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Characterization of the relationship between the resistivity and gas hydrate concentration in the subsurface of mud volcanoes in Baratang Island, Andaman through Electromagnetic (terra TEM) technique

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Summary

Documentation of mud volcanoes owing to their role in global ethane budget, explosive expansion of trapped methane and as indicator of petroleum are made in Caspian Sea, Gulf of Mexico, Azerbaijan, Trinidad and Makran coast of Pakistan. Mud volcanoes located in the frontal thrust areas of Andaman active tectonic zone where seismic pumping enhance stress perturbation triggered methane mud volcano eruption after 2004 great Sumatra- Andaman earthquake with M9 . Intend of the present study is to characterize the relationship between resistivity and gas hydrate concentration in the subsurface of mud volcanoes through Transient Electromagnetic technique. Pseudo section by coincident loop of 90x90 m reveal the average resistivity values of 4.0Ωm; 3.5Ωm and 6.3Ωm for mud and host sedimentary formations, whereas gas hydrate accumulated in chambers and vertical pipes in three mud volcanoes show very high resistivity values viz; 192.0 Ω m for mud volcano at Pusi and 250.0 Ω m for mud volcano at Rajathgarh and 1666.0 Ωm for mud volcano Mirchitikiri. The higher resistivity variation implies that the higher gas hydrate concentration. Of the three mud volcanoes, Mirchitikiri is in dormant stage and consequently higher gas pressure accumulated in the pressure chamber and vertical pipe may be the cause for increasing of higher resistivity than the other two. Comparatively low resistivity values observed as in the case of other two mud volcanoes can be assigned due to hydrate dissociation where eruption of mud volcanoes are in progress . Mud volcanoes in locations of Rajathgarh, Mirchtikiri and Pusi in Baratang Island are aligned to the deep seated faults in N-S direction. From Transient Electromagnetic (TEM) survey, it is evident that the zones containing gas hydrate are more resistive than the surrounding host sedimentary formation and also seen that the resistivity of the gas hydrate increases proportionately with increase of gas hydrate concentration . The characterization of the gas hydrate concentration through TEM technique is dependent on the true resistivity (conductivity) rather than apparent resistivity of the hydrated sediments.

***Keywords**: Mud Volcano, Gas Hydrates, Terra TEM, Andaman*

Introduction

In recent years interest in mud volcanoes has increased in many parts of the world, because of petroleum exploration, but also due to the role of mud volcanoes in global ethane budget, and a potential green house gas. Worldwide distribution of mud volcanoes have been documented in areas of overpressure where explosive expansion of trapped methane has occurred during argillokinesis. Mud volcanoes emitting methane are associated with substantial hydro carbon deposits in Caspian sea, Gulf of Mexico, Azerbaijan in Absheron peninsula , Trinidad , Romania and Makran coast of Pakistan . The mud volcanoes often associated with the frontal thrusts of accretionary margins in tectonically active areas due to overpressure. Overpressure can be associated with rapidly deposited sediments which have not had enough time to dewater before being covered with impermeable material. Pressure can be further increased by tectonic stresses i.e. lateral migration of fluids by seismic pumping such as in the active margin. It has been suggested that strain and stress perturbations from large earthquakes can also trigger large

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methane volcanoes eruption. Gas emissions from the on shore mud volcanoes are primarily of methane (70-99%) and CO_2 (Kopf, 2002). The horizon which contains fluid conduit carrying of free gas to the summit it is being seen as resistor by Controlled Source of Electromagnetic data but not by the well data .Zones containing gas hydrates are more resistive than surrounding sediments creating a contrast, which is measurable with electromagnetic technique (Collett and Ladd, 2000). The resistivity of gas hydrate increases proportionally with increase in gas hydrate concentration assessed by sonic velocities (Pearson et al, 1983)

Study area

The eruption of mud volcanoes and throwing of mud above the height of the surrounding trees in Baratang island , middle Andaman occurred within several minutes after the 2004 great Sumatra – Andaman with M 9 earthquake (Geological Survey of India , 2005) . Present study is concentrated over mud eruption spread over in the areas at Rajathgarh, (N12˚07 19.76 E92˚45 37.52) Pusi (N12˚047 20.35 E92˚76 01.26) and at Mirchtikkri (N12˚07 46.82 E92˚47 31.23) at Baratang Island (Figure 1).

