Physical properties of hydrate-bearing and baseline sediment: laboratory and field studies

NETL Hydrate Program Review Meeting

National Energy Technology Laboratory

26-27 August 2008

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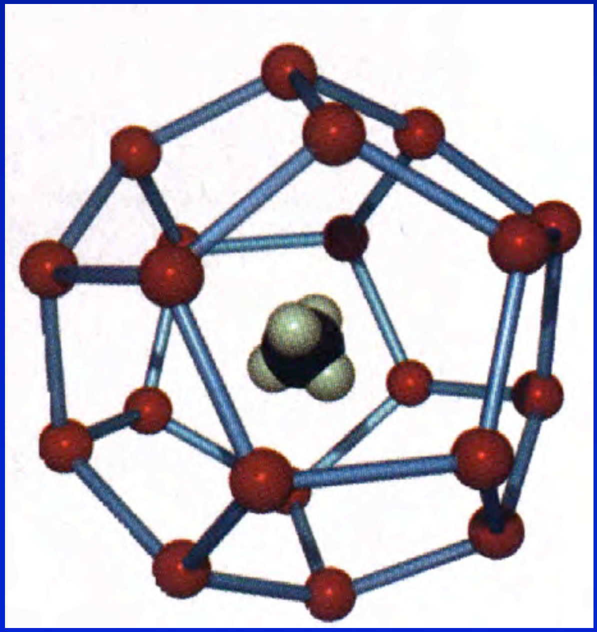
U.S. Geological Survey
Woods Hole, MA 02543



Outline

- Multifaceted project -Field and lab aspects
  - Overview/Accomplishments
    - Technological advances
      - GHASTLI
      - Ties to pressure coring
  - Collaborations
  - Finances
  - Publications
- Physical properties
  - Why do we measure them?
- Field programs
  - Types of measurements
  - Characterize sediment
  - Determination of geologic controls - key
  - Ground truth well logs
  - Support for other shipboard studies
- Shore-based studies
  - Grain-size analyses…
    - Regional trends
    - Relation to samples w/ IR anomalies
    - Impotance for production testing
  - GHASTLI (USGS)
    - Samples containing natural gas hydrate
    - Lab-formed gas hydrate
- Path forward
  - Field - Challenge for pressure coring
  - Lab

Overview/Field Accomplishments

Supports DOE’s need for: samples…ground-truth tools…

…testing production strategies

USGS PP field program involvements:

•ODP Leg 164 (1995)

First dedicated GH ODP leg

PCS - Gas tool, no samples

•Mallik 2L (1998)

Additional press. Coring dev

•Marion Dufresne - GOM (2002)

Piston coring

•Mallik 5L (2002)

•NGHP-01 - India (2006)

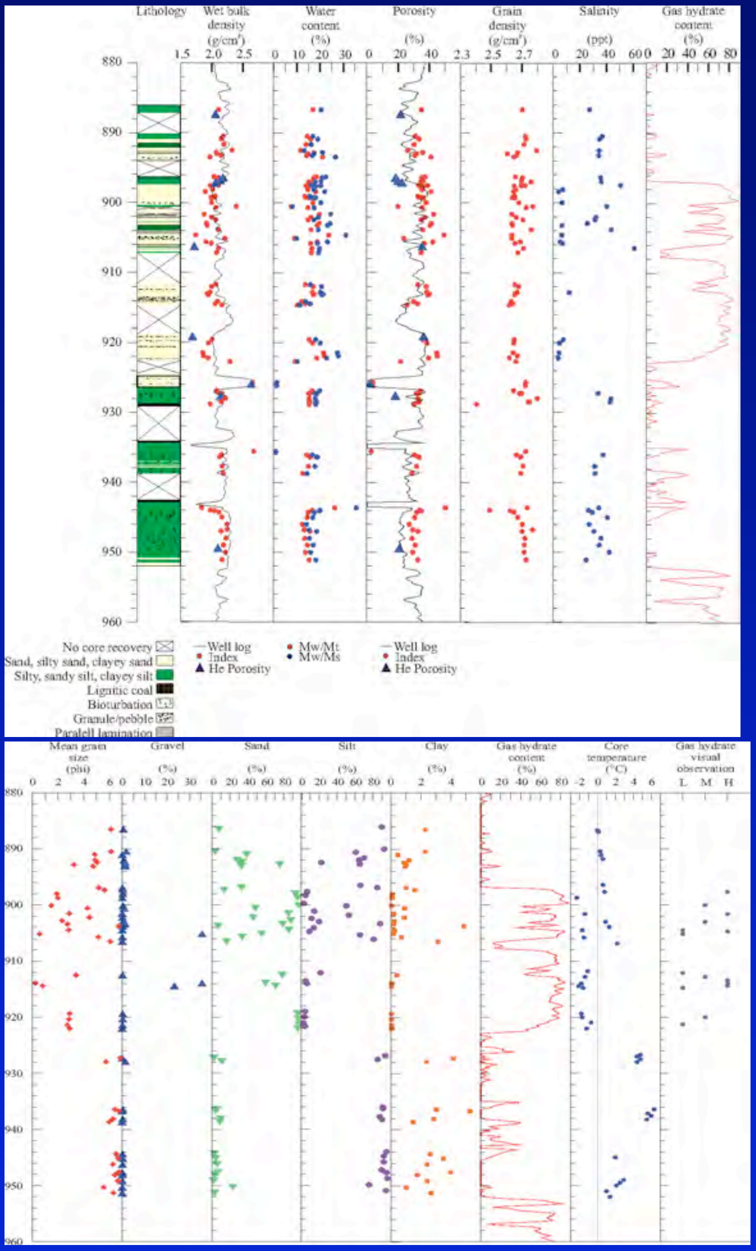
Press. core transfer

•Mt. Elbert - North Slope Alaska (2007)

Tested samples from: ODP Leg 204, 2005 JIP

- Quantify porous-media effect to study geologic controls on gas hydrate occurrence
- Ground truth well-log and other field results
- Provide formation properties for models

•Transfer of LN2 samples from USGS to NETL

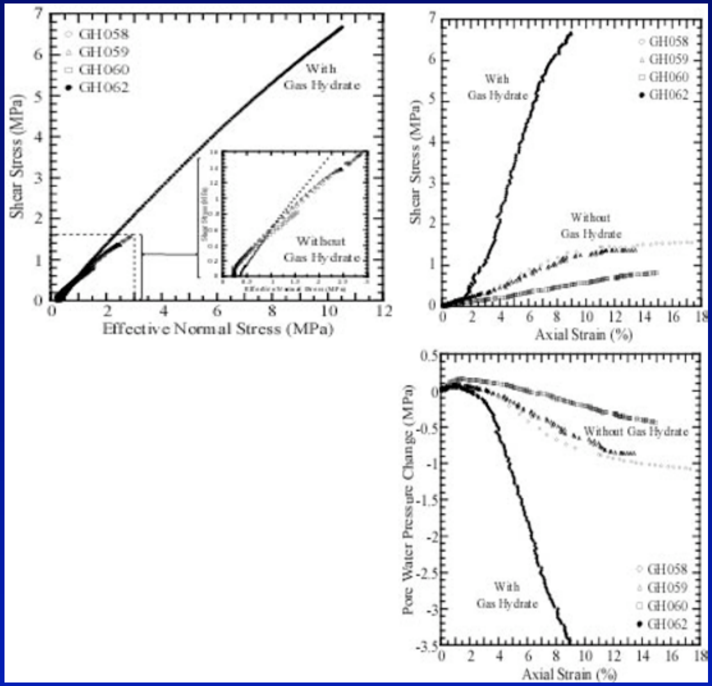


Mallik 2L-38 Physical Properties

Overview/Lab Accomplishments

Properties of sediment that
contain NATURAL gas hydrate
-a progression in technical capability

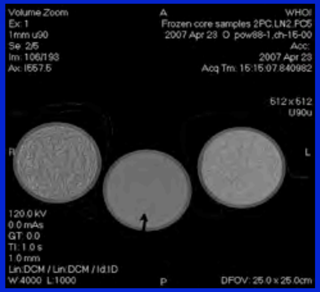
-Supports DOE’s need for: determining effect of natural
gas hydrate on sediment properties…
quantify properties at known experimental conditions



Samples related to field programs:
Mallik 2L and 5L (above)
NGHP-01 (India) (below)

It is easier to perform measurements on frozen coarse-grained sediments. Gas hydrate dissociates during recovery and transfer of those samples into a testing device such as GHASTLI.

Evidence suggests that storage with pressurized methane reforms lost hydrate.



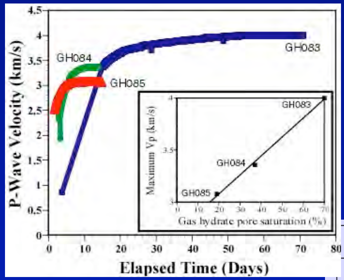
Advances in pressure-core technology now provide a means to make measurements on samples that have not been depressurized

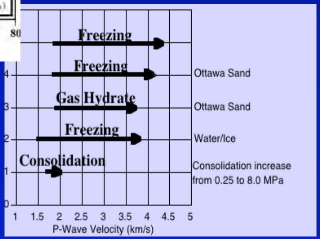
Overview/Lab Accomplishments

Properties of laboratory-formed methane gas-hydrate-bearing sediment

-Supports DOE's need for: characterizing hydrate in sediment
using remote techniques…input into models…
sediment properties under different GH formation and
experimental conditions

GHASTLI

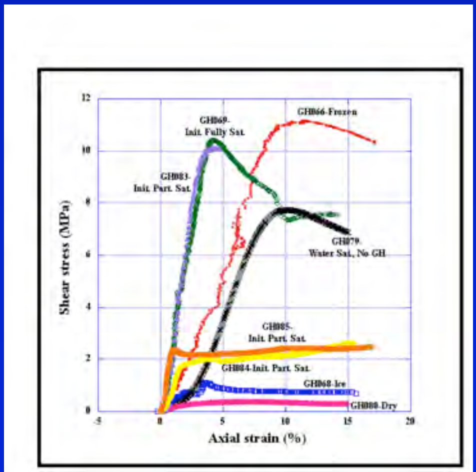




Acoustics

- Simulate natural formation mechanisms in the presence of free gas
  - initially fully water saturated
  - partially water saturated
- Effect of:
  - pore contents on acoustic and strength properties
  - grain size
  - effective stress
  - pore-pressure response
- Formation mechanism influences measured results
- Expand hydrate formation technique to include dissolved phase (next presentation)

Triaxial shear strength



Collaborations/relationships

- IODP - Membr. Env. Protection & Safety Panel
- GaTech
- Geotek, Ltd.
- Omni Laboratories
- WHOI
- NETL
- Univ. New Hampshire
- Scripps
- Oregon State Univ.
- Univ. Calgary
- Lawrence Berkely Nat. lab
- MBARI
- Geol. Survey Canada
- Schlumberger…

OCEAN DRILLING PROGRAM

ChevronTexaco

Finances

Fiscal Year	Task	DOE Net (K)	USGS Assessment Rate (%)	USGS Total (Salary/OE) (net)
2004	GHASTLI	28	33	249
	Geotechnical Testing (baseline Properties)	15		
2005/2006	Laboratory Analysis of:		37	235
	Pressurized Cores	21		
	Non-Pressurized Cores	52		
	Travel	6		
2006/2007	India	145	38	278

Note: Relatively low USGS assessment rate
Salaries paid by USGS

Publications (last 5 years)

Papers: 27 total (14 first authored)

Abstracts: 36 (17 first authored)

Note: This list does not duplicate those in the next presentation

Outreach

Expand and update existing:

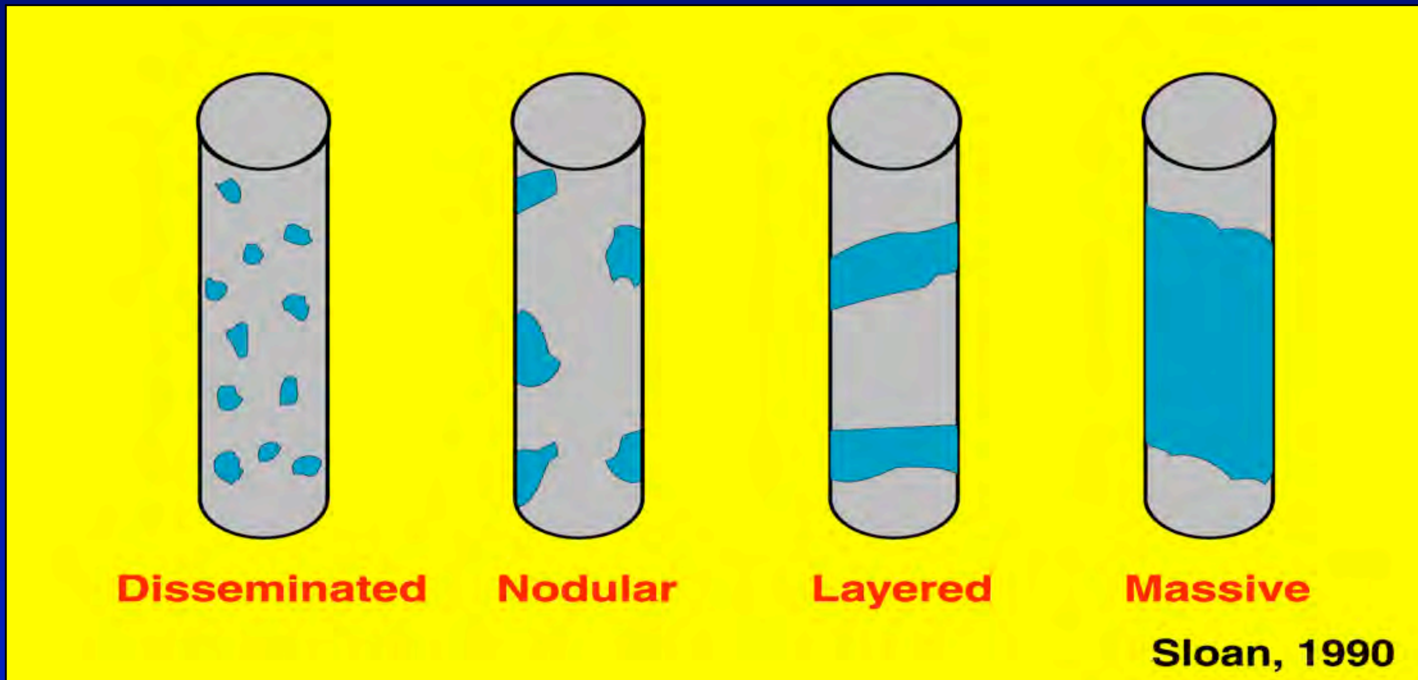
- Lab Websites
- Databases

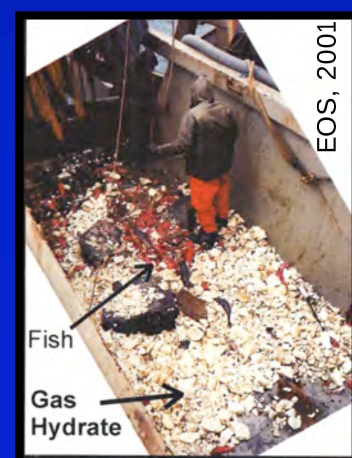
Field Studies

Reservoir and hydrate characteristics vary considerably and these variations present a challenge for predicting sediment behavior;

It is difficult to form GH "naturally" in the lab

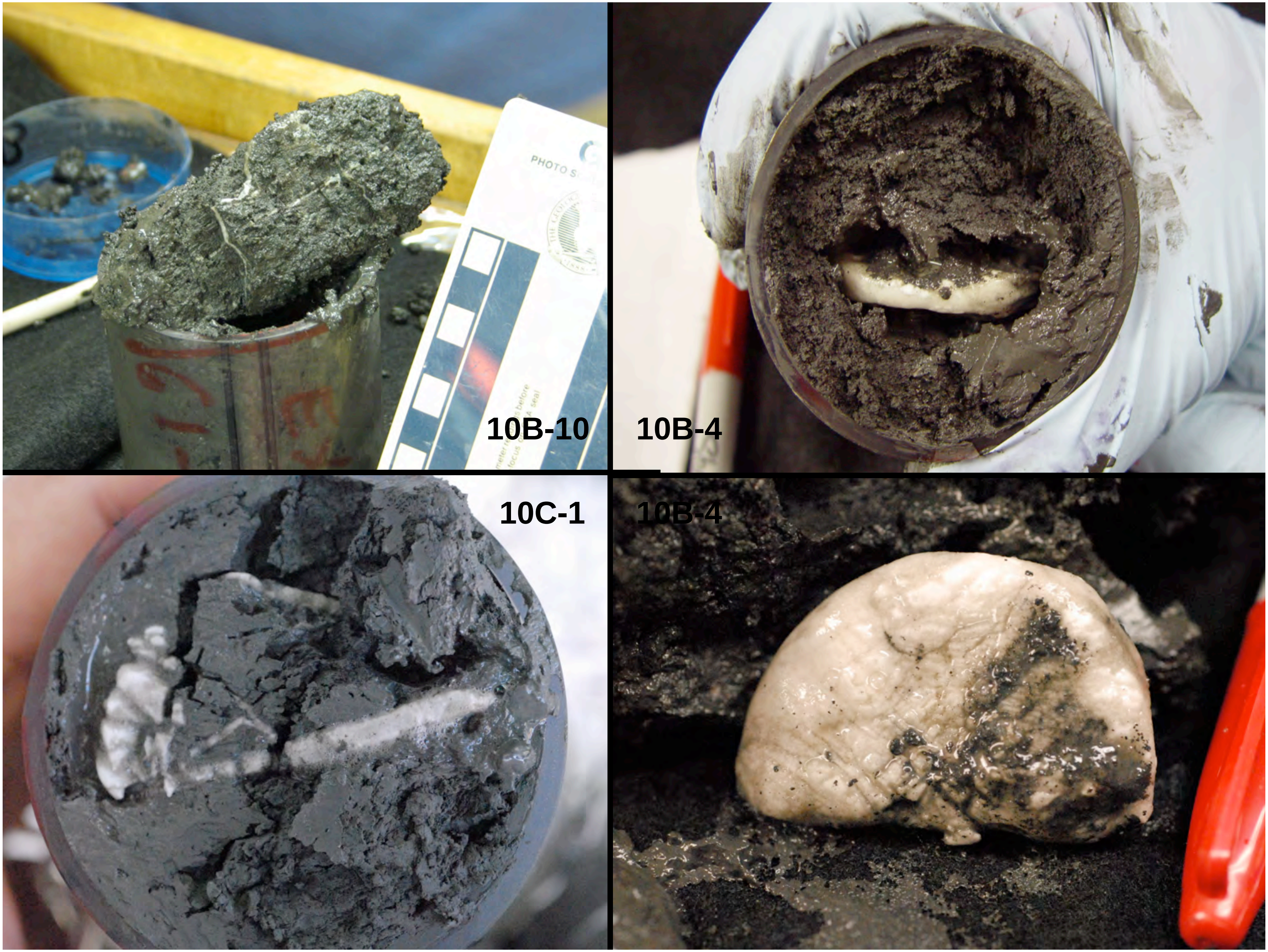
It naturally occurs in many forms





Disseminated Nodular Layered

Challenging to study Whispy (NGHP) Massive


10B-10
10B-4
10C-1
10B-4

Goals of Field Physical Properties Program

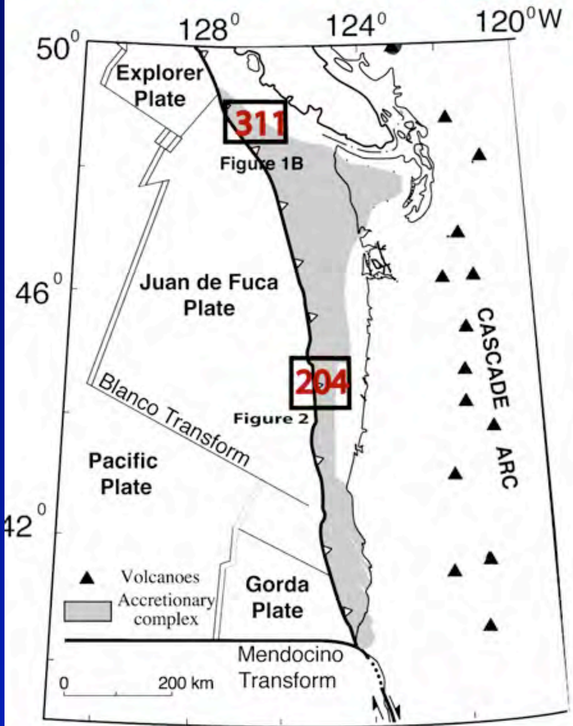
Determine numerous sediment characteristics to:

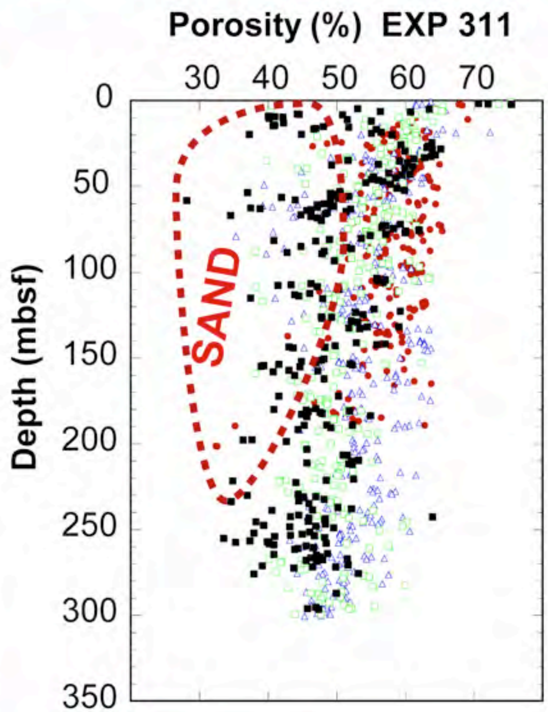
- Better understand the interaction between host media and gas hydrate (porous media effect)
- Relate to geologic controls and stratigraphy
  - Reservoir and seals
- Ground truth well-log and other field results
- Provide input to well logs
- Provide baseline measurements of porosity, grain size, densities… for models
- Correlate to other shipboard measurements (e.g., SMI)
- Provide estimates of other properties and behavior
  - Without gas hydrate
  - With intact gas hydrate
  - During/after dissociation

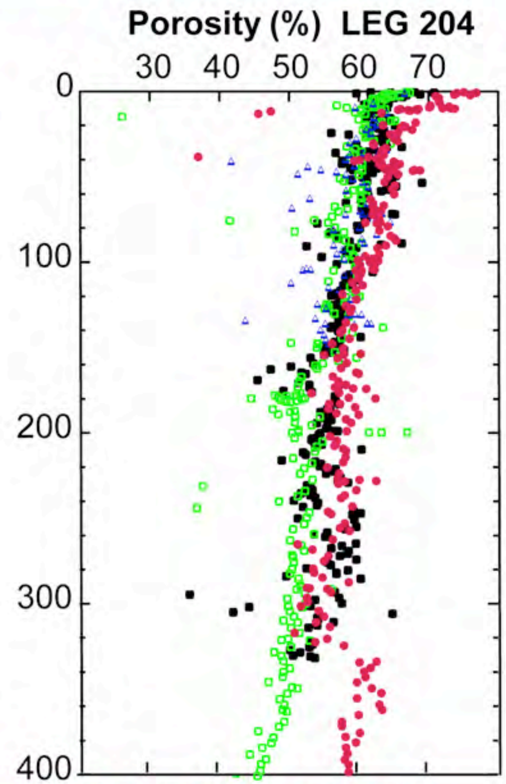
Why is gas hydrate present at one location and not another?

