

Gas hydrates: A global perspective

N. K. Thakur and T. Gangadhara Rao

The ever-increasing demand of fossil fuel resources and depletion of global energy reserves have necessitated looking for possible alternative source. An alternative energy source that has caught much attention during the recent times is the gas hydrates.

GAS hydrates, also called gas clathrates, are natural-occurring solids belonging to a special category of inclusion compounds, in which a molecule of chemical component gets trapped inside a host molecule of another component¹. Gas hydrates are ice-like structures in which the methane gas molecules are caged in the lattice voids of water molecules. The maximum amount of methane that can be trapped depends on the geometry, i.e. free space available in the lattice of water molecules². In a fully saturated structure, 1 m³ of gas hydrate can contain up to 164 m³ of methane at standard pressure and temperature conditions (Figure 1). The gas hydrates in shallow reservoirs, less than about 1.5 km depth, have more methane per unit volume than the free gas contained in the same space. In nature, other gases such as ethane, carbon dioxide, etc. are also trapped in the water molecules. However, these are not of much importance as a substitute to natural gas.

The chemistry of gas hydrates was discovered in the early 19th century, when in 1810 Sir Humphrey Davy found that ice-like crystals were formed when the aqueous solution was cooled³. Hydrates became a nuisance in the 1930s and 1940s when they were found to be formed in the gas pipelines obstructing the flow of gas. However, the interest in gas hydrates has increased steadily since about 1969, when gas hydrate deposits were first discovered in the Soviet Union⁴. Most methane in the gas hydrates is of microbial origin formed by decomposition of living organisms, though some thermogenic forms (thermocatalytic cracking of more complex compounds) have also been observed.

High pressure and low temperature are required for the formation of gas hydrates. This requirement restricts their natural occurrence to deep ocean bottom sediments and areas of permafrost. Gas hydrates actually occur in less than 10% of the total ocean area, because they are generally restricted to the slopes and rises of the outer continental margins where the water depth exceeds 300 m (ref. 5). Sub-aquatic gas hydrates are also found in the polar continental shelf sediments associated with relict permafrost below depths of about 100 m.

Compilation of world-wide gas hydrate occurrences was first undertaken by Kvenvolden and McMenamin⁶. The world-wide distribution of gas hydrate occurrences, based on the geophysical, geochemical and geological information, is presented in Figure 2. The most significant factor controlling hydrate accumulation appears to be rate of sedimentation. Areas of rapid hemipelagic times are favourable for the accumulation of considerable amount of organic detritics and preserve them from oxidation at the sea floor by rapid burial so that it is converted into abundant methane by the bacteria within the sediments⁷.

P-T conditions

The influence of pressure, temperature and composition on the stability of hydrate phase is illustrated in Figure 3. In the pressure-temperature domain, the stability position of hydrate phase is not only determined by the mixture of methane and other gases but also by associated ionic impurities. Since the exact composition of gas and water is not known, a system of pure methane and pure water is commonly assumed to estimate the depth and temperature, where naturally-occurring gas hydrates are stable⁷. The hydrothermal and geothermal information coupled with phase boundary information suggests that the upper limit for depth to gas hydrate formation is of the order of 100 m in the continental polar regions, where the surface temperature is below 0°C. In the

