Gravity signatures of gas hydrate

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In the present study we have performed two-dimensional gravity modelling to evaluate the gravity anomaly generated by hydrate distribution. By varying the thickness of gas hydrate-bearing layer, gravity values were estimated at the seafloor and different levels in the water column. Density estimates for free gas-bearing layers are not readily available in the literature. Hence an approximate density value representing free-gas has been incorporated to model for gas below the hydrates. The results indicate that this density configuration produces a small-magnitude gravity anomaly, which can be detected at the seafloor. The gravity response for gas-hydrate configurations of Blake Ridge and Vancouver Islands is observable only at the seafloor and falls sharply away from the source. As such, gravity observations at the sea surface are devoid of gravity anomalies in these regions. The gravity anomaly falls sharply and vanishes, if the observations are taken 1000 m above the seafloor. In view of this, it is concluded that the ship-borne and satellite gravity observations are devoid of gravity anomaly signature from gas hydrate-bearing layers. Future endeavours with deep-towed, high-resolution gravimeters may prove the utility of gravity studies for gas hydrate exploration. The high resolution data acquired from these observations have to be processed applying proper terrain correction and using techniques such as pattern recognition to separate relevant signal from noise due to small-scale gravity perturbation.

GAS hydrate is an ice-like crystalline solid formed from a mixture of water and natural gas, usually methane. It occupies the lattice of water molecules present in the pore spaces of sediments. Gas hydrates are found in sub-oceanic sediments in the polar region (shallow water) and in continental sediments (deep water), where pressure and temperature conditions are favourable for their stability. Natural gas hydrate contains highly concentrated methane, which is important both as an energy resource and as a factor in global climatic change. The high methane content in hydrates makes them an alternate, viable energy resource for future. Gas hydrate apparently cements sediments, and therefore, it can have a significant effect on sediment strength. Its formation and breakdown may influence the occurrence and location of submarine landslides. Such landslides may release methane into the atmosphere, which may affect global climate.

Although gas hydrate has been recognized in drilled cores, its presence over large areas can be detected much more efficiently by acoustic methods, using seismic reflection profiles. Hydrate has a strong effect on acoustic reflection because it has a high acoustic velocity (approximately 3.3 km/s, about twice that of seafloor sediments). Thus grains cemented with hydrate produce a high-velocity deposit due to the mixing of hydrate with the sediments. The high impedance contrast produced by the hydrate-cemented sediments above and low-velocity zone due to the sediment saturated with water (water velocity 1.5 km/s) or free gas produce strong reflection at the interface. Because the base of the gas hydrate stable zone occurs at an approximately uniform sub-bottom depth throughout a small area, this well-defined seismic reflection from the base of the zone roughly parallels the seafloor and is called the bottom simulating reflector (BSR).

Seismic reflection techniques have been extensively used to identify the BSRs, which are primary indicators of presence of hydrate-bearing layers[1–3]. It has been suggested[4,5] that the impedance contrast (velocity × density) is mainly controlled by seismic velocity, as the density contrast between water (1.05 g/cm^3) and hydrate (0.95 g/cm^3) is significantly small. However, it may be argued that the hydrates are formed at shallow depths below the seafloor, and as such, the density contrast should produce some gravity anomaly in their vicinity. In the present exercise we try to compute the effect of such density contrast and establish that gravity could be one of the tools for the exploration of gas hydrates in future.

Gravity measurements (observation) are made over the surface of the earth at discrete points and deviation of these observations from standard earth model produces gravity anomalies. These anomalies are interpreted in terms of density distribution or shape of the causative source below the surface of the earth. Forward or inverse formulation is attempted to determine the density distribution, keeping the shape (geometry) of the body constant or vice versa. Generally, the causative source is approximated as 2D, 2.5D or 3D body. In recent times, algorithms have been developed to vary both density and shape of the body as in the case of the inverse problem. In the present study we have attempted to simulate the gas hydrate configuration below the seafloor and tried to estimate the gravity anomaly associated with such configuration.

