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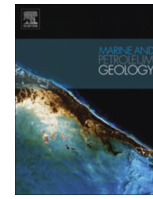

Gas-hydrate stability thickness map along the Indian continental margin

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A B S T R A C T

The gas-hydrate stability thickness (GHST) map along the Indian continental margin is prepared from available bathymetry, sea-bottom temperature and geothermal gradient data. The bottom-simulating reflector (BSR) often marks the base of gas-hydrate stability zone. The prior information about the stability thickness in a particular area will help in identifying BSR on seismic data. The map is also useful to the exploration scientists to set a depth window within which proxies for gas-hydrate can be looked into. A GHST map was initially prepared in 1998 based on the-then available data. A lot of new data has been generated by various organizations under the Indian National Gas Hydrate Programs for the advancement of exploration and exploitation activities. By incorporating the new data from the published and available documents, we have modified the GHST map along the Indian margin. Besides filling the data gap, the new map shows the gas-hydrate stability zone in the Andaman offshore. In addition, we show maps of sea-bottom temperature, sediment thickness, geothermal gradient and heat flow to provide a bird's eye view of these parameters along the continental margin of India.

1. Introduction

Gas-hydrates are ice-like crystalline substances in which methane molecules reside inside the cages formed by water molecules at high pressure and moderately low temperature and when the methane concentration exceeds the solubility limit (Sloan, 1998; Kvenvolden, 1998). The above conditions are met in the permafrost regions and in the shallow sediments of outer continental margins. Gas-hydrate formation provides a long-term mechanism for accumulating methane (Max and Lowrie, 1997). Oceanic methane is produced largely by microbial biogenic processes. The methane in gas-hydrate can also be thermogenic or mixture of both thermogenic and biogenic in nature. The presence of gas-hydrate in sediments is inferred commonly by identifying an anomalous seismic reflector, known as the bottom-simulating reflector or BSR. This often coincides with the predicted phase boundary at the base of the Gas-hydrate Stability Thickness (GHST). The BSR marks the interface between high-velocity hydrate-bearing sediment above and low-velocity gas-saturated sediment below, and can be mapped on seismic sections based on the characteristic features of (i) polarity reversal with respect to the sea-bottom; (ii) crosscutting through the inclined sedimentary strata; and (iii) most importantly mimicking the shape of sea-bottom, controlled by the prevalent thermo-baric conditions. The base of gas-hydrate stability increases with the (i) increasing water depth; (ii) decreasing sea-bottom temperature; and (iii) decreasing geothermal gradient, etc. For the calculation of the GHST map, it is imperative that all these parameters are to be known.

The biogenic methane can be formed if the sediment accumulation rate is more than 3 cm/kyr and the total organic carbon (TOC) exceeds 0.5% (Milkov et al., 2002; Davie and Buffet, 2001). Several parameters such as bathymetry (500 m–4000 m), sea-bottom temperature (1.2 °C–9 °C), sediment thicknesses (2 km–16 km), rate of sedimentation (3.5 cm/kyr–40 cm/kyr) and TOC (0.14%–6.18%) content (Sain and Gupta, 2008) indicate good prospects of gas-hydrate in the vast offshore regions of India. The TOC content in the eastern offshore (the Bay of Bengal) is less than that in the western offshore (the Arabian Sea). However, the sediment thickness in the eastern offshore is more than that in the western offshore. Thus, the deep water sediments in both the Bay of Bengal and the Arabian Sea are thought of conducive for the formation of gas-hydrate. The methane in gas-hydrate in India is speculated to be of 1894 trillion cubic meters (tcm) (http://www.dghindia.org/NonConventionalEnergy/), which is more than one thousand and five hundred times the country's present natural gas reserve. Even if we tap only 10% of this gigantic source of energy, it can fulfill India's energy requirement for about a century.

India has launched a research-oriented national program with more comprehensive scientific study and technology development

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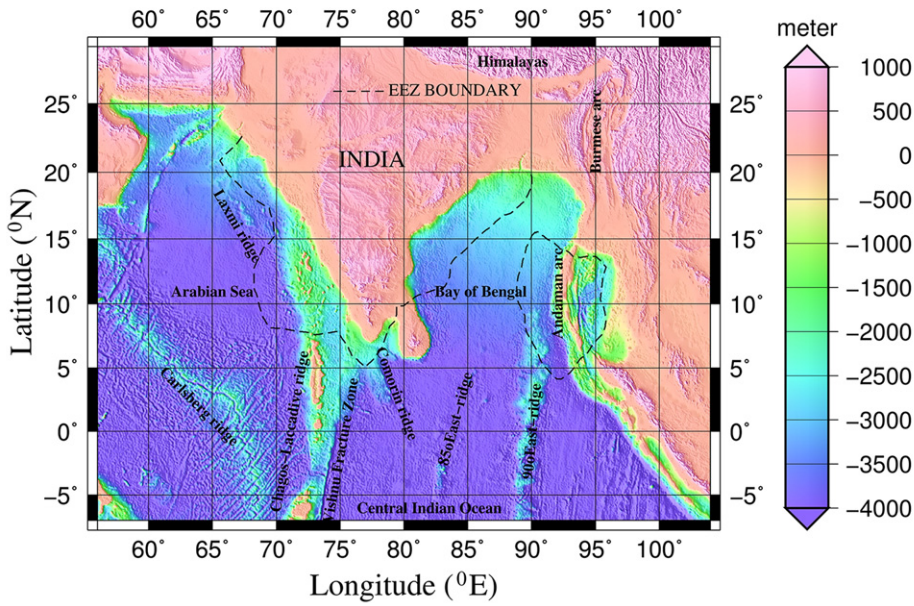