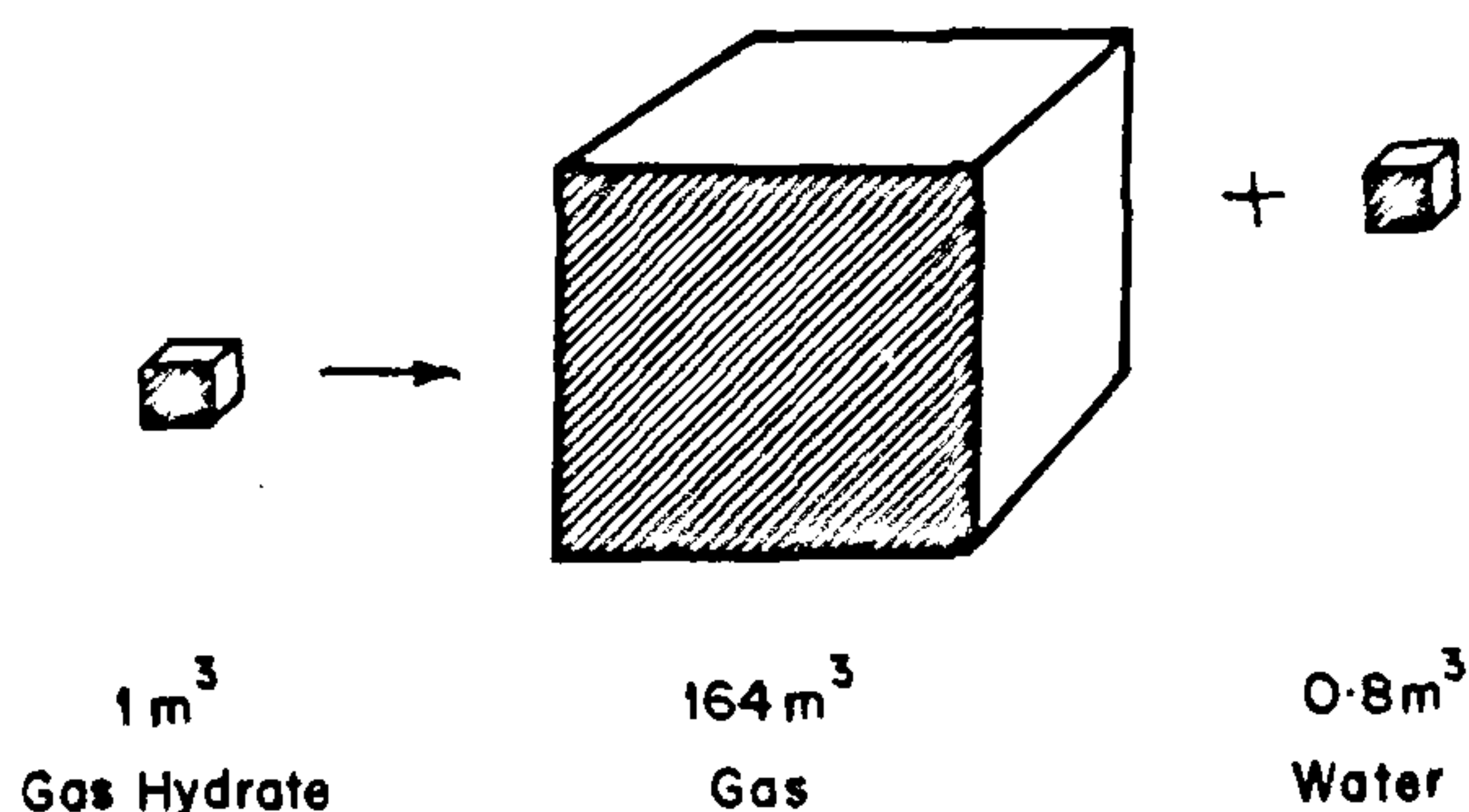


Figure 1. Volume expansion of gas hydrate molecule¹⁸.

The authors are at the National Geophysical Research Institute, Hyderabad 500 007, India.