Two-dimensional approach is attempted as forward modelling for gas hydrate and gravity anomalies as produced thereupon. The lateral extent of the area of investigation was of the order of 10 km. The first sedimentary layer covered the entire area. Two segments of gas hydrate layer of one km length were placed at an interval of 2 km from the edge. Depending upon this configuration, the host sedimentary layer varies in its lateral extent. With this configuration, the edge effect generally

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encountered in the gravity modelling is at minimum. Varying the thickness of the gas hydrate layer, the gravity effect is estimated at the seafloor and at different levels in the water column. Keeping the gas hydrate thickness as 50 m, gravity anomalies are estimated at the seafloor and 250, 500 and 1000 m above the seafloor, as if the observations are taken in the water column at different levels. Density contrast for sediments and hydrated sediments is taken from the published literature[6]. A model for free gas below the hydrated layer is also attempted, with thickness of 50 m. The density of sediments saturated with free gas is not available. An approximate density contrast is taken to estimate the gravity anomaly due to free gas below the gas hydrate layer.

In the present study the configuration chosen is water of density 1.05 g/cm^3 and the first sediment layer with thickness of 200 m and density 1.7 g/cm^3 overlying the target, i.e. hydrate layer with density 2.19 g/cm^3. The hydrate layer is in segments, which is embedded in the host sediment layer with density 2.30 g/cm^3. A sediment layer of density 2.36 g/cm^3 underlies these layers.

Analysis through 2D modelling indicates that gas hydrate with layer thickness of 50 m produces gravity anomaly, which can be observed at the seafloor. The anomaly is of the order of 0.5 mGal (Figure 1 *a*). Computed gravity anomaly decreases sharply, when the estimates are made at 250 and 500 m above the seafloor (Figure 1 *b* and *c*). The gravity anomaly almost vanishes at 1000 m above the seafloor (Figure 1 *d*). The decrease in gravity from the causative source at different levels is in accordance with the inverse square law.

Further, we attempted to simulate the free gas condition below the gas hydrate layer by considering a free gas layer (sediments saturated with gas) of 50 m with gas hydrate layer of the same thickness, producing a gravity anomaly of the order of one mGal at the seafloor (Figure 2 *a*). At 250, 500 and 1000 m, the fall in gravity values is in similar lines as in the previous cases (Figure 2 *b–d*).

