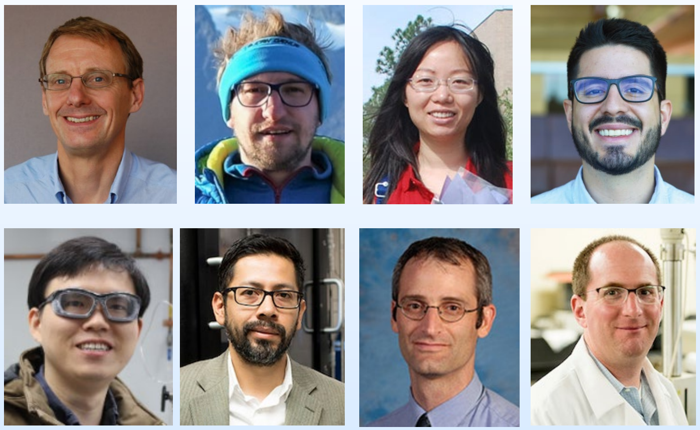
Two GC955 AAPG volumes

GC 955 Science – International Effort

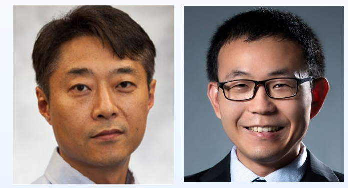
Pressure cores & depressurized samples sent to multiple institutions: Geomechanics, Petrophysics, Sedimentology, X-ray

GC 955 Science – International Effort

UT Austin

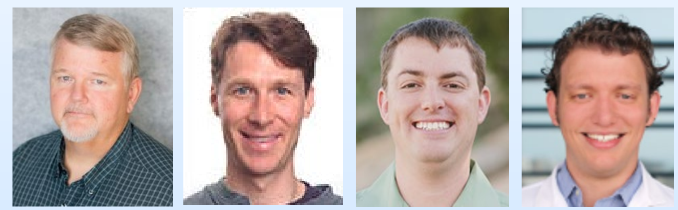


NETL



Lamont

USGS



OSU

UW

JAIST

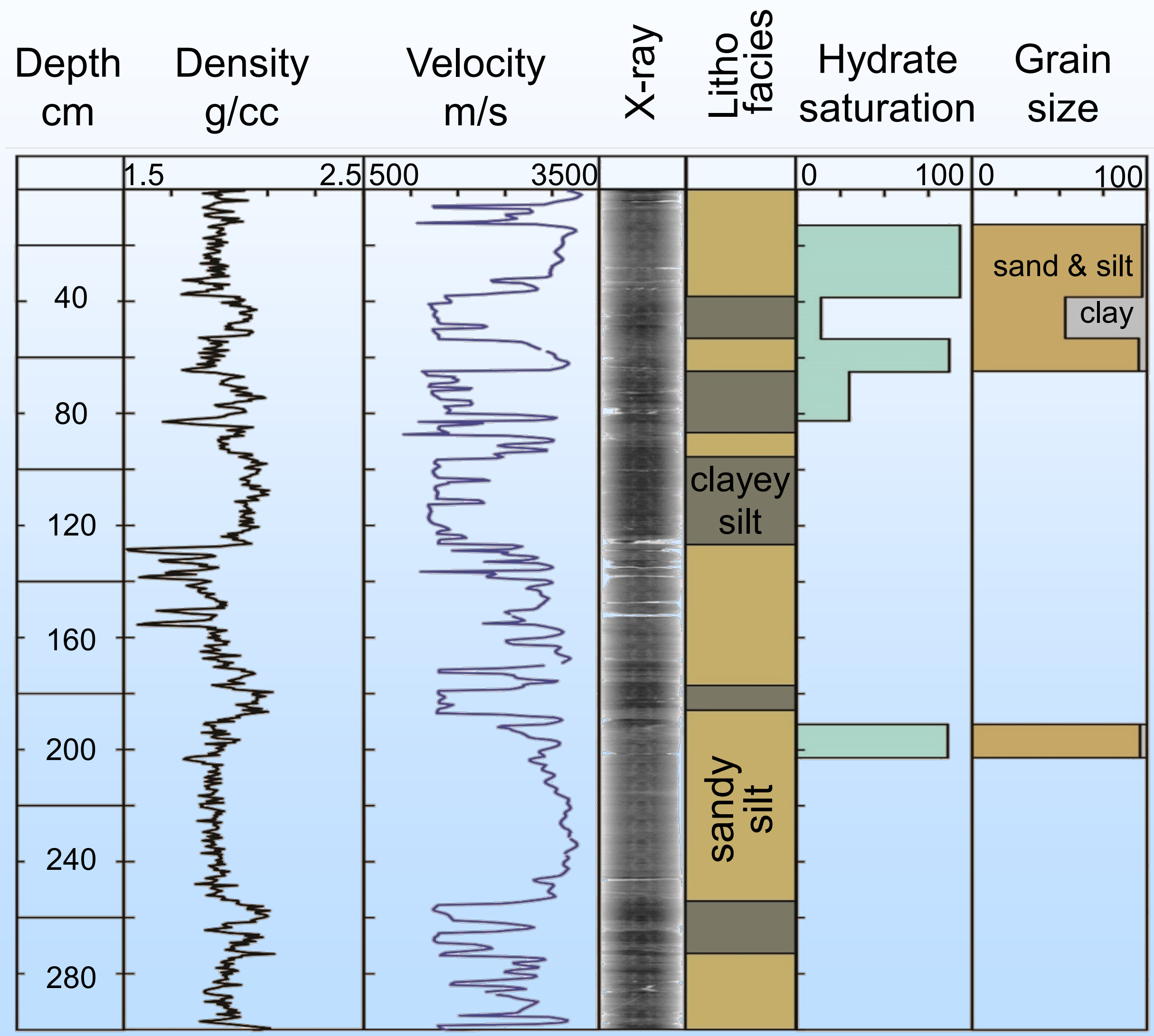
GaTech

Ohio

UNH

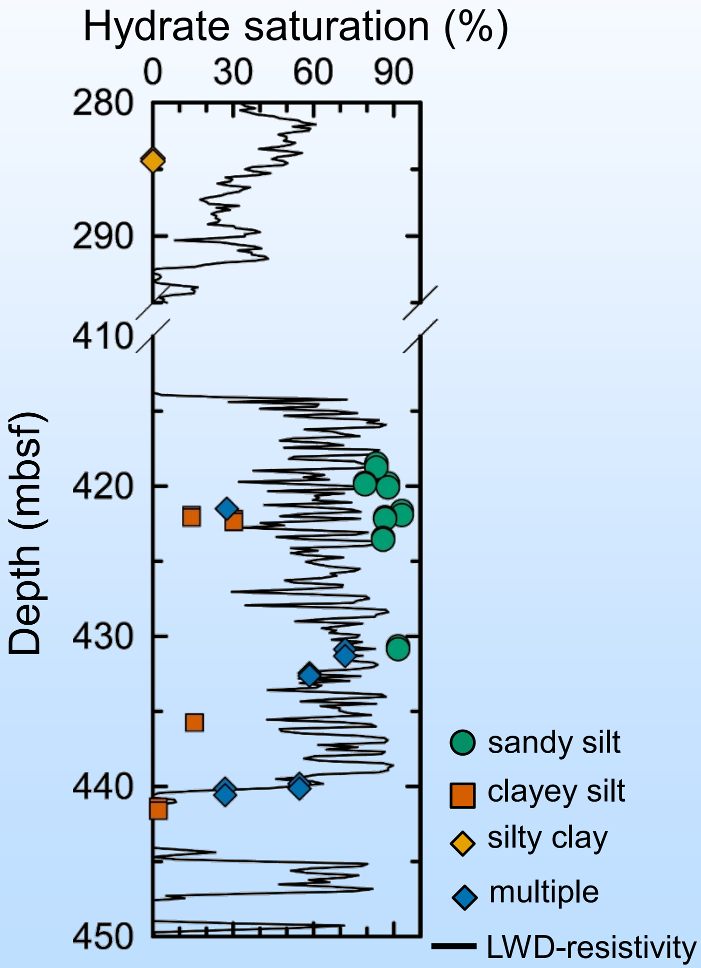
+90 scientists have been co-authors of GOM2-1 publications

