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Potential distribution of methane hydrates along the Indian continental margins

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Bathymetry, sea-bottom temperature, geothermal gradient within the sediments and latitude are some of the important parameters that control the thickness of Hydrate Stability Zone (HSZ) in marine environment. This thickness for Indian continental margins is calculated from simultaneous solutions of gas-hydrate phase and pressure–temperature equations using the available data set for the parameters listed above. These results are presented as a contour map of potential thickness of HSZ which helps in searching for bottom simulating reflectors. If gas-hydrates occur along the Indian continental margins, then the potential thickness of HSZ can be inferred from this map.

GAS-HYDRATES are ice-like crystalline compounds of water and gas molecules that are stable at sufficiently low temperatures and high pressures. Generally, these conditions can be met either in deep continental margins or in permafrost regions of the world[1]. It is estimated that energy in gas-hydrate reserves is twice the known fossil fuel energy reserves of the world. In marine environment, gas-hydrates can be inferred from an anomalous reflector encountered on marine seismic records. These reflectors are observed to mimic the seafloor topography and hence are called the bottom simulating reflectors (BSRs). BSRs are observed to be in close coincidence with the theoretical base of the methane hydrate stability zone[2].

Gas hydrates can form and accumulate in marine sediments with sufficient gas molecules in pore water, if the thermodynamic conditions are favourable. For the production of biogenic methane there must be a sedimentation rate greater than 30 m Ma^{-1}, an organic carbon content exceeding 0.5% and a residual methane content > 10 ml l^{-1} (ref. 3). Along the Indian continental margins, sedimentation rate and organic carbon content are in excess of the minimum requirements, the average content of organic carbon being 1.5% (ref. 4).

The gas-hydrate exploration program requires identification of BSRs at the appropriate depth corresponding to the base of hydrate stability zone on the seismic sections. In this paper, theoretical base of hydrate stability for the Indian continental margins is computed and presented as a contour map. This map will be useful to the explorationist in setting a depth window for searching BSRs.

The well-known gas-hydrate phase diagram illustrates the phase equilibrium among gas-hydrates, free-gas and aqueous solution, and also the physical parameters controlling the formation of gas-hydrate (P, T, and salinity). Phase diagram for continental margins (Figure 1) shows that these conditions can be met in the shallow layers of the sediments at water depths exceeding 500 m to some depth below the seafloor controlled by geothermal gradient. Along the Indian continental margins these conditions can be met at water depths exceeding 750 m (ref. 5). This corresponds to the intersection point of hydrothermal gradient curve for tropical conditions with phase boundary curve. However, introduction of higher molecular weight gases (ethane, propane) to methane allows the gas-hydrates to form at low pressures and