Is there a porous media effect?

Expedition 311 and Leg 204: sediment properties control gas hydrate distribution



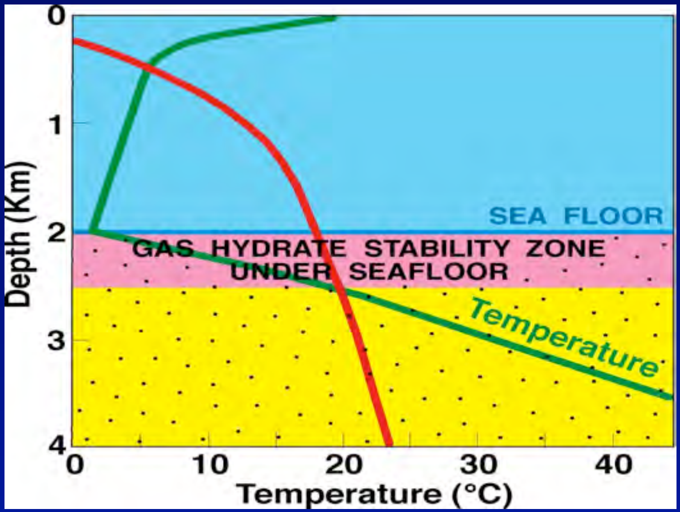




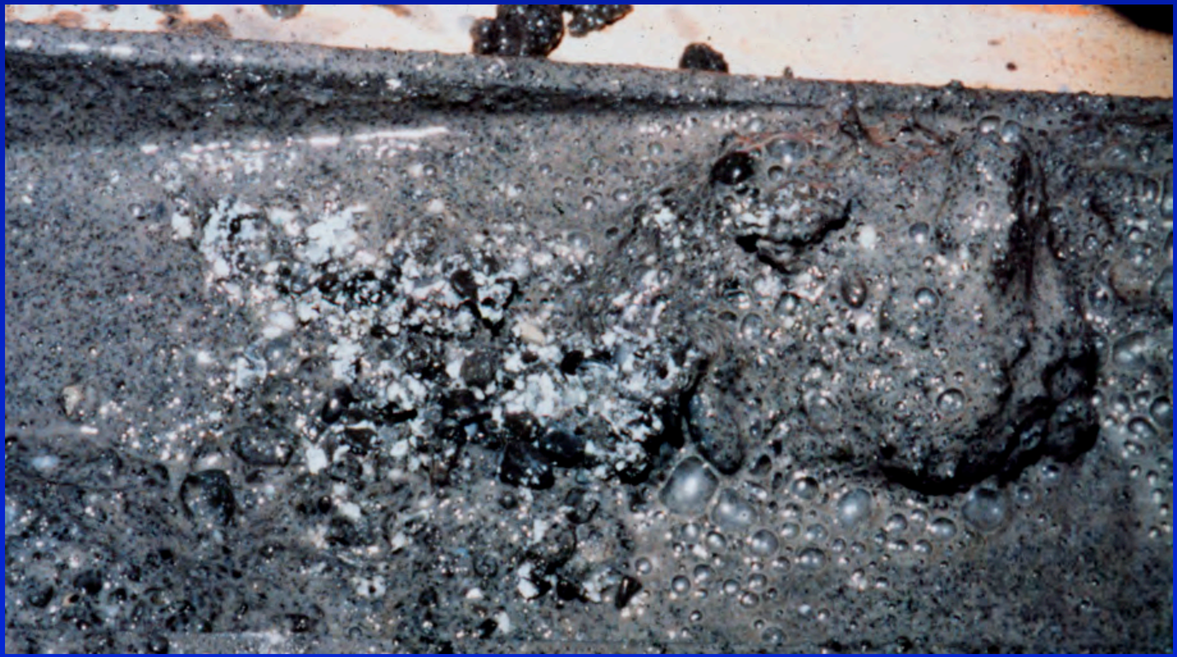
Gas hydrate sand reservoirs

Gas hydrate fracture reservoirs

Design Against Hazards



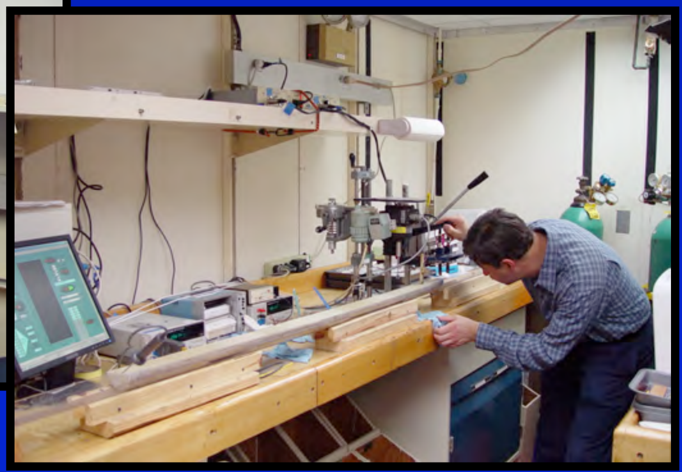
NGH doesn't like to be removed from in situ P-T conditions.



Field Studies NGHP-01 (India)

JOIDES Resolution Shipboard Laboratories

- Physical Properties Measurements
- Sedimentologic Descriptions
- Organic Geochemisty
- Inorganic Geochemistry
- Microbiology Studies



Teamwork - critical

Physical Properties

Whole Rounds

Thermal Conductivity

MSCL

- **Gamma density**
- **Vp**
- **Electrical Resistivity**
- **Magnetic Susceptibility**

Split Cores

Contact electrical resistivity

Vp (double-spade technique)

Shear strengths

- **Mini vane shear**
- **Torvane**
- **Pocket penetrometer**

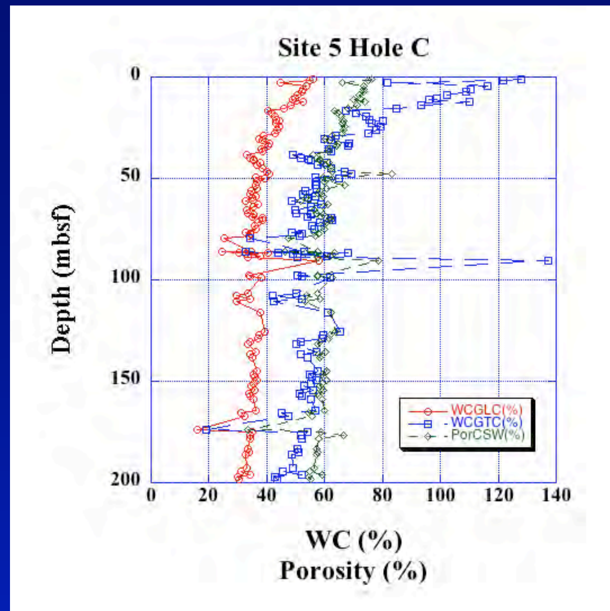
Index

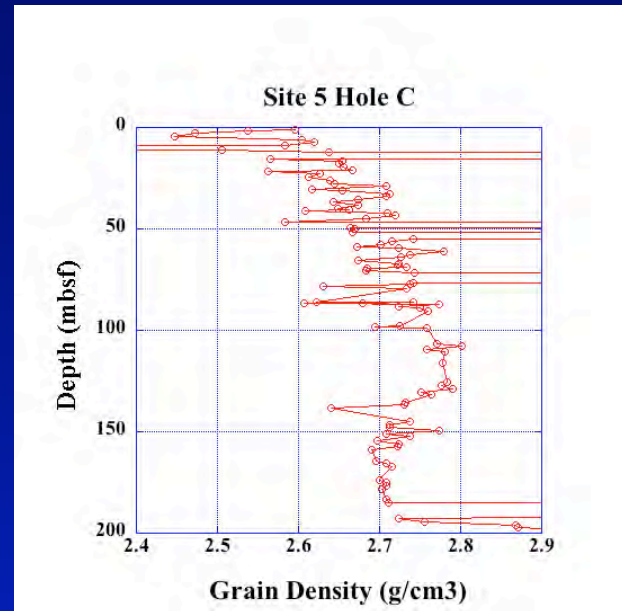
- **Water content**
- **Grain density**
- **Porosity**
- **Densities**
- **Vertical stress**

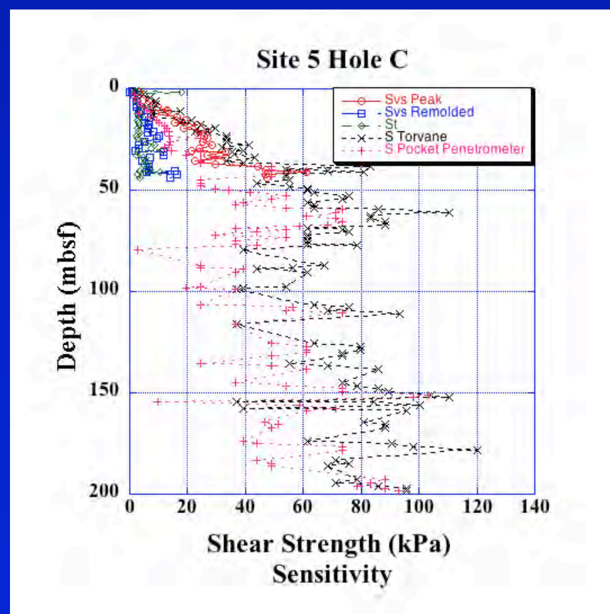
Shore based studies

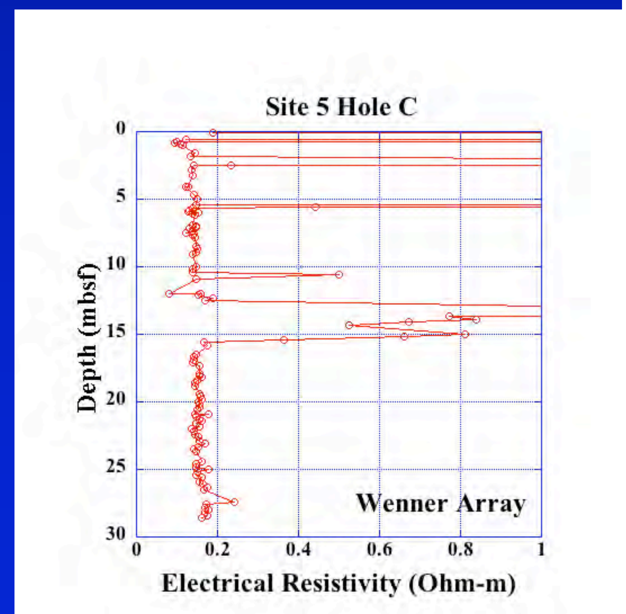
Grain size

Consol/triaxial/GHASTLI

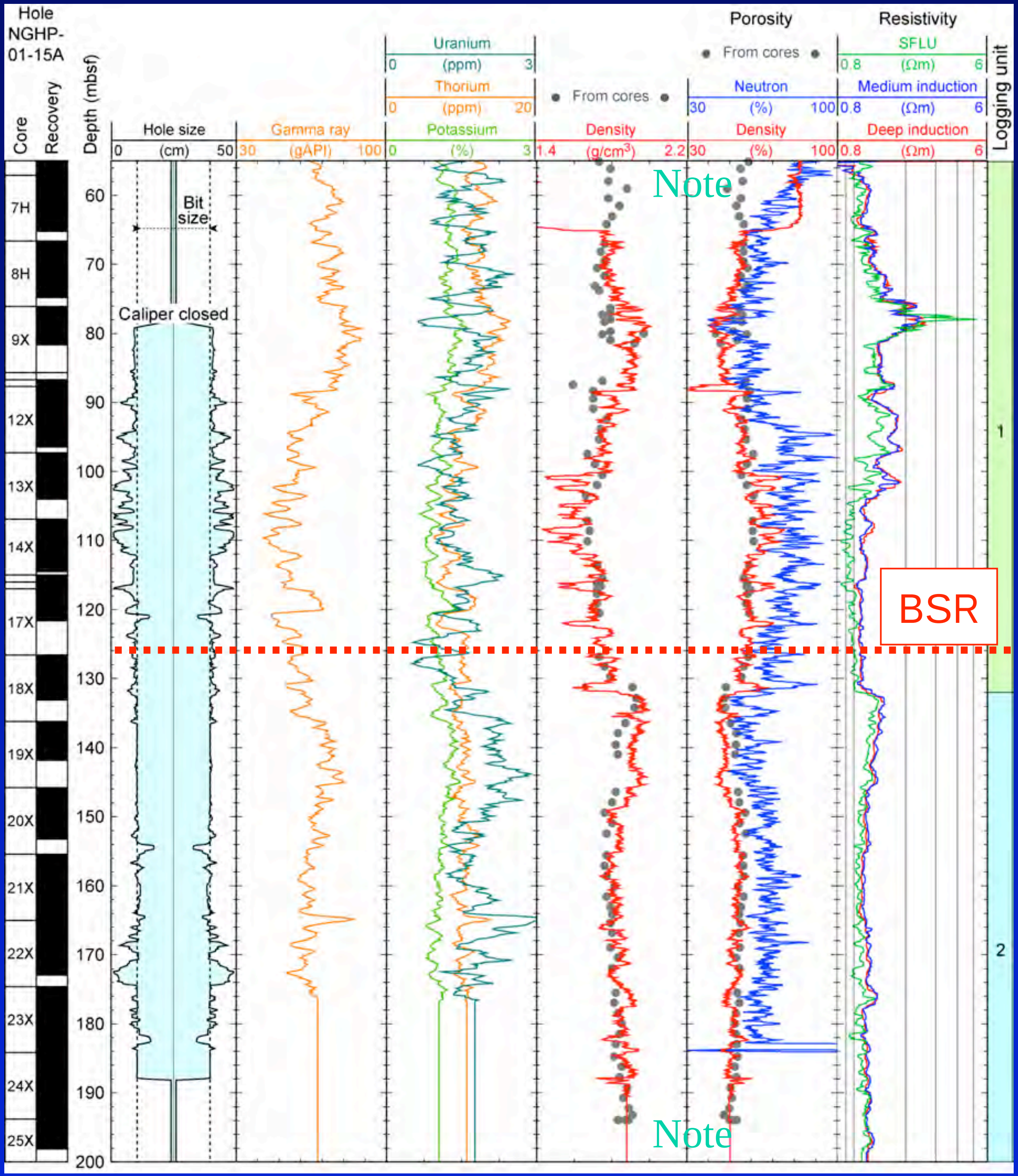


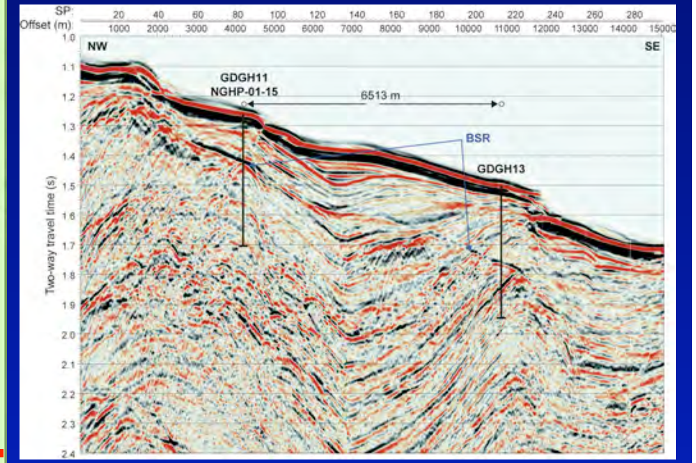




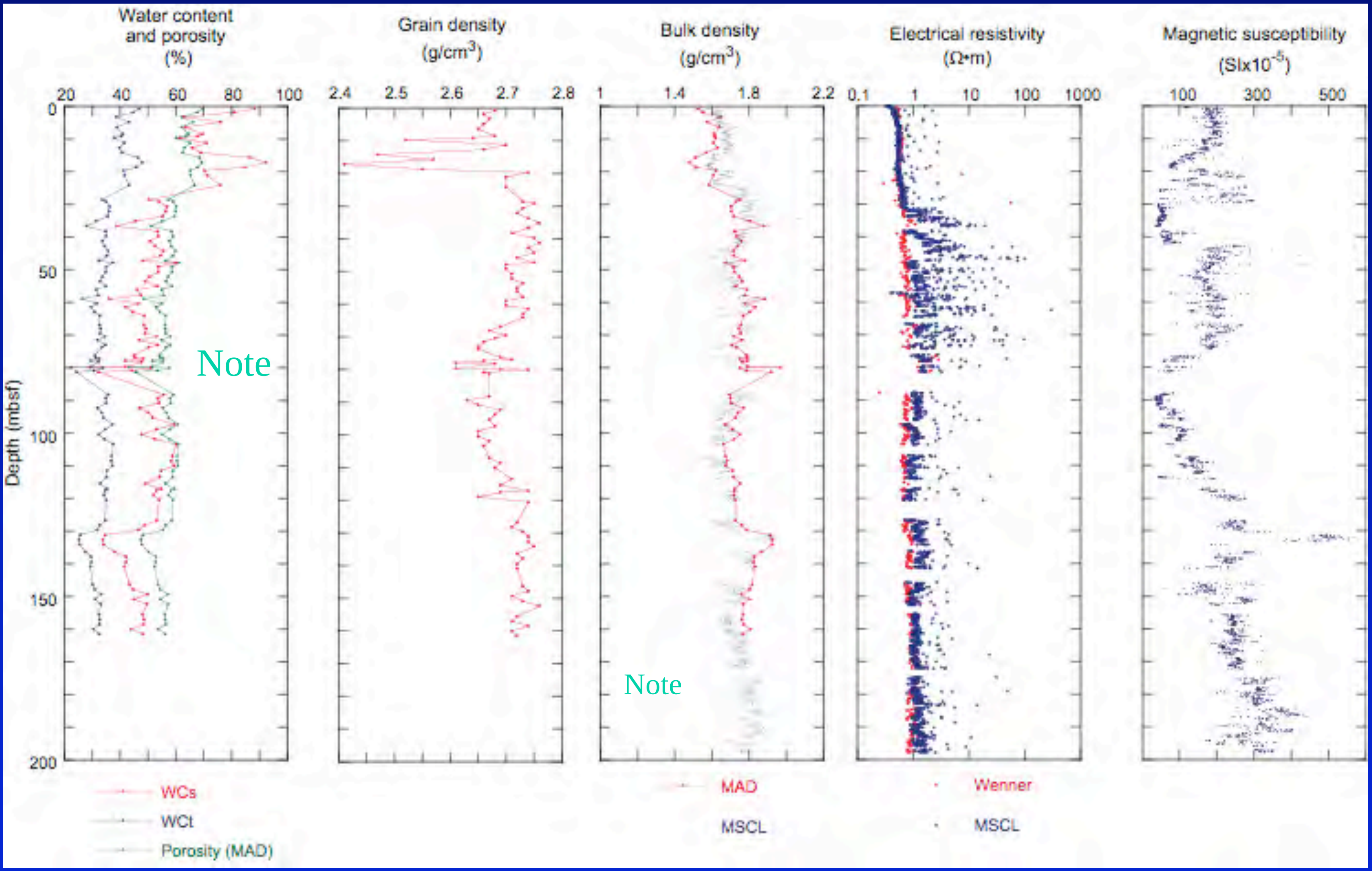


Krishna-Godawari Basin Site 15



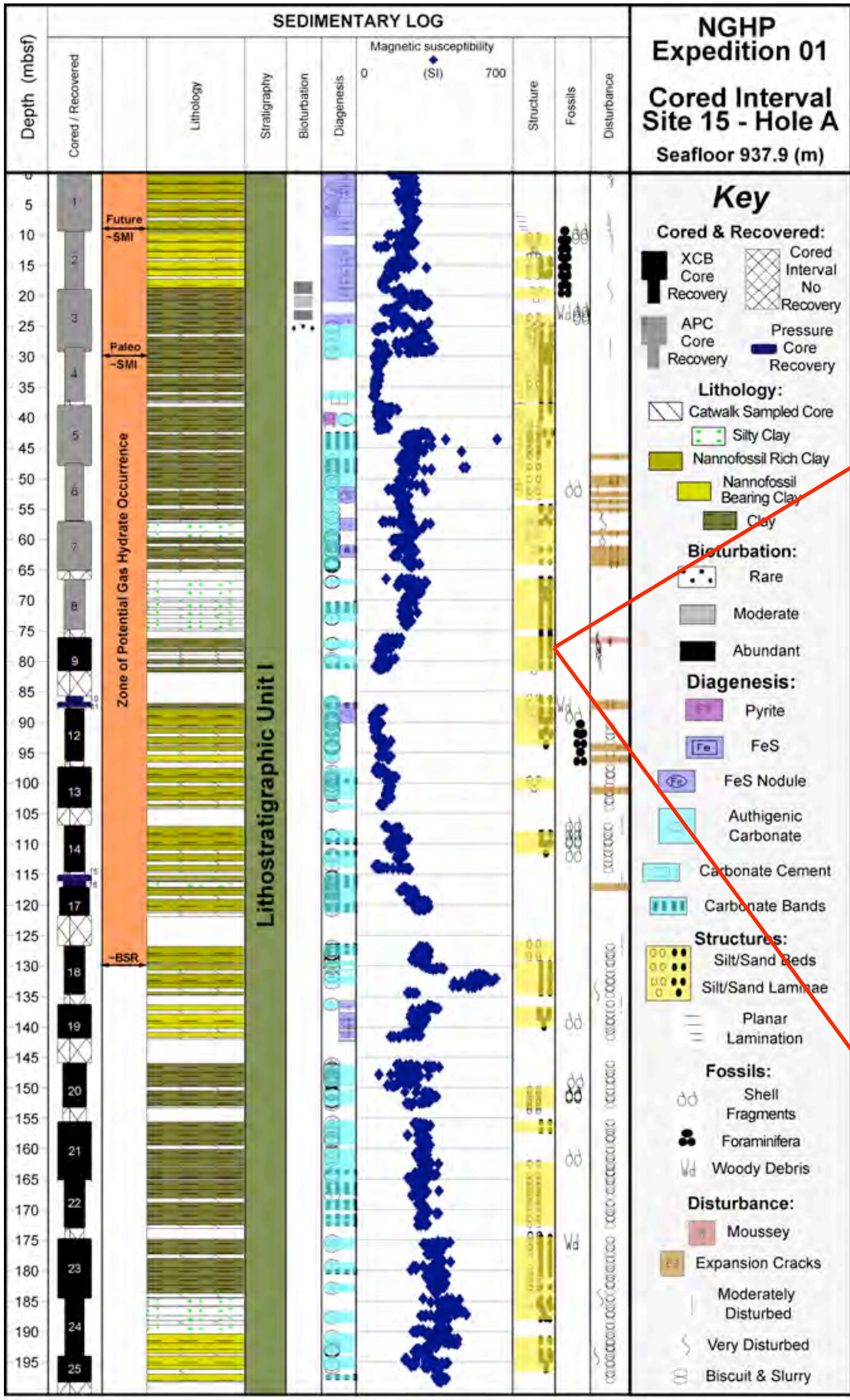


Hole 15A

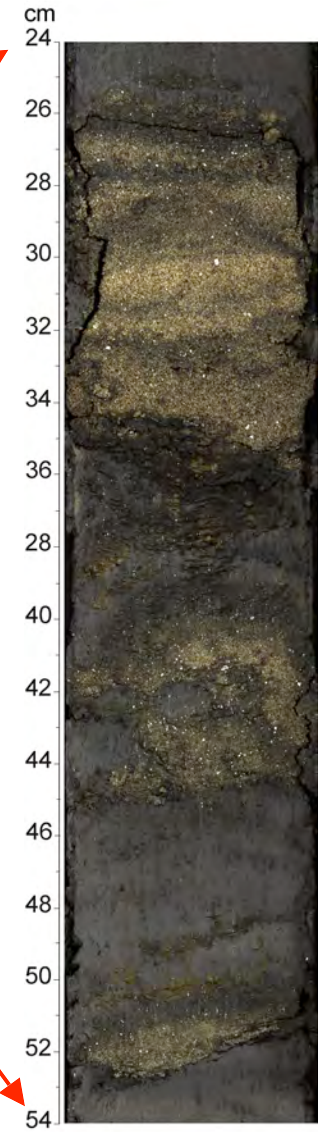


Water content and porosity (%)
20
40
60
80
100
Grain density (g/cm3)
2.4
2.5
2.6
2.7
2.8
Bulk density (g/cm3)
1
1.4
1.8
2.2
Electrical resistivity (Ω•m)
0.1
1
10
100
1000
Magnetic susceptibility (SIx10-5)
100
300
500
Depth (mbsf)
0
50
100
150
200
Note
Note
WCs
WCt
Porosity (MAD)
MAD
MSCL
Wenner
MSCL

