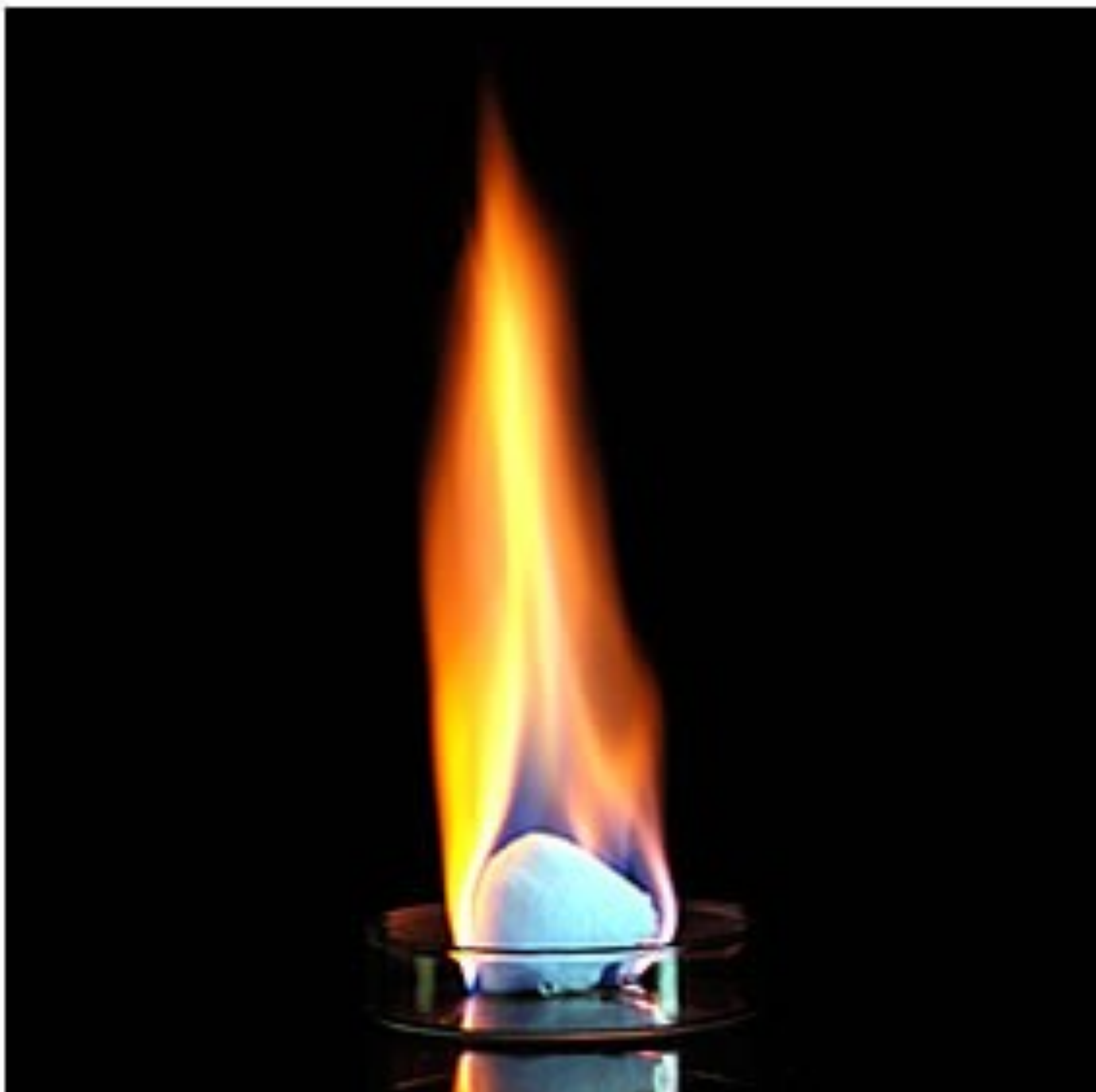
Gas Hydrates Resource Potential of South Asia



SAARC Energy Centre
Islamabad, Pakistan
2010

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ABBREVIATIONS AND ACRONYMS

AIST	National Institute of Advanced Industrial Science and Technology, Japan
A&M	Agricultural & Mechanical
ACS	Autonomous Coring System
atm	Atmosphere (Normal atmospheric pressure)
b cu m	Billion Cubic Meter
b kWh	Billion Kilo Watt Hour
BAPEX	Bangladesh Petroleum Exploration & Production Company Ltd.
bbl	Barrel
BGHS	Base of Gas Hydrate Stability
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe, Germany
BOP	Blow-Out-Preventer
BP	British Petroleum
BSR	Bottom-Simulating Reflector
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CSMHI	Consortium for Scientific Methane Hydrate Investigations
CTD	Coiled Tube Drilling
DGH	Directorate General of Hydrocarbons,
DSDP	Deep Sea Drilling Project
DVTP	Davis-Villinger Temperature Probe
EcoSCOPE	EcoScope Multifunction Logging while Drilling
EDBOE	Experimental Design Bureau of Oceanological Engineering, Russia
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMRD	Energy & Mineral Resources Division, Bangladesh
FMS Sonic	Intensity (F), Inclination (Inc) Declination (Dec) of the total magnetic field.
FPC	Fugro Pressure Corer
FTIR-	Fourier Transform Infrared Spectroscopy
FUGRO	FUGRO McClelland Marine Geosciences
GAIL	Gas Authority of India Limited

GDP	Gross Domestic Product
GEOTEK	Geotek Ltd,
GeoVISION	Geo VISION Borehole Camera Systems
GFZ	Geo Forschungs Zentrum Potsdam
GH	Gas Hydrate
GHSZ	Gas Hydrate Stability Zone
GIS	Geographical Information System
GoB	Government of Bangladesh
GSB	Geological Survey of Bangladesh
GSC	Geological Survey of Canada
HCU	Hydrocarbon Unit, Bangladesh
HDIP	Hydrocarbon Development Institute of Pakistan
HRC	HYACE Rotary Corer
HSE	Health, Safety, and Environment
HYACE	Hyace Ltd.
HYACINTH	Deployment of hyace tools in new tests on hydrates
IEA	International Energy Agency
IEOT	Institute of Engineering and Ocean Technology, ONGC Panvel
IOCs	International Oil Companies
IOC	Indian Oil Corporation Ltd.
IODP	Integrated Ocean Drilling Programme
IRCGH	Indo-Russian Gas Hydrate Centre at NIOT, Chennai
Japex	Japan Petroleum Exploration Company Ltd.
JNOC	Japan National Oil Corporation
JOGMEC	Japan Oil, Gas and Metals National Corporation
JR	JOIDES Resolution
KDMIPE	Keshav Dev Malaviya Institute of Petroleum Exploration
KG	Krishna-Godavari
KK	Konkan-Kerala Basin
LDEO	Lamont-Doherty Earth Observatory
LWD	Logging-While-Drilling
MCS	Multichannel Seismic
MH	Methane Hydrate
MH21	Research Consortium for Methane Hydrate Resources in Japan

MMcfd	Million Cubic Feet per Day
MN	Mahanadi Basin
MoES	Ministry of Earth Sciences, Government of India
MOPEMR	Ministry of Power, Energy & Mineral Resources, Bangladesh
MOPNG	Ministry of Petroleum and Natural Gas, India
MTOE	Million Tons of Oil Equivalents
MWD	Measurement-While-Drilling
NELP	New Exploration Licensing policy
NETL	National Energy Technology Laboratory Department of Energy USA
NGHP	National Gas Hydrates Programme, India
NGRI	National Geophysical Research Institution, Hyderabad
NIO	National Institute of Oceanography
NIOT	National Institute of Ocean Technology, Chennai
NMI	Nautical Miles
NMR	Nuclear Magnetic Resonance
NRCan	Natural Resources, Canada
NSF	National Science Foundation
ODL	Overseas Drilling Limited
OECD	Organization for Economic Co-operation and Development
OIL	Oil India Ltd
OMZ	Oxygen Minimum Zone
ONGC	Oil and Natural Gas Corporation Ltd., India
PAKOMIN	Pakistan Oxygen Minimum
PCS	Pressure Core Sampler
ProVISION	Logging while drilling tool for Nuclear Magnetic Resonance Service
PSC	Production Sharing Contract
PTCS	Pressure Temperature Core Sampler
R&D	Research & Development
R/V	Research Vessel
RMS	Root Mean Square
ROV	Remotely Operated Vehicle
SAARC	South Asian Association for Regional Cooperation
SEC	SAARC Energy Centre

SonicVISION	Sonic while Drilling
SSBB-	Small Size Benthoic Biota
SUGAR-	Submarine Gas hydrate Reservoirs
TAMU	Texas A&M University
TCF	Trillion Cubic Feet.
TCM	Trillion Cubic Meters
TeleSCOPE	Telemetry while Drilling
USDOE	United States Department of Energy
USDOE	US Department of Energy
USGS	United States Geological Survey
VSP	Vertical Seismic Profiling
XCB	XCB Coring System

EXECUTIVE SUMMARY

Gas hydrates are ice-like crystalline substances occurring in nature where a solid water lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure, also known as clathrate. Gas hydrates form under conditions of relatively high pressures and low temperatures, such as those found in the shallow subsurface under many of the world's oceans. Gas hydrates, which are known to occur in the marine sediments on the continental margins, are widely considered as a promising alternate energy resource. One cubic foot of hydrate at reservoir temperature and pressure yields approximately 160-180 cubic feet (ft^3) of gas at atmospheric temperature and pressure. The amount of natural gas in gas hydrate worldwide is estimated to be far greater than the entire world's conventional natural gas resources. This is what makes the Gas Hydrates a potential energy resource for the future.

The diminishing fossil fuels and energy security concerns of nations have attracted international attention from governments to the scientific communities to work on gas hydrate as a potential energy resource. Energy starved SAARC countries will benefit enormously from the successful development of gas hydrates and production of natural gas from marine gas hydrates.

This document reviews the status of technology pertaining to exploration and exploitation of gas hydrates, research initiatives that have been taken by India and other SAARC countries, that has contributed significantly in the research and development of gas hydrates, and suggests a mechanism for the technology transfer and promotion of R&D activities in the SAARC region.

Gas hydrate interests are multifaceted and intertwined. Gas hydrate has been known for many years as a problem in blocking cold-region natural gas pipelines, and as a drilling hazard in the arctic. However, natural gas hydrate studies have rapidly expanded globally in recent years, with large programs in Japan and USA, and considerable efforts in Canada, India, Korea, China, and numerous other countries.

Many groups are actively participating in a wide variety of gas hydrate research. The Department of Energy (DOE) of the US is coordinating gas hydrate research activities and provides a foundation to pursue the goal of producing methane from hydrates by the year 2015. The U.S. Geological Survey (USGS) has conducted extensive geophysical surveys and established a specialized laboratory facility to model the formation and dissociation of oceanic gas hydrates.

Gas hydrate research and resource development are also underway in Japan, India, Canada, the United Kingdom, Germany, Brazil, Norway, Russia, China and Korea. India has been actively involved in the research and development of gas hydrates for more than a decade. In association with USGS and other international organizations, India's gas hydrates research reached a matured state. Under the National Gas Hydrates Programme, Phase II India now plans to look for sands within the GHSZ and thereafter shortlist a candidate for pilot Production test.

SAARC countries having a vast coast line and deep water environment may consider forming a consortium for exploration and development of marine gas hydrates. This will help member states to share their experience with each other. For energy deficient SAARC region an alternative energy source like methane gas from the gas hydrates will be great boost in ensuring the energy security of the region.

Resources are not estimated in any of the SAARC countries except India which recently updated the map (Figure1) which shows the Gas Hydrate Stability Thickness Map along the Indian continental margins. The occurrence of gas hydrates in the marine sediments is confirmed by direct sampling. However, worldwide, their preliminary detection over large areas is inferred based on identification of Bottom Simulating Reflector (BSR) in the conventional seismic reflection data. In view of preliminary indications the NGHP has initiated systematic exploration of gas hydrates on the continental margins of India by reprocessing the available multi-channel seismic reflection data with a specially designed sequence of processing and mapping the spatial distribution of BSR-like features. The predicted thickness map matches quite accurately with the observed depths of BSRs, marker for gas hydrates.

Parameters like sedimentary thickness, rate of sedimentation, total organic carbon content, seabed temperature, geothermal gradients indicate good prospects of gas hydrates in deep water regions of the vast Indian offshore (Sain and Gupta, 2008, Curr. Sci.). Analysis of MCS data exhibits BSRs in the Krishna-Godavari (KG), Mahanadi (Mn), Andaman (Am), Kerala-Konkan (KK) and Saurashtra (S) offshore basins. The geological, geochemical and microbial proxies wee also studied, which led suitable locations for ground truth validation.

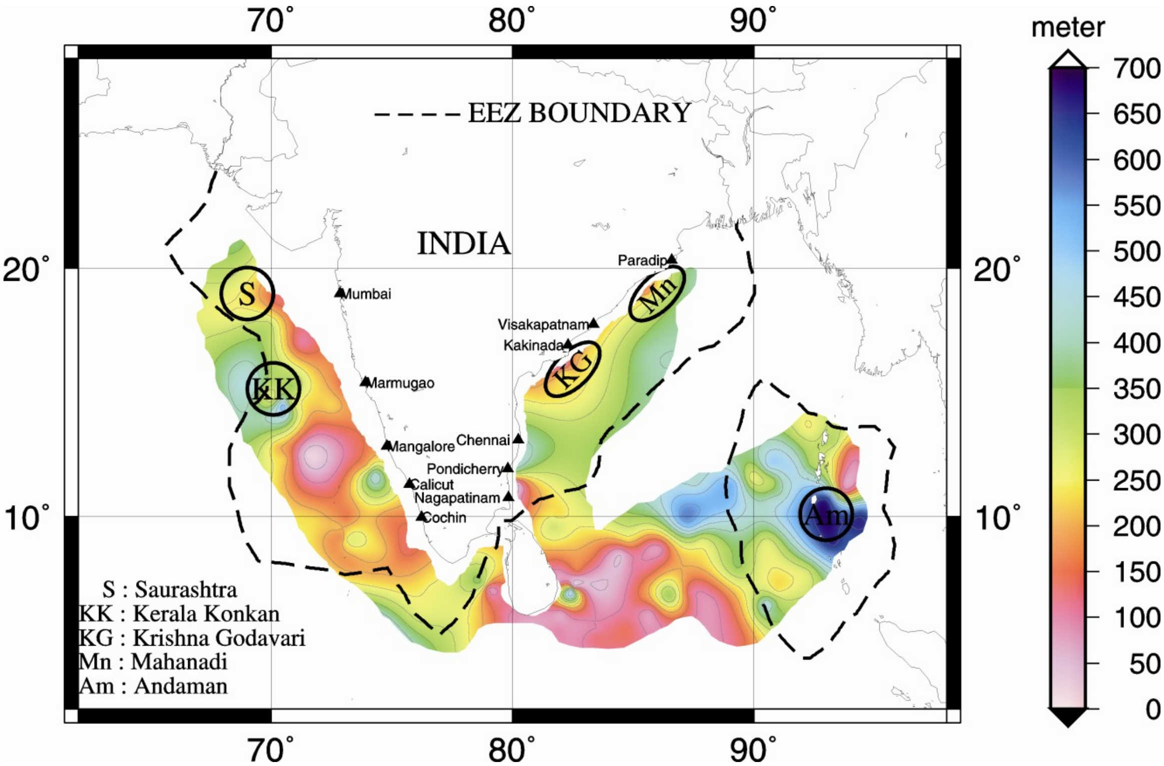

Figure 1: Gas Hydrate Stability Thickness Map along the Indian continental margins (Sain et al., 2010, Mar. & Petrol. Geol., accepted).

The drilling and coring by the Indian NGHP has established the presence of gas hydrates in the Eastern Indian margin. This has boosted further the Indian efforts to tap this huge treasure of energy from ocean. The Drilling Vessel JOIDES Resolution has been engaged for period of 115 days during 2006 and drilled 39 cores at 21 sites covering the Arabian Sea, Bay of Bengal (Passive margin) and Andaman Sea (Active margin). The expedition has posted few scientific achievements: i) Discovered gas hydrate in numerous complex geological settings and collected an unprecedented number of gas hydrate cores, ii) Delineated and sampled one of the richest marine gas hydrate accumulations yet discovered in Krishna-Godavari Basin, Bay of Bengal, iii) Discovered one of the thickest and deepest gas hydrate occurrences yet known (Andaman Islands) which revealed gas-hydrate-bearing volcanic ash layers as deep as 600 meters below the seafloor, iv) Established the existence of a fully developed gas hydrate system in the Mahanadi basin of the Bay of Bengal, v) Demonstrated the utility of employing advanced logging-while-drilling operations to high-grade potential sites for later coring operations; and vi) Demonstrated a series of significant advances in infra-red imaging and pressure coring data acquisition and analysis techniques.

Future NGHP Expedition-02 is aimed at the identification of sites having sand dominated gas hydrate occurrence, reasonably compacted sediments and occurrence of free gas below the gas hydrate stability zone. Environmental hazard studies also are planned to be carried out. NGHP Expedition-03 is planned to carry out pilot production testing of at least one site in the Indian deep-water environment. The expeditions are planned for 2011-2020 and would require extensive R&D work in association with International scientists. The commercial exploitation of methane from hydrates would largely depend upon the success of these expeditions.

Other activities, include i) delineation and resource assessment of the Gas Hydrates in KG & Mahanadi area, ii) R&D on methodology of production testing along with environmental hazard studies, iii) Techno-economic studies on the exploitation of methane from hydrates, and iv) Policy framework for award of acreage for Gas hydrates commercial production.

The importance of the Gas hydrate commercialization efforts are founded on the fact that even if 1% of the Prognosticated resources of this potential resource which is estimated at 1894 TCM, can be exploited, the exploitable resources would give rise to 3100 TCM of methane since at standard temperature and pressure per cubic meter of hydrate yields on an average 164 m^3 of methane and 0.8 m^3 of water. This is a significant amount and on its own can sustain the energy requirement of India for over a decade.

The study also describes the status of research on offshore gas hydrates discovered on Makran margin, Pakistan. Scientific information, data and interpretation of the Pak-German, Research vessels (1993, 1997-1998) provided better understanding of the occurrences of gas hydrates in offshore region of Makran. The gas hydrates occurrences in marine sediments offshore Pakistan was earlier reported by White (1982 and 1983) but their extent and widespread presence offshore Makran was confirmed by Seismic methods employed during the Pak-German Cruise SO-122 in 1997.

Federal Institute for Geosciences and Natural Resources (BGR) Germany conducted some Research Surveys in the deeper part of the Bay of Bengal in collaboration with Geological Survey of Bangladesh (GSB). During 2006 different physical techniques including 2D Seismic Survey were used but the data was not interpreted for identification of BSRs. However, Petrobangla has a programme to look for presence of BSRs in Seismic data that will be acquired from the deep-sea blocks to be awarded under production sharing contracts (PSC) to the IOCs in near future. If, exploration activities are conducted with specific objectives of searching for gas hydrates in Bangladesh portion of Bay of Bengal or even, if exploration activities are conducted for traditional oil and gas exploration and production in deep-sea bottom in more than 2.00 kilometers. It is most likely that in the continental rise portion of the continental margins BSRs could be traced and thus gas hydrate zone could be demarcated.

The potential gas hydrates zone offshore Sri Lanka could lie between the 600 meters and 3,000 meters bathymetric contours and covers an area of approximately 50,000 km^2. Using an area of 50,000 km^2 a 200 meters thick hydrates stability zone, a pore volume of 50% in shallow sediments and 3% as percentage of hydrate in the pore space. The amount of gas hydrates offshore Sri Lanka could be $225x10^9m^3$. This is equivalent to a gas volume of 369×10^{11} or 364×10^{14} kwh of energy.

The purpose of this regional study is to assess the programs on gas hydrates in the region, resource potential, to gauge the economic viability and to facilitate and promote R &D activities on gas hydrates in the SAARC region.

It is therefore recommended that the SAARC Energy Centre may facilitate through relevant organizations in India, Bangladesh, Pakistan and Sri Lanka a mechanism of joint seminars and conferences which would enable the scientists in the SAARC countries working in the field of Gas Hydrate research to interact with each other. This would be an icebreaker in the long term collaboration in the field of Gas hydrate research in the SAARC Region. It is also recommended that a Research Center may be set up in India to cater to the needs of the Researchers on Gas hydrates in the SAARC member countries and to have a Steering Committee in place to chalk out a long tern (10 to 15 years) focused programme in the Region keeping in mind the commercial importance of Gas Hydrates.

CHAPTER – 1
INTRODUCTION AND BACKGROUND

Introduction

Gas hydrates are ice-like crystalline substances occurring in nature where a solid water lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure, also known as gas hydrate, clathrate, clathrate hydrate, Ice-that-burns, etc. The main component of the natural gas, with which everybody is familiar, is methane. This is one of the most popular primary energy resources of the world for it being used in power generation, urea fertilizer production, room heating, cooking and in many other daily needs. It is so associated with our everyday life that in modern days one cannot think of living a single day without methane gas.

Methane contains one atom of carbon and four atoms of hydrogen. Other gases like propane and butane contains more carbon and hydrogen atoms and consequently they are known as heavier hydrocarbons. One of the fundamental characteristics of hydrocarbons is that most of them burn. When methane burns, the carbon in the methane combines with oxygen (O) to form carbon dioxide (CO_2). The hydrogen in the methane combines with oxygen to form H_2O, or water.

Difference Between Natural Gas and Gas Hydrate

The 'natural gas' that we burn everyday in our daily life for different purposes is extracted from between the earth's strata, and then supplied to different consumers according to the need. The gas hydrate is also trapped between the earth's strata. The basic difference between the 'natural gas' and the gas hydrate, though the principal constituent of both is methane, is that the natural gas is found is gaseous state, while the later is a solid. Thus to produce natural gas from the gas hydrate will require breaking down these gas-hydrate-solids and extracting the methane and other hydrocarbons. If methane can be successfully extracted from gas hydrate, it should be possible to develop it using methods similar to those used to develop natural gas.

Different Names of Gas Hydrates

A piece of gas hydrates that exactly looks like a piece of ice is highly inflammable. It keeps on burning until there is nothing left but water. And that is why, while gas hydrates are often called 'Methane Hydrates', it is also phrased as "Fiery ice" and "Ice that burns" (Figure 2). "It's like white ice that burns until there's nothing left but water" - a very mysterious phenomenon indeed. Even the US Department of Energy (USDOE), under the National Methane Hydrates R & D Programme, publishes a quarterly newsletter titled 'Fire in the Ice' to highlight the latest development in the international gas hydrates R & D.

Figure 2: Ice That Burns (Research Consortium for Methane Hydrate Resources in Japan, MH21 Research Consortium)

Understanding the Gas Hydrates

If the structure of gas hydrate is understood clearly, we will be able to know why it is flammable, though it looks exactly like ice. Methane hydrate or gas hydrate is often described as "methane gas surrounded by ice." But this description is though easy to understand, is not completely accurate. The accurate description should be that gas hydrate consists of "methane gas trapped inside cage-like crystal structures made up of water molecules."

The size of these ‘cages’ is comparable with the magnitude as atoms and molecules, not visible with the naked eyes. The Figure 3 (From MH21 Research Consortium) shows this crystal structure at the atomic level. Water molecules are made up of one oxygen atom (red) and two hydrogen atoms (white). These molecules join and break apart from each other in liquid form, creating a structure that resembles a cage. This type of structure is known as a cluster. A cluster is unstable in liquid form but becomes stable when pressurized or cooled to preserve its cage-like structure.

Figure 3: Structure of Gas Hydrates

When gas molecules such as methane are introduced into these cages, a three-dimensional cluster structure is created. Gas hydrate is made up of cage-like clusters of water molecules with methane trapped inside. The cavities in these clusters usually have a radius of between 0.39 and 0.47 nm (1 nm=1/10,000,000 cm). Under appropriate temperature and pressure conditions, not only methane, but other gases such as carbon dioxide, hydrogen sulfide, ethane and propane can easily reside into cluster structures to form hydrates. "Gas hydrates" is the generic term used to describe these hydrates with various gases.

Cluster structures into which methane gas reside are referred to as gas hydrate. Under normal temperature and pressure, the amount of methane gas that can be contained in gas hydrate is equivalent to about 170 times (160-180 times) the volume of gas hydrate. We can also say that one volume of gas hydrate releases 170 volume (160-180 volume) of methane and 0.8 volume of fresh water (Figure 4).

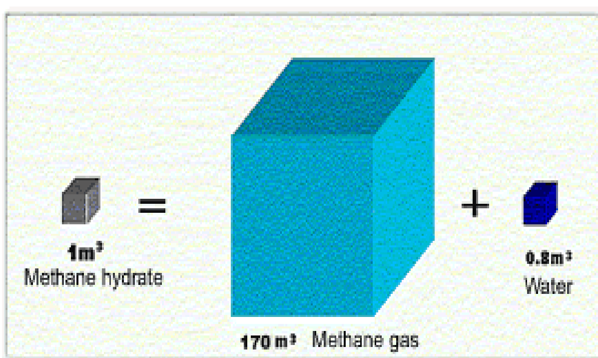

Figure 4: Gas Water Ratio in Gas Hydrates

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Gas Hydrate Environments

It is not only the cold temperatures that help form gas hydrate, but it also requires high pressure. The diagram below (Figure 5) shows the range of conditions under which gas hydrates can exist in stable form. In environments in which the temperature is 0^0C, gas hydrate will form only if the atmospheric pressure is 23 times normal atmosphere (i.e., 23 atm). Under normal atmospheric pressure, gas hydrate will only exist in stable form if the temperature is -80^0C or below.

In other words, gas hydrate can only exist in stable form in a low-temperature, high-pressure environment. If gas and water are present in such low-temperature, high-pressure environments, then gas hydrate may also be present. This is the type of environment in which natural gas hydrate has been discovered. There are only two types of places where such environment exists. These are (1) beneath the permafrost and (2) in the strata of earth beneath deep ocean floors.

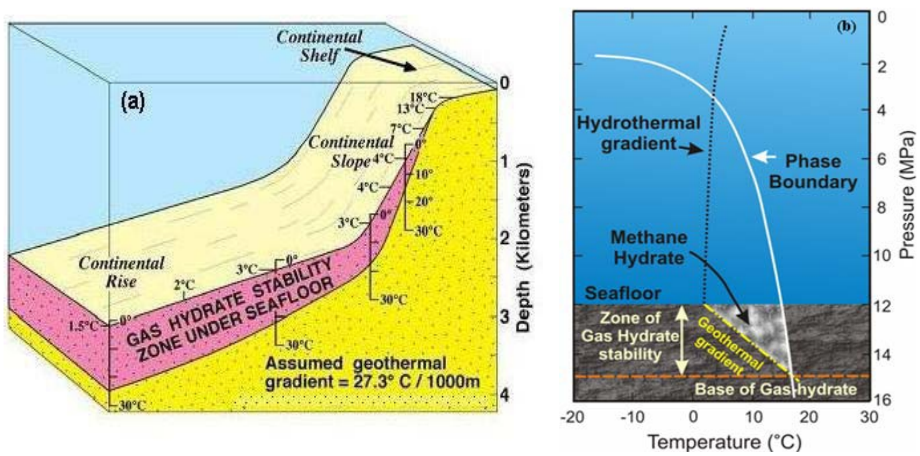

Figure 5: (a) Stability Thickness Map of GH in the Continental Margin (Kvenvolden & Barnard, 1982) and (b) Phase Curve for GH Stability (Sloan, 1998)

In the North and South Polar Regions, strata of earth remain frozen even in summer. These strata are known as permafrost. Under this permafrost there exists low-temperature, high-pressure environments in which gas hydrate can be found in its natural state. On the other hand water near the bottom of deep oceans is as cold as 0 to 4^0C. Moreover, because of the heavy weight of the water above, the seafloor is under high pressure. Accordingly, the earth under the seafloor in deep oceans is the type of low-temperature, high-pressure environment in which gas hydrate can exist naturally.