Hydrate Reservoir at GC 955

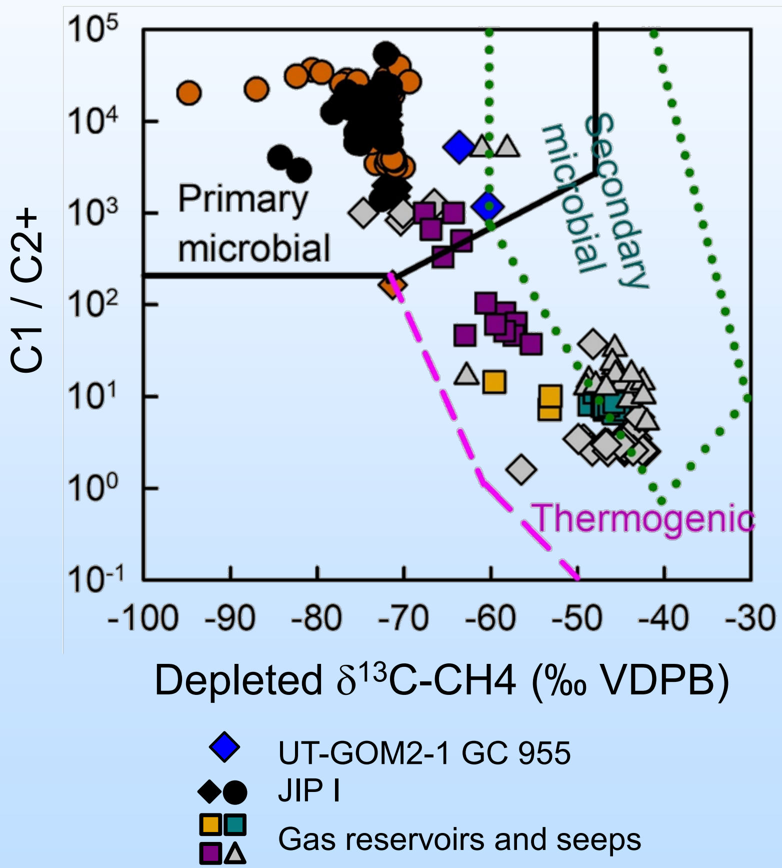


Gas Concentration & Composition at GC 955

Gas Concentration

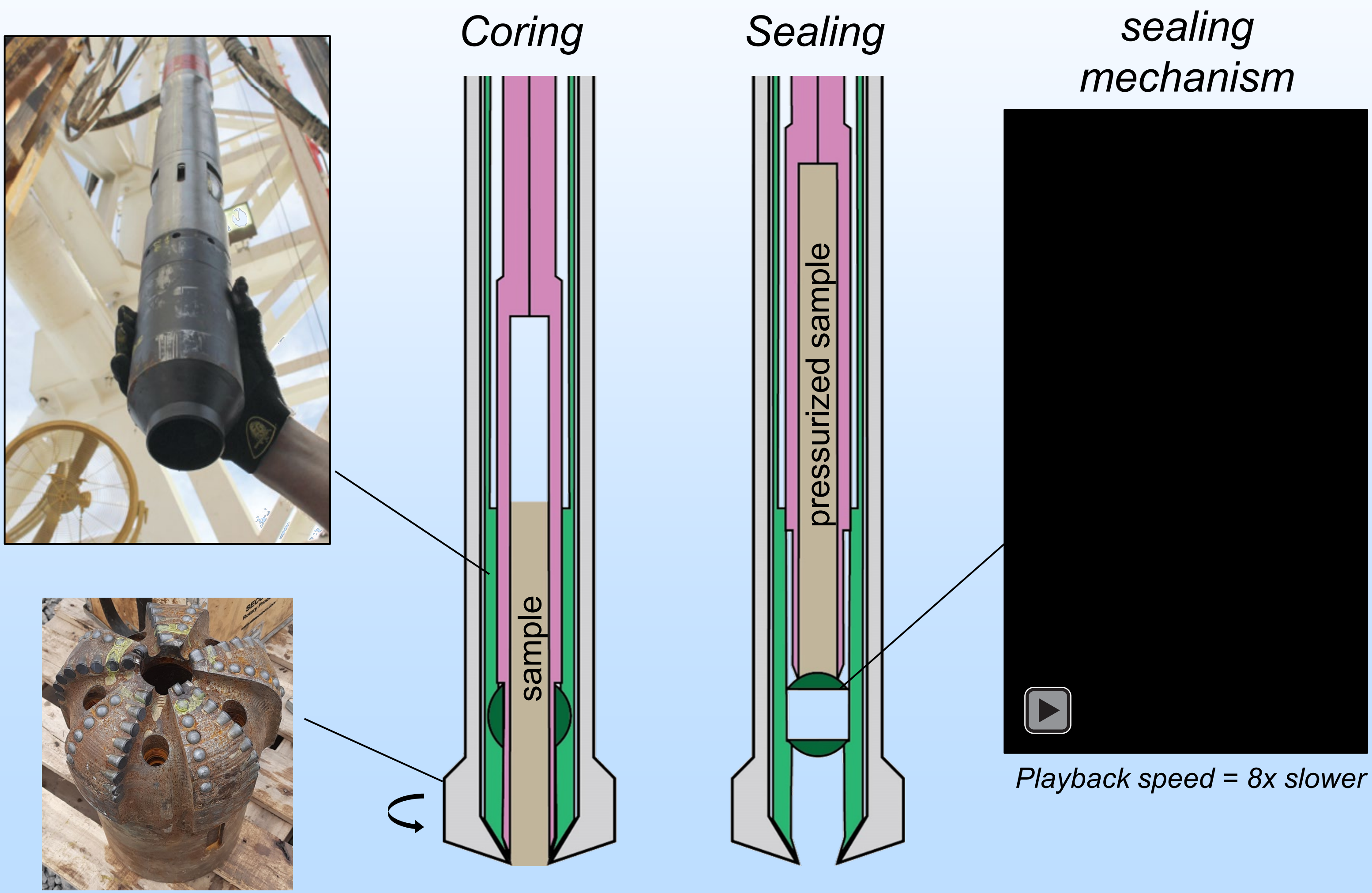


Gas Composition



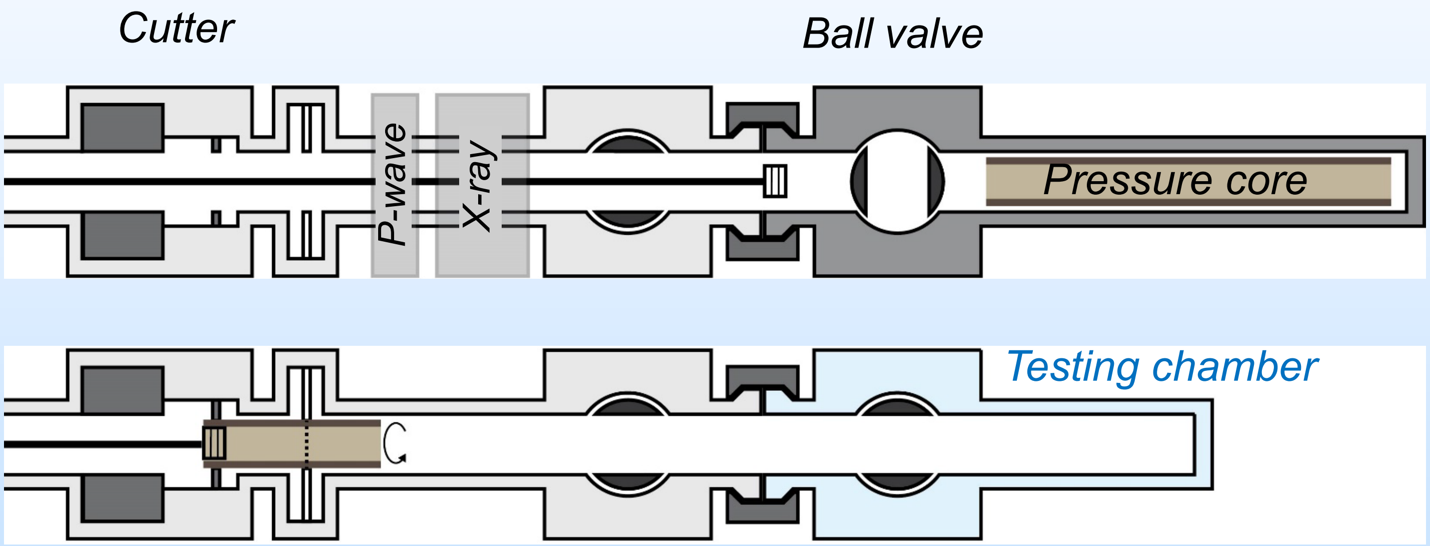
Pressure Cores: Coring→ Preparation→ Lab

High pressure and low temperature – from sampling to testing



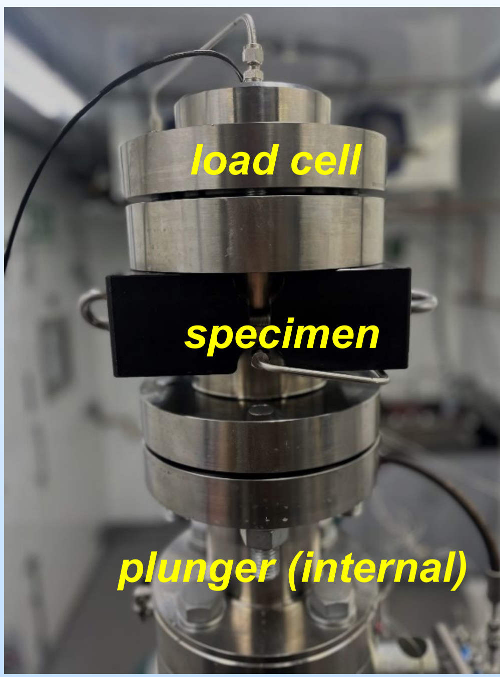
Pressure Cores: Coring→ Preparation→ Lab

High pressure and low temperature – from sampling to testing



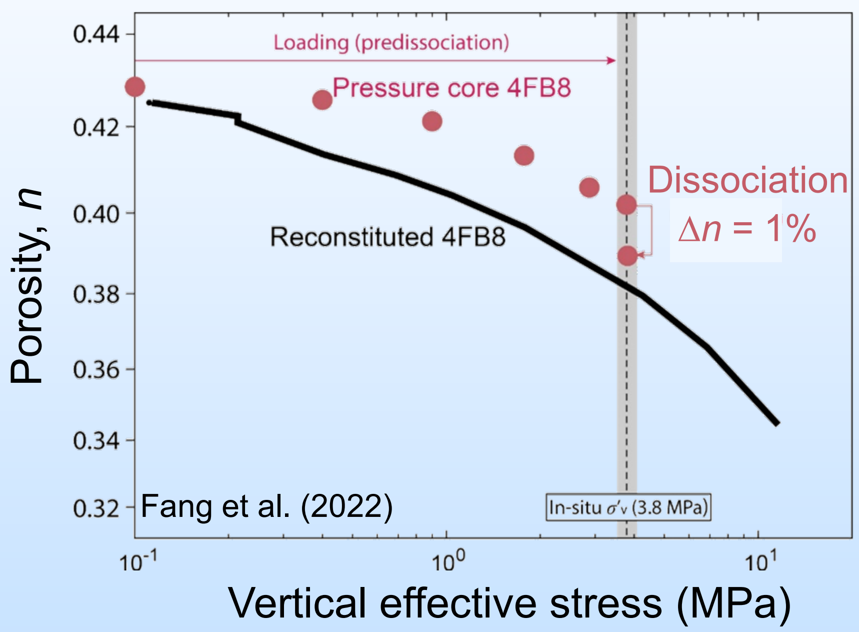
Pressure Cores: Coring→ Preparation → **Lab**

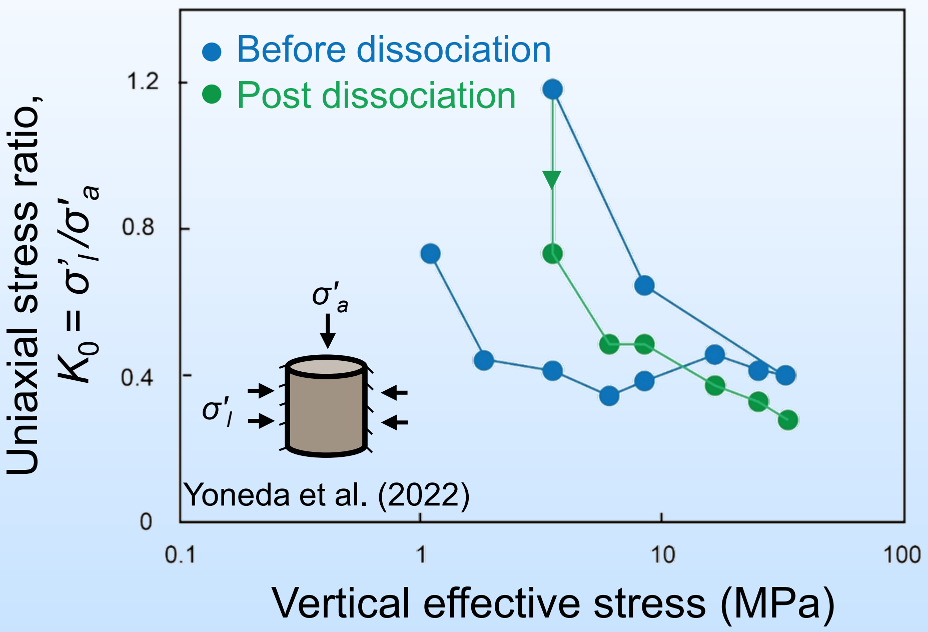
High pressure and low temperature – from sampling to testing



Testing chamber → Petrophysical & Geomechanical Properties

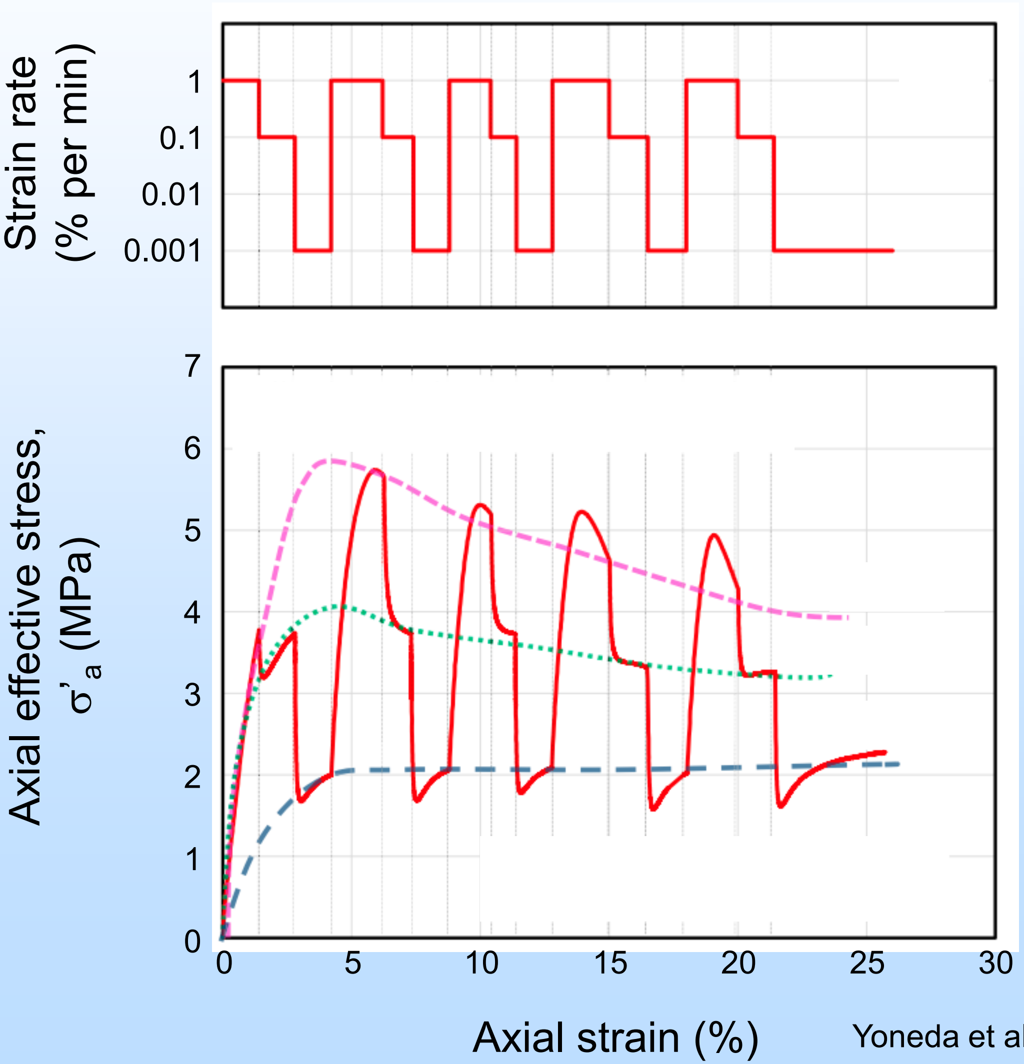
Hydrates: Geomechanical Behavior

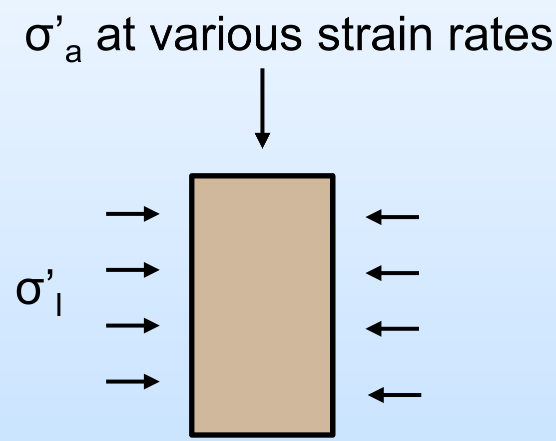




- Hydrate-bearing sediments are stiffer than hydrate-free counterparts
- Sediments compress during dissociation at constant stress
- The uniaxial stress ratio (K_0) is higher in hydrate sediments

