

Methane hydrates in the Chilean continental margin

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In the coming years the worldwide energetic resources based on hydrocarbons will diminish, and methane hydrates can become an alternative source, given its huge deposits. Chile does not have great amounts of energetic resources; however, during the cruise C-2901 on board the R/V CONRAD in 1998, seismic profiles that took place in the Chilean continental margin between 35° and 45°S show the presence of methane hydrates through BSR analysis. The following parameters for the hydrate layer can be assumed: Thickness = 100 m, Longitude E-W = 20 km, Latitude N-S = 1000 km, hydrate concentration in the sediments = 10%, and 160 m³ of gas per m³ of hydrate. With these figures, the volume of estimated gas is 3.2 x 10¹³ m³.

Throughout these last decades, the demand for hydrocarbon-based fuel has been increasing rapidly. To meet this ever-increasing demand, exploration and exploitation of the vast resources of conventional oil and gas has been keeping place. These resources however, are not renewable, and we shall encounter severe depletion in the not too distant future. In this scenario, natural gas hydrates appear as an alternative and represent a great potential energy source, and even, if only a small percentage of this is renewable, it will constitute a major stock of energy.

Marine gas hydrates have come under increased worldwide attention. The large volumes of methane stored in these deposits represent a significant fraction of the global methane budget, and may be an almost inexhaustible resource for the future.

Then, gas hydrates constitute the Earth's biggest fossil fuel reservoir. The quantum of organic carbon in gas hydrates is twice that in all known fossil-fuel deposits, compared on the basis of the mass of carbon. Notwithstanding all content estimates of methane hydrates are highly speculative at the present time, the consensus value of 10 teratonnes (teratonne=10¹⁸g) is a reasonable estimate of carbon stored in methane hydrate (Kvenvolden and Lorenson, 2001).

Gas hydrates were discovered by Sir Humphry Davy in 1811, when it was observed that under certain conditions, water and chlorine form a crystalline substance – chlorine

hydrate. In 1888, scientists succeeded in proving that hydrocarbons (methane - ethane) can form gas hydrates. However, until the beginning of the 1930's, gas hydrates were looked upon solely as a scientific curiosity, for which there appeared to be no practical use. Gas hydrates caught the attention of industry in 1930's when it was realized that the long distance oil and gas transmission pipelines in the USA were being clogged by formation of gas hydrates within the pipelines. In order to overcome this problem, researchers spent time in studying the compositions and structure of gas hydrates and identifying inhibitors which could prevent formation of gas hydrates (Desa, 2000).

In the 1960's scientists discovered that hydrates could also form in natural environments. In 1972, the first pressurized specimen of naturally occurring gas hydrate was recovered from the north slope of Alaska in the Prudhoe oil field. In the 1970's geophysicists of the Lamont-Doherty Earth Observatory of Columbia University found the earliest indication of methane hydrates beneath the seafloor from the seismic data collected over the Blake Ridge, along the south east US coast. Since then, the presence of gas hydrates has been inferred in many places around the world. In 1997, the first drilling campaign specifically designed for hydrate and related issues such as methane generation and flux was carried out by the international scientific Ocean Drilling Program (ODP) on the Blake Plateau. This effort greatly increased the understanding of the deposits (Desa, 2000).

The government of Japan in 1995 was first to establish a national exploratory hydrate research program and in 1998 the Japan National Oil Corporation (JNOC) sponsored drilling tests of known hydrate deposits in the McKenzie Delta of Canada in consort with the Geological Survey of Canada, the U.S. Geological Survey (partly funded by the U.S. Department of Energy, Federal Energy Technology Center, Morgantown, WV) and contract university and research institutes. The Japanese National Oil Corporation (JNOC) is conducting extensive research of a potential hydrate resource off Hokkaido Island and is on target to drill test wells in two locations in 1999. Commercial production is targeted for 2010, barely 10 years away. It is estimated that recovery of only one tenth

for 100 years. The Japanese government has authorized a second five year plan, headed by NEDO (New Energy and Industrial Technology Development Organization) which is intended to develop methane recovery engineering (Cruickshank, 1999).