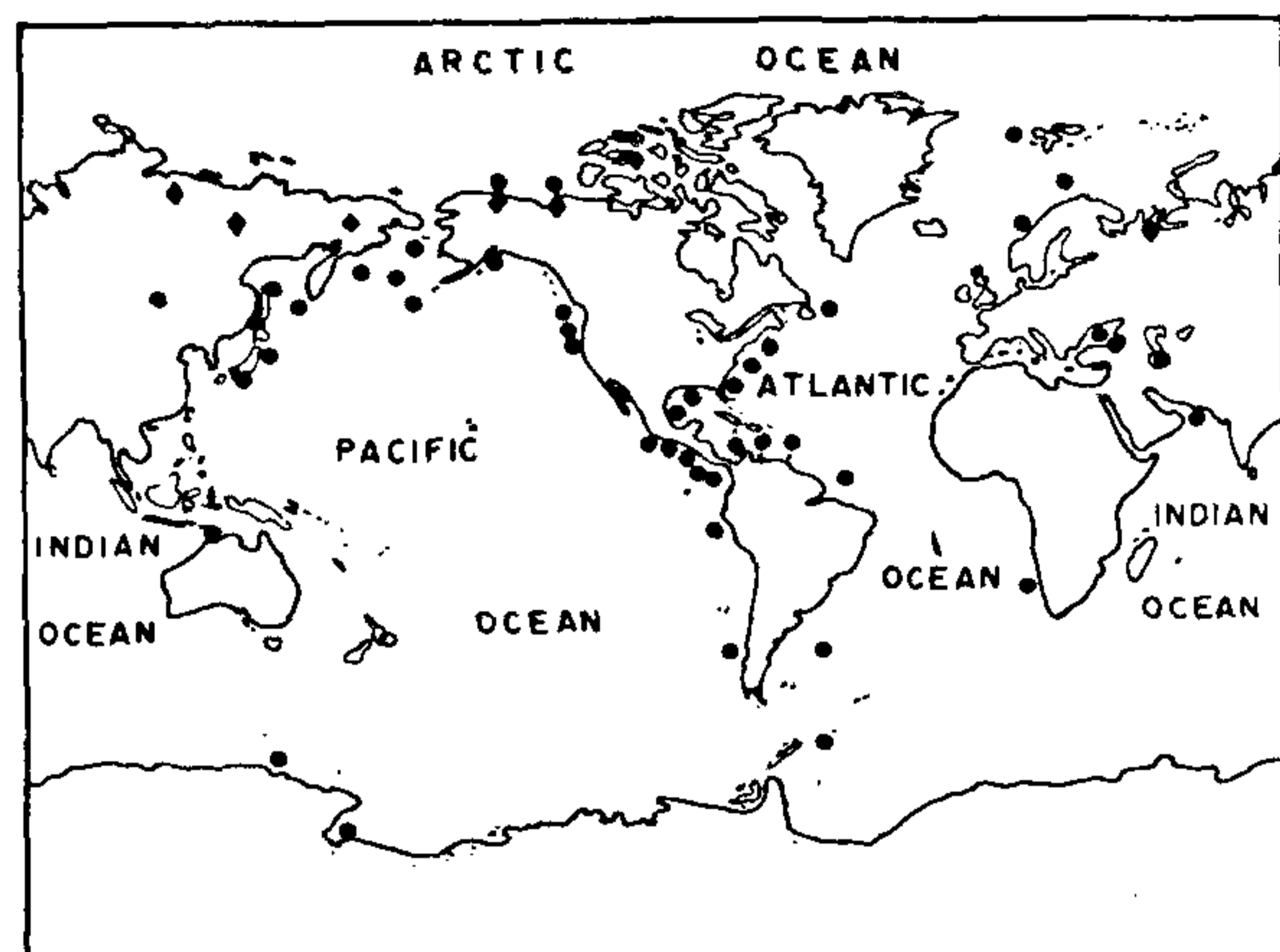


Figure 2. Global distribution of gas hydrate occurrences.