It is an established phenomenon that whether on dry land or under the seafloor, the ground temperature keeps on rising as we go deeper. This is because the earth is hotter at its core than the surface. In general, the ground temperature increases by 2^0C to 5^0C for every 100m we go down. This is called the geothermal gradient, and is usually expressed in the form $2\text{-}5^0$C/100m. At a depth of 1000m, with 4^0C/100m thermal gradient, the temperature will be 40^0C. Since the likelihood of finding gas hydrate decreases with the increase in temperature, gas hydrate is unlikely to be present too deep below the earth whether on dry land or on the seafloor. It has been established by various calculations that gas hydrate will only be found up to 280m below the seafloor in areas where the water is 1,000m deep, and up to 570m below the seafloor in areas where the water is 4,000m deep.

Study of Structure and Composition of Gas Hydrate

Studies have revealed that composition and crystal structure of gas hydrate varies by environment and types of gases involved. For example, water molecules exhibit three basic types of polyhedral structures (Figure 6).

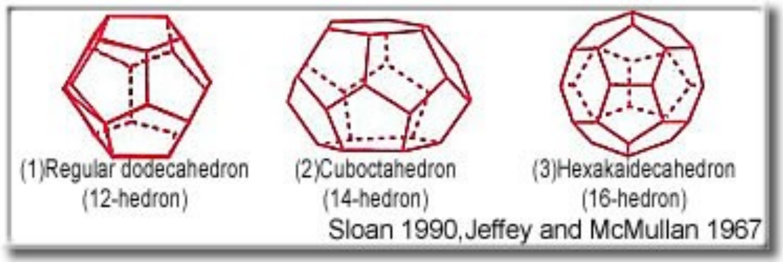

Figure 6: Different Structure of Hydrates Depending on Different Type of Gas.

These polyhedral water molecule structures combine to form two kinds of hydrate structures. Those consisting of two regular dodecahedrons (12-hedron) combined with six cuboctahedrons (14-hedron) are referred to as Type I structures (Figure 7), while those consisting of 16 regular dodecahedrons combined with eight hexakaidecahedrons (16-hedron) are referred to as Type II structures.

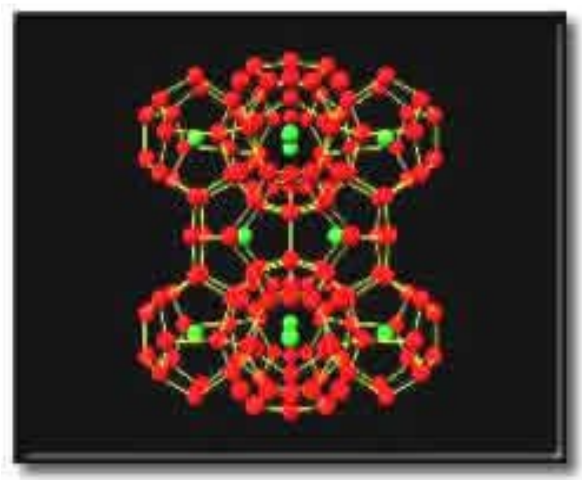

Figure 7: Type I Crystal Structure.

Virtually all natural gas hydrates have either Type I or Type II structures. Natural gas hydrate contains not only methane, but other similar gases such as ethane and propane. Depending on the mix of gases present, gas hydrate may exhibit a Type I structure, a Type II structure, or a mixture of Type I and II structures.

Through examinations by X-ray diffraction, nuclear magnetic resonance (NMR), and Raman spectroscopic methods, it has been observed that the amount of gas contained in gas hydrate differs depending on whether it has a Type I or a Type II structure. Gas hydrates with Type II structures holds slightly more gas than gas hydrates with a Type I structure. Consequently, developing a natural gas hydrate deposit with a predominant Type II structure gas hydrate is likely to result in the production of more methane than a deposit with a predominant Type I structure gas hydrate. In addition, a hydrate that contains propane as well as methane will have a Type II crystal structure. It has also been observed that gas hydrate with Type II structure is more stable than pure gas hydrate with a Type I structure. For example, while pure gas hydrate requires a temperature of -80^{0}C to remain stable at normal atmospheric pressure, gas hydrate containing propane will remain stable up to around -20^{0}C.

The fundamental data obtained from the study of compositions and structure of gas hydrates will be extremely valuable in the future development of natural gas hydrate. The studies noted that density, heat conductivity, sound wave characteristics, electrical resistance, and other fundamental properties of gas hydrate differ depending on factors such as composition and crystal structure.

Distribution of Gas Hydrate

USA, Canada, Japan, India, Norway, Germany, UK, France, Belgium, Bulgaria, South Korea, China, Taiwan, Australia, Nigeria, Turkey, Egypt, Italy, New Zealand, Greece etc. are the countries, which are actively involved in gas hydrates research. Figure 7 shows the worldwide locations where gas hydrates have been established from remote geophysical, geochemical and geological experiments and sampling by deep sea or ocean drilling programs in both the continental margins and the permafrost regions and also places where gas hydrates are thought to exist. Areas where natural gas hydrate is thought to exist are generally areas under the ocean where BSR (Bottom-Simulating Reflector) seismic reflection profiles show a continuous behavior, indicating the presence of gas hydrate. Looking at these distribution maps (Figure 8), we can clearly see that gas hydrate is present in locations that meet a certain temperature-pressure conditions.

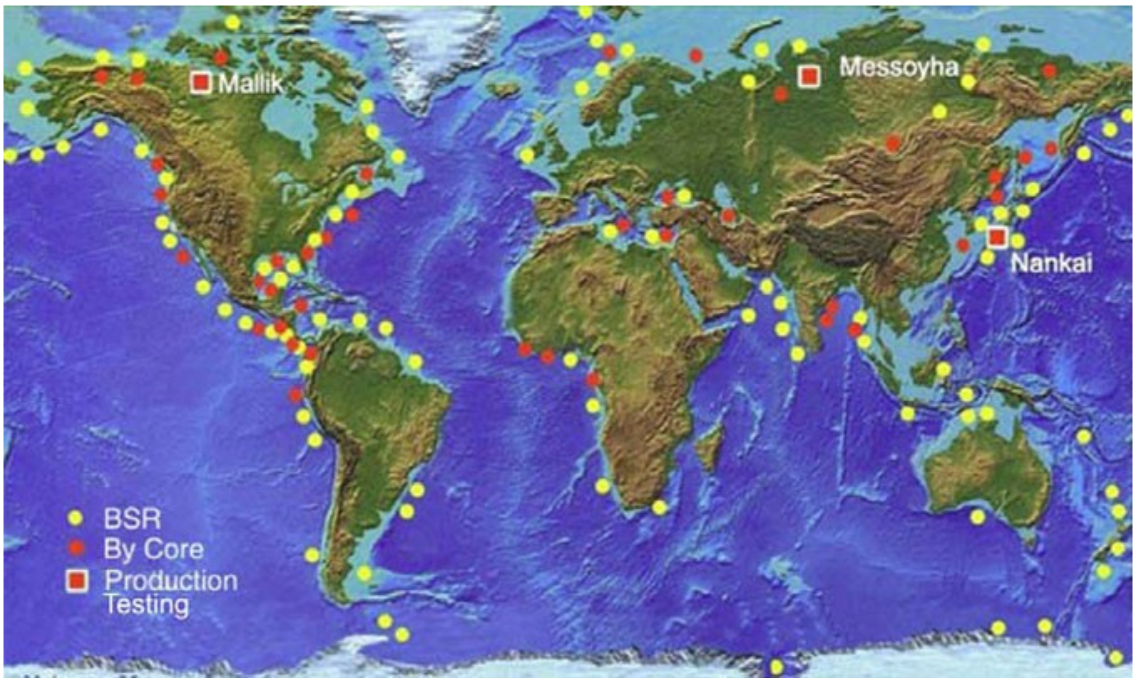

Figure 8: Locations of GH in Permafrost & Continental Margins (Makogon, 2007)

Origin of Gas in Gas Hydrates

For gas hydrates to be present, it is not only a specific temperature-pressure environment to be met as outlined above, but also there has to be sufficient quantity of methane present in order for gas hydrate to form. The methane found in natural gas hydrate is thought to be formed by dead organic matter trapped between the earth's layers, and then broken down by micro-organisms and the earth's heat.

Methane is a hydrocarbon, so it also needs carbon sourced by the remains of dead animals and plants to form hydrocarbon. There are thought to be two processes by which the carbon in dead organic matter is transformed into hydrocarbon. In the first, micro-organisms turn dead organic matter into methane and methane so produced is known as “biogenic” methane. In the second, methane is formed by thermo-chemical reduction of organic matter in absence of oxygen and methane thus produced is known as “thermogenic” methane. Through isotope analysis, it can be confirmed whether natural methane is biogenic or thermogenic. Analyses of methane gas from different parts of the world indicate that most of the methane found close to the earth's surface is biogenic, while most of the methane from deep deposits is thermogenic methane. However, between these two extremes, there is a mixture of biogenic and thermogenic methane.

Test drilling carried out in different places showed that gas hydrate is present especially in thick concentrations in layers of sand beneath the earth's surface in the stability zones, a very interesting phenomenon, which made researchers curious.

Whether biogenic or thermogenic, methane is generated only if temperatures are higher than gas hydrate's stability zone. Since gas hydrate at normal atmospheric pressure contains 170 times its own volume of methane, it needs to gather methane from a relatively large area. In layers of sand and mud, the gaps between the various particles vary in size. Water and gas can move around constantly in the layers of sand where gaps are relatively large, but in the layers of mud the same is not possible. This is considered to be the reason why gas hydrate is found in thick concentrations in layers of sand.

Many countries have been working on gas hydrates for quite some time. India is one of the fastest growing economies in the world and with this the demand for energy is also growing exponentially. This situation calls the development of new energy resources such as coal bed methane, gas hydrates and shale gas in addition to the other alternate sources of energy. Some progress has been achieved in the area of CBM but a lot is needed to be done for the exploration and exploitation of gas hydrates. But the real boost to Indian programme has been experienced in the last five years with the discovery of gas hydrates deposits in Indian offshore particularly in Krishna-Godavari, Mahanadi and Andaman Sea areas, which has prompted the need to deal with lots of technological challenges for exploitation of this resource. The present programme of gas hydrate coring/drilling and scientific investigations in Indian offshore is an important milestone in this direction. The national institutes and oil companies are taking the lead role for the exploratory efforts on gas hydrates. India is committed to the development of this important natural resource. With the dedicated efforts of national oil companies and the government, India has become the third country in the world to undertake such an ambitious programme on gas hydrates in offshore areas. Production from gas hydrates is a long-term goal but gas hydrates are very important to India from energy security perspective.

Affordable energy is a key requirement for the economic growth of any nation. In Sri Lanka thermal power plants provide nearly half of the country's energy needs and foreign exchange requirement to quench the country's demand for petroleum products amount to nearly $ 2 billion per year. Recently, Sri Lanka embarked on oil exploration by awarding an exploration block off the west coast and more acreage with petroleum potential is available offshore around the island. In this context gas hydrates could be another source of energy from the ocean surrounding the island that could contribute to the current energy mix to satisfy the rising demand for affordable energy in the country.

The nature, origin and the mode of occurrence of gas hydrates have been discussed by many (Kvenvolden 1993, Bhatangar et al. et al. 2007). The methane in the gas hydrates could be biogenic or thermogenic in origin. However, much of the gas hydrates around the world is believed to have been derived as result of methane generated due to microbial activity (Collett et al. 2008) on organic carbon buried with sediments.

Background

The South Asian Association for Regional Cooperation (SAARC) region basically is energy deficient and one of the poorest regions of the world with fast growing and thick population. Skyrocketing price of commercial oil in recent times, coupled with all other prevailing miseries has seriously impeded the economy of the region as a whole. The region is home to 23% of total world population.

However, during the 1995-2005 decade the region has been witnessing an impressive average annual GDP growth rate of 5.6%. Countries such as Bangladesh, India, Pakistan and Sri Lanka have had a GDP growth rate of 6 to 9% in the recent years. Since there is a direct co-relationship between economic growth and energy demand, the accelerating economic growth in the region is expected to boost the energy demand. Moreover, even to sustain the robust economic growth, it is necessary that the energy demand of the region be sufficiently met by a continuous supply of energy in various forms. Despite these impressive economic growth levels, a large proportion of population of the region is living below the poverty line. Thus for poverty alleviation and supporting the economic growth it is important to explore all possible options to ensure and enhance regular supply of energy in the region.

In terms of energy consumption pattern, most of the SAARC Member States, except for India and Pakistan rely primarily on one predominant form of commercial energy. Afghanistan and Maldives are heavily dependent on oil. Bhutan, Nepal and Sri Lanka meet a large part of their commercial energy needs, especially electricity from hydropower, but are heavily dependent on imported petroleum products to meet the energy needs in other sectors of the economy. Bangladesh is heavily reliant on natural gas. Such a dependence on a single energy form having no alternative way -out not only limits the options of meeting diverse energy demands but also increases energy security concerns.

Under such a backdrop search for alternative energy source has become imperative upon the SAARC region as a whole. A time will come, sooner or later, when there will be no non-renewable energy. Keeping this in mind particularly the developed nations, are gradually switching over to renewable sources, such as wind, sunlight, tide, geothermal heat, etc. However, since energy generation from the renewable sources is very expensive, most of the developing nations are largely dependent on the non-renewable sources. Again because of the cleanliness of renewable energy, its generation is steadily increasing globally. At the same time another non-renewable alternative energy source, the gas hydrates, drew the attention of scientists and hydrocarbon explorers all over the world because of its abundance in oceanic sediments and permafrost regions.

Among the SAARC countries one or more sides of India, Pakistan, Sri Lanka, Bangladesh and the Maldives are surrounded by the oceans like the Indian Ocean, the Bay of Bengal and the Arabian Sea. There is a great likelihood that oceanic sediments adjacent to these countries shall contain substantial amount of gas hydrates. In the era of diminishing non-renewable energy sources and high oil price SAARC Energy Center (SEC) took the initiative to gather all the available information regarding the alternate and non-conventional energy resources like gas hydrates in the SAARC region through a study project entitled “Gas Hydrates Resource Potential of South Asia”. Albeit the idea of producing gas from the gas hydrates is still in the brains of researchers and some research laboratories, a proven reserve of gas hydrates in the region shall certainly give confidence that some day energy security of the region shall be secured while import dependence shall be significantly reduced through production of significant amount of natural gas from the gas hydrates.

CHAPTER–2
OBJECTIVES

The objectives of the project "Gas Hydrates Resource Potential of South Asia " are:

- To strengthen South Asia's capacity to collectively address global and regional energy issues
- To explore and evaluate an alternate and non-conventional energy resources for meeting increasing energy demands of South Asia, thereby contributing towards more sustainable development in the SAARC member countries
- To ensure energy security of the region and to reduce the import dependence.
- To facilitate and promote regional R&D activities on gas hydrates.
- To assess the resource potential of gas hydrates in the offshore regions of the SAARC countries.
- To develop methodology or adopt existing technology of production testing along with environmental hazard studies,
- To enhance cooperation in the use of unconventional energy sources in the region.
- To serve as a focal point for providing reliable energy data for the individual member countries and the South Asian region
- To enhance SAARC expertise in energy development and management
- To promote private sector investment and participation in energy activities in the region.
- To undertake programs to achieve the goals mentioned above.

CHAPTER – 3
METHODOLOGY

SEC engaged short-term experts from Member States (Bangladesh, India, Pakistan and Sri Lanka) having gas hydrates potential to prepare the position paper on Gas Hydrates Resource Potential of their respective countries based on published information and data with relevant regional and international organizations. Mr. Malcolm V. Lall was selected by the SEC as the Regional Expert to prepare the Regional Report. The Regional Report has been synthesized from the country reports of Bangladesh, India, Pakistan and Sri Lanka. The country reports were reviewed by SEC professionals and the regional expert while the regional report was reviewed by the country experts and the SEC professionals.

This report has been compiled placing into record all that has transpired in the Indian context pertaining to the Research and Development work associated with Gas Hydrates. There have been frequent interactions with the scientists working in this area of research from premier industries ONGC, OIL, GAIL, Reliance etc., and the national institutes/academia such as NIO, NGRI, NIOT, IIT, etc. There has been an attempt to share all relevant information and evaluate a methodology to the working of Scientists in the area of Gas hydrate R&D in a manner wherein information is freely shared so as to avoid repetitive work. The report has been critically reviewed by NIO, NGRI, DGH and the SAARC Energy Center and all the necessary recommendations have been incorporated.

For this study no direct attempt has been made to map and assess the gas hydrate potential in the offshore areas of the SAARC region. This report is mainly based on the available published and unpublished literature and seismic data available.

CHAPTER – 4
REVIEW OF TECHNOLOGY

Formation of Gas Hydrates

Methane hydrate, an ice like material, which is pressure and temperature sensitive' it requires a host of conditions to form and be stable. Disturb these conditions, it will dissociate into water and methane gas. A key area of basic hydrate research is the precise description of these conditions so that the potential for occurrence of hydrates in various localities can be adequately predicted and the response of that hydrate to intentional, unintentional, and/or natural changes in conditions can be assessed.

In naturally occurring methane hydrate the fundamental controls on hydrate formation and stability are (1) adequate supplies of water and methane, (2) suitable temperatures and pressures, and (3) geochemical conditions.

In the arctic, many hydrate accumulations represent pre-existing free gas accumulations that have been converted to hydrate by subsequent change in environmental conditions (onset of arctic climate post-dated the migration of gas into shallow sandstone "traps"). In the marine environment, hydrate is often considered to have formed from solution, as methane is generated by in-situ microbial processes to the point where the water becomes saturated with methane and hydrate growth begins. There is also a high likelihood that methane hydrate could accumulate in coarser-grained marine sediments by the migration of gas from deeper, warmer zones, up through various pathways such as faults, and into water-bearing shallow sediments where it is then converted to methane hydrate.

Methane is formed in two ways. Biogenic methane is the common by-product of bacterial ingestion of organic matter (as described in the equation below:

$$(CH_20)106(NH_3)16(H_2PO_4) \longrightarrow 53CO_2+53CH_4+16NH_3+H_2PO_4$$

How methane is produced in shallow subsurface environments through biological alteration of organic matter (with original ratio of Carbon: Nitrogen: Phosphorus of 106:16:1). The equation summarizes successive stages of oxidation by oxygen and reduction by nitrates, sulfates, and carbonates. (from Sloan, 1990)

The same process that produces methane in swamps, landfills, rice paddies, and the digestive tracts of mammals occurs continually within buried sediments in geologic environments all around the globe. Biogenic processes are capable of producing vast amounts of methane, and are considered to be the dominant source of the methane trapped in hydrate layers within shallow sea floor sediments.

Thermogenic methane is produced by the combined action of heat, pressure and time on buried organic material. In the geological past, conditions have periodically recurred in which vast amounts of organic matter were preserved within the sediment of shallow, inland seas. Over time and with deep burial, these organic-rich source beds are literally pressure-cooked with the output being the production of large quantities of oil and natural gas. Along with the oil, the gas (largely methane, but also ethane, propane and other larger molecules) slowly migrates upwards due to its buoyancy relative to water. If sufficient quantities reach the zone of hydrate stability, the gas will combine with local formation water to form hydrate.

Temperatures and Pressures: Figure 9 shows the combination of temperatures and pressures (the phase boundary) that marks the transition from a system of co-existing free methane gas and water/ ice solid methane hydrate. When conditions move to the left across the boundary, hydrate formation will occur. Moving to the right across the boundary results in the dissociation (akin to melting) of the hydrate structure and the release of free water and methane. In general, a combination of low temperature and high pressure is needed to support methane hydrate formation.

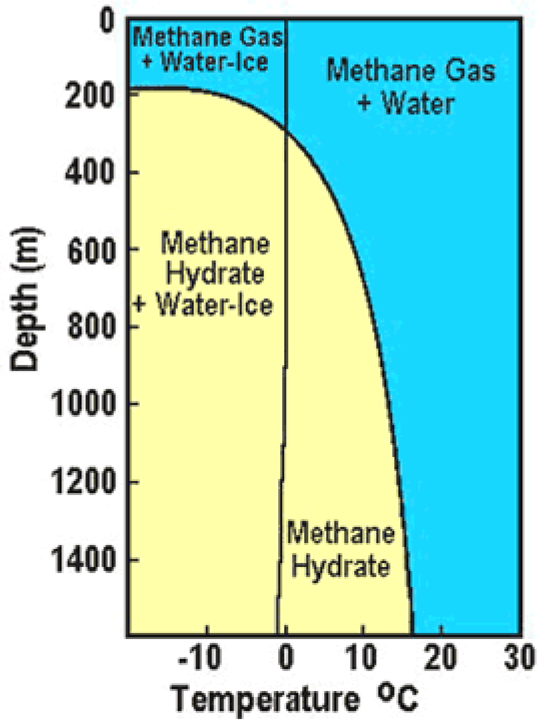

Figure 9: Methane Hydrate Phases

Geochemical Conditions: In addition to temperature and pressure, the composition of both the water and the gas are critically important when fine-tuning predictions of the stability of gas hydrates in specific settings. Experimental data collected thus far have included both fresh water and seawater. However, natural subsurface environments exhibit significant variations in formation water chemistry, and these changes create local shifts in the pressure/temperature phase boundary (higher salinity restricts hydrate formation causing the phase boundary to shift to the left). Similarly, the presence of small amounts of other natural gases, such as carbon dioxide (CO_2), hydrogen sulfide (H_2S) and larger hydrocarbons such as ethane (C_2,H_6), will increase the stability of the hydrate, shifting the curve to the right. As a result, hydrates that appear to be well above the base of hydrate stability (from pressure-temperature relationships) may actually be very close to the phase boundary due to local geochemical conditions. These local variations may be very common, as the act of forming hydrate, which extracts pure water from saline formation waters, can often lead to local, and potentially-significant increases in formation water salinity.

Simplified Examples of Hydrate Stability: Commonly, methane hydrate phase diagrams are presented with pressure being converted to depth to place the diagram in a geologic perspective. In addition, the natural geothermal gradient is shown to indicate the range of temperatures expected to exist as depth (i.e. pressure) increases. The range of depths in which the temperature gradient curve is to the left of the phase boundary indicates the Gas Hydrate Stability Zone (GHSZ). This zone only delineates where hydrates will be stable if they form. Local conditions and a region's geological history will determine where and if hydrates actually occur within the GHSZ (see our Geology of Methane Hydrates section for more information).

The phase diagram in Figure 10 illustrates typical conditions in a region of arctic permafrost (with depth of permafrost assumed to be 600 meters). The overlap of the phase boundary and temperature gradient indicates that the GHSZ should extend from a depth of approximately 200 meters to slightly more than 1,000 meters. (Note that both the permafrost thickness and pressure/temperature gradients in the chart are examples and can vary with locality, so specially-tailored diagrams must be made before site-specific predictions of hydrate stability can be attempted.)

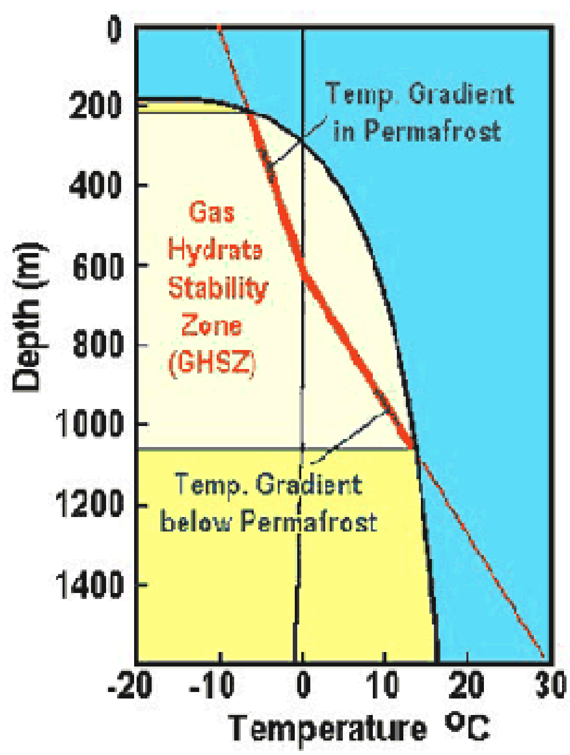

Figure 10: Specific Hydrate Stability for Arctic Permafrost

The phase diagram in Figure 11 shows a typical situation on deep continental shelves. A seafloor depth of 1,200 meters is assumed. Temperature steadily decreases with water depth, reaching a minimum value near 0°C at the ocean bottom. Below the sea floor, temperatures steadily increase. In this setting, the top of the GHSZ occurs at roughly 400 meter - the base of the GHSZ is at 1,500 meters. Note, however, that hydrates will only accumulate in the sediments or as mounds on the seafloor over point sources of methane release.

From the phase diagram in Figure 11 for oceanic settings, it would appear that hydrates should accumulate anywhere in the ocean-bottom sediments where water depth exceeds ~400 meters. However, very deep (abyssal) sediments are generally not thought to house hydrates in large quantities. The reason is that deep oceans lack both the high biologic productivity (necessary to produce the organic matter that is converted to methane) and rapid sedimentation rates (necessary to bury the organic matter) that support hydrate formation on the continental shelves.

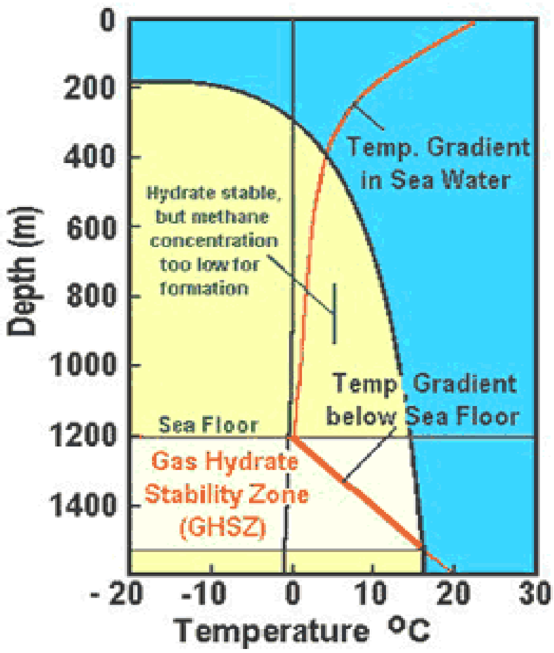

Figure 11: Typical gas hydrate stability zone on deep-water continental margins.

The final phase diagram in Figure 12 illustrates why no hydrates are found in interior basins at sub-polar latitudes. At every depth (pressure), subsurface temperatures are too high for methane hydrate to be stable.

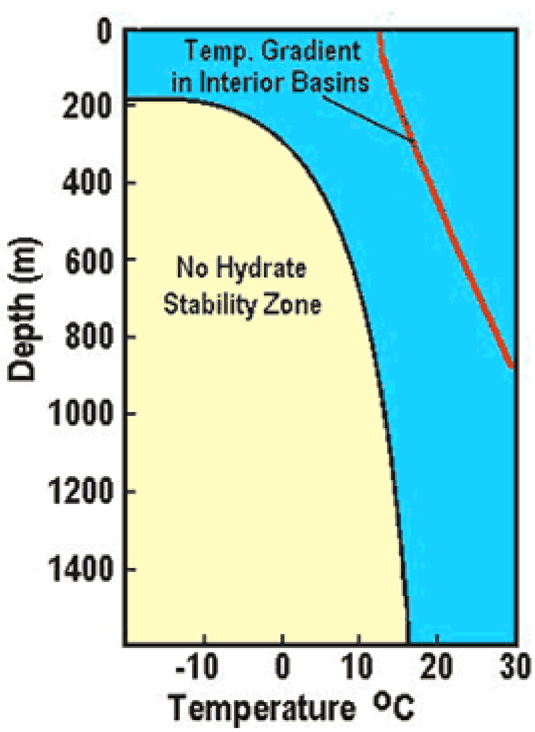

Figure 12: At sub-polar latitudes temperatures are too high at every depth for methane

Technology Used for the Exploration of Gas Hydrates in the Region:

Gas hydrates are solid in nature and they are formed at certain combination of low temperature and high pressure. The bottom of gas hydrate stability zone (GHSZ) is strong reflector of seismic waves. This reflector is named as bottom simulating reflector (BSR) in the seismic section. Since gas hydrates are not continuous in the GHSZ, BSR may not be continuous. But in 3D seismic interpretation not only resolution of BSR increases but also the depositional history of basin and formation of gas hydrates can be well studied.