Hydrates Sediments: Visco-Plastic Behavior

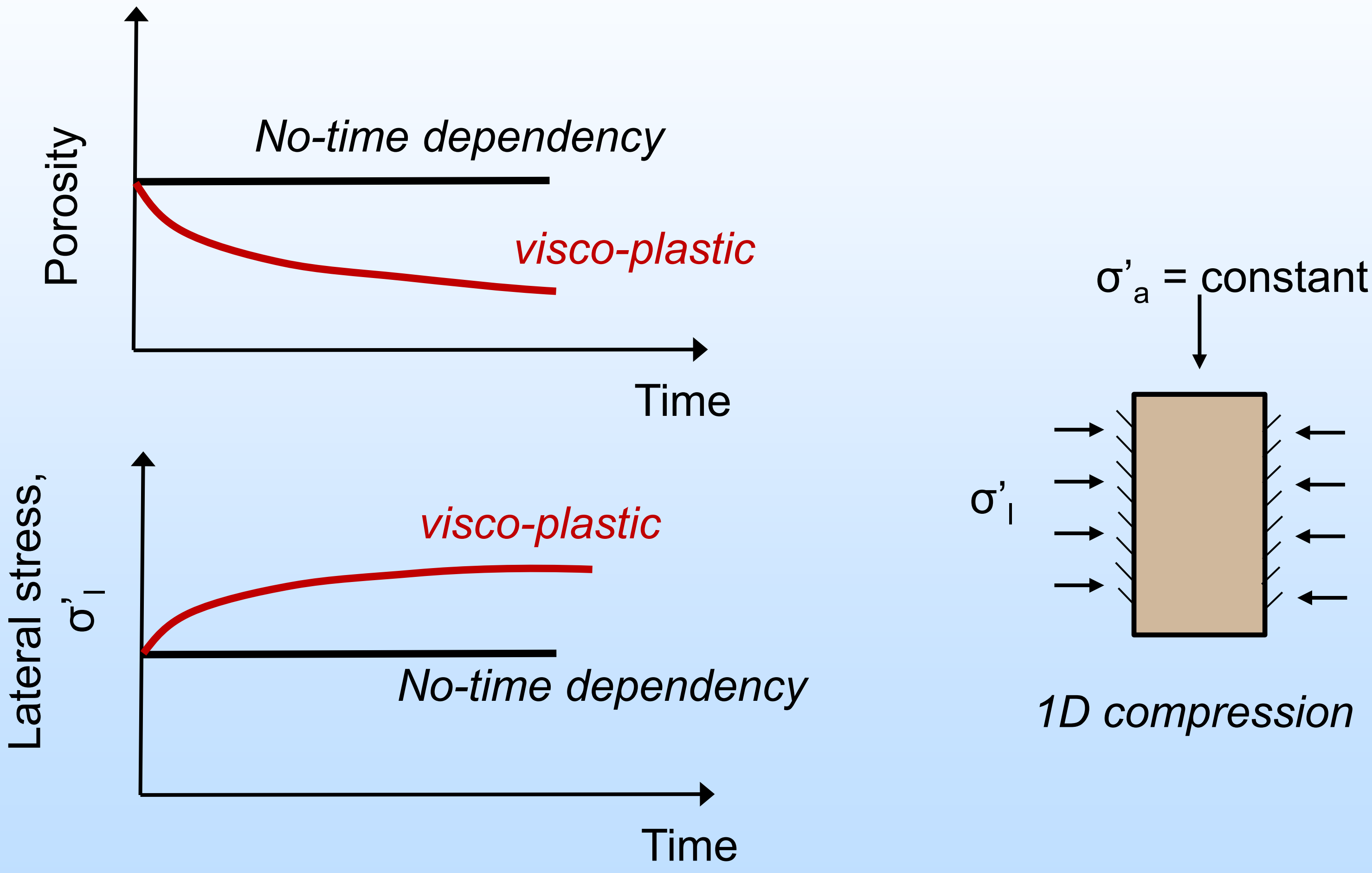




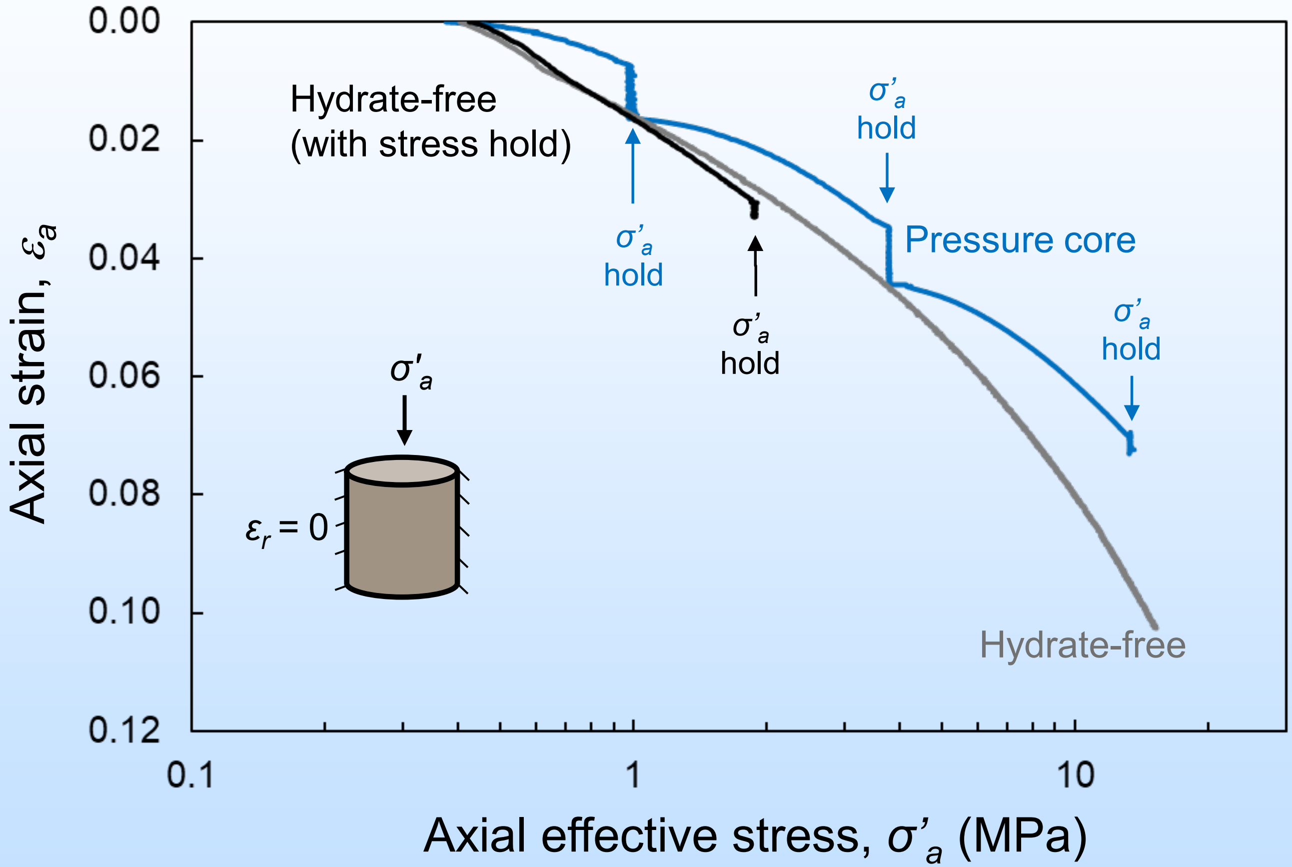
Triaxial compression

Yoneda et al. (2022)

Hydrates Sediments: Visco-Plastic Behavior



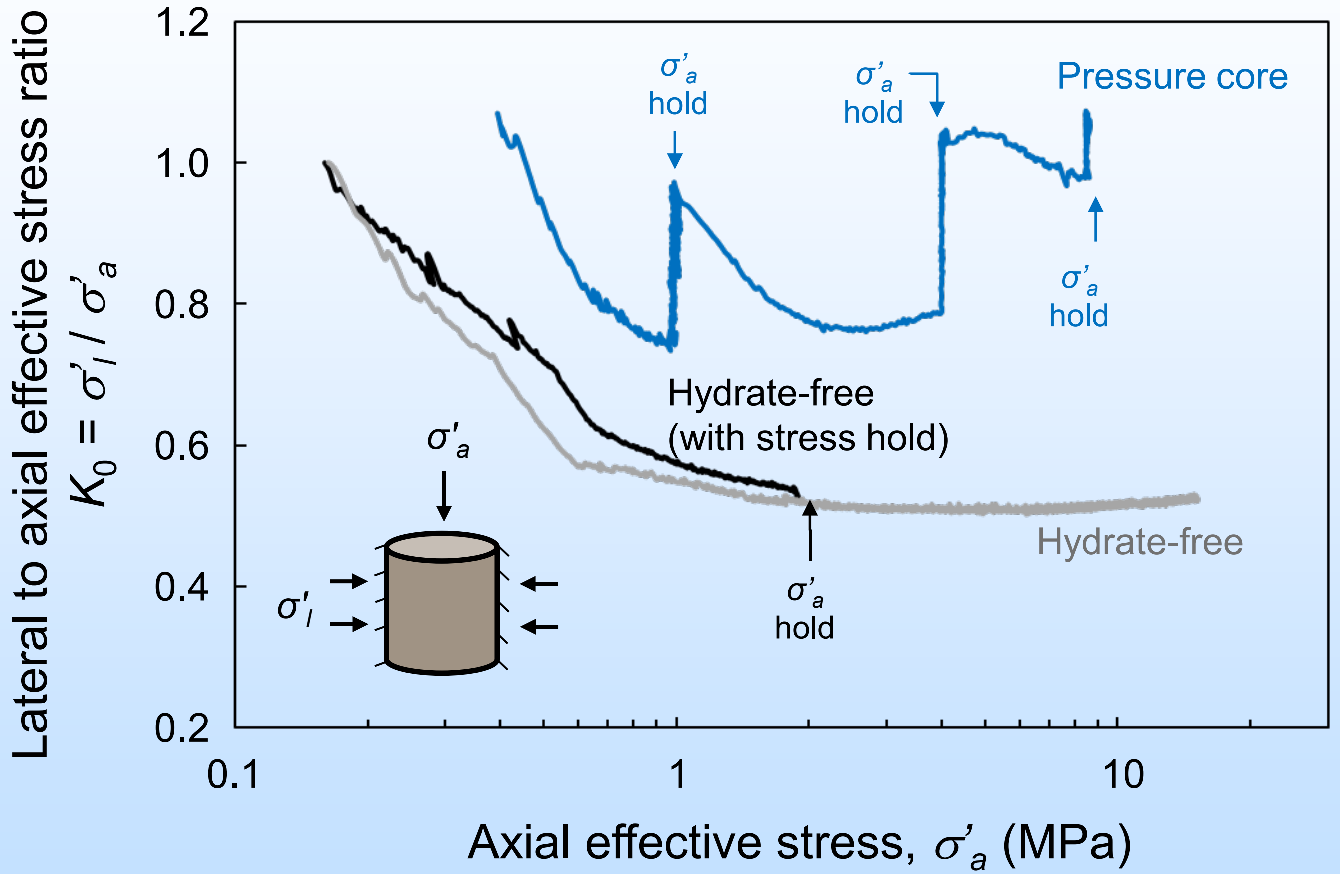
Hydrates Sediments: Visco-Plastic Behavior



The hydrate-bearing sediment (pressure core) behaves visco-plastically:

- The pressure core compresses significantly during the stress holds.

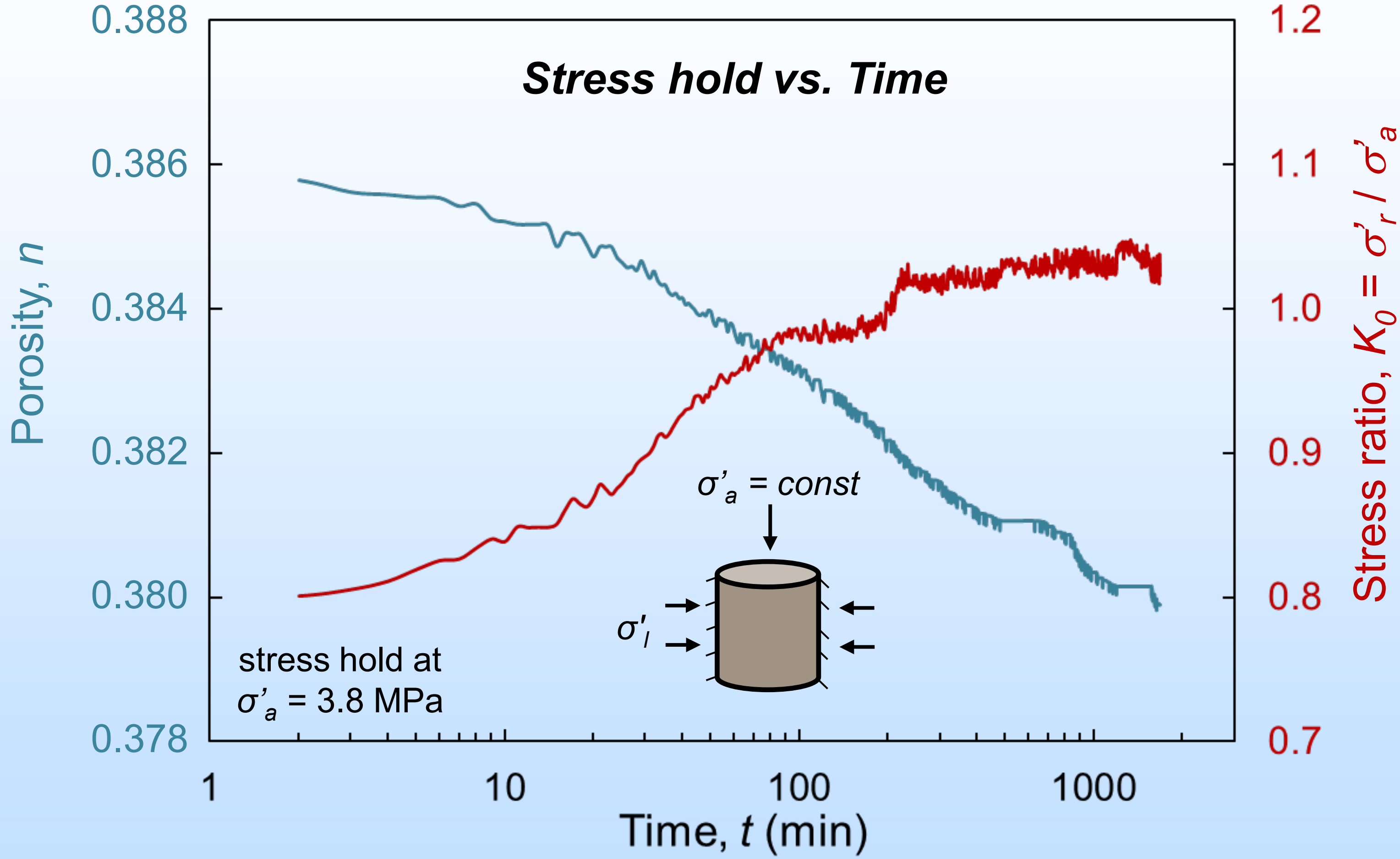
Hydrates Sediments: Visco-Plastic Behavior