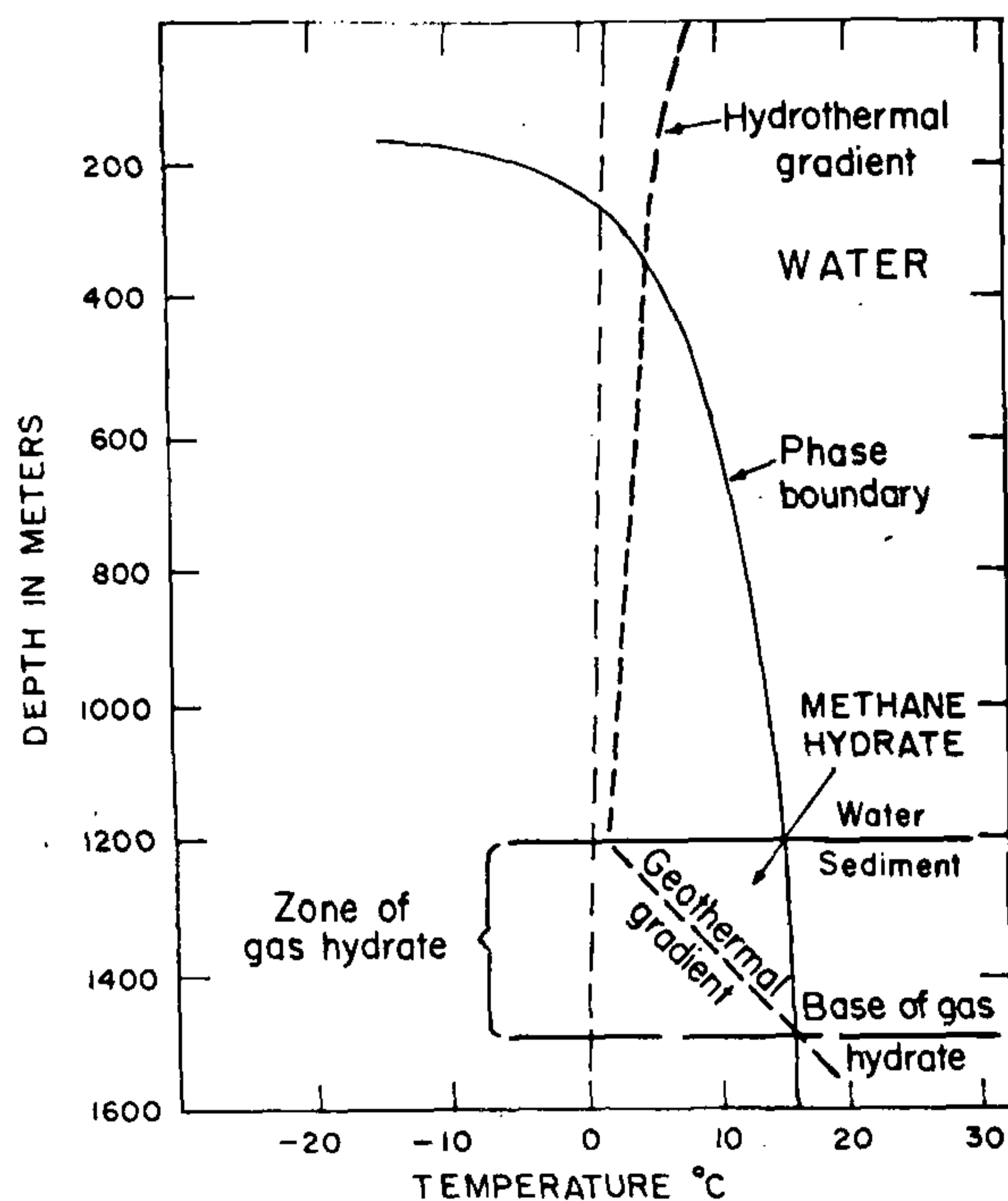


Figure 3. P-T phase diagram for gas hydrate stability¹⁹.

oceanic sediments, gas hydrates are stable when the bottom temperature approaches 0°C and the water depth exceeds 300 m. The lower limit of the hydrate stability is determined by geothermal gradient. Though this limit is normally much less, the maximum lower limit may sometimes go to as much as 2000 m below the ocean bottom depending upon the local conditions. Thus the occurrence of gas hydrates is restricted to shallow geosphere. One feature of gas hydrate occurrence that is

not apparent from phase diagram is the amount of methane that is required for gas hydrate formation. Gas hydrates will form with about 90% of the cages of the clathrate filled, i.e. 150 parts of methane at standard temperature and pressure (STP) per unit volume of water³. As methane solubility in sea water is very low, about 0.045 parts of methane at STP per unit volume of water⁸, the amount of methane required for the formation of gas hydrate greatly exceeds the solubility of methane in water. The large amount of free methane required for gas hydrate formation limits the occurrence of gas hydrate to regions of methane abundance.