Figure 1: Location Map of the Study Area

Burning of flame of methane gas continued more than two weeks at the centre of the mud spread after the earthquake. Mud eruptions were reported at eight locations of Baratang Island in middle Andaman. The blow up materials from mud volcanoes are composed of clay and ejected argillaceous matrix with polymictitic rocks assemblages, expelled brine water, dark tinged organic material and methane gas (Figure2) . Evidently ejection of mud from the subsurface is pressure dependent. Mud volcanoes are the resultant of overpressure and the formation of diatremes normally associated with mud diapirism (Brown, 1990). The driving force of the eruption is enhanced fluid pressure and the expansion of dissolved methane (Kopf, 2002).

Figure 2: Eruption of mud volcano with gas and organic matter in Pusi Mud volcano.

Mud volcanoes in Baratang Island are aligned along lines of weak zones followed the North –South oriented extension fault tectonics over the top of the underlying diaper. Andaman and Nicobar Island arc - a sliver plate is located between the active margin of Indian plate moving NE direction and subducting under Burmese plate obliquely. Hence the horizontal shortening and lateral migration of fluids by seismic pumping in this active margin increased the pressure.

Mechanism of Mud Volcano formation

The free gas diffusion through clay or silt as a function of the median pore and kinematic diameter of gas molecules has developed ‘shale gases ’even over impermeable shale section (Fertl, 1976).Often ‘shale gas’ is associated with abnormal pressure environment ; however lack of such gas does not guarantee normal hydrostatic pressure conditions. The hydrocarbon migration with various intensity in all stages of their existence in the earth crust both dispersed and concentrated state (Fertl, 1976). The amplification of overburden pressure owing to accretionary wedge setting and thrusting of off scraped material in Andaman Sliver

Plate enhanced the pathways for migration of fluids through the system (Figure 3).

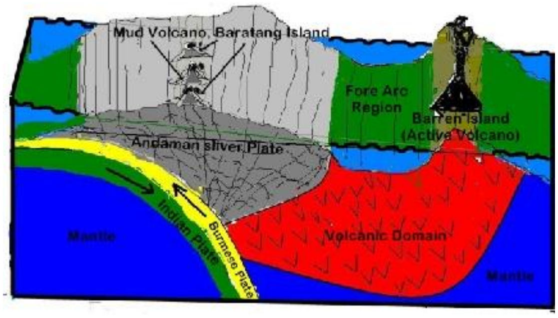

Figure 3: Accretionary prism showing avenues of fluid escape forming mud volcanoes due to seismic pumping.

Strain hardenings at depth (2.5-3 km) furnish a characteristic scaly fabric to mud for migration of gas saturated brine. While, the strain softening of these formation in the upper part (1.0-1.5 km) has allowed dissolved gas to rapid expansion of as it comes out of solution and developed migration pathways to the surface through lines of weakness prevailed to extensional tectonic over the top of the underlying diaper (Ware and Ichram, 1997).

The overpressure which gives rise to the mud volcanism also causes increased expulsion efficiency. Depending on the geometric distribution of hydrate, Archie Law may not be representative model especially if hydrate is found in veins and fractures. The external bounds for effective conductivity are Hashin Shtrikman bounds (HS bounds) (Schmelisng , 1986). The HS lower bound $\sigma HS-$ corresponds to resistive spherical inclusion within a conductive matrix and the HS upper bound $\sigma HS+$ corresponds to conductive spherical inclusion within resistive matrix (Hashin and Shtrikman, 1963). In terms of hydrate, the HS lower bound may represent a lower concentration of granular disseminated hydrate distributed in isolated spheres within the conductive sediment. In the clay rich sediments the hydrate may occur in veins or fracture and be better represented by HS upper bound where resistive material occur in sheets impeding currents flow through the matrix fluid.

Relationship between resistivity and hydrate concentration

The presence of gas hydrate based on the identification of Bottom Simulating Reflection (BSR) is inadequate to infer gas hydrate as suggested by drilling results elsewhere (Ramana et al, 2006). Controlled Source Electromagnetic (CSEM) technique has applied to identify the gas hydrate. This technique is sensitive to electric resistivity of the sedimentary formation, porosity, permeability and pore fluids (Weitemeyer et al, 2006, Schwalenberg et al, 2005). Consequently this technique has great potential to detect gas hydrate when no BSR is present (Yuan and Edwards, 2000).

Existence of hydrate or free gas in seismic blank zones is representing as hydrate bearing pipes (Schwalenberg et al, 2005). To characterize gas hydrate distributed in the subsurface of mud volcanoes in Rajathgarh, Mirchtikkiri and Pusi in Baratang Island, Transient Electromagnetic technique (Duncan Massie, 2009) with coincident square loop configuration of transmitter (Tx) and receiver (Rx) size of 90x90 m were used.