The hydrate-bearing sediment (pressure core) behaves visco-plastically:

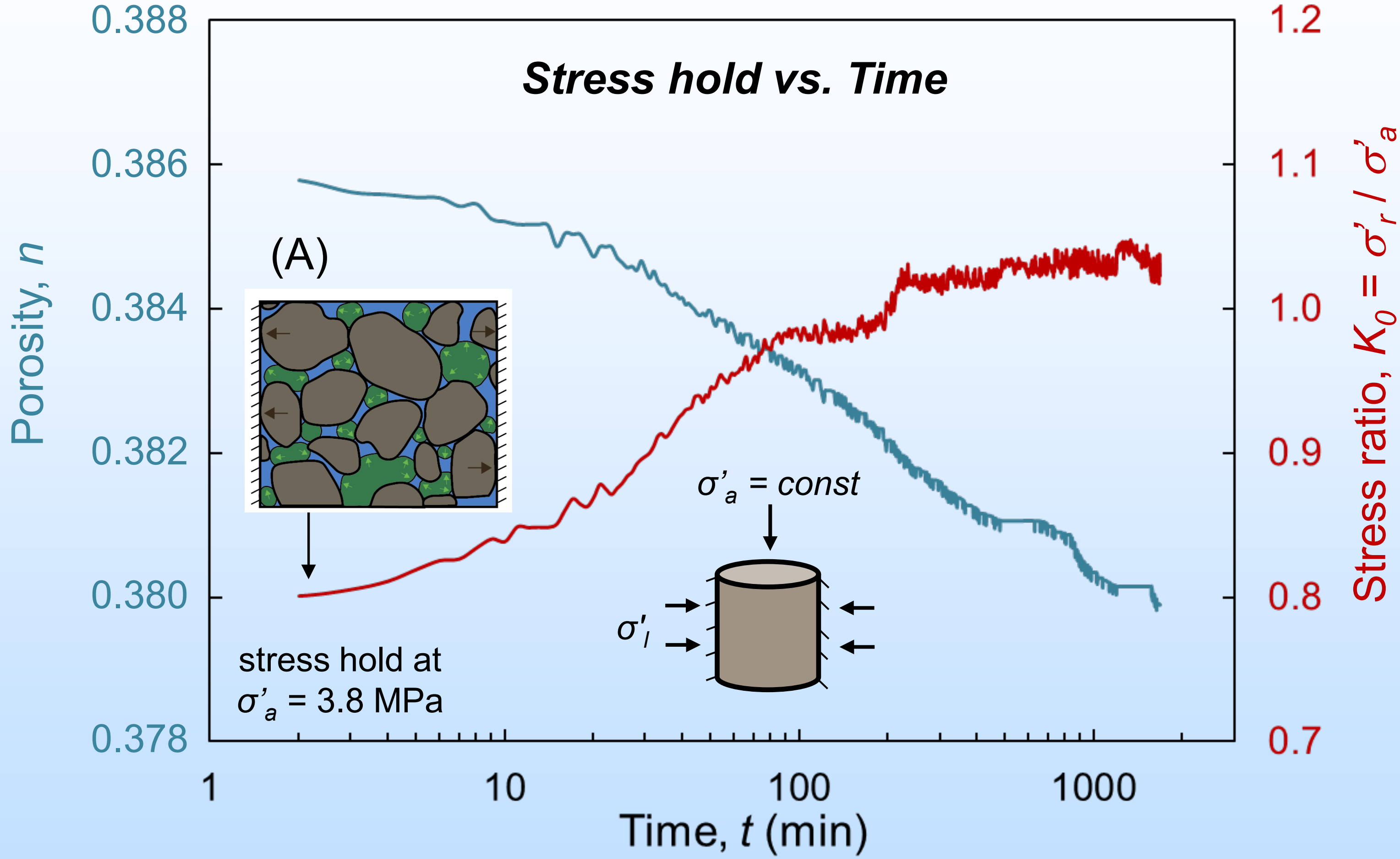
- The pressure core compresses significantly during the stress holds.
- The stress ratio K_0 increases during stress holds.

Hydrates Sediments: Visco-Plastic Behavior



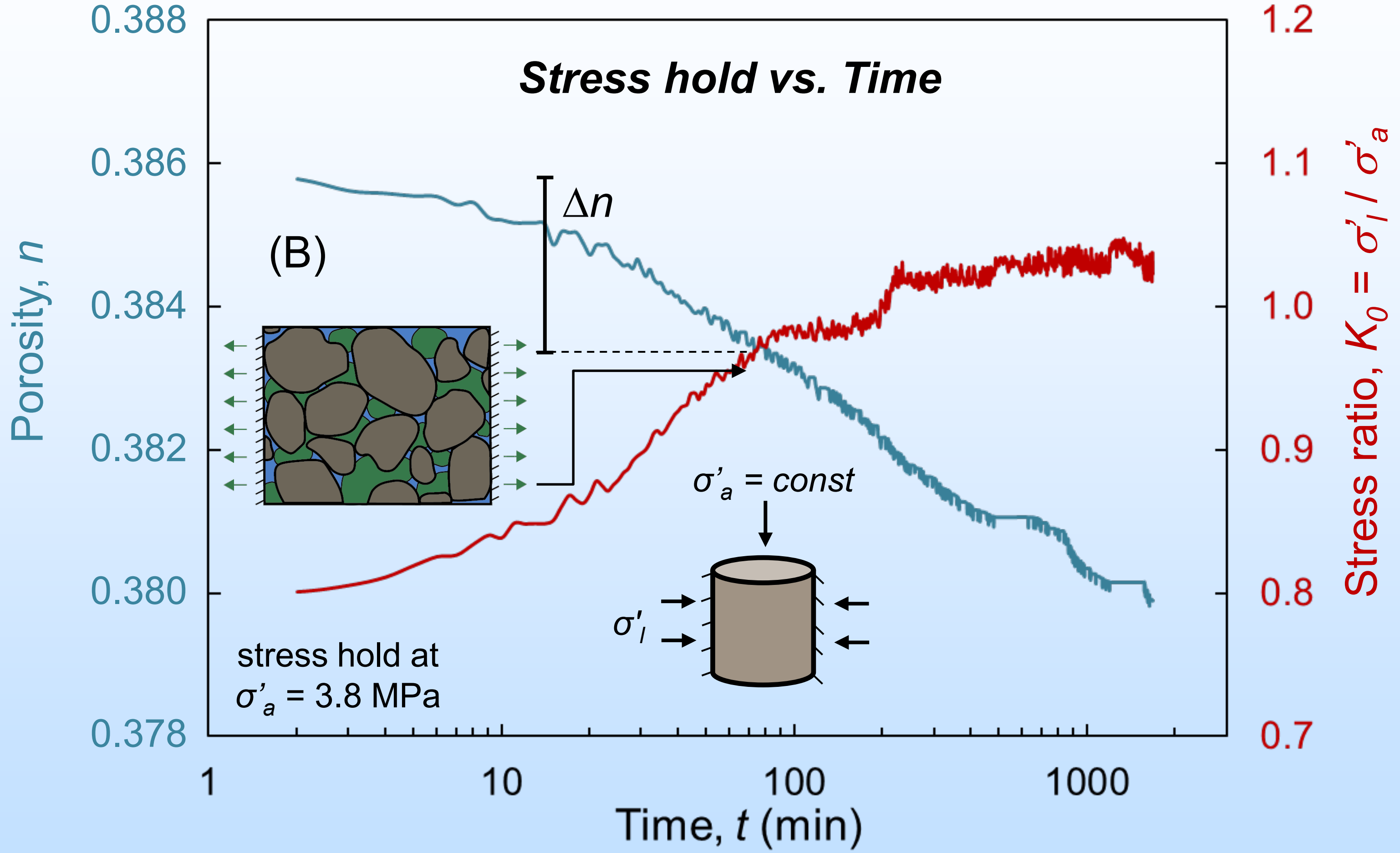
The hydrate-bearing sediment is a viscoplastic medium:

Hydrates Sediments: Visco-Plastic Behavior



The hydrate-bearing sediment is a viscoplastic medium:
(A) The hydrate is load bearing

Hydrates Sediments: Visco-Plastic Behavior



The hydrate-bearing sediment is a viscoplastic medium:
(B) Hydrate "flows" and re-distributes the load

Hydrates Sediments: Visco-Plastic Behavior

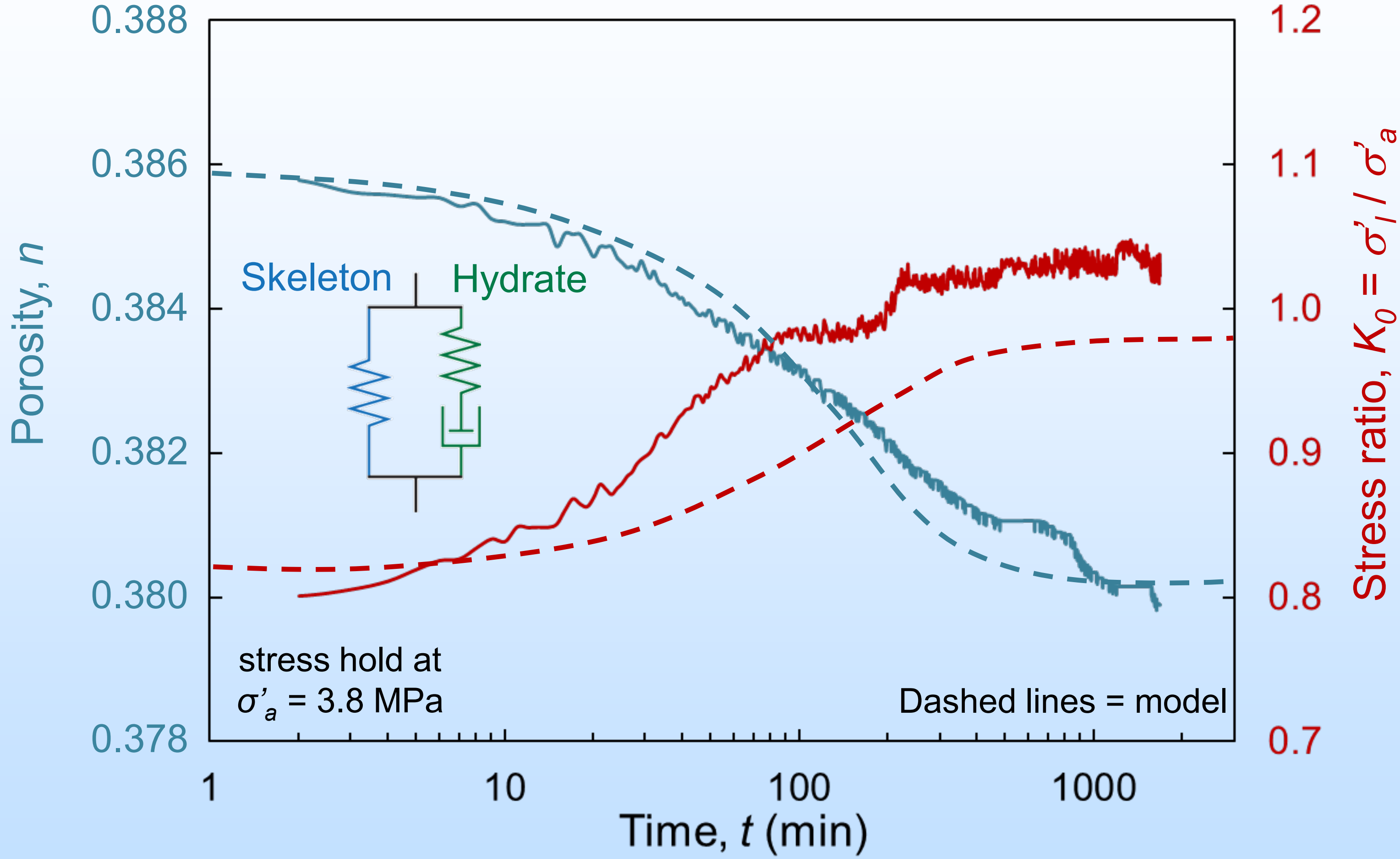
Modeling Visco-Plastic Behavior

$$\Delta\sigma = \Delta\sigma'^{s} + \Delta\sigma^{h}$$

Hydrate-bearing sediment | Sediment | Hydrate (viscous)