India, in 1996, was the second nation to establish a gas hydrate research program. The Indian approach was somewhat different from that of Japan, which already possesses a large, high-technology industrial base and can call on large foreign currency reserves. The Oil Industry Development Board of India, as part of its plan to boost natural gas resources, earmarked \$56 million for a program of methane hydrates research carried out largely under the auspices of the Gas Authority of India, Ltd. (GAIL). India is aiming at defining the national hydrate resource, and is encouraging industry to develop hydrate leases advantageous tax structures and other economic incentives (Cruickshank, 1999).

Other nations are also conducting assessment of deep water hydrocarbons, including hydrates. Canada, which closed its offshore minerals program some years ago, is revitalizing its program. The European Union has allocated funds for development of methane sensors, specialized hydrate coring apparatus, and marine research to identify hydrate and quantify methane in European North Atlantic waters. In the United States, the first National U.S. Gas Hydrate Workshop in 1998 brought together government, industry, and academic research interests and proposed that research on hydrates should take place as a broad, integrated program.

Chile has already started exploration work on this field, in the areas that according previous research should have hydrates in its margin. This research work, already started,

has a very important support of European and North American researchers, and this will allow in the coming years to gather scientific and technologic information, that would permit the start of its eventual exploitation.

In the 2000's, considerable evidence accumulated that huge quantities of carbon are stored in ocean sediments in the forms of free and dissolved gas as well as gas hydrates, a solid phase made of "cages" of water molecules that hold gas molecules, primarily methane.

Gas hydrates form when pore water becomes saturated with gas and the required temperature and pressure conditions prevail. Conversely, an increase in temperature or a decrease in pressure should cause hydrates association. Heat and fluids circulate inside the hydrate stability zone, causing redistribution of methane. Similarly, pore water and sediment compositions affect the amount, composition, and distribution of the hydrate.

Gas hydrates are ice-like crystalline accumulations formed from natural gas and water. The building block of this crystalline is a cage-like structure "clathrate", in which water molecules form the rigid lattice and the void is occupied by a guest gas molecule. Many gases have molecular sizes suitable to form hydrates, including such naturally occurring gases as carbon dioxide, hydrogen sulfide and several low-carbon number hydrocarbons, but the most common gas hydrates in nature are methane hydrates. Because of the arrangements of the gas molecules within this framework gas hydrates can store large percentage of gas per unit volume. Gas hydrate is thus a gas concentrator; the break down of one unit volume of gas hydrate at standard temperature and pressure produces about 164 unit volume of gas (Kvenvolden, 1993a).