Exploration

Seismic reflection technique is the most important tool for locating gas hydrate zones. Hydrates have very strong effect on the acoustic reflection because of high acoustic velocity (3.3 km/s), since the cementation of grains by hydrate produces a high velocity deposit. Sediments below the hydrate cemented zone, if saturated with water, will have low velocities. If gas is trapped in these sediments, the velocity of the layer will be still lower. Because the strength of the reflected signal is proportional to the change in acoustic impedance (the product of velocity and density), the base of hydrate cemented zone produces strong reflections. The reflecting horizon almost mimics the sea-floor and hence is called Bottom Simulating Reflector (BSR).

The velocity configuration produces characteristic reduction in amplitude in the reflection above the hydrate base. It is attributed to the homogenization of sediment velocity above the BSRs. The degree to which the amplitudes are diminished depends on the amount of gas hydrates present. The zone above the BSR is devoid of any strong reflecting horizon and is termed as Blanking Zone.

The third manifestation in the BSR reflection characteristics is the polarity reversal of the wavelet. The abrupt change in the velocity pattern from high velocity zone associated with gas hydrate to low velocity water saturated or gas-filled sediments just below the BSR produces a reversal in the polarity.

There are several diagenetic and chemical boundaries in the marine sediments, some of them producing changes in velocity and density. They may also produce seismic reflection signals identical to BSR. To distinguish between the two categories of BSRs, constraints from pressure-temperature at the sea floor and geothermal gradient can be utilized.

As the thermal gradient is fairly constant over the continental rise regions and gas hydrates become stable at high temperature with increase of pressure, one would expect simple pattern in which the BSR would become uniformly deeper with the increase in water depth⁹.