Hydrate and sediment share any applied external load

Hydrates Sediments: Visco-Plastic Behavior

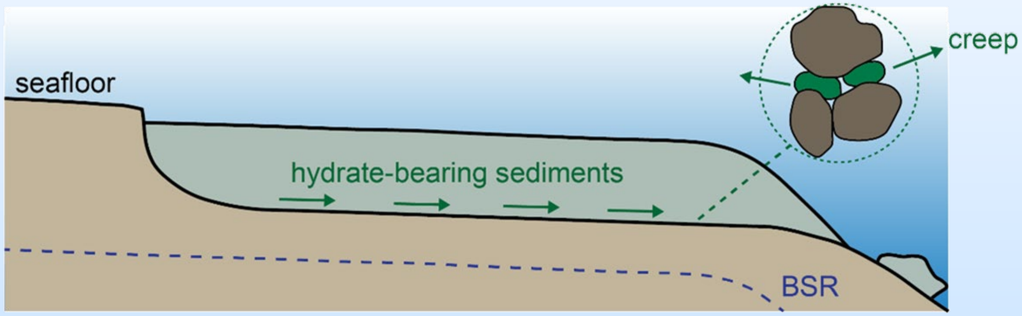


Linear solid model (spring-dashpot) to predict compression and K_0 trends with time

Visco-Plastic Behavior: Implications

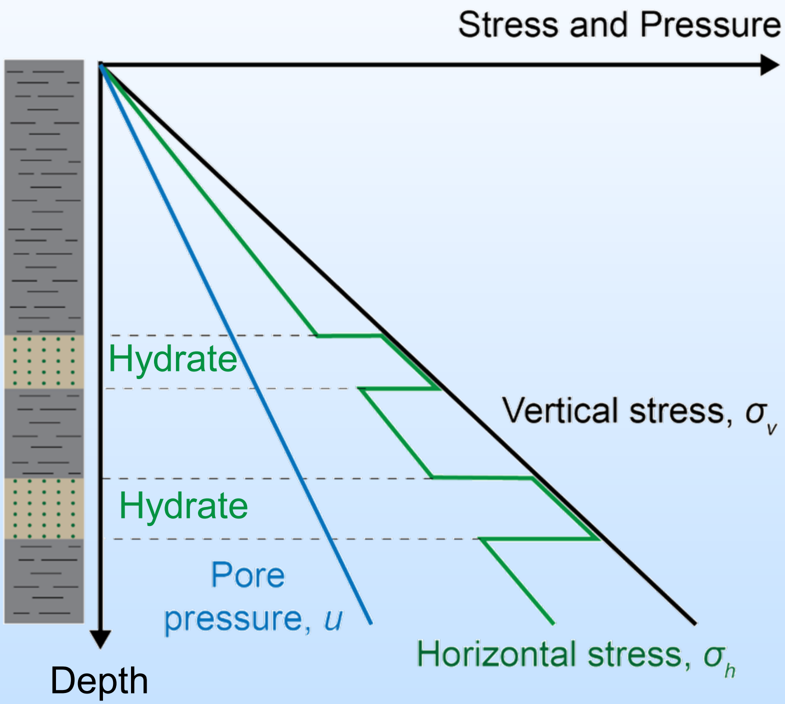
Submarine landslides

Hydrate glacier



After Mountjoy et al. (2014)

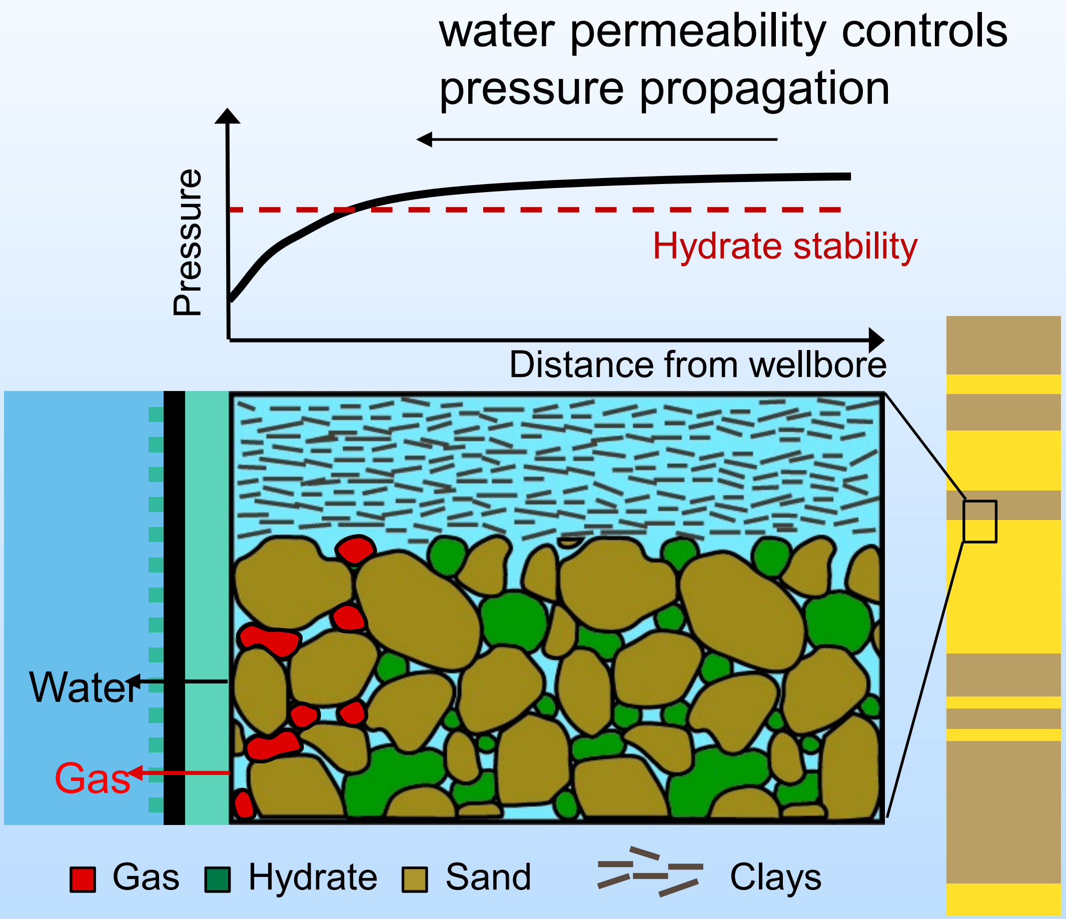
High in-situ stresses



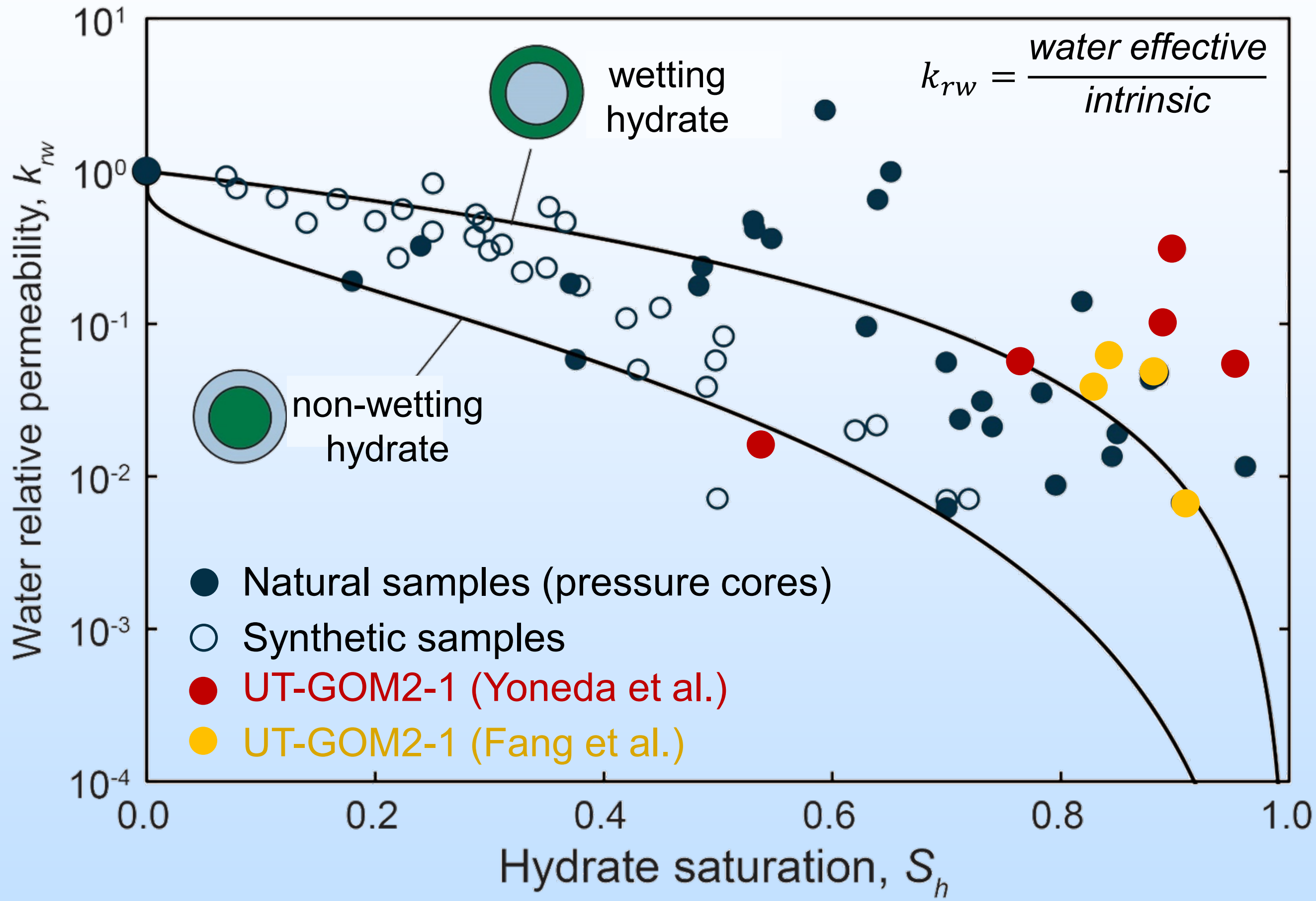
- Landslides can happen as a slow process (without hydrate dissociation)
- In-situ stresses in hydrate layers are isotropic