Study of fallowing seismic parameters ensures the presence of BSR.

HIGH INTERVAL VELOCITY: Identification of areas of interpreted high interval velocities may indicate the presence of gas hydrate.

HIGH AMPLITUDES WITHIN THE GHSZ: Strong amplitudes above the BSR are viewed as potential “direct” indicators of gas hydrate, particularly when 1) the amplitude is opposite polarity to the sea-floor, and 2) when the amplitude is organized in a manner that reflects control by geologic structure, including anomalous terminations against faults and conformance to structural highs. Such amplitudes within the GHSZ are also strongly prospective when they occur in sediment packages that show indicators of reservoir quality elsewhere, for example, analogous amplitude features where the strata can be traced below the BSR.

High amplitudes within the GHSZ are commonly observed with apparent positive polarity. The potential for such amplitudes to represent gas hydrate bearing sands (and not regional lithologic boundaries) is strengthened when structural conformance of amplitude response is noted (the amplitude is not regionally extensive - see above) or when the amplitudes occur within favorable seismic facies.

ENHANCED REFLECTIONS BELOW THE BSR: Anomalous amplitudes of appropriate polarity (where polarity are clear) below the BSR are a strong indicator of gas sourcing.

BSR is not the failsafe indicator of gas hydrate occurrences. To confirm the presence of gas hydrate and to evaluate its potential advance coring/drilling tools must be needed. Since gas hydrates are unconventional resources, conventional coring drilling systems cannot work. To maintain the pressure and temperature of gas hydrates cores advance coring and drilling systems and logging while drilling would be better.

Exploration Techniques for Identifying Gas Hydrate Resources

The surface area of gas hydrate layers can be calculated measuring the extent of bottom-simulating reflectors (BSR) in the seismic reflection profiles, while depths can be calculated by drilling wells. Thus multiplying these two factors, the thickness of gas hydrate bearing layers can be obtained.

Porosity can be measured by recovering a sample (core) of the layers during drilling, or by putting a logging tool to take measurements.

The rate of volume change of methane contained in gas hydrates tells us how many times the methane volume increases when fully extracted from gas hydrate-bearing layers by comparing the volume of the gas hydrate-bearing layer and the methane volume when extracted and at normal temperature and pressure. One unit volume of a gas hydrate is generally thought to yield around 170 unit volumes of gas. Based on the assumption that 90% of this gas would be methane, this gives a rate of volume change of around 150.

Seismic Survey

In oil and natural gas prospecting seismic survey is a common tool for studying the distribution of oil or natural gas-bearing sediments. Seismic survey makes it possible to search wide areas of land and ocean efficiently. Reflection seismic survey is capable of gathering information from as deep as 15,000 m or even below the sea floor.

Seismic cross sections depict the boundaries between strata of earth with different physical properties. These boundaries show natural arrangement of the strata, and give a vivid picture of the geological structure of the area. Because gaining a clear picture of the geological structure of an area is an important part of hydrocarbon prospecting, seismic survey is always performed before wells are drilled in search of hydrocarbon.

Seismic sections not only show the distribution of evenly arranged geological formations, but it also shows many other anomalous features present in the subsurface such as, (1) inconsistent reflectors that are not in line with the distribution of surrounding evenly arranged geological strata indicating geological faults, channels, etc., (2) reflectors that run more or less parallel to the seafloor indicating a multiple reflection or a "Bottom Simulating Reflector (BSR), (3) reversed polarity relative to the seafloor or nearby reflectors, confirming a BSR or presence of hydrocarbons, (4) high amplitude reflection signal intensity confirming the presence of hydrocarbon, etc.

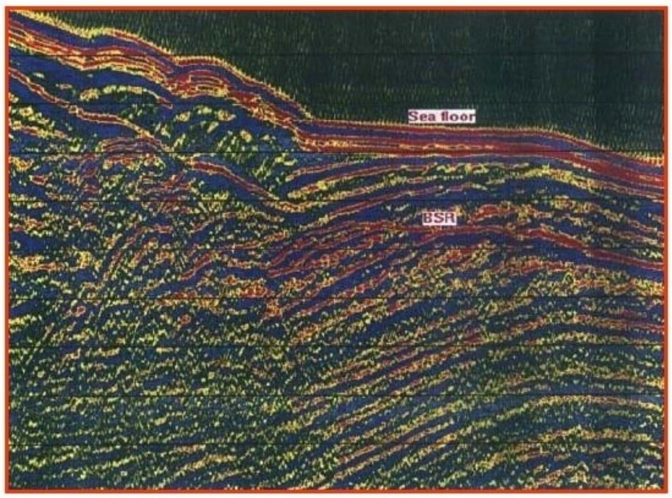

Figure 13: Seismic Section Showing BSR, from KG Basin (A. K. Sethi, et, el.)

An anomalous reflector was first identified in 1970 that mimics the sea-bottom. But since it was not twice the travel-time of acoustic signal to the sea-bottom, it could not be designated as a multiple reflection. It was designated as "Bottom-Simulating Reflector" (BSR) and inferred to be related with the base of gas hydrate-bearing sediment zone. The BSR, often cuts the dominant stratigraphy (Fig-13), and is characterized by a strong reverse-polarity event. The BSR is usually interpreted as a reflection from the boundary between the high-velocity gas hydrate-bearing sediments and the underlying low velocity gas-bearing sediments. The base limit of the hydrate-bearing sediment zone on continental margins is often marked by BSR on seismic profiles, thus the distribution of marine gas hydrates is easily mapped by seismic survey. Gas hydrate-related BSRs are widely distributed on the continental margins.

In 1980s, there was less works of seismic studies of gas hydrates. Since 1990s, seismic studies of gas hydrates have developed vigorously. Numerous studies involving forward modeling and inversion of seismic reflection have been carried out. These studies are post-stack reflection amplitude analysis, post-stack reflection waveform modeling, and calculation of interval velocities from RMS stacking velocities, travel time inversion, post-stack acoustic impedance inversion, amplitude-versus-offset analysis, attenuation analysis and full waveform inversion. These researches were focused on extraction of physical properties, better understanding of the distribution of gas hydrates and free gas, and discussion about origin of BSRs (Hai-bin, SONG; China).

By actually drilling wells in areas where seismic surveys confirmed the BSRs that point to the existence of natural gas hydrate, the following facts have been verified:

- Gas hydrate deposits occur in areas above BSRs, which indicate the bottom of a gas hydrate-bearing layer.

- Free gas is often found below gas hydrate-bearing layers. The density contrast between the gas hydrate and free gas makes the BSR significantly apparent on the seismic survey record.

In most cases the seismic data studied were acquired for mostly hydrocarbon exploration. Consequently BSR thus noticed did not give significant information regarding the thickness of the gas hydrate bearing sand, concentration of gas hydrate in the sand and the volume of free gas in the underlying sediment. Thus contemporary research is exploring various ways of processing seismic survey data to obtain the following information:

- The precise thickness of gas hydrate-bearing layers
- The concentration rate of gas hydrates contained in the layers
- The volume of free gas present

Seismic survey is an important but indirect method for determining the presence of gas hydrate-bearing layers. However, information mentioned above remain unknown and more specifically we cannot even see the real gas hydrate for ourselves using the seismic survey techniques.

Drilling for Gas Hydrate in Deep Waters and Challenges Posed

After the seismic survey confirms the presence of gas hydrate, it is essential to drill wells and to recover samples of gas hydrate from beneath the sea-floor with a view to assessing the true amount of gas hydrate deposits and to studying its characteristics. To collect samples of gas hydrate, wells need to be drilled in areas with water depth varying from 500mto 3000m. But drilling of wells at such water depth is very difficult. For producing valuable hydrocarbon resources, despite the difficulty of drilling wells in such water depths, wells are being drilled around the world in waters as deep as 3,000m.Efforts are currently underway to apply these deep-sea oil and natural gas drilling techniques to drilling for gas hydrate-bearing layers.

Drilling in Deep Waters

As has been stated gas hydrate-bearing layers are often found in waters over 500m deep. Moreover, gas hydrate layers at shallow depths tend to be thin. Thicker layers of gas hydrates normally exist at depths of 1000 m or below. Drilling of wells in the offshore is generally expensive. However, among three different types of drilling rigs used in offshore drilling, ‘Jack-up rig’ that rest on legs is the least expensive. But it cannot be used for drilling in water depths beyond 120 m. The only resort left for drilling in such water depths where gas hydrates exists are semi-submersible rigs or drill ships, but they are too expensive. Consequently, research is currently underway for custom-designed rigs to drill for gas hydrate-bearing layers. It is expected that rigs so designed for the sole purpose of gas hydrate drilling will be more cost-effective. Thus improving the efficiency of deep water drilling is a great challenge.

Drilling in Unstable Formation

It was pointed out earlier that stability conditions are met for gas hydrates to be found between 280m and 570m below the seafloor in earth’s strata having water depths between 1000m and 4000m respectively. Since the gas hydrates exist at quite shallow depths below the sea-floor, it apparently seems that development and production of gas should be easy. Unfortunately there are unique problems associated with production of gas from gas hydrates at shallow depths.

Rivers flowing onshore bring millions of tons of sediments to the oceans everyday that are accumulating on the sea-floor. The perpetual sedimentation process causes the lower sediments solidify and harden, while the uppermost layers of the sediments always remain soft and weak. The depths at which gas hydrate bearing layers exist are among these weak and unstable layers of sediment.

Wells drilled in the loose and unstable formation may enlarge or even collapse, making further drilling impossible. Moreover, since the objective is to intersect a large area of gas hydrate layer, it is desirable that wells should be oblique or more preferably horizontal. On the other hand, drilling horizontally in the loose sediments is less stable than drilling vertically. Thus critical drilling hazards stand as deterrent to drilling and production efficiency. In the oil and gas exploration and production problems of this sort are overcome by casings.

Studies are currently underway for developing safe methods of drilling wells for exploration and production of gas from gas hydrates that require fewer casings. Thus the problem of drilling in unstable formation appears as another challenge.

Preventing Gas Hydrate Dissociation

Dissociation of gas hydrates into methane gas and water is the most desirable phenomenon for gas production, but the same is most undesirable and thus must be avoided during normal drilling. Since dissociation of gas hydrates would result in gas invasion into the well. If dissociated methane gas gets channel into the well, it may re-form in togas hydrate inside the blow-out-preventer (BOP) installed on the seafloor, preventing the proper functioning of the BOP.

Thus, during drilling, temperatures should be maintained at such levels that gas hydrate does not dissociate. By cooling down the temperature of the drilling mud on the drilling rig, its temperature can be controlled. In addition, well temperature simulators have also been developed as part of continuing efforts to control temperatures inside wells during drilling.

However, cooling of drilling mud has its irony of facts that cooled drilling mud becomes more viscous, making drilling less efficient. That is why; instead of simply cooling the drilling mud, chemicals and other additives are mixed with the mud to prevent the dissociation and reformation of gas hydrate.

Strong Ocean Currents

Strong ocean-current in the deep sea has serious impact particularly on the ability of a drilling rig to maintain its position. Drilling rigs use moorings and/or ship-thrusters to maintain their positions. In strong currents, they require mooring systems of enough strength and/or thrusters of sufficient power to counter the force of the current. If the mooring system or thrusters break down, drilling must be suspended.

There are very few drilling rigs anywhere in the world capable of operating in currents as strong as 5 to 9 km/hour (3 to 5 knots). In the deep sea even fewer drilling rigs can function in such currents. High operating costs are just one of the problems arising under these conditions. As mentioned earlier, research is underway on designing specialized gas hydrate drill ships able to function in strong ocean currents.

Gas Hydrate Recovery

Gas hydrates needs to be carefully recovered and analyzed to having a clear view of the physical properties of gas hydrate to ensure efficient drilling and production of gas hydrate. Coring is a standard technique used in drilling for oil and gas exploration to collect samples of sediments from the zone of interest beneath the earth. By attaching a ‘core barrel’ or ‘core sampler’ with the drill string, sediment samples are normally collected.

If a sample of gas hydrate is brought to the surface using standard coring technique, it will face a totally different temperature and pressure environment resulting in dissociation and other dramatic changes in physical characteristics. Thus it is not possible to assess the physical properties of gas hydrates by analyzing denatured and dissociated core samples collected by using standard coring methods.

With a view to overcoming this problem, core barrels have been designed that can keep the core samples in conditions closely resembling those of the formation in which gas hydrate is present.

Because coring takes place under controlled temperatures and pressure, this core barrel is referred to as a pressure-temperature-core-sampler (PTCS).

Estimates of Gas Hydrate Resources

As stated earlier one unit of methane in gas hydrate contains about 170 units of methane (160-180 units). Thus obviously with price escalation of crude oil and natural gas, interest on gas hydrate grew tremendously to know how much gas is there in the gas hydrates under the earth in ocean and permafrost environment. Using geological and geophysical techniques attempts were made to quantify the amount of gas hydrate.

Methodologies for Exploitation of Gas Hydrates

Presently there is R&D going on for the exploitation of methane from gas hydrates using the following methodologies

1. Thermal dissociation – A Method in which heat is introduced into the gas hydrates thereby destabilizing the same which yields the production of methane and water from the gas hydrates e.g. Mckenzie delta Canadian Permafrost Area (2007).
2. De-pressurization: A method in which the pressure is reduced within the Gas Hydrates Stability Zone (GHSZ) leading to the dissociation of gas hydrates into water and gas e.g. Mckenzie delta (2008).
3. CO_2 substitution: - A method in which CO_2 is injected into the gas hydrates and CO_2 replaces the CH_4 in the cage of the hydrates releasing CH_4 and forming CO_2 hydrates e.g. No fields example yet although the experiments has been successfully in laboratory conditions.
4. A combination of all three methods can also be used for the exploitation of gas hydrates.

A completion of two or more of the above methodologies of mining, if the hydrates are found on the Seabed of near the Seabed, may proved to be a breakthrough in the production of Methane from hydrates.

Hence for commercialization the following are note worthy:

- Under appropriate conditions, large volumes of gas can be readily produced at high rates for long times from Class 1, 2 and 3 gas hydrate accumulations, by means of depressurization-induced dissociation.
  - The well designs does not exceed current industry capabilities
  - Water production rate Qw remains low in Class 1 deposits; in Class 2 and 3, Qw and the water-to-gas ratio decline continuously during production (performance improves with time)
- The depressurization-based production from any class of hydrate deposits is characterized by the development of an upper dissociation interface and a zone of high gas saturation at the top of the hydrate interval
  - The importance of confining boundaries cannot be overemphasized
- Production from hydrates using currently-available technology does not appear promising under conditions that include (among other things):
  - The use of pure thermal stimulation
  - Deep water zones and permeable boundaries in Class 2 deposits
  - Any Class 4 accumulation

- Gas production from oceanic hydrate-bearing sediments by depressurization may cause reservoir yielding, significant settlement, and well bore stability problems.

    - Unconsolidated sands do not pose significant challenges
    - Unless addressed, the problem may affect the feasibility and or viability of production from hydrates in fine-grained media
    - It is possible that geo-mechanical concerns may not allow production from otherwise tempting hydrates.

- The results of the recent Indian NGHP Expedition 01, and the corresponding analyses, provide very encouraging insights:

    - They confirm the existence of conditions that are conducive to the formation and stability of hydrates at high saturations over large areas
    - They allowed the testing of hypotheses, evaluation of approaches and equipment, and the definition of the steps that need to be taken toward production

- CO_2 substitution method is considered favorable because

    - Replacing CH_4 hydrate by CO_2 hydrate is thermodynamically favorable
    - Offsetting Dissociation Enthalpy: Heat of formation for CO_2 hydrate is approximately 20% larger than CH_4 hydrate heat of dissociation
    - Reforming CO_2 hydrate mechanically stabilizes the hydrate-bearing sediment
    - Zero net carbon balance

Conventional Production Method for Oil and Natural Gas

Oil and natural gas that are produced from the wells are found beneath the earth at very high pressures caused by the strata of earth. The deeper we go the higher is the pressure. Oil and natural gas at this incredible pressure flow naturally to surface through the wells drilled down to those depths.

On the other hand, gas hydrate is a solid substance and thus unlikely to flow out naturally in the same manner as oil and natural gas. However, if a method could be devised to force gas hydrate dissociate underground and generate methane gas, it would have been possible to apply the same techniques used in the production of oil and natural gas.
It is thus obvious that finding an efficient and safe method of triggering the dissociation of gas hydrate is an important factor in production. The following are three methods used in the experiments for methane gas production from gas hydrates.

Gas Hydrate Production

Thermal Recovery Method

Attempt has been made to dissociate gas hydrate by circulating hot fluid (water or steam) through the drilled well into the gas hydrate bearing layers. The fluid is heated in the surface in a boiler. This causes gas hydrate to decompose and generate methane gas. Dissociated methane gas mixes with the hot water and returns to the surface, where the gas and hot water are separated.

The fundamental problem with this method is that application of heat to the gas hydrate bearing layer is not a very simple task. It is rather an inefficient attempt to try to transfer heat throughout a gas hydrate-bearing layer. Moreover, there is the possibility that hot water pumped down the well from the offshore rig will cool before it reaches the gas hydrate-bearing layers. Because gas hydrate-bearing layers are found in deep seas, the surrounding sea water will reduce the temperature of the fluid.

Moreover, generating the hot water for pumping down to the gas hydrate-bearing layers requires tremendous amounts of energy, increasing production costs.

Depressurization Method

We know that oil and natural gas are found beneath the earth at very high pressures caused by the strata of earth above. During drilling for exploration and production of oil and gas, a high specific gravity mud is used to overcome the pressure exerted by the formation fluid or gas. The mud also prevents the gas or other fluid to come into drill pipe causing an undesirable blow-out. Gas hydrate bearing layers are also pressurized by the combined overburden weight of seawater and the formation pressure.

Conversely, the depressurization method is an attempt to lowering the pressure inside the well and encouraging the gas hydrate to dissociate into methane gas and water when depressurized.

However, depressurizing inside the well will not necessarily lead to depressurization of the entire gas hydrate-bearing layer. Research is continuing in an endeavor to find an efficient method of evenly reducing the pressure of gas hydrate-bearing layers.

Inhibitor Injection Method

Inhibitor, such as, methanol is injected from surface down to gas hydrate-bearing layers. This method enables gas hydrate to dissociate without changing the pressure or temperature of the gas hydrate-bearing layer.

However, research is still being carried out to devise a means of injecting the inhibitor evenly throughout the entire gas hydrate-bearing layer.

In March 2002, the first-ever production test was carried out on a gas hydrate-bearing layer under land in Canada's Mackenzie Delta region. On this occasion, both the hot water circulation method and depressurization method were applied to induce gas hydrate decomposition. A certain amount of methane gas was produced as a result of the test. Research is continuing, with the goal of improving production techniques and devising even more efficient production methods.

Production Tests by Simulation Study

Oil and natural gas production through drilling wells is a tested and established phenomenon. However, the environment in which gas hydrates occur and the properties of gas hydrates are totally different from that of oil and natural gas. Thus similar wells drilled for exploration and production of oil and natural gas will never bring any positive result in the case of gas hydrates. Every failed attempt for production of gas from the gas hydrates, demands for a new and different attempt with newer idea. However, drilling wells again and again with new ideas and methodology is obviously very expensive.

To avoid expensive drilling in deep waters, computers are used to simulate the amount of methane gas generated by each of the various methods. Oil and natural gas industry uses a number of production simulation software packages to optimize production and minimize drilling and production costs, and these are in the process of being modified for use in the simulation of production of gas hydrate.

Different groups and organizations of different countries, dedicated to studying gas hydrate's properties, are currently undertaking research with the goal of improving the accuracy of these simulations. By applying the results of production tests in the future on gas hydrate-bearing layers, it is hoped to further develop the simulation software, eventually creating effective tools for commercial production of gas from gas hydrate.

Gas Hydrate Production Research and Development

USA, Japan, India, Canada, the United Kingdom, Germany, Brazil, Norway, Russia, China, Korea, etc., are the countries actively involved in research and development of gas hydrates. Among other countries Japan is executing the most systematic R & D programs on development of gas hydrates. “Japan’s National Methane Hydrate R&D Programme, Phase-1” started in 2001 and continued up to 2008. During this period 2D/3D seismic surveys and exploratory drilling offshore Japan, onshore production test and basic research on exploration techniques, dissociation methods, production technologies, simulator development, environmental impact assessment, etc., were carried out.

Seven organizations from five countries, Japan National Oil Corporation (JNOC, former JOGMEC), Japan, Geological Survey of Canada (GSC), Canada, Geo Forschungs Zentrum Potsdam (GFZ), Germany, the Department of Energy (DOE) and United States Geological Survey (USGS), US, the India Ministry of Petroleum and Natural Gas (MOPNG)-Gas Authority of India (GAIL), India, and the BP-Chevron Texaco Mackenzie Delta Joint Venture joined a research and development programme of gas hydrate in 2002 known as “Mallik 2002 Gas Hydrate Well Research Programme” and attempted the first gas production test. Thermal stimulation by hot water circulation was tried in the test. During the 123.7 hour operation, 470m^3 gas was produced from the formation. Although the success of the test proved that gas hydrate can be a potential gas reserve, the difficulty of the heat transport from a well to the formation limited the productivity of the thermal stimulation technique. Also the continuous injection of heat to the formation decreases the energy efficiency. More specifically, there can be many technical challenges of heat generation and transportation in deep water conditions for producing gas from marine environment.

On the other hand, the depressurization technique has advantages of operation and energy efficiency. The pressure decrease can be achieved by a simple operation of dropping the fluid level in wellbore by pumping water. However, the formation response to the high degree of depressurization was unknown in 2002 and many scientists were skeptical of the applicability of the technique. Nevertheless, in 2002 scientists attempted small scale pressure drawdown tests using wireline pressure logging tools in gas hydrate formations. The results of the test suggested the applicability of the simple depressurization technique for gas production. The subsequent series of laboratory tests and numerical works done by National Institute of Advanced Industrial Science and Technology (AIST), Japan as a part of the MH21 (Research Consortium for Methane Hydrate Resources in Japan) study proved the applicability quantitatively.

As a result of the accumulated knowledge and experience, and with the expectation of the future application to the Japanese domestic resources, Japan Oil, Gas and Metals National Corporation (JOGMEC) and Natural Resources Canada (NRCan) signed an agreement to carry out a second production test at the same site for the field scale verification of the depressurization technique.

Operation Overview

The test site was located 130 km north of Inuvik, in the Mackenzie Delta, and accessible only in the winter season after ice road (a road on frozen river or ocean) construction was completed. All of the field activities had to be terminated before the close of the ice roads. Due to the narrow seasonal operation window, the field work was divided into two winters (January-April 2007 and January-April 2008).

JOGMEC and NRCan funded the programme and led the research and development studies. Aurora College/Aurora Research Institute, Canada acted as the operator for the field programme with support from Inuvialuit Oilfield Services who were the project managers. Because the site was located in the very sensitive and weak northern environment, and various precious natural species live around the site, the project was required to maximize environment protection measures to assure that there was no impact on the wildlife and delicate arctic ecosystem. The test was conducted under the strict environmental regulations of Canadian authorities and with the consent of local communities.

Winter 2007 operations

A well drilled for the 1998 research programme (Mallik 2L-38) was reused for the production test for reducing drilling waste volumes. In the first winter, the well was modified for the production test, after geophysical data acquisition by state-of–the-art logging tools and deployment of downhole monitoring devices.

Severe cold (temperatures often reached -40^{0}C) led to delay of the operation, but the test operation could start on the 2nd of April (local time) after the perforation (operation to make holes in the steel casing by gun powder) in a 12m interval at 1100m in depth was done and a set of a downhole pump systems to decrease the water level were installed.

Sand production (flow-in of formation sand to the borehole with fluid) prevented the continuous pumping, and the operation was terminated 60 hours after the start of the pumping. However, during the most successful 12.5 hours duration, at least 830m^3 of the gas was produced and accumulated in the borehole. This attempt was the world's first gas production by the depressurization of natural gas hydrate in geological formation, and the volume of 830 m^3 exceeded the production volume of five-day-operation of 2002. The test result verified the effectiveness of the depressurization method even for such a short duration, but left technical challenges.

Winter 2008 operations

The goal of the winter 2008 field activities was to undertake longer term gas hydrate production testing with countermeasures to the problems of 2007. After the ice road and site construction, and preparatory operations on the well, a modified pumping system was run into the hole with sand control devices. The pump operation started in the afternoon of March 10 and continued until noon of March 16, 2009.

Preliminary results

Sustained gas flow ranging from 2000-4000 m^3/day was maintained throughout the course of the 6 day (139 hours) test. Cumulative gas production volume was approximately 13,000m^3 . Detailed analyses though not found, but the test results almost confirmed the hypothesis that the depressurization method is the right approach for production of gas from gas hydrates.
During the test, a lot of data and samples, such as produced gas and water, their rate and volume, and downhole and surface pressure and temperatures were obtained. The analyses of the data and samples will help understanding gas hydrate dissociation behavior in formations, and contribute to the development of more sophisticated production techniques. Japanese and Canadian research teams are analyzing the data and will publish scientific and technical papers duly.

Within the MH21 research programme of Japan, AIST is developing a reservoir simulation model called MH21-HYDRES. The predicted gas production rate by the MH21-HYDRES has fairly matched with the observed value for the stable production terms. By analyzing the data of the production test, there will be further improvement in the modeling.

Extensive research programme is being implemented for the development of effective production techniques to change the naturally occurring gas hydrate to a valuable energy resource. The success of the production test in northern Canada is a great step forward.

A simulation result of MH21-HYDRES applied to one concentrated zone of the Eastern Nankai

Trough, Japan revealed that the potential gas production rate from a single wellbore by the depressurization method can exceed 50,000m^3/day. The difference from the onshore production test result is caused by the extent of production interval, temperature and pressure conditions, geological and petro-physical conditions.

However, many technical glitches are standing out there as challenges for the application of depressurization techniques in marine sediments beneath deep water. Such technical challenges should be solved and verified through future production tests.

The future Gas Hydrate development should be environmentally friendly. Experience gathered and lessons learnt in the delicate northern environment of Mackenzie Delta will help take necessary research programs on environmental assessment and protection issues.

CHAPTER – 5
ECONOMIC AND ECOLOGICAL ASPECTS OF GAS HYDRATES

Economical Importance of Gas Hydrates

According to the 2009 World Energy Outlook published by the International Energy Agency (IEA), a scenario in which current laws and policies remain unchanged throughout the projection period - world marketed energy consumption is projected to grow by 44 percent over the 2006 to 2030 period. Fossil fuels account for 77% of the increase in world primary energy demand during the period 2007-2030 (Figure 14). Given the large matrix of parameters affecting energy supply and demand, economic conditions, and population growth, predicting the growth in energy consumption and the availability of energy sources is risky and prone to wide uncertainty. However, historical trends show that changes in consumption pattern occur rather slowly, given the large infrastructure that supports resource extraction, conversion, and supply, and the current patterns of energy utilization. Changes require massive investment and a population willing to support such investment. Changes also follow the discovery of more convenient forms, such as the rise in petroleum and fall of coal in mid-twentieth century, and technologies that enable the large-scale introduction of alternatives, such as nuclear energy. Economic factors largely rule energy source utilization and its penetration.

