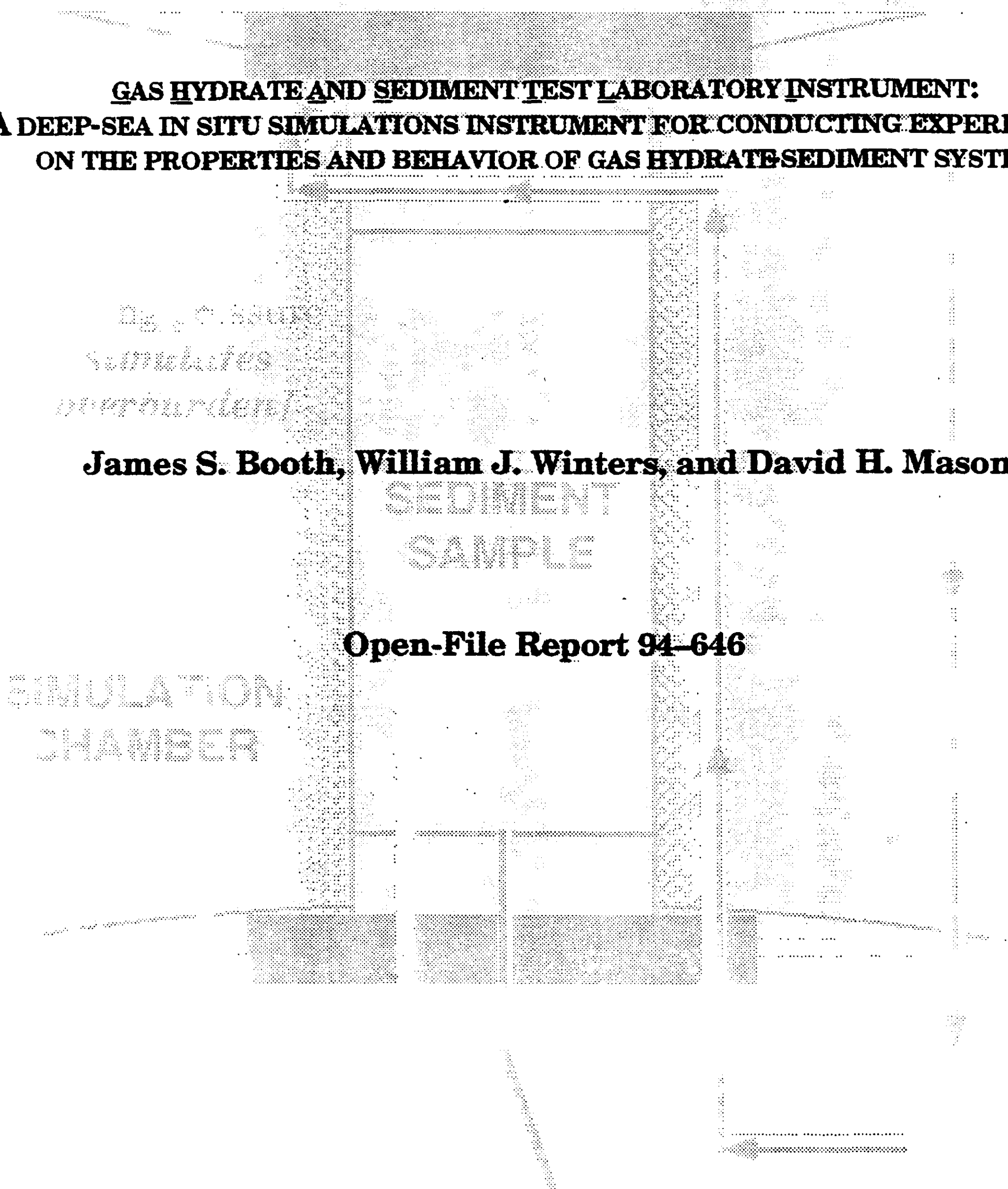
DEPARTMENT OF THE INTERIOR
U.S.GEOLOGICAL SURVEY

Capabilities of GHASTLI for Geo-Gas Hydrate Research

GAS HYDRATE AND SEDIMENT TEST LABORATORY INSTRUMENT: A DEEP-SEA IN SITU SIMULATIONS INSTRUMENT FOR CONDUCTING EXPERIMENTS ON THE PROPERTIES AND BEHAVIOR OF GAS HYDRATE-SEDIMENT SYSTEMS