Hydrates Sediments: Water Permeability

Production by pressure drawdown

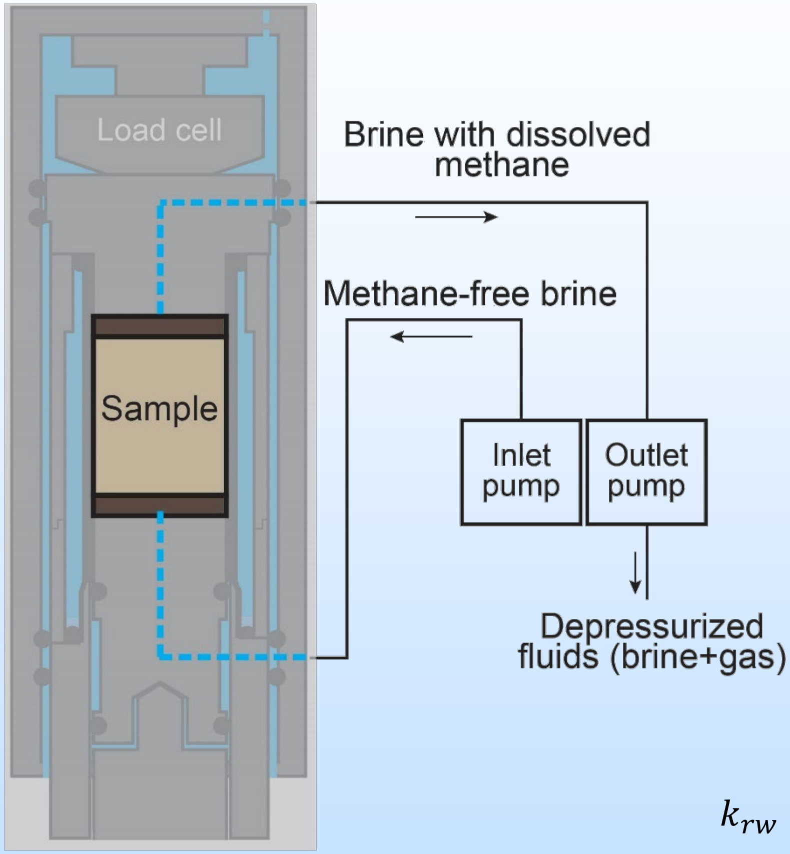


Hydrates Sediments: Water Permeability



Relative permeability in pressure cores ≫ measured on synthetic samples

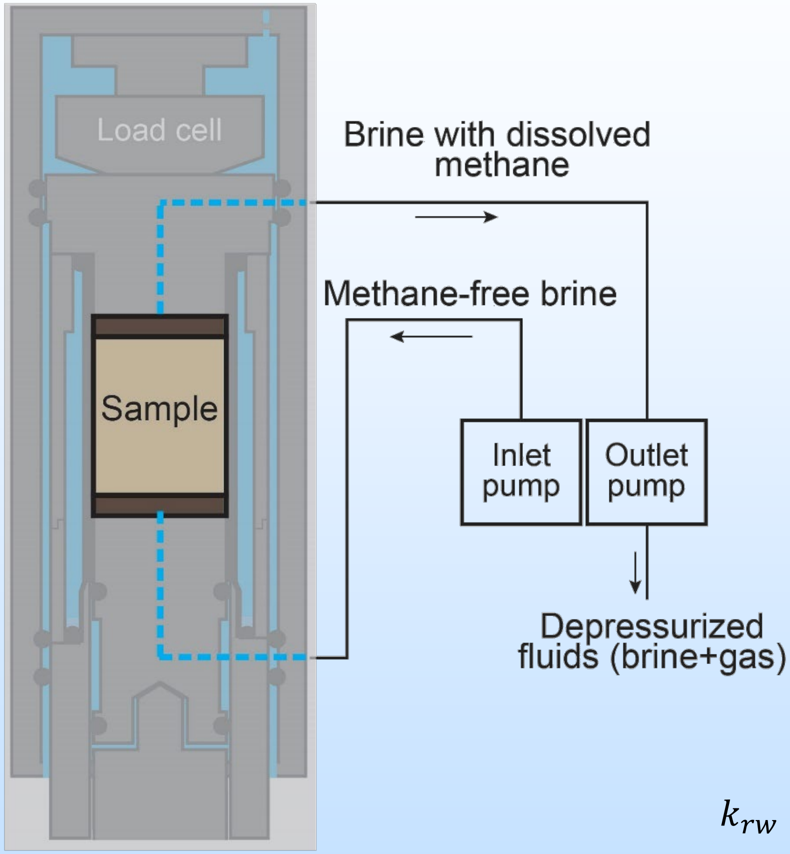
Hydrate Dissolution to Avoid Fines Migration

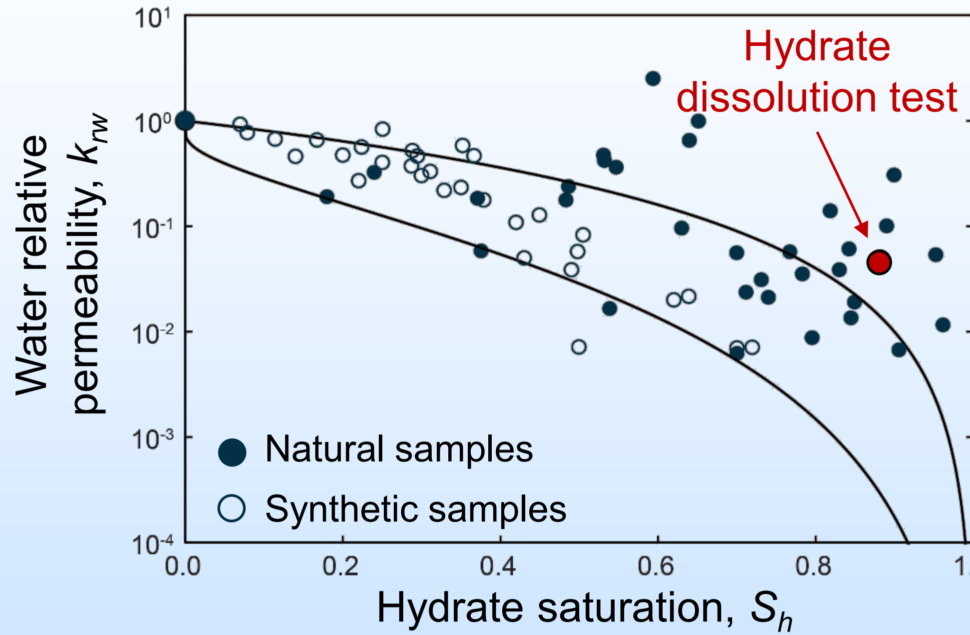


$$k_{rw} = \frac{\textit{water effective}}{\downarrow \textit{intrinsic}}$$

- Hydrate dissolution experiment removes the hydrate **without free gas.** This avoids fines migration and provides closer estimates of the intrinsic permeability (k_{int})

Hydrate Dissolution to Avoid Fines Migration



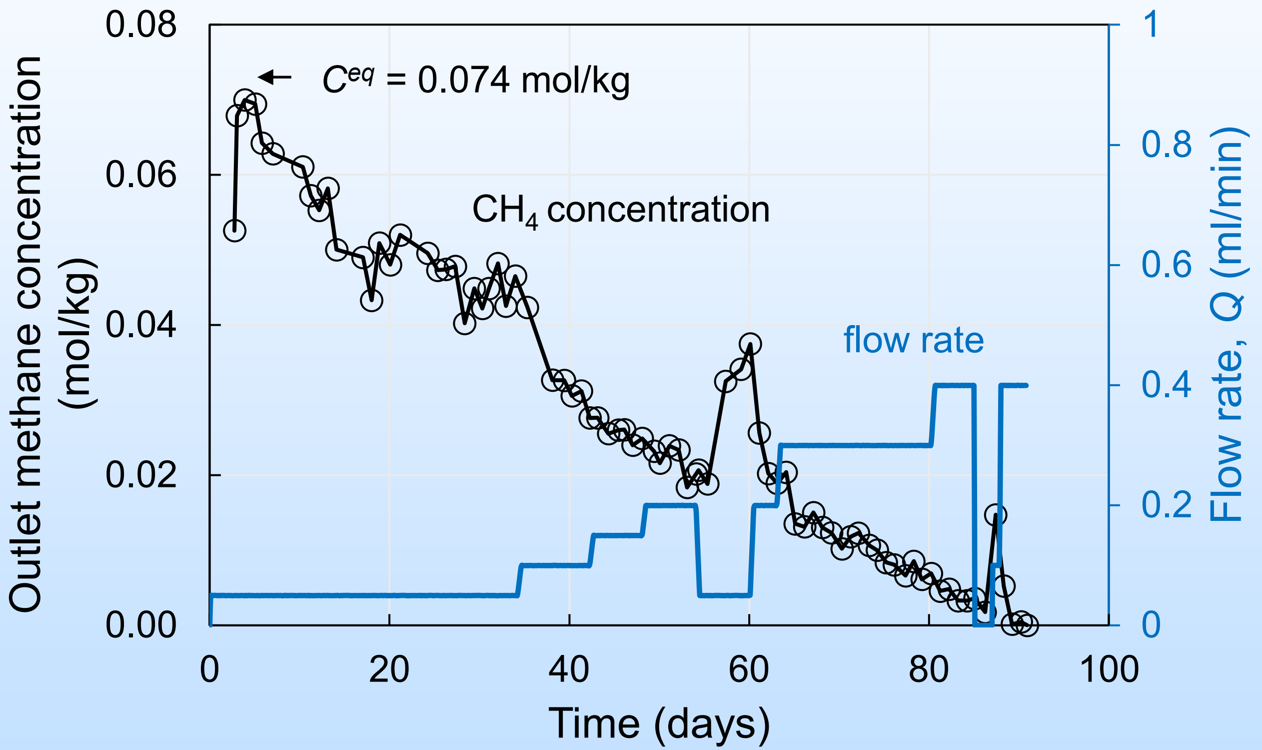


$$k_{rw} = \frac{\textit{water effective}}{\downarrow \textit{intrinsic}}$$

- Hydrate dissolution experiment removes the hydrate **without free gas.** This avoids fines migration and provides closer estimates of the intrinsic permeability (k_{int})
- After dissolution, the water relative permeability is still high.

Hydrate Dissolution & Flow Channeling

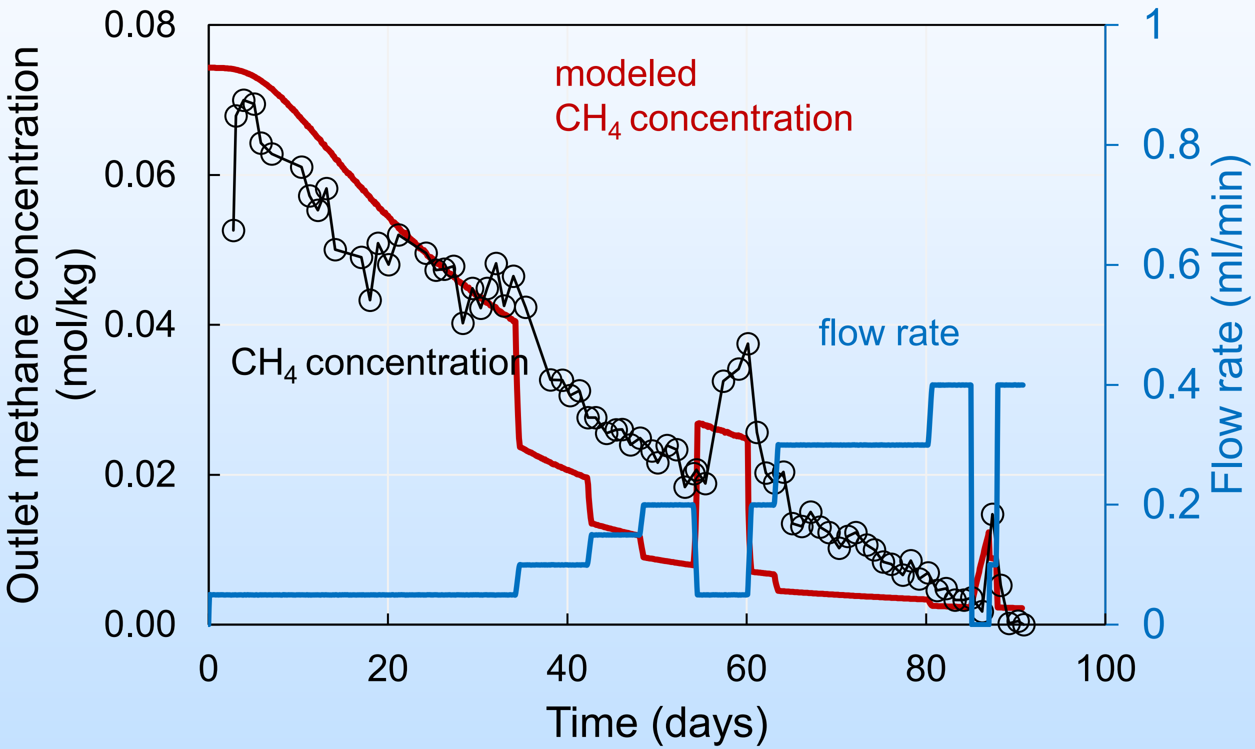
Hydrate Dissolution → Flow Channeling

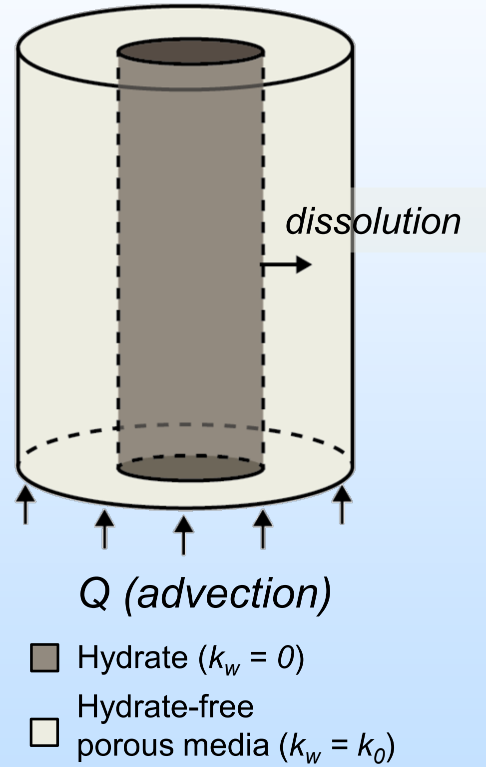


- Hydrate dissolution test revealed that the injection of methane-free water channelizes flow.
- This is evidenced by the CH_4 concentration vs. flow rate trends.