A steady current is run through the 'Tx' transmitter loop for sufficiently long time to allow turn on transients in the ground to dissipate. The current is then sharply terminated in a controlled manner in accordance with Faraday's Law and electromotive force (emf) is induced into the ground. This 'emf' causes eddy currents through horizontal loops flow into the ground expanding in radius and diffusing to greater depths with time. By measuring the secondary magnetic field from the eddy currents developed, depth wise information of subsurface is retrieved successively through 'Rx' loop through sampling delay time of 7.625 ms to 465.9765 ms with 24 windows (40 to 63). Advanced software is imbedded to store the survey files with *.BIN extensions and transform the data into conductivities with Terra TEM Plot on site and display it in the form of plans or sections. Survey parameter manipulation and numerical transforms can be accessed by Spiker Algorithm (Apparent Conductivity Transformation). Images can be saved in bitmap and transformed directly in report ready format.

Results

The depth penetration through the coincident loop size of 90 x 90m recorded 350m, 830m and 2000m depths in three sites of Rajathgarh, Pusi and Mirchtikkiri. Three pseudo sections acquired from the subsurface across the three mud volcanoes (Figure 4,5 & 6) show the distribution pattern of resistivity (conductivity) of mud sediments and gas hydrate is tabled (Table 1A,B & C). The high electrical conductivity for mud or clay rich sediments and low electrical conductivity for hydrate in the laboratory condition have proposed (Winters et al 2003). Gas hydrate delineated in pseudo sections show the variation of high resistivity of 192.00 Ωm to 1666.00 Ωm than the host sedimentary formation surrounded with low resistivity values of 1.50 Ωm to 10.00 Ωm for the in the study area. The highest resistivity values measured for hydrates in three mud volcanoes viz; 192.00 Ω m for mud volcano at Pusi and 250.00 Ω m for mud volcano at Rajathgarh and 1666.00 Ωm for mud volcano Mirchitikiri can be accounted for types of sediments, gas hydrate concentration /dispersion and pore fluids. The resistivity variation of the gas hydrate with host sedimentary deposits is calculated as 62.00; 465.00 and 30.00. The higher variations of resistivity clearly replicate higher gas hydrate concentration. The higher resistivity variation implies the higher gas hydrate concentration. Of the three mud volcanoes, Mirchitikiri is in dormant stage and consequently gas pressure accumulated in the pressure chamber and vertical pipe may be the cause for increasing of higher resistivity than the other two. Comparatively the low resistivity values observed as in case of mud volcanoes at Rajathgarh and Pusi can be assigned due to hydrate dissociation where eruption of mud volcanoes are in progress.

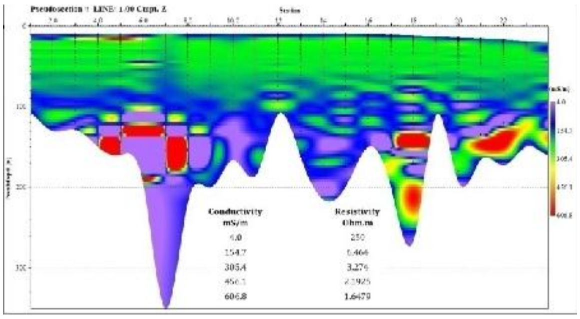

Figure: 4 Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Rajathgarh

Table: 1A: Resistivity values retrieved for host sedimentary formations and gas hydrates accumulated in gas chambers and vertical pipes from the pseudo section across the mud volcano through TEM.

Profile 1	
Location of Mud volcano	Rajathgargh Tx and Rx loop size: 90 x 90 m
Depth wise Distribution pattern of mud and other sediment	Mud and other sediments with resistivity values 1.647Ωm to 6.4 Ωm (606.8 mS/m to 154.7mS/m) distributed to depth of 200 m from surface in the form of horizontal layers. The average resistivity values for the host sediments = 4.0Ωm
Depth wise distribution pattern of gas hydrate	Gas hydrate accumulated in chambers and vertical pipes extended from 100 m to 350 m depth with resistivity values of 250 Ωm (4mS/m). The average resistivity values of the gas hydrate is 250Ωm
Remarks	Mud volcano erupts mud and gases through orifice and release gas pressure accumulated and reduce the gas pressure. The resistivity variation of gas hydrate with host sediments is 250/4.0=62.00

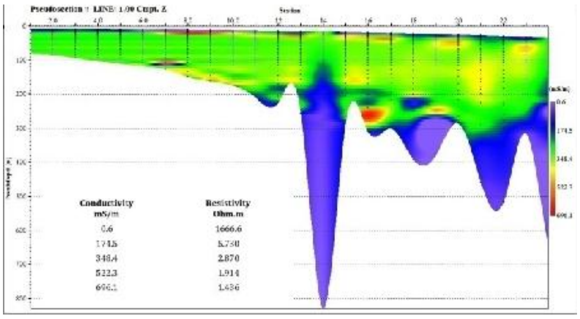

Figure: 5 Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Mirchitikiri.