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Woods Hole, Massachusetts
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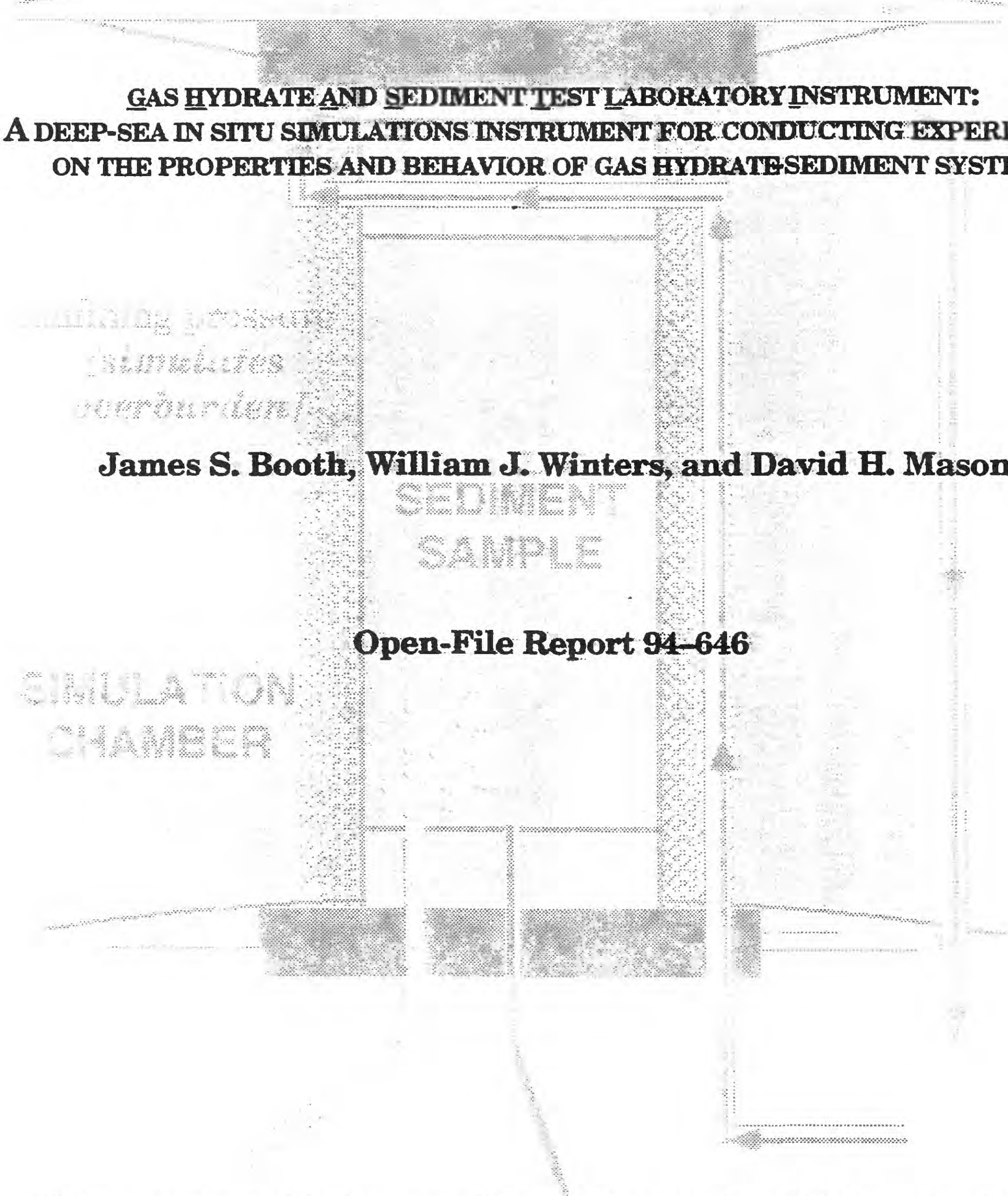

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INTRODUCTION

Gas hydrate is abundant in deep-sea sediments, it contains immense amounts of methane (concentrated by a factor of up to 170 relative to standard temperature and pressure) as well as other hydrocarbon gases, and it has a marked effect on the physical characteristics of the sediments. Therefore, gas hydrate may be: 1. a significant energy resource (because it is present in large quantities), 2. important to the global greenhouse (because methane is an order of magnitude more effective as a greenhouse gas than carbon dioxide), and 3. a significant control on sea-floor landslides and other, related processes (because formation and breakdown of gas hydrate can cause substantial changes in sediment strength and deformation properties). Gas hydrate in offshore sediments was first recognized more than 20 years ago (e.g., Stoll and others, 1971) and discovery of hydrate sites continues (fig. 1), but after more than two decades of seismic studies, sampling by the Deep Sea Drilling Project/Ocean Drilling Project, and some laboratory studies, little is known about these substances as a geologic phenomenon either regarding their own properties and behavior under deep-sea conditions or regarding their direct effects on the properties of their host sediment and environment. Some of the major needs for gas-hydrate research are analyses of the physical characteristics of gas hydrate-bearing sediments under sea-floor conditions and measurements of the changes of those characteristics as conditions change.