Krishna-Godavari Basin
Site 15

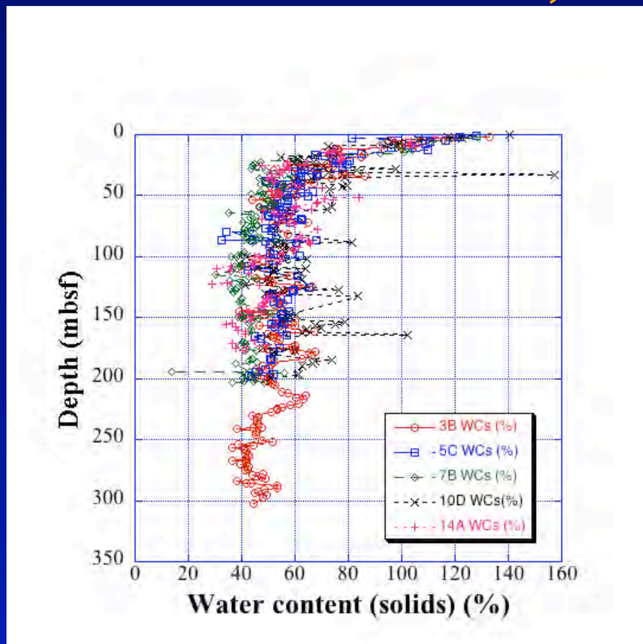


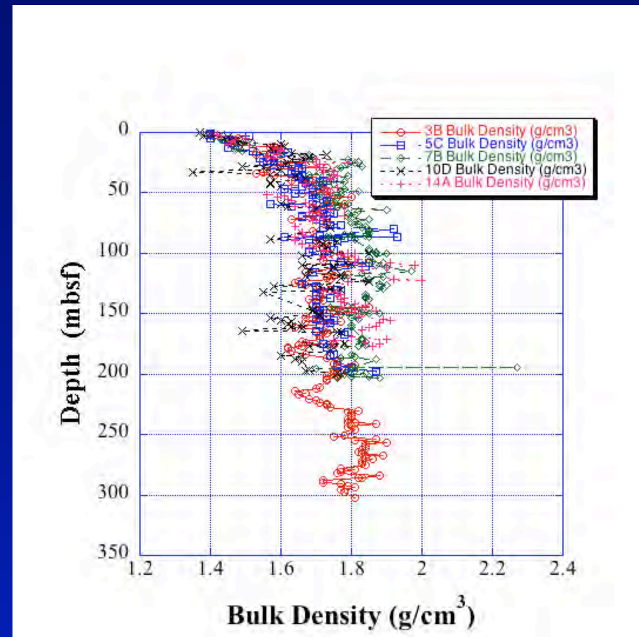
Core NGHP-01-15A-09X-04

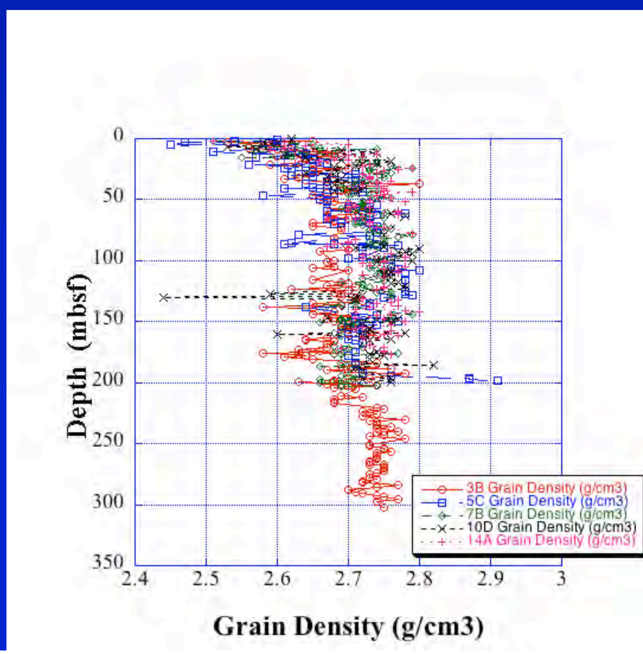


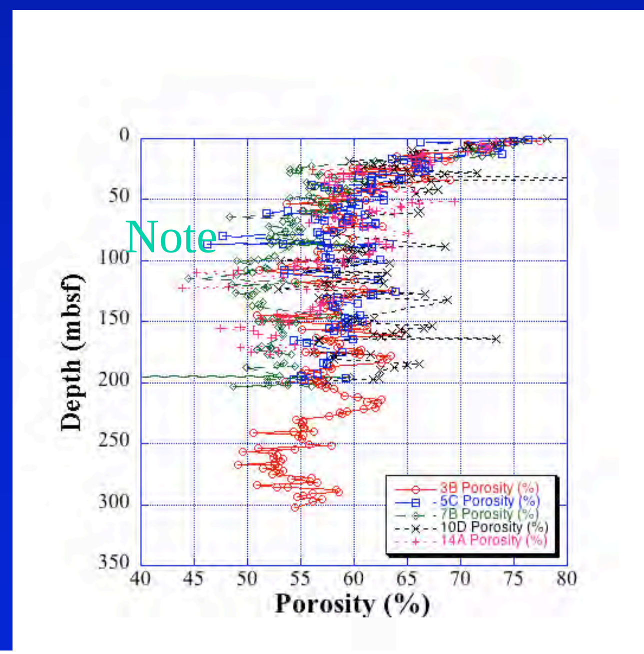
From:
Sedimentology
Group

Sites 3, 5, 7, 10, 14

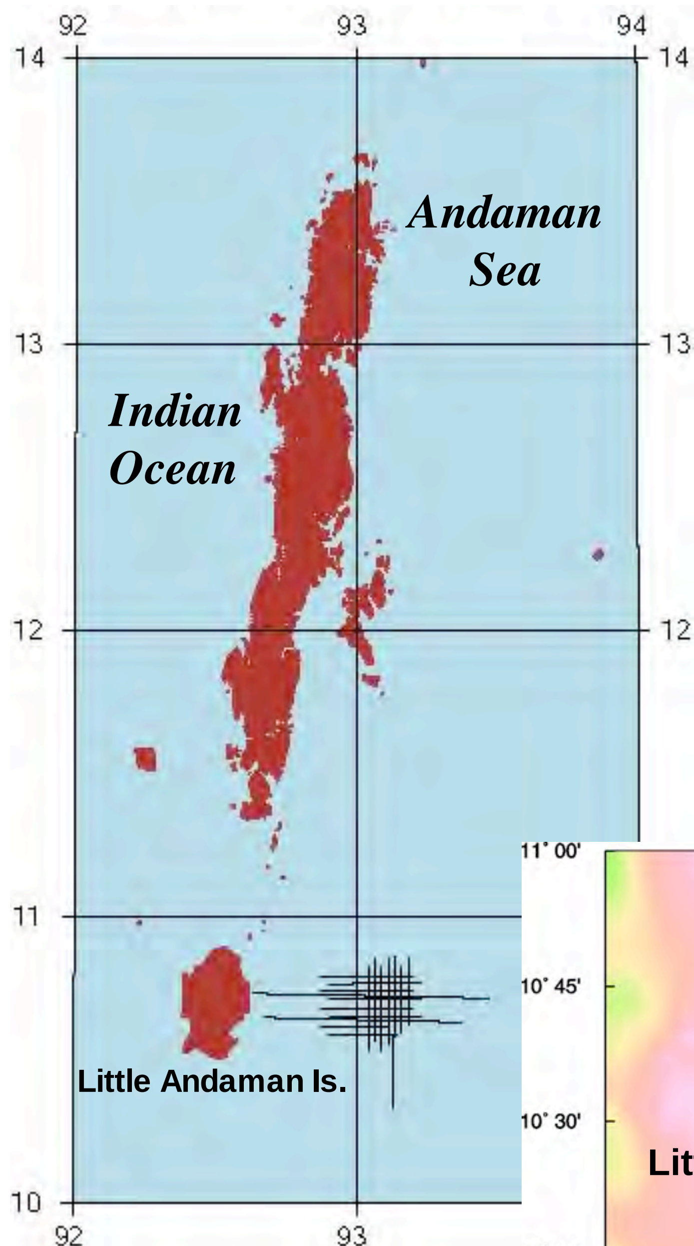


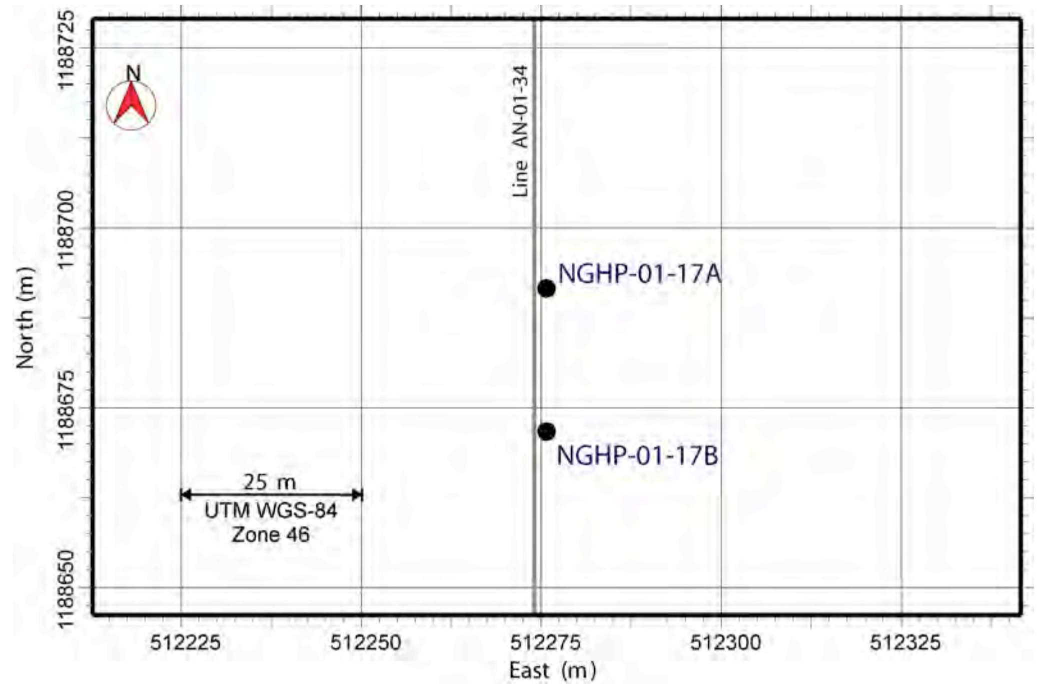


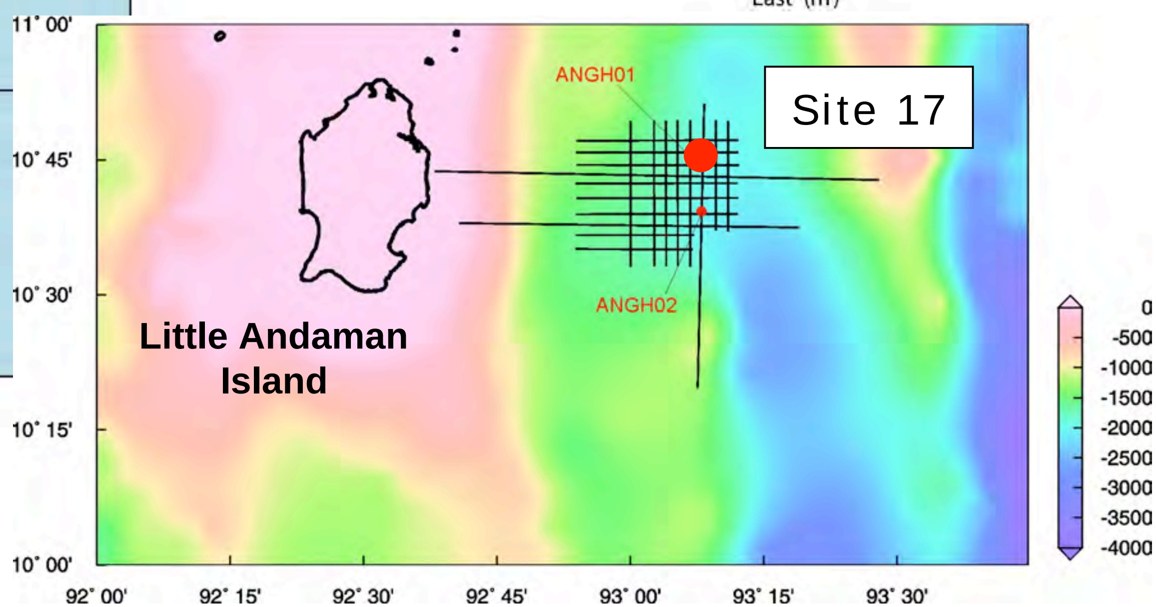




Andaman Islands – Site 17



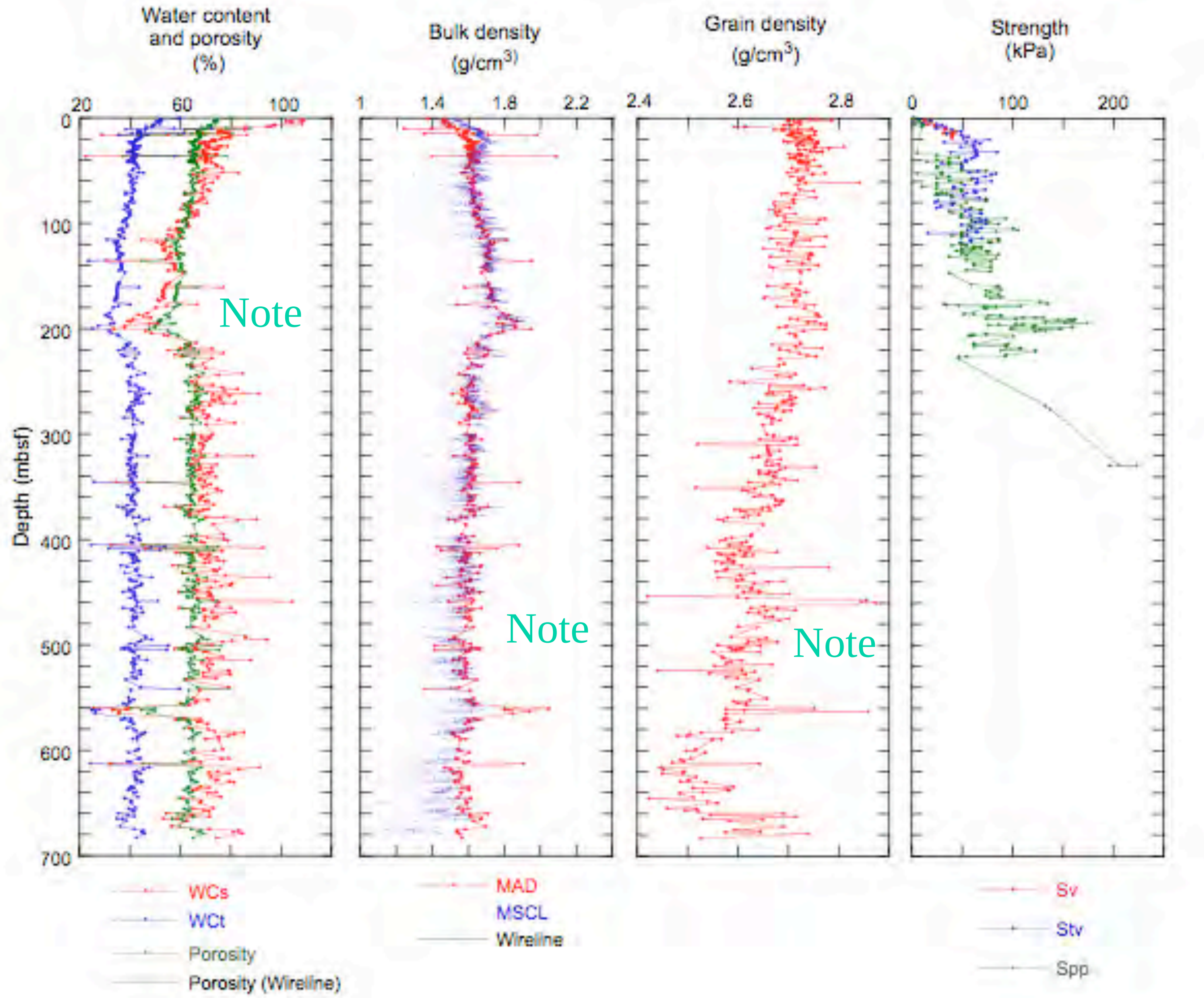




Site 17 Hole A 3 Physical Property Behavior Units

mbsf	WC	Porosity	Bulk Density	Grain Density	Strength	Magnet. Suscept.
0-13 SF Effect	Decreases	Decreases	Increases	Constant	Increases	NA
13-200	Decreases	Decreases	Increases	Decreases	Increases Slowly	V. Low
200-680	Constant	Constant	Constant	Decreases	Maxed out	V. Low

Site 17 Hole A

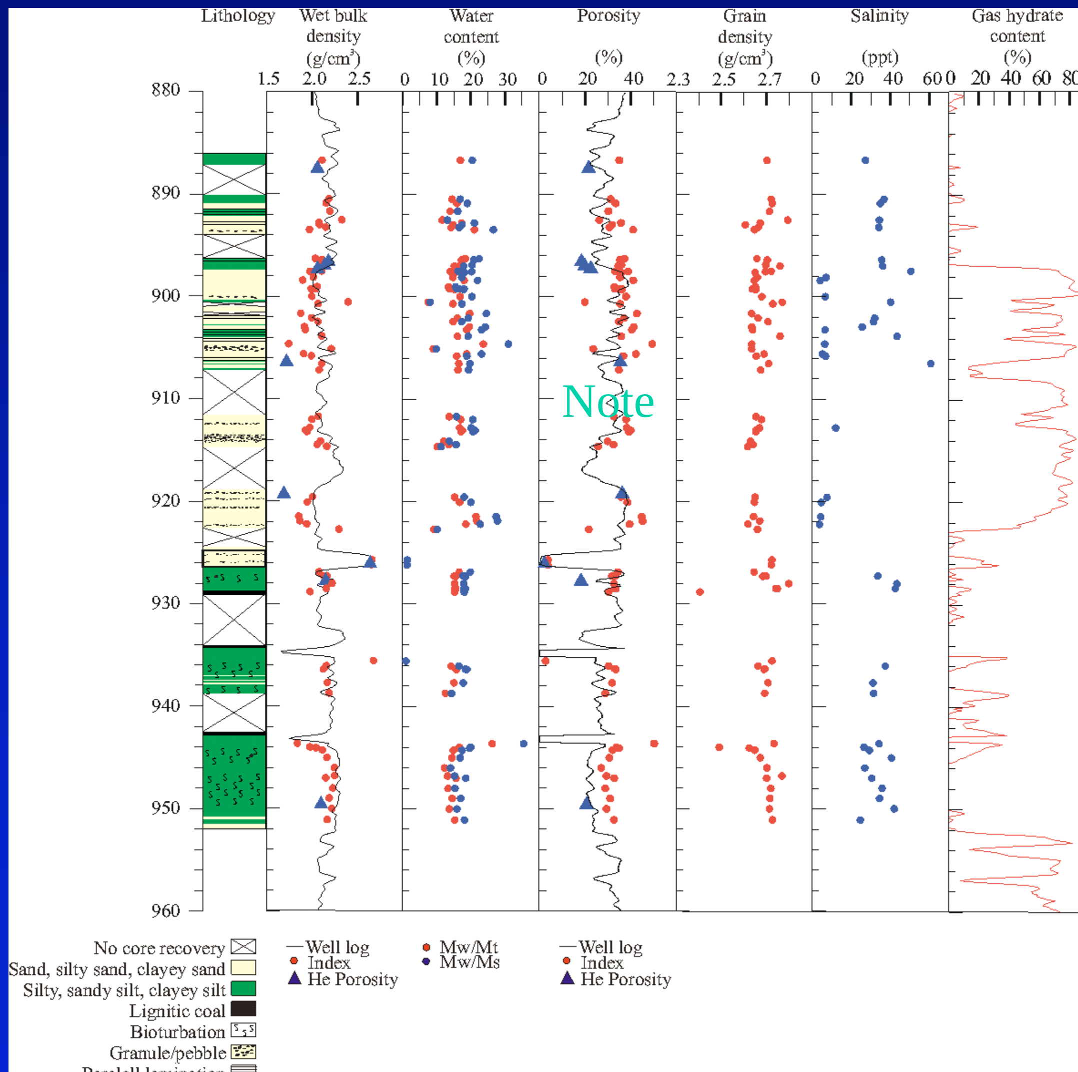


Comparison of NGHP-01 to a less complicated physical properties study at Mallik 2L well NWT