Figure 1. Tectonic features of Indian offshore (Shuttle Radar Topography Mission (SRTM) map from NGDC). Bathymetric contours derived from GEBCO are also shown.

for the exploration and exploitation of gas-hydrate under the aegis of the Ministry of Earth Sciences (MoES) and the Ministry of Petroleum & Natural Gas (MoP&NG). Organisations such as the Directorate General of Hydrocarbons (DGH), Oil & Natural Gas Corporation (ONGC) Limited, Oil India Limited (OIL), Gas Authority of India Limited (GAIL), National Geophysical Research Institute (NGRI) and National Institute of Oceanography (NIO), Reliance Pvt. Ltd., National Institute of Ocean Technology (NIOT), Indian Institute of Technology and several Universities are actively pursuing research on gas-hydrate with a view to mapping the hydrate-prospective zones within the Indian Exclusive Economic Zone (EEZ) (http://dod.nic.in/bathy1.htm) using various geological, geophysical, geochemical and microbiological data sets followed by technology advancement for producing gas from gas-hydrate. The discovery of gas-hydrate samples by the Indian National Gas-hydrate Program (NGHP) Expedition 01 (Collett et al., 2008) drilling and coring has boosted the Indian effort.

The Opal-A to Opal-CT silica phase transformation also causes the BSR-like feature (Berndt et al., 2004). This diagenetic BSR occurs at greater depth. As the theoretical base of gas-hydrate stability zone is often associated with the hydrate-BSR, the GHST map helps in identifying the BSR related to gas-hydrate and not to the Opal-A/Opal-CT boundary. Large volumes of multi-channel seismic (MCS) data, acquired for the exploration of conventional hydrocarbons, are being utilized for the identification of gas-hydrate along the Indian margin. Major portions of the deep-water regions within the Indian EEZ are yet to be explored. Recently, NGRI has acquired huge volume of MCS and ocean-bottom seismic (OBS) data in the Bay of Bengal for characterization, delineation and quantification of gas-hydrate. It is essential to prepare the GHST map that will help to ascertain whether the BSR is related to gas-hydrate by comparing the depth of BSR with the theoretical base of gas-hydrate stability field.

Many researchers have estimated the GHST map using different approaches. Rao et al. (1998) first published the GHST map using the analytical approach of Miles (1995) based on the-then available data in both the eastern and western margins of India. A similar exercise was carried out by Rastogi et al. (1999) using the GIS-based approach. In both these maps, the stability thickness in the Andaman region is not complete. During the last 12 years, lot of new data sets have been generated in both the margins by various organizations under the Indian national program. We use these data sets to modify the GHST map along the margins of India. The new map fills the data gap to better serve the purpose for identifying gas-hydrate in the Indian deep water regions.

2. Tectonic framework of Indian margin

The Indian sub-continent is bounded by the Bay of Bengal and the Andaman Sea in the east and the Arabian Sea in the west (Fig. 1). The offshore regions are characterized by a series of sedimentary basins, which are evolved through rift and then drift in a passive set up of divergent margin.

The western continental margin of India (WCMI) has been developed by sequential rifting from East Africa (180 Ma),

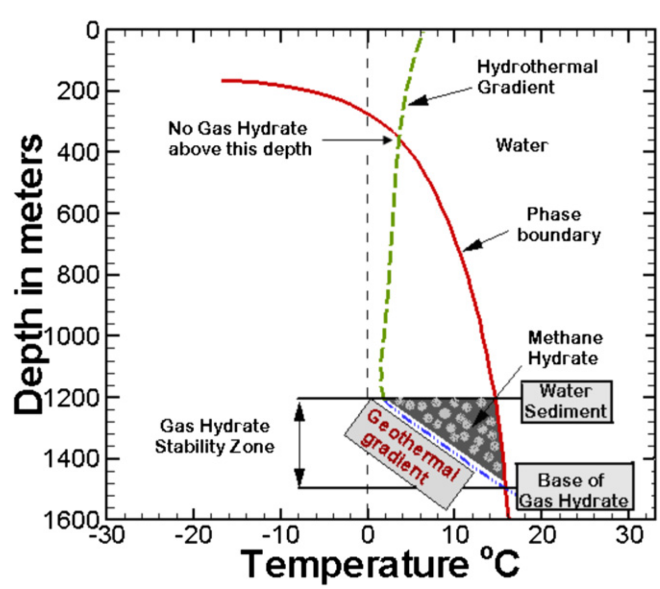

Figure 2. Gas-hydrate phase diagram in marine environment (for a location with 1200 m water depth, sea-bottom water temperature of 2 °C, and subsurface temperature gradient of 5.5 °C per 100 m).