A considerable part of our lack of knowledge about hydrates may be attributable to the relative absence of laboratory analyses and experimental work. More specifically, of the three classic prongs of attack in geologic research for this type of problem —field work,

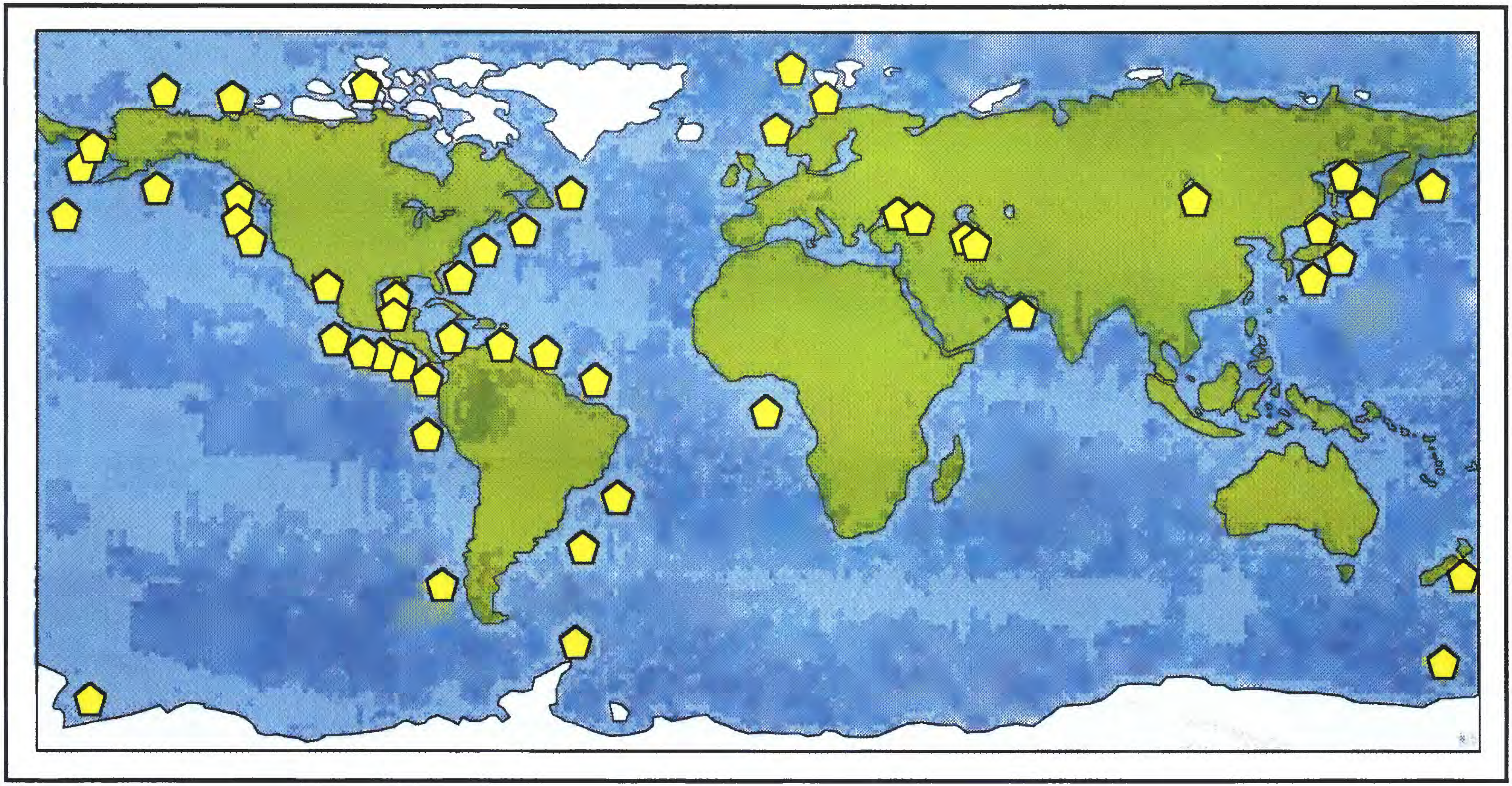

Fig. 1: Known or inferred occurrences of gas hydrate in offshore sediment. Figure based primarily on Kvenvolden and others (1993).

theoretical work and experimental work— only the first two have been pursued energetically. Yet, without actual laboratory measurements and simulations, field work cannot be optimized and theory lacks testing. And modelling, often a derivative of both field observations and theory, can suffer from an inadequate foundation of empirical observations.

