Mud diapirs around Indian continental margin – Indicator of potential gas hydrate zone

Mud diapirs in sedimentary strata are dome-shaped features usually formed by the squeezing out of plastic clay from the subsurface level. According to Milkov[1], all the terms such as mud mound, mud lump, mud pie, mud ridge, diatreme, mud diapir, gas dome etc. are synonymous and can be termed as ‘mud volcanoes’. Researchers on mud volcanoes (diapirs) have proposed four main reasons for their origin, viz. squeezing of subsurface shale layer due to overloading of terrigenous sediment, rapid subsidence or lateral tectonic compression, hydrocarbon generation in the deep subsurface and fluid flow along fracture zones[1].

Ever since the commissioning of the research vessel *R.V. Samudra Manthan* in 1983, Geological Survey of India has been systematically collecting echo sounding data (3.5 kHz) by line scan recorder (LSR) from the continental margins of India along pre-determined tracks, in connection with systematic seabed mapping. During these surveys, several mud diapiric structures have been recorded (Figure 1) from the deep continental margins around India, i.e. West of Swatch of No Ground (Figure 1 *a*, around lat. 20°30′N; long. 89°03′E), off Point Calimere (Figure 1 *b* around lat. 10°43.040′N; long. 81°01.522′E) and off Saurashtra (Figure 1 *c* around lat. 20°03.723′N; long. 68° 09.713′E), similar to the mud volcanoes described elsewhere[1]. They occur either as single diapir or in clusters (Figure 1 *b*). These diapiric structures have been described as mere geomorphic features ranging in relief from 20 to 85 m, formed by squeezing of underlying sediment by overload and lateral tectonic movements[2–4]. The surrounding areas of mud diapirs are carpeted by greenish hemipelagic clay. These mud diapirs are not sampled. Core log of mud diapir from Ryukyu Trench, NW Pacific Ocean exhibits an upper normal hemipelagic sediment and the lower mud supported breccia, signifying an extruding nature associated with methane emanation[5]. The recorded mud diapirs from India may also exhibit similar internal structures, since they are expected to have been pierced from gas hydrate zone. However, it has to be confirmed by sampling.

The area with mud diapirs off Point Calimere is a part of petroliferous Cauvery Basin which encompasses thick pile of sediment cover and is known for tectonically fragmented sub-basins[6]. Similarly, the area with mud diapirs off Saurashtra is also a part of the petroliferous basin of Kachchh and Bombay High with a huge pile of sediment cover and is known for tectonic movement[7]. Commercial production of petroleum and natural gases from these localities is well-known. Therefore, the occurrences of mud diapirs off Point Calimere and off Saurashtra have become very significant due to their association with petroliferous basins known for thick pile of sediments and tectonic movement, which are the prerequisites for the genesis of mud diapirs associated with gas hydrates reported elsewhere[1,8,9].

Gas hydrates resembling ice are crystalline solids formed of water molecules and methane gas[10]. They commonly exist under low temperature and high pressure conditions below the sea floor, at water depths of more than 500 m (ref. 9). Methane gas, the major constituent of gas hydrates is either thermogenic, biogenic or mixed in origin. Nearly four decades ago, when petroleum geologists first reported the occurrence of gas hydrates from Siberia, it was believed that their occurrence is possible only in permafrost regions. Later, studies proved their occurrence from non-permafrost areas in continents as well as offshore areas. Keeping in view their potential as an energy source, the exploratory work for marine gas hydrates had intensified all over the world since 1980. As a consequence, over the past two decades, several papers have been published on occurrence of gas hydrates along the deep continental margin areas[11–16]. Studies also suggest that gas hydrates are one of the best alternate source of fossil fuel energy.

As the gas hydrate occupies the pore spaces of the host sediment, its presence usually changes the acoustic and geotechnical properties of the sediment[12]. Hence, gas hydrate zone in marine domains can at best be detected by seismic survey. Seismic records from the known gas hydrate zones display a distinct subsurface reflection, more or less parallel to the sea floor between gas hydrate layer and the gas hydrate-free sediment layer, which is known as ‘bottom simulating reflection’ (BSR). The BSRs are believed to be the most common indicator for marine gas hydrates. Recent trends in the exploration for gas hydrates reveal that in the absence of seismic records, there are alternative