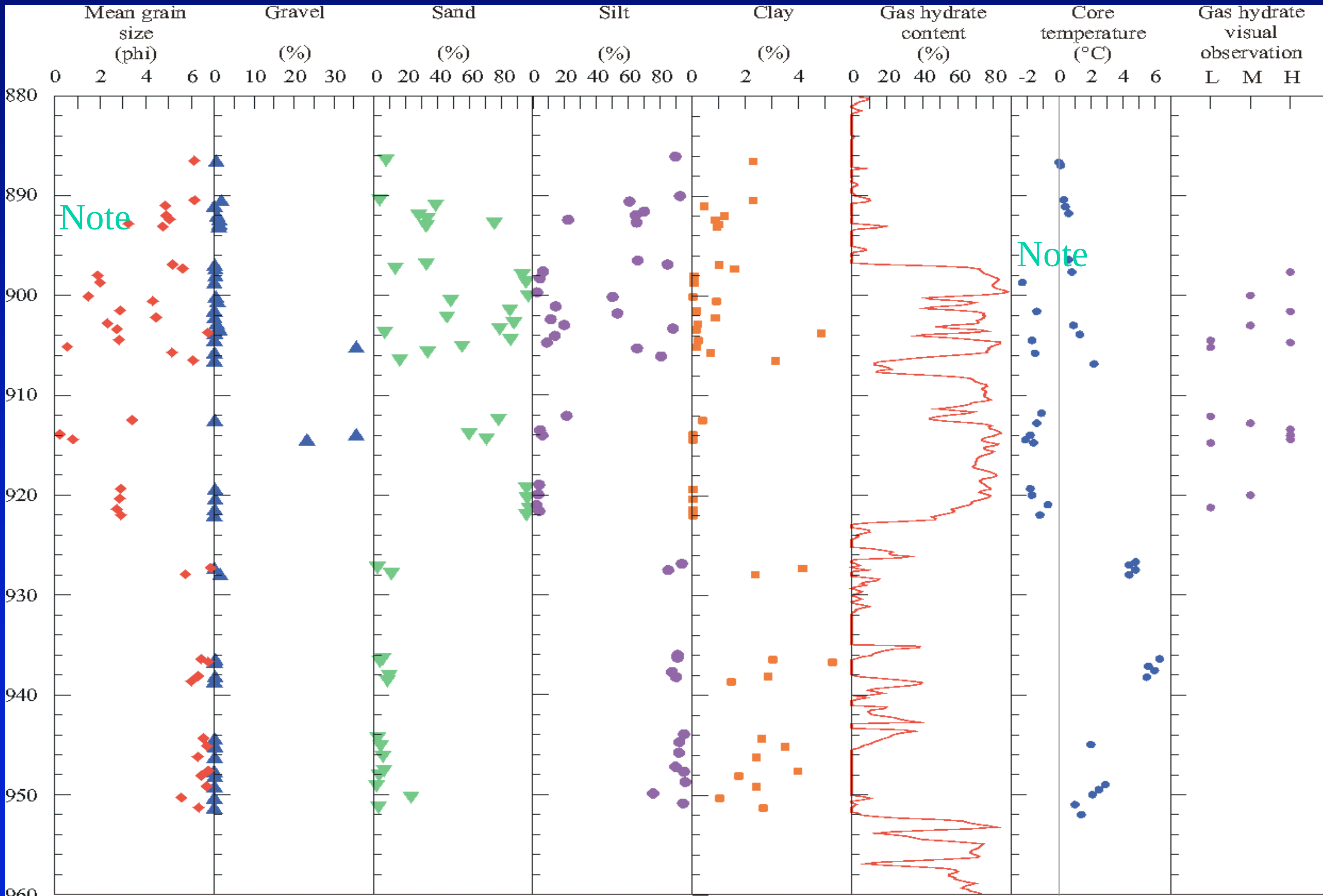
Field Studies
Mallik 2L well
NWT

Our northern point of view
northern transportation
company limited

Mallik 2L-38 Physical Properties



Mallik 2L-38 Physical Properties

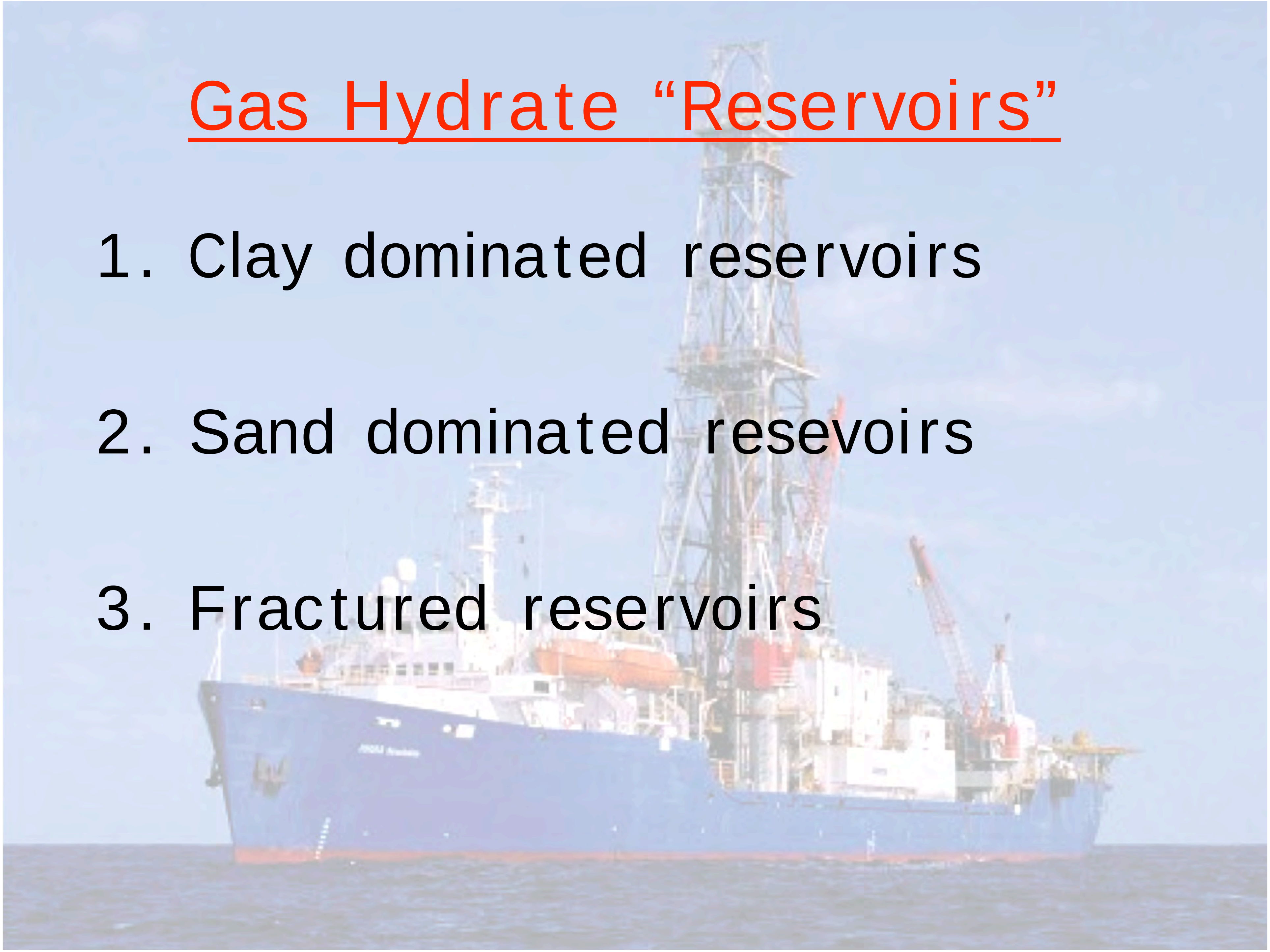


Gas Hydrate “Reservoirs”

1. Clay dominated reservoirs

2. Sand dominated resevoirs

3. Fractured reservoirs



Lithologic control on GH:

Sites: 3, 5, 7, 14, 15, 16, 17, 19, 20 (9)

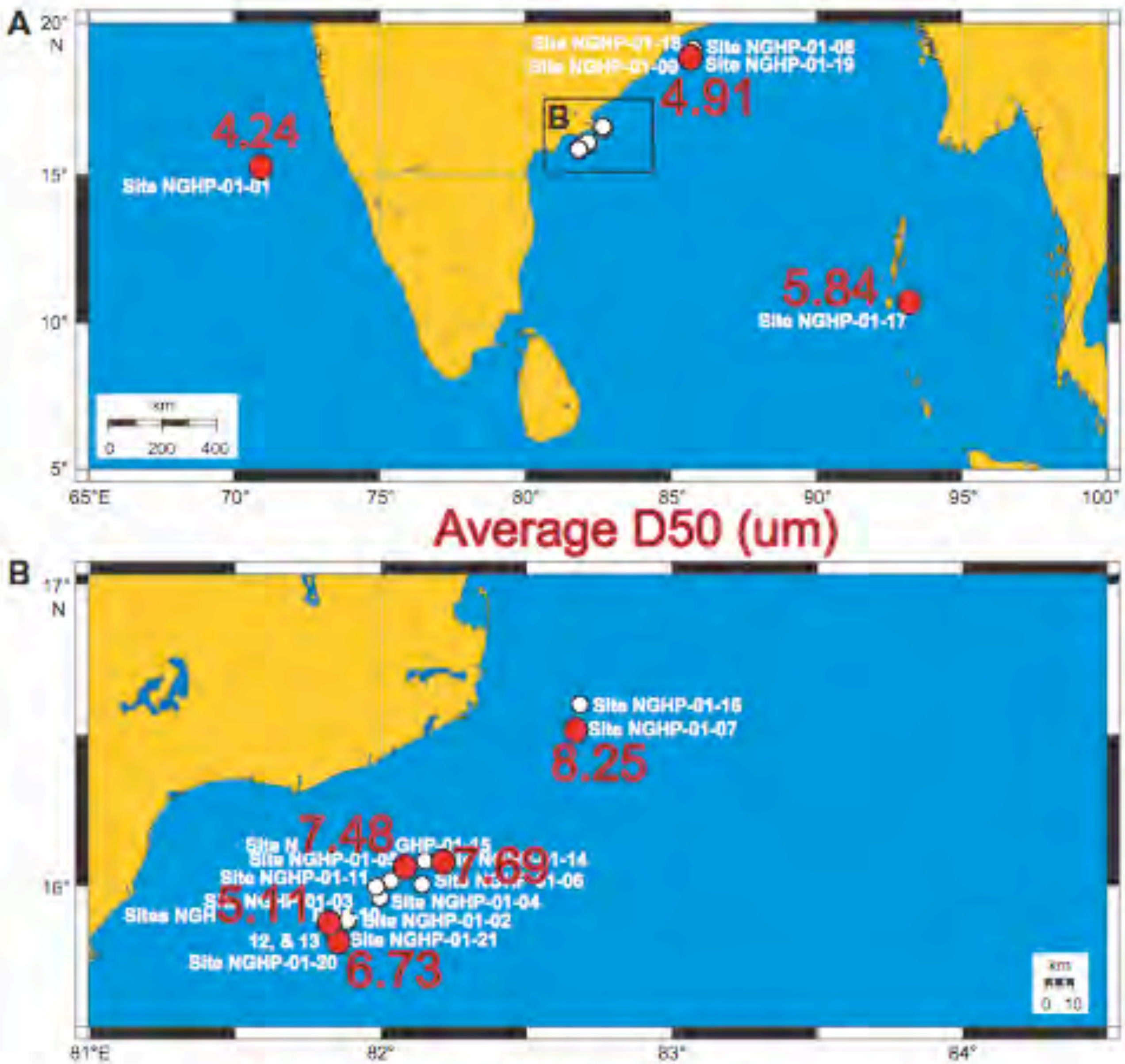
Combination reservoirs - Partial lithologic control:

Sites: 2, 4, 5, 6, 7, 8, 9, 11 (8)

Fracture conduits - No lithologic control:

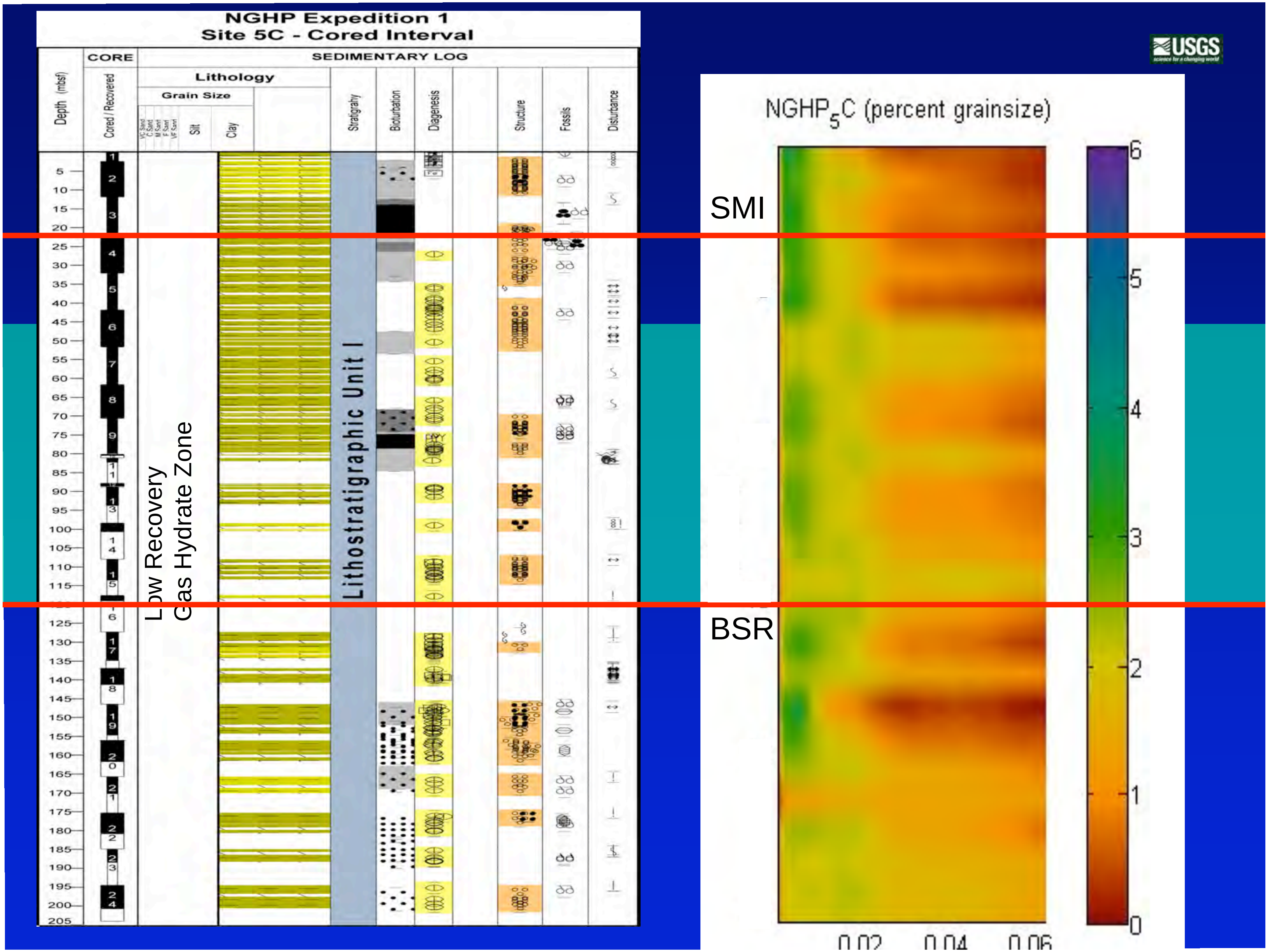
Shore-based grain-size analysis at WHOI

NGHP Expedition 01 Site Map

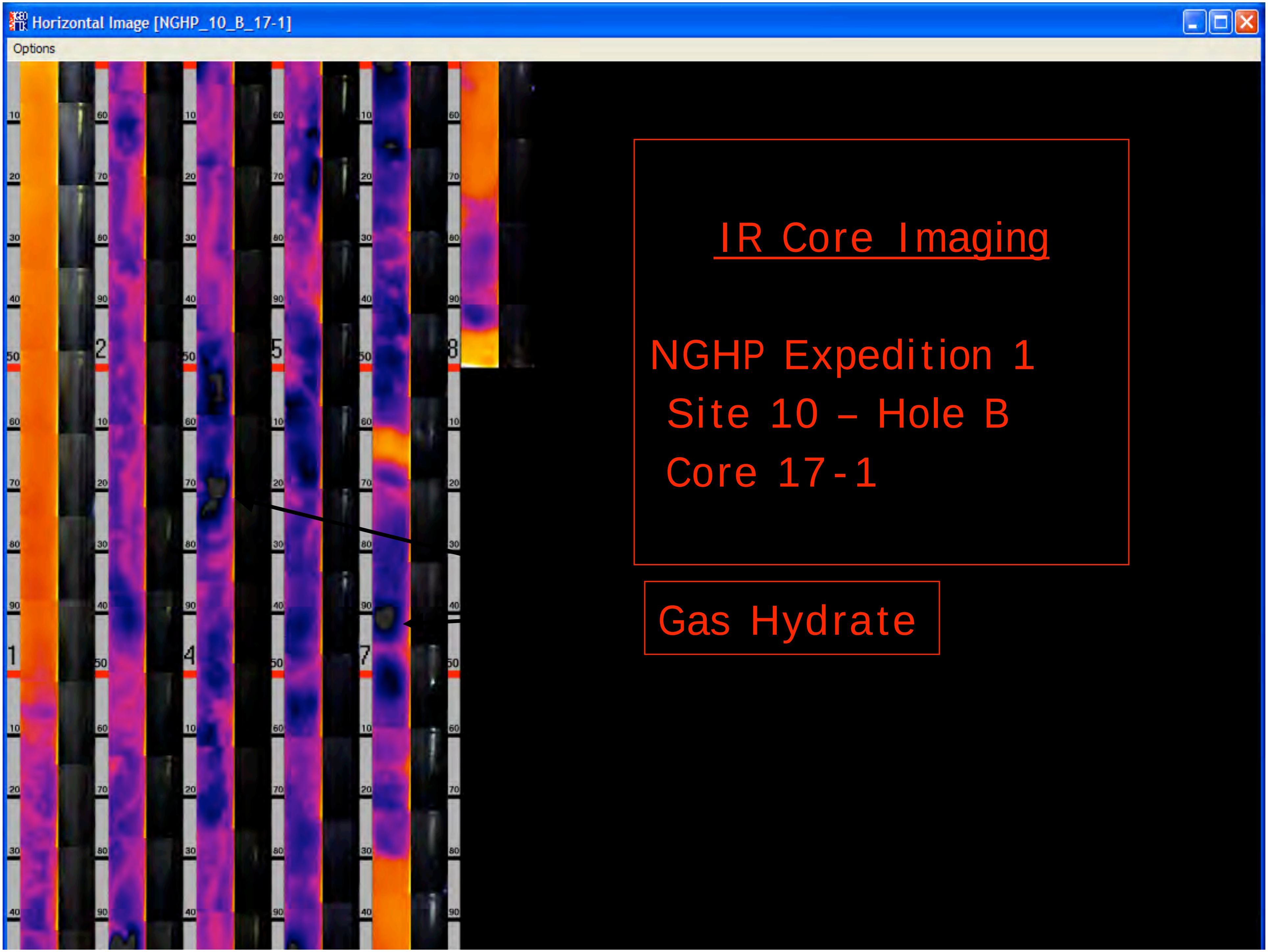


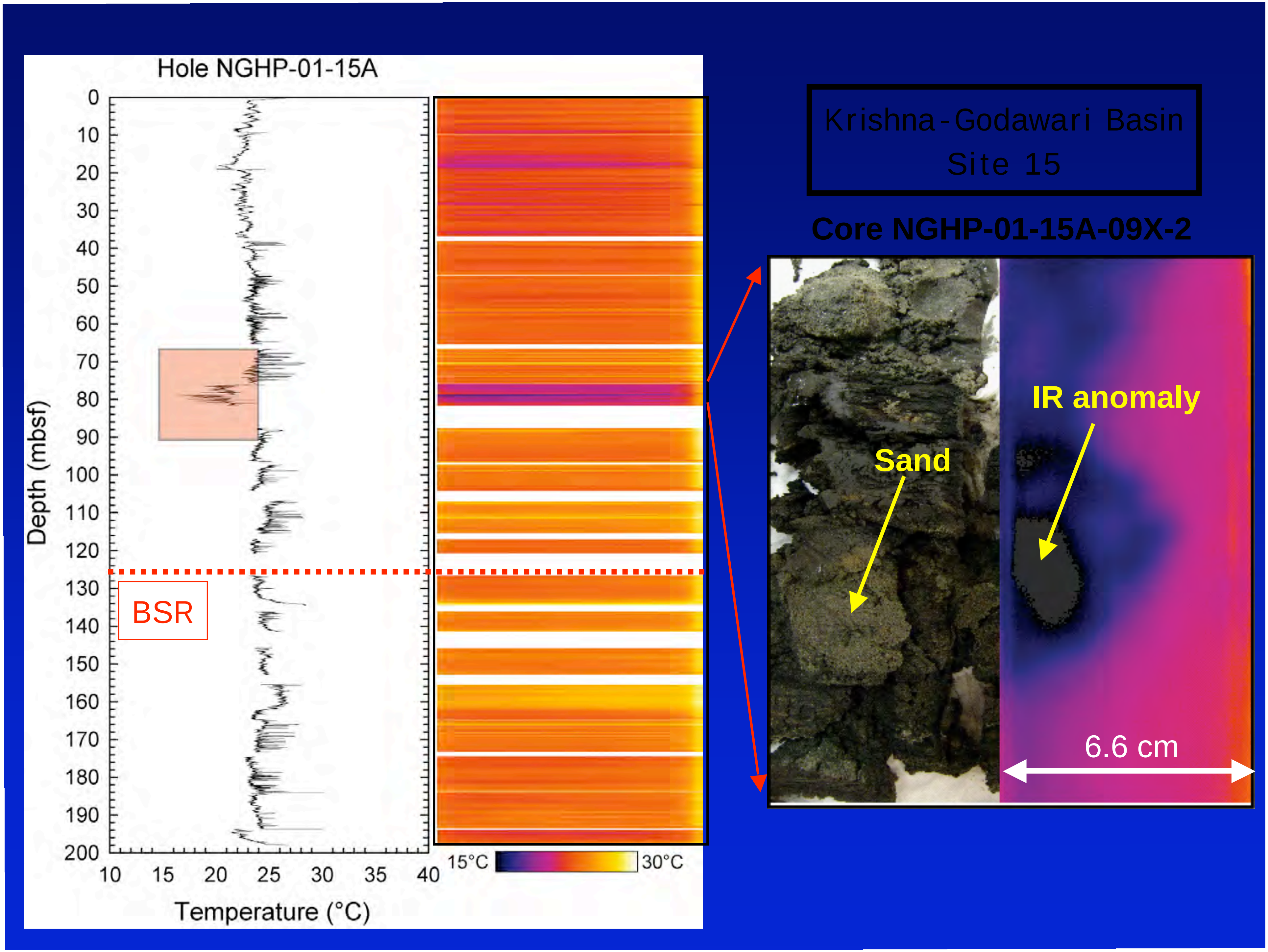
All sites have D50 of vf silt

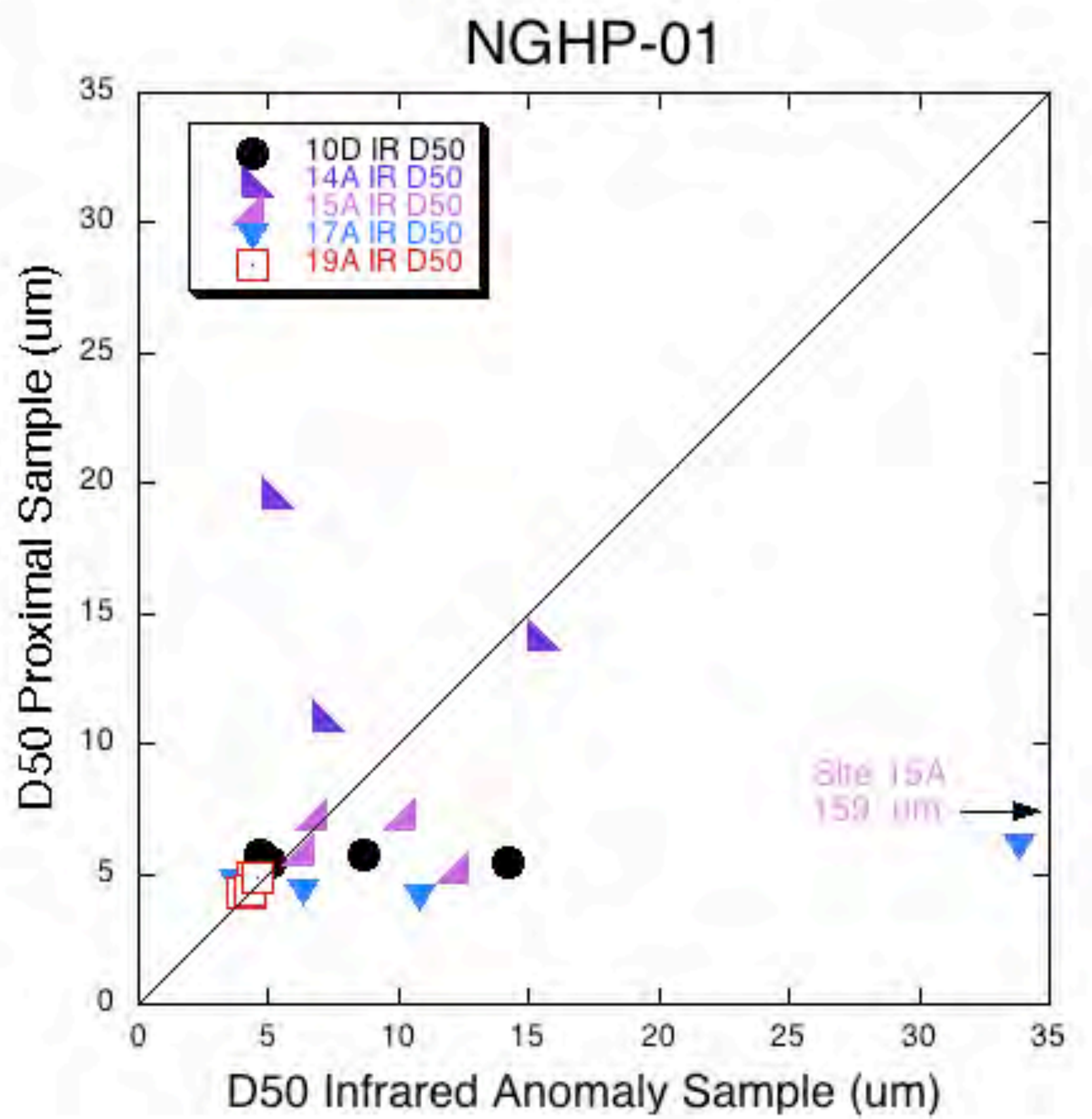
Except Site 07 which grades as fine silt


NGHP Expedition 1
Site 5C - Cored Interval
CORE
SEDIMENTARY LOG
Depth (mbsf)
Cored / Recovered
Lithology
Grain Size
Silt
Clay
Stratigraphy
Bioturbation
Diagenesis
Structure
Fossils
Disturbance
Lithostratigraphic Unit I
Low Recovery
Gas Hydrate Zone
SMI
BSR
NGHP5C (percent grainsize)
0.02
0.04
0.06
0
1
2
3
4
5
6

IR Core Imaging


Horizontal Image [NGHP_10_B_17-1]
Options
IR Core Imaging
NGHP Expedition 1
Site 10 – Hole B
Core 17-1
Gas Hydrate


Krishna-Godawari Basin
Site 15
Core NGHP-01-15A-09X-2
Hole NGHP-01-15A
Depth (mbsf)
Temperature (°C)
BSR
15°C
30°C
Sand
IR anomaly
6.6 cm


NGHP-01
10D IR D50
14A IR D50
15A IR D50
17A IR D50
19A IR D50
Site 15A
159 um
D50 Proximal Sample (um)
D50 Infrared Anomaly Sample (um)
0
5
10
15
20
25
30
35

Field Studies
Mt. Elbert
North Slope Alaska

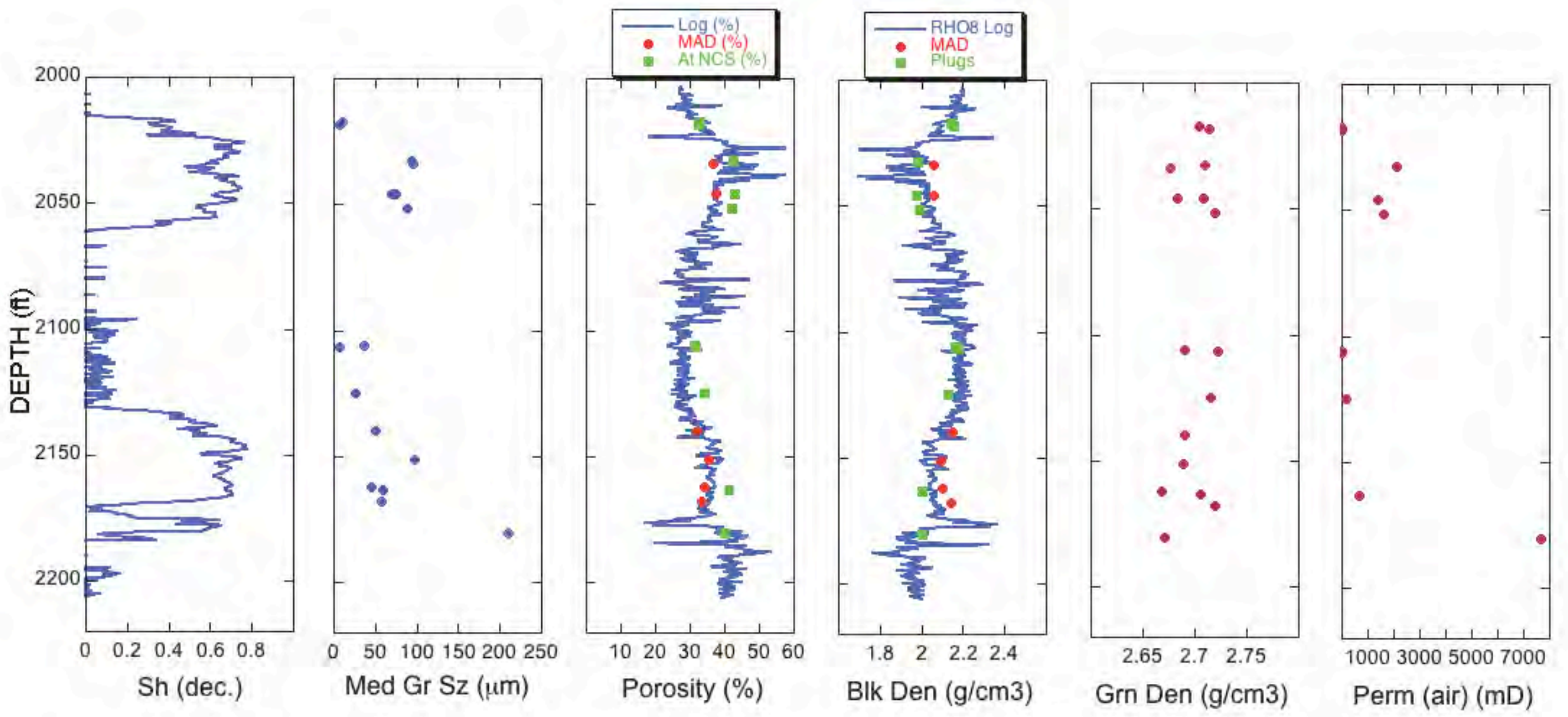
Sample Number	Sample Type	Core Run	Section Number	Sample Section Top (ir	Sample Section Bottom (	Top Depth (	Bottom Depth (f	Actual Depth	Total Sample ID	Overburden Pressure	Brine Salinity	Routine Core Analys	LGSA	NMR Analysis	Petrographic Analysis	Advanced Core Analy	Rock Mechanics	Grain Density	Water Content
1	Proposed	2	1	20	26	2015.66	2016.17	2016.00	2-1-17	572			X					X	X
2	Proposed	2	2	7	13	2017	2017.5	2017.10	2-2-8	572		X	X		x				
3	Existing	2	2	21	27	2018.17	2018.62	2018.35	2-2-21-27B	572		X	X		x		x		
4	Proposed	2	5	14	20	2026.46	2026.96	2026.70	2-4-17	575			X					X	X
5	Proposed	2	7	11	17	2031.92	2032.42	2032.40	2-5-17	576		X	X	X	X	X			
6	Existing	2	8	14	20	2035.17	2035.62	2035.40	2-8-14-20A	577			X					X	X
7	Proposed	3	4	2	8	2045.75	2046.25	2045.90	3-7-3	580		X	X	X	X	X			
8	Existing	3	5	28	34	2051.17	2051.62	2051.45	3-5-28-34B	582		X	X						
9	Existing	5	8	1	6	2106.33	2106.75	2106.60	5-8-1-6A	597		X	X	X	X	X			
10	Existing	6	5	30	36	2124.58	2125	2124.75	6-5-30-36A	602		X	X		x				
11	Existing	7	5	8	14	2146.67	2147.12	WC	7-5-8-14A	609			X					X	X
12	Proposed	8	3	7.5	13.5	2163	2163.5	2163.40	8-12-12	613		X	x	x	x	x			
13	Existing	8	5	9	13	2169.12	2169.58	2169.20	8-5-9-13A	615			X					X	X
14	Existing	9	1	2	7	2180.17	2180.54	2180.25	9-1-2-7A	618		X	x	x	x	x			
15	Existing	12	3	6	12	2224.08	2224.58	2224.15	12-3-6-12A	631		X	x		x		x		
16	Existing	14	4	30	33	2274.58	2274.79	2274.70	14-4-30-33A	645		X	x						
17	Proposed	15	5	4	10	2301	2301.5	2301.10	15-17-5	652		X	x						
18	Proposed	18	2	3	9	2363	2363.5	2363.20	18-18-5A	670			X					X	X
19	Existing	20	2	32	36	2414.92	2415.25	2414.85	20-2-32-36A	685			X					X	X
20	Existing	21	4	30	35	2433.25	2433.67	2433.35	21-4-30-35A	690		X	x						
21	Existing	22	4	20	23	2454.87	2455.12	2454.95	22-4-20-23B	696		X	x	X	x	X			
22	Proposed	23	1	6	12	2470.5	2471	2470.60	23-22-7	700		X	x						
23	Existing	23	5	0	5	2481.96	2482.33	2482.15	23-5-0-5B	704		X	x						

Sample Mid Depth (Ft)	Omni Sample ID	Core/ Sample ID	Water Content (Total) (%)	Oil Content (% of total mass)	Total Fluid Content (% of total mass)	Water Content (Solids) (%)	Porosity (%)	Bulk Density (g/cm3)	Grain Density (g/cm3)	Water Saturation (%)	Water Content (Solids) (%)	Net Confining Stress (psi)	Porosity at Ambient (%)	Porosity at NCS (%)	Bulk Density (g/cm3)	Permeability to Air (millidarcy)	Permeability (Klinkenberg) (millidarcy)	Median Grain Size (microns)	Sand Volume (%)
1997.435	9P	1-3-33-36							2.67	100.0	16.6	800	30.7	30.7	2.16	0.155	0.096	13.4	16.8
2017.1		2-2-8							2.70			572	33.2	33.1	2.14	12.2	10.1	10.3	
2018.35		2-2-21-27B							2.71			572	32.6	32.5	2.16	4.74	3.78	6.8	
2032.4		2-5-17							2.71			576		42.6	1.98	2100	2020	94.5	
2033.875	3	2-7-33-36	17.5	0.35	17.86	21.7	36.8	2.06	2.68									94.7	74.5
2045.75	6	3-3 34-36	17.9	0.30	18.15	22.2	37.3	2.06	2.68									68.9	55.7
2045.9		3-7-3							2.71			580		43.0	1.97	1370	1310	74.5	
2051.45		3-5-28-34B							2.72			582		42.3	1.99	1630	1570	88.6	
2106.085	7P	5-7 34-36							2.69	100.0	17.0	800	31.3	31.3	2.16	0.069	0.038	36.9	27.9
2106.6		5-8-1-6A							2.72			597	32.0	31.9	2.17	1.46	1.15	6.9	
2124.75		6-5-30-36A							2.72			602		34.2	2.13	145	131	25.2	
2139.79	1	7-2-33-35	14.8	0.22	14.99	17.6	32.2	2.15	2.69									49.6	39.4
2151.085	2	7-6-24-26	16.7	0.24	16.97	20.4	35.5	2.09	2.69									97.2	73.8
2162.295	4	8-2-35-37	16.0	0.34	16.30	19.5	34.2	2.10	2.67									45.8	35.8
2163.4		8-12-12							2.71			613		41.0	2.01	675	636	58.4	
2167.855	5	8-4-29-31	15.4	0.18	15.61	18.5	33.5	2.14	2.72									57.1	45.1
2180.25		9-1-2-7A							2.67			618		39.9	2.00	7650	7470	210.1	
2224.15		12-3-6-12A							2.74			631	29.0	28.9	2.23	1.01	0.789	15.6	
2225.415	8P	12-3-21-23							3.19	80.2	3.0	800	8.5	8.5	3.00	0.0031	0.0008	11.6	7
2274.7		14-4-30-33A							3.21			645	27.5	27.4	2.60	2.68	2.12	8.0	
2301.1		15-17-5							2.71			652		40.1	2.02	815	772	62.2	
2396.335	10P	19-4-32-34							2.67	98.9	15.5	800	29.2	29.2	2.18	0.039	0.019	7.3	0.1
2433.35		21-4-30-35A							2.71			690	29.4	29.3	2.21	1.31	1.03	12.8	
2454.95		22-4-20-23B							2.70			696	30.4	30.3	2.19	1.34	1.06	10.0	
2470.6		23-22-7							2.72			700	30.5	30.4	2.20	0.887	0.685	7.2	
2482.15		23-5-0-5B							2.71			704	29.5	29.4	2.21	0.77	0.586	10.8	

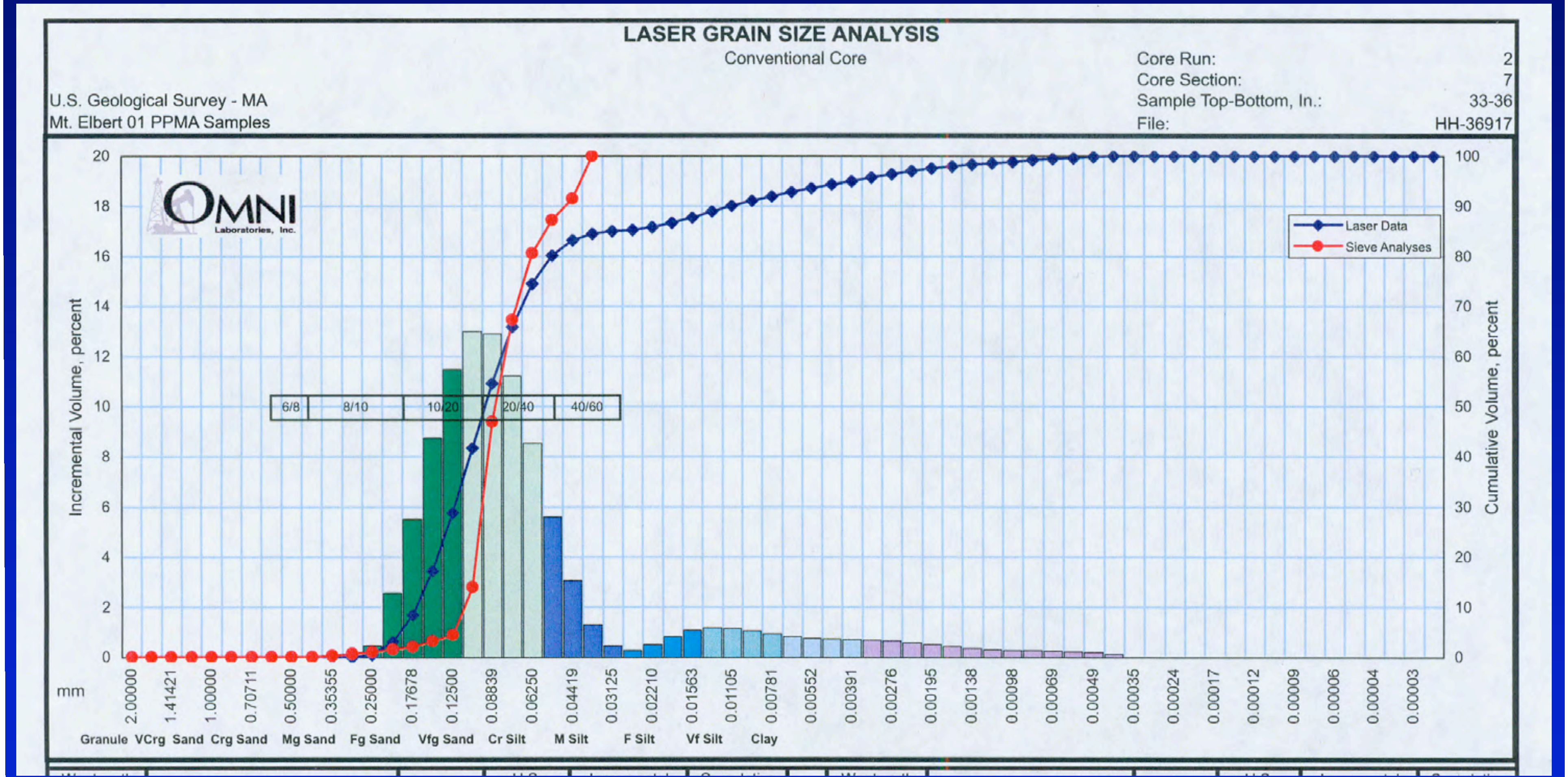
	Porosity at NCS (%)	Bulk Density (g/cm3)	Permeability to Air (millidarcy)	Permeability (Klinkenberg) (millidarcy)	Median Grain Size (microns)	Sand Volume (%)
GH Zones (ave.)	41.76	1.99	2685	2601	85.4	54.1
Outside GH Zones (ave.)	29.80	2.25	66	62	16.3	13.0

Mt. Elbert-01 Physical Properties Samples sent to Omni Laboratories 04April2007
Testing performed at Omni Laboratories, Inc. Houston
Convection dried at 220°F
Net confining stress: 800 psi (5.52 MPa)
Assume: In situ water content is equivalent to total fluid content (water was displaced by oil)