Accordingly, the USGS provided scientific and technical criteria to build a laboratory instrument that would permit genesis and decomposition of gas hydrates in a sediment matrix under simulated in-situ conditions (fig. 2). This instrument, GHASTLI (Gas Hydrate And Sediment Test Laboratory Instrument), is a custom-built computer-controlled laboratory test system that is capable of addressing questions concerning geohazards, greenhouse effects, and hydrates as a potential energy resource, as well as providing a basic set of data that will benefit the geological gas hydrate research community.

ANATOMY OF GHASTLI

GHASTLI consists of a chamber in which a 15-cm by 7.5-cm cylindrical sediment sample is subjected to predetermined external (overburden) and internal (hydrostatic and/or gas) pressures, and temperatures to simulate a subseabed environment (fig. 3). Moreover, the sample may be subjected to an axial load and sheared or deformed at any time. GHASTLI comprises 6 subsystems: gas, pore water, chamber pressure, heat exchange, axial loading and back pressure. Liquid and gas pressures within GHASTLI originate from a hydraulic power supply and are controlled by a computer. "Computer control" herein means that a computer operates the system *in toto* during a simulation experiment, including establishing and varying simulations and pressures as specified, and regulating the interaction between the subsystems.

The computer serves a dual role in that it also acquires the test data. Up to 32 channels of data may be monitored and a total of 50 channels can be logged virtually simultaneously. The sampling rate of those channels, as well as the interval of integrating and recording (saving) the data, are preset by the operator, but can be altered so that burst sampling may be accommodated (i.e., during times when a much higher sampling rate is desirable, such as when a hydrate is in the process of forming) as can times when rather low rates of data acquisition would appear to be sufficient. The specific measuring capabilities (monitored channels) of the system are as shown in table 1.