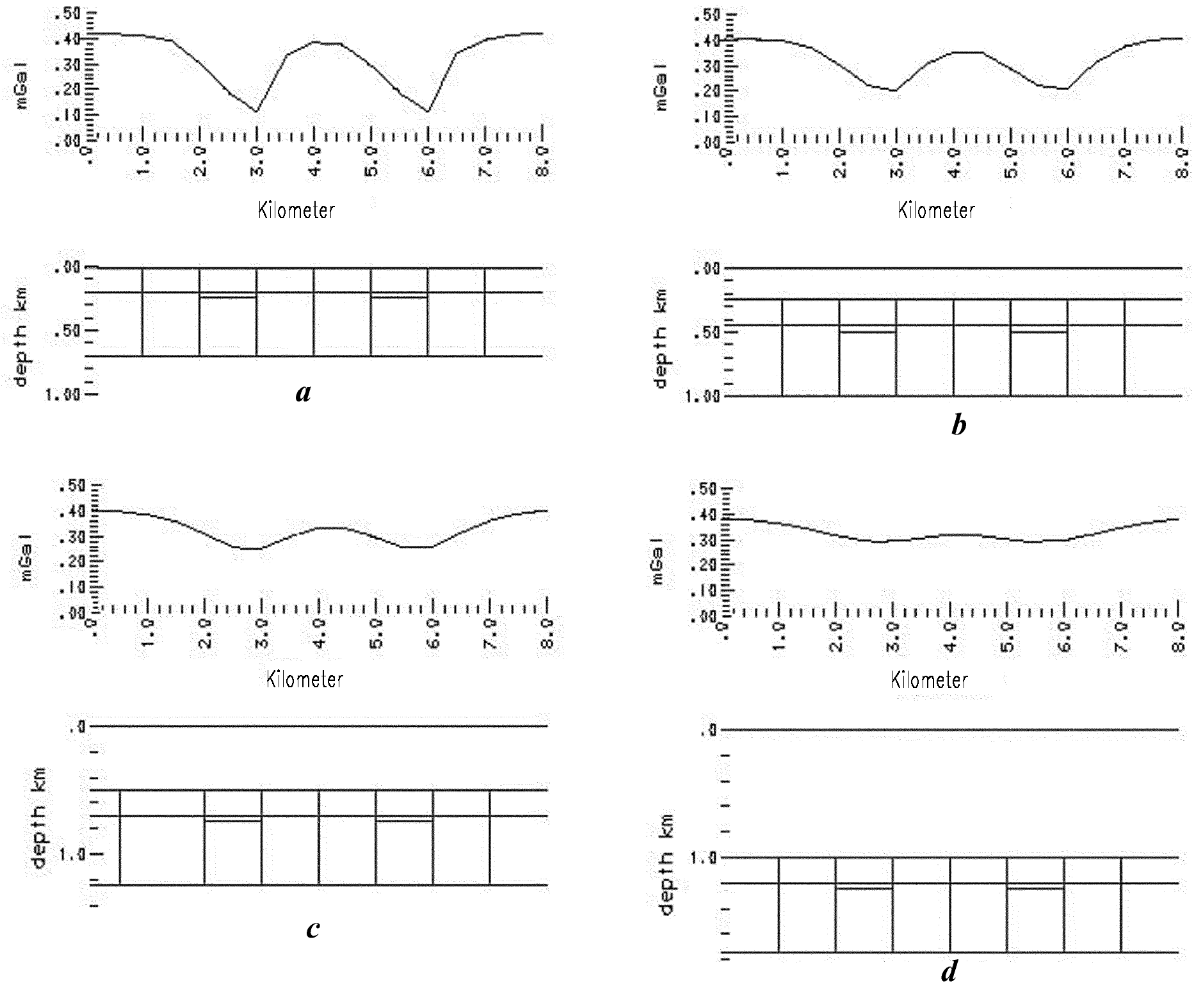

Figure 1. Gravity anomaly response computed for gas hydrate layers of 50 m thickness (***a***) at the seafloor, (***b***) at 250 m above the seafloor, (***c***) at 500 m above seafloor and (***d***) at 1000 m above the seafloor.