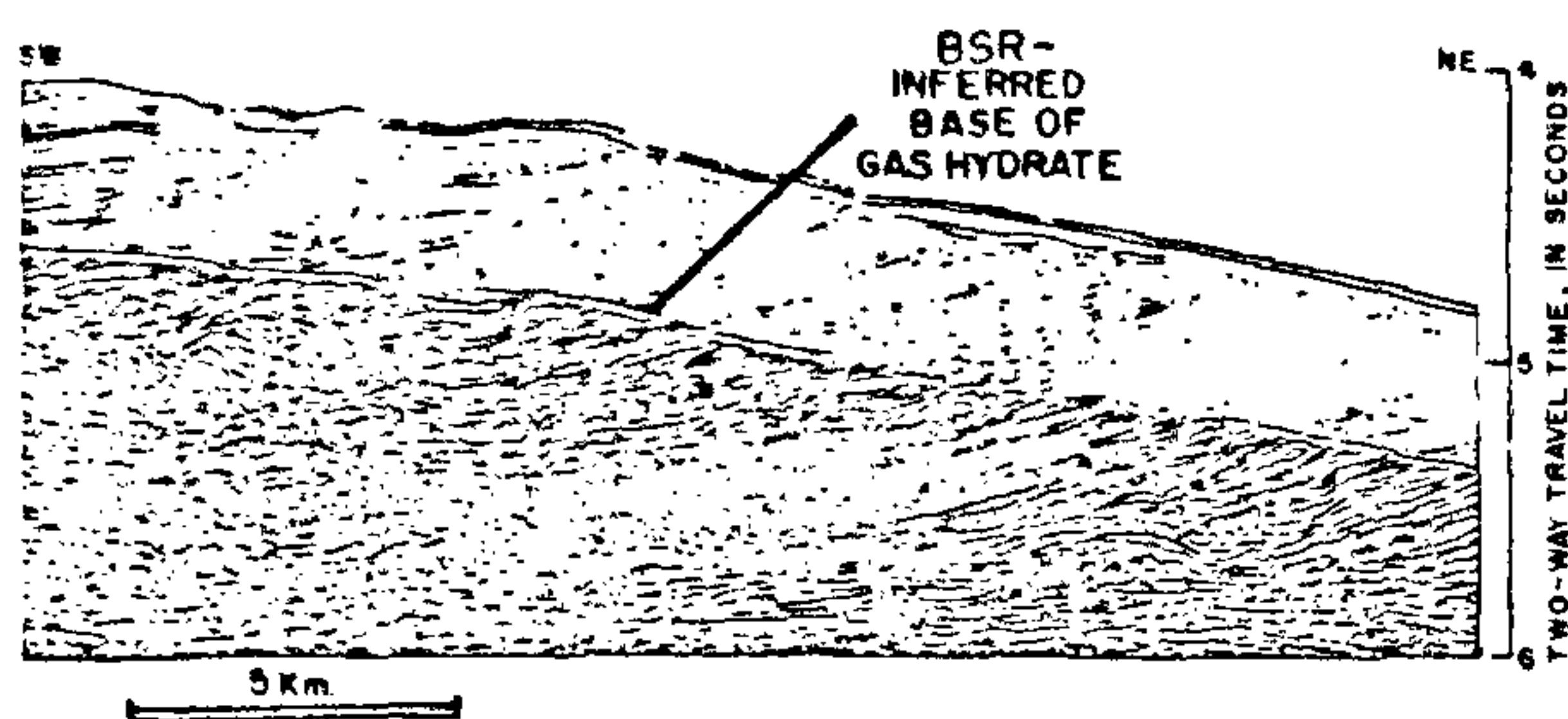


Figure 4. Typical seismic section indicating prominent BSR over Blake Ridge region⁵.

The three manifestations of hydrates in the sea-floor sediments mentioned above (BSR, Blanking Zone and Polarity Reversal) have been used to recognize gas hydrates in seismic profiles across US Atlantic margins^{5,10-12}. The BSR and polarity reversal are related to the bottom boundary of the hydrate zone. The blanking effect, however, occurs across the hydrate cemented zone and can be quantified to estimate the amount of gas hydrate present above the BSRs¹³. The most prominent and well-documented evidence for gas hydrates in US Atlantic margin are the Hudson Canyon at Lower Rise Hills¹⁴ (deep waters > 5000 m), Blake Ridge (Figure 4) and Carolina. The other prominent areas that have been investigated for gas hydrates, include the Gulf of Mexico and Nankai Trough in Japan.

It has been observed that most of the BSRs are detected at depths shallower than predicted from phase diagram. It may mean that either they have migrated above or they are the relicts of an earlier temperature-pressure regime, perhaps of Pleistocene age¹⁵.

Quantification of hydrate reserves

The thickness of the hydrated zone and the amount of hydrates present in the hydrate sediments are difficult to be evaluated from the processed seismic section. This requires modern tools like seismic waveform inversion and modelling. It is also difficult to differentiate from the processed seismic section whether the BSR is underlain by 'free gas' or water-saturated sediments. Singh *et al.*¹⁶ have demonstrated that application of a waveform inversion technique could provide the necessary constraint in estimating the thickness of the zones above and beneath the BSR by determining the velocity structure across a BSR. There is thus the need to carry out waveform inversion on the seismic data in a routine manner before launching any drilling programme.

The total volume of methane contained in oceanic hydrated sediments can be estimated only after detailed geophysical surveys. The factors controlling these estimates are: thickness and aerial extent of the hydrated

sediments, sediment porosity, concentration of methane hydrate in the sediment pores and volumetric gas expansion factor of methane hydrate to methane upon decomposition. While it is believed that gas hydrates could possibly represent the largest fossil fuel reserve globally, there is a general agreement that quantification of methane in gas hydrate and the free gas underlying it is poorly constrained. However, the pressurized core samples over the Blake Ridge have brightened the prospects of gas hydrates and the estimated gas hydrate deposits exceed very much from what is estimated from seismic data analysis¹⁷.