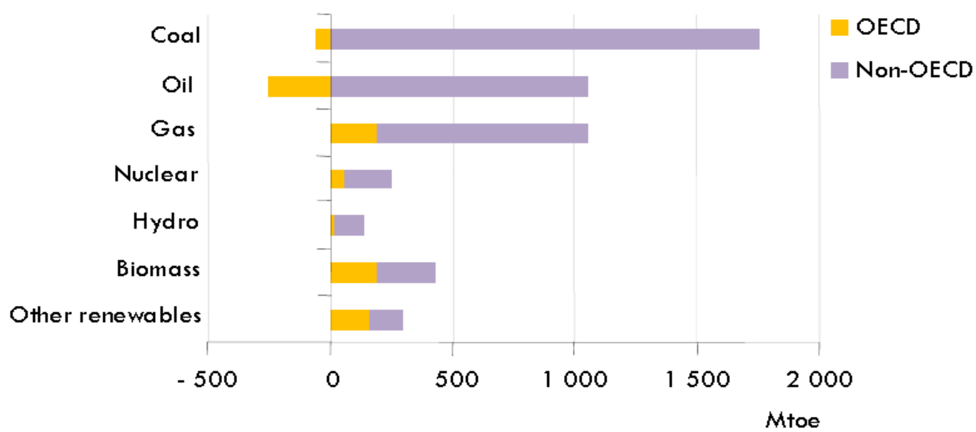

Figure14: Expected change in world's primary energy demand during the period 2007 to 2030. Fossil fuels account for 77% of the increase in world primary energy demand in 2007-2030, with oil demand rising from 85mb/day in 2008 to 88mb/day in 2015 and 105mb/day in 2030 (World Energy Outlook, 2009).

Fossil fuels reserves and resources (those believed to exist, but their extraction requires different economic and operating conditions) have a finite lifetime, perhaps 100 to 300 years, depending on the fuel type, recovery rate, search and production technologies, exploration, and consumption rates. Current predictions indicate that the lifetime of oil ranges from 50 to 75 years for the reserve, whereas resources are predicted to last for 150 years (Ghoniem, 2008).

Natural gas is expected to last longer, nearly twice as long as oil. Coal, however, is plentiful and is expected to last for several hundreds to thousands of years. These estimates are approximate at best because the recoverable amount of the resource is strongly dependent on the available technology, cost, and consumption pattern. With the current projections of reserves and resources, it is coal that will last the longest, with oil running out the fastest. Coal is available worldwide and playing major role in many of the fast-developing economies, such as China and India. Taking into account other heavy sources of hydrocarbon, such as oil shale and tar sands, recoverable liquid fuel estimates increase substantially. Other hydrocarbon resources include deep ocean methane hydrates which constitute a new unconventional gas play, and may prove to be one of the major energy resources of the 21st century. For a number of countries, hydrate may be the only indigenous option for non-renewable, combustible energy resources.

Based on the degree of economic feasibility of gas hydrates recovery the gas hydrate resources are categorized broadly into three categories (Milkov and Sassen, 2002). Numerous geological, technological, and economic factors affect the economic feasibility of gas hydrate recovery. i). Economic gas hydrate reserves include gas hydrate accumulations from which natural gas might be produced profitably under defined investment assumptions, ii) Gas hydrate reserves (marginal and economic) are part of the identified gas hydrate resources that may border on being economically extracted or produced at the time of determination but would be producible if economic or technological factors change, and iii) Sub-economic gas hydrate resources are that part of identified resources that do not meet the economic criteria of economic reserves and marginal reserves. However, more detailed quantitative economic analysis is needed to determine the reserve status of gas hydrate accumulations. The preliminary qualitative analysis below may be useful for directing further gas hydrate exploration (Figure 15).

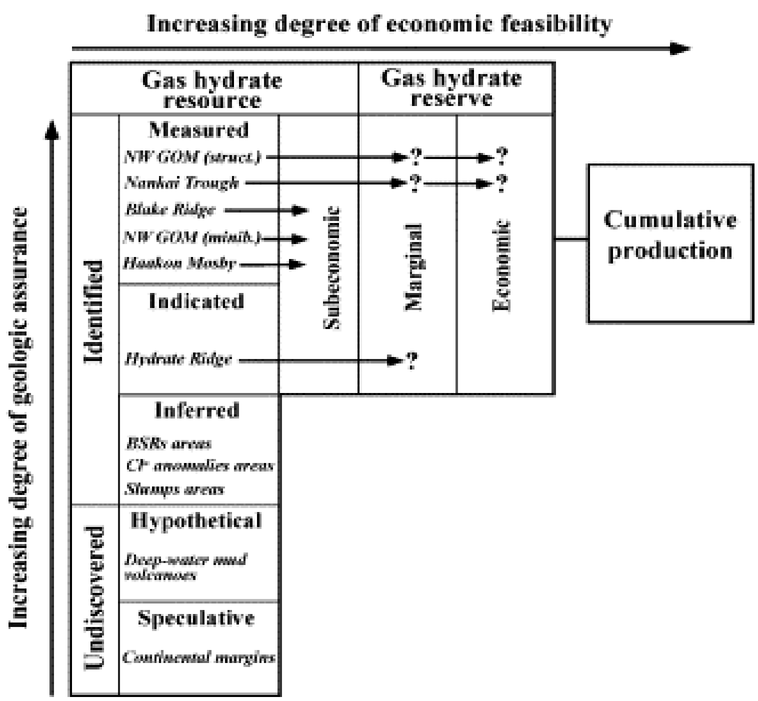

Figure 15: Resource/reserve classification scheme for natural gas hydrates with examples (after,Milkov, 2002)

The world's Gas hydrate resources are estimated at 7100 TCM of gas hydrates under standard temperature and pressure conditions. From the Fig.19, it is understood that most of the gas hydrates are found in reservoirs having poor permeability and would therefore be classified as Non extractable. However gas hydrates which are found in massive occurrences in fractured reservoirs may be extractable. This leaves a very small percentage of the global gas hydrate reserves which can be placed in the category of extractable resources.

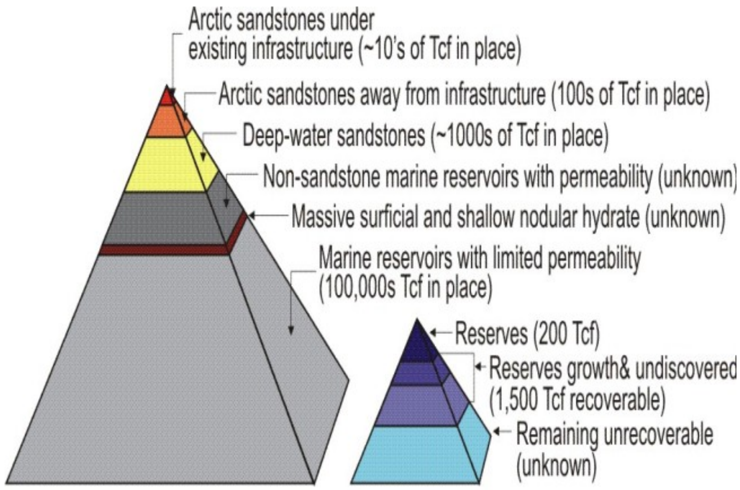

Figure16: The environmental distribution of the gas hydrates globally

The disseminated gas hydrates in sands from the Nankai Trough area, Japan (Figure 17) and presumed to be the easiest for extraction. The gas hydrates recovered from the Indian Deep water area of Krishna Godavari are massive in fractured shales (Figure 18) and the technology for its extraction has to be very different from what is currently perceived.

Figure 17: Disseminated gas hydrates in sands from the Nankai Trough area, Japan

Figure18: Gas hydrates in fractured shales in Deep water area of K-G basin, India

Ecological Implications of Gas Hydrates

When natural gas (hydrocarbon, containing carbon and hydrogen atoms) is burned, it emits carbon dioxide, one of the substances that lead to global warming. But the amount released is less than when coal or oil is burned, making natural gas a relatively clean source of energy. For this reason, it is anticipated that gas containing methane sourced from gas hydrate will rank with natural gas as a clean source of energy. Oil and coal, when burned, emit air pollutants such as sulfur oxides and nitrogen oxides. Natural gas, however, when burned, results in virtually no emissions of sulfur oxides, or nitrogen oxide.

However, burning a gas whose principal component is methane obtained from gas hydrate will definitely emit some sulfur dioxides and nitrogen oxides. But the level of this emission is not yet known to date. It is though anticipated that, like natural gas, methane from gas hydrate will be cleaner than oil and coal. But since methane itself is a greenhouse gas with 21 times the potency of carbon dioxide, its release into the atmosphere without being burned is undesirable.

Both carbon dioxide and methane break down over time after being released into the atmosphere. However, whereas it takes around 50 to 100 years for carbon dioxide to break down, methane dissolves after around 7 to 12 years. For this reason, it would be unwise to approach the greenhouse effects of methane in the same way that carbon dioxide is approached. This doesn't mean it is desirable for large quantities of methane to be released into the atmosphere. Research is still being carried out on the environmental impact of methane.

To produce methane gas from gas hydrate safely and without harming the environment, many wide-ranging environmental issues will be needed to be addressed. For this reason, before going into development and production, it is essential to undertake appropriate investigations and research in regard to its environmental impact. Prime consideration should be that attempts for the development and production of methane from gas hydrates are for the benefit of the humankind. If the production of methane from the gas hydrates, instead of benefiting, proves to be detrimental to the humanity, its development and production should not be continued further.

Methane gas hydrates are receiving increasing attention because they are regarded as a major energy source suitable for future exploitation (Sommer et al., 2002). Moreover, the global climate of the geological past might have been repeatedly effected by greenhouse gases released from hydrates. Marine hydrates are common in sediments deposited at polar continental shelves and at the slope and rise of productive continental margins. Usually, they occur at depths well below the sediment surface because methane is rapidly oxidized by microbial consortia using pore water sulfate as oxidizing agent. Nevertheless, near-surface gas hydrates have been discovered at a constantly increasing number of continental margin sites affected by gas and fluid venting over the last years (Sassen et al., 1998; Sassen et al., 2001; Egorov et al 1999; Ginsburg et al., 1999; Ginsburg et al., 1993; Suess et al., 1999). In these areas, methane is rapidly transported to the surface sediments with ascending fluids or gas bubbles so that a strong supply of methane from deep layers compensates for methane oxidation and decomposition. Methane transport from below and the constant dissolution of gas hydrates produce a steady flux of methane to the surface, supporting rich benthic ecosystems based on the anaerobic and aerobic oxidation of methane and dissolved sulfide. The oxidation of the ascending methane by sulfate occurs in narrow zones near the sediment surface, where sulfide and bicarbonate are released into the pore water:

$$CH_4+SO_4^{2}-\rightarrow HCO_3-+HS-+H_2O \qquad \text{(Eqn.1)}$$

The sulfide is transported to the sediment surface where it is further oxidized by aerobic bacteria using oxygen and nitrate as terminal electron acceptors. Bicarbonate released during anaerobic methane oxidation (Eqn. 1) increases the alkalinity and supports the precipitation of authigenic carbonates according to (Berner, 1980):

$$Ca_2++2HCO_3- \Leftrightarrow CaCO_3(s)+CO_2+H_2O \qquad \text{(Eqn.2)}$$

High- and low-magnesium calcite as well as aragonite precipitates are abundant around cold vent sites where methane-rich fluids are present in surface sediments (Kulm et al., 1986; Bohrmann et al., 1998). Carbonate precipitation in these sediments is regarded as a major sink of methane derived carbon and seawater Ca (Han and Suess,1989) even though precipitation mechanisms and rates are still poorly understood.

The studies at Hydrate Ridge, a segment of the Cascadia convergent margin site have revealed high and variable rates of fluid venting (Linke et al., 1994, Tryon et al., 1999; Tryon and Brown, 2001), gas venting and out-cropping of gas hydrates (Suess et al., 1999), abundant carbonate precipitates (Bohrmann et al., 1998), and rich benthic ecosystems relying on the oxidation of methane and sulfide (Suess et al., 1999; Boetius et al., 2000; Elvert et al., 2001). The effects of methane released from decomposing surficial and subsurface gas hydrates on standing stocks and activities of the small-sized benthic biota (SSBB; i.e. bacteria, fungi, protozoa, and meiobenthic organisms) is essential to be studied in the Indian offshore region.

Environmental Impact of Submarine Gas Hydrates

Natural gas hydrates are important since they are: i) a huge energy resource, (ii) a factor in global climate change, and (iii) a submarine geohazard (Kvenvolden, 1999). Since gas hydrates have been viewed as an alternate energy resource, we need to understand the impact of their exploitation in terms of ecology and economics. We shall now discuss briefly the impact in terms of climate change and geohazards such as slope failure. Since the recent drilling indicated the presence of thick accumulation of gas hydrates in the Krishna-Godavari offshore area, an understanding of the effects of methane gas release is vital (Ramana et al., 2007).

Slope failure

Gas hydrate not only holds a huge volume of gas under high pressure in an ice-like crystalline solid substance, but it also acts as a binding agent that holds together the sand and mud that make up the strata under the seafloor.

Some of the seismic sections and the high resolution swath bathymetry map of Krishna-Godavari offshore area, a part of the eastern continental margin of India and situated in the upper slope with a steep gradient show the presence of slumping/ sliding, collapse depressions and rollover structures (Figs.19 & 20). These slumping structures are attributed to the slope failure either caused by the neotectonism or destabilization of gas hydrate zone due to the fluctuations in the sea level and rapid deposition of sediments. Dillon et al., (1998) suggested that these processes such as slumping/ sliding, collapse depressions, rollover structures, sea level fluctuations and any tectonic disturbances can alter the in situ pressure or temperature regime. In adjusting to the new pressure/temperature conditions, the gas hydrates dissociate, producing an enhanced fluidized layer at the base of the gas-hydrate zone, and trigger expulsion of pressurized fluid/ gases. Submarine slope failure can follow, giving rise to debris flows, slumps, slides, and collapse depressions, etc. During gas-hydrate formation, methane and water become immobilized, restricting pore space and retarding fluid migration (McIvor, 1992). This results in decrease of permeability in the sediments. Eventually, gas hydrates may occupy much of the pore space within the gas hydrate stability zone, and continued deposition of sediments leads to deeper burial of the gas hydrate; and with depth, the temperatures increase at the base of the stability zone resulting in destabilization of GHSZ. The solid gas/water mixture (i.e. the gas hydrate) will become a liquid gas/water mixture. Thus, the basal zone of the gas hydrate becomes under consolidated and possibly over pressurized because of the newly released gas, leading to a zone of weakness. Slope failures and/or submarine landslides result because of low shear strength, triggered by gravitational loading or seismic disturbances.

Recent studies elsewhere also suggest that slope failure may be accompanied by the release of methane gas into the water column, but much of the methane is likely to be oxidized unless the gas release is catastrophic. Low to medium concentrations of methane are reported in the deeper levels of the water column in the Bay of Bengal (Berner et al., 2003). The deep methane anomalies may not exchange with surface waters, and hence may not form a source of atmospheric methane. Several researchers take the view that unless a major catastrophic event occurs, the amount of methane that will be released from the gas hydrates either by destabilization due to minor variations of pressure and temperature conditions or by low order neotectonism to atmosphere may not pose a serious greenhouse threat. Periodic Pleistocene eustatic sea level transgressions and regressions provide mechanisms to account for the waxing and waning of submarine gas hydrates (Kayen and Lee, 1991). In the present study, the observed methane anomalies can be related to gases emanating from the sediments as seen by the presence of several gas escape features on the seismic records.

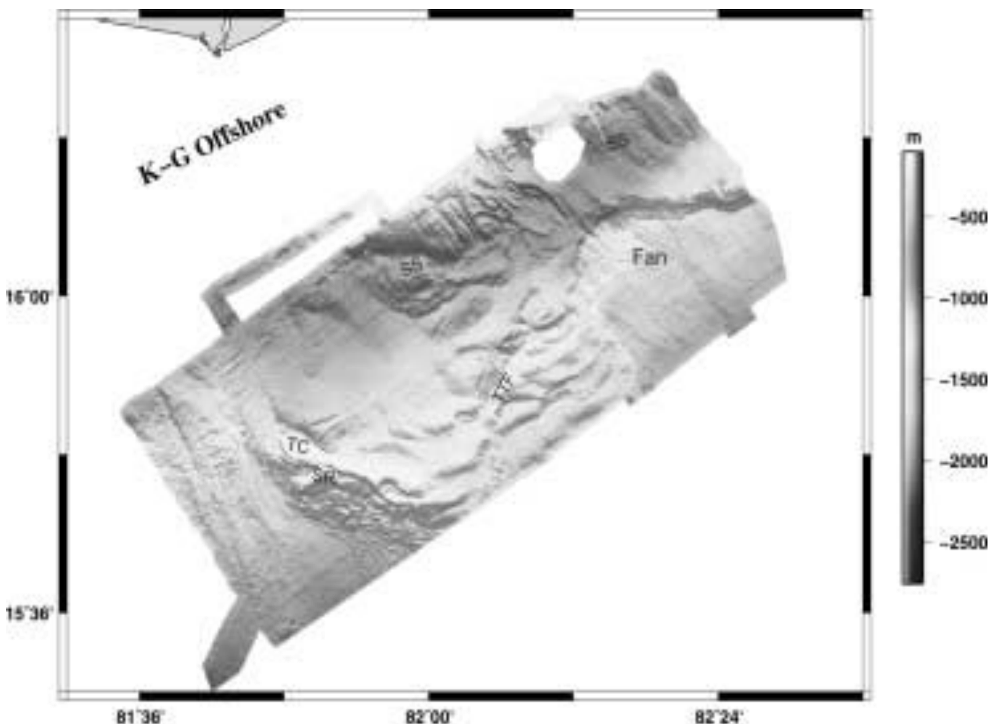

Figure19: Swath bathymetry map showing the high resolution seafloor mosaic of the Krishna-Godavari offshore. TC: Turbidity Channel; SR: Sedimentary Ridge; SS: Sliding/ Slumping; TTF: Toe Thrust Fault

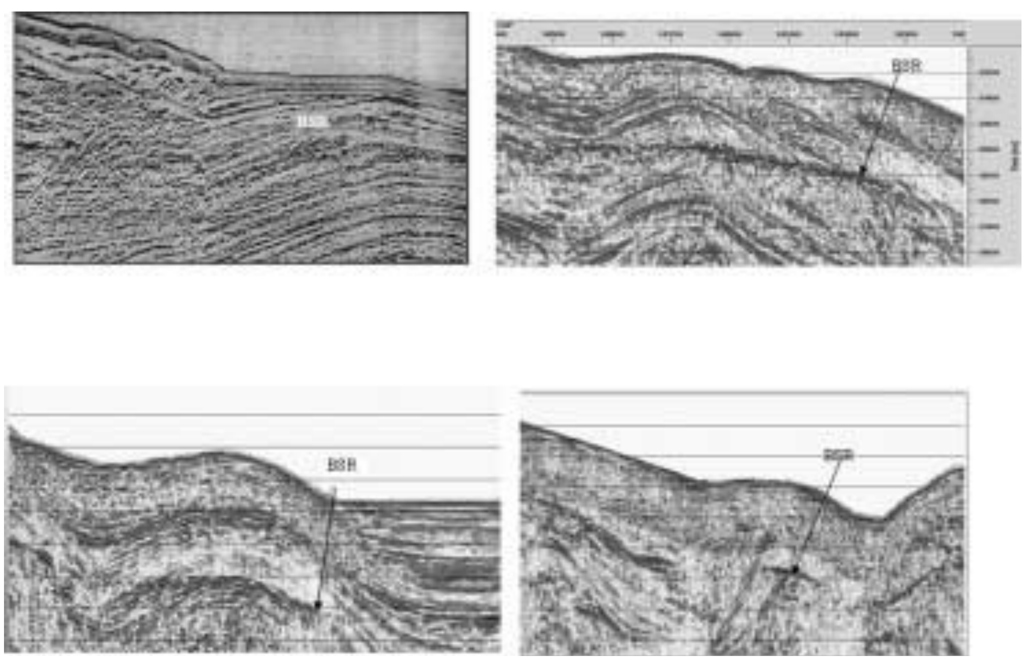

Figure20: Anomalous seismic reflections (BSRs) are seen distinctly mimicking the seafloor topography in most of the multichannel seismic records

Geohazards

Due to the destabilization of gas hydrate zones, fluid expulsions take place and the seabed will be associated with pockmarks and loose sediments. These disruptions of the seafloor caused by gas hydrate dissociation affect manmade structures if they are located in regions of potential failure. Borowski and Paull, (1997) expressed similar views about geo-hazards. With mankind's increasing interest in the deeper offshore areas (search for oil and gas), the stability of the seafloor becomes increasingly important for any engineering structure. The gas saturated sedimentary columns are also characterized by least shear strength. Installation of offshore structures needs a firm ground either for drilling, construction of a production platform or jacking up of a rig. Dissociation of gas hydrates will result in increased fluid pressure, dilation of the soils and developing of gas bubbles, all of which substantially weaken the soils. The factor of safety for a submarine slope containing gas hydrates will decrease with decreasing water depth, decreasing the depth to hydrate below the seabed and increasing the percentage of hydrate within the soil (Nixon and Grozic, 2006). Risks such as sediment casing collapse, gas leakage outside the conductor casing, and gas blowouts in case of drilling gas hydrates from deeper offshore areas have been discussed by Yakushev and Collett, (1992). The geohazard aspects particularly the seabed characteristics and shallow subsurface geological environment affected by gas saturated sediments, free gas, unconsolidated sediments/loose sediments due to continuous fluid expulsions caused by various external factors like sea level fluctuations, slope failure, neotectonism, etc. should be assessed before undertaking exploitation of gas hydrate as a future energy resource.

The geology of the Krishna-Godavari offshore area from our studies and from literature is known for the occurrences of gas escape features at shallow subsurface levels, and clays dominate the gas hydrate formation. The Krishna and Godavari deltas supply the clastic input, which passes directly into an extensive coeval slope and deep water sedimentation system, which exhibit a range of deformation features such as growth faults, slides and contorted thin bed turbidite, slide blocks and chutes filled with slope related mudstone, thick and thin bedded discontinuous turbidites and debris flows (Sahu, 2005). Minor faults are identified on the seismic reflection data particularly within the top few hundred meters, and these faults appear to be serving as the conduits/pathways to the migration of methane gas.

The gas hydrate occurrences on the ocean bottom in the Gulf of Mexico area (Figure21) are extremely sensitive from the ecological point of view since they support organisms like the tube worms and many other methanotrophs.

Figure21: Gas hydrates on seafloor associated with organisms

The study carried out in India on the ecological aspects, the preliminary molecular data suggests numerous taxa detected including: Archaea: methanogens, anaerobic methanotrophs, thermophiles Bacteria: sulfate reducers, sulfur oxidizers, metal reducers, ANAMMOX, acetogens, aerobic methanotrophs.

Effect of Methane Emission into the Sea and Atmosphere

Methane gas compared to the other commercial fuel is considered to be the cleanest fuel, because once it is burnt, it leaves minimum residue in the environment. Thus it does least harm compared to the other fuels. However, free methane gas in the atmosphere is never desirable. All attempts of production of methane gas involve dissociation of gas hydrate present beneath the seafloor into methane and water. Since it is undesirable for methane to leak into the sea or atmosphere during the production process, efforts must be made to ensure absolute minimum leakage of methane during development and production.

Other Environmental Considerations

Production of “cuttings” during drilling of wells for oil and gas exploration and production, is a common phenomenon. Similarly drilling wells as part of the development of gas hydrate will produce significant amount of cuttings containing methane gas. In addition, it is anticipated that recovering methane from gas hydrate-bearing layers will produce large quantities of water as a by-product. Research is being carried out to investigate the impact of these and other actions may have on the environment.

Environmental Impact Assessments Before and After Production Testing

It has been mentioned earlier that MH21 Research Consortium of Japan is conducting a R&D programme aiming at commercial gas production from offshore gas hydrates and for the assessment of the environmental impact on gas production from methane hydrate based on the implementation of offshore production test and Assessment of the possibility for safe and economic development of methane hydrate offshore Japan.

Before and after these drilling and production tests, various sensors and other equipment will be used to measure changes, if any, in the marine environment arising from these activities to assess their impact on marine life, the seafloor, and the surrounding water.

The information gathered will be used to formulate a set of indices for assessing the environmental impact of future production activities and to help determine appropriate development and production systems, with the ultimate goal of maintaining a healthy environment.

Health, Safety, and Environment (HSE)

Based on the assumption that offshore gas hydrate development will be similar to oil and natural gas drilling and development work, involving work with heavy equipment in extreme weather conditions and rough seas, the safety issues must be carefully considered.

Extensive research is being carried out on health, safety, and environmental (HSE) management that takes account of the working conditions of those involved in production of gas hydrate.

Gas Hydrates and Climate Change

Methane is a powerful greenhouse gas. Despite its short atmospheric half-life of 7-12 years, methane has a global warming potential of 62 over 20 years and 21 over 100 years. The sudden release of large amounts of natural gas from methane hydrate deposits has been hypothesized as a cause of past and possibly future climate changes. Events possibly linked in this way are the Permian-Triassic extinction event, the Paleocene-Eocene Thermal Maximum.

Climate scientists such as James E. Hansen expect that methane hydrates in the permafrost regions will be released as a result of global warming; unleashing powerful feedback forces which may cause runaway climate change that cannot be controlled.

Recent research carried out in 2007 (Kim Fulton-Bennett, 2007) and 2008 in the Siberian Arctic has shown millions of tons of methane is being released (Volker Mrasek 2008). The Independent, September 23, 2008 issue writes, “The first evidence that millions of tons of a green-house gas 20 times more potent than carbon dioxide being released into the atmosphere from beneath the Arctic seabed has been discovered by scientists.” (Connor, Steve, September 23, 2008) and (Connor, Steve; September 25, 2008). The concentrations of the gas in some regions are reaching up to 100 times above normal.

CHAPTER – 6
REGIONAL SCENARIO, INSTITUTIONS AND ORGANIZATIONS INVOLVED IN GAS HYDRATE PROGRAMMES

Programmes by Other Countries

It has been observed that the technology, used for production of conventional hydrocarbons, cannot be applied to produce gas from gas hydrates as unlike coal, minerals and conventional hydrocarbons they are not stable at standard temperature and pressure. Development of exploitation technology is a real challenge. So far nowhere in the world the proven exploitation technique exists. However, Japan, Canada and the USA are the leading countries actively engaged in developing such tools. India is also in the race at almost equal pace with them.

Different efforts so far made to produce commercial gas from the gas hydrates, did not produce considerable amount of gas. As such a definite method of production of gas from the gas hydrates could not yet be established. However, considering the emphasis being given on development of exploitation techniques for producing gas from the gas hydrates, it is believed that days are not very far for gas trapped in the gas hydrates to be produced. For economic production of gas, the location of gas hydrates deposits should be as close as possible to the shoreline and reserves of gas hydrates should be of sizeable amount.

One of the three methods as mentioned earlier, (I) thermal recovery, (ii) depressurization and (iii) inhibitor injection or a combination of two or all of these methods are being considered for commercial production of gas from gas hydrates. The replacement of methane by carbon dioxide through a process called CO_2 sequestration is also thought of for production. Since dissociation of gas hydrates causes global warming and slope failure, the extraction method should also be environmentally-caring (Sain, 2009).