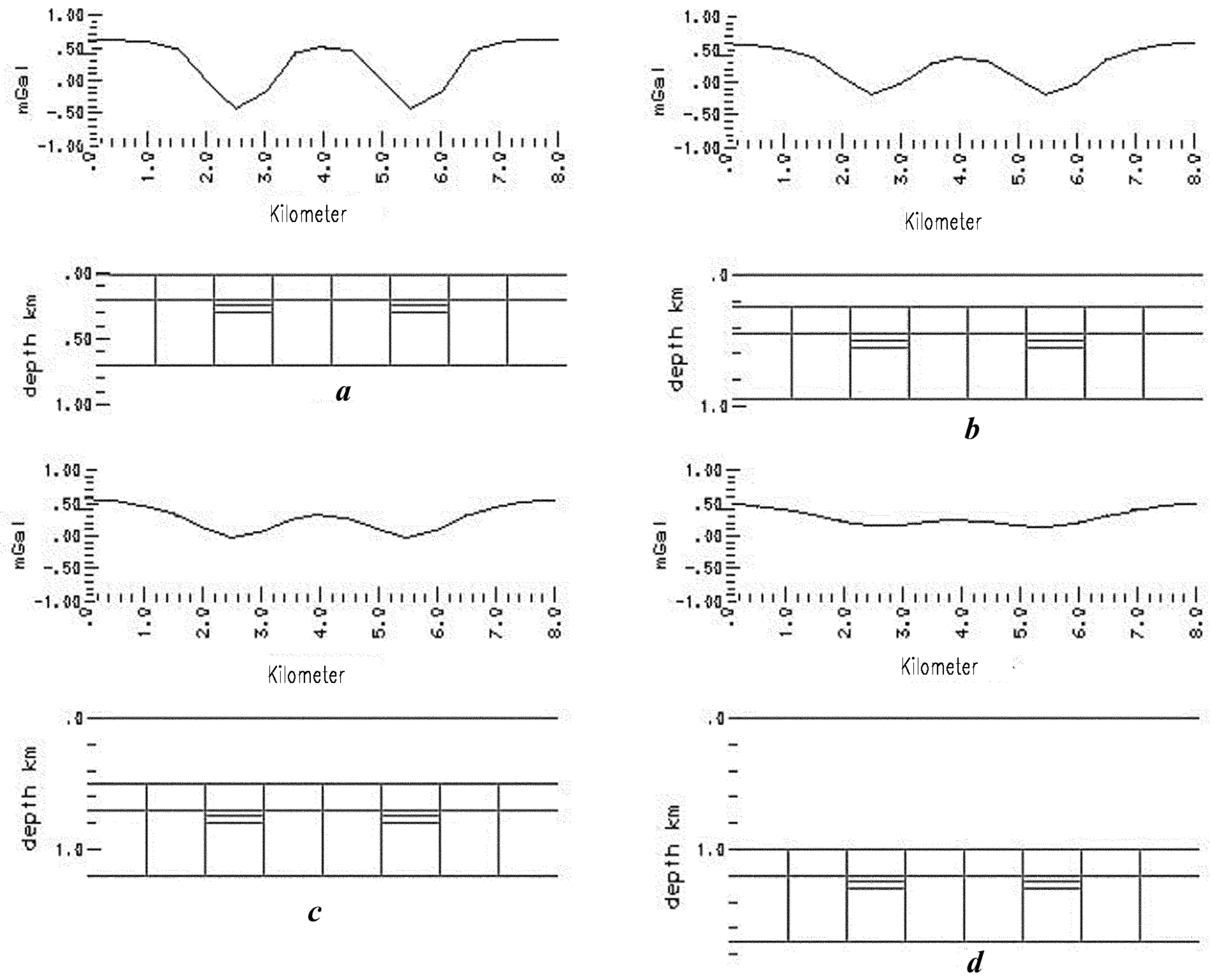

Figure 2. Gravity anomaly response computed for gas hydrate and free gas layers of 50 m thickness (***a***) at the seafloor, (***b***) at 250 m above the seafloor, (***c***) at 500 m above the seafloor and (***d***) at 1000 m above the seafloor.

Geophysical investigations over the continental margins of India by various organizations have demarcated three major areas, i.e. Krishna–Godavari, offshore Andaman Islands and the Kerala–Konkan basins. The inference of these hydrated layers is based on the identification of BSRs in multi-channel seismic data in different regions. However, there are no estimates of the thickness of hydrate, and free gas layers for these are available in the published work. Hence, we attempted to model gravity effect of well-known gas hydrate regions of the world, i.e. Blake Ridge and Vancouver Island in Canada.

The Blake Ridge is a positive topographic sedimentary feature on the continental slope and rise of the United States. The Blake Ridge is thought to be a large sediment drift that was built upon transitional continental to oceanic crust by the complex accretion of marine sediments deposited by longitudinal drift current. It consists of tertiary to quaternary sediments of hemipelagic mud and silty clay. The thickness of methane-hydrate stability zone in this region ranges from zero along the northwestern edge of the continental shelf to a maximum thickness of about 700 m along the eastern edge of the Blake Ridge.

Vancouver Island yielded a wealth of data penetrating to *in situ* gas hydrate on the Cascadia margin. Indirect evidence from recovered cores and down-hole geophysical surveys suggests that most of the gas hydrates occur as finely disseminated pore-filling substances. Most of the gas hydrates occur in six laterally continuous sandstone and conglomerate units; all these gas hydrates are geographically restricted to the area overlying the eastern part of the Kuparuk River Oil Field and the western part of the Prudhoe Bay Oil Field.