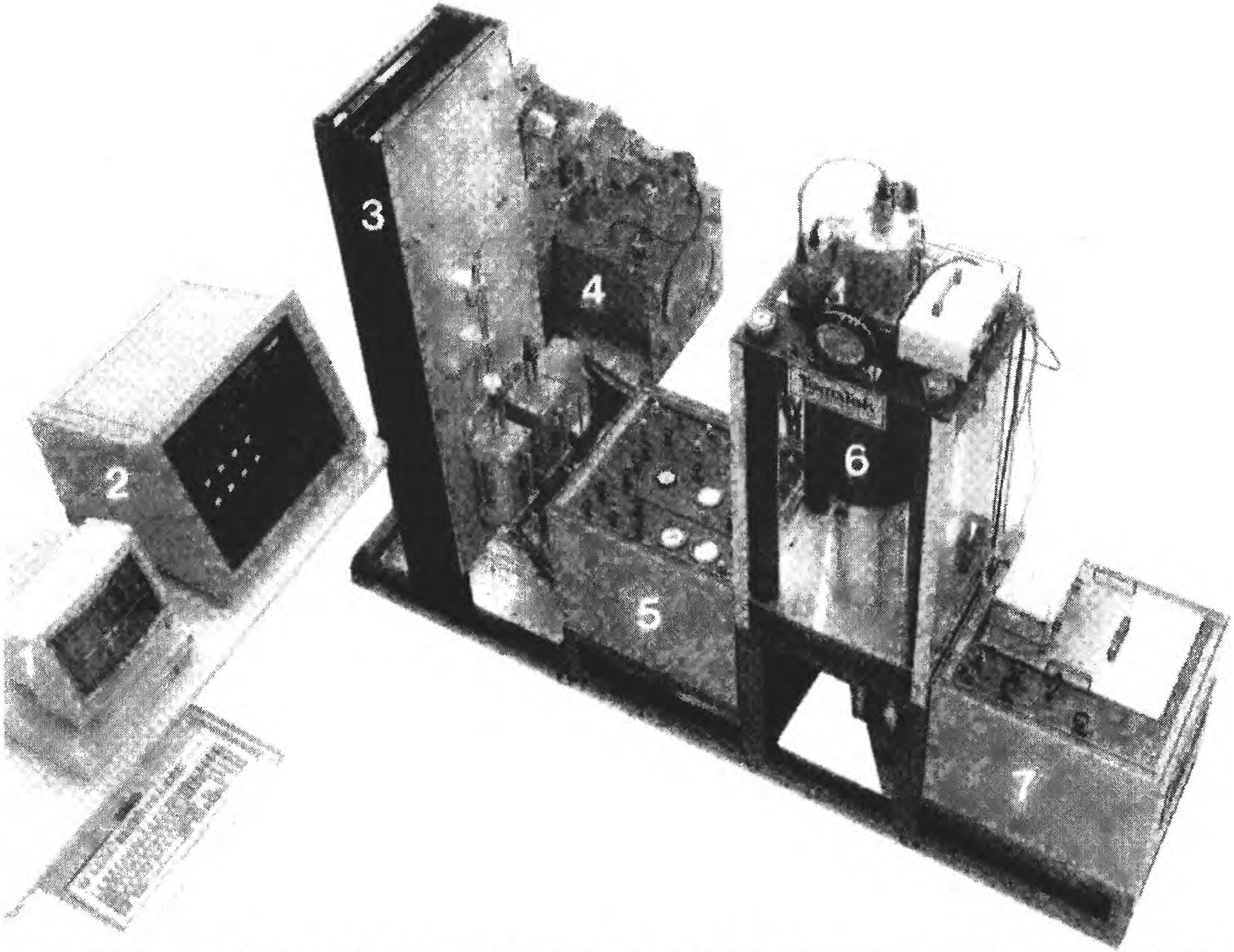

Fig. 2: Oblique view of gas hydrate-sediment test system illustrating the major components: 1) computer (systems control and data acquisition), 2) pressure control panel (links computer, subsystems, hydraulic power supply), 3) confining pressure, back pressure, seawater, and gas pressure intensifier support panel, 4) hydraulic power supply, 5) main valve control panel, 6) specimen chamber and load frame, and 7) heat exchange system and valve control