It can also be noted that JOGMEC and AIST have organized new MH21 Research Consortium made up of government organizations, universities and private companies to implement Phase 2 of Japan's National Methane Hydrate R&D programme, a 7-year programme (2009-2015).The Goal and Research Themes of this phase are as follows:

1. Implementation of offshore production tests (in the Eastern Nankai Trough) to verify production technology applying depressurization method and to clarify required technical breakthrough for commercial production
2. R&D to enhance productivity by injecting external energy of any kind along with depressurization
3. Resource assessment of methane hydrate offshore Japan other than the Eastern Nankai Trough
4. Assessment of the environmental impact on gas production from methane hydrate based on the implementation of offshore production test
5. Assessment of possibility for safe and economic development of methane hydrate from offshore Japan

The programme will give special emphasis on environmental aspect of methane production by depressurization:

- The R&D programme will focus on production of methane by depressurizing the hydrate filling pore spaces of sand layers several hundred meters below the sea-bottom.
- Dissociated methane and water will be produced by means of the same well and production systems as the well matured technology of conventional oil and gas production.
- The research consortium will be investigating any issues special to the hydrate than conventional offshore gas production and plan to establish production system without environmental problems.
- The production by depressurization basically utilizes inherent energy of hydrate layers. When the depressurizing operation is halted, methane gas in the sand layers will become hydrate again. A kind of natural failsafe mechanism should work.

The research methodology for Environmental Impact Assessment (EIA) will be as follows:

1. Ocean Environment Data Collection:
    - Baseline surveys
    - Assessment of sub-bottom physical properties
    - Existing Data
2. Development of prediction model
    - Ocean environmental impact
        - Methane gas leak
        - Water emission
    - Stratum deformation
3. Development of Monitoring Technology
    - Methane gas leak, stratum deformation
    - Monitoring system
4. Environmental Impact Assessment Procedures
    - Select reference indexes for EI assessment
    - Baseline monitoring of marine ecosystem
    - System for environmental monitoring

Programmes in the Region

Various research institutions, organizations and oil & gas companies from the region like, Directorate General of Hydrocarbons (DGH), Ministry of Petroleum and natural gas, Government of India; National Institute of Oceanography (NIO), India; National Geophysical Research Institute (NGRI), India; National Institute of Ocean Technology (NIOT), India, ONGC, IOCL, OIL, GAIL (India); National Institute of Oceanography, Pakistan; Hydrocarbon Development Institute of Pakistan; Petroleum Resources Development Secretariat, Sri Lanka; Energy & Mineral Resources Division (EMRD) and the Power Division under the Ministry of Power, Energy & Mineral Resources (MOPEMR), Bangladesh are involved in gas hydrate programme.

India

Gas hydrate exploratory research in India is being steered by the Ministry of Petroleum & Natural Gas under National Gas Hydrate Programme (NGHP) with participation from Directorate General of Hydrocarbons (DGH), National E&P companies like the Oil and Natural Gas Corporation Ltd 'ONGC', GAIL India Ltd, Indian Oil Corporation Ltd 'IOC' & Oil India Ltd 'OIL' and National Research Institutions like the National Institute of Oceanography (NIO), National Geophysical Research Institute (NGRI) and National Institute of Ocean Technology (NIOT). Several initiatives have been taken by NGHP for gas hydrate exploration in Indian offshore. Geophysical, geological and geochemical data have been collected from East and West Coasts and Andaman areas for identification of gas hydrate reservoirs. Based on these studies, areas were identified for gas hydrate coring/drilling operations. A dedicated gas hydrate coring/drilling/LWD/MWD operation was carried out in four Indian Offshore areas under NGHP during 28th April 2006 to 19th August 2006 through a Consortium consisting of Overseas Drilling Ltd (ODL), Fugro McClelland Marine Geosciences, Geotek Ltd, Lamont-Doherthy Earth Observatory (LDEO) and scientists from numerous universities and national laboratories. The research vessel JOIDES Resolution was used for the Indian gas hydrate programme with much of the coring/drilling equipment and tools from Integrated Ocean Drilling Programme (IODP). The Directorate General of Hydrocarbons was the lead agency from Government of India and coordinated the NGHP Expedition 01, 2006. United States Geological Survey (USGS) was the main technical collaborator of NGHP for this effort. The technical manpower from the NGHP constituent organizations participated and contributed in this programme.

The NGHP efforts in Indian offshore for gas hydrate exploration led to the following:

- Comprehensive analyses of gas-hydrate-bearing marine sediments in both passive continental margin and marine accretionary wedge settings;
- Discovery of gas hydrate in numerous complex geologic settings and collected an unprecedented number of gas hydrate cores (more than 2800 m from 21 sites and 39 holes);
- Delineation and sampling of one of the richest marine gas hydrate accumulations yet discovered in the world (Krishna-Godovari basin)
- Discovery of one of the thickest and deepest gas hydrate occurrences yet known (Andaman Islands) which revealed gas-hydrate-bearing volcanic ash layers as deep as 600 meters below the seafloor;
- Establishing the existence of a fully developed gas hydrate system in the Mahanadi basin of the Bay of Bengal;

NGHP is currently focusing on gas hydrate reservoir delineation and resource estimation in the K. G. area. 40 sites for NGHP Expedition 02 for a largely LWD operation have been identified and are currently being evaluated for sand provenance.

NGHP Expedition 01 was designed to study the gas hydrate occurrences both spatially and temporally off the Indian Peninsula and along the Andaman convergent margin with special emphasis on understanding the geologic and geochemical controls on the occurrence of gas hydrate in these two diverse settings. The primary goal of NGHP Expedition 01 was to conduct scientific ocean drilling/coring, logging, and analytical activities to assess the geologic occurrence, regional context, and characteristics of gas hydrate deposits along the continental margins of India in order to meet the long term goal of exploiting gas hydrates as a potential energy resource in a cost-effective and safe manner. During NGHP Expedition 01, dedicated gas hydrate coring, drilling, and down hole logging operations were conducted from 28 April, 2006 to the 19 August, 2006.

Based on analysis of geological and geophysical data, the Expedition was planned to visit ten sites in four areas: the Kerala-Konkan Basin in the Arabian Sea – western continental shelf of India; the petroliferous Krishna-Godavari Basin and Mahanadi Basin in the Bay of Bengal – eastern continental shelf of India; and the previously unexplored Andaman Islands. The goals of the cruise were to conduct scientific drilling, well logging, coring, and shipboard scientific analyses of recovered samples from each site to provide further insight into:

- the distribution and nature of gas hydrate in marine sediments
- the geologic controls on the formation and occurrence of gas hydrate in nature
- the processes that transport gas from source to reservoir
- the effect of gas hydrate on the physical properties of the host sediments
- the microbiology and geochemistry of gas hydrate formation and dissociation

the calibration of geophysical and other predictive tools to the observed presence and concentration of gas hydrates.

Pakistan

The scientists of Hydrocarbon Development Institute of Pakistan and National Institute of Oceanography have participated in Pak-German Oceanographic cruises jointly under taken by Pakistan and Germany in 1993, 1997 and 1998 onboard German Research Vessel R/V Sonne (SO-90, SO-122 and SO-130). During these cruises gas seeps off Makran Coast were surveyed and sampled. Later, NIO scientists along with BGR scientists visited the Malan Island and series of Mud Volcanoes along the Makran Coast (von Rad, et al., 2000). Recently, R/V Meteor visited Pakistan offshore area in 2007 and Pak-German scientists extended the research previously done on Makran gas seeps in offshore areas. The National Institute of Oceanography is presently preparing a project proposal to assess the geo-resource potential, including gas hydrates, in the Pakistan maritime area.

Sri Lanka

In Sri Lanka, the Petroleum Resources Act, No.26 of 2003 has vested the absolute ownership of all petroleum resources occurring within the sub-surface land area and within the internal waters, historic waters, territorial sea, contiguous zone, continental margin, and the exclusive economic zone of Sri Lanka with the State. Therefore, the State, through the Minister of Petroleum and Petroleum Resources Development, is responsible for the exploration and exploitation of petroleum resources, in this case gas hydrate deposits. The Petroleum Resources Act also states that no person shall conduct petroleum operations in Sri Lanka unless such person has entered into a Petroleum Resources Agreement or any other appropriate agreement with the State or is authorized by or under this Act to conduct petroleum operations. The Petroleum Resources Development Committee (PRDC) is given the responsibility to invite persons to enter into Petroleum Resources Agreements with the State with respect to defined exploration blocks. The Act has kept the responsibility of acting on behalf of the State for all purposes related to Petroleum Resources Agreements with the Petroleum Resources Development Secretariat (PRDS). Thus day to day administration of petroleum exploration and exploitation operations rest with the PRDS while the responsibility of inviting persons to invest, explore and exploit petroleum resources lie with the PRDC.

The Ministry of Power & Energy is responsible for implementation of policies, plans, and programmes in respect of Power & Energy and which shall includes investigation, planning, implementation and coordination of energy matters specially focusing in Hydro Power, Thermal Power, Mini Hydro Power & Coal Power etc. In this regard this ministry would have an interest in gas hydrate investigations in terms of identifying possible future energy sources. In fact, one cubic metre of methane hydrate could produce 164 cubic metres of free gas and thus could represent a significant source of cost effective, safe and environmentally-friendly source of energy in the future.

There have been no focused investigations of gas hydrate potential offshore Sri Lanka. In fact Sri Lanka renewed its effort to explore for oil and gas offshore only in 2008 after a lapse of nearly 25 years. One exploration block in the Mannar Basin was awarded to Cairn Lanka (Pvt) Ltd in 2008 for an exploration period of 8 years consisting of three exploration phases made up of 3, 2 and 3 years respectively. Certain agreed upon work commitments must be completed to advance from one phase to the succeeding phase. The Exploration Block SL2007-01-001 is 3000 sq. Km in area and covers only 10 percent of the potential area available within the Mannar Basins. Existing data also suggest oil and/or gas potential exist in the Mannar Basin to the west, Cauvery Basin to the north, Bengal fan deposits to the east and newly identified sedimentary basins to the south of the island (Fig.- 22).

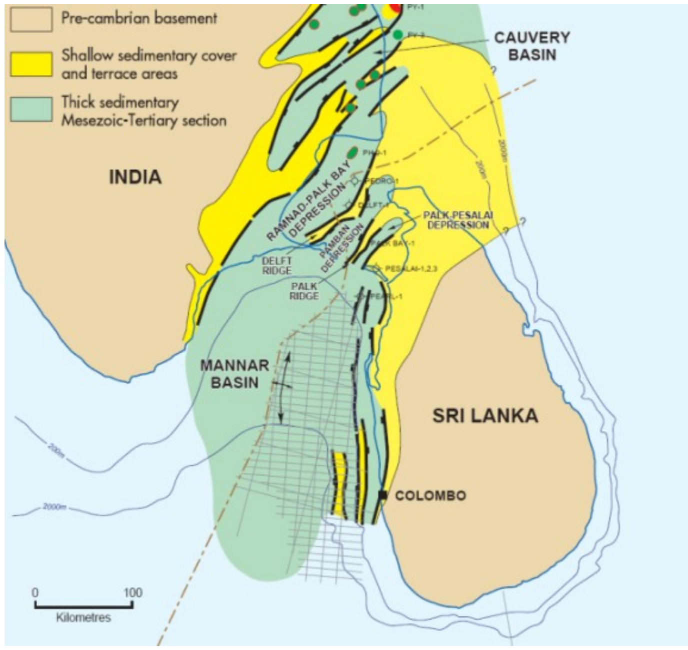

Figure 22: Mannar and Cauvery Basins

Bangladesh

The responsibility for planning, development and management of different types of commercial energy and power in Bangladesh are being shouldered by the Energy & Mineral Resources Division (EMRD) and the Power Division under the Ministry of Power, Energy & Mineral Resources (MOPEMR). The two divisions manage the gas and power sector utilities by two state corporations Bangladesh Oil, Gas and Mineral Corporation (BOGMC), nick-named Petrobangla and the Bangladesh Power Development Board (BPDB) respectively.

Energy and Mineral Resources Division (EMRD) of Ministry of Power, Energy and Mineral Resources is the administrative authority of all energy and mineral resources (oil, gas, coal and other minerals) of the country. Bangladesh Oil, Gas & Minerals Corporation (Petrobangla) on behalf of the Government (EMRD) holds the shares of the companies dealing in oil, gas & minerals exploration and development. Petrobangla operates hydrocarbon (oil & gas) exploration, development, transmission, distribution and compressed natural gas (CNG) conversion together with development and marketing of minerals.

In addition, as upstream regulator, Petrobangla administers Production Sharing Contracts (PSCs) with the international oil companies (IOCs) on behalf of the GoB. The Hydrocarbon Unit (HCU) serves as a support wing of the EMRD.

With a view to identifying the presence of gas hydrates in the offshore Bay of Bengal no project, either alone or jointly with any regional or international organization, was undertaken by Petrobangla. However, Petrobangla has a programme to look for the presence of BSRs in the seismic data that will be acquired from the deep-sea blocks to be awarded under Production Sharing Contracts (PSC) to the IOCs in the near future.

CHAPTER – 7

JOINT PROJECTS OF SAARC COUNTRIES ON GAS HYDRATES WITH INTERNATIONAL ORGANIZATIONS

India

The challenges in Gas Hydrates R&D can only be overcome by sustained commitment of our scientists and establishment of a proper gas hydrate R&D center in India. The global gas hydrate communities of scientists and researchers have to work in tandem with each other. DGH on behalf of the NGHP has signed Memoranda of Understanding in the field of Gas Hydrates with Japan Oil, Gas, Metal Corporation JOGMEC, the US Department of Energy (USDOE) the US Geological Survey (USGS). and the US MMS. DGH has been closely associated with the USGS, USDOE and JOGMEC scientists which has helped the NGHP scientists to gain a lot in terms of knowledge, understanding and experience. The NGHP Team is also collaborating with the SUGAR Project of Germany for the CO2 substitution for the production of methane from hydrates and have signed an MOU with IFM GEOMAR.

Pakistan

Scientific information and data collected on board German research vessel R.V. Sonne (1993, 1997-98), provided greater insight into various Geo-environmental conditions of the Northern Arabian Sea along Makran Coast. A joint collaborative research programme PAKOMIN between BGR Germany and National Institute of Oceanography, Pakistan envisaged investigating the influence of the oxygen minimum zone (OMZ) on the sedimentation at the continental margin off Pakistan. The co-operative programme had the main topic "Tectonic evolution and Fluid Transport in the Makran Accretionary Wedge (Pakistan)" and had considerably broadened the geo-scientific knowledge about Pakistan's EEZ off the Makran margin. During these cruises the Pak-German scientists investigated the Makran accretionary wedge off Pakistan in detail to search for submarine gas seeps, vents of fluids, gas hydrates, and the detailed sampling of "cold seep" sites within the Makran accretionary complex. Detailed sea floor sediment sampling (coring/grabbing), heat flow measurements, in-situ qualitative and quantitative gas and interstitial water sampling at cold seeps were also carried out.

The preliminary scientific results of the Pak-German cruise represented a substantial step forward for a better understanding of the long-time storage and migration mechanisms of natural gases present in enormous quantities in 'gas hydrate' in marine sediments offshore Pakistan. Though the gas hydrates were reported earlier by White (1982 and 1983) but their extent and widespread presence offshore Makran was confirmed by seismic methods employed during the Pak-German cruise onboard R/V Sonne SO-122 (Roeser et al., 1997). During the geological cruise of the Makran Margin (SO-130; 1998) when the solid hydrates were brought to the surface and put into hot water, the methane gas was released (von Rad, et al., 1998). The presence of numerous gas seeps at water depths of typically 300m and 600 to 800 m was established. The escaping gas, dissolved in the seawater migrates laterally and can be traced for distances of tens of Km from the seep region. By towing a camera-TV sled at a distance of 2m above the sea floor, various locations were detected, where gas is leaking from the sediments. These spots were made visible by white and black mats on the sea floor, formed by bacteria, which are fed by the gas flow emerging from the sediments. The geochemical analysis of the recovered sediments confirmed high gas concentrations. The seeps are apparently the result of gas hydrate melting processes, induced by uplift of marine sediments out of the pressure and temperature field, where gas hydrates can exist.

In essence, gas hydrates offshore Pakistan are slowly melting today in zones of shallow water depth under the influence of warm bottom waters while new gas hydrates are being formed ocean ward in deeper levels within the sediment.

A surprising result of this research is the confirmation that unlike in other geologically similar marine sediment accumulations around the Pacific and Atlantic Oceans, methane losses are largely confined to the shallow water regions. Outflow of gas, where the sediments of the continental slope meet the abyssal plain, is rather limited. This fact is tentatively attributed to the low permeability of the more than 600meter thick gas hydrates layers, which largely prevent the upward migration of fluids or gasses. One inactive 60 meter high mud volcano at about 300-meter water depth was discovered. Sediment samples taken from its centre cone proved that the former conduit is now completely frozen up by gas hydrates.

Later in October-November 2007, R/V METEOR Cruise M74/3 investigated fluid venting at the sea floor along the Makran subduction zone (Continental slope of Pakistan). The expedition was strongly related to the previous cruise of METEOR M74/2, during which geophysical investigations on fluid seepage were conducted in the same area. Both cruises were planned together as part of research area E of the DFG Research Center Ocean Margins at the University of Bremen (RCOM). Fluid and gas seepage (cold seeps) at the sea floor is of global importance and leads to a major material exchange between sediments of the ocean, the hydrosphere and/or the atmosphere. The cruise and the research programs were planned, coordinated and carried out by the Department of Earth Sciences and the MARUM Center for Marine Environmental Sciences of the University of Bremen. The scientists of National Institute of Oceanography of Pakistan were involved in the scientific analyses and interpretation of the data (Figure 23).

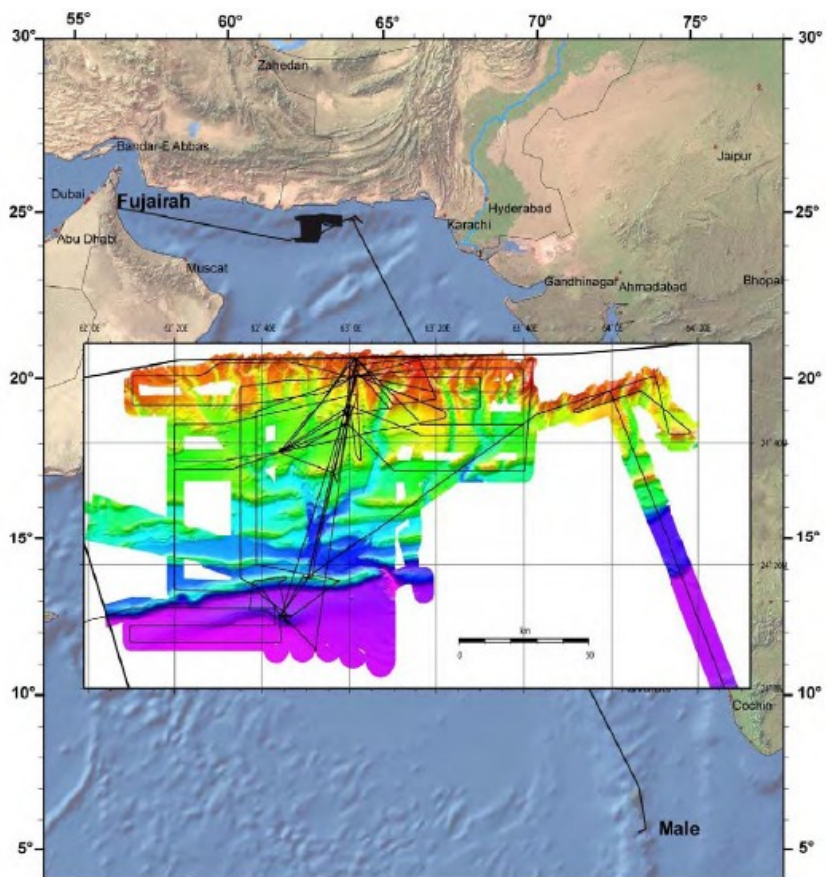

Figure23: Survey area of R/V Meteor Cruise M74/3, 30 October - 28 November, 2007. Cold Seeps of the Makran Subduction Zone,

CHAPTER – 8
R&D ACTIVITIES AND PROGRAMMES ON GAS HYDRATES IN THE REGION

In India Expedition NGHP-01 resulted from collaboration between the Directorate General of Hydrocarbons (DGH) and the United States Geological Survey (USGS). The DGH coordinates the National Gas Hydrate Programme (NGHP) of India. The USGS helped to develop and carry out this research programme under the direction of the Consortium for Scientific Methane Hydrate Investigations (CSMHI). Primary members of the CSMHI included Overseas Drilling Limited (ODL), a subsidiary of Transocean, Inc., and FUGRO McClelland Marine Geosciences. The platform for the drilling operation was the research drill ship JOIDES Resolution (JR), operated by ODL. Much of the drilling/coring equipment used was provided by the Integrated Ocean Drilling Programme (IODP) through a loan agreement with the National Science Foundation (NSF). Wireline pressure coring systems and supporting laboratories were provided by IODP/Texas A&M University (TAMU), FUGRO, U.S. Geological Survey, and HYACINTH/GEOTEK.

Expedition -02 and Expedition-03 of NGHP represented by DGH are also planned and would process in collaboration between DGH and USGS.

NIOT, India scientists developed a Remotely Operated Vehicle (ROV) in collaboration with EDBOE, Russia for imaging the seafloor, which hosts a number of sensors such as Methane, Oxygen, Conductivity, Temperature Sensors, water samplers and Multi beam Sonar and an Autonomous Coring System (ACS) with help of M/S Williams Inc, USA mainly for coring through the gas hydrates layers up to 100m below the sea floor.

R&D Activities and Programmes on Gas Hydrates in India

NGHP Expedition-01 has shown that conventional sand and fractured-clay reservoirs are the primary emerging economic targets for gas hydrate production in India. Because conventional marine exploration and production technologies favor the sand-dominated gas hydrate reservoirs, investigation of sand reservoirs will likely have a higher near-term priority in the NGHP programme. It is perceived that the NGHP effort will likely include future seismic studies, drilling, coring, and field production testing. It has been concluded that Site 10 represents a world class shale dominated fracture gas hydrate reservoir, worthy of further investigation.

From the laboratory analysis and the studies carried out, the following are concluded:

- Gas hydrates occur in grayish green fine sediments, gray medium sands and white volcanic ash as pore-filling hydrate. The visible massive gas hydrates are developed in black fine sediments, especially at Site NGHP 1-10B, 10C and 10D in K G area.

- The structures of the gas hydrates in the studied samples are all SI, with methane as the dominant guest.
- The occupancy of methane in large cage is almost complete, while it is variable in the small cage (0.75 to 0.99).
- The hydration number is 6.10 ± 0.15 for most of the hydrates in the samples studied.

This data is required for calculations of hydrate reserve and the gas entrapped in the Indian hydrate reservoirs. The measured thermal data of Indian gas hydrate samples will be very useful for designing of the gas recovery schemes and evaluation of the associated cost economics.

Wireline log data has already provided us with inputs on porosities and saturation of the gas hydrates in this region. Based on the above inputs and the petrophysical properties derived by logs recorded during the Expedition 01, NGRI Hyderabad is in the process of carrying out Areal extent and quantitative assessment of gas-hydrates in Krishna-Godavari offshore from large-offset MCS data, while Nio, Goa has taken up a project to carry out Qualitative estimates of the spatial extent of hydrate deposits using seismic attenuation studies, and modeling of BSR over the scattered gas hydrates zones for various source frequencies. Both these projects would be completed over a period of 2 years after which the Resource estimation calculation would enable us to estimate the amount of gas hydrate resources present in the KG area which has been identified as the focus area for carrying out further NGHP expeditions.

As per the Road Map, the commercial production of methane from gas hydrates is still a far fetched thought although NGHP has set itself a deadline of mid 2015 as the time to commence commercial production, the commercial production of methane from Indian Gas Hydrate resources has its own set of challenges, a few would perhaps be :

- Absence of representative deepwater gas hydrates field anywhere in the world
- Gas production rate (Gas in the production testing of Mallik well in Canada's permafrost area have yielded very low production rate and could not sustain more than 7 days of production using thermal and depressurization methods)
- Managing Water production rate (High amount of water is expected to be produced along with the dissociation of hydrates)
- Sand control since the hydrate reservoirs exist at very shallow depth below sea bed (200-400 mbsf) the sands here would not be consolidated due to absence of overburden pressure.

Expedition-02

NGHP Expedition 02 would aim at the identification of sites for carrying out pilot production testing. The expedition is planned in the mid of 2010 and would aim at identifying sites which would ideally have:

- Sand dominated gas hydrate occurrence
- Reasonably compacted sediments
- Occurrence of free gas below the gas hydrate stability zone

The identification of locations for the expedition which would be primarily an LWD operation is in progress. Various vessels like the Chikyu, JOIDES and other conventional drilling vessels are being shortlisted.
Gas hydrate exploration is a nascent science and various countries are carrying out R & D activities to develop dependable techniques for detection and quantification of gas hydrates in sediments. In view of the above Ministry of Earth Sciences (MoES) have started a mission mode mega programme for gas hydrate studies in India during 2004 and entrusted these jobs to three national laboratories: National Geophysical Research Institute (NGRI), Hyderabad, National Institute of Oceanography (NIO), Goa and National Institute of Ocean Technology (NIOT), Chennai. Monitoring and Programme coordination is being carried out by NIOT with the advice of MoES.(Fig.-24)

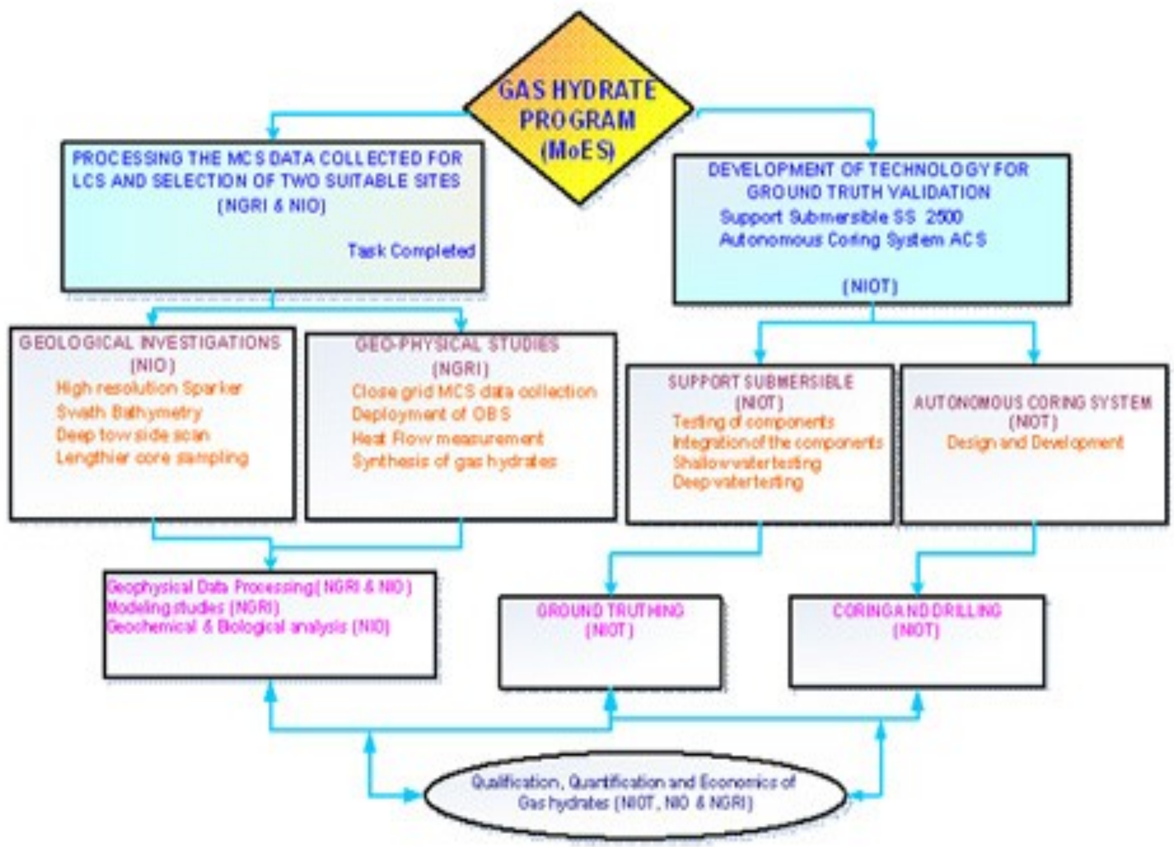

Figure24: Gas hydrate programme of MoES

Under this programme initially scientific studies will be carried out from already collected Multi Channel Seismic data to identify Bottom Simulating Reflector (BSR) for selecting two suitable blocks in the east coast of India. This will enable for detail scientific exploration survey and analysis for gas hydrate occurrence. From the detail geophysical, geological and microbial studies few suitable sites will be selected for ground truth validation by drilling. Technology developments for the exploration and ground truth validation have been divided into two parts. Developments of Work Class Remotely Operated Vehicle for fine tuning the selected sites with necessary gas hydrate sensors and samplers. Development of suitable autonomous coring system for sampling the gas hydrates. After completion of necessary infrastructure and exploration activity; pilot scale production, transportation and environmental monitoring techniques shall be taken up.