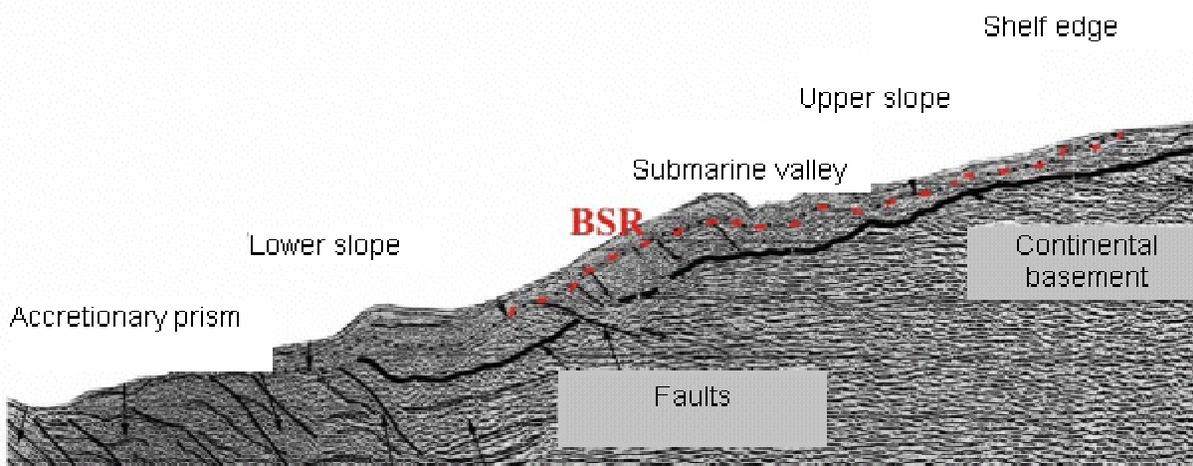


Figure 1. The most commonly acoustic signature for identification of gas hydrates in marine sediments has been the presence of anomalous signature on marine seismic records, know as Bottom Simulating Reflections BSR. Seismic profile, Line ENAP 6. From Diaz, 1999.

In appearance, hydrates are intergrown, transparent-to-translucent, white-to-grey and yellow crystals, with poorly defined crystal form. Hydrates may “cement” sediments in which they occur, or they may also occur in pore spaces in uncemented sediment grains. Hydrates occupy significant percentage of pore space in high-porosity sediment, and occur in large, contiguous deposits.

Three types of crystal structures are found in nature; type I and II belong to the cubic system, and type H to the hexagonal crystal system. The formation of gas hydrates depends on the presence of sufficiently high gas content, elevated pressure, and low temperature. Their dominant component, methane (CH₄), is largely a diagenetic product of fermentative decomposition of organic matter or of bacterial CO₂ reduction on sediments. Methane also is sometimes formed, along with higher hydrocarbons, by thermocatalytic conversion of organic material in the deeper subsurface. In the latter case, the methane migrates from these deeper sources, often from hydrocarbon reservoirs, into the hydrate stability zone (Suess, 2002).

The occurrence of gas hydrates in nature is controlled by an interrelation among the factors of temperature, pressure and composition. Gas hydrates respond rapidly and completely to changes in pressure and temperature by re-equilibration or dissociation. Compositional changes in the environment allow exert a significant rule on stability. In deep sediments, the temperature is usually increased with depth and can possibly reach a point in which the hydrate is unstable, in spite of the continuous increment of the pressure with the depth. Therefore, inside the sediments exists an area in which the gas hydrate is potentially stable, usually from the marine bottom up to several hundred of waters below them. This defines the hydrate stability zone (HSZ), inside it, and if gas saturation exists within (methane), it gives place to gas hydrate formation (Kvenvolden, 1993b).

Natural gas hydrates should occur globally wherever the pressure and temperature conditions were favourable. Although these parameters constrain restrict methane hydrate to two main environments on Earth, in oceanic sediment of continental margin of active and passive margins, and in polar sediment on both continents and continental shelves. Thus, natural gas hydrates is restricted to the shallow geosphere (Kastner, 2001).

The stray and prospecting of gas hydrates inside the marine sediments are usually carried out through indirect geophysical methods. The most common sign used for the identification of gas hydrate in marine sediments is the presence of an anomaly on marine seismic registration called BSR (Bottom Seismic Reflector) which is a negative polarity compressional (p)-wave reflection parallel to the seafloor that is imaged at the base of the HSZ. Previously, the BSR was assumed to result from the contrast between the high acoustic impedance of hydrate-filled sediment overlying a lower impedance hydrate-free-zone. However,

seismic modelling studies, new data, and high-resolution wide-angle multi-channel seismic reflection (MCS) data have shown that the development of a strong BSR requires the presence of certain amounts of free gas beneath the hydrate-cemented sediment (Bangs et al. 1993; Pecher et al. 1996; Mienert et al. 2001). Leg 164 data support these interpretations; a BSR is present in a zone containing free gas immediately beneath the hydrate, but no BSR is present where free gas is absent (Holbrook et al. 1996). Thus, although the presence of a BSR means that gas hydrates are present, the converse is not true. The absence of a BSR does not mean there are no hydrates.

The tectonic environment affects several parameters for the evolution of gas hydrate system.