Simulating Subseabed Conditions with GHASTLI

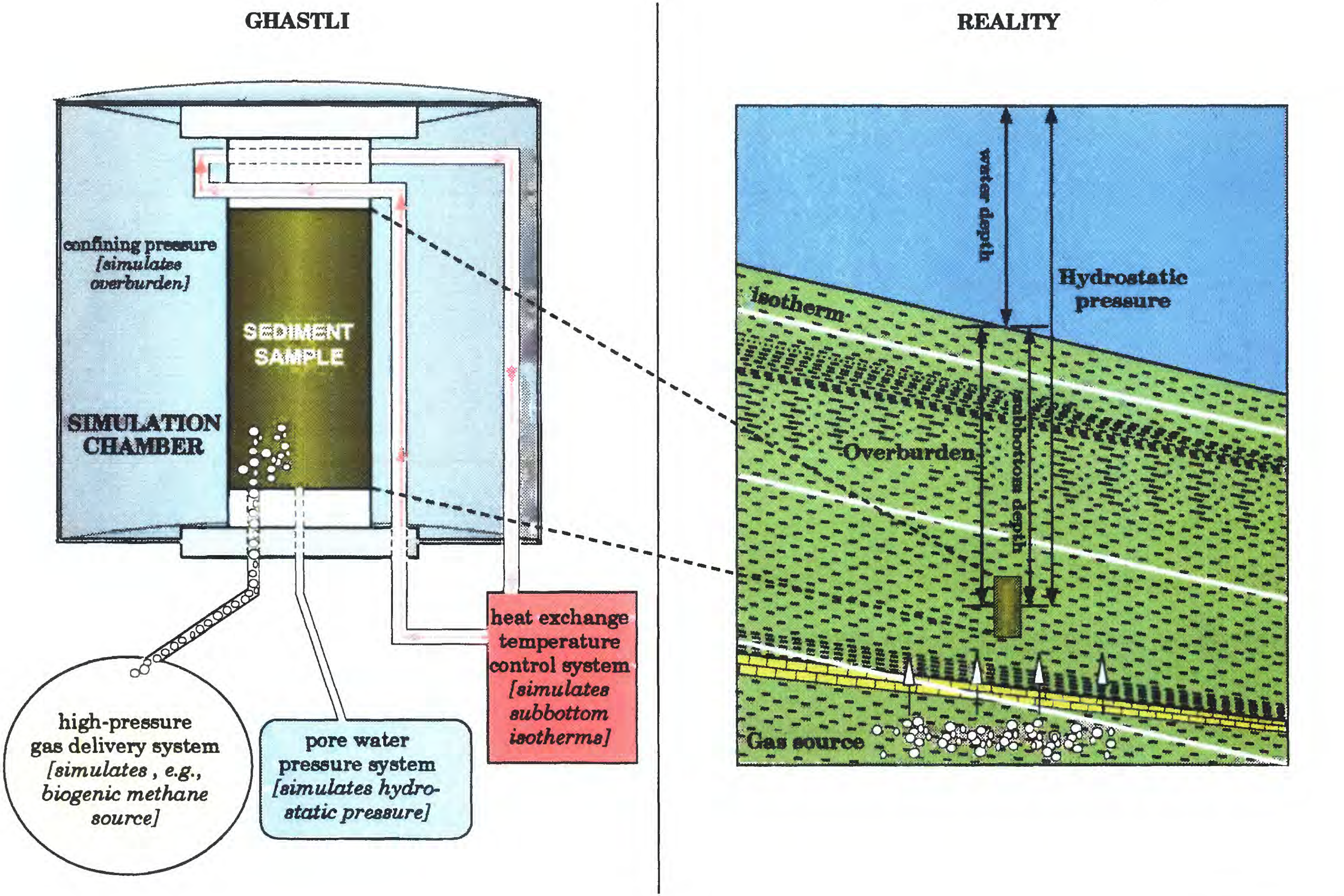

Fig. 3: Concept of GHASTLI simulation capability.

variable	Table 1 GHASTLI Data Acquisition *definition and comments*	*purpose*
1. Axial load	vertical force exerted on the sample test specimen by the load ram	used to determine shear strength or deformation behavior of a sediment
2. Axial displacement	vertical strain of the sample test specimen	shows effect on sample of consolidation, of hydrate formation, of shearing
3. Confining pressure	external pressure applied to the sample in the test chamber; ambient pressure	simulates effect of geostatic stress; i.e., stresses due to overlying (overburden) and adjacent sediment
4. Seawater (hydrostatic) pressure	sample internal pressure; typically, this is hydrostatic pressure; applied through base of sample	simulates weight of water column (water depth + subbottom depth times water density)
5. Gas pressure	pressure under which gas is introduced into the sample; applied at base of sample	required to assure occupation of sample by test gas, and simulate gas bubble migration
6. Back pressure	pressure applied counter to seawater and gas pressure (applied through top of sample)	permits establishing pressure gradient within sample
7. Differential pressure	difference between internal (as set by seawater, gas, or back pressure) and external (confining) pressures	direct measure of effective stress after consolidation
8. Seawater intensifier volume	volume of seawater added or subtracted to sediment sample with respect to start of test	shows flow of water as hydrate is formed or decomposed; water content of sample is fundamental to many calculations
9. Gas intensifier volume	volume of gas that has entered or passed through the sediment voids	shows sample gas content and thus conditions for hydrate formation
10. Confining pressure intensifier volume	volume of fluid flow into or out of chamber	indicates change in volume of sample due to hydrate formation or decomposition
11. Back pressure intensifier volume	volume of liquid expelled through the top of the sample	with collector volume, enables determination of amount of gas that bypassed the sample or was released as hydrate decomposed
12. Collector volume	total volume of seawater and gas that have been expelled through the top of the sample	see above; float separates liquid and gas, position of float is measured
13. Acoustic velocity (P & S waves)	velocity of P (compressional) and S (shear) acoustic waves as they travel longitudinally (vertically) through the cylindrical test specimen	verifies hydrate formation, correlate with amount, habit, etc. of hydrate, with offshore acoustic data from seismic survey resource assessments
14. Temperature (4 thermo-couples)	Temperature (°C) at top, middle (2), and bottom of test specimen	simulates subbottom isotherms, required information to induce hydrate nucleation
15. Resistivity (16 wire pairs from 8 leads)	electrical resistivity along many pathways through the test specimen	verifies hydrate formation; 3D map of hydrate occurrence; correlate with field studies

Computer output, both in real time and after a experimental run is complete, is set by the operator. Virtually any calculation using acquired data or any format for data listing is possible. Also, because of the inherent stability of hydrates, a sample of the test specimen with hydrate can be removed as a part of the post-test activity and placed in a scanning electron microscopic (SEM) before it begins to decompose. The SEM (here equipped with a cryogenic stage to retard decomposition of the gas hydrate) can then be used to observe grain-hydrate boundaries or conduct other analyses.

All sediment samples used in GHASTLI will undergo complete grain-size, mineralogy, carbonate content, and organic carbon content analyses. Additionally, a full set of geotechnical index tests will be conducted on each sample. Standard seawater will be used as the default pore liquid.