Ground truth validation of gas hydrates is a difficult task after completing the targeted exploration activity from ship based system and ROV. Gas hydrates occurs in deep waters in high pressure and low temperature condition and as per Indian temporal climatic conditions, gas hydrates are expected to be present below 100 m in the sea bed at around 1000 m water depth. In present scenario validating the occurrence of gas hydrates in ocean basins for detail scientific research is possible only with giant drilling ships like JOIDES operated by consortia of different countries. Schedule of ship timings and cost involved are big constraints for repeated ground truth validation of hydrate occurrence.

In view of the above Autonomous Coring System concept has been initiated by NIOT and the system is under development in joint collaboration with M/s Williamson & Associates, USA. Design concept is such that, it can sit on the sea bed of up to 3000 m water depth and it will drill and collect 100 m sediments in 3 meter sections. After collecting the sediment cores in the storage magazine, system will be taken back to the ship deck for sub sampling and further investigations. System is designed to operate in wire-line drilling technology

System is designed to interface with pressure core sampler and can be effectively used at the gas hydrate layers for sampling and sealing with pressure at in-situ condition. It has a sequence of starter barrel assembly followed by outer casing, outer barrel and inner barrel for sampling sequence continuously. Coring system is 5.7 m in height in leg retrieved position, 7.5 m in length and 2.7 m in breadth. Total weight of the system is 12 Ton in air and expected sediment sample for 100 m core could be 2 ton. The frame of the subsurface is fabricated from 6061 T6 aluminum structural shapes and protected with zinc sacrificial anodes. Three legs are connected with hydraulic cylinders for leveling the drilling system at the site.

Tool handling subsystem is made of number of actuators designed for specific functions in the drilling sequence for handling drilling tools. It removes drill rod from magazine and turns 90 degree to drill rotary position and moves to the centre position of the drilling mast below the rotary and same reversed after completion of drilling operation to take back to the magazine. Complete sequence of operation is controlled with proximity switches feedback to the control software from the subsurface unit to the deck during real time operating System. It has hydraulic thrusters for positioning in the sea bed; cameras, lights, sensors and sonar for monitoring. System detail design, fabrication, assembly and integration have been completed and expected its deep water sea trial by this year end.
With the development of challenging technological high-end tools, deliverables are expected from gas hydrate site in India by 2009 onwards.

Indo -Russian Gas Hydrate Centre (IRCGH) at NIOT

The Indo – Russian Science & Technology Centre for Gas Hydrate studies-IRCGHS was established at NIOT with the following objectives :

- Define the infrastructure need for carrying out necessary research and development in line with the envisaged major projects defined by MoES and ILTP.
- Identify skill requirement for carrying out the necessary activities.
- Identify suitable instruments and equipments for information collection carrying out the analysis pertaining to the major projects
- Create suitable storage systems for the collected samples.
- Create suitable facilities for integration and testing of GH technological hardware systems
- Define the methodology of working and interaction
- Create a centralized databank
- Facilitate carrying out of projects as identified and approved by MoES and ILTP

Identified Projects by NIOT

As the end objectives of the establishment of the Centre the following areas of the Gas Hydrate Science and Technology projects will be implemented by taking up bilateral collaborative projects between different Indian and Russian Institutes. Following are the areas identified for joint participation :

A) Geology of Gas Hydrate
B) Natural processors involved in Gas Hydrate.
C) Estimation and modeling of Gas Hydrate resources.
D) Physical, chemical, mechanical and other basic properties of Gas Hydrates.
E) Technology for exploration, recovery, purification and transportation of Gas from Gas Hydrate
F) Ecological aspects of Gas Hydrate processing.
G) Economics of Gas Hydrate exploitation
H) Joint research of Gas Hydrate in Lake Baikal and its application to Indian conditions
I) Design and Develop necessary instruments, equipments and observing devices for the above mentioned scientific and technical problems.

Under the Lake Baikal project NIOT scientists participated in the Summer and winter expeditions. Gas Hydrate cores were extracted and studies were carried out. ROV jointly developed NIOT & EDBOE Russia was modified to suit the needs of Gas hydrate exploration by augmenting the pay load with Methane, Oxygen, Conductivity, Temperature Sensors , water samplers and Multi beam Sonar.

In the other projects exchange visits have been facilitated and the suitable project proposals are being prepared for the implementation. Infrastructure has been developed at NIOT for the centre and for data warehousing. An Indo Russian Workshop on Gas Hydrate was conducted at NIOT in 2006.The scientific practices followed at NIO and NGRI are as per the international standards. The scientific problems are tackled from the multi disciplinary and multi parameter research to provide viable solutions. The results form the studies carried out at these institutions are published in peer reviewed national and international journals. This is a mandatory requirement of the scientists involved in the scientific research.

As such the researchers worldwide are carrying out research on gas hydrates independently. Similarly, in India also the research is carried out independently in specific fields and the involved organizations are coming together on common platforms organized by NGHP and Ministry of Earth Sciences (MoES). The Researchers in India keep abreast with the latest developments in the gas hydrate research worldwide through the published literature in the national and international publications, workshops, symposia and conferences.

The different agencies involved in gas hydrates research India are of two kinds. One of those organizations involved in scientific research and pursue their interest to publish the results in the scientific journals, which is a mandatory requirement for the scientists involved and the other organizations mainly from the industry who have the experience and data sets acquired for hydrocarbon exploration and allied facilities for processing and interpretation. The research organizations like NIO and NGRI have no or few geophysical data sets acquired for the gas hydrate or hydrocarbon exploration. However, in recent times these organizations have developed their capabilities in processing, developing new tools for the interpretation of seismic data sets. Under the umbrella of NGHP, few data sets are shared by the organizations in the hydrocarbon industry with the research organizations and academia.

The geophysical studies on the LWD and wireline data provide hydrate saturation and free gas below Gas Hydrate stability zone in KG and Mahanadi Basins (Dewangan et al., 2009). Identified and mapped shale diapirs and associated shallow features in KG offshore basin, which serve as a better constraint in understanding the genesis and occurrence of gas hydrate deposits in KG offshore basin. The inferred toe-thrust and shale diapiric zones are favorable locales for gas hydrate accumulation (Dewangan et al., 2010). Apart from the geology and geophysics, the gas hydrate research emphasizes the involvement of other fields of research such as geochemistry and microbiology. These studies are being carried out at NIO. An NIO publication, Mazumdar et al., (2009) gives comprehensive details of paleo cold seeps in KG Basin. The multidisciplinary investigations in the Krishna–Godavari Basin offshore suggest that the physicochemical conditions prevailing in the study area are highly conducive to methane generation and gas hydrate occurrence (Ramana et al., 2009).

R&D Facilities

The Institutes and Organisations actively involved in the Gas hydrate Research along with the facilities available are listed below:

Keshav Dev Malaviya Institute of Petroleum Exploration (KDMIPE), ONGC, Dehradun

KDMIPE is adequately equipped with technologies (both in terms of Lab studies and Processing and Interpretation of Geochemical, Geological and Geophysical data) in the context of G&G R&D for Gas Hydrate exploration. To support Lab studies, state of the art equipments which are operational in under mentioned Labs.

i. **Geology Group**

Sedimentology Lab, Paleontology Lab, Geochronology Lab, Palynology Lab, Fission Track Lab.

ii. **Geochemistry Group**

Microbiology Lab, Hydrochemistry Lab, Stable Isotope Lab, Source Rock Lab.

iii. **Petrophysics Lab**

In addition to this KDMIPE has state of art Processing and Interpretation Software for G&G R&D which can be effectively employed for Gas Hydrate R&D. Further, KDMIPE is in the process of acquiring state-of-the-art PVT equipment which will facilitate phase behavior study of Gas Hydrate. An ongoing project at IIT Kharagpur is being monitored by KDMIPE which is aimed at developing technology for exploitation of GH form marine sediments.

Institute of Engineering and Ocean Technology (IEOT) ONGC Panvel

IEOT has developed technologies related to gas hydrates over the last ten years and was very actively involved in the planning, execution and monitoring of NGHP Expedition 01, 2006. IEOT has following expertise in the area of gas hydrates:

i. Gas hydrate prediction and characterization
ii. Measurement of physical and thermal properties of gas hydrates and hydrate bearing sediments
iii. Structural characterization of gas hydrates in cores
iv. Laboratory evaluation of thermodynamic and kinetic properties of gas hydrates and hydrates in sediments
v. IR Imaging of cores for hydrate identification and quantification
vi. CT Scan of hydrate bearing cores for hydrate assessment in sediments
vii. Geo mechanical properties of hydrate bearing sediments
viii. Technologies for gas production from hydrate bearing sediments using thermal and depressurization methods
ix. Molecular substitution in hydrates using CO_2 and other gases for methane recovery
x. Preservation and archival of hydrate/non hydrate cores
xi. Identification of specialized tools and technologies for gas hydrate coring/drilling/onboard studies
xii. Planning, execution and monitoring of dedicated coring/drilling/logging/onboard studies for gas hydrate expedition in Indian offshore

National Institute of Oceanography (NIO) Goa

NIO scientists developed expertise in acquisition, analyses and interpretation of the geophysical, sedimentological, geochemical and microbiological data and samples for delineation of proxies related to gas hydrate exploration in marine sediments. The following equipment are available for the acquisition of underway geological, geophysical and microbiological data and samples.

Geophysical

Field equipment

i. Geo-Acoustics Deep tow digital side scan sonar & chirp sonar
ii. G876 Geometrics Proton precession Magnetometer

iii. Sub-bottom profiler
iv. Geo-Acoustics Chirp sonar
v. Geo-Resources High resolution sparker system
vi. MAC 9.1 system with Geo-Pro 4 software

Laboratory facilities

i. IBM workstation
ii. Software for modeling and inversion of seismic data (NIO)
iii. Facilities for measurement of physical properties (NIO)
iv. Laboratory for measuring Paleomagnetic and environmental magnetic measurements (NIO)
v. ProMAX 2D seismic processing software (NIO)
vi. Geographix -SeisVision seismic interpretation software(NIO)
vii. Sun workstations (NIO)
viii. Seismic Unix Software (Public Domain)
ix. GMT Software (Public Domain) and GIS
x. OpendTect 2D/3D interpretation software (Public Domain)
xi. Sun SPARC Ultra 60 workstation and GMT software
xii. Windows / Linux PCs and MS Office
xiii. HP 2550 C Plus Plotter
xiv. OCE TDS 600 Plotter System

Geological / geochemical

Field equipment

i. Gravity Corer
ii. Spade Corer with reversible thermometer and Niskin water sampler
iii. Sea Bird CTD unit with rosette and Ocean -Test Niskin water Bottles

Laboratory facilities

i. Pore-water extraction system using hydraulic press
ii. Analytical facilities for measurement of pore water/gas composition
iii. Experimental setup for solid phase sulfur and iron speciation
iv. Facility for sample preservation (Reefer Container)
v. Ion and gas Chromatographs
vi. Gas Generators
vii. Depth Finding Pingers
viii. Water purification System
ix. Planetary Ball mill for powdering the samples with four bowl fasteners (4x225ml) capacity.
x. GO-FLO Non metallic water sampling bottles with reversing thermometer assemblies
xi. IRMS (NIO)

xii. GCMS (NIO)
xiii. Refrigerated Centrifuge
xiv. Water and sediment degassing systems
xv. Cryocans
xvi. Thermal Graphic Recorders
xvii. Freeze dryer
xviii. Corbon coulometer
xix. Sulfur coulometer
xx. Nickhon Stereozoom microscope
xxi. Leica Stereozoom microscope
xxii. Cryo Centrifuge
xxiii. Micro balance
xxiv. High pressure cell being built (in progress)
xxv. Sediment Degassing Unit -GCA (German make)
xxvi. Water Degassing Unit -GCA (German make)
xxvii. CE-8000 Top Gas Chromatograph
xxviii. Biofuge Stratos Heraeus Centrifuge
xxix. Ion Chromatograph
xxx. Laser Grain Sizer
xxxi. ICPAAS, Perkin Elmer Optima 2000
xxxii. Atomic Absorption Spectrophotometer (AAS)
xxxiii. Scanning Electron Microscope
xxxiv. X-Ray Difractometer
xxxv. Autoclave, laminar flow, centrifuge refrigerator, microscopes.
xxxvi. Laboratory Analytical equipment

<u>Microbiological (Laboratory)</u>

i. Laminar air flow
ii. Bright field and Epifluorescence microscope
iii. Nano drop
iv. Autoclave
v. Electronic water bath with shaker
vi. Cooling/refrigerated centrifuge
vii. Transilluminometer
viii. Gel DOC system
ix. BOD incubator
x. PCR machine (for amplification of DNA)
xi. -80°C deep freezer
xii. -20°C deep freezer
xiii. Refrigerated incubator (4°C)

National Geophysical Research Institution (NGRI) Hyderabad

NGRI undertakes basic understanding on gas hydrate formation, kinetics, stability and dissociation under laboratory conditions. The following technologies are available here

a. Basic Characterisation methods:

i. Micro-Raman having chemical mapping (x,y,z) and remote probing facility
ii. FTIR spectroscopy for gas hydrate characterisation
iii. Low temperature DSC to probe dissociation kinetics of gas hydrates

b. Indigenous Facilities developed at NGRI:

i. Developed bulk (~ 50 ml) pressure cells, bomb type, to synthesised gas hydrates in laboratory environment. We have cells with acrylic and SS materials and are using them to gas hydrates. We are using SS cell, with typical working pressure of 8MPa, to synthesise methane hydrates
ii. Developed small volume (~ 1 ml) SS cells, having working pressure of 10 MPa, with optical (sapphire or quartz) windows. We synthesise gas hydrates in small quantities and use them for in-situ characterisation
iii. Developed some prototype models to measure thermal conductivity in gas hydrates
iv. Working model cells to probe molecular exchange (CH_4 – CO_2) process in sediments saturated with gas hydrates

National Institute of Ocean Technology (NIOT) Chennai

NIOT scientists developed a Remotely Operated Vehicle (ROV) in collaboration with EDBOE, Russia for imaging the seafloor, which hosts a number of sensors such as Methane, Oxygen, Conductivity, Temperature Sensors, water samplers and Multi beam Sonar and an Autonomous Coring System (ACS) with help of M/S Williams Inc, USA mainly for coring through the gas hydrates layers up to 100m below the sea floor.

Overview of programs on gas hydrate in India (National Gas Hydrate Programme, NGHP)

Expeditions

The entire NGHP exercise is split into phase or Expeditions. The Indian Expeditions / Phases would be primarily three in number. The Expedition 01 which was to verify the physical presence of gas hydrates in the Indian Deep waters has been completed and the details of the same are discussed later in the paper. The Expedition-02 would largely be an LWD operation primarily focused to identify locations / sites for the pilot production testing and finally subject to the success of the Expedition-02, the Expedition-03 would be the Pilot production test itself. This may be at one or more than one sites depending upon the results obtained. NGHP scientists work in close association with the global counterparts.

International Collaborations

The challenges in Gas Hydrates R&D can only be overcome by sustained commitment of our scientists and establishment of a proper gas hydrate R&D center in India. The global gas hydrate communities of scientists and researchers have to work in tandem with each other. DGH on behalf of the NGHP has signed Memoranda of Understanding in the field of Gas Hydrates with Japan Oil, Gas, Metal Corporation JOGMEC, the US Department of Energy (USDOE) the US Geological Survey (USGS). and the US MMS. DGH has been closely associated with the USGS, USDOE and JOGMEC scientists which has helped the NGHP scientists to gain a lot in terms of knowledge, understanding and experience. The NGHP Team is also collaborating with the SUGAR Project of Germany for the CO_2 substitution for the production of methane from hydrates and have signed an MOU with IFM GEOMAR.

Expedition Overview

The drill ship JOIDES Resolution (JR) was mobilized in Mumbai, India in preparation for the planned programme of gas hydrate research commissioned by the NGHP. Initial planning called for ten sites to be occupied and twenty seven holes were scheduled for drilling. Of these, eight sites were scheduled for LWD/MWD drilling and two sites were scheduled for coring and wireline logging only. In support of the drilling operation there was a mobilization port call in Mumbai, India and four port calls in Chennai, India. The last port call was for demobilization and offloading of all core samples to stay in India. In addition, there was one scientific crew change made on-site using three helicopter transfers flying out of the heliport at Rajahmundry, India.

Expedition NGHP-01 began at 0600 hr 28 April 2006 with the arrival of the drill ship in Mumbai, India, and ended 113.5 days later in Chennai, India with the last line away North Quay at 1912 hr 19 August 2006. Ultimately twenty one sites were occupied with five sites re-occupied at least once. Thirty nine holes were drilled. Of these, twelve holes were LWD/MWD drilled, twenty two holes were cored, and four holes were drilled as dedicated wireline logging holes. Thirteen holes were wireline logged and temperature gradients were established in eleven holes.

During Expedition NGHP-01 there were 494 cores cut with 2847.01 meters of core recovered reflecting 78.7% of the interval cored. The APC coring system recovered 125 cores with 1116.74 m of core recovery or 101.6% of the formation penetrated. The XCB coring system recovered 272 cores with 1661.79 meters of core recovery or 68.6% of the formation penetrated. In addition, 97 pressure coring attempts were made with 49 recovering core under pressure. Three different pressure coring systems were used and the criteria for success, was defined as “measurable core” recovered under “measurable” pressure. Actual recoveries and pressures can be found in the referenced data sheets. The number of cores recovered under pressure versus the number attempted reflected an overall success rate of 50.5%. Pressure coring accounted for the total recovery of 68.48 m of core; with 42.44 m recovered “under pressure”. The Pressure Core Sampler (PCS) was deployed 42 times recovering 28.99 m of core or 69.9% of the formation cored. Twenty PCS deployments recovered core under pressure for a 47.6% success rate. The Fugro Pressure Corer (FPC) was deployed 31 times recovering 24.10 m of core or 77.7% of the formation cored. Twelve FPC deployments recovered core under pressure for a 38.7% success rate. The HYACE Rotary Corer (HRC) was deployed 24 times recovering 15.39 m of core or 64.1% of the formation cored. Seventeen HRC deployments recovered core under pressure for a 70.8% success rate. Even more notable is the fact that this tool (HRC) was successful on the last 9 deployments and was successful on 13 of the last 15 deployments. The HRC should definitely be considered an operational pressure coring tool for the JR platform. A total of 76 in situ temperature measurements were also attempted using three different wireline temperature tools. The APC/T was deployed 8 times, the APC/3 24 times, and the DVTP 44 times. Using this data, formation temperature gradients were established for each site where wireline coring took place.

For organizational purposes, Expedition NGHP-01 was divided into five operational segments. The first segment, or leg, consisted of a single hole cored and wireline logged in the Konkan-Kerala (KK) Basin off the West coast of India. The second leg was a transect comprised solely of LWD/MWD holes. During leg 2, twelve holes at ten sites were drilled in the Krishna-Godavari (KG) Basin off the west coast of India. Leg 3A consisted of six cored holes and two dedicated wireline logging holes at four sites located in the KG Basin. Two sites were re-occupied sites that were previously LWD/MWD drilled on Leg 2 and two sites were new. Leg 3B consisted of seven cored holes plus one hole that was abandoned due to hole conditions before any coring or logging could be initiated. Five sites were occupied including two that were re-occupied LWD/MWD sites and three that were new additions. All sites were located in the KG Basin. The expedition was completed on Leg 4 with the drilling of two holes (one dedicated to wireline logging) at one site located in the Andaman Sea, three holes at two sites located in the Mahanadi (MN) Basin off North Eastern India, and two holes back in the Krishna-Godavari Basin off the South Eastern coast of India.

Expedition operations included Logging-While-Drilling/Measurement-While-Drilling (LWD/MWD); standard APC/XCB coring; pressure coring using the IODP/TAMU Pressure Core Sampler (PCS), the Fugro Pressure Corer (FPC), and the HYACINTH Rotary Corer (HRC); temperature measurements, wireline logging including the Triple Combo, FMS-Sonic, and VSP tool strings, and detailed scientific laboratory analysis of the recovered core samples both aboard ship and ashore.

Other Studies

Globally gas hydrate is, in general, predicted by identifying BSR on seismic section. However, gas hydrates are found in areas where no BSRs were observed, and drilling at many locations with BSR couldn't recover any gas hydrates. It demands for studying some attributes for qualifying BSR or identifying gas hydrates. The BSR like acoustic feature may result from temperature-controlled diagenetic effects. During Deep Sea Drilling Project (DSDP) Leg 19, seismic reflections akin to BSR in some Bering Sea sediments draped on the Umnak Plateau were observed (Kvenvolden, 1987 and references therein). However, drilling at one of these sites (site 185), indicated presence of only methane in sediment but gave no evidence of the existence of gas hydrates. In view of this, Scholl and Creager (1973, cited by Kvenvolden, 1987) attributed those BSR like seismic reflections to a lithologic transition from hemipelagic diatom ooze to indurated claystone. Later, Hein et al. (1978, cited by Kvenvolden, 1987) confirmed that opal-A is transformed to opal-CT at the depth of the BSR in the Bering Sea sediments. Thus, there are two types of BSRs, one indicating the base of the gas hydrate zone and the other signaling a diagenetic boundary (Marlow et al., 1981, cited by Kvenvolden, 1987). Since the BSRs represent acoustic velocity contrast in the sediment, it is not necessary that all BSRs reflect the existence of hydrates, similarly a BSR may not always be discernible when a hydrate is present (Haq, 1996). This paradox in the seismic data prompts the gas hydrate research to encompass other proxies that are related to the generation, migration and preservation in the favorable geological environment. These mainly include geochemical, geological and biological proxies.

To qualify whether an identifiable BSR is related to gas hydrates, we have computed seismic attributes such as the blanking, reflection strength, instantaneous frequency, and the attenuation. Presence of gas hydrates causes amplitude 'blanking' due to cementation. Underlying free-gas saturated sediments exhibit high reflection strength due to variation in gas saturation. Free-gas is also indicated by 'shadows' in the instantaneous frequency plot. Seismic blanking over the BSR indicates gas hydrates whereas the high reflectivity (Figure.25) and low frequency 'shadows' over a large time window below the BSR show a large thickness of alternate gas-rich and gas-poor strata in the Makran acrretionary prism (Ojha and Sain, 2009, Episodes). Therefore, the reflection-strength, instantaneous-frequency and 'blanking' etc can be used for the exploration of gas hydrates and free-gas. Computation of these attributes has qualified that the deep BSR in Andaman region is related to gas hydrates (Satyavani et al., 2008, Mar. Geophys. Res.).

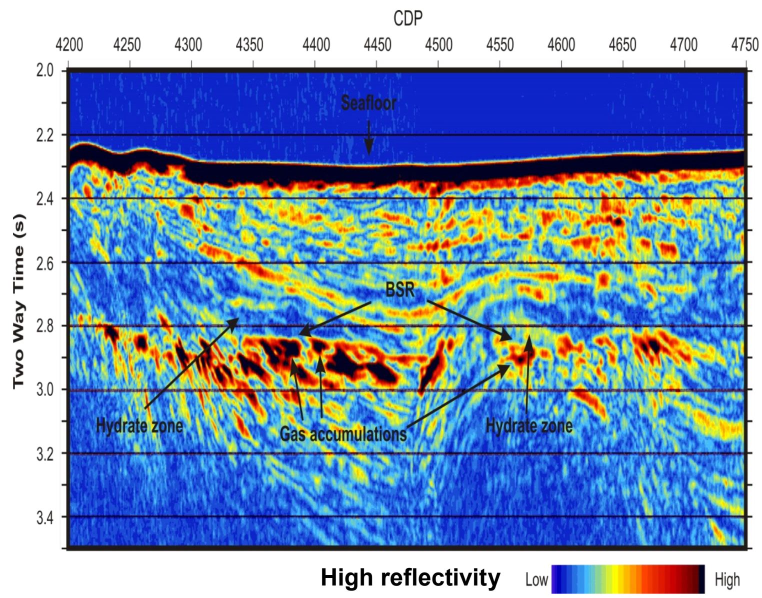

Fig.25: Seismic attributes implying gas hydrates and free-gas across the BSR along a seismic line in the Makran accretionary prism (Ojha and Sain, 2009, Episodes).

Presence of gas hydrates decreases the attenuation (Q-1) that again depends on nature of distribution. Thus, estimating Q provides a useful input for both detection and quantification of gas-hydrates. We have proposed a simple technique for deriving interval Qs based on the logarithm of spectral ratio, and estimated these for three sedimentary layers bounded by seafloor, BSR, one reflector above (reflect-1) and another reflector (Reflect-2) below the BSR at three locations with moderate (4286), strong (4372) and no BSR (4524) along a seismic line in the Makran offshore (Sain and Singh, 2010, Mar. & Petrol. Geol., accepted). The interval Qs for hydrate-bearing sediments above the BSR are estimated as 191±11, 223±12, and 117±5, whereas interval Qs for underlying gas-bearing sediments are calculated as 112±7, 107±8 and 124±11 at moderate, strong and no BSR locations, respectively (Figure.26). The large variation in Q at strong BSR implies that the Q can be used to ascertain whether the observed BSR is due to gas-hydrates, and to identify gas-hydrates where detection of BSR is rather doubtful. Based on estimation of Q in the western continental margin of Indian (WCMI), Sain et al. (2009) is of the opinion that gas hydrates are also prospective in the WCMI.

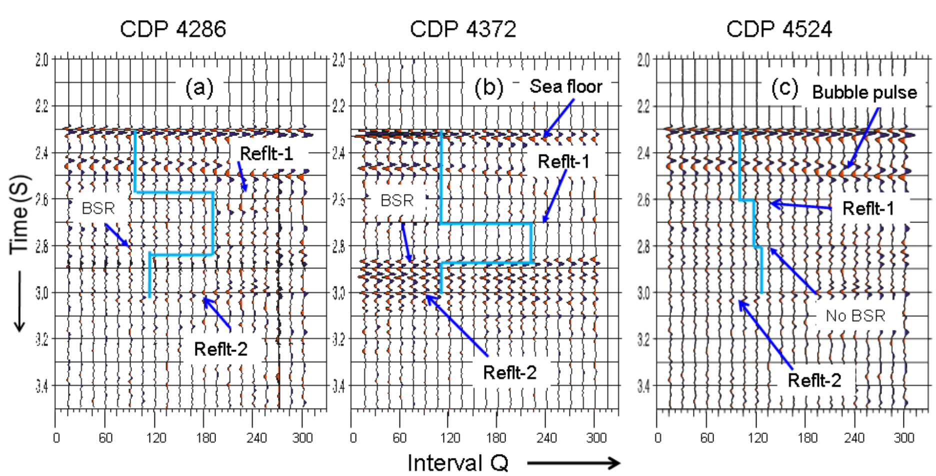

Fig.26: Field seismic gathers at CDPs 4286 (moderate), 4372 (strong), and 4524 (no-BSR), respectively, each superimposed with estimated interval Qs (Sain and Singh, 2010, Mar. & Petrol. Geol., accepted).