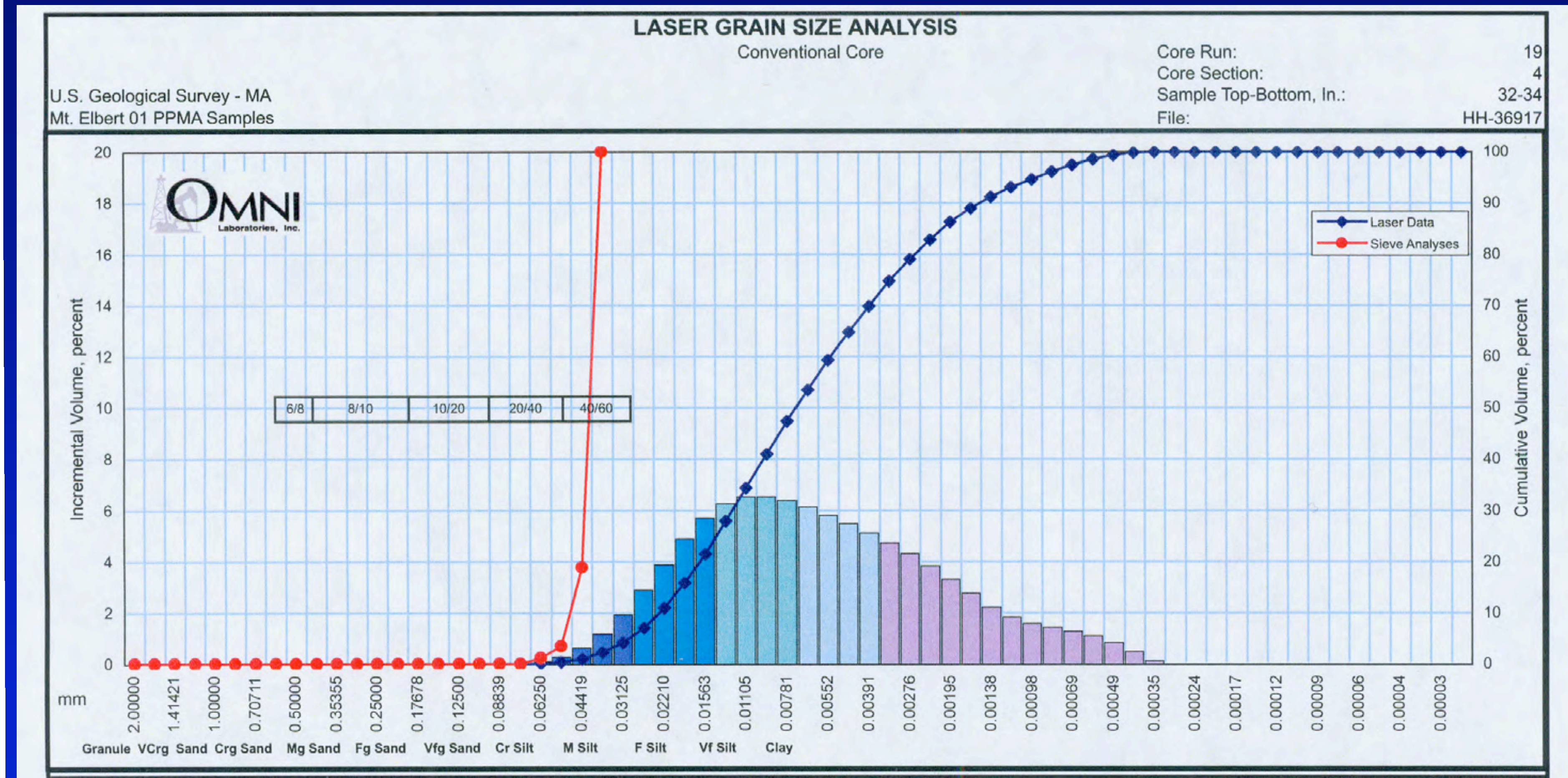
Notes:
- Because of low pore-water salinity, values have not been corrected for salt content
- Calculated sediment properties assume 100% pore saturation
- Potential issue between sample and well-log depths
- Gas-hydrate zone
- Black numbers - MAD samples
- Blue numbers - Recent test program



DEPTH (ft)
2000
2050
2100
2150
2200
Log (%)
MAD (%)
At NCS (%)
RHOB Log
MAD
Plugs
0 0.2 0.4 0.6 0.8
Sh (dec.)
0 50 100 150 200 250
Med Gr Sz (µm)
10 20 30 40 50 60
Porosity (%)
1.8 2 2.2 2.4
Blk Den (g/cm3)
2.65 2.7 2.75
Grn Den (g/cm3)
1000 3000 5000 7000
Perm (air) (mD)



USGS
science for a changing world
LASER GRAIN SIZE ANALYSIS
Conventional Core
U.S. Geological Survey - MA
Mt. Elbert 01 PPMA Samples
Core Run: 2
Core Section: 7
Sample Top-Bottom, In.: 33-36
File: HH-36917
OMNI Laboratories, Inc.
Incremental Volume, percent
Cumulative Volume, percent
Laser Data
Sieve Analyses
6/8
8/10
10/20
20/40
40/60
mm
2.00000
1.41421
1.00000
0.70711
0.50000
0.35355
0.25000
0.17678
0.12500
0.08839
0.06250
0.04419
0.03125
0.02210
0.01563
0.01105
0.00781
0.00552
0.00391
0.00276
0.00195
0.00138
0.00098
0.00069
0.00049
0.00035
0.00024
0.00017
0.00012
0.00009
0.00006
0.00004
0.00003
Granule
VCrg Sand
Crg Sand
Mg Sand
Fg Sand
Vfg Sand
Cr Silt
M Silt
F Silt
Vf Silt
Clay


LASER GRAIN SIZE ANALYSIS
Conventional Core
U.S. Geological Survey - MA
Mt. Elbert 01 PPMA Samples
Core Run: 19
Core Section: 4
Sample Top-Bottom, In.: 32-34
File: HH-36917
OMNI Laboratories, Inc.
Incremental Volume, percent
Cumulative Volume, percent
Laser Data
Sieve Analyses
6/8
8/10
10/20
20/40
40/60
mm
2.00000
1.41421
1.00000
0.70711
0.50000
0.35355
0.25000
0.17678
0.12500
0.08839
0.06250
0.04419
0.03125
0.02210
0.01563
0.01105
0.00781
0.00552
0.00391
0.00276
0.00195
0.00138
0.00098
0.00069
0.00049
0.00035
0.00024
0.00017
0.00012
0.00009
0.00006
0.00004
0.00003
Granule
VCrg Sand
Crg Sand
Mg Sand
Fg Sand
Vfg Sand
Cr Silt
M Silt
F Silt
Vf Silt
Clay

OMNI Laboratories, Inc.

2-28-08

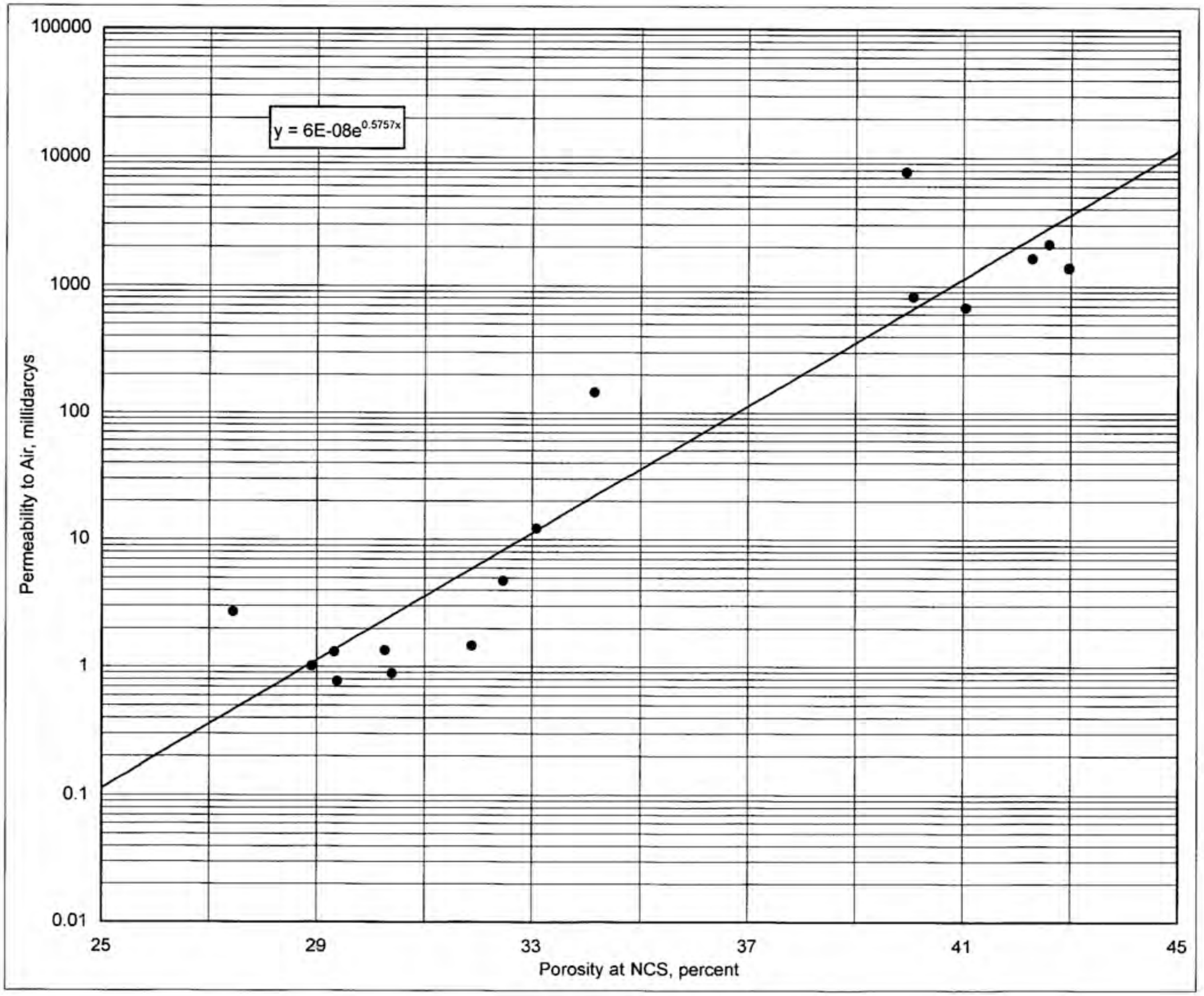
USGS

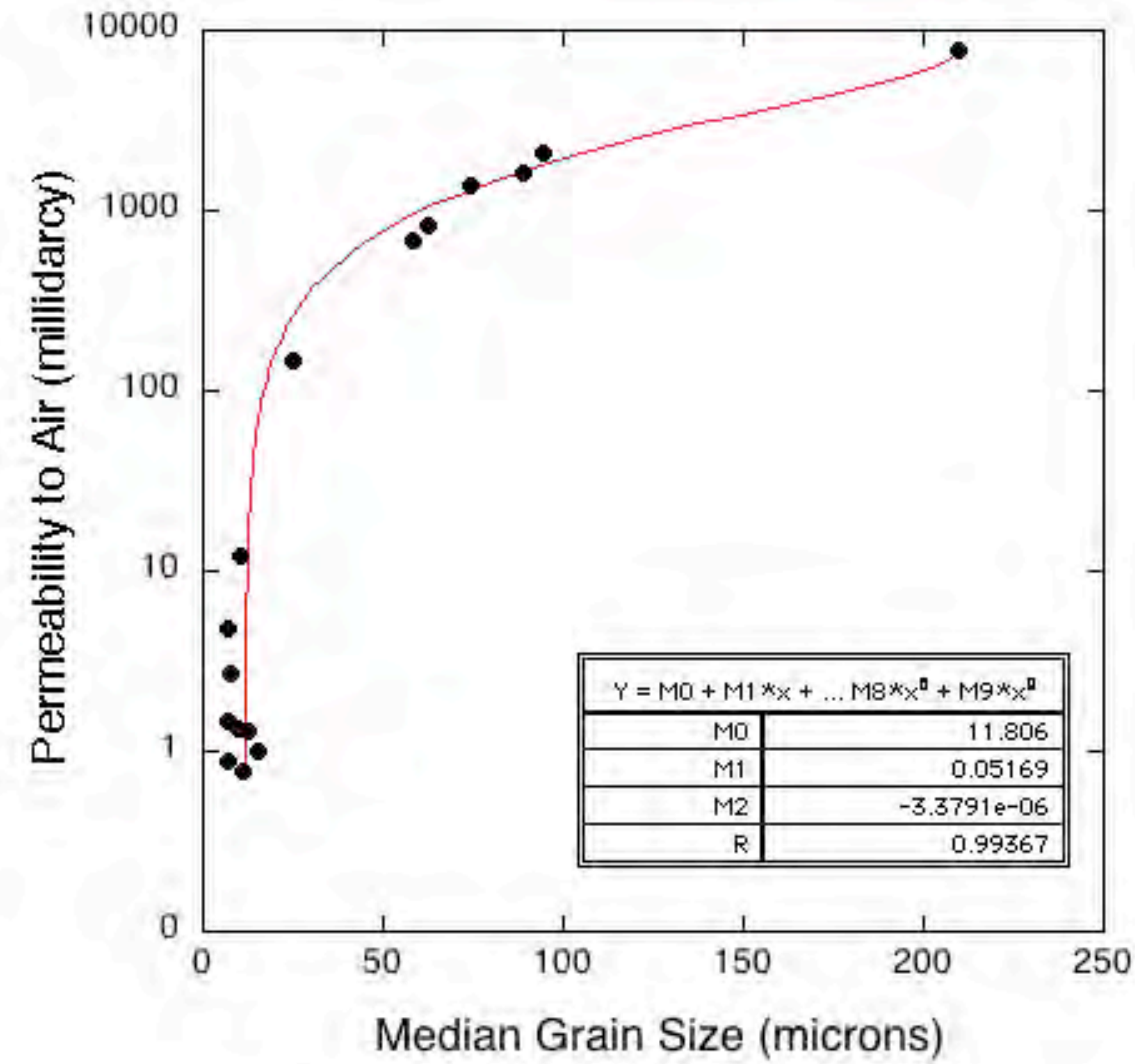
PERMEABILITY VERSUS POROSITY

Vacuum Oven Dried at 140°F

BP Alaska
MT. Elbert - 01 Well

Alaska, USA
File: HH-36510



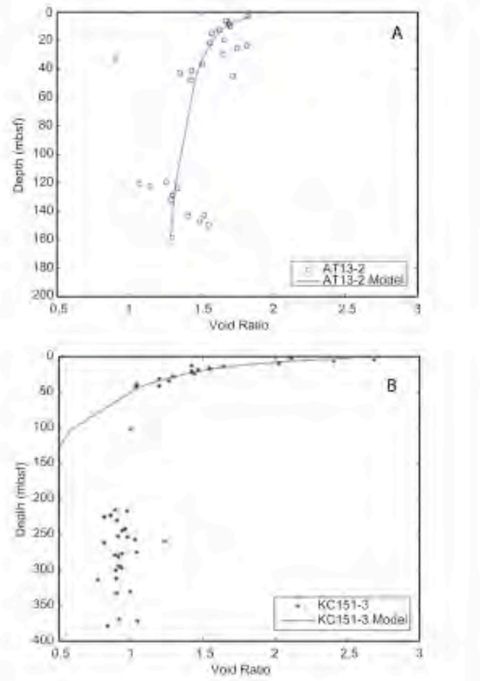


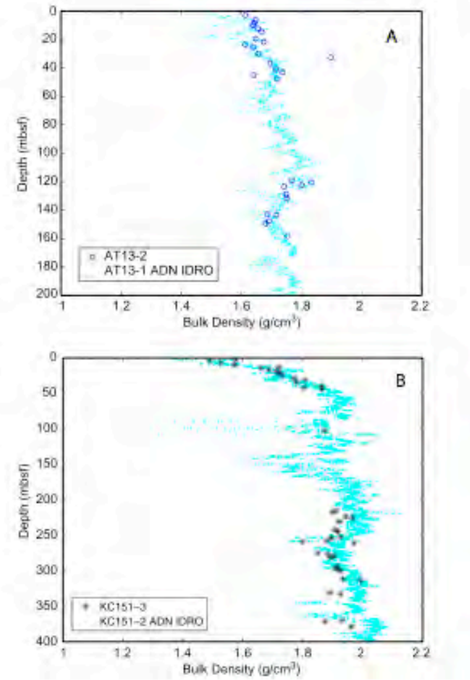
Permeability to Air (millidarcy)
10000
1000
100
10
1
0
0
50
100
150
200
250
Median Grain Size (microns)
Y = M0 + M1*x + ... M8*x + M9*x
M0 11.806
M1 0.05169
M2 -3.3791e-06
R 0.99367

Average properties within and outside gas hydrate layers

	Porosity at NCS (%)	Bulk Density (g/cm3)	Perm. (air) (mD)	Perm. (Klin.) (mD)	Median Grain Size (Micrn)	Sand Volume (%)
Within GH layers	41.8	1.99	2685	2601	85	54
Outside GH layers	29.8	2.25	66	62	16	13

2005 JIP Gulf of Mexico





Lab Studies

GHASTLI

Goals of GHASTLI Studies

- Physical properties for:
  - Understanding deformation behavior
    - Geohazards, well-bore stability
  - Gas hydrate formation mechanisms
    - Relation to measured properties (acoustics…)
  - Modeling parameters
    - Remote determination of gas hydrate presence in the field
- Natural gas hydrate
  - Important to test natural gas hydrate bearing sediment samples because of the difficulty in making similar samples within fine-grained sediment in a laboratory setting

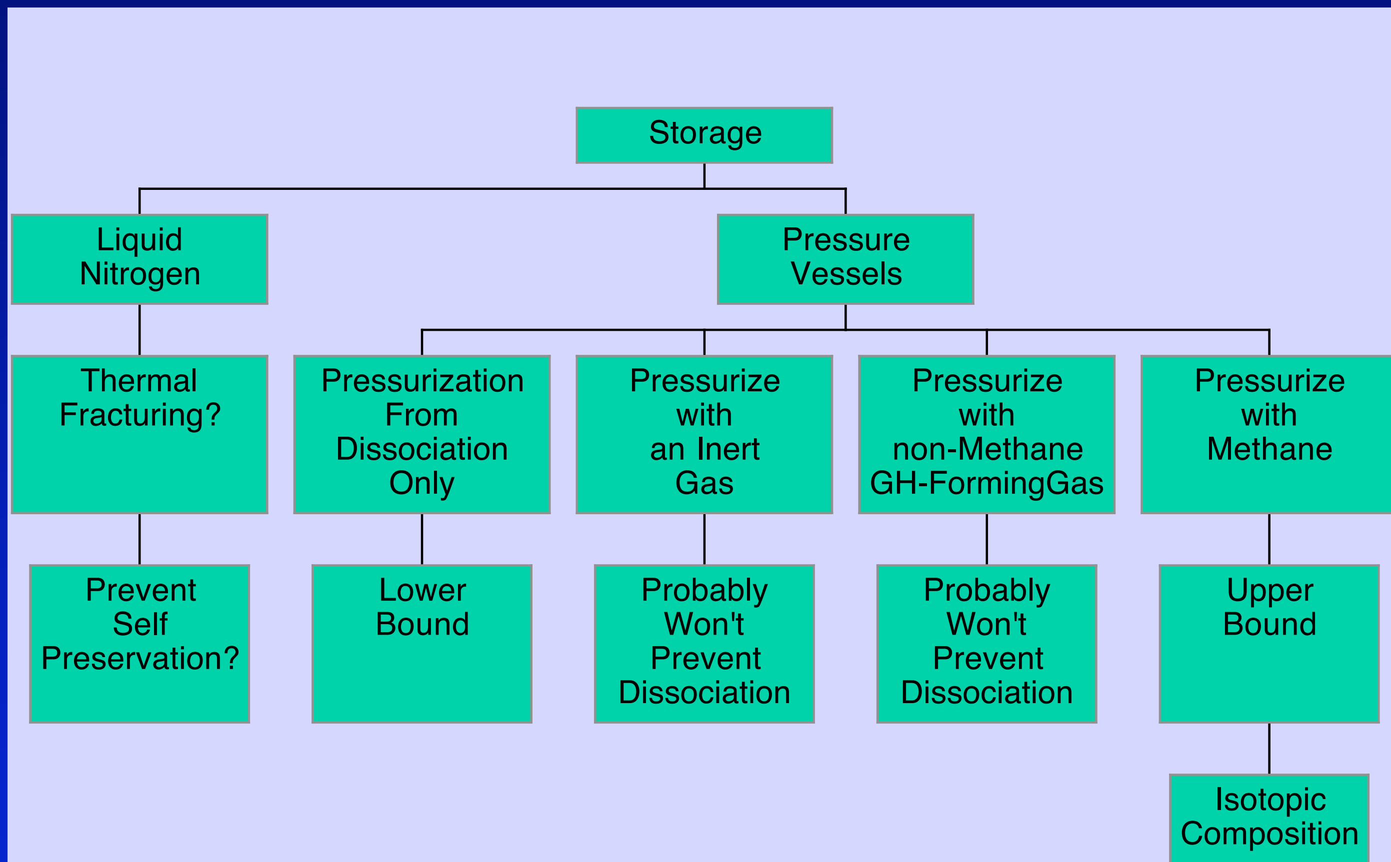
How do we get sediment samples containing natural gas hydrate back to the laboratory for study?

From Mallik 2L-38 to GHASTLI

Conventional core recovery

- Gravity/piston coring, conventional drilling, PC
  - Problems:
    - Some or all of NGH will dissociate
  - NGH preservation techniques
    - Liquid nitrogen
      - Not good for some test measurements
        - » (e.g., strength)
        - » Thermal cracking (GH loss)
        - » Textural/rate effects
        - » Tim Kneafsey's imaging
    - Pressure vessels
      - Storage issues
        - » Gas type
        - » Pressure
        - » Temperature
        - » Transportation issues ($$$)

Preservation and Storage of Gas Hydrate for Engineering Testing



Plus “self-preservation” (Differences between Arctic & marine)

Pressure Core Recovery

- Preserves NGH better
  - Considerations
    - May cut a smaller sample
    - Effectiveness may depend on sediment characteristics
    - Best utilized if transferred and tested without depressurization
    - Techniques and/or equipment were modified to improve recovery after GOM JIP
    - VG recover offshore India 2006
    - Expense of transporting

Sample from GOM JIP in W.H.