Hydrate Dissolution & Flow Channeling

Hydrate Dissolution → Flow Channeling



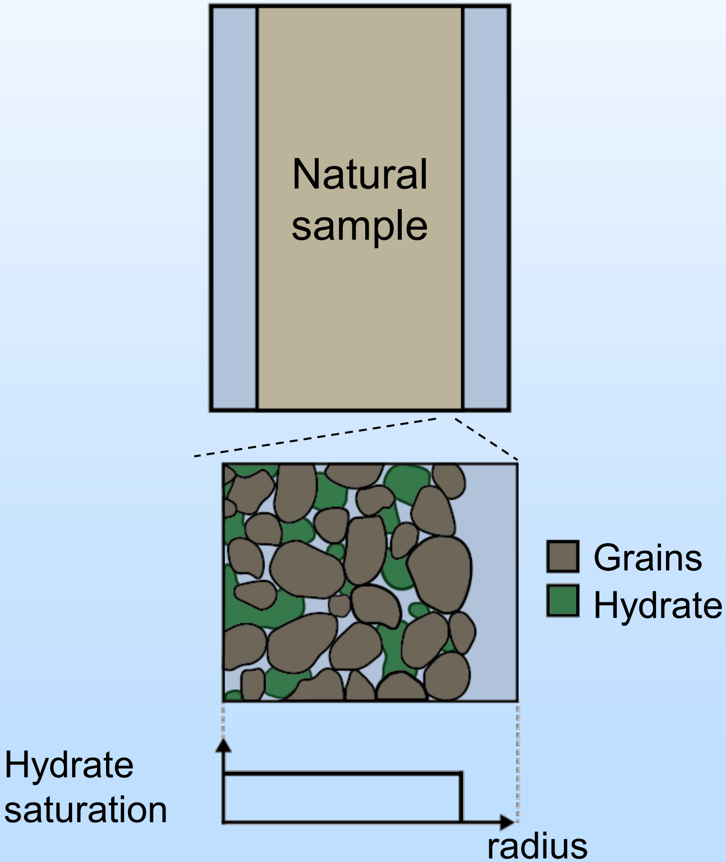


- We modeled this process with an advection-diffusion model.

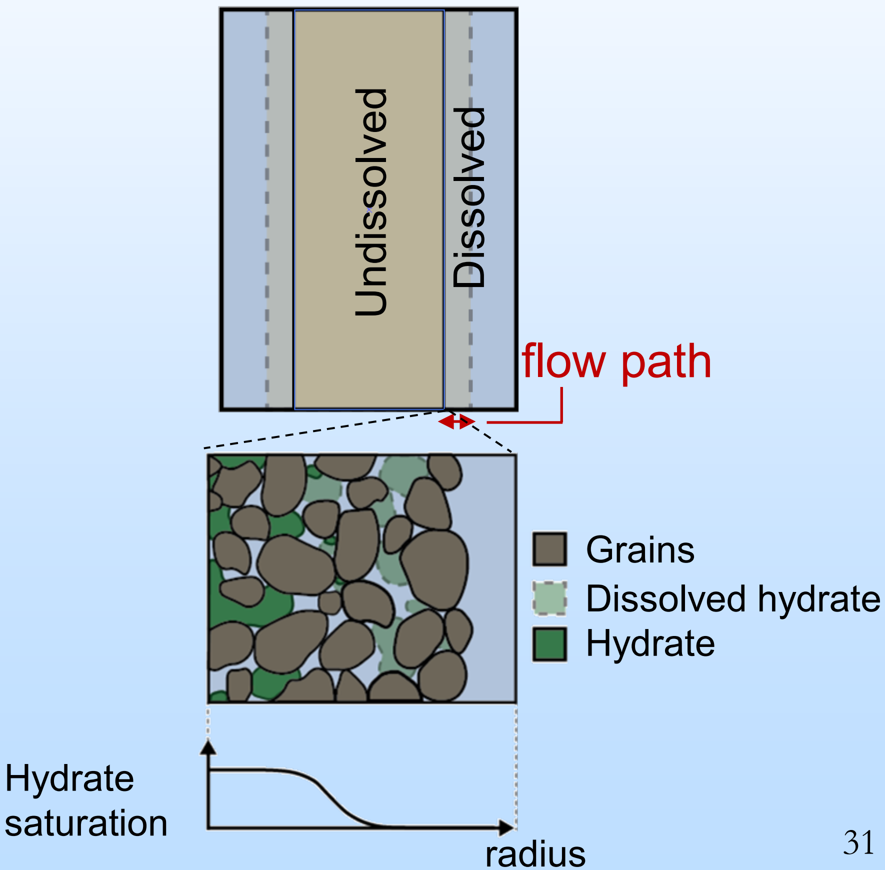
Hydrate Dissolution: Implications for Permeability

Long-term storage → Hydrate Dissolution → Flow Path → High permeability

Immediately after coring

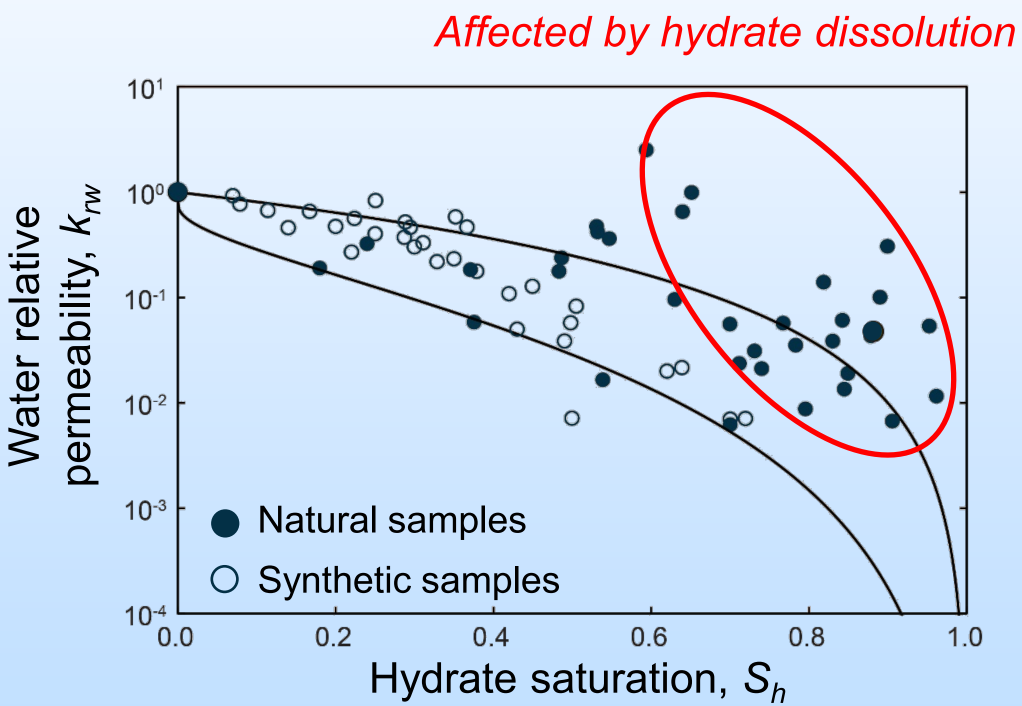


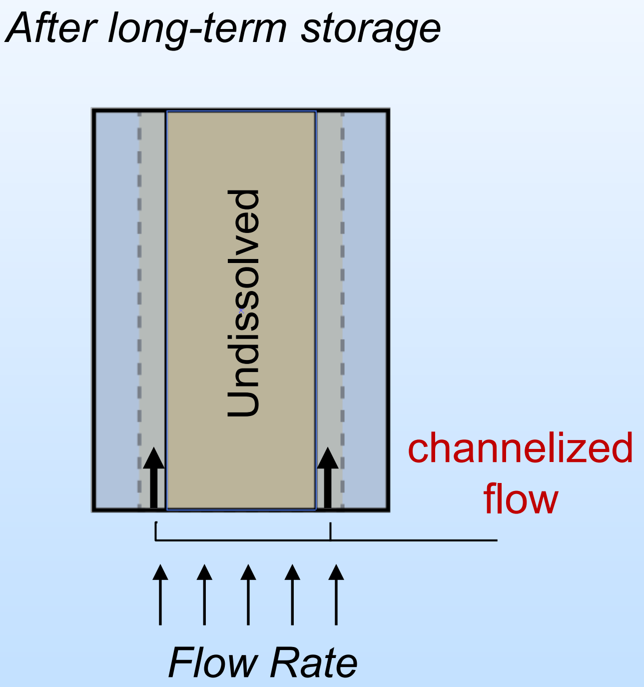
After long-term storage



Hydrate Dissolution: Implications for Permeability

Long-term storage → Hydrate Dissolution → Flow Path → High permeability





$$k_{rw} = \frac{\uparrow \textit{water effective}}{\textit{intrinsic}}$$

Key Points

GC 955 Expedition in 2017

- International collaboration
- Test pressure core technology for material characterization

Geomechanical behavior

- Hydrates are visco-plastic materials
- Stress and compression are time-dependent

Water relative permeability (k_{rw})

- Pressure cores show higher k_{rw} vs. synthetic samples
- Long-term storage causes hydrate dissolution and explains k_{rw} trends

Appendix

GOM2 Publications

Bhandari, A.R., Cardona, A., Flemings, P.B., Germaine, J. T. (In Review). Geomechanical behavior of sandy silt from Green Canyon 955 hydrate reservoir - Deepwater Gulf of Mexico for gas hydrate dissociation, Marine and Petroleum Geology

Boswell, R., Collet, T.C., Cook, A.E., Flemings, P.B., 2020, Introduction to Special Issue: Gas Hydrates in Green Canyon Block 955, deep-water Gulf of Mexico: Part I: AAPG Bulletin, v. 104, no. 9, p. 1844-1846, http://dx.doi.org/10.1306/bltnintro062320.

Cardona A., Bhandari A., and Heidari M. and Flemings P.B. (2023). The viscoplastic behavior of natural hydrate bearing sediments under uniaxial strain compression (K0 loading), Journal of Geophysical Research: Solid Earth, v. 128, e2023JB026976, doi:10.1029/2023JB026976

Chen, X., and Espinoza, D. N., 2018a, Ostwald ripening changes the pore habit and spatial variability of clathrate hydrate: Fuel, v. 214, p. 614-622. https://doi.org/10.1016/j.fuel.2017.11.065

Chen, X., Verma, R., Espinoza, D. N., and Prodanović, M., 2018, Pore-Scale Determination of Gas Relative Permeability in Hydrate-Bearing Sediments Using X-Ray Computed Micro-Tomography and Lattice Boltzmann Method: Water Resources Research, v. 54, no. 1, p. 600-608. https://doi.org/10.1002/2017wr021851

Chen, X. Y., and Espinoza, D. N., 2018b, Surface area controls gas hydrate dissociation kinetics in porous media: Fuel, v. 234, p. 358-363. https://doi.org/10.1016/j.fuel.2018.07.030

Chen, X.Y., Espinoza, D. N., Tisato, N., Flemings, P. B., in press, Gas Permeability, Pore Habit and Salinity Evolution during Methane Hydrate Dissociation in Sandy Sediments: Energy & Fuels, Manuscript ID: ef-2022-017204.R2

Cook, A. E., and Portnov, A., 2019, Gas hydrates in coarse-grained reservoirs interpreted from velocity pull up: Mississippi Fan, Gulf of Mexico: COMMENT: Geology, v. 47, no. 3, p. e457-e457. https://doi.org/10.1130/g45609c.1

Cook, A. E., and Sawyer, D. E., 2015, The mud-sand crossover on marine seismic data: Geophysics, v. 80, no. 6, p. A109-A114. https://doi.org/10.1190/geo2015-0291.1

Cook, A. E., and Waite, W. F., 2018, Archie's Saturation Exponent for Natural Gas Hydrate in Coarse-Grained Reservoirs, v. 123, no. 3, p. 2069-2089. https://doi.org/10.1002/2017jb015138

Appendix

Daigle, H., Fang, Y., Phillips, S.C., Flemings, P.B., 2022, Pore structure of sediments from Green Canyon 955 determined by mercury intrusion: AAPG Bulletin, v. 106, no. 5, p. 1051-1069. https://doi.org/10.1306/02262120123

Darnell, K. N., and Flemings, P. B., 2015, Transient seafloor venting on continental slopes from warming-induced methane hydrate dissociation: Geophysical Research Letters, p. n/a-n/a. https://doi.org/10.1002/2015GL067012

Darnell, K. N., Flemings, P. B., and DiCarlo, D., 2019, Nitrogen-Driven Chromatographic Separation During Gas Injection Into Hydrate-Bearing Sediments: Water Resources Research. https://doi.org/10.1029/2018wr023414

Ewton, E., 2019, The effects of X-ray CT scanning on microbial communities in sediment coresHonors]: Oregon State University, 21 p.

Fang, Y., Flemings, P. B., Daigle, H., Phillips, S. C., Meazell, P. K., and You, K., 2020, Petrophysical properties of the Green Canyon block 955 hydrate reservoir inferred from reconstituted sediments: Implications for hydrate formation and production: AAPG Bulletin, v. 104, no. 9, p. 1997–2028, https://doi.org/10.1306/01062019165

Fang, Y., Flemings, P.B., Daigle, H., Phillips, S.C., O'Connel, J., 2022, Permeability of methane hydrate-bearing sandy silts in the deepwater Gulf of Mexico (Green Canyon block 955): AAPG Bulletin, v. 106, no. 5, p. 1071-1100. https://doi.org/10.1306/08102121001

Fang, Y., Flemings, P.B., Germaine, J.T., Daigle, H., Phillips, S.C., 2022, Compression behavior of hydrate-bearing sediments: AAPG Bulletin, v. 106, no. 5, p. 1101-1126. https://doi.org/10.1306/01132221002

Flemings, P. B., Phillips, S. C., Boswell, R., Collett, T. S., Cook, A. E., Dong, T., Frye, M., Guerin, G., Goldberg, D. S., Holland, M. E., Jang, J., Meazell, K., Morrison, J., O'Connell, J., Pettigrew, T., Petrou, E., Polito, P. J., Portnov, A., Santra, M., Schultheiss, P. J., Seol, Y., Shedd, W., Solomon, E. A., Thomas, C., Waite, W. F., and You, K., 2020, Pressure coring a Gulf of Mexico Deepwater Turbidite Gas Hydrate Reservoir: Initial results from the UT-GOM2-1 hydrate pressure coring expedition: AAPG Bulletin, v. 104, no. 9, p. 1847-1876. https://doi.org/10.1306/05212019052

Flemings, P. B., Phillips, S. C., Collett, T., Cook, A., Boswell, R., and Scientists, U.-G.-E., 2018, UT-GOM2-1 Hydrate Pressure Coring Expedition Summary, *in* Flemings, P. B., Phillips, S. C., Collett, T., Cook, A., Boswell, R., and Scientists, U.-G.-E., eds., UT-GOM2-1 Hydrate Pressure Coring Expedition Report: Austin, TX, University of Texas Institute for Geophysics.