For quantifying gas hydrates and free- gas across a BSR, we have used traveltime inversion and amplitude modeling followed by rock physics modeling (Ojha and Sain 2008; Sain and Ojha, 2008). We have proposed a simple approach for estimating saturations of gas hydrates and free gas based on measurements of seismic reflection amplitudes versus offsets from a bottom simulating reflector (BSR) coupled with rock physics modeling (Ojha, Sain and Minshull, 2010, Geophysics). The application of this method to Multi-channel seismic (MCS) data along a seismic line in the Arabian Sea reveals lateral variations of gas hydrates between 4.5±1.1% at CDP 4362 to 15±1.4% at CDP 4412, and free gas saturations <4.0±0.2% respectively (Figure 27).

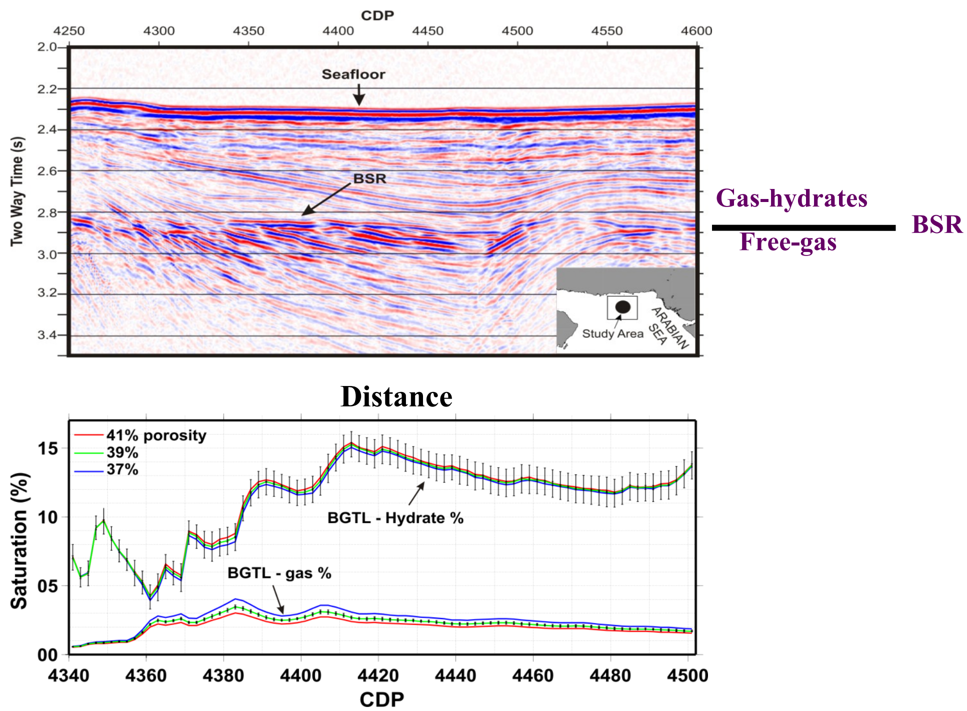

Figure27: BSR on seismic section (top panel) and lateral variation of gas hydrates and free-gas at BSR (bottom panel), based on AVO A-B crossplot coupled with a rock physics modeling in the Makran accretionary prism, (Ojha, Sain and Minshull, 2010, Geophysics).

The coring and drilling by NGHP has established gas-hydrates in fractured shale in the Krishna-Godavari (KG) basin. The gas hydrate morphology varies from complex vein structures (grain-displacing) to invisible pore-filling. The existing rock physics modeling, which generally assumes pore-filling morphology, may mislead the estimation of gas-hydrates in fractured fine grained sediments. We estimated the saturation of gas-hydrates, for the first time, by employing the sophisticated effective medium theory (EMT) to the sonic velocities considering the combination of grain-displacing and pore-filling morphology (Ghosh, Sain and Ojha, JGR, 2010). The average saturation of gas-hydrates is estimated as 33-41% of total porosity between 60 to 140 meters below the sea floor (Figure.28). Application of EMT has been demonstrated in different geological environments (Sain et al., 2010; Ghosh et al., 2010).

There are three types of gas hydrate accumulations 1) thermogenic, 2) bacterial, or 3) mixed gases are rapidly transported from the subsurface petroleum systems to the gas hydrate stability zone along faults, mud volcanoes, and other structures (e.g. northwestern Gulf of Mexico, Hydrate Ridge, and Haakon Mosby mud volcano). The economic potential of offshore gas hydrate accumulations and provinces is assessed qualitatively based on consideration of geological, technological, and economic factors. These accumulations are generally characterized by high gas hydrate concentration in sediment, high resource density, high recovery factors, as well as low development and production costs. It is likely that structural accumulations provide marginal or economic gas hydrate reserves if they represent significant volumes of hydrate-bound gas. Stratigraphic accumulations occur in relatively permeable sediments and form largely from bacterial methane generated in situ or physics modeling in the Makran accretionary prism, shown in right-bottom corner of top panel (Ojha, Sain and Minshull, 2010, Geophysics).

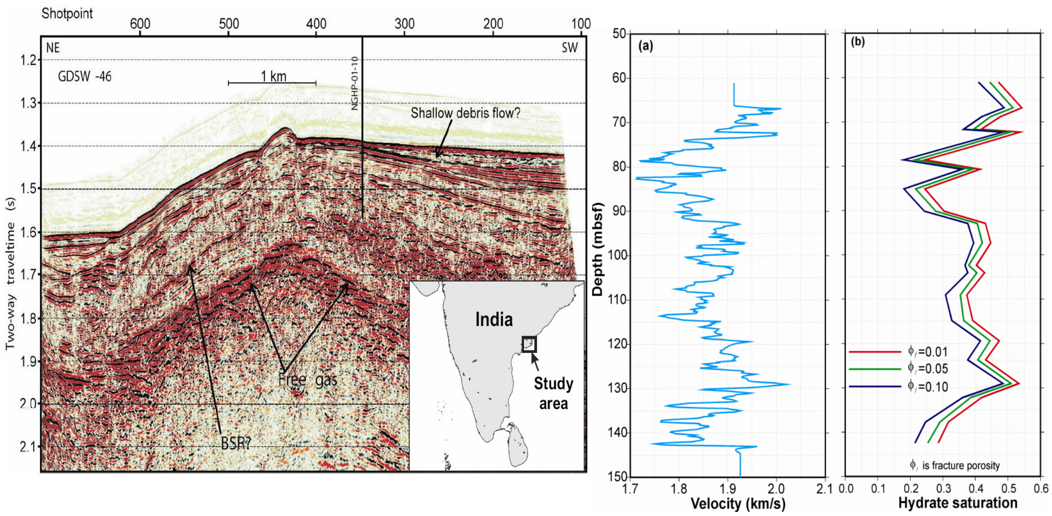

Figure28: BSR and gas hydrates in 80 m thick fractured shale in KG basin. (a) Sonic velocity and (b) gas hydrates saturation for different volume fractions of fracture for combined grain-displacing and pore-filling morphology (Ghosh, Sain and Ojha, 2010, JGR).

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India is the only SAARC country that took part in the five nation research programme the “Mallik 2002 Gas Hydrate Production Research Well Programme” in Canada. The project was undertaken as a partnership among organizations JNOC, GSC, USGS, GFZ, USDOE, GAIL and ONGC; the International Continental Drilling Programme (ICDP); and the Mackenzie Delta exploration joint-venture of BP Canada Energy Company, Chevron Canada Resources and Burlington Resources Canada. The Japan Petroleum Exploration Company Ltd. (Japex) coordinated the field operations for the project and the Geological Survey of Canada coordinated the science programme. In all more than one hundred engineers and scientists from more than six countries worked to bring the results to the international gas hydrate research community.(http://www.gfz-potsdam.de, http://www.mh21japan.gr.jp, http://energy.usgs.gov).

India, like Japan, has also initiated a very ambitious national gas hydrate research programme. In March 1997, the government of India announced new exploration licensing policies, which included the release of several deep water lease blocks along the east coast of India between Madras and Calcutta. Recently acquired seismic data have revealed possible evidence of widespread gas hydrate occurrences throughout the proposed lease blocks. Also announced was a large gas hydrate prospect in the Andaman Sea, between India and Myanmar, which is estimated to contain as much as 212 trillion cubic feet (TCF) of gas. The government of India has indicated that gas hydrates are of "utmost importance to meet their growing domestic energy needs".

R&D Activities and Programmes on Gas hydrates in Pakistan

Makran comprises the southern part of Pakistan and Iran between Sonmiani Bay near Karachi and the Straits of Hormuz. It is a great festoon of folded and faulted Tertiary sediments extending 800 km from the Las Bela axial fold belt on the east to the Oman Line on the west. Makran Coast is generally acknowledged as a subduction zone where the Indian Ocean plate moves northward under continental crust. The geologic history deduced from facies and structures is complex (Harms et al., 1984). Coastal Makran and the area to the north is an accretionary wedge of deformed sediments ranging in age from perhaps Late Cretaceous to Recent, piled up at an oceanic subduction margin. The structure and depositional setting has been compared to "a typical arc model" composed of upper-slope deposits followed by lower-slope and trench deposits, progressively deformed by continuing subduction (Farhoudi and Karig, 1977).

Pakistan has yet to embark upon the gas hydrate programme, however, scientists of Hydrocarbon Development Institute of Pakistan and National Institute of Oceanography have participated in Pak-German Oceanographic cruises jointly under taken by Pakistan and Germany in 1993 and 1997 onboard German Research Vessel R/V Sonne (SO-90, SO-122 and SO-130). During these cruises gas seeps off Makran Coast were surveyed and sampled. Later, NIO scientists along with BGR scientists visited the Malan Island and series of Mud Volcanoes along the Makran Coast (von Rad, et al., 2000). Recently, R/V Meteor visited Pakistan offshore area in 2007 and Pak-German scientists extended the research previously done on Makran gas seeps in offshore areas. Details of these programmes are described in Chapter 7. The National Institute of Oceanography is presently preparing a project proposal to assess the geo-resource potential, including gas hydrates, in the Pakistan maritime area.

Overview of Programme on Gas Hydrate in Pakistan

Two major locations have been classified as gas hydrate occurrences along the margins of the Arabian Sea (Kvenvolden and Lorenson, 2001), as inferred from the presence of BSRs in the shallow subsurface. These two provinces are located on the Indian Continental Slope (Veerayya et al., 1998; Rastogi et al., 1999; Rao et al., 2001) and in the Makran Accretionary Prism (White, 1977; Minshull and White, 1989; Grevemeyer et al., 2000; Kaul et al., 2000; Von Rad et al., 2000; Sain et al., 2000). Recently, Calvès et al., 2010 reported two sectors in the northern Arabian Sea where bottom-simulating reflectors (BSR) and potential gas hydrates are recognized by seismic reflection profiles (Figure 29). In Sector 1 the seafloor dips to the south with water depths ranging from 1040 to

1325 m, whereas in Sector 2 the seafloor slopes to the southwest from 1587 to 2086 m. In the two sectors, hydrate is predicted to be stable in sediment from 116 to 625 m below seafloor. Sector 1 is the northernmost observed BSR along the margin before the BSRs in the Makran Accretionary Prism observed further west (e.g., White, 1977; Von Rad et al., 2000). The BSRs observed adjacent to the present-day Indus Canyon (Sector 2) are comparable setting to the BSR observed by Veerayya et al. (1998) in the Indian deep-water area (Calves et al., 2010).

The range of water depths at which BSRs occur in the Makran Accretionary Prism is 500-3000 m (Kaul et al., 2000), while the estimated maximum depth of BSRs below the seafloor is 500-800 m (Von Rad et al., 2000; Grevemeyer et al., 2000). Along the Indian Margin, the occurrence of BSRs or gas-charged amplitude anomalies is confined to water depths ranging from 500 to 3000 m, and depths below the seafloor up to 450 m (Rao et al., 2002; Shankar et al., 2004, 2006). The source of methane and gases at these locations is thought to be related to deep thermogenic gas formation.

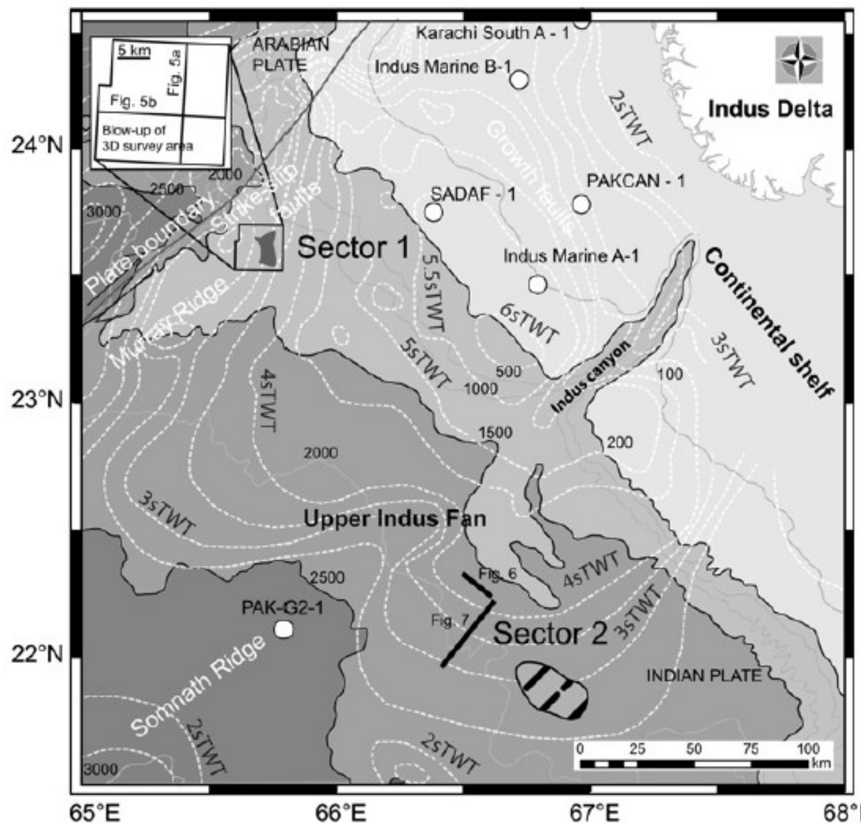

Figure29: Location map of Sector 1 & 2 as referred by Calves et al., 2010.

Programmes on Gas Hydrates in Bangladesh

Until now, there has not been any research and development activity on exploration and development of gas hydrates.

Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR), Hannover, Germany conducted some research surveys in the deeper part of the Bay of Bengal, in three different campaigns in collaboration with the Geological Survey of Bangladesh (GSB) using their Research Vessel 'RV Sonne'. It was learnt that during the last survey conducted in 2006, different geophysical techniques including 2-D seismic survey were used. However, when contacted, GSB was able only to show the acquisition reports and it was found that GSB does not have any interpretation report of any of those surveys conducted in different times by BGR.

During 2006 and 2007 significant volume of high resolution seismic data were acquired by Marion Dufresne from offshore Myanmar and Bangladesh covering north-eastern Bay of Bengal. The author viewed the seismic data acquired in Bangladesh offshore during 2007 and also went through the publication by Maurin and Rangin (2009), "Impact of the 900E Ridge at the Indo-Burmese Subduction Zone Imaged from Deep Seismic Reflection Data" based on the acquired data. "Two sets of deep penetration seismic reflection profiles were acquired in the north-eastern Bay of Bengal, in 2006 and 2007 during the MD154 and the Bengal 3 cruises conducted by GENAVIR (Figure30). The 2006 survey recorded up to 2400 km of seismic data along the Myanmar coast, with a 4.5 km long streamer and 50m spaced shot-points. Data were recorded up to 15s TWT. The source was a 2600 in. 3 air gun array. This seismic acquisition was operated by GENAVIR on board Marion Dufresne (IFREMER, MD154). The 2007 survey has recorded up to 3500 km of seismic reflection data, offshore Bangladesh, with a 10 km long streamer and 50 m spaced shot-points. The source was a 6180 in.3 air gun array (50 guns ranging from 20 to250 in.3). The source gun array was set at 8m depth whereas the 10 km long streamer was set at about 9–12 m depth. Data were recorded up to 20s with a low frequency processing in order to image the deep structure of the crust." (Maurin and Rangin, 2009).

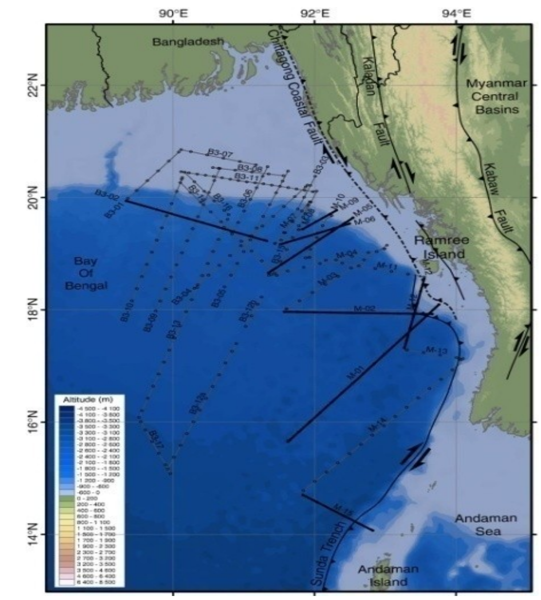

Figure 30: Map Showing Some Seismic Lines Shot in 2006-07 (Maurin & Rangin, 2009)

The above-mentioned survey was aimed at studying the nature and structure of the Bengal Basin. The authors also recognize that due to lack of sufficient seismic data the Bengal Basin was so far very poorly understood. However, though the study does not make any mention of presence of gas hydrate signatures like BSRs or Blanking in the seismic data of offshore Bay of Bengal acquired during the campaign, it is worth reviewing the available seismic sections for the purpose of this presentation. The only section presented in the paper B3-02 running in almost north-south direction, is in along the continental slope (Fig-31), where, because of the continuous sedimentation process ongoing there, environment for formation of gas hydrates does not exist.

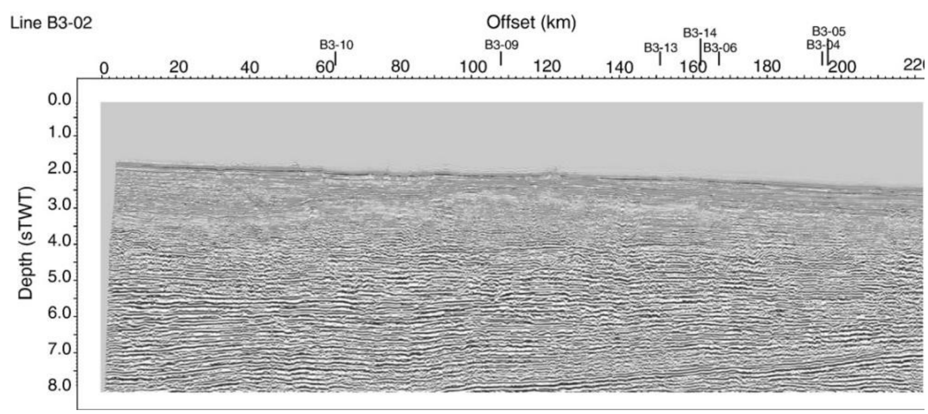

Figure 31: Seismic Section of Line B3-02 (Maurin&Rangin, 2009)

Programmes on Gas Hydrate in Sri Lanka

The exploration of deep water regions with hydrate potential for hydrocarbon resources is new in Sri Lanka. In 2001 and 2005 some five thousand kilometers of 2D seismic data were collected in the Mannar Basin (Figure 6) with most of the seismic lines extending to deep water area. In addition 700 km of seismic data were collected to the south of the island. However no BSR was observed in any of the data, perhaps more purpose oriented processing of the data may be needed. The first step taken by Sri Lanka on gas hydrate studies is participation in this SAARC initiated regional study.

CHAPTER – 9
TECHNOLOGY TRANSFER AND PROMOTION OF R & D ACTIVITIES IN THE REGION

The commercial production of methane from gas hydrates is still a far-fetched thought globally. Currently NGHP is carrying out Delineation & Resource estimation studies for the Gas hydrates discovered in the Krishna Godavari & Mahanadi areas. When talking of commercial exploitation of methane from Hydrates the following have to be kept in mind:

No representative deepwater gas hydrates field exists anywhere in the world.

Gas production rate in the production testing of Mallik well in Canada's permafrost area have yielded very low production rate and could not sustain more than 7 days of production using thermal and depressurization methods. Following are some of the challenges :

- Managing Water production rate
- Sand control since the hydrate reservoirs exist at very shallow depth below sea bed (200-400 mbsf) the sands here would not be consolidated due to absence of overburden
- Reservoir subsidence

India is among a select league of nations to have embarked upon the establishment of commerciality in the area of exploration of Methane from Methane hydrates. It is ranked third only after USA & Japan as regards the progress made in this direction The National Gas Hydrates Programme (NGHP) under the Ministry of Petroleum & Natural Gas is Steered by the Secretary Petroleum himself & technically guided by the Director General, Directorate General of Hydrocarbons.

The NGHP Expedition-01 conducted in 2006 proved the physical presence of the methane hydrates, but could not bring out any sand dominated area within the gas hydrate stability zone from which the exploration of methane becomes comparatively easier. Most of the hydrates encountered during the expedition were in clay, silty clay & volcanic ash.

The Expedition-02 and 03 which are planned under the Indian NGHP, for the exploration of Gas hydrates in Sand prone areas and the pilot production are being done through collaboration with the Global Gas hydrate community and gives it an advantage in being abreast with the latest technologies and developments in the area of Gas hydrate research.

India therefore, can offer technical assistance to the SAARC countries for the exploration of Gas hydrates in their maritime boundaries.

The regional countries like India, China and Japan are actively pursuing R&D activities with respect to the gas hydrate programme. It would be a good starting point to assess the need of the country and launch professional and institutional capacity building programme by organizing training programmes in collaboration with regional and international experts as well as by sending relevant marine geologists, marine geophysicists to the regional countries for acquiring latest state-of-the-art technology in the field of gas hydrate exploration and exploitation.

However, keeping in view of the rapid progress made in the technological developments worldwide in the area of Gas Hydrate Research it is believed that the scientists community working to explore the possibility of utilizing Gas Hydrates as a potential energy resource should at tandem join hands, more so since this area has a huge research component. Hence, even for the SAARC region SEC Islamabad in collaboration with country like India put in place a Steering Committee which in turn should create opportunities for the Scientists in the SAARC region to develop expertise and technology for Exploration and Exploitation of Gas Hydrates in the Region. India can play a vital role here.

CHAPTER – 10
GAS HYDRATE RESOURCE POTENTIAL OF SAARC REGION

Assessment of the amount of gas hydrate resources

Gas hydrate resources are assessed on the basis of the amount of methane they contain. Once the figures outlined below have been determined, one can come up with a rough estimate of the amount of the resources.

(1) Volume of gas hydrate-bearing layer: This is calculated by multiplying the surface area of the gas hydrate-bearing layer by its thickness.

(2) Porosity of the gas hydrate-bearing layer: The proportion of open spaces in the strata in which gas hydrate may exist. This is generally 30% or more under the seafloor.

(3) The hydrate saturation ratio of the gas hydrate-bearing layer: The ratio of gas hydrate in the pores of the earth's strata. This varies depending on a variety of factors.

(4) The rate of volume change of methane contained in gas hydrates: The rate of volume change by which gas hydrate dissociates into methane gas. This is considered to be 170.

Multiplying the values from (1), (2), (3) and (4) above, the volume of gas in the gas hydrates in one particular area can be determined.

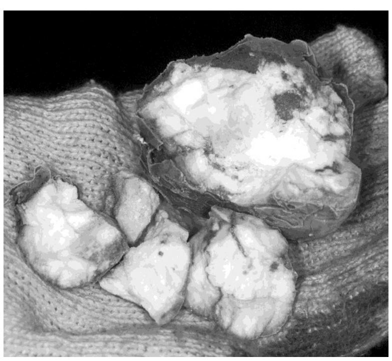

Figure32: (a) GH Recovered from Beneath Seafloor, (b) Burning Methane Released from GH. (SOURCES: (a) Figure courtesy of the Ocean Drilling Project at Texas A&M University, and photographer John Beck; (b) Courtesy Dr. Stephen Masutani, University of Hawaii, Hawaii Natural Energy Institute, Ocean Resources Applications Laboratory. Copyright © 2003 Ocean Resources Applications Laboratory. Photographer Liujuan Tang.)

Various researchers have performed such calculations to estimate the amount of methane that can be extracted from gas hydrate-bearing layers around the world. The amount of natural gas contained in the world's gas hydrate accumulations is enormous, but these estimates, as summarized by the Potential Gas Committee (1981), are speculative and range over three orders of magnitude from about 3.1 x 1015 to 7,600 x 1015 cubic meters of gas. By comparison, conventional natural gas accumulations (reserves and technically recoverable undiscovered resources) for the world are estimated at approximately 440 trillion cubic meters as reported in the USGS World Petroleum Assessment 2000 (http://pubs.usgs.gov/dds/dds-060/).The upper limit estimates above are from Dobrynin et al. (1981)and appear to be overly optimistic. They are ‘‘rough estimates’’ based on permafrost cover-age and zones of gas-hydrate stability in oceanic sediments without apparent regard for distributions of sedimentary basins or sources of methane. Estimates made during the period from 1980 to 1990 of the amounts of methane in oceanic sediments were summarized by Kvenvolden (1993). During this decade, an increased understanding of gas-hydrate occurrence has generally resulted in estimates within the lower ranges of previous ones. For example, Kvenvolden (1988) estimated the methane content of global gas-hydrate occurrence at 21 x 1015 m^3. By using a completely independent approach in which the organic carbon content of sediment was used as one guide; MacDonald (1990) estimated the amount of methane in worldwide gas-hydrate deposits at 21 x 1015 m^3. This estimate neglects any gas hydrate in sediment at water depth over 3,000m. That the estimates of Kvenvolden (1988) and MacDonald (1990) are equal at 21 x 1015 m^3 is a coincidence, but the convergence of ideas has made this value the consensus estimate, Kvenvolden (1989).

The Resources for gas hydrates are estimated at 40 TCF for the Nankai Trough (Fig 33) and the Prognosticated resources of India for the gas hydrates are in the order of 1894 TCM. While the method adopted for resource estimation by Dr Fujii is apt for dispersed hydrates in sandy reservoirs, the Rock physics model of Dr Sain et, al appears to be more effective for massive hydrates in clayey deposits.