MIMICKING NATURE

GHASTLI can simulate the continental margin sea floor pressures and temperatures that are conducive to gas hydrate formation. After placing a sediment sample in the system test chamber at ≈25° C., the water depth and overburden pressures are set, and any gas (typically methane) is introduced into the sample until the requisite gas to seawater ratio has been reached (≈1:19 to 1:6). A heat exchanger on the upper surface of the sample then creates a unidirectional cooling front that moves downward through the sample. This super-cools the methane-rich seawater enabling it to pass through the hydrate phase boundary and begin crystallizing as a hydrate. While the hydrate genesis phase of the test is in progress, selected physical properties (e.g., sample volume, pore pressure) as well as acoustic and electrical properties, are monitored constantly. At any time (with or without a hydrate present) the sample can be sheared, and the strength or deformation properties determined. The hydrate also can be made to decompose, and pore pressures and other variables can be measured. Many geologic conditions can be created *a priori* and then changed while the experiment is in progress.

Although the pressure range of GHASTLI is to 25 MPa (3,600 psi) and temperatures may be from -30 ° to +30 °C., the practical limits of GHASTLI with respect to subseabed simulation. i.e., temperature always above freezing and pressure values that must represent both water depth and overburden, are shown in figure 4. Also shown is the phase boundary for methane hydrate in seawater. Note that the limits of simulation shown on figure 4 are the limits that may be simultaneously applied by the subsystems during the execution of a test. Samples may be consolidated (simulating overburden) to a much greater extent than indicated on figure 4 as part of a separate step in preparation for a test, which then may be conducted using the full, available pressure (25 MPa).

The sediment characteristics and seawater composition also can be controlled (pre-established) and many geological processes can be simulated. These include eustasy, deposition or erosion, mass movement, and faulting. Moreover, unconformities, overcompaction, the presence of salt diapirs and other specific geologic conditions may be imposed on GHASTLI.

GHASTLI was conceived to contribute to the scientific requirements of various USGS research programs. Therefore, research directions are multifaceted and include studies of:

1. Resource analysis and assessment
2. Geohazards
3. Global climate change
4. Geological processes and environments
5. Sea floor acoustic modelling
6. Engineering behavior of sediments

Each experiment, ideally, would supply data applicable to as many of the above topics as possible. However, this applicability will largely be a function of the particular simulation, which has many components. To wit, the following broad categories for simulation also have been identified:

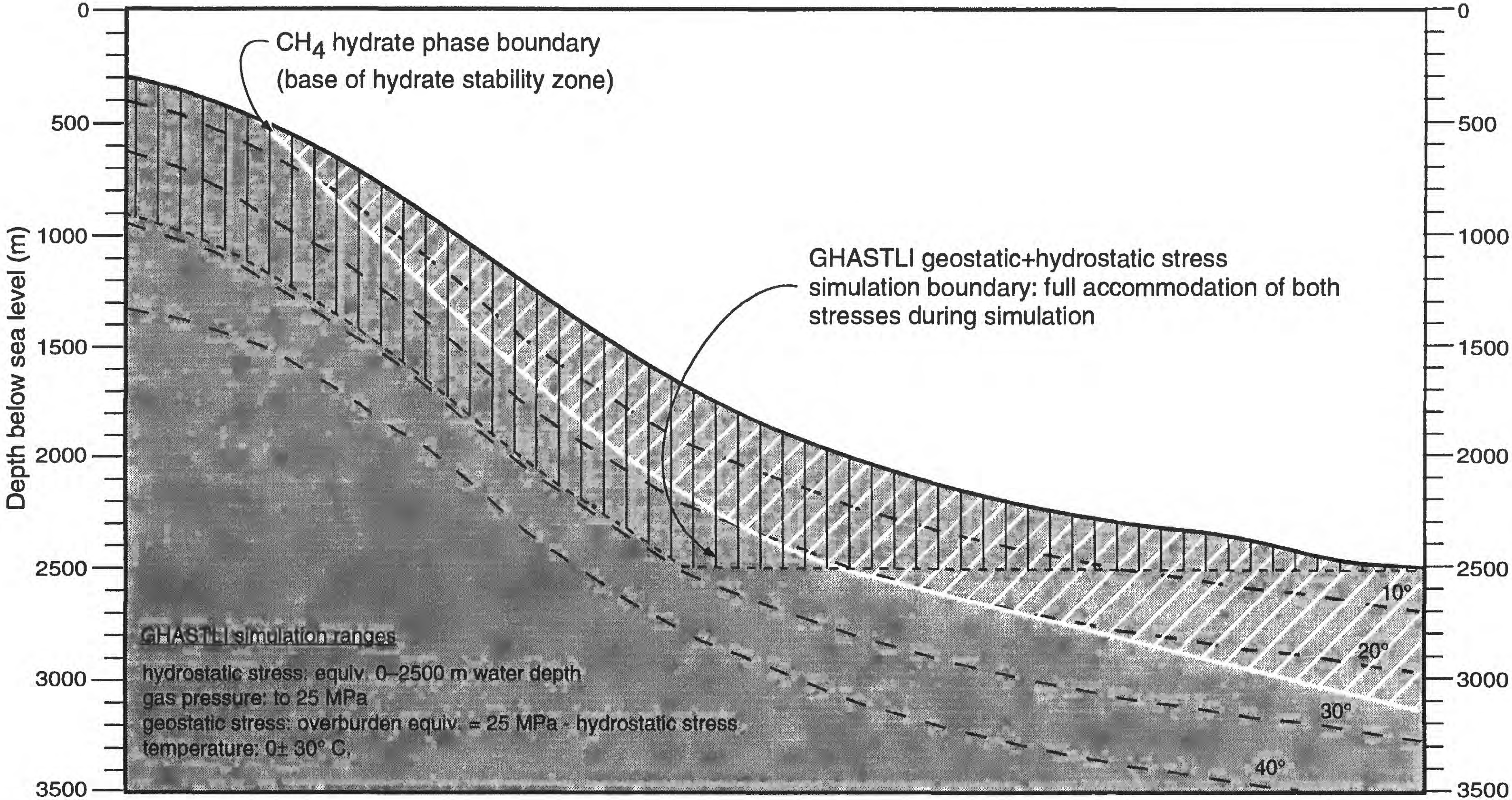

Fig. 4: Deep-sea and subseabed simulation limits of GHASTLI with respect to phase boundary of methane hydrate.

1. Sea floor or subseabed conditions (specifically, pressure and temperature at the point in the sediment to be simulated).
2. Overburden thickness
3. Gas or gas mixture (e.g, methane or mixed methane and carbon dioxide)
4. Sediment (e.g, silty clay with smectites dominant)
5. Pore fluid (e.g, normal salinity but depleted in sulphate)
6. Geologic conditions (e.g., change in sea level or the presence of joints)

A matrix formed from the two lists above yields an approach to planning the experimental work (fig. 5). More detail is required for executing individual experiments, however. For example. "Resource analysis..." may involve studying the effect of hydrates on acoustic velocity, on resistivity, on habit of formation, and so on. The research topics are thus represented by more specific cause and effect relationships in figure 6. These relationships, in turn. are controlled by specific simulation parameters; that is, "Gas" requires selection of the type of gas, the amount of gas, the rate at which the gas is delivered into the test specimen, the relative abundance of the gas with respect to other gases. and so forth. These simulation parameters also are presented in figure 6. Figure 6 serves as a basic planning template and also provides a gross summary of GHASTLI's performance capabilities for geologic research.

SUMMARY STATEMENT

GHASTLI was specifically designed to simulate the deep-sea environment, specific geological conditions, and geological processes in the presence of free gas and gas hydrates. It should enable comprehensive laboratory programs to be carried out that will bear on USGS and other research programs appropos to energy resources, global climate change, and geohazards.

SIMULATION FACTORS / RESEARCH TOPICS	Sea floor conditions (P,T)	Overburden	Gas	Sediment	Pore fluid	Geologic
Resource analysis and assessment						
Geohazards						
Global climate change						
Geologic processes						
Sea floor acoustic modelling						
Engineering behavior of sediments						
Basic Research						

Fig. 5: Designing GHASTLI experiments: research topic vs. factors that may be controlled by GHASTLI.

GAS HYDRATE TEST MATRIX

SIMULATION PARAMETER / TEST OBJECTIVE	Effects on Hydrate Formation and Habit	Effects on Index Properties		Effects on Strength Properties		Effects on Pore Pressure		Effects on Acoustic Velocities		Effects on Resistivity		Effects on Pore water Chemistry		Effects on Permeability		Effects on Structure and Fabric	
		hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd	hydrate	post-hyd
Water Depth																	
Overburden Thickness																	
Temperature																	
Rate of Temperature Change																	
Gas or Gas Mixture Type																	
Gas Injection Mode																	
Gas(es) Injection Rate																	
*Pore Fluid Chemistry**																	
Hydrate Formation Rate																	
Hydrate Decomposition Rate																	
Shear Rate																	
*Sediment Composition**																	
*Grain Size Parameters**																	
*Grain Geometry and Surface**																	
*Geotechnical Index Properties**																	
*Initial Geologic Conditions**																	
*Imposed Geologic Conditions**																	

* *Complex parameters*

Fig. 6: Gas hydrate-sediment test matrix: template for planning simulations and test runs. Not all simulation parameters bear on a specific test objective.

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