The encouraging results from Blake Ridge have opened up new vistas to consider gas hydrates as a potential alternative source of energy for future. Several countries like Mexico, Japan and India have recently launched national projects for the exploration of gas hydrates. With the initial indications of the presence of BSRs and Blanking Zones on some of the existing offshore seismic reflection profiles, there seems to be a significant promise for the gas hydrate exploration along the continental margins of these regions.

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Fuel for power*

Yoginder K. Alagh

Of late, cases of black-outs and brown-outs are becoming increasingly frequent. In view of this, power calls for special attention. India needs to produce cost-effective and sustainable energy for its millions of farmers, workers and households.

INDIA is passing through a critical phase. Economic growth of the country is picking up. The Seventh Five-Year-Plan saw the economy grow at a rate of about 5.7%. During the Eighth Five-Year Plan, the performance was even better and the growth rate of the economy registered a high of 6.5%. During the Ninth Plan, the Planning Commission has set a target of 7%. However, in order to maintain growth at this impressive rate and to increase it further we need dependable and efficient infrastructural support. Power calls for special attention, particularly in view of the fact that of late the growth in power supply capacities has not been keeping pace with demand and cases of black-outs and brown-outs are becoming increasingly frequent. The growth rate of demand for power in developing countries is generally higher than that of GDP. The elasticity of demand tends to come down as the economy grows. In India, the ratio which was as high as 3.06 in the First Five-Year Plan, peaked at 5.11 during the Third Five-Year Plan and reduced to 1.65 from 1980–81 to 1992–93. For the coming decade, a ratio of 1.5 is projected. Considering the targeted GDP growth rate of over 7%, an average growth rate of nearly 10 to 11% would be required for the power sector. In terms of capacity, it would imply an incremental capacity addition rate of nearly 10,000 MW per annum.

Electricity is a secondary form of energy. For electricity generation, primary energy resources such as hydro-electric potential, different forms of fossil fuels, fissile materials, renewable and non-conventional energy resources, etc. are needed. Of different modes of power generation, fuel as primary source is required only in the cases of thermal and nuclear generation. In hydro-

electric power generation, the source of primary energy is the high kinetic and potential energies of the water head while for power to be generated from the non-conventional sources such as wind energy, solar energy, geothermal tidal energy, etc. it is the energy potential of the respective source that is converted into electricity through appropriate conversion technology. For thermal power generation, different technologies are available to exploit the energy content of different forms of fossil fuels ranging from conventional boiler and steam turbine combination to technologically more advanced fluidized bed boilers. The gas turbine technology, to primary handle the liquid and gaseous fuels, also ranges from the simple gas turbines to more complicated integrated combined cycle gas turbine plants (ICCGTs). In the same way, depending on the available fissile material, suitable technologies are available for power generation. Fuel is essential for power.

India has almost all types of primary sources of energy, though available in varying quantities and at different locations. Therefore our generation mix comprises of power generation from almost all possible modes. Because of the inherent operation and long-term economic advantages, hydro-electric power generation assumes special importance. As a result, the planners in the country, till the mid sixties, accorded very high priority to this mode of power generation. This resulted in a generation mix, till the mid sixties, decisively in favour of hydel power. However, hydel power generation also has its shortcomings in terms of environmental and rehabilitation implications coupled with huge capital requirements, long gestation periods elongated further by the natural and geological surprises, etc. The relative ease with which thermal plants could be set up in much shorter time, with relatively low investments and the pressing need to add quick capacities to generate large quantities of power brought upon a paradigm shift in the power planning in the country with far-reaching implications. India was lucky to have a Fuel Policy Commit-

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Yoginder K. Alagh is the Minister of State for Power and Science & Technology, Government of India, Technology Bhavan, New Mehrauli Road, New Delhi 110 016, India.