Pressure core samples can now be shipped by domestic air freight

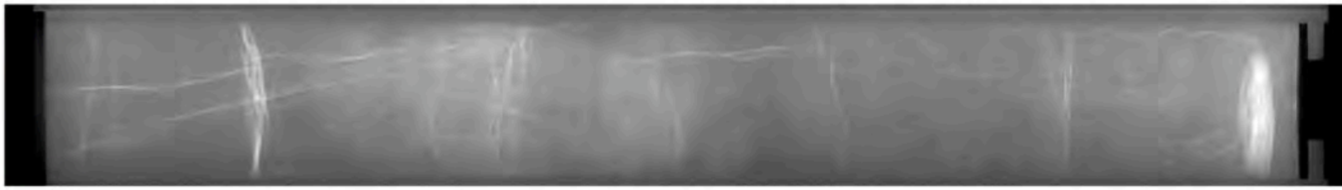
Measurements at In-Situ Pressure

- X-rays images
- Gamma density
- Acoustic velocity

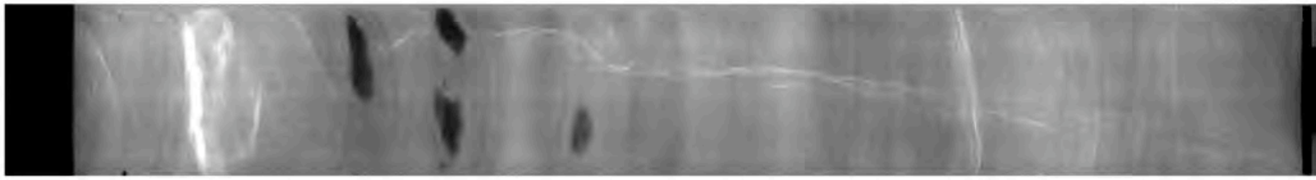
Thanks Peter Schultheiss/Geotek, Ltd. and Carlos Santamarina/GA Tech
for transferring core sections in Singapore post cruise

HYCINTH Storage Chambers

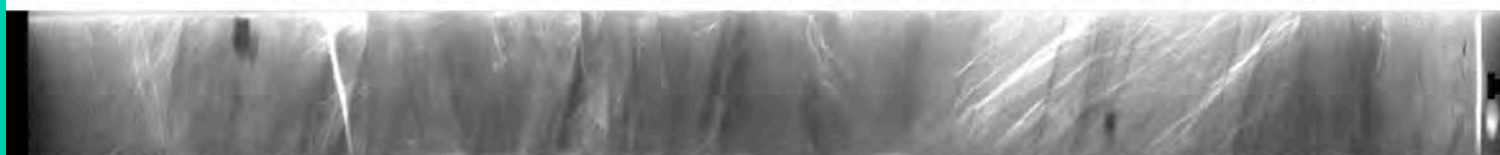
Core NGHP-1-10B-8Y 50.1 mbsf, 110 bar, gas hydrate nodules & veins, stored at pressure (SC-1)



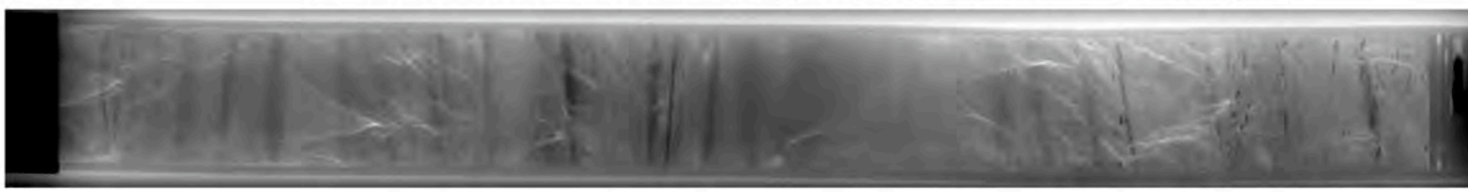
Core NGHP-1-21A-2Y 111 bar, 58.0 mbsf, gas hydrate veins, stored at pressure (SC-2)



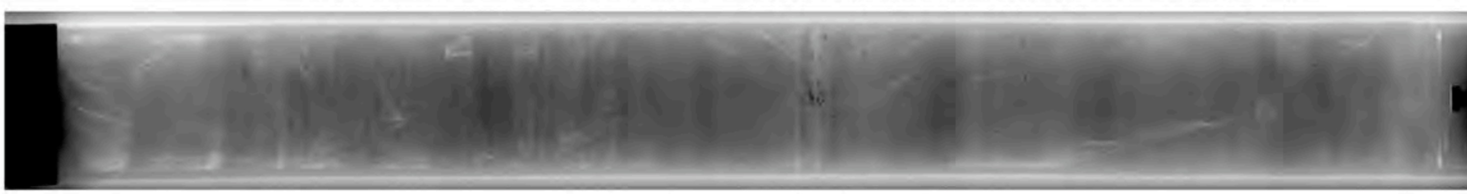
Core NGHP-1-21A-3E 111 bar, 59.0 mbsf, large cluster of gas hydrate veins, stored at pressure (SC-3)



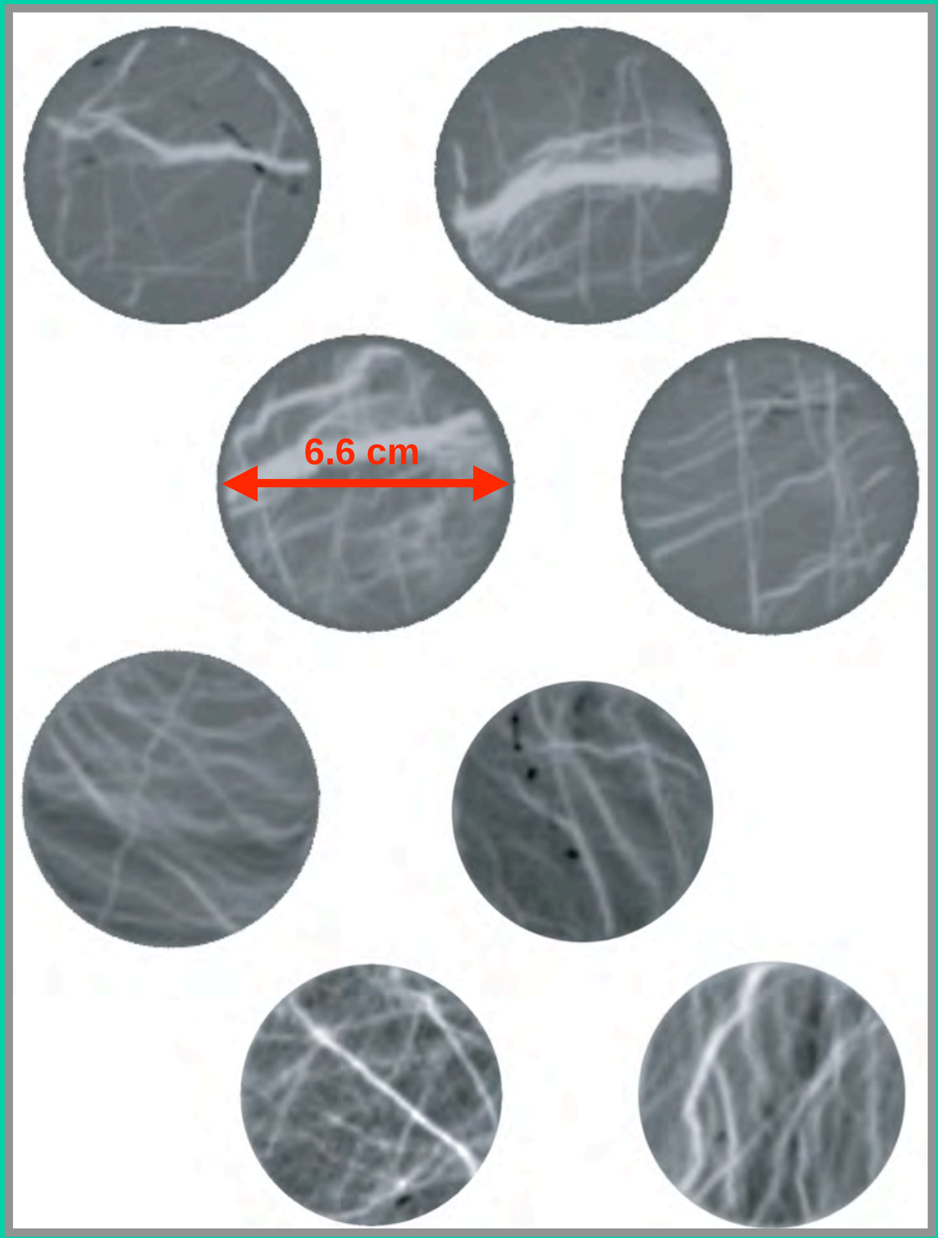
Core NGHP-1-21C-2E 111 bar, 56.5 mbsf, gas hydrate veins, stored at pressure (SC-4)



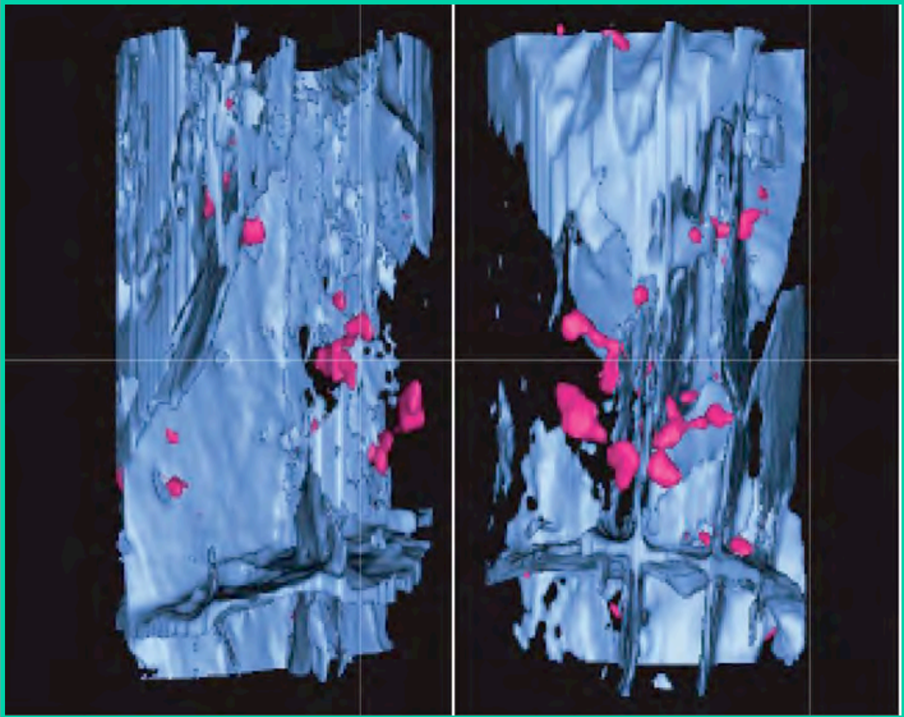
Core NGHP-1-21C-4E 113 bar, 77.0 mbsf, gas hydrate veins, stored at pressure (SC-5)



one meter (approx)



NGHP Expe 01 Site 10: 3D X-ray images of fractured gas hydrate occurrences

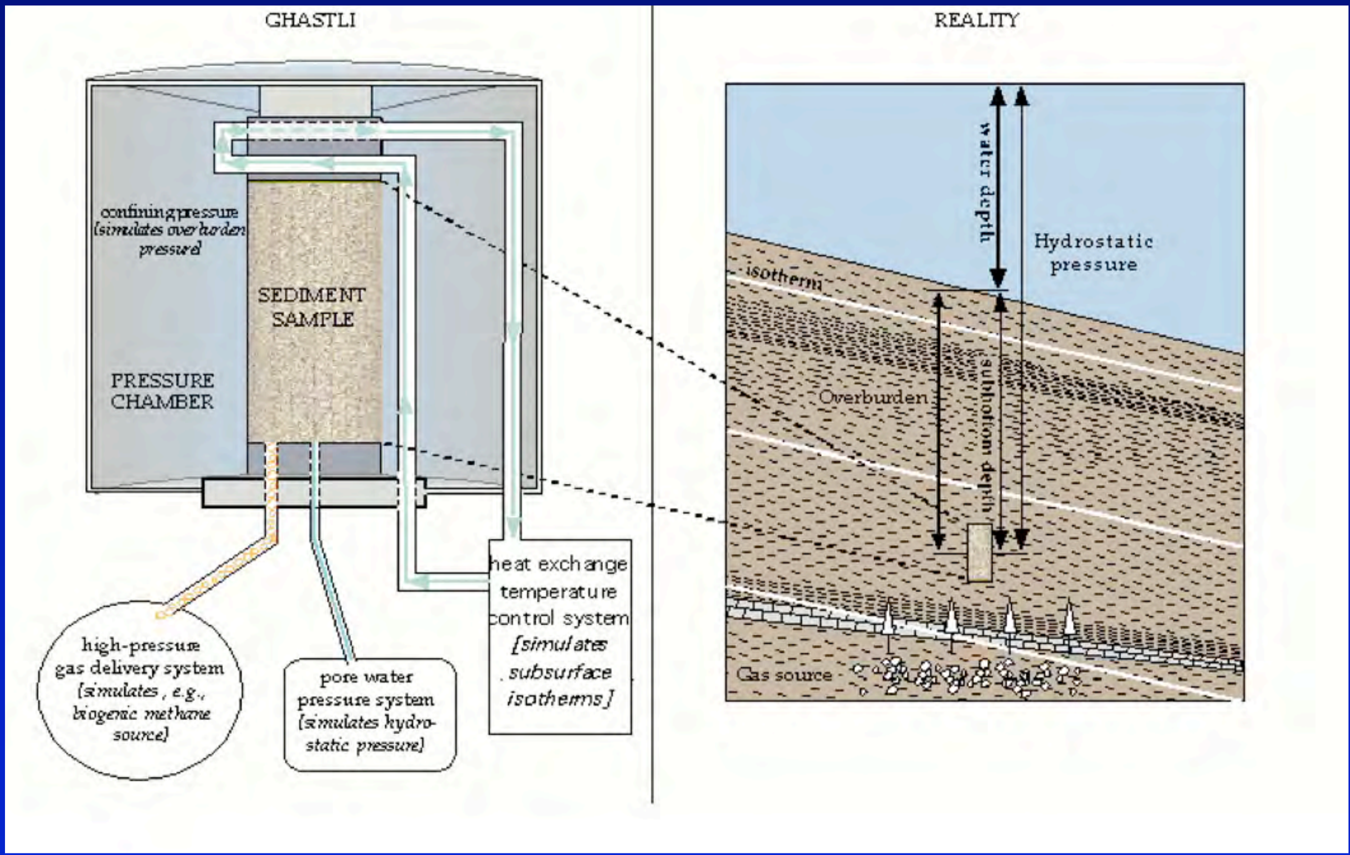


USGS

Recent samples from NGHP-01 in W.H.

Shipping pressure core samples internationally is involved and expensive

GHASTLI Simulation



GHASTLI - Bridging the gap

Main Strengths: 1. Ability to simulate natural conditions
2. Versatility in testing procedures

Measure properties of:
- Natural gas hydrate
- Lab-formed gas hydrate

Determine input props. for computer models

Understand effect of lab procedures on results

Capabilities
- •Overburden
- •25 Mpa press.
- •-3 to 25°C
- •Acoustics
- •Triaxial strength
- •Permeability
- •Elec resistance

GHASTLI Test Specimen

71 mm diam

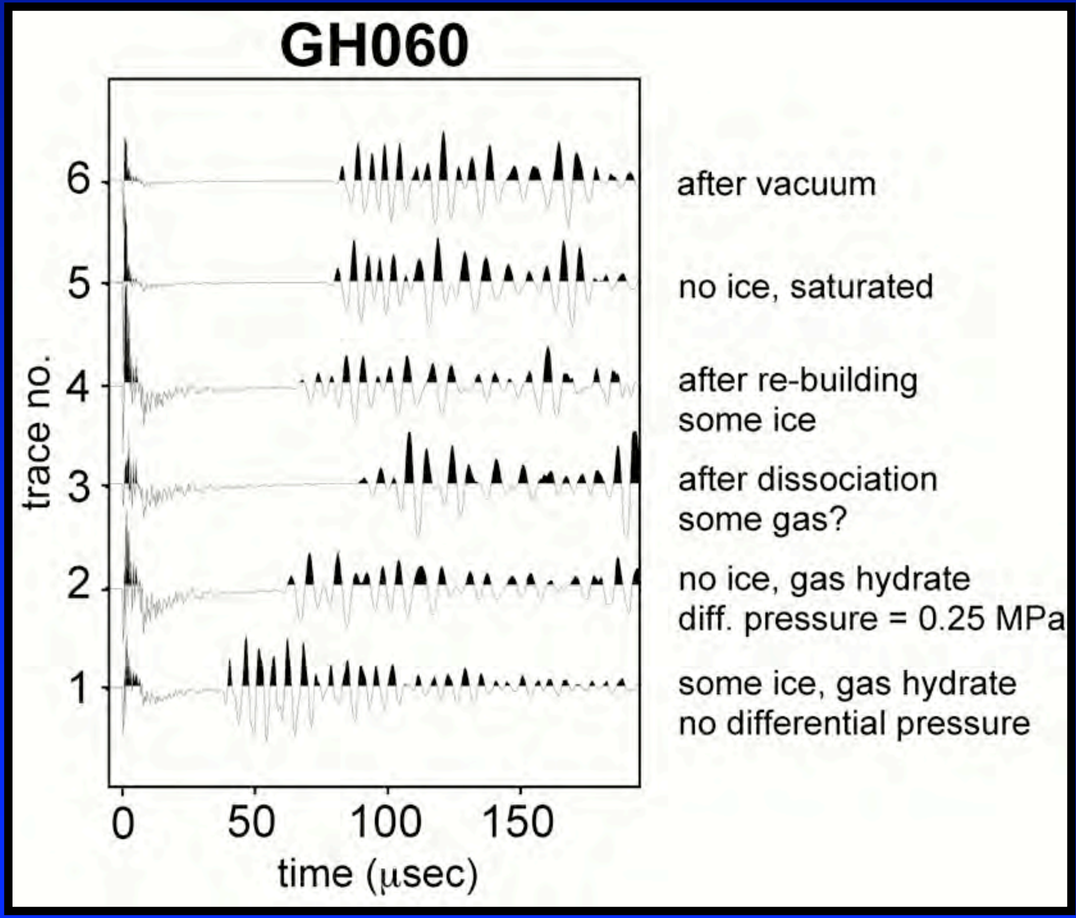
140 mm height

Typical Lab Research Objectives (NGH)

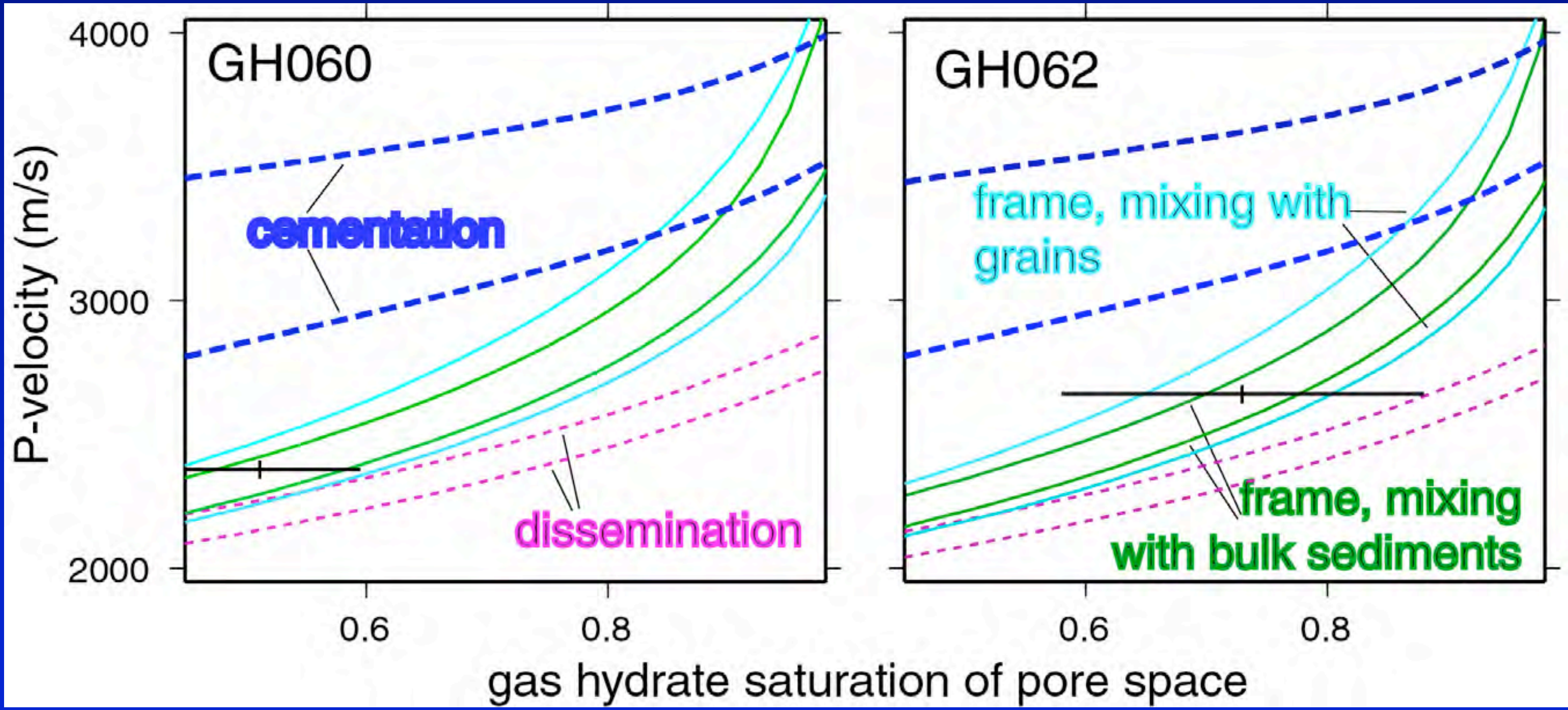
- Measure physical properties using GHASTLI
  - Preserve natural gas hydrate in sediment samples
  - Test at in situ conditions
  - Measure acoustic and strength properties
  - Determine amount of gas hydrate present
- Relate amount of hydrate to properties
- Model acoustic behavior