Flemings, P.B., Cook, A.E., Collett, T., Boswell, R., 2022 Gas hydrates in Green Canyon Block 955, deep-water Gulf of Mexico: Part II, Insights and future challenges: AAPG Bulletin, v. 106, no. 5, p. 937-947. https://doi.org/10.1306/bltnintro030922

Appendix

Hillman, J. I. T., Cook, A. E., Daigle, H., Nole, M., Malinverno, A., Meazell, K., and Flemings, P. B., 2017a, Gas hydrate reservoirs and gas migration mechanisms in the Terrebonne Basin, Gulf of Mexico: Marine and Petroleum Geology, v. 86, no. Supplement C, p. 1357-1373. https://doi.org/10.1016/j.marpetgeo.2017.07.029

Hillman, J. I. T., Cook, A. E., Sawyer, D. E., Küçük, H. M., and Goldberg, D. S., 2017b, The character and amplitude of 'discontinuous' bottom-simulating reflections in marine seismic data: Earth and Planetary Science Letters, v. 459, p. 157-169. https://doi.org/10.1016/j.epsl.2016.10.058

Johnson, J.E., MacLeod, D.R., Phillips, S.C., Purkey Phillips, M., Divins, D.L., 2022. Primary deposition and early diagenetic effects on the high saturation accumulation of gas hydrate in a silt dominated reservoir in the Gulf of Mexico. Marine Geology, Volume 444, 2022, 106718, https://doi.org/10.1016/j.margeo.2021.106718.

MacLeod, D.R., 2020. Characterization of a silty methane-hydrate reservoir in the Gulf of Mexico: Analysis of full sediment grain size distributions. M.S. Thesis, pp. 165, University of New Hampshire, Durham NH, U.S.A.

Majumdar, U., and Cook, A. E., 2018, The Volume of Gas Hydrate-Bound Gas in the Northern Gulf of Mexico: Geochemistry, Geophysics, Geosystems, v. 19, no. 11, p. 4313-4328. https://doi.org/10.1029/2018gc007865

Majumdar, U., Cook, A. E., Shedd, W., and Frye, M., 2016, The connection between natural gas hydrate and bottom-simulating reflectors: Geophysical Research Letters. https://doi.org/10.1002/2016GL069443

Meazell, K., Flemings, P., Santra, M., and Johnson, J. E., 2020, Sedimentology and stratigraphy of a deepwater gas hydrate reservoir in the northern Gulf of Mexico: AAPG Bulletin, v. 104, no. 9, p. 1945–1969, https://doi.org/10.1306/05212019027

Meyer, D. W., 2018, Dynamics of gas flow and hydrate formation within the hydrate stability zone [Doctor of Philosophy: The University of Texas at Austin.

Meyer, D. W., Flemings, P. B., and DiCarlo, D., 2018a, Effect of Gas Flow Rate on Hydrate Formation Within the Hydrate Stability Zone: Journal of Geophysical Research-Solid Earth, v. 123, no. 8, p. 6263-6276. https://doi.org/10.1029/2018jb015878

Meyer, D. W., Flemings, P. B., DiCarlo, D., You, K. H., Phillips, S. C., and Kneafsey, T. J., 2018b, Experimental Investigation of Gas Flow and Hydrate Formation Within the Hydrate Stability Zone: Journal of Geophysical Research-Solid Earth, v. 123, no. 7, p. 5350-5371. https://doi.org/10.1029/2018jb015748

Appendix

Moore, M., Phillips, S., Cook, A.E. and Darrah, T., (2020) Improved sampling technique to collect natural gas from hydrate-bearing pressure cores. Applied Geochemistry, Volume 122, November 2020, p. 104773, https://doi.org/10.1016/j.apgeochem.2020.104773.

Moore, M.T., Phillips, S.C., Cook, A.E., Darrah, T.H., 2022, Integrated geochemical approach to determine the source of methane in gas hydrate from Green Canyon Block 955 in the Gulf of Mexico: AAPG Bulletin, v. 106, no. 5, p. 949-980. https://doi.org/10.1306/05272120087

Naim, F., Cook, A.E., Moortgat, J. (2023) Estimating P-wave Velocity and Bulk Density in Near-seafloor Sediments Using Machine Learning, Energies. 16(23) doi:10.3390/en16237709. https://www.mdpi.com/1996-1073/16/23/7709

Oti, E.A., Cook, A.E., Phillips, S.C., Holland, M.E., 2022 Using X-ray Computed Tomography (XCT) to Estimate Hydrate Saturation in Sediment Cores from Green Canyon 955, northern Gulf of Mexico: AAPG Bulletin, v. 106, no. 5, p. 1127-1142. https://doi.org/10.1306/05272120051

Phillips, S. C., Flemings, P. B., Holland, M. E., Schulthiss, P. J., Waite, W. F., Jang, J., Petrou, E. G., and H., H., 2020, High concentration methane hydrate in a silt reservoir from the deep-water Gulf of Mexico: AAPG Bulletin, v. 104, no. 9, p. 1971–1995. https://doi.org/10.1306/01062018280

Phillips, S. C., Flemings, P. B., You, K., Meyer, D. W., and Dong, T., 2019, Investigation of in situ salinity and methane hydrate dissociation in coarse-grained sediments by slow, stepwise depressurization: Marine and Petroleum Geology, v. 109, p. 128-144. https://doi.org/10.1016/j.marpetgeo.2019.06.015

Phillips, S.C., Flemings, P.B., You, K., Waite, W.F., 2022, Thermodynamic insights into the production of methane hydrate reservoirs from depressurization of pressure cores AAPG Bulletin, v. 106, no. 5, p. 1025-1049. https://doi.org/10.1306/08182120216

Portnov, A., You, K., Flemings, P.B., Cook, A.E., Heidari, M., Sawyer, D.E. and Bünz, S. (2023) Dating submarine landslides using the transient response of gas hydrate stability. Geology. doi: 10.1130/G50930.

Portnov, A., Flemings, P. B., You, K., Meazell, K., Hudec, M. R., and Dunlap, D. B., 2023, Low temperature and high pressure dramatically thicken the gas hydrate stability zone in rapidly formed sedimentary basins: Marine and Petroleum Geology, v. 158, p. 106550.

Portnov, A., Cook, A. E., Heidari, M., Sawyer, D. E., Santra, M., and Nikolinakou, M., 2020, Salt-driven evolution of a gas hydrate reservoir in Green Canyon, Gulf of Mexico: AAPG Bulletin, v. 104, no. 9, p. 1903–1919, http://dx.doi.org/10.1306/10151818125

Appendix

Portnov, A., Cook, A. E., Sawyer, D. E., Yang, C., Hillman, J. I. T., and Waite, W. F., 2019, Clustered BSRs: Evidence for gas hydrate-bearing turbidite complexes in folded regions, example from the Perdido Fold Belt, northern Gulf of Mexico: Earth and Planetary Science Letters, v. 528. https://doi.org/10.1016/j.epsl.2019.115843

Portnov, A., Santra, M., Cook., A.E., and Sawyer, D.E, (2020) The Jackalope gas hydrate system in the northeastern Gulf of Mexico. Journal of Marine and Petroleum Geology. https://doi.org/10.1016/j.marpetgeo.2019.08.036

Santra, M., Flemings, P., Meazell, K., and Scott, E., 2020, Evolution of Gas Hydrate-bearing Deepwater Channel-Levee System in Abyssal Gulf of Mexico – Levee Growth and Deformation: : AAPG Bulletin, v. 104, no. 9, p. 1921–1944, https://doi.org/10.1306/04251918177

Santra, M., Flemings, P.B., Heidari, M., You, K., 2022, Occurrence of High-Saturation Gas Hydrate in a Fault-Compartmentalized Anticline and the Role of Seal- Green Canyon, Abyssal Gulf of Mexico: AAPG Bulletin, v. 106, no. 5, p. 981-1003. https://doi.org/10.1306/08182120149

Sawyer, D. E., Mason, R. A., Cook, A. E., and Portnov, A., 2019, Submarine Landslides Induce Massive Waves in Subsea Brine Pools: Scientific Reports, v. 9, no. 1, p. 128. https://doi.org/10.1038/s41598-018-36781-7

Sheik, C. S., Reese, B. K., Twing, K. I., Sylvan, J. B., Grim, S. L., Schrenk, M. O., Sogin, M. L., and Colwell, F. S., 2018, Identification and Removal of Contaminant Sequences From Ribosomal Gene Databases: Lessons From the Census of Deep Life: Front Microbiol, v. 9, p. 840. https://doi.org/10.3389/fmicb.2018.00840

Smart, K (2018). Modeling Well Log Responses in Hydrate Bearing Silts. Ohio State University. Undergraduate Thesis.

Smith, A. J., Flemings, P. B., Liu, X., and Darnell, K., 2014, The evolution of methane vents that pierce the hydrate stability zone in the world's oceans: Journal of Geophysical Research: Solid Earth, p. 2013JB010686. https://doi.org/10.1002/2013JB010686

Thomas, C., Phillips, S. C., Flemings, P. B., Santra, M., Hammon, H., Collett, T. S., Cook, A., Pettigrew, T., Mimitz, M., Holland, M., and Schultheiss, P., 2020, Pressure-coring operations during the University of Texas Hydrate Pressure Coring Expedition, UT-GOM2-1, in Green Canyon Block 955, northern Gulf of Mexico: AAPG Bulletin, v. 104, no. 9, p. 1877–1901. https://doi.org/10.1306/02262019036

Appendix

Varona, G. M., Flemings, P.B., Portnov, A., 2023, Hydrate-bearing sands record the transition from ponded deposition to bypass in the deep-water Gulf of Mexico, Marine and Petroleum Geology, v. 151. https://doi.org/10.1016/j.marpetgeo.2023.106172

Wei, L., Cook, A., Daigle, H., Malinverno, A., Nole, M., and You, K., 2019, Factors Controlling Short-Range Methane Migration of Gas Hydrate Accumulations in Thin Coarse-Grained Layers: Geochemistry, Geophysics, Geosystems, v. 20, no. 8, p. 3985-4000. https://doi.org/10.1029/2019gc008405

Wei, L., Cook, A.E., You, K., 2022, Methane migration mechanisms for the Green Canyon Block 955 gas hydrate reservoir, northern Gulf of Mexico: AAPG Bulletin, v. 106, no. 5, p. 1005-1023. https://doi.org/10.1306/06022120134

Yoneda, J., Jin, Y., Muraoka, M., Oshima, M., Suzuki, K., Waite, W.F., Flemings, P.B., 2022, Comprehensive pressure core analysis for hydrate-bearing sediments from Gulf of Mexico Green Canyon Block 955, including assessments of geomechanical viscous behavior and NMR permeability: AAPG Bulletin, v. 106, no. 5, p. 1143-1177. https://doi.org/10.1306/04272120204

You, K., Summa, L., Flemings, P., Santra, M., and Fang, Y., 2021, Three-Dimensional Free Gas Flow Focuses Basin

Wide Microbial Methane to Concentrated Methane Hydrate Reservoirs in Geological System: Journal of Geophysical Research: Solid Earth, v. 126, no. 12, p. e2021JB022793. https://doi.org/https://doi.org/10.1029/2021JB022793

You, K., and Flemings, P. B., 2018, Methane hydrate formation in thick sandstones by free gas flow: Journal of Geophysical Research: Solid Earth, v. 123, p. 4582-4600. https://doi.org/10.1029/2018JB015683

You, K., Flemings, P. B., Malinverno, A., Collett, T. S., and Darnell, K., 2019, Mechanisms of Methane Hydrate Formation in Geological Systems: Reviews of Geophysics, v. 0, no. ja. https://doi.org/10.1029/2018rg000638

You, K., Kneafsey, T. J., Flemings, P. B., Polito, P., and Bryant, S. L., 2015, Salinity-buffered methane hydrate formation and dissociation in gas-rich systems: Journal of Geophysical Research: Solid Earth, v. 120, no. 2, p. 643-661. https://doi.org/10.1002/2014JB011190

You, K., Summa, L., Flemings, P. B., Santra, M., and Fang, Y., (2021), Three-dimensional free gas flow focuses basin-wide microbial methane to concentrated methane hydrate reservoirs in geological system, Journal of Geophysical Research: Solid Earth, 126, e2021JB022793.

You K., and Flemings, P. B., (2021), Methane hydrate formation and evolution during sedimentation, Journal of Geophysical Research: Solid Earth, 126, e2020JB021235.