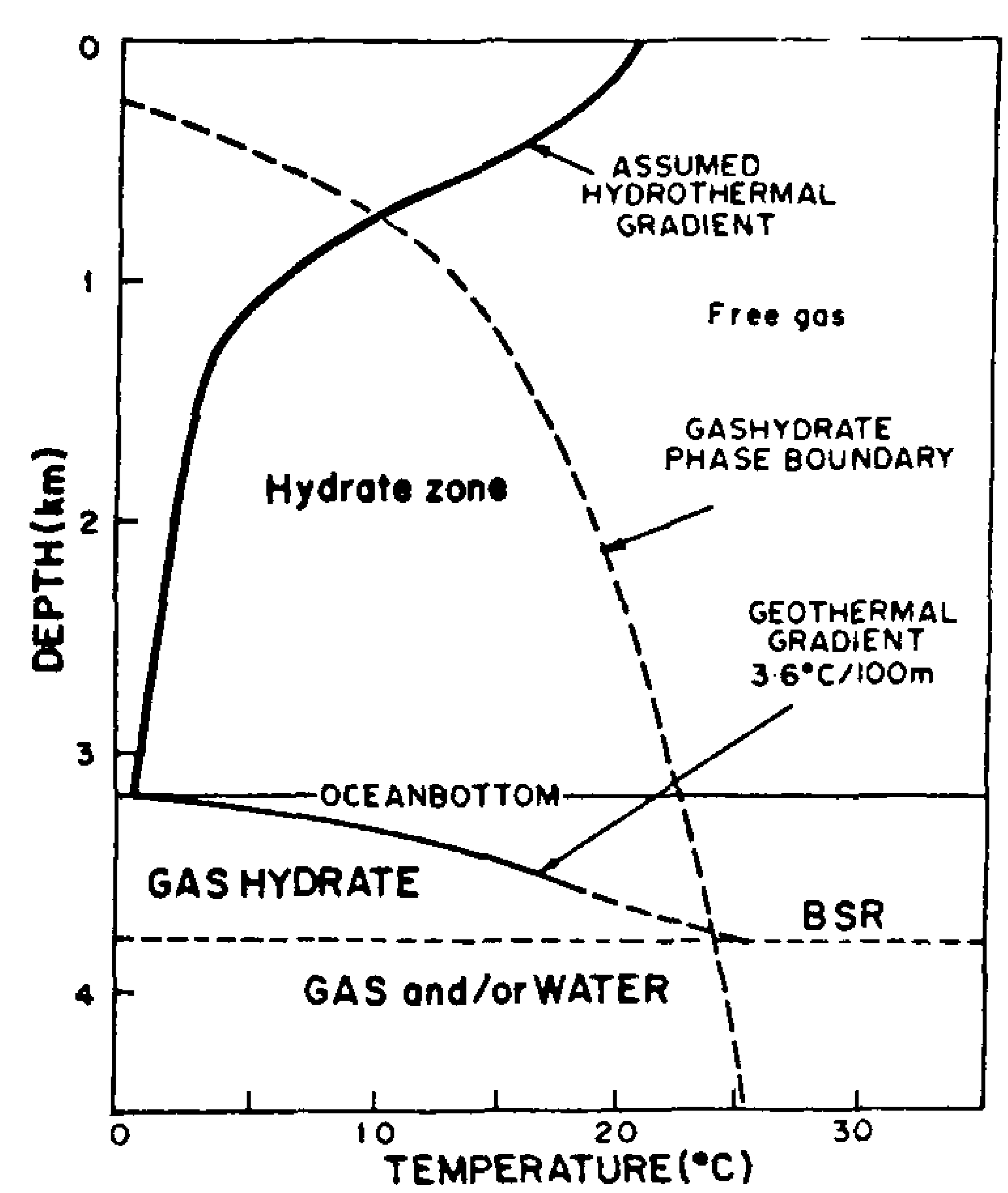

Figure 1. Phase diagram of methane hydrate in marine environment.

*For correspondence. (e-mail: postmast@ngri.uunet.in) higher temperatures, i.e. in shallow waters[6]. Vertical extent of sediment layer from seafloor to the intersection point of phase boundary curve with geothermal gradient curve in the sediments gives the thickness of HSZ. The presence of salts in pore water shifts the gas-hydrate phase boundary to the left, which reduces the thickness of HSZ.

Miles[7] described a method by which the depth to HSZ can be determined on the basis of gas-hydrate pressure–temperature phase diagram.

$$P = 2.8074023 + aT + bT^2 + cT^3 + dT^4, \tag{1}$$

where $a = 1.559474 \times 10^{-1}$; $b = 4.8275 \times 10^{-2}$; $c = -2.78083 \times 10^{-3}$; $d = 1.5922 \times 10^{-4}$.

The temperature–depth function from the seabed temperature (T_0) and the geothermal gradient is

$$T_z = T_0 + (\Delta T/\Delta Z)Z, \tag{2}$$

where T_z (°C) is the temperature at depth D in the sediment

$D = Z_0 + Z$ (mbsl), where Z_0 is the water depth (m).

The pressure (MPa) to depth D (m) conversion gives

$$P = [(1 + C_1)D + C_2D^2] \times 10^{-2}, \tag{3}$$

where $C_1 = (5.92 + 5.25 \sin^2(\text{lat})) \times 10^{-3}$; lat in degrees; $C_2 = 2.21 \times 10^{-6}$. Transforming eq. (2) into a function for Z and substituting into eq. (3) gives

$$P = [(1 + C_1)(Z_0 + (T_z - T_0)\Delta Z/\Delta T) + C_2(Z_0 + (T_z - T_0)\Delta Z/\Delta T)^2]10^{-2}, \tag{4}$$

which is the hydrostatic pressure–temperature relationship within the sediment in the same units as in eq. (1). The simultaneous solution of eqs (1) and (4) can be found analytically by an algorithm.

To estimate the potential distribution of methane hydrate stability zone along the Indian continental margins, information on bathymetry, ocean bottom temperature and geothermal gradient in the sediments is required. Bathymetry and ocean bottom temperature data were obtained from the Oceanographic Data Centre (ODC) at National Institute of Oceanography (NIO), India as well as from NOAA (USA). Geothermal gradient is one of the important parameters, which controls the lower limit of hydrate stability zone. For the West Coast, geothermal gradient data were digitized from the contour map of Pande *et al.*[8]. The average geothermal gradient values (derived from scanty data) for each basin of the East Coast regions available from the unpublished reports of ONGC, were adopted in the computation. Therefore, an average geothermal gradient for each subbasin of the East Coast region has been used in computations.