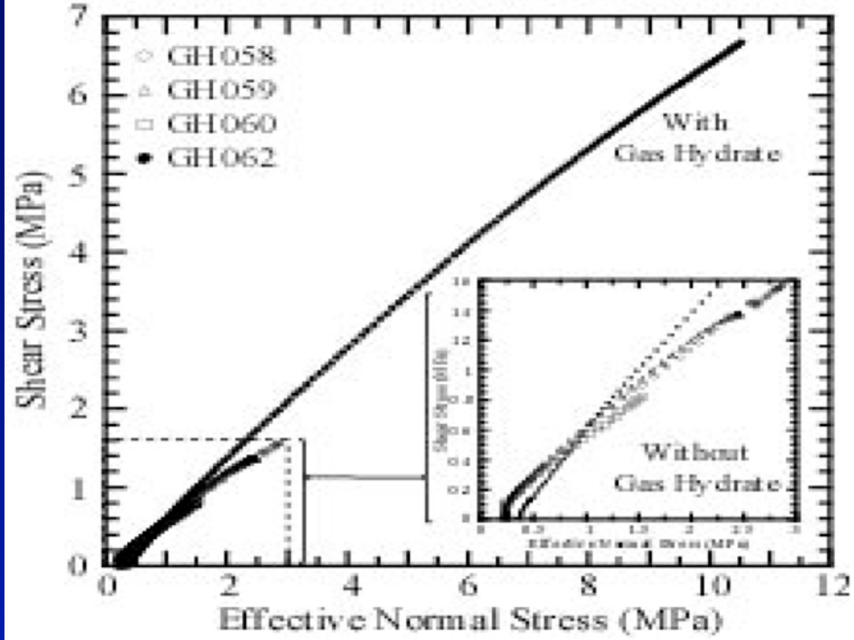
Pore Contents Effect on Acoustics

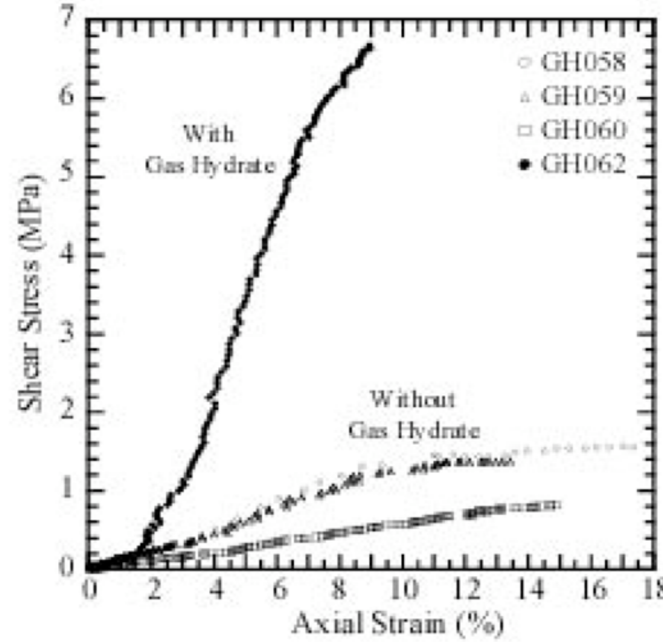
- Pore contents (at different times):
  - Ice
  - Gas hydrate
  - Water
  - Methane gas
- Vp decreased after:
  - Ice melted
  - Gas hydrate dissociated

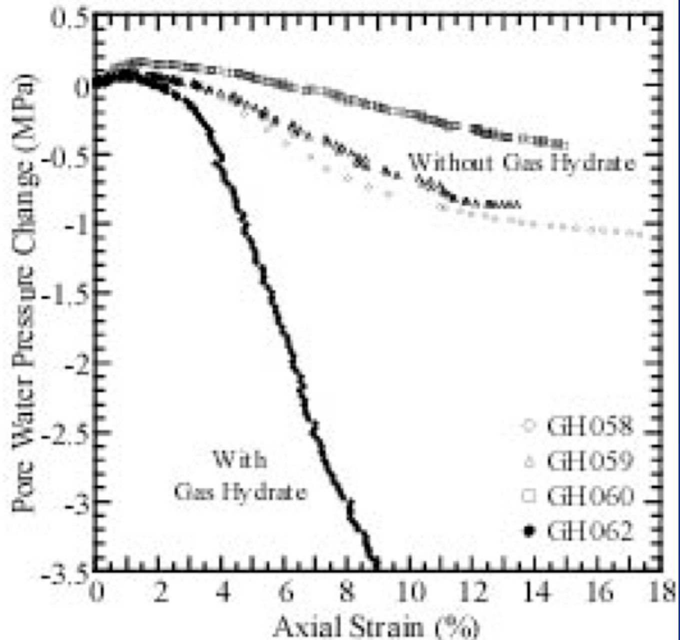


Mallik 2L-38 Acoustic Modeling Results



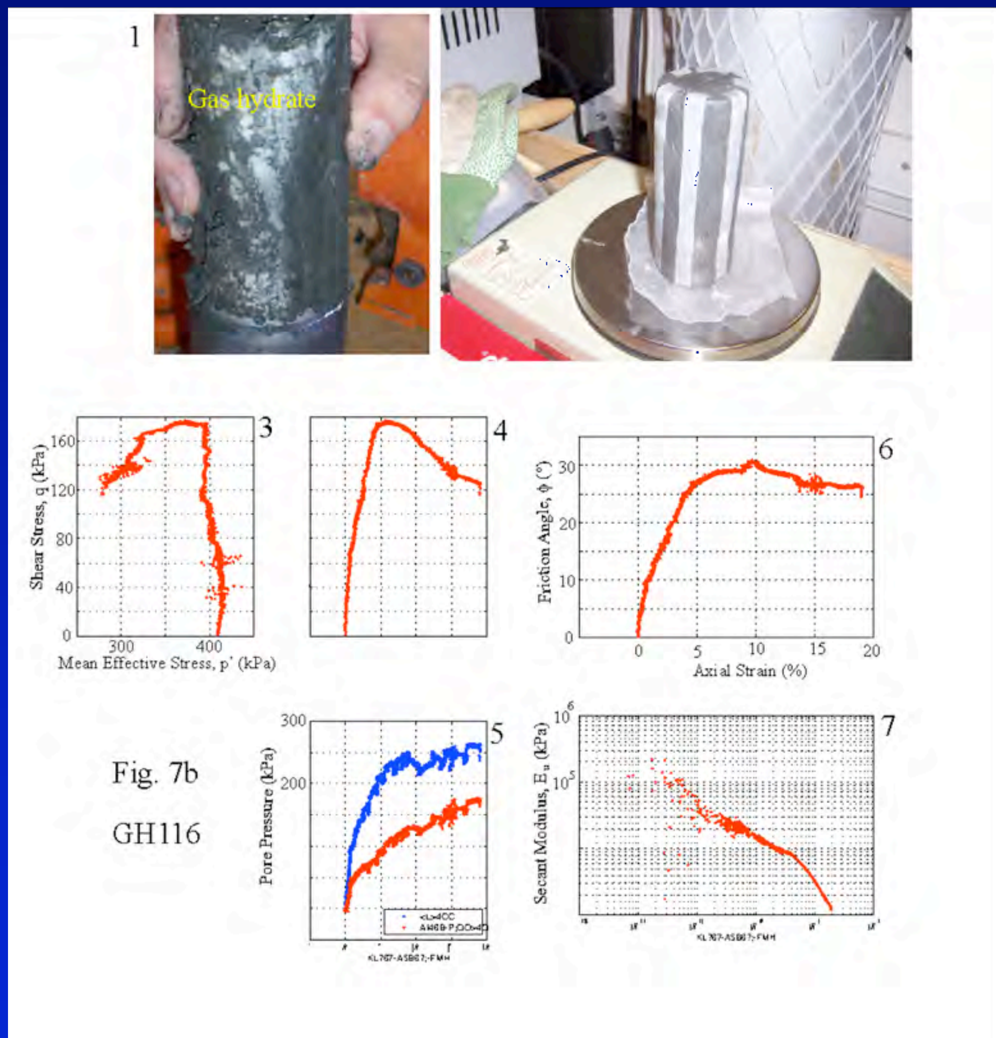






Triaxial strength results
for samples containing and
without natural gas hydrate

NGHP-01 (India) GHASTLI Triaxial Tests



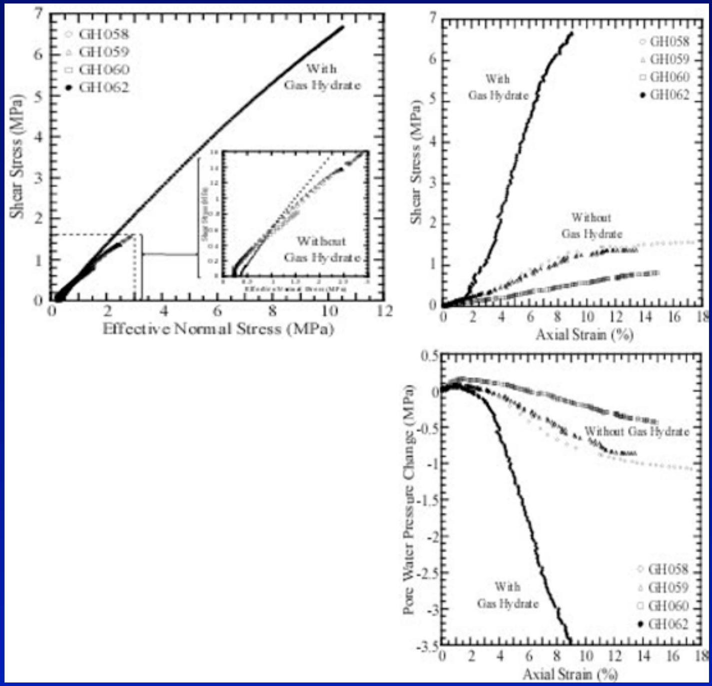
Natural gas hydrate samples
Comparison of Mallik to NGHP-01 (India)

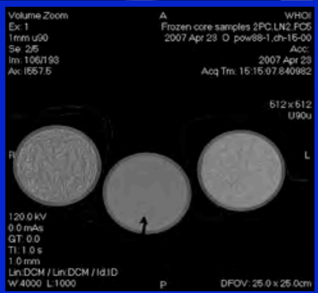
It is easier to perform measurements on frozen coarse-grained sediments, although some gas hydrate dissociates during recovery and transfer of those samples into a testing device such as GHASTLI.

Evidence suggests that storage with pressurized methane reforms lost hydrate.

Advances in pressure-core technology now provide a means to make measurements on samples that have not been depressurized.

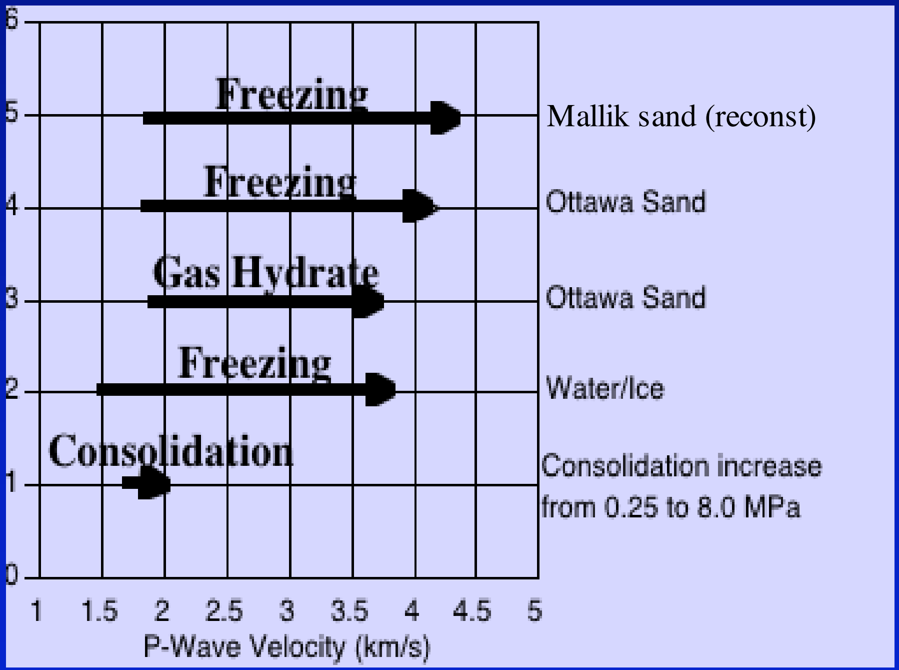
This is crucial for fine-grained marine sediment.



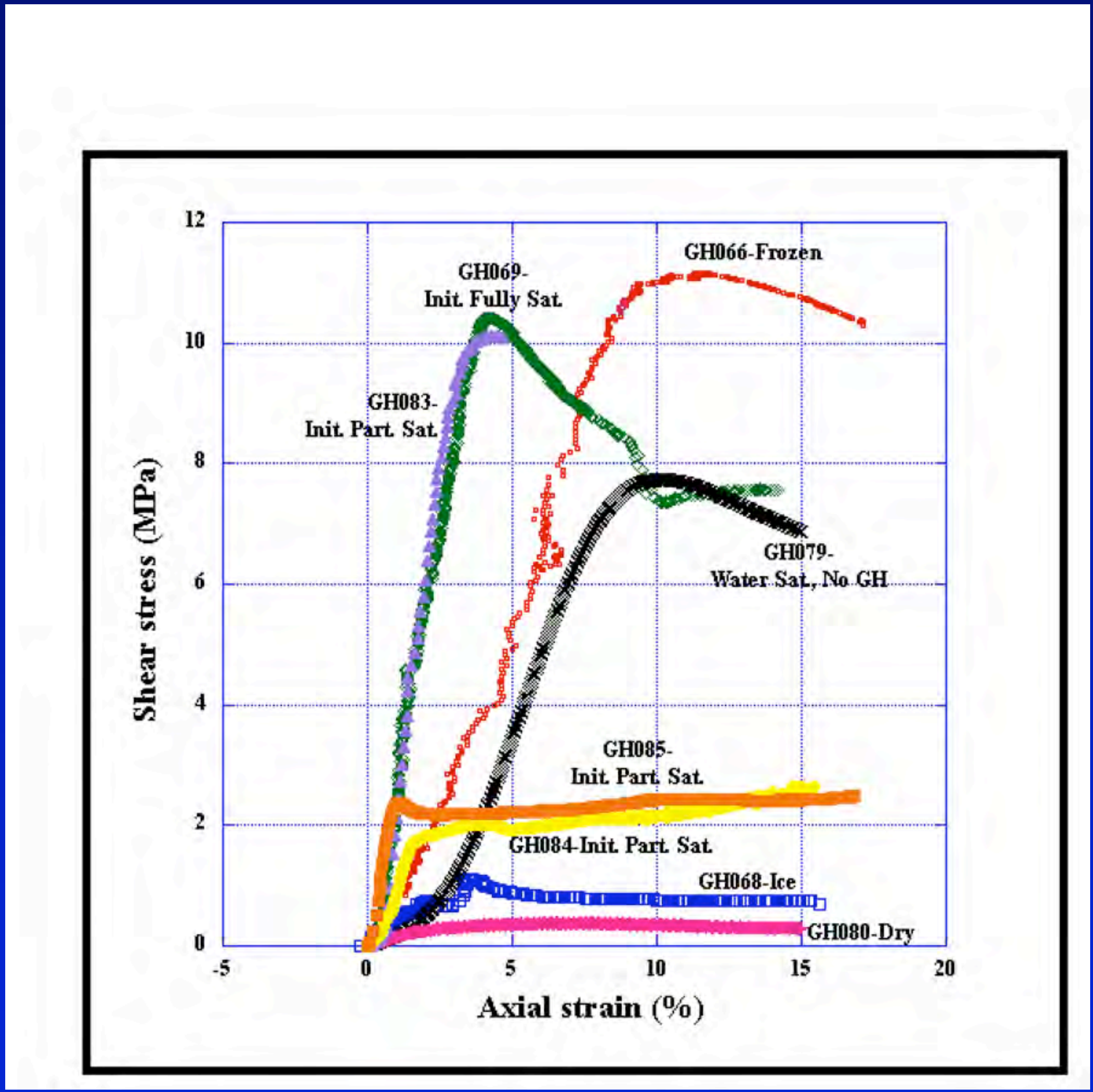


RECONSTITUTED SAMPLES
Pore content effect on Vp

- Consol stress has effect
- Grain size and porosity affect the degree to which GH increases Vp
- GH can double Vp



Strength properties - lab GH



Some lab results from GHASTLI

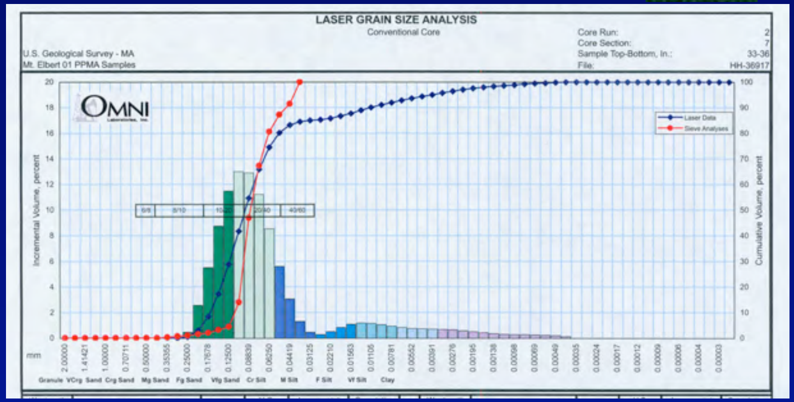
- It is possible to recover, preserve, and measure physical properties of depressurized-repressurized FROZEN sediment samples containing natural gas hydrate; but this is not ideal.
- It is much more difficult to test fine-grained sediment containing natural gas hydrate.
- Differences between natural and laboratory-formed methane hydrate.
  - NGH from Mallik in the lab does not cement coarse grained sediment.
  - Laboratory-formed methane gas hydrate, using excess gas, does cement sediment grains.
- Acoustic velocity and shear strength of sediment containing gas hydrate can vary widely, depending on the amount of hydrate present and presence of gas in the void space.
- Grain size effects are significant
  - Acoustic velocity
  - Pore pressure effects during shear
- Testing NGH is important because laboratories can synthesize gas hydrate in sediment and determine their properties, but perfectly simulating some natural hydrate-forming conditions is difficult.

Summary

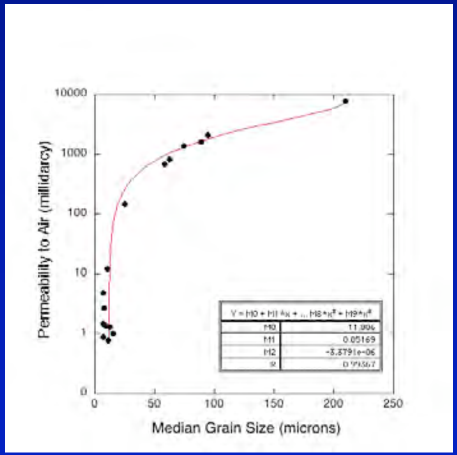
- The physical property program characterizes and quantifies properties of sediment that is host to gas hydrate
- These measurements provide baseline corroboration for well logging, lithostratigraphy, geochemistry, and other at-sea programs
- Physical property measurements are important to the design of production and hazard mitigation programs
- Lithology may influence the occurrence of many but not all gas-hydrates
- It is important to determine properties of sediment containing natural gas hydrate since laboratory methods to form gas hydrate in fine-grained sediment do not yet adequately simulate complex natural hydrate structure
- It is critical that physical properties of hydrate-bearing sediment are measured on samples that have never been depressurized under simulated in situ effective stress conditions

Path Forward

Mt Elbert well, North Slope AK

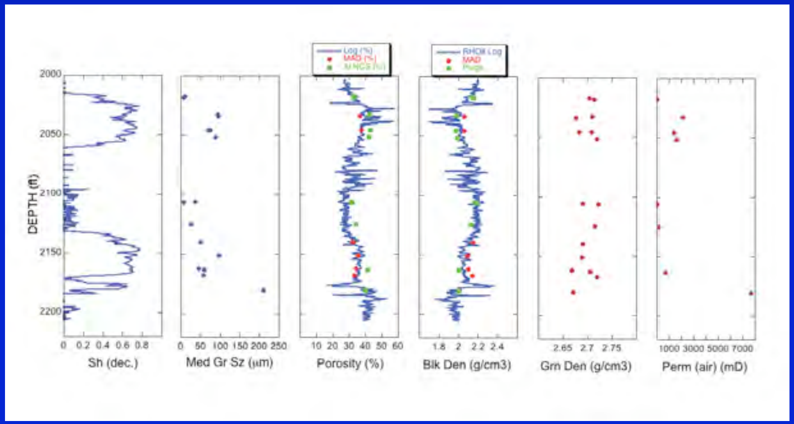


Objective 1: Continue to provide geologic expertise and measurements on hydrate-free host sediment as needed to design short (month to year) and long (50 year) term production wells



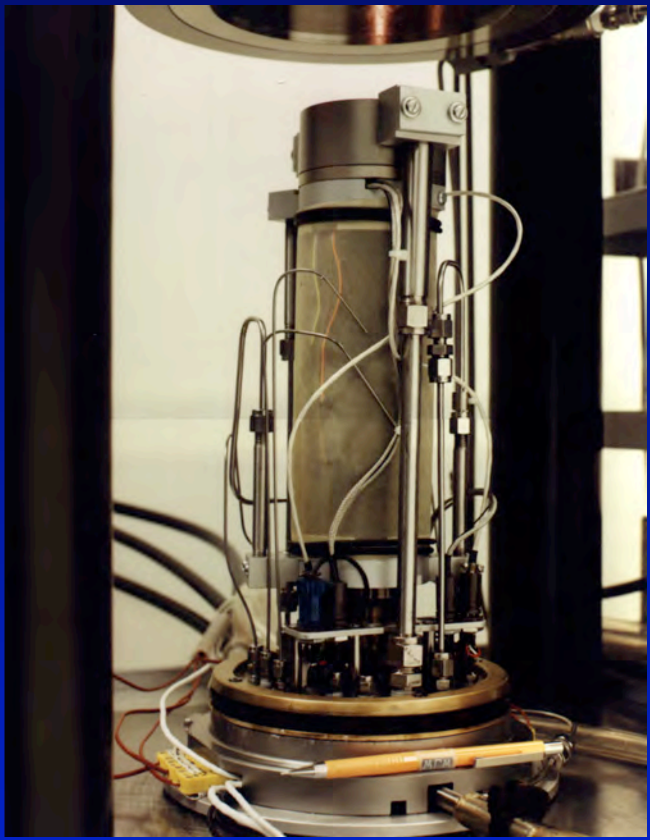
- Quantify porous-media effect and geologic controls for additional projects according to the new 5-year plan

- Continue to work with modelers and well designers to provide sediment properties needed to predict well behavior



Objective 2: Determine the effect of laboratory-formed gas hydrate on sediment physical properties as a function of hydrate saturation and effective stress

- Different sediment types
- Different gas hydrate formation techniques
    - Acoustics
    - Bulk and shear moduli
    - Permeability
    - Shear strength



In the past we've made gas hydrate using bubble-phase gas

Now we're trying to make gas hydrate from the dissolved phase (next presentation)

We're also going to attempt to measure radial strain during gas hydrate formation and dissociation as a means to determine volume change

Objective 3. Determine properties of recovered samples containing natural gas hydrate that have never been depressurized

- Partner with existing pressure coring systems and measuring devices
  GaTech's IPTC
- Determine properties needed by scientific community and assist in delivery
- Geotek's PCATS2
  Univ. Southampton