Rapid tectonism along convergent margin leads to high fluid flow rates and introduces other variables of significance for gas hydrates formation, such as vertical movements of the seafloor, mass wasting, and potentially high rates of terrigenous sediments input from adjacent mountains range.

The Chilean convergent margin is one of the most dynamic regions on Earth. The tectonic activity is intense as manifested in tectonic uplift, folding and fracturing. Over time, tectonics has produced a dominant morphology, steeped topography gradient between the Peru-Chile trench and the Andes Mountains that often exceeds the 12 Km change in elevation over a horizontal distance of 250 km. Although the rate of convergence between the plates change only gradually with latitude and ages of the two plates along the join, only a relatively small amount vary, marked along-trench variations in trench depth, trench curvature, slope gradient, coastal geology, elevations of the Andes mountains, volcanism, and depths to earthquake hypocenters indicate that the subduction process is indeed variable and complex.

At the Chilean margin, seismic marine studies have allowed the identification of gas hydrates by means of BSR identification. The survey area was located across the Chilean convergent margin between approximately 35° and 45°S.

Three seismic lines collected in 1998 during the cruise C-2901 on board the R/V CONRAD indicate methane hydrate presence in the Chilean continental margin.

The line ENAP I cover from the outer trench slope across the continental shelf for 155 km, in the mean latitude of 35° 57'S. The BSR, in an almost continuous line at a distance ranging 400 to 700 m depth, at the upper slope, where the water depth equals 750 m. Through a distance of approximately 35 km long, there can be observed three well developed basins of 1200 m; 1200 m, and 800 m thick respectively (Diaz-Naveas, 1999).

The line ENAP2 in the mean latitude of 36° 15'S extends

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146.5 km from the outer trench slope to the continental shelf. In this area a series of slope basins showing a staircase-like shape can be observed. The BSR can be followed from one of the basins with 1300 m to the basins of 1650 m thick and lies at a depth of 400 to 600 m for 25 km of longitude (Diaz-Naveas, 1999).

The line ENAP4 at mean latitude of 37° 55'S and covers from the trench to the lower slope in a distance of 116.1 km. No BSR presence was found (Diaz-Naveas, 1999).

The line ENAP6 in the mean latitude 39° 15'S extends 153.1 km across the continental margin mainly in the middle slope. In this region the BSR crosses the sediment layer at a depth of 400 m beneath the seafloor in a discontinuous line of 35 km (Diaz-Naveas, 1999).

Although relevant, these studies are not a precise estimate of the available resource. However, inferences based on reasonable and independent approaches, allow an estimate in the range of 10^{13} - 10^{14} m³. On one hand, this estimate is approximately 3% of the world total, corresponding to the Chilean proportion of the world continental margin. On the other hand, this quantity is also result of the following considerations derived from the BSR seismic characterization in the Chilean margin. Conservatively, the following parameters for the hydrate layer can be assumed: Thickness = 100 m, Longitude E-W = 20 km, Latitude N-S = 1000 km (it is considered that only ~20% of the margin contains hydrates), hydrate concentration in the sediments = 10%, and 160 m³ of gas per m³ of hydrate. With these figures, the volume of estimated gas is 3.2×10^{13} m³ (Morales et al. 2001).

Chile lacks fossil fuel reservoirs and therefore is strongly dependent of the resources price offer at international level. In consequence, a great part of the national economy is affected by the international fluctuations in the hydrocarbon price and offer.

Therefore, the natural gas generation in Chile from methane hydrates would allow replacing the gas that nowadays arrives from foreign countries. This energy source would mean an extraordinary support for the generations of energy policies in our country. For this reasons the identification of gas hydrates in the Chilean margin has a strategic relevance.

It is necessary to point out that the gas quantity before estimated, 10^{13} - 10^{14} m³, it is approximately superior in 3 orders of magnitude to the annual consumption of gas in Chile. In consequence, even if a small fraction of the resource indeed could be exploited, its economic impact would be considerable.

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