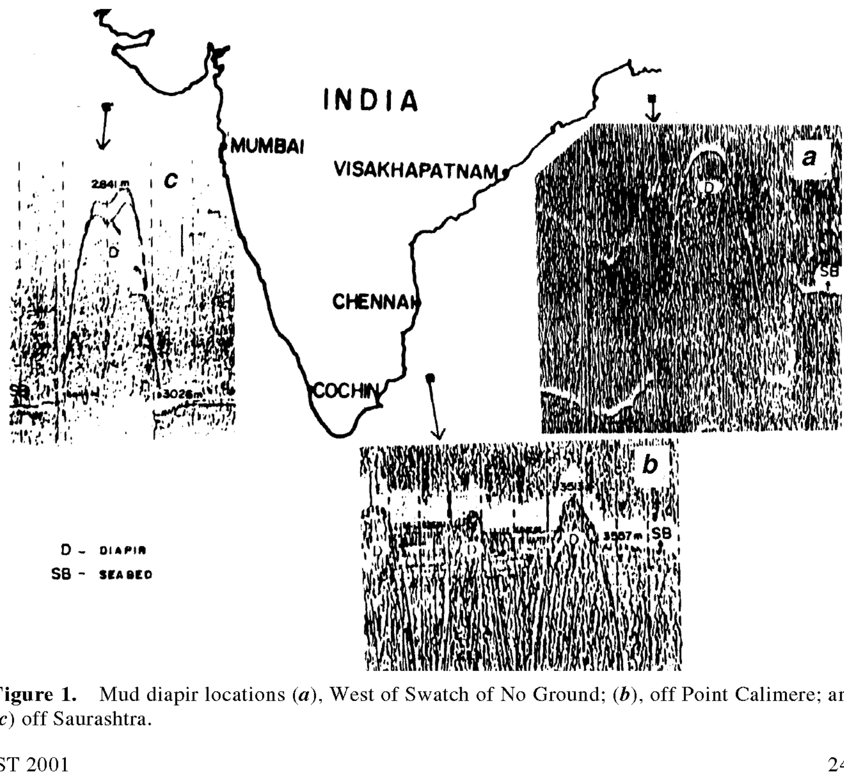

Figure 1. Mud diapir locations (***a***), West of Swatch of No Ground; (***b***), off Point Calimere; and (***c***) off Saurashtra.

indicators to locate possible gas hydrate zones in the deep continental margins.

The association of gas hydrates with submarine mud volcanoes has been recorded in the Adriatic Sea[17], Caspian Sea[18], Norwegian Sea[8], off Barbados[19] and Blake Ridge, off USA[9]. Milkov[1] has summarized the association of submarine mud volcanoes and gas hydrates in all the oceans of the world. The above documentations suggest that the submarine mud volcanoes (diapirs) are also reliable indicators of the subsurface occurrence of gas hydrates.

In India, the hydrocarbon potential is related to the basin and sedimentary evolution of Arabian Sea, Bay of Bengal and their north-eastern extensions. Since 1950s, the detailed petroleum exploratory work has led to the discovery of several new petroliferous sedimentary basins around India, both onshore and offshore, with good accumulations of oil and natural gas of commercial value. However, the exploration for marine gas hydrates around India is not yet intensified.

The eastern continental margin of India adjacent to the major sedimentary basins, viz. Cauvery, Krishna and Godavari is presumed to have great potential for gas hydrate deposits[20]. Compilation of available data on bathymetry, sea-bottom temperature and geothermal gradient of continental margin of India has indeed helped to bring out maps depicting the probable thickness of gas hydrate stability zone (GHSZ) and sea-bottom temperature variation[21]. These maps greatly facilitated preliminary assessment about the depth of occurrence of gas hydrates and clues to search for BSR and its depth around the Indian continental margin. However, a systematic seismic survey in the offshore areas of India is necessary to confirm the depth of BSR.

It is interesting to note that the zones of mud diapirs reported off both Point Calimere and Saurashtra – Mumbai fall in the predicted shallow zones of GHSZ. These (Figure 1) are geologically potential zones for gas hydrates. Collection of additional geoscientific data is now recommended through (i) 3.5 kHz echo sounding in these areas, along closely spaced tracks; (ii) side scan sonar survey to pick up the locations of more diapirs; (iii) multibeam hydro-sweep survey to understand the distribution pattern of the mud diapirs; (iv) sampling of the diapirs using gravity or piston corers, and (v) vertical splitting of the cores, logging and methane gas analysis on-board.

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Molecular characterization of *Piper nigrum* L. cultivars using RAPD markers

Black pepper, *Piper nigrum* L., often referred to as the 'king of spices' is the most important spice in the world. The pepper of commerce is the dried, mature berries of *P. nigrum*. Indian black pepper is known for its quality and fetches premium price in the market. Majority of the present-day Indian cultivars, numbering about 100, are land races representing direct introduction from the wild[1]. Advanced cultivars have been derived mostly by clonal selection from land races, though a few are of hybrid origin. As India is the primary centre of diversity of *P. nigrum*, the indigenous genetic resources are reservoirs of useful genes for plant improvement programmes. Unambiguous characterization of cultivars and selected germplasm is an urgent requirement in tune with the globalization of agriculture. Molecular markers offer means of identifying cultivars with much greater reliability than the morphological traits which are governed by complex genetic interactions[2].

Of the several PCR-based techniques, random amplified polymorphic DNA