Table: 1B: Resistivity values retrieved for host sedimentary formations and gas hydrates accumulated in gas chambers and vertical pipes from the pseudo section across the mud volcano through TEM.

Profile II	
Location of Mud volcano	Mirchtikkiri Tx and Rx Loop size: 90 x 90 m
Depth wise Distribution pattern of mud and other sediment	Horizontal layers of mud and other sedimentary deposits distributed from surface to depth of 300m with resistivity values ranging from 1.50 Ωm to 6.0Ωm(696.1mS/m to 174.5mS/m) The average resistivity values for the host sediments= 3.6Ωm
Depth wise distribution pattern of gas hydrate	Gas hydrate occurs in pipes extended from 250m to 800m. Vertical depth of the resistivity values for gas hydrate exhibits as 1666.00Ωm (0.6mS/m) The average resistivity values of gas hydrate is 1666.00 Ωm
Remarks	In this site mud volcano is dormant stage; hence accumulations of gas hydrates in the vertical pipe have increased the gas pressure and ultimately increase the resistivity values of gas hydrates. The resistivity variation of the gas hydrate with host sediments is 1666.00/3.6=465.00

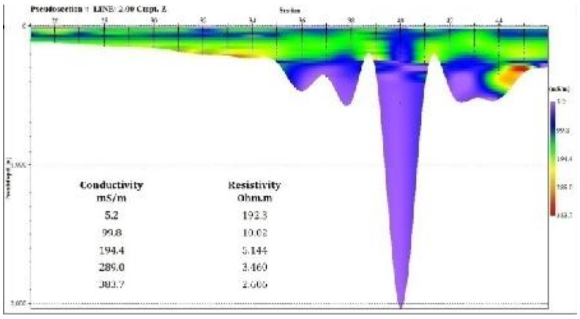

Figure: 6 Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Mirchitikiri.

Table: 1C: Resistivity values retrieved for host sedimentary formations and gas hydrates accumulated in gas chambers and vertical pipes from the pseudo section across the mud volcano through TEM.

Profile III	
Location of Mud volcano	Pusi Tx and Rx Loop size: 90 x 90 m
Depth wise Distribution pattern of mud and other sediment	Mud and other sedimentary deposits are distributed as horizontal layers from surface to a depth of 250m with resistivity values of 2.6062Ωm to 10.00Ωm (383.7mS/m to 99.8mS/m). The average resistivity of the host sediments =6.5Ωm
Depth wise distribution pattern of gas hydrate	Gas hydrate occurs in the form of vertical pipes at the depths of 200m to maximum of 2000m. Gas hydrates also exist in chambers surrounded by mud chambers at shallow depth of 100 m to 400m. Resistivity values recorded for gas hydrate is 192.0Ωm. (5.2mS/m). The average resistivity of the gas hydrate is 192.0Ωm
Remarks	This mud volcano is active and release gas hydrate and records resistivity value as 192 Ωm. The resistivity variation of the gas hydrate with host sediment is 192.0/6.5= 30.00

Conclusions

Gas hydrates detected in the realm of mud volcanoes in locations of Rajathgarh, Mirchtikiri and Pusi in Baratang Island are aligned to the deep seated faults in N-S and E-W direction. From transient Electromagnetic survey it is evident that the zones containing gas hydrate are more resistive than the surrounding host sedimentary formation and also seen that the resistivity of the gas hydrate increases proportionately with increase in gas hydrate concentration. The characterization of the gas hydrate concentration through TEM technique is dependent on the true resistivity (conductivity) rather than apparent resistivity of the hydrated sediments. The relatively low resistivity pattern observed for the gas hydrates at Rajathgarh and Pusi mud volcanoes in the study area can be accounted to dissociation of gas hydrates and high resistivity values observed for gas hydrate in Mirchtikiri mud volcano is due to high concentration of gas hydrates.

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