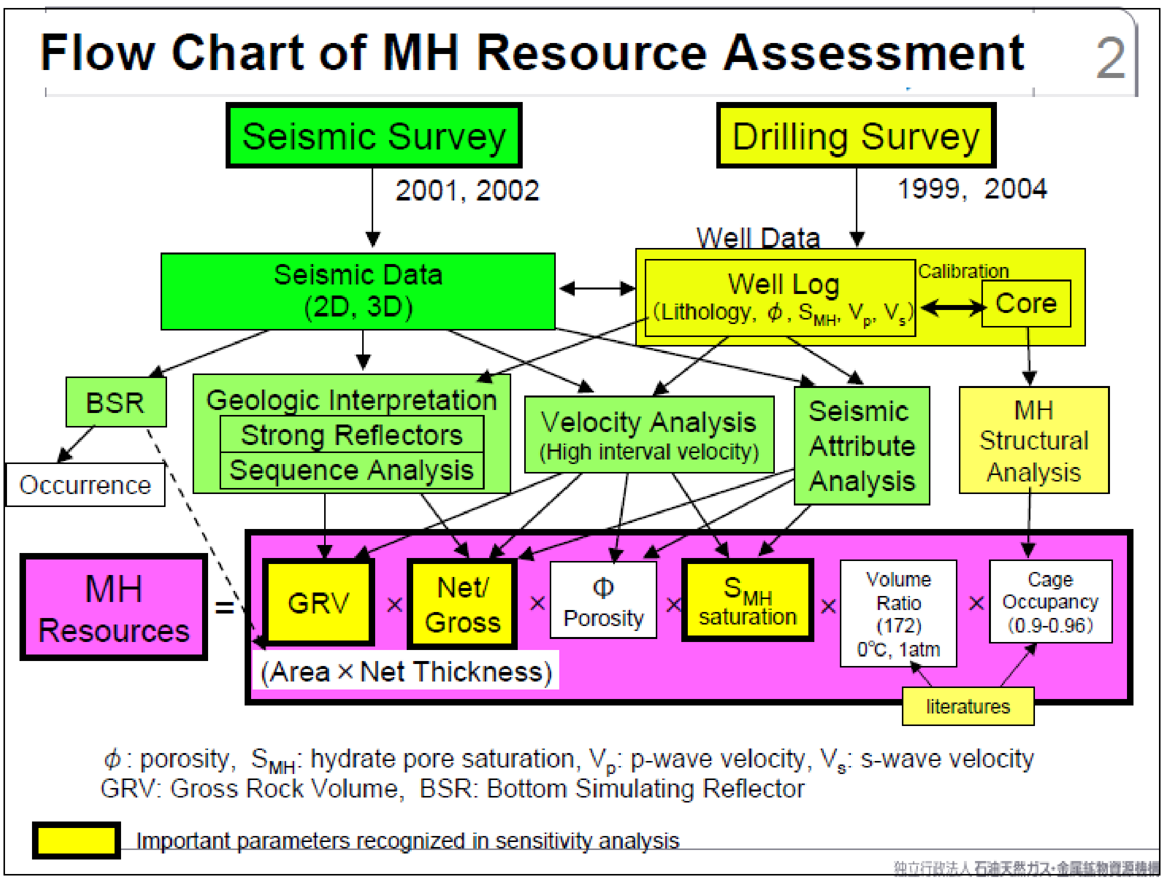

Figure33: Resource estimation carried out in Nankai Trough, Source: Dr. Tetsuya Fujii

Assessment of Gas Hydrate Resources in SAARC Region

Not much work has been done for estimating the Resource Potential of the SAARC Region, However there have been some estimates in terms of Prognosticated Resources

In India the prognosticated Resources for Gas Hydrates are calculated to be 1894 TCM. These have been estimated based on the following:

DEEP WATER	**PROBABILITY**		
AREA	**95%**	**50%**	**5%**
Bombay offshore	135	454	852
Kerala-Konkan offshore	62	1137	2299
North Arabian sea	226	595	1092
South Arabian sea	----	312	1094
Eastern offshore	1038	2168	4525
N Bay of Bengal	245	468	937
S Bay of Bengal	188	1022	3773
Total Resources (TCM)	**1894**	**6156**	**14572**

As is evident from the above tabulation, the volumetric estimates wherein 95% probability exists has been taken into consideration. These figures, however , are based on the Gas Hydrate Stability map based on temperature and pressure conditions which are feasible for Stability of Gas Hydrates and the BSR's observed in the seismic data available.

It may however be prudent to mention that even if 1% of the above resources could be exploited, it would take care of India's energy need for the next decade.

Two major locations have been classified as gas hydrate occurrences along the margins of the Arabian Sea (Kvenvolden and Lorenson, 2001), as inferred from the presence of BSRs in the shallow subsurface. These two provinces are located on the Indian Continental Slope (Veerayya et al., 1998; Rastogi et al., 1999; Rao et al., 2001) and in the Makran Accretionary Prism (White, 1977; Minshull and White, 1989; Grevemeyer et al., 2000; Kaul et al., 2000; Von Rad et al., 2000; Sain et al., 2000). Recently a BSR was also recognized in the Indus Fan region (Calvès et al., 2008). The range of water depths at which BSRs occur in the Makran Accretionary Prism is 500-3000 m (Kaul et al., 2000), while the estimated maximum depth of BSRs below the seafloor is 500-800 m (Von Rad et al., 2000; Grevemeyer et al., 2000). Along the Indian Margin, the occurrence of BSRs or gas-charged amplitude anomalies is confined to water depths ranging from 500 to 3000 m, and depths below the seafloor up to 450 m (Rao et al., 2002; Shankar et al., 2004, 2006). The source of methane and gases at these locations is thought to be related to deep thermogenic gas formation (Rastogi et al., 1999; Grevemeyer et al., 2000; Satyavani et al., 2005; Calvès et al., 2008).

Makran coast occupies nearly 670Km of the 990Km long coastline of Pakistan. Geology of the Makran offshore area is as uniquely interesting and intricate as that of mountainous area in the Himalayas and northern areas of Pakistan. The Makran Subduction Zone, which has been subjected to folding and faulting, is interlained by sediments of undetermined thickness and age. From Jiwani in the west to Sonmiani in the east of the Makran margin is marked by fascinating geological features including the mud volcanoes (surface indicators of gas hydrates) which dot the coastline (Figure 6). It is well established that gas hydrates occur also in the offshore region of Makran, although their distribution and extent were not well known earlier (White, 1979, 1982).

Offshore part of the Makran accretionary wedge was studied in considerable details during Sonne Cruises SO 122 & 130 led by BGR and investigated the structure and origin of the accretionary wedge, searched for submarine gas seeps, vents of fluids and gas hydrates and sampled "cold seep" sites at the sea floor and in the water column (von Rad et al., 2000). Previously, the tectonic structure of the offshore part of the active Makran margin was studied by geophysical surveys of the University of Cambridge (e.g., White 1982, 1983, White and Louden 1983) and by the BGR, GEOMAR (Kiel) and the University of Bremen (Roeser et al. 1997; Villinger et al. 1998; Bohrmann et al., 2008).

Gas analyses of the water column offshore the Makran coast in 1993, 1998 firmly established the presence of extensive (several tens of km wide in N-S-direction) gas plumes of bacterial CH_4 in the sea water (Delisle & Berner 2002). The plumes emerge at water depths of less than 800 m from the sea floor. The 800 m boundary coincides with the limit, at which gas hydrates can exist under the p-T-conditions prevalent in the Arabian Sea. This observation led Delisle & Berner (in press) to postulate that the gas hydrate layer in the Makran accretionary complex acts as a cap rock to free gas and fluids which are constantly being produced by bacterial activity and sediment compaction. This scenario suggests a landward migration of free gas and fluids, which leads to numerous gas seeps in the shallow waters of the upper slope. The lateral range of this landward migration is unknown.

The scientific results of the Pak-German cruise represented a substantial step forward for a better understanding of the long-time storage and migration mechanisms of natural gasses present in enormous quantities in ‘gas hydrate’ in marine sediments offshore Pakistan. Though the gas hydrates were reported earlier by White (1982 and 1983) but their extent and widespread presence offshore Makran was confirmed by seismic methods during the Pak-German cruise with R/V Sonne SO-122 (Roeser et al., 1997). During the geological cruise of the Makran Margin (SO-130; von Rad et al., 1998) when the solid hydrates were brought to the surface and put into hot water, the methane gas was released. The seeps are apparently the result of gas hydrate melting processes, induced by uplift of marine sediments out of the pressure and temperature field, where gas hydrates can exist.

In fact all the projects that were implemented in the offshore Bay of Bengal by Petrobangla, the gas entity of the country, were for exploration of conventional fossil fuel (oil and gas) and the leased areas were all in shallow waters where water depth was not more than 200m. With a view to identifying the presence of gas hydrates in the offshore Bay of Bengal no project, either alone or jointly with any regional or international organization, was undertaken by Petrobangla. However, Petrobangla has a programme to look for the presence of BSRs in the seismic data that will be acquired from the deep-sea blocks to be awarded under Production Sharing Contracts (PSC) to the IOCs in the near future.

Among the four IOCs presently engaged in hydrocarbon exploration and production three are working in the onshore while Cairn Energy, the only company is producing gas from the lone offshore field, Sangu. In the recent past a joint venture of Tullow, Total and PTTEP conducted exploration survey in an offshore block. But since the results of the survey were not encouraging, the block was later relinquished.

The surveys so far conducted in both onshore and offshore Bangladesh were exclusively for exploration of conventional hydrocarbons, the fossil fuel. No emphasis was given for finding any trace of gas hydrates in those surveys. Moreover all exploration surveys and drilling operations so far carried out in the offshore did not cross the 20^0N latitude towards south and were within the water depth less than 200m. The temperature and pressure conditions at such depths do not favor accumulation of gas hydrates below the strata of earth.

For economic production of gas, the location of gas hydrates deposits should be as close as possible to the shore line and reserves of gas hydrates should be of sizeable amount. But unfortunately, Bangladesh has one of the longest continental shelves, more than 200 km in the south and the continental rise, that is even farther south, is about 300 km from the shoreline.

Sri Lanka renewed its efforts to explore for oil and gas offshore in 2008 after a lapse of 25 years. Existing data suggest that petroleum potential exist in the Mannar Basin to the west, Cauvery Basin to the north, Bengal fan deposits to the east and a newly identified sedimentary basin to the south of the island. One exploration block in the Mannar Basin was awarded to Cairn Lanka (Pvt) Ltd. in 2008 for an exploration period of 8 years consisting of three exploration phases made up of 3,2 and 3 years respectively. This block, SL 2007-01-001, is 3000 sq. km in area and covers only 10 percent of the potential area available within the Mannar Basin. Certain agreed upon work commitments must be completed to advance from one exploration phase to the succeeding phase.

The data available to evaluate the possible gas hydrates zones in Sri Lanka and to estimate the potential gas hydrates resources in the country are very scanty. Therefore, most of the data and concepts used here to establish the extent of the hydrate stability zone offshore Sri Lanka were derived from studies done in other areas, particularly offshore Pakistan, India and Taiwan (Chi etal. 2006, Collett etal. 2008, Grevemeyer etal. 2000, Gupta 2003, Rastogi etal. 1999, Yuan etal. 1996).

Sri Lanka has a unique offshore morphology in that it has a very narrow shelf, a very steep slope and a vast continental rise. The average distance from the shore to edge of the continental shelf is less than 20 km. The total area of Sri Lanka's continental margin is approximately 3 100 1000 sq.km and it is mostly underlain by sediments of the extensive Bengal Fan. In addition, sedimentary basins with several kilometers of sedimentary rocks have been seen in seismic data to the north, west and south of the island. These are called the Cauvery Basin, Mannar Basin and the Southern Basin respectively.

No BSR has been interpreted in seismic data offshore Sri Lanka. However, examples from elsewhere in the oceans around the world indicate that the absence of a BSR is not proof that gas hydrates are not present (Bhatangar etal.2007). Given that pressure and temperature conditions could be right for the formation of gas hydrates below 600m water depth offshore Sri Lanka, the other necessary requirement would be a gas source. Gas hydrates have been already discovered in many parts of the Bengal Fan which extends to the deep water portion offshore Sri Lanka to the east and to the south of the island. Furthermore, thermogenic gas occur within the sedimentary section in the Mannar Basin and a live gas seep has been observed onshore on the west coast of the island in sedimentary rocks belonging to the onshore extension of the Mannar Basin

It is believed that naturally occurring gas hydrates could derive their methane from two sources biogenic and thermogenic. Biogenic and thermogenic methane could be supplied form below but more likely the methane in the hydrates could have been produced locally by decomposition of organic matter buried with the sediments. Grevemeyer etal.(2000) stated that adequate sources of gas for hydrate formation are generally found to occur in the continental slope regions. Water depth at the foot of the slope offshore Sri Lanka is around 3000 m. Given a hydrate stability zone below 600 m water depths and the probable source area for gas the slope region, the potential gas hydrate zone offshore Sri Lanka could lie between the 600 m and 3000 m bathymetric contours and cover an area of approximately 50000 km ^{2}.

It has been estimated that 40 to 70 percent of the sediment volume in the upper section in deep ocean sediments is occupied by fluids (Chi etal. 2006; Winters 2000). The percentage of this volume occupied by gas hydrates as measured in core samples and inferred from geophysical measurements range from 1.5 to 6 and a value of 3 percent appears to be consistent with most of the investigations (Bhatangar etal. 2007). Using an area of 50000 km ^{2}, a 200 m thick hydrate stability zone, a pore volume of 50 percent in the shallow sediments and 3 percent as the percentage of hydrate in the pore space, the amount of gas hydrates offshore Sri Lanka could be 225.10^9 m^3. This is equivalent to a gas volume of $369x10^{11}$ m^3 or $369x10^{14}$ kwh of energy. At the current demand of 8 billion kwh per annum in Sri Lanka, this would be enough power for $30x10^3$ years and therefore if exploited could represent a significant source of cost effective, safe and environmentally-friendly source of energy for Sri Lanka. However, since the recovery factor of methane from gas hydrates is not known these numbers cannot be taken very seriously.

In is therefore suggested that each SAARC nation should endeavor to construct a Gas hydrate stability map of the country in order to estimate some prognosticated resources for each country which could then be used to assess the Resources for the SAARC Region. It may however be recorded that due to the existence of the petroleum systems existing in the Deep water areas of all the SAARC countries notwithstanding the possibility of the Biogenic gas in the area, add to it the temperature and Pressure conditions that would necessarily form Gas Hydrate Stability zones, Occurrence of Gas Hydrates of Structure I and/or Structure II is extremely likely in the Deep water environment of Pakistan, Sri Lanka and Bangladesh.

CHAPTER –11

ROAD MAP FOR COMMERCIALIZATION OF THE GAS HYDRATES IN THE REGION

Bangladesh

Technically Bangladesh has still a long way to go before the country can think of taking any development programme on gas hydrate resources. A national body should be formed taking scientist and professionals engaged in the energy industry and oceanographic institute of the country to take forward the research and development of gas hydrates resources of the country. Identification of the gas hydrate zone and assessment of the gas hydrate resources will be the first task that the country shall have to accomplish. For accomplishing the task, due emphasis should be given to identify BSRs in the seismic sections running across the deep sea blocks that would be awarded in the near future for exploration of hydrocarbons. Again seismic survey alone will not be enough to identify the gas hydrate zone. Drilling followed by logging will be essential for determination of the thickness of gas hydrate layer and also for studying different parameters and characteristics of gas hydrates.

All the technologies pertaining to the exploration and development of gas hydrates are still in their primary stages of development. For a developing country like Bangladesh it will not be possible to mobilize and deploy all such technologies alone. From the seismic sections Bangladesh can at best identify the BSRs from which the gas hydrate zone could be delineated. However, thickness, porosity, hydrate saturation ratio and many other critical parameters will still remain unknown, without which a development programme of gas hydrate cannot be thought of. For going ahead with the research and development of gas hydrates, the country along with other SAARC countries may consider forming a consortium incorporating the scientists and professionals engaged in the development of hydrocarbon and marine resources.

Unfortunately, except India other SAARC Member States like Bangladesh, Pakistan and Sri Lanka having sea in one or more sides of the countries, do not have the capability of drilling even in the shallow waters of the offshore, not to speak of drilling in the deep sea where the water depth would be more than a couple of kilometers. Drilling in the shallow waters of offshore Bangladesh and Pakistan had always been carried out by the international oil companies (IOCs). Likewise few wells drilled in offshore Sri Lanka were all done by the IOCs. On the other hand in the Indian territorial offshore both IOCs and national oil companies are frequently drilling wells for hydrocarbon exploration and production.

India

India has been relentlessly working for the development of gas hydrates. Under the Indian "National Gas Hydrates Programme" (NGHP), in association with USGS, India has extensively studied the gas hydrate bearing marine sediments in Krishna-Godavari (KG) Basin, Mahanadi Basin and the offshore Andaman Islands. Under the programme they already delineated and sampled one of the richest marine gas hydrate accumulations yet discovered in the K-G Basin and discovered one of the thickest and deepest gas hydrate occurrences yet known in the offshore of the Andaman Islands. They have already identified more than 80,000 sq. km. of gas hydrate zone in the KG Basin area of the Bay of Bengal (A. K. Sethi, A. V. Sathe, and M. V. Ramana).

Further to note that India's NGHP Expedition 01 was planned and managed through collaboration between the Directorate General of Hydrocarbons (DGH) under the Ministry of Petroleum and Natural Gas (India), USGS, and the Consortium for Scientific Methane Hydrate Investigations (CSMHI) led by Overseas Drilling Limited (ODL) and FUGRO McClelland Marine Geosciences (FUGRO). The platform for the drilling operation was the research drill ship JOIDES Resolution (JR), operated by ODL. Much of the drilling/coring equipment used was provided by the Integrated Ocean

Drilling Programme (IODP) through a loan agreement with the US National Science Foundation (NSF). Wireline pressure coring systems and supporting laboratories were provided by IODP/Texas A & M University (TAMU), FUGRO, USGS, USDOE and HYACINTH/GeoTek. Downhole logging operational and technical support was provided by Lamont-Doherty Earth Observatory (LDEO) of Columbia University. (Indian Continental Margin Gas Hydrate Prospects: Results of the Indian National Gas Hydrate Programme (NGHP) Expedition 01, Collett et al.)The science team was led by Dr. Timothy Collett of the USGS, and consisted of more than 100 leading scientists and professionals representing the different organizations from all over the world (http://energy.usgs.gov/other/gashydrates /india.html).

Bangladesh and other SAARC countries have a lot to learn from the Indian experience of gas hydrates research and development. Each and every stage of the gas hydrate research and exploration mission is in the frontier of the available technology and hence challenges are to be faced at every stage. For successfully facing all the probable challenges, India not only streamlined the national organizations involved in the energy industry, but also successfully organized a good number of international organizations associated with the research and development of gas hydrates from all over the world along with more than 100 scientists and professionals to contribute in their search for gas hydrates in the East Coast of India.

Initially Bangladesh and other SAARC countries of the region having sea in one or more sides of the country should give specific emphasis on identification of bottom simulating reflectors (BSR) in their future seismic survey programme in the deep sea leading to oil and gas exploration. If necessary, high resolution seismic data should be acquired from the offshore and during processing of the acquired data special care may be taken for clearly identifying the BSRs. Once the BSRs are identified over an area, delineation of gas hydrates zone would be rather simple.

NGHP Expedition 01 has shown that conventional sand and fractured-clay reservoirs are the primary emerging economic targets for gas hydrate production in India. Because conventional marine exploration and production technologies favor the sand-dominated gas hydrate reservoirs, investigation of sand reservoirs will likely have a higher near-term priority in the NGHP programme. It is perceived that the NGHP effort will likely include future seismic studies, drilling, coring, and field production testing. It has been concluded that Site 10 represents a world class shale dominated fracture gas hydrate reservoir, worthy of further investigation.

Expedition-02

NGHP Expedition 02 would aim at the identification of sites for carrying out pilot production testing. The expedition is planned in the mid of 2010 and would aim at identifying sites which would ideally have:

Sand dominated gas hydrate occurrence
Reasonably compacted sediments
Occurrence of free gas below the gas hydrate stability zone

Thereafter after the short-listing of the right candidate location, Pilot Production test would be carried out as Expedition-03

Pakistan

Gas Hydrates have been studied in numerous ocean drilling programme (ODP) and deep sea drilling project boreholes (McIver, 1981; Shipley and Didyk, 1982; Kvenvolden and Barnard, 1983; Kvenvolden and McDonald, 1985; Mathews and Huene, 1985; Shipboard Scientific Party, 1988). There is lot of interest in developing technology and methodology to explore the gas hydrates by the developed countries. In this regard, Integrated Ocean Drilling Programme (IODP) Expedition 311 cored the Northern Cascadia margin during Integrated Ocean Drilling Programme Expedition 311 to study gas hydrate occurrences and formation models for accretionary complexes (Riedel et al., 2009). While in 2006 the scientific research drill ship `JOIDES Resolution', hired by the Indian Government to explore deep-sea gas hydrate reserves of the coast of India, carried out drilling, coring, and logging operations at several locations in the Indian Ocean (Collett et al., 2006). Gas hydrates deposits can be detected more efficiently by much less expensive multichannel seismic reflection profiling in offshore areas. Pure hydrates have a seismic velocity in the range 3.3–3.8 km/s

(Whalley, 1980; Sloan, 1990), much higher than normal oceanic sediments in the depth range of the hydrate stability field. The cementation of pore spaces of marine sediments by hydrates above the BSR causes the velocity to increase by an amount that increases with hydrate concentration (Pearson et al., 1983; Lee et al., 1996; Jakobsen et al., 2000) whereas the presence of even a small amount of gas in the pore spaces below the BSR causes a dramatic decrease in seismic velocity (Domenico, 1977). Hence the BSR acts as a strong seismic reflector with negative polarity, the amplitude of which depends on the degree of saturation of sediments by hydrates above and by gas or water below it.

Seismic reflection profiling is the best technique for remotely probing hydrate-bearing sediments few hundred meters below sea floor (mbsf) and lying beneath another few hundred meters of water column. The presence of gas hydrate increases both the P and S wave seismic velocities of sediments, whereas underlying free-gas reduces the P-wave velocity considerably, but hardly affects the S-wave velocity. Interpreting seismic velocities in order to deduce the amount of gas hydrate requires a relationship between the hydrate fraction in the sediments and the elastic properties of the sediment composites (Ghosh & Sain, 2008). Effective medium theories (Helgerud et al. 1999; Jakobsen et al. 2000) have been developed to interpret seismic velocity in terms of saturations of gas hydrate and free-gas.

The work carried out by Pak-German scientists onboard R/V Sonne and R/V Meteor had focused on documenting the presence of gas hydrate in the offshore Makran area. Since the objectives of these scientific expeditions were not to explore the resource potential of the Makran gas hydrates therefore a targeted effort is required both by the R&D Institutions and also by the Oil & Gas industry. The assessment of potential gas hydrate resource requires heavy investment therefore an inter-ministerial National Gas Hydrate Programme is required to be launched by the Planning Commission of Government of Pakistan.

Following roadmap is proposed for the development of gas hydrate in the Pakistan offshore area:

i. Establishing of Gas Hydrate Research Cell under the Ministry of Petroleum & Mineral Resources in collaboration of Ministry of Science & Technology with a charter to prepare Gas Hydrate Programme of Pakistan.
ii. Compilation and assessment of all the 2D multi-channel seismic data along the Makran Coast of Pakistan to map the Bottom Simulating Reflectors.
iii. Identification of potential sites for detail and target oriented 2D/3D Multi-channel Seismic surveys.
iv. Interpretation of data and preparation of report. Formulation of recommendation for offshore drilling and sampling for characterization and assessment of gas hydrate potential in the offshore areas of Pakistan by identifying prime locations for exploration of gas hydrates.

Sri Lanka

Sri Lanka is far from addressing development and commercialization of its gas hydrates. First Sri Lanka needs to make an assessment of gas hydrate resources in its jurisdiction. This requires development of databases and human and other resources needed to map, analyze, evaluate and accurately establish the extent and characteristics of hydrates.

All the technologies involved in the research and development of has hydrates are still in their primary stages. Consequently for smaller and developing SAARC countries like Bangladesh, Pakistan and Sri Lanka it may not be possible to deploy all these new and emerging technologies for the development of gas hydrates in their countries all by themselves. Rather a consortium of professionals and scientists from the energy sector and oceanographic institutes of SAARC countries like Bangladesh, India, Pakistan and Sri Lanka having sea in one or more of their sides will be able to take the responsibility to take forward the search for the gas hydrates in the offshore adjacent to the countries. Such a consortium will immensely benefit from India's past experience in the research and development of gas hydrates. Moreover, incorporation of other organizations and scientists and professionals involved in the research and development of gas hydrates from around the globe will be rather easy for the consortium.

CHAPTER – 12
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Gas hydrates is termed as the 'Energy for the Future', 'New Source of Energy', 'Ice that Burns', 'World's Largest Potential Energy Resource', etc. Studies of gas hydrates by scientists all over the world suddenly took a new dimension mainly because of a number of facts. On one hand it is likely to be the new and clean energy source of the future. No doubt that there is a huge amount of natural gas tied up in the gas hydrates globally. On the other hand gas hydrates may play a vital role in climate change. Methane is a strong greenhouse gas. Its escape from natural gas hydrates into the atmosphere could result in global warming.

Availability of natural gas from the gas hydrates trapped between the earth's strata in the deep sea generates a very high expectation among the SAARC countries having sea in one or more of their sides. It would not be unjust for these countries to dream of some golden days in future when gas from the gas hydrates would be contributing to their economies and energy crises shall not perturb the development of these countries any more. However, except India, no other SAARC countries has yet done any methodical and systematic studies for delineating the gas hydrate zone and assessing the amount of gas that might be available in the gas hydrates underlying the oceans adjacent to these countries.

Appropriate exploration and exploitation of gas hydrates shall be able to meet the ever-increasing demand of energy of the SAARC region. At the same time proper exploitation shall also ensure a clean energy for the region reducing the environmental hazard to a great extent. However, this should be kept in mind that gas hydrate research is still in its basic stage even for the countries like Japan and the US, who are conducting extensive research for the development and exploitation of the resource. Systematic and concerted effort in the study of gas hydrates can only lead to technological development leading to the successful development and exploitation of natural gas from the gas hydrates. While energy sources like oil, gas and coal are stable at standard temperature and pressure, gas hydrates are not stable. Its improper exploitation and hence dissociation will have serious impact upon the environment. Therefore unique technologies will be needed to be developed such that the exploitation and dissociation of gas hydrates do not affect the environment negatively. If such technologies can be evolved, only then it can be expected that gas hydrates will prove to be a viable energy source during the years to come for the SAARC region, when fossil fuel will keep on depleting and the price of oil particularly will continue to surge up.

The initial efforts both by the research institutions and oil industry provided expertise in mapping the of gas hydrate bearing zones only in India, particularly in Krishna-Godavari offshore and prime indications in Mahanadi offshore basin and Andaman Sea. The experiments also indicated the presence of huge reserves of methane gas in the form of hydrate. The areal distribution of gas hydrates resources need to be mapped in these areas.

These expeditions forced Indian Oil majors for development/adaptation of suitable technologies towards exploitation. India is considering seriously launching expedition 02 and 03 towards resource estimation and conducting pilot well testing.

As a follow up the countries of the SAARC Region need to explore continuously their continental margins with state-of-the-art technology to map the potential hydrate bearing zones in the SAARC Region.

Recommendations

It is recommended that SAARC Energy Centre may facilitate through relevant organizations in India, Bangladesh, Sri Lanka and Pakistan a mechanism of joint Seminars and conferences which would enable the scientists in the SAARC countries working in the field of Gas Hydrate research to interact with each other. This would be an icebreaker in the long term collaboration in the field of Gas hydrate research in the SAARC Region. It is also recommended that a Research Center may be set up in India to cater to the needs of the Researchers on Gas hydrates in the SAARC member countries and to have a Steering Committee in place to chalk out a long-tern (10 to 15 years) focused programme in the Region keeping in mind the commercial importance of Gas Hydrates.

In order to sustain and move forward the SAARC initiative on gas hydrates it is necessary to coordinate, cooperation research and development in the region. Furthermore, a number of countries such as Japan, Canada and USA are far advanced in hydrate research. A mechanism to exchange expertise and information and technology transfer between these countries and the SAARC countries would be very beneficial. This could save time and many and avoid duplication of efforts.

It is also suggested that each SAARC nation should endeavor to construct a Gas hydrate stability map of the country in order to estimate some prognosticated resources for each country which could then be used to assess the Resources for the SAARC Region. It may however be recorded that due to the existence of the petroleum systems existing in the Deep water areas of all the SAARC countries notwithstanding the possibility of the Biogenic gas in the area, add to it the temperature and Pressure conditions that would necessarily form Gas Hydrate Stability zones, Occurrence of Gas Hydrates of Structure I and/or Structure II is extremely likely in the Deep water environment of Pakistan, Sri Lanka and Bangladesh.

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