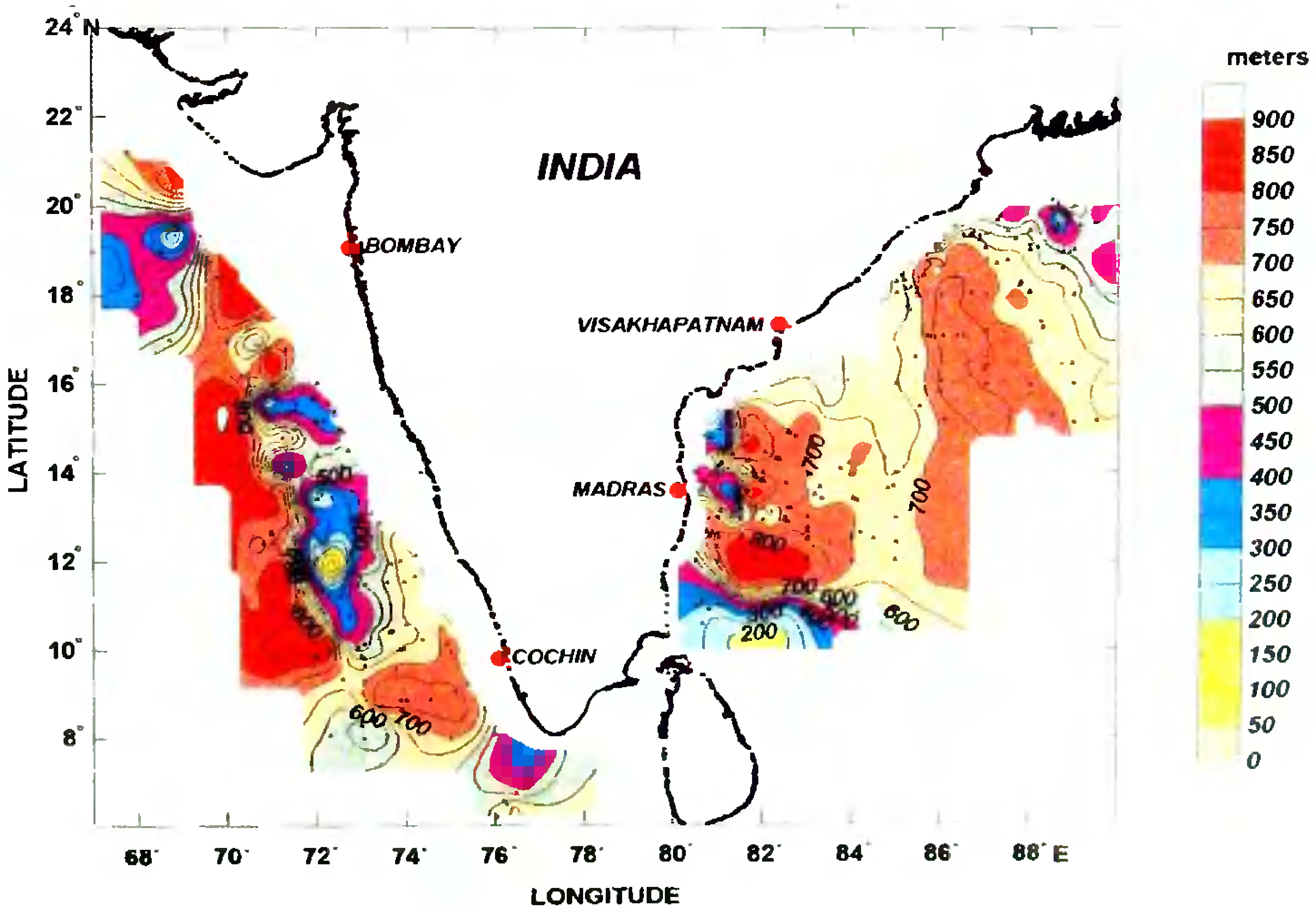

Figure 2. Potential thickness of HSZ for Indian continental margins. Δ represents location of HSZ computation.

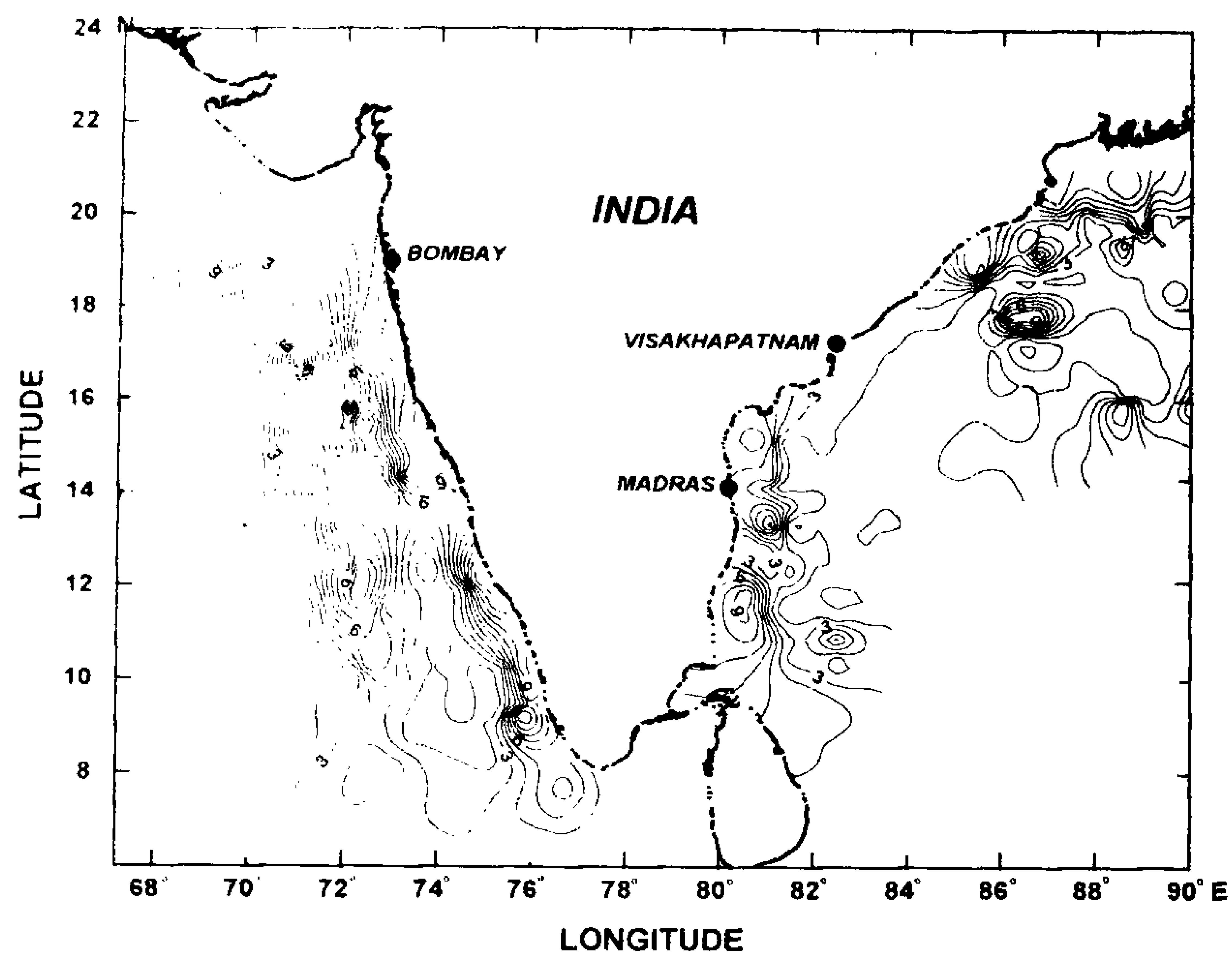

Figure 3. Seabottom temperature contour map (contour values in °C) for Indian offshore regions.

Simultaneous solutions to gas-hydrate phase and pressure–temperature equations were obtained for HSZ thickness at a number of spot locations. This HSZ thickness is presented as a contour map together with location of computation points in Figure 2. Seabottom temperature contour map for Indian offshore regions is given in Figure 3. The validity of this map assumes significance provided the presence of gas-hydrate is confirmed on the basis of BSRs. Beyond this depth even if methane gas exists, it will be available as free gas only.

The stability of gas-hydrate phase diagram calls for a minimum water depth of 750 m for Indian margins, as discussed earlier. This 750 m bathymetry territory is demarcated as blank zone where the possibility of occurrence of gas-hydrate is minimal. In this zone, even if sediments are rich in organic carbon content, pressure–temperature conditions may not favour the formation and existence of gas-hydrate. The HSZ map indicates that the depth to BSR is generally great along the continental margins in regions of low temperature gradient and high bathymetry. Off Mangalore coast, an increase in BSR depth is associated with low temperature gradient whereas off Bombay coast, shallowing of BSR due to high temperature gradient can be observed. As mentioned earlier, the geothermal gradient data for East Coast basins are very sparse. Therefore, drawing similar conclusion for this region may not be appropriate. Off Madras coast, an increase in BSR depth is observed with an increase in water depth.

The study presents a HSZ map and a first order estimate of the probable thickness of HSZ along the continental margins of India from the available geophysical data. This map guides the explorationist to set the depth window to search for BSRs. The validity of derived results could only be ascertained by carrying out systematic reflection seismic surveys in the Indian offshore regions.

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