In order to get the gravity response of two prominent gas hydrate deposits of the world, we have simulated the geological configuration of Blake Ridge[7] and Vancouver Islands[8,9]. In the case of Blake Ridge, the gas hydrate and free gas layers have equal thickness of the order of 100 m and the gravity response of this configuration at the seafloor is of the order of 2 mGal (Figure 3 *a*). In the case of Vancouver Islands, the hydrate layer is of the order of 100 m, whereas the underlying free gas layer is 50 m

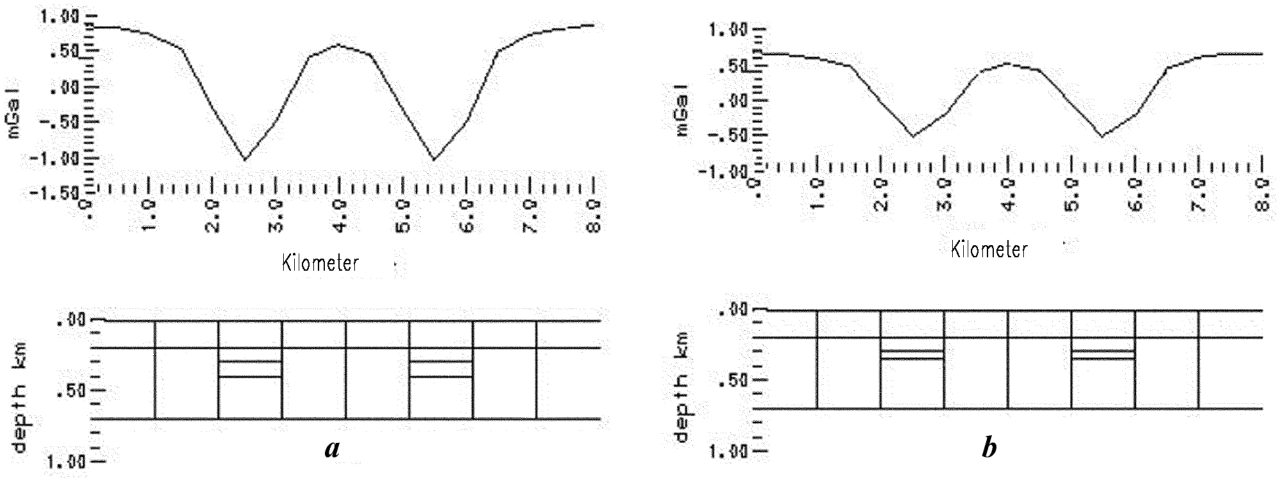

Figure 3. Gravity anomaly response computed for (*a*) Blake Ridge–gas hydrate and free gas layers of 100 m thickness at the seafloor and (*b*) Vancouver Islands–gas hydrate layers of 100 m and free gas layers of 50 m thickness at the seafloor.

Table 1.

Models with different layers thicknesses	Estimated gravity anomalies (in mGal) at			
	Seafloor	250 m	500 m	1000 m
Gas hydrate (50 m)	0.5	0.2	0.1	Negligible
Gas hydrate (50 m)/free gas (50 m)	1.0	0.6	0.3	Negligible
Blake Ridge (100 m)/(100 m)	2.0	–	–	–
Vancouver Island (100 m)/(50 m)	1.0	–	–	–

thick. This configuration produces a gravity anomaly of the order of above 1 mGal (Figure 3 *b*). The gravity anomaly falls off sharply above the seafloor; for the same the gravity anomalies, if measured over the sea surface, may not have any signature due to the presence of gas hydrate/free gas-bearing layers.

The present study indicates that density distributions associated with gas hydrate formation do produce gravity anomaly, but of significantly smaller magnitude (Table 1). The study concludes that the response of the gas hydrate in sediment columns can be identified with the gravity measurements near the seafloor with highly sensitive gravimeters, provided the seafloor has a flat topography and the effects due to terrain correction are minimal. In future, if such type of gravimeters are available, we can use them as ocean bottom gravimeters (OBGs) like the ocean bottom seismometers (OBSs) to compliment the inferences drawn from seismic and electrical methods for the identification of gas hydrates in